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(Bhavisya Entrepreneurs)

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PREFACE

It is with immense pleasure and pride that We present the proceedings of the National Symposium on Entrepreneurship and Innovation, centred around the transformative theme of "Smart Village". This symposium stands as a testament to our collective efforts toward reimagining rural India — not as a recipient of urban charity, but as a cradle of innovation, sustainability, and inclusive growth.

In recent years, the Smart Village concept has gained momentum, inspired by the need to bridge the rural-urban divide. It envisions villages that are self-sufficient, digitally connected, economically vibrant, and environmentally sustainable. To realize this vision, entrepreneurship and innovation must be placed at the heart of rural development — empowering individuals to create solutions tailored to local challenges.

This symposium brings together a diverse group of scholars, entrepreneurs, policy-makers, technocrats, and students, all unified by a common goal: to explore how entrepreneurial thinking and innovative technologies can be harnessed to build smarter, more resilient rural communities. The deliberations, case studies, and research presented in this volume reflect a rich tapestry of ideas, models, and success stories that hold promise for scalable and replicable impact.

As the Editors, we have had the privilege of curating these contributions, each offering a unique perspective on the dynamic intersection of innovation, sustainability, and social impact. We are confident that the insights shared here will inspire further discourse, collaboration, and action toward creating villages that are not just smart in infrastructure, but also in spirit and opportunity.

We extend our heartfelt gratitude to all the contributors, reviewers, organizing committee members, and participants whose dedication and enthusiasm have made this symposium a meaningful and enriching experience.

Let this be more than a collection of papers — let it be a call to action.

Editor

National Symposium on Entrepreneurship and Innovation

ABOUT THE SYMPOSIUM

The **National Symposium on Entrepreneurship and Innovation** served as a vibrant platform for thought leaders, innovators, researchers, and practitioners to come together and engage in meaningful dialogue on the theme of "**Smart Village**". With a focus on reimagining rural development through the lenses of entrepreneurship, sustainability, and digital inclusion, the symposium highlighted cutting-edge research, practical case studies, and innovative models aimed at transforming villages into hubs of economic activity and social well-being. The event fostered interdisciplinary collaboration and knowledge sharing, encouraging participants to explore scalable solutions that empower rural communities, promote self-reliance, and bridge the rural-urban divide. Through dynamic discussions and insightful presentations, the symposium reaffirmed the critical role of innovation and entrepreneurial spirit in shaping a more equitable and resilient rural India.

ABOUT THE INSTITUTE

Guru Nanak Institute of Technology (GNIT), Kolkata, is a premier engineering and management college established under the JIS Group. Affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT) and approved by AICTE, GNIT is committed to providing quality technical education and fostering innovation. The institute offers undergraduate and postgraduate programs across various disciplines, including engineering, technology, and management, with state-of-the-art infrastructure, well-equipped laboratories, and experienced faculty. GNIT also emphasizes industry-academia collaboration, research, and extracurricular activities to ensure holistic student development and prepare them for global opportunities.

ABOUT THE AICTE IDEA LAB

The AICTE IDEA (Innovation, Design, and Entrepreneurship Academy) Lab is an initiative by the All India Council for Technical Education to promote experiential learning, creativity, and problem-solving skills among students. It provides access to modern tools such as 3D printers, IoT kits, robotics platforms, and prototyping equipment, enabling students to transform ideas into working models and products. The lab nurtures an innovation-driven ecosystem where students, faculty, and industry experts can collaborate on interdisciplinary projects, startups, and research. By bridging classroom learning with real-world applications, the AICTE IDEA Lab empowers students to become innovators, entrepreneurs, and contributors to the nation's growth.

Managing Director’s Message

Bhavisya Entrepreneur 2025 stands as a national platform to inspire action and bridge the gap between academia, industry, and society. By focusing on “Smart Village Adoption,” we aim to demonstrate how entrepreneurship can create sustainable ecosystems in energy, agriculture, and healthcare. This symposium is not only about dialogue but also about driving initiatives that bring tangible impact to rural India. I welcome all participants, mentors, and innovators to join hands in shaping an inclusive future where growth is shared, and progress is sustainable.

Best Wishes!

Mr. Taranjit Singh
Managing Director, JIS Group Educational Initiatives

Director’s Message

At Bhavisya Entrepreneur 2025, we celebrate the power of young minds to reimagine the future. This symposium is not just about innovation—it is about channeling creativity into impactful solutions for rural India. The theme of “Smart Village Adoption” resonates with our mission to empower communities through technology, sustainability, and entrepreneurship. I invite each participant to embrace this opportunity, collaborate across disciplines, and transform bold ideas into meaningful change. Together, let’s sow the seeds of innovation that will bloom into a brighter tomorrow.

Best Wishes!

Sardar Simarpreet Singh
Director, JIS Group Educational Initiatives

Pro Chancellor's Message

I am delighted to note that *Bhavisya Entrepreneur 2025: National Symposium on Entrepreneurship & Innovation* is being organized under the aegis of the AICTE IDEA Lab at GNIT. The theme of *Smart Village Adoption* is both visionary and pragmatic, linking entrepreneurial energy with the imperative of sustainable rural transformation.

The IDEA Lab represents more than an infrastructural initiative; it is a carefully designed ecosystem for nurturing curiosity, creativity, and competence. Conceived to bridge the divide between learning and doing, it has steadily evolved as a national framework where both students and teachers engage in problem-centric inquiry, experiment with technology-enabled solutions, and internalize the ethos of heutagogy—self-determined, lifelong learning. I have had the privilege of contributing to the early shaping of this model, and it is gratifying to witness its growing impact across institutions.

In this context, the emphasis placed by Hon'ble Prime Minister Shri Narendra Modi on "new-age learning" finds a natural resonance. The IDEA Lab nurtures precisely the mindset he has envisioned—of learners as innovators, teachers as co-learners, and institutions as incubators of social transformation. When such a platform intersects with the urgent priorities of green energy, agriculture and agro-processing, and healthcare, it opens pathways not just for economic development but also for inclusive nation-building.

I am confident that the discussions and exchanges at this symposium will illuminate practical models for *Smart Villages*, inspire collaborations across academia, industry, and society, and contribute meaningfully to India's aspiration of becoming a *Viksit Bharat by 2047*.

I extend my warm wishes to the organizers, participants, and partners of this symposium for a fruitful and impactful dialogue.

Dr. Neeraj Saxena
Pro Chancellor
(Former Advisor, AICTE/ MOE and Former Scientist, TIFAC/ DST)
JIS University

Principal’s Message

It is with great pride and immense satisfaction that we present the proceedings of the Bhavisya Entrepreneur 2025: National Symposium on Entrepreneurship; Innovation organized in our institute on September 18–19, 2025, as an outreach activity of the AICTE IDEA Lab. AICTE IDEA LAB symposium on “Smart Village Adoption”. This event has been a true testament to encourage the power of youthful imagination and the potential of technology to drive meaningful social impact. The IDEA LAB initiative by the All India Council for Technical Education was designed to encourage students to apply fundamental principles of Science, Technology, Engineering, and Mathematics (STEM) to develop creative solutions for real-world problems. It is an incubator for hands-on learning, critical thinking, and design thinking. This symposium perfectly embodies that spirit by channelling the energy and inventiveness of our young innovators toward a cause that is fundamental to our nation’s progress: sustainable rural development. India’s strength lies in its villages, and the concept of a “smart village” is a vision for a future where tradition and modernity coexist harmoniously. It is about leveraging technology not as an end in itself, but as a tool to improve the quality of life, boost economic opportunities, and ensure ecological sustainability in our rural communities.

The symposium has been divided into two tracks (i) Paper Presentation (ii)

Mini Hackathon with the following topics

- Green Energy
- Agriculture and Agro Processing
- Healthcare

The ideas presented in the symposium has a spectrum form prototypes for precision farming and waste management systems to digital platforms that empower local artisans—showcase an inspiring blend of innovation and social consciousness. Our students have gone beyond the boundaries of their academic disciplines to engage with the multifaceted realities of rural life. They have learned that true innovation is not just about complexity, but about creating simple, accessible, and scalable solutions that solve human problems.

As you read through these pages, you will not only discover a compilation of technical papers and project summaries but also a reflection of our students' journey of empathy and discovery. The solutions documented here are the initial blue prints of a brighter, more inclusive future for our villages.

The deepest gratitude is extended to AICTE for its IDEA LAB scheme, which provides a national platform for such initiatives. Thanks are also given to faculty mentors for their guidance, the organizing committee for its efforts, and all participants for their contributions.

It's also my sincere thanks to my JIS Group Management , specially our respected (MD Sir) Sardar Taranjit Singh for his constant support and encouragement.

My sincere gratitude and thankfulness to Prof. Neeraj Saxena in shaping the hope to reality. He always encourages the activity based learning and problem solving practice as best practice of institute which is an initiation through this symposium as a flagship event of AICTE IDEA LAB.

Also my grateful thanks to Sardar Simarpreet Singh for his constant guidance and support.

This is a step toward realizing the vision of a self-reliant India, powered by the youth's creativity and commitment.

Best Wishes!

Dr. Swarup Kumar Mitra
Principal
Guru Nanak Institute of Technology

Message from the Desk of Dean-Academics

It gives me immense pleasure to extend my warm greetings to all participants of Bhavisya Entrepreneur 2025: National Symposium on Entrepreneurship & Innovation, organized under the banner of the AICTE IDEA Lab at GNIT. This national-level symposium represents a significant initiative to bring together academicians, researchers, industry leaders, entrepreneurs, and students on a common platform to deliberate upon ideas that can shape a better future.

The central theme, "Smart Village Adoption", is particularly meaningful in today's context, as it underscores the urgent need to bridge the urban–rural divide and promote inclusive, technology-driven growth. Villages are the backbone of India, and nurturing sustainable solutions in areas such as **green energy, agriculture and agro-processing, and healthcare** will not only empower rural communities but also contribute to the nation's long-term progress.

On behalf of GNIT, I take pride in supporting this endeavour and commend the Organizing Committee for its efforts in curating such a relevant and forward-looking theme. I am confident that the discussions and outcomes of this symposium will inspire new pathways for sustainable entrepreneurship and contribute to the larger vision of building Atmanirbhar Bharat.

I wish Bhavisya Entrepreneur 2025 grand success and extend my best wishes to all participants for an enriching and transformative experience.

Prof. (Dr.) Kakali Bandyopadhyay
Professor (FT)
Dean, Academics
Guru Nanak Institute of Technology, NAAC A+

Message from the Desk of Dean R & D

AICTE IDEA Lab of Guru Nanak Institute of Technology (GNIT), organizes a two-days National Symposium on Entrepreneurship & Innovation" on 18th & 19th September, 2025 in collaboration with IEEE R10 Adhoc Committee on Entrepreneurship & Innovation. The Symposium seeks to contribute to presenting novel research results in all aspects of "SMART Village Adoption". It also provides the premier interdisciplinary forum for scientists, engineers, and practitioners to present their latest research results, ideas, developments and applications on SMART Village Adoption through a Mini Hackathon. The Symposium aims to bring together leading entrepreneurs, researchers to exchange and share their experiences and views about on the subject topic.

GNIT is involved in many collaborative research programmes with renowned universities across the globe in diverse techno commercial and academic verticals. This programme directly links the innovation-focused IIC with the startup-oriented EDC.

There will be several invited talks and oral presentations blended with the main thematic discourses. Young entrepreneurs and startups are encouraged for collaboration; promote professional interaction and lifelong learning. The conference will be an ideal confluence for innovators to present their innovations, compare notes, develop new ideas, benchmark their work in view of TRL level, exchange views and widen the scope and range of their entrepreneur activity through dynamic networking.

This symposium emphasizes the collective impact of these efforts on personal and national economic development and GNIT cherishes to collaborate with the most talented and bright incubatee and wish a fruitful entrepreneur journey ahead.

With best regards
Dr. Sunipa Roy
Associate Professor (ECE)
Dean, Research and Development
Guru Nanak Institute of Technology, NAAC A+

Message from the Desk of Dean- Student Affairs

It is a pleasure to welcome all to Bhavisya Entrepreneur 2025, a national symposium fostering innovation and entrepreneurial thinking. Hosted at GNIT under the AICTE IDEA Lab, the event provides a platform for academicians, entrepreneurs, industry experts, and students to collaborate and exchange ideas.

With the theme "Smart Village Adoption," the symposium highlights our commitment to sustainable rural development through innovation. I thank all contributors for supporting this initiative and invite everyone to join us in building a smarter, self-reliant India.

With best regards
Dr. Sucharita Chakrabarti
Associate Professor (ASHU)
Dean, Student Affairs
Guru Nanak Institute of Technology, NAAC A+

AICTE IDEA LAB

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- Mrs. Jayshree Majumdar, Asst Prof, FT, GNIT

KEY NOTE SPEAKERS

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Director,
CALNESTOR Foundation

Mr. Chirantan Mukherjee,
CEO, M-KIN Technology Services

Dr. Farhana Hoque, Scientist,
ICAR-Central Institute of
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Chatterjee Enterprise

MD. Razib Ahmed,
Owner and CEO of Merchant
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Edible Hydrogel: A Modern Drug Carrier System in Bioactive Phytochemical Delivery

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Abstract — Throughout the years, a diverse array of polysaccharides—such as chitosan, alginate, hyaluronic acid, κ-carrageenan, xanthan gum, carboxymethyl cellulose, pectin, and starch—has been skillfully employed, either alone or alongside proteins or synthetic polymers, to develop hydrogels with remarkable properties. These innovative hydrogels effectively address crucial challenges related to bioavailability, solubility, stability, and targeted delivery of phytocompounds, thereby driving the advancement of groundbreaking drug delivery systems and functional foods. This review meticulously outlines the preparation, defining features, and versatile applications of polysaccharide/phytocompound hydrogel-based hybrids in fields like wound care, drug delivery, functional foods, and the food industry. Additionally, it delves into the structural, functional, and biological factors that significantly impact their performance across a range of applications, underscoring their potential to revolutionize these industries.

Keywords- *Polysaccharides, Hydrogels, Phytochemicals, Encapsulation, Food packaging, Bioactive compounds*.

I. Introduction

Polysaccharides, abundant in nature, are outstanding for encapsulating bioactive phytocompounds [1]. Due to their functional groups, biodegradability, and biocompatibility. Commonly used polysaccharides like chitosan, alginate, and carrageenan enhance solubility and stability of compounds such as polyphenols and essential oils. Hydrogels, including double network (DN) hydrogels, are promising for medicinal and pharmaceutical uses due to their ability to mimic biological tissues, absorb water, and enable controlled release. DN hydrogels combined with phytocompounds offer innovative materials for wound healing. Encapsulation within polysaccharide-based hydrogels enhances the stability and effectiveness of bioactive compounds, providing benefits like improved water solubility and extended shelf life. These hybrid systems find applications in various fields such as tissue engineering, food packaging, and medication

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delivery. While some polysaccharides are extensively studied, others like hyaluronic acid and starch are less explored. Nonetheless, research in this area is growing, reflecting increasing interest from the scientific community. Recent studies focus on using polysaccharide-based hydrogels loaded with phytochemicals for purposes like wound healing and drug delivery & many more. [2].

II. CONSTITUENTS OF EDIBLE HYDROGEL POLYMER

Marine-origin Polysaccharides Chitosan (CS) [2], Alginate (ALG), and κ-Carrageenan (κ-CAR) are marine-origin polysaccharides with diverse applications. Plant/Seed-origin Polysaccharides Carboxymethyl cellulose (CMC) [3], Pectin (PEC) [4], and Starch (ST) [4] are plant/seed-origin polysaccharides used in hydrogel development. Bacterial-origin polysaccharides: Xanthan gum [5], Dextran [6], and Gellan gum [7] are bacterial-origin polysaccharides with versatile applications. Animal-origin polysaccharides: Hyaluronic acid (HA) [8] is an animal-origin polysaccharide valued for its biocompatibility and biodegradability. Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract.

III. ENCAPSULATION OF EDIBLE HYDROGELS AND IT'S MECHANISM;

Solvent Casting is a widely used technique for fabricating polysaccharide-based hydrogel films [9]. A polymer solution is prepared and poured into molds, commonly Petri dishes made of inert materials like glass or polystyrene. As the solvent evaporates, a hydrogel film is formed. Water is the preferred solvent due to its benign nature. The flexibility of the resulting hydrogels can be tuned by incorporating plasticizers like glycerol. This method offers precise control over size and shape by selecting appropriate molds and manipulating the polymer solution composition. It also enables the formation of multilayer hydrogels with varying compositions through sequential casting. A key advantage is the ability to stabilize hydrogels through physical or chemical cross-linking. However, the limited availability of polymers capable of forming stable films can be a constraint [10]. *Porogen templating* involves introducing porogens (pore-forming agents) like polymeric nanoparticles or salts into the polymer solution [11]. After gelation, the porogens are removed, leaving behind a porous hydrogel matrix. While offering control over porosity, challenges include efficiently removing the porogens, often requiring organic solvents, and limited control over pore interconnectivity and orientation [12]. *Lyophilization* (Freeze-drying) is a process where aqueous polymer solutions are frozen, and the ice is subsequently removed by sublimation under vacuum [13]. The resulting hydrogels exhibit interconnected pores, with porosity and pore characteristics dependent on factors like polymer concentration, cross-linker content, freezing conditions, and applied vacuum pressure. However, this technique suffers from poor control over pore size, potential collapse at the matrix-air interface, and low elasticity. Additionally, the solvent removal process is time and energy-intensive [14]. *Cryogelation* utilizes ice crystals formed during freezing as porogens [15]. Cryogels exhibit desirable properties like elasticity, shape memory, and rapid swelling, and can be

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fabricated into various forms like membranes and microspheres [16], [17]. *Freeze-thawing* is similar to cryogelation, where successive freeze-thaw cycles are applied to the polymer solution, enhancing physical cross-linking without chemical cross-linkers [18]. Properties depend on freezing/thawing conditions, polymer structure, and concentration. While biocompatible and stimuli-responsive, these cryogels often have poor mechanical properties, and the process is time-consuming. *Extrusion* involves slowly dripping or extruding polymer solutions into a gelation bath to form granular hydrogel particles [19]. Techniques like electrostatic and co-extrusion enable control over particle morphology and encapsulation of bioactive compounds. However, challenges include controlling particle size distribution and optimizing process parameters for uniformity. *Dripping* precursor mixtures into liquid nitrogen forms microparticles with anisotropic porous structures suitable for encapsulating heat-sensitive substances. This method offers advantages for enteric drug delivery, enabling rapid degradation in simulated intestinal fluid. It also allows the production of soft capsules with superior mechanical and thermal properties. Polyphenols, a remarkable class of phytocompounds, are distinguished by their phenolic hydroxyl groups and are primarily found in the vibrant leaves, blossoms, and fruits of vascular plants. This diverse group includes both flavonoids and non-flavonoids. Widely recognized for their powerful antioxidant, antimicrobial, phytoestrogenic, and anti-inflammatory properties, polyphenols are essential not only for plant health but also for enhancing human well-being [20]. Moreover, terpenes, composed of isoprene units, exhibit a fascinating variety in size and functional groups. They are systematically classified into hemiterpenes, monoterpenes, sesquiterpenes, diterpenes, sesterpenes, triterpenes, tetraterpenes, and polyterpenes, showcasing the incredible complexity and potential benefits these compounds provide in both nature and human applications. [21]. Present in essential oils, terpenes exhibit antimicrobial, antioxidant, carminative, and antispasmodic activities, contributing to their significance in both plants and therapeutic applications.

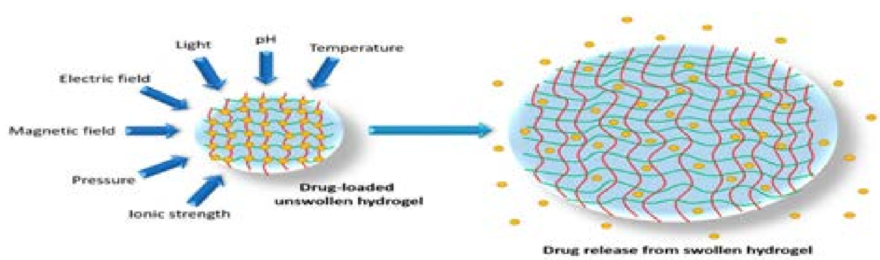

Fig.1 Encapsulation of Edible Hydrogel. Adopted from Mohan et al. 2019 with open-source license [22].

IV. APPLICATION OF HYDROGEL IN FOOD

Conventional food packaging materials made of synthetic polymers are not biodegradable and so have an adverse effect on the environment [22]. In order to replace the materials now in use, it is imperative to design new environmentally friendly methods using renewable resources. Polysaccharide-based hydrogel films are particularly attractive to the food packaging industry because of their compositional versatility as well as the mechanical, biological, and barrier qualities that make them suitable substitutes

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for food freshness monitoring. Food shelf life might be increased thanks to the unique hybrid systems that were made possible by the encapsulation of phytocompounds in such films and their greatly improved qualities [23]. Considering that the packaging materials are the food's contact with the outside world, the phytocompound-rich polysaccharide hydrogels need to have a low permeability to oxygen and odors and a high permeability to water vapor to keep the food from being dehydrated. Elasticity, resistance to traction, mechanical stress, biodegradability, and chemical and thermal stability are all necessary qualities at the same time. They ought to have potent antibacterial and antioxidant qualities from a biological standpoint. The breakdown of proteins and microbial activity during food storage can produce volatile gases that are acidic or basic, changing the pH of the surrounding air. Acid-base indicators that are adaptable are called phytocompounds [22]. Phytocompound-loaded polysaccharide hydrogels serve as indicators of food freshness by detecting surface pH changes. The type of food (meat, fruits, milk, baked goods), storage conditions, and encapsulated phytocompounds (like anthocyanin and curcumin) all influence the color change. As pH increases, the color shifts from pink-red to green, depending on the concentration of anthocyanins in the hydrogels [23]. High ammonia levels from protein breakdown can raise meat surface pH. Hydrogel films containing PEC/Cur/sulfur nanoparticles and κ-CAR/Cur utilize curcumin's color-changing properties to detect ammonia vapor, with interactions between ions and curcumin causing a visible color shift. These hydrogels show promise for assessing the freshness of meat products, such as shrimp and pork [22]. In functional foods, polysaccharide-based hydrogels containing nutraceuticals (NTs) effectively address challenges like chemical instability and poor bioavailability. For instance, grape seed extracts are encapsulated in Ca^{2+} crosslinked alginate microparticles, which maintained their bioactivity even when mixed with rice milk or cow's milk. The antioxidant potential of these extracts is significantly higher than that of vitamins E and C [21, 15]. Additionally, polyphenols are used to inhibit advanced glycation end products (AGEs) in baked goods. A dual-network hydrogel made from chitosan-folic acid and genipin successfully reduced AGE formation in a cake model by 44.75% with just a 0.5% addition. However, the mechanism of how this hydrogel interacts with AGE formation requires further investigation [13].

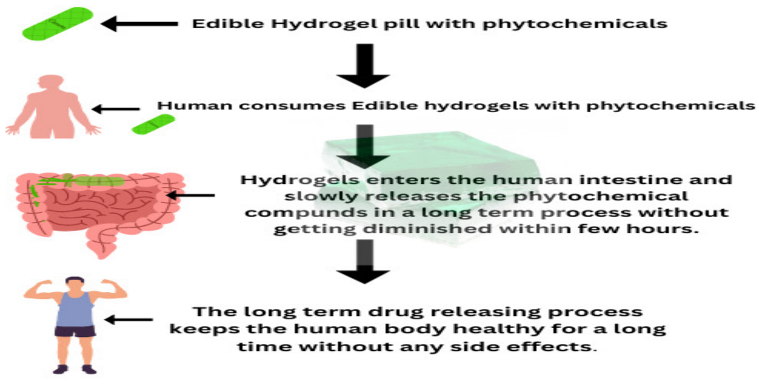

Fig.2 Mechanism of phytochemical delivery by edible Hydrogels

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V. LIMITATION AND FUTURE SCOPE

This review emphasized the beneficial interaction between phytochemicals and polysaccharides, especially when it comes to hydrogel-based platforms. Polysaccharide based hydrogels have drawn a lot of interest over time as adaptable platforms for maximizing phytocompounds' bioavailability and bioactivity. *Tailor-Made Shape:* Polysaccharide-based hydrogels are highly versatile, customizable into films, membranes, sponges, fibers, or microparticles. Innovative processes such as solvent casting, gas foaming, and freeze-drying allow for this adaptability, with freezing methods leading to porous three-dimensional networks with extensive interconnected pores. *Customizable Properties:* These hydrogels can be tailored made for specific phytocompounds, utilizing non-covalent and covalent interactions to stabilize them, thereby enhancing the materials' overall functionality. *Enhanced Solubility:* Poor solubility of many phytocompounds limits their bioavailability. Polysaccharide-based hydrogels address this by encapsulating hydrophobic substances, significantly improving their solubility and absorption [10]. *Protection from Degradation:* Acting as protective matrices, these hydrogels prevent enzymatic breakdown and environmental degradation, ensuring phytochemicals remain intact until they reach their target site. *Sustained Release and Targeted Delivery:* They offer continuous release of phytocompounds over time, facilitating effective targeted delivery. *Biocompatibility*: Mimicking the natural extracellular matrix, polysaccharide-based hydrogels are biocompatible, making them suitable for a wide array of biomedical applications [11].

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References

1. Abazari, M., Akbari, T., Hasani, M., Sharifikolouei, E., Raoufi, M., Foroumadi, A., ... & Khoobi, M. (2022). Polysaccharide-based hydrogels containing herbal extracts for wound healing applications. Carbohydrate polymers, 294, 119808.
2. Leyva-Jiménez, F. J., Oliver-Simancas, R., Castangia, I., Rodriguez-Garcia, A. M., & Alañón, M. E. (2023). Comprehensive review of natural based hydrogels as an upcoming trend for food packing. Food Hydrocolloids, 135, 108124.
3. Rahman, M. S., Hasan, M. S., Nitai, A. S., Nam, S., Karmakar, A. K., Ahsan, M. S., ... & Ahmed, M. B. (2021). Recent developments of carboxymethyl cellulose. Polymers, 13(8), 1345.
4. Dinu, M. V., Lazar, M. M., Ghiorghita, C. A., & Raschip, I. E. (2023). Multicomponent hydrogels for controlled drug release and delivery.
5. Petri, D. F. (2015). Xanthan gum: A versatile biopolymer for biomedical and technological applications. Journal of Applied Polymer Science, 132(23).
6. Petrovici, A. R., Anghel, N., Dinu, M. V., & Spiridon, I. (2023). Dextran-chitosan composites: Antioxidant and anti-inflammatory properties. Polymers, 15(9), 1980.
7. Dinu, M. V., Lazar, M. M., Ghiorghita, C. A., & Raschip, I. E. (2023). Multicomponent hydrogels for controlled drug release and delivery.

ISBN: **978-93-343-9865-6**

8. Dahiya, S., Rani, R., Kumar, S., Dhingra, D., & Dilbaghi, N. (2017). Chitosan-gellan gum bipolymeric nanohydrogels—a potential nanocarrier for the delivery of epigallocatechin gallate. BioNanoScience, 7(3), 508-520..
9. Hu, J., Chen, Z., Huang, X., Yan, Z., Li, Y., Zhu, Y., ... & Zhou, P. (2023). Hyaluronic acid applied as a natural flavor enhancer and its mechanism exploration. Food Bioscience, 55, 102969.
10. Celebioglu, A., Saporito, A. F., & Uyar, T. (2022). Green electrospinning of chitosan/pectin nanofibrous films by the incorporation of cyclodextrin/curcumin inclusion complexes: pH-responsive release and hydrogel features. ACS Sustainable Chemistry & Engineering, 10(14), 4758-4769.
11. Wu, C., Li, Y., Sun, J., Lu, Y., Tong, C., Wang, L., ... & Pang, J. (2020). Novel konjac glucomannan films with oxidized chitin nanocrystals immobilized red cabbage anthocyanins for intelligent food packaging. Food Hydrocolloids, 98, 105245.
12. Roy, S., & Singha, N. R. (2017). Polymeric nanocomposite membranes for next generation pervaporation process: Strategies, challenges and future prospects. Membranes, 7(3), 53.
13. Zhang, B., Liu, Y., Wang, H., Liu, W., Cheong, K. L., & Teng, B. (2021). Characterization of seaweed polysaccharide-based bilayer films containing essential oils with antibacterial activity. Lwt, 150, 111961.
14. Dinu, M. V., Přádný, M., Drăgan, E. S., & Michálek, J. (2013). Morphogical and swelling properties of porous hydrogels based on poly (hydroxyethyl methacrylate) and chitosan modulated by ice-templating process and porogen leaching. Journal of Polymer Research, 20(11), 285.
15. Dragan, E. S., Ghiorghita, C. A., Dinu, M. V., Duceac, I. A., & Coseri, S. (2023). Fabrication of self-antibacterial chitosan/oxidized starch polyelectrolyte complex sponges for controlled delivery of curcumin. Food Hydrocolloids, 135, 108147.
16. Adnan, N., Ghazali, S., & Jamari, S. S. (2019). Utilization of NaHCO3 as foam additive in synthesis of superporous hydrogels. Materials Today: Proceedings, 17, 995-1000.
17. Adnan, N., Ghazali, S., & Jamari, S. S. (2019). Utilization of NaHCO3 as foam additive in synthesis of superporous hydrogels. Materials Today: Proceedings, 17, 995-1000.
18. Memic, A., Colombani, T., Eggermont, L. J., Rezaeeyazdi, M., Steingold, J., Rogers, Z. J., ... & Bencherif, S. A. (2019). Latest advances in cryogel technology for biomedical applications. Advanced Therapeutics, 2(4), 1800114.
19. Dragan, E. S., & Dinu, M. V. (2020). Advances in porous chitosan-based composite hydrogels: Synthesis and applications. Reactive and Functional Polymers, 146, 104372.
20. Waresindo, W. X., Luthfianti, H. R., Priyanto, A., Hapidin, D. A., Edikresnha, D., Aimon, A. H., ... & Khairurrijal, K. (2023). Freeze–thaw hydrogel fabrication method: Basic principles, synthesis parameters, properties, and biomedical applications. Materials Research Express, 10(2), 024003.
21. Saqib, M. N., Khaled, B. M., Liu, F., & Zhong, F. (2022). Hydrogel beads for designing future foods: Structures, mechanisms, applications, and challenges. Food Hydrocolloids for Health, 2, 100073.
22. Abedi-Firoozjah, R., Yousefi, S., Heydari, M., Seyedfatehi, F., Jafarzadeh, S., Mohammadi, R., ... & Garavand, F. (2022). Application of red cabbage anthocyanins as pH-sensitive pigments in smart food packaging and sensors. Polymers, 14(8), 1629.

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Outlook of Near-Infrared Spectroscopy in Foodstuff Analysis

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Abstract- Near-infrared spectroscopy (NIRS) is a transformational tool in the analysis of food products. The two primary factors contributing to the success of the food sector are food quality and safety compliance. As a result, understanding the composition and utilizing technology to improve the food's quality, safety, and efficacy is essential. NIRS can significantly contribute to this. It may enhance the food industry by expediting the quality assessment of food. There are abundant references to the effectiveness of NIRS measurements combined with machine learning in determining food item quality, with auxiliary food item quality comprising constituents. This study aims to explain all the aspects of the research that have applied NIRS technology regarding food integrity analysis.

Keywords- Near-infrared spectroscopy, Quality control, Food safety, Chemometric techniques

I. Introduction

Food is the conglomeration of multiple components that can be labeled either nutrients or non-nutrients. Nutrients are usually categorized as macronutrients or micronutrients. Macronutrients (carbohydrates, proteins, and fats) are required in vast quantities to serve as foundations for cellular frameworks and substrates for energy in all living beings, whereas micronutrients (vitamins and minerals) are required in trace amounts for protein and enzyme activity [1]. There are deeply intimate links between humans and food. Most importantly, food security recognizes the cultural dimension of food security [2]. By 2050, the number of people worldwide is expected to reach 9.7 billion, presenting issues in accessing safe, nutritious, healthy food for all. To meet demand, food production must increase by over 50% of 2012 levels by 2050 [3]. In an ideal scenario, food is safe and conducive to good health, with the sole concern being the level of nutritional quality it possesses. However, complications arise when natural phenomena and human-related influences come into play, thereby

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giving rise to the issue of food safety, which encompasses matters such as freshness, microbial contamination, physical impairment, the presence of harmful substances, and instances of adulteration [4]. Today, food industries around the world face product quality and safety demands from consumers because of the growing need for health, quality, safety, and trust. Unsafe food consumption is having an adverse effect on both the health and social advancement of individuals. It is a difficult challenge for food manufacturers, processors, and operators to guarantee that the food they produce will not negatively impact consumers' health [5]. Hence, we need fast and non-disruptive methods that can be applied for assessing the quality of food products. Quality of food depends on its nutritional, physical properties, and flavors. Food that might be toxic, or food with poor nutrients, can all affect the quality of food, and perhaps even the health of the customer.

The development of quick and accurate diagnostic instruments has been further mandated to address the issue of food fraud, which is a big concern in the field of food safety [6,7]. Adulteration in postharvest processing has become more feasible due to the rising cost of produced food and agro-products and the ever-increasing population [8]. Pesticides and adulterants in food may cause a health risk. Pesticides can damage our human health, especially to the skin, digestive tract, and the respiratory system. Eating food contaminated by pesticides is one of the most common ways people come into contact with pesticides [9]. In a variety of scientific and analytical fields, traditional detection technologies, including “high performance liquid chromatography”, “ultra performance liquid chromatography”, “gas chromatography”, and “mass spectrometry” are generally used [10]. Although these processes are effective, they are known to be intrusive and non-real-time, involving time-consuming sample preparation and data processing [11]. In that light, the option of spectroscopy technology, encompassing near-infrared wavelengths, presents a potent solution to tackle several of the previously mentioned drawbacks, as it facilitates a non-invasive assessment that is swift, straightforward, environmentally friendly, and conducted directly on-site[12, 13].

The combination of Near-infrared spectroscopy (NIRS) with a machine learning based chemometric technique has been widely demonstrated to be an efficient food analysis technique. These techniques are essential for fully utilizing data and maximizing the knowledge gathered about processes, interactions, and features of the sample [14]. Chemometric technique extracting information about mutual relations between variables and reducing the multidimensionality of data. When multidimensional data is acquired through spectroscopic methods, chemometric methods appear to be highly beneficial [15]. Conventional approaches, particularly those that utilize "principal component analysis(PCA) and partial least squares (PLS)", have proven efficient in modeling near-infrared, or NIR, data when combined with spectroscopic methods of pre-processing based on experience. However, to improve model efficiency and effectiveness, deal with non-linearities in data, machine learning non-linear models are employed [16]. This approach has been extensively employed for qualitative analysis, product authentication, adulteration detection, and the differentiation of sample geographical origin, also to study molecules, aromatic, and biological compounds in food

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[17].

II. DETECTION OF QUALITY PARAMETERS

I. *Moisture Content*

The amount of moisture present in a food is regarded as a critical factor in the assessment of food quality and is typically expressed as the proportion of water present in the food. The optimal moisture content for a food product will vary for various types of food products and their intended use. For example, low moisture content is desirable for food products that are going to be stored for a long time, such as dried fruits and vegetables. High moisture content is desirable for food products that are going to be eaten fresh, such as fruits and vegetables. To restrict microbial multiplication, it is necessary to keep the amount of moisture and water activity below approximately 10% and 0.60-0.65, respectively, based on the specific food category. Perishable food items, characterized by high moisture content, typically exhibit a water activity level nearing 0.99, rendering them highly susceptible to microbial propagation. Hence, an assessment of the moisture content in food items is essential to facilitate appropriate measures for preservation or alteration of the food product [18].NIRS detects harmonics and combination bands in molecular vibrations. Within organic molecules, common vibrations are observed in "functional groups" such as CH, -NH, -SH, and -OH, with the -OH component having an especially strong near-infrared absorber. This is also why the quantification of moisture is a fundamental application of NIR spectroscopy. NIR spectroscopy finds utility in determining water content in solids, liquids, and slurries. The moisture detection limit for solids is approximately 0.1%, whereas for liquids, it falls within the range of 0.02% (200 mg/L). Nevertheless, in specific instances, moisture detection limits as low as 40–50 mg/L have been attained [19].

The moisture content (MC) is a critical quality factor that is monitored and measured throughout the food industry& processing, and storage processes. Some commercial devices use measurements of near infrared radiation to measure the amount of moisture present in different types of products made from grains without requiring a sample for processing. However, the kernels of peanuts need to be broken up into smaller pieces and put into the “measuring cell” to use these devices to measure the MC of peanuts. This is harmful, takes a lot of time, and also comes with a lot of burden. Research has introduced an “NIR reflectance method” that enables the rapid and non-destructive determination of the average MC of approximately 100g of whole kernels.

The peanut grains that were tested had a MC range of 8%to 26%. Firstly, "partial least squares regression (PLSR)” was utilized to predict the results, and NIR reflectance observations were made at 1-nm gaps between 1000 and 1800 nm in wavelength. According to the conventional air-oven procedure, the numbers were compared to the predicted values of the samples analyzed in the aforementioned range. The readings from the "air oven" agreed closely with the ones that were anticipated, as evidenced by an R2 value of 0.96 and a standard error of prediction (SEP) of 0.83.

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II. *Protein*

Polymers of amino acids make up proteins. Proteins contain twenty distinct kinds' amino acids... Variation in proteins arises from the amino acid type, number, and sequence in the polypeptide backbone. This leads to differences in molecular structures, nutritional qualities, and physicochemical characteristics. Protein has an important function in cuisine because of its many advantages. They deliver vital amino acids, including "methionine", " tryptophan", and "lysine", as well as energy. Although the body is unable to manufacture certain amino acids, they are essential for human health. Furthermore, proteins are essential structural elements found in a variety of natural diets, influencing texture. Analysts study proteins in food to understand their concentration, type, structure, and functions."Brewer Johann Kjeldahl" developed the "Kjeldahl technique" in 1883.

Food is treated with a strong acid to release nitrogen, which is then measured through titration. The quantity of protein is determined by the percentage of nitrogen in the diet. Though several advancements have been made to expedite the procedure and acquire more precise measurements, the identical fundamental methodology is still applied today. The "Kjeldahl method" is commonly accepted as the method for determining the concentration of protein because it does not directly test the protein content. A conversion factor (F) is needed to translate the measured nitrogen concentration into a protein concentration. Each protein has a unique factor of conversion based on its amino acid composition [21]. The amino acids include groups like the amide group (-CON)and C-H bonds present in the side chains and backbone of amino acids in proteins that absorb light from the NIR region and are the key absorption bands relevant to proteins.

Rice is commonly acknowledged as a fundamental crop, serving as a substantial source of energy for individuals globally. The market value of rice is greatly impacted by its quality. Rice varieties with elevated protein levels tend to exhibit a firmer texture post-steaming, consequently influencing the overall flavor profile. The NIR spectra often display notable correlations and overlapping peaks, necessitating the utilization of "partial least squares regression (PLSR)" to manage spectral covariance. The integration of NIR spectroscopy with PLSR has garnered significant acceptance in the food sector, particularly for activities like estimating "Total flavonoid content" plus "phenols" in peanuts, evaluating reducing sugars in sweet potatoes, and. In quality of rice evaluation, "NIR spectra" are utilized to ascertain both amylose and amino acid concentrations in rice kernels. To assess various algorithms' modeling performance, PLS calibration models were created using Feature Wavelengths (FWs) chosen by "BiPLS", "BiPLS-GSA", and "BiPLS-SABPSO". Models were evaluated against "CARS", "Full-PLS"," BiPLS-GA", "BiPLS-SA", and "BiPLS-BPSO".

In terms of wavelength selection, "BiPLS-GA"," BiPLS-SA", and "BiPLS-BPSO" were in line with "BiPLS-GSA" and "BiPLS-SABPSO". Lowest "RMSECV" wavelengths were chosen as "FWs" after five runs of "CARS"." R2"," RMSE", "rRMSE", and "RPD" were used to assess the model's efficiency. Rice protein regression models using multiple "FW" methods of choice outperformed the

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full spectrum model with “R^2s” greater than 0.94, “RMSEs” less than 0.24%, “rRMSEs” less than 3.41%, and “RPDs” greater than 4.03, showing superiority to full spectrum models. The “BiPLS-SABPSO” model detects accurately than the “BiPLS-GSA” model, with R^2 of 0.949 and 0.956, rRMSE of 2.621% and 3.118%, and RPD of 4.235 and 4.500 for Vset and Tset, meeting rice protein content determination needs. The SABPSO algorithm was found to be more stable than “GSA”, and "SABPSO" and "BiPLS" were combined to create "BiPLS-SABPSO", which demonstrated effective FWs optimization efficiency. Therefore, it was determined that the NIRS combination and "BiPLS-SABPSO wavelength” and choosing fersanew is a novel concept for a quick, easy, and inexpensive model for detecting the quality of agri commodities. [22]. Intermolecular hydrogen bonds may enable them to be distinguished by their absorption intensity even though the sugar configurations are similar and exhibit similar NIR absorption peaks [23]. The primary vibration simplified encompasses the stretching and bending of these linkages. In a broad sense, Monosaccharides (glucose, fructose), Disaccharides (sucrose, lactose), and Polysaccharides (amylose, fructan) are able to be analyzed via NIRS [24]. Although they are still detectable, the absorption bands associated with the O-H and C-H groups in sugars—sucrose has eight O-H functional groups, while glucose and fructose each have five—have a major influence on the spectrum variations [23].

A prompt and accurate quantification technique was developed and authenticated for the simultaneous and non-destructive measurement of the sugar levels(Glucose, Fructose, and Sucrose)in intact apples by utilizing Fourier transform near-infrared(FT-NIR)spectroscopy in diffuse reflectance mode. Spectral pre-processing techniques, including mean centering, the second derivative of Savitsky-Golay, and multiplicative scatter correction (MSC), were used. Partial least squares (PLS) regression analysis was used to build the calibration models, and the high-performance liquid chromatography (HPLC) method was followed for method validation. To obtain the correlation coefficient of determination (r) and the least root-mean-square error of prediction (RMSEP), the spectral range and PLS factors number were optimized.

The most effective models exhibited reliable predictions, with RMSEP and r values for glucose being 0.201 and 0.950, for fructose 0.298 and 0.968, and for sucrose 0.335 and 0.969, respectively. The FT-NIR assessment of sugar levels in intact apples was observed to be more adaptable and efficient compared to the HPLC approach [25]. Amylose plays a crucial role in determining the nutritional value of rice. The quantity of amylase present impacts various characteristics, including the texture, retrogradation behavior, and viscoelasticity dynamics of rice starch gel.

Traditional methods for measuring amylase levels, like the iodine binding technique, face limitations due to species-specific iodine affinity and inconsistencies in reproducibility among different research institutions. Consequently, there is a demand for more accurate and effective analytical approaches, such as Near-Infrared (NIR) spectroscopy, which provides non-invasive analysis requiring minimal sample preparation. A study conducted by [26] utilized Near Infrared Spectroscopy (NIRS) to forecast the amylase concentration in 186 samples of yam flour. Partial least squares (PLS) and

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convolutional neural networks (CNN) were the two calibration techniques developed and tested on a different dataset. Metrics, including the coefficient of determination (R2), root mean square error (RMSE), and the ratio of performance to deviation (RPD), were calculated using predictions from an independent validation dataset in order to evaluate the final model performances.

The examined models exhibited varying performances (specifically, R2 of 0.72 and 0.89, RMSE of 1.33 and 0.81, RPD of 2.13 and 3.49, respectively, for the PLS and CNN models). In accordance with the standards of quality for NIRS model prediction in the realm of food science, the PLS approach was deemed unsuccessful (RPD3 and R20.8) in the prediction of amylase content in yam flour, whereas the CNN model was validated as a dependable and effective methodology. This study demonstrated the feasibility of utilizing NIRS as a high-throughput phenol typing method to accurately predict amylase content, a critical factor in the quality and acceptability of yams, through the implementation of deep learning techniques.

III. Fats

Triglycerides, or fats, are lipids that consist of three fatty acid molecules and glycerol. Long hydrocarbon chains with a carboxyl group (-COOH) at one end are known as fatty acids. The chemical structures of dietary fats can be used to differentiate between saturated and unsaturated fats. At ambient temperature, saturated fats are solid due to the complete bonding of carbon atoms with hydrogen. These fats, which are composed mainly of saturated fatty acids, can be found in red meat, poultry, whole-milk dairy, butter, eggs, and specific oils, which have the potential to elevate LDL cholesterol and increase the risk of chronic heart disease if eaten in excess with no physical exercise.

Oils are lipids that are liquid at room temperature. They are typically derived from plants and fish. Common examples include olive oil, canola oil, and fish oil. Oils are rich in unsaturated fatty acids. This category includes both monounsaturated and polyunsaturated fats, which are considered beneficial for heart health [27]. Fatty acids; carbon-hydrogen (C-H) bonds are the most significant factors in the NIR absorption spectra. In the near-infrared region, these bonds show overtone and combination bands. Specifically, the second and third harmonics of the C- H stretching vibrations (approximately 1700-1800 nm and 2100-2300 nm, respectively) are conspicuous in NIR spectra and are employed to quantify fat content. The absorption of NIR is also substantially influenced by the methylene (CH2) and methyl (CH3) groups in fatty acids and triglycerides. The characteristic absorption bands that these groups produce are correlated with fat content due to the symmetric and asymmetric stretching and bending vibrations [28]. A study on hamburgers suggested a substitute analytical method for determining the fat level of industrial chicken, which is based on the Successive Projections Algorithm for Interval Selection in Partial Least Squares Regression (iSPA-PLS) and Near Infrared Spectroscopy (NIR).

In order to achieve this, 70 chicken hamburger samples were prepared with a fat content ranging from 14.27 to 32.12 mg kg^{-1}, in accordance with the Argentinean Food Codex maximum limit of 20% (w/w). After that, the NIR spectra were obtained. The intense spectral bands at 5150 cm^{-1} (a result of O-H stretch and deformation) are mainly responsible for the water. The first overtone of the O-H stretch

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vibration is 6900 cm−1. As an amide, the protein is associated with the absorption band at 5900 cm^{-1}. Other peaks at 8350cm−1 (the second overtone of-CH stretch), 5800–5700cm−1 (the first overtone of-CH stretch), and 4300–4260cm−1 (combined stretch and deformation band) correspond to fat content. The data were preprocessed using a variety of methods, including baseline correction, SNV, MSC, and Savitzky-Golay smoothing.

Additionally, the Interval PLS and full-spectrum PLS are implemented for comparison. With a window size of 19 points and a second-order polynomial, the first derivative Savitzky-Golay smoothing obtained the best results for the prediction set, with an RPD of 3.02, an RSP of 7.69%, an RMSEP of 1.59 mg kg-1, and a correlation coefficient of 0.94. Because it doesn't produce pollution and doesn't call for the use of chemical reagents or solvents, the suggested methodology is a better option than the conventional Soxhlet extraction method and is consistent with the core ideas of green chemistry. At a 95% confidence level, the results of the analysis of chicken hamburgers using the novel method agreed with the reference values. As such, it is very attractive for regular analysis. [29].

IV.CONCLUSION

The utilization of Near-Infrared (NIR) spectroscopy in food quality analysis has exhibited exceptional potential, offering a non-destructive, eco-friendly, and efficient approach to the monitoring of a variety of food components. The utilization of sophisticated machine learning algorithms, including neural networks, in conjunction with NIR spectroscopy has substantially improved the reliability and accuracy of food quality assessments. It has been demonstrated in research that NIR spectroscopy is capable of accurately detecting adulterants, predicting the talc content in wheat flour, and determining the moisture content in food products. In spite of its numerous benefits, there are still obstacles, including the necessity for user-friendly data processing solutions and robust calibration models. These obstacles are anticipated to be surmounted by advancements in data fusion and deep learning technologies, which will facilitate the implementation of NIR spectroscopy in the food industry on a more widespread scale. In conclusion, one promising method for guaranteeing the quality and safety of food is NIR spectroscopy, which is in line with the increasing demand for rapid and dependable food analysis techniques.

REFERENCES

1. Chen,Y., Michalak, M., & Agellon, L.B.(2018).Importance of nutrients and nutrient metabolism on human health. In Yale Journal of Biology and Medicine (Vol. 91, Issue 2).
2. Briones Alonso, E.,Cockx, L.,& Swinnen,J.(2018).Culture and food security. In Global Food Security (Vol. 17).https://doi.org/10.1016/j.gfs.2018.02.002
3. Garcia, S. N.,Osburn, B. I., & Jay-Russell, HM.T.(2020).One Health for Food Safety, Food Security, and Sustainable Food Production. In Frontiers in Sustainable Food Systems (Vol. 4).https://doi.org/10.3389/fsufs.2020.00001
4. Liang, N., Sun, S., Zhang, C., He, Y., & Qiu, Z. (2022). Advances ininfrared spectroscopy combined with artificial neural network for the authentication and traceability of food. In Critical Reviews in Food Science and Nutrition (Vol. 62, Issue 11).https://doi.org/10.1080/10408398.2020.1862045

ISBN: **978-93-343-9865-6**

5. Zareef, M., Chen, Q., Hassan, M. M., Arslan, M., Hashim, M. M.,Ahmad, W., Kutsanedzie, F. Y. H., & Agyekum, A. A. (2020). An Overview on the Applications of Typical Non-linear Algorithms Coupled With NIR Spectroscopy in Food Analysis. In Food Engineering Reviews (Vol.12, Issue2).
6. https://doi.org/10.1007/s12393-020-09210-7
7. Nobari Moghaddam, H.,Tamiji,Z.,AkbariLakeh,M.,Khoshayand, HGM. R., & Haji Mahmoodi, M. (2022). Multivariate analysis of foodfraud: A review of NIR based instruments in tandem with chemometrics In Journal of Food Composition and Analysis (Vol.107).
8. https://doi.org/10.1016/j.jfca.2021.104343
9. Valand,R., Tanna,S., Lawson,G., & Bengtström,L.(2020).A review of Fourier Transform Infrared (FTIR) spectroscopy used in food adulteration and authenticity investigations. In Food Additives and Contaminants-Part A Chemistry, Analysis, Control, Exposure and Risk Assessment (Vol.37, Issue1).https://doi.org/10.1080/19440049.2019.1675909
10. Sitorus,A., & Lapcharoensuk,R. (2022).A comprehensive overview of near infrared and infrared spectroscopy Engineering, 67(2), 465–486.https://doi.org/10.35633/INMATEH-67-47
11. Manggala, B., Chaichana, C., Syahputra, W. N. H., & Wongwilai, W.(2023). Pesticide Residues Detection in Agricultural Products. In Natural and Life Sciences Communications (Vol. 22, Issue 3).https://doi.org/10.12982/NLSC.2023.049
12. Tian,W., Li,Y., Guzman,C., Ibba,M.I., Tilley,M., Wang,D.,& He, Z. (2023).
13. Quantification of food bioactives by NIR spectroscopy: Current in sights, long-lasting challenges, and future trends. In Journal of Food Composition and Analysis (Vol.124).https://doi.org/10.1016/j.jfca.2023.105708
14. [11] Hussain,N., Sun,D.W., & Pu,H.(2019).Classical and emerging non-destructive technologies for safety and quality evaluation of cereals: A review of recent applications . In Trends in Food Science and Technology (Vol.91). https://doi.org/10.1016/j.tifs.2019.07.
15. Galvin-King, P., Haughey,S.A., & Elliott,C.T.(2020).The Detection of Substitution Adulteration of Paprika with Spent Paprika by the Application of Molecular Spectroscopy Tools. Foods, 9(7).https://doi.org/10.3390/foods9070944I.
16. Ndlovu,P.F.,Magwaza,L.S.,Tesfay,S.Z.,& Mphahlele,R.R.(2019).Rapid visible–near infrared (Vis–NIR) spectroscopic detection and quantification of unripe banana flour adulteration with wheat flour.Journal of Food Science and Technology, 56(12).https://doi.org/10.1007/s13197-019-04020-0
17. Houhou, R., & Bocklitz, T. (2021). Trends in artificial intelligence, machine learning, and chemometrics applied to chemical data. In Analytical Science Advances (Vol. 2, Issues 3–4).https://doi.org/10.1002/ansa.202000162
18. Kucharska-Ambrożej, K., & Karpinska, J. (2020). The application of spectroscopic techniques in combination with chemometrics for detection adulteration of some herbs and spices. In Microchemical Journal (Vol. 153). https://doi.org/10.1016/j.microc.2019.104278
19. Mishra,P., Passos,D., Marini, F., Xu,J., Amigo,J.M., Gowen, A. A., Jansen, J. J., Biancolillo, A., Roger, J. M.,Rutledge, D. N., & Nordon, A. (2022). Deep learning for near-infrared spectral datamodelling: Hypes and benefits. In TrAC - Trends in Analytical Chemistry (Vol. 157). https://doi.org/10.1016/j.trac.2022.116804
20. Nagy, M. M., Wang, S., & Farag, M. A. (2022). Quality analysis and authentication of nutraceuticals using near IR (NIR) spectroscopy: A comprehensive review of novel trends and applications In Trends in Food Science and Technology (Vol. 123).https://doi.org/10.1016/j.tifs.2022.03.005Y.
21. Vera Zambrano, M., Dutta, B., Mercer, D. G., MacLean, H. L., & Touchie, M. F. (2019). Assessment of A review. In *Trends in Food Science and Technology* (Vol. 88). https://doi.org/10.1016/j.tifs.2019.04.006
22. Staveren, D. van; (2020, April 20). *Moisture Analysis – Karl Fischer Titration, NIRS, or both? Metrohm.* . https://www.metrohm.com/en_in/discover/blog/20-21/moisture-analysis---karl-fischer-titration--nirs--or-both-.html
23. Kandala, C. V. K., Konda Naganathan, G., & Subbiah, J. (2008). NIR reflectance method to determine moisture content in food products. *Reflection, Scattering, and Diffraction from Surfaces, 7065*. https://doi.org/10.1117/12.793267
24. Sáez-Plaza, P., Michałowski, T., Navas, M. J., Asuero, A. G., &Wybraniec, S. (2013). An Overview

ISBN: **978-93-343-9865-6**

of the Kjeldahl Finish. *Critical Reviews in Analytical Chemistry*, *43*(4). https://doi.org/10.1080/10408347.2012.751786

25. Shi, S., Zhao, D., Pan, K., Ma, Y., Zhang, G., Li, L., Cao, C., & Jiang, Y. (2023). Combination of near-infrared spectroscopy and key wavelength-based screening algorithm for rapid determination of rice protein content. *Journal of Food Composition and Analysis, 118*. https://doi.org/10.1016/j.jfca.2023.105216
26. Simeone, M. L. F., Parrella, R. A. C., Schaffert, R. E., Damasceno, C. M. B., Leal, M. C. B., & Pasquini, C. (2017). Near infrared spectroscopy determination of sucrose, glucose and fructose in sweet sorghum juice. *Microchemical Journal*, *134*. https://doi.org/10.1016/j.microc.2017.05.020
27. López, M. G., García-González, A. S., & Franco-Robles, E. (2017). Carbohydrate Analysis by NIRS-Chemometrics. In *Developments in Near-Infrared Spectroscopy*. https://doi.org/10.5772/67208
28. Liu, Y., Ying, Y., Yu, H., & Fu, X. (2006). Comparison of the HPLC method and FT-NIR analysis for quantification of glucose, fructose, and sucrose in intact apple fruits. *Journal of Agricultural and Food Chemistry*, *54*(8). https://doi.org/10.1021/jf052889e
29. Houngbo, M. E., Desfontaines, L., Diman, J. L., Arnau, G., Mestres, C., Davrieux, F., Rouan, L., Beurier, G., Marie-Magdeleine, C., Meghar, K., Alamu, E. O., Otegbayo, B. O., & Cornet, D. (2024).
30. Sanders, T. A. B. (2016). Introduction: The Role of Fats in Human Diet. The Role of Fats in Human Diet. In *Functional Dietary Lipids: Food Formulation, Consumer Issues and Innovation for Health*. https://doi.org/10.1016/B978-1-78242-247-1.00001-6
31. Núñez-Sánchez, N., Martínez-Marín, A. L., Polvillo, O., Fernández-Cabanás, V. M., Carrizosa, J., Urrutia, B., & Serradilla, J. M. (2016). Near Infrared Spectroscopy (NIRS) for the determination of the milk fat fatty acid profile of goats. *Food Chemistry*, *190*. https://doi.org/10.1016/j.foodchem.2015.05.083
32. Krepper, G., Romeo, F., Fernandes, D. D. de S., Diniz, P. H. G. D., de Araújo, M. C. U., Di Nezio, M. S., Pistonesi, M. F., & Centurión, M. E. (2018). Determination of fat content in chicken hamburgers using NIR spectroscopy and the Successive Projections Algorithm for interval selection in PLS regression (iSPA-PLS). *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, *189*. https://doi.org/10.1016/j.saa.2017.08.046

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Evaluating Machine Learning Approaches for Early Detection of Alzheimer's Disease: Bridging Gaps in Rural Healthcare

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Abstract-Now a days common people are going through erratic schedule and suffering from many neurological diseases. A progressive neurological disorder in older adults termed as Alzheimer's disease occurs because of abnormal accumulations of two harmful proteins: amyloid, which forms plaques around neurons, and protein tau, which creates tangles inside the brain cells. Although it appears to occur at old age, the disease develops at slow pace at early stage gradually leading to deterioration in memory, thinking capability, decision making and performing regular activities. Research to date indicates that there is no cure to stop the progression of Alzheimer's disease, which makes early diagnosis crucial for effective management and care. Early prediction is specifically tough in rural healthcare settings, due to limited access of neurologists, scarcity of diagnostic facilities and updated clinical resources leads to delay of disease detection and treatment. Considering these facts, contribution of Machine Learning/Deep Learning along with advanced sensors for monitoring the healthcare has proved to be incredible and offers a positive pathway to bridge the gap by mitigating these challenges. In this paper, we analyze patient data related to Alzheimer's disease using various Machine Learning techniques to predict the likelihood of the condition in suspected cases. Specifically, we employ algorithms such as Support Vector Machine (SVM), Decision Tree (DT), and XGBoost. The study emphasizes a comprehensive evaluation of Machine Learning methods, comparing different data processing approaches and assessing their accuracy, efficiency, and error rates, while also discussing the strengths and limitations of each algorithm. Furthermore, the proposed model aims to enable early-stage prediction of Alzheimer's disease, which can help reduce patient risk and lower the mortality rate associated with the condition and considers feasibility for deployment in rural healthcare infrastructure

Keywords- Alzheimer, Machine Learning, MMSE, SVM, XGBOOST, Decision Tree

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I. INTRODUCTION

The causes of Alzheimer's disease arise from a combination of age-related brain changes along with genetic, environmental, and lifestyle factors [1]. The condition primarily affects individuals over the age of 65, though in some cases, it may develop earlier, during a person's 40s or 50s, which is referred to as early-onset Alzheimer's disease [2]. On average, patients live with this illness for 8 to 10 years, and approximately one in eight people over the age of 65 are affected. The Mini-Mental State Examination (MMSE) is widely recognized as a cognitive assessment method and plays a vital role in identifying Alzheimer's disease [3]. At the stage of MCI, individuals show higher levels of memory loss and cognitive challenges compared to what is usual for their age group. In this condition, Mild Cognitive Impairment (MCI) often leads to memory loss, and is likely to progress into dementia. Since Alzheimer's disease has no definitive cure, identifying it at the MCI stage is essential, as it enables individuals to adopt healthier lifestyle practices and make better plans for managing memory decline [4].We utilize SVM, Decision Tree, and XGBoost algorithms in this research to analyze their predictive efficiency for Alzheimer's disease. SVM is known by its good generalization ability and robustness to high dimensional data, like those used in this paper. Decision Trees have been applied in Alzheimer's detection, with new approaches comparing enhanced Decision Tree models against traditional versions. XGBoost, on the other hand, utilizes parallel tree boosting and is recognized as one of the most powerful machine learning libraries for tasks such as regression, classification, and ranking.

Organization of the paper is as follows: Section II discusses related literature, Section III describes the methodology, and Sections IV and V present results and conclusions.

II. LITERATURE REVIEW

A deep learning approach was proposed in [5] which integrates brain network analysis with clinically significant information such as the subject's age and gender for aimed at identifying Alzheimer's disease in its early stages. In this method, data obtained from resting-state functional MRI (R-fMRI) scans is used to estimate functional connectivity across different brain regions. These functional networks are then modeled using an autoencoder, which helps in identifying detailed patterns connected to early Alzheimer's symptoms and the transition into MCI . For this work, the dataset was sourced from the ADNI database. For early diagnosis, raw R-fMRI data first undergoes preprocessing. From this, time-series data in the form of a 90×130 matrix is generated, representing blood oxygen levels across brain regions over time. This information is then transformed into a 90×90 correlation matrix to construct brain networks. A three-layer autoencoder is applied to extract meaningful network features, simulating neural system growth and capturing essential attributes of the brain. Given the restricted size of the dataset, the k-fold cross-validation technique was used to minimize overfitting issues. Additionally, a multistage classifier using machine learning algorithms such as Support Vector Machine (SVM) was explored to improve classification performance across Na¨ıve Bayes and K-Nearest Neighbor (KNN) methods were proposed in [6] for classifying different subject groups. In addition, a Particle Swarm

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Optimization (PSO) technique was applied to identify the most relevant biomarkers indicating Alzheimer’s disease (AD) or Mild Cognitive Impairment (MCI). The dataset was obtained from the Alzheimer’s Disease Neuroimaging Initiative (ADNI), and the MRI scans underwent preprocessing before further analysis. Then feature is selected in terms of volumetric and thickness measurements. To distinguish between subjects, algorithms such as Gaussian Na¨ıve Bayes (GNB), K-Nearest Neighbor (KNN), and Support Vector Machine (SVM) have been employed. At the initial stage of classification, the GNB classifier was used to separate subjects into Alzheimer’s disease (AD), Mild Cognitive Impairment (MCI), and Normal Control (NC) groups. In later stages, SVM and KNN were applied to further analyze the subjects based on the outcomes of the initial classification. In [7] the authors proposed a model that utilizes consecutive MRI scans to track disease progression over time, enabling more precise diagnosis. Specifically, MRI brain images captured at six different time intervals (each six months apart) from the ADNI database were used as input. A 2×2×2 convolutional operation was applied to extract features, followed by pooling of neurons through linear combinations. The architecture included fully connected layers that transmitted data through nonlinear activation functions, culminating in a softmax layer. This softmax function assigned probabilities (ranging from 0 to 1) to each class, ensuring that the sum of outputs equaled 1. It was optimized using backpropagation to predict class probabilities accurately. This method allowed dimensional and longitudinal features to be integrated for distinct identification. In [8] the authors introduced a multimodal framework where medical images were used for training two independent convolutional neural networks (CNNs). One CNN processed MRI scans, while the other handled PET scans. The CNN structure included a sampling layer for downscaling, convolutional and fully connected layers, pooling layers, and finally an output layer. The advantage of this approach is its ability to combine clinical neuropsychological data with neuroimaging results, thereby enhancing diagnostic accuracy.

III. METHODOLOGY

In this project, three Machine Learning (ML) algorithms are applied to predict Alzheimer’s disease at an early stage. The following subsections provide a detailed discussion of these algorithms.

I. *Machine Learning Algorithm*

In this paper we have used three ML algorithms are discussed below:

- *Support Vector Machine:* In n-dimensional space, there may be several lines or decision boundaries used to separate the classes, but we must choose the optimum decision boundary that best aids in classifying the data points. The hyper plane of SVM is a name for this optimal boundary [9]. The dataset’s features determine the hyper plane’s dimensions, therefore if there are just two features (as in the example image), the hyper plane will be a straight line. Additionally, if there are three features, the hyper plane will only have two dimensions. We always build a hyper plane with a maximum margin,

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or the greatest possible separation between the data points.By presenting an example, the SVM algorithm's operation may be better understood. Consider a dataset with two tags (green and blue), two features (x1 and x2), and two tags. We're looking for a classifier that can classify the 14 pair of coordinates (x1, x2) as either green or blue.The SVM technique may be used to identify the optimal line or decision boundary; this line or area is known as a hyper plane. Which point between the two classes is closer is determined using the SVM algorithm. These areas of attention are known as help vectors [10]. The margin is the separation of the vectors from the hyper plane. The goal of SVM is to maxim this margin. The hyper plane with the largest margin is the ideal hyper plane. SVM is a powerful controlled computation that performs well on smaller yet more complicated datasets. Support Vector Machine, often known as SVM, may be used for both relapse and order tasks, although they typically perform well in characterization-related problems. They were invented in the 1990s and quickly became quite popular. They are now the most often used method for developing algorithms that work well with little adjustments. Depending on how many characteristics you have, you can decide between SVM and logistic regression. SVM performs better with a condensed and compact dataset. The best way to test out logistic regression is often to use it. SVM can be used without a kernel if it doesn't

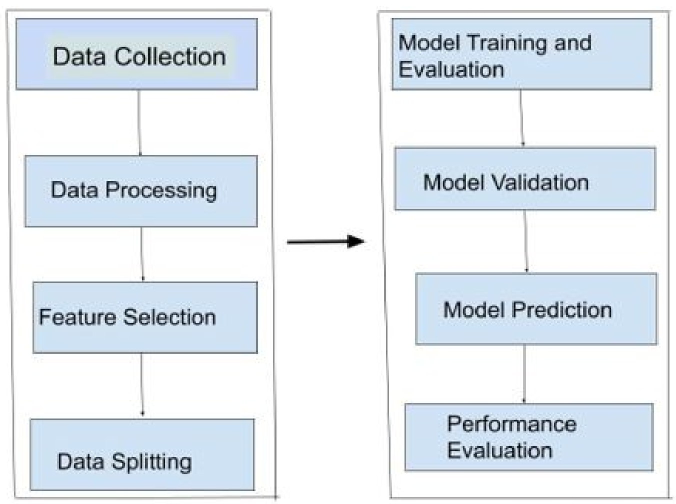

Fig. 1. Proposed workflow

perform well [11]. Logistic regression and SVM both operate similarly in the absence of a kernel, however your features may affect how efficiently they work.SVM is characterized to such an extent that it is characterized as far as the help vectors just, we don't need to stress over different perceptions since the edge is made utilizing the focuses which are nearest to the hyper plane (support vectors), while in calculated relapse the classifier is characterized over every one of the places. As a result, SVM enjoys some inherent speedups.

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o *Decision Tree:* Decision Trees are structured like trees, where data is recursively partitioned based on selected feature values. Each split divides instances into subsets, where the intermediate subsets form internal nodes and the final outcomes are represented by leaf nodes [12] .Decision Trees are especially useful for identifying significant interactions between features and the target variable.They are called "Decision Trees" because their structure resembles a tree: starting from a root node, the tree expands into branches and eventually reaches leaf nodes that represent decisions or outcomes [13].In this structure, there are two node types: Decision Nodes, responsible for making splits and branching, and Leaf Nodes, which denote final outcomes with no further branching.The process of testing or making decisions is carried out using the dataset provided, and the model is often illustrated using graphical representations. This visual format helps to outline all possible solutions or decisions that can be derived under given conditions. To construct a Decision Tree the CART (Classification and Regression Tree) algorithm is commonly used. This algorithm works by asking a series of questions, typically in a binary format (Yes/No), and based on the answers, the tree is split into different subtrees. Decision Trees resemble the way humans make decisions, which makes them intuitive and easy to interpret [14]. The underlying logic is straightforward because of the tree-like structure: the procedure starts at the root node, where the algorithm examines the value of a chosen attribute. Depending on the evaluation, it proceeds along the corresponding branch to the next node. At each subsequent node, the algorithm performs additional comparisons with other attributes, continuing this process until a final classification or decision is reached at the leaf nodes

o *XGBoost:* XGBoost is a powerful and scalable gradient boosting library designed for building machine learning models efficiently. As an ensemble technique, it integrates the outputs of several simpler models to generate a stronger and more precise outcome. The name "XGBoost" stands for "Extreme Gradient Boosting," and it has become extremely popular in the machine learning community due to its ability to handle large datasets effectively and deliver high performance across a variety of tasks, such as classification and regression [15]. One of XGBoost's key strengths is its ability to handle missing values naturally, allowing it to process real-world datasets without extensive preprocessing. Additionally, it supports parallel computation, which makes training on large datasets faster and more practical.

II. *Dataset Description*

This dataset comprises a longitudinal collection of 150 individuals whose ages range between 60 and 96 years. Each participant underwent multiple scans, with at least one year between each visit, resulting in a total of 373 recorded imaging sessions. For each participant, the dataset provides three to four separate T1-weighted MRI scans, each obtained during a single scanning session. The

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participant pool consists of both men and women who are all right-handed. Among the participants, 72 individuals consistently exhibited no signs of dementia over the course of the study. Additionally, 64 participants were

Model	Accuracy	Precision	Recall	F1-Score
XGBoost	83.92%	0.81	0.85	0.83
Decision tree	79.46%	0.74	0.83	0.79
Support vector machine	77.67%	0.71	0.88	0.79

Fig. 2. Comparison of Performance of different ML model

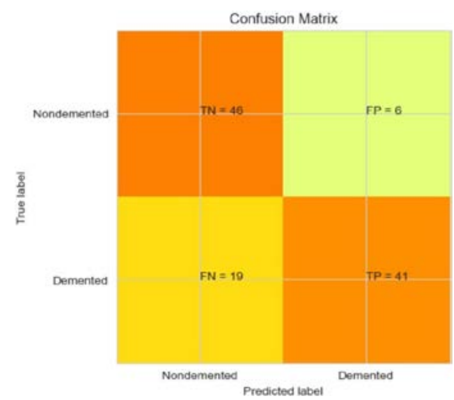

Fig. 3. Confusion Matrix of SVM

initially diagnosed with dementia during their initial assessments and continued to exhibit dementia in subsequent scans. This group consisted of 51 participants who had been identified as having mild to moderate Alzheimer's disease. Furthermore, 14 participants initially presented as no demented but were subsequently diagnosed with dementia during later visits.

III. *Data Preprocessing*

In this phase, various data mining techniques are employed to clean and preprocess the dataset. This includes handling missing values, extracting relevant features, and transforming them as needed. Missing values can be addressed in two primary ways. The simplest approach is to remove the rows containing missing data. Alternatively, missing values can be filled using imputation methods. In this study, nine rows with missing values in the SES attributes were removed, and the median value was used to perform imputation for the remaining missing entries.

IV. Prediction Model Design and Result Analysis

As mentioned earlier, we developed a predictive model utilizing three different machine learning

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techniques: Support Vector Machine (SVM), Decision Tree, and XGBoost. The workflow of the prediction system is presented in Fig. 1. The performance of the resulting models is compared by accuracy, recall, precision, and F1 scores. Fig. 3, Fig. 4, and Fig. 5 represent the confusion matrices of SVM, Decision Tree, and XGBoost respectively. Table 1 presents the evaluation metrics—accuracy, recall, precision, and F1 scores—for the three predictive approaches.

V. CONCLUSION

Alzheimer's disease is a significant public health concern. Since there is currently no cure, efforts are focused on reducing risk, providing early interventions, and accurately diagnosing symptoms at an early stage. As highlighted in the literature, numerous studies have attempted to detect Alzheimer's disease using various machine learning algorithms and microsimulation techniques. However, identifying the most relevant features for early detection remains a challenging task. Future work will aim to extract and analyze new features that could enhance the early detection of Alzheimer's, while also removing redundant or irrelevant features from existing datasets to improve predictive accuracy. By incorporating metrics such as MMSE scores and education levels into our model, it will be better equipped to differentiate between healthy individuals and those with

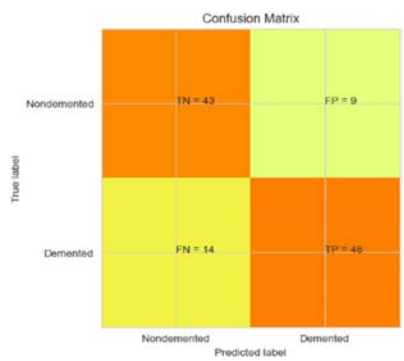

Fig. 4. Confusion Matrix of Decision Tree

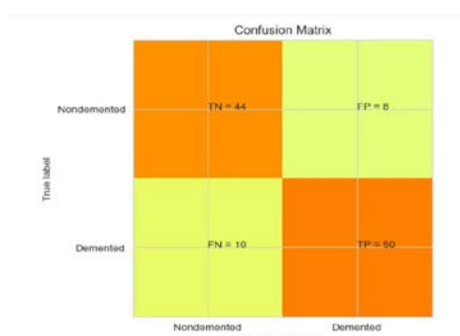

Fig. 5. Confusion Matrix of XGBoost

Alzheimer's. This study compares and evaluates different machine learning algorithms, including pre-processing and prediction steps for Alzheimer's detection. In the proposed approach, missing

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values were addressed by deleting columns in the SES and MMSE attributes. The experimental findings show that the XGBoost algorithm surpasses the other classifiers, obtaining the highest accuracy of 83

REFERENCES

1. Sarah Parisot, Sofia Ira Ktena, Enzo Ferrante, Matthew Lee, Ricardo Guerrero, Ben Glocker, and Daniel Rueckert. Disease prediction using graph convolutional networks: Application to autism spectrum disorder and alzheimer’s disease. *Medical Image Analysis*, 48:117–130, 2018.
2. Aunsia Khan and Muhammad Usman. Early diagnosis of alzheimer’s disease using machine learning techniques: A review paper. In *2015 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K)*, volume 01, pages 380–387, 2015.
3. Baiying Lei, Mengya Yang, Peng Yang, Feng Zhou, Wen Hou, Wenbin Zou, Xia Li, Tianfu Wang, Xiaohua Xiao, and Shuqiang Wang. Deep and joint learning of longitudinal data for alzheimer’s disease prediction. *Pattern Recognition*, 102:107247, 2020.
4. Tong Tong, Katherine Gray, Qinquan Gao, Liang Chen, and Daniel Rueckert. Multi-modal classification of alzheimer’s disease using nonlinear graph fusion. *Pattern Recognition*, 63:171–181, 2017.
5. Ronghui Ju, Chenhui Hu, pan zhou, and Quanzheng Li. Early diagnosis of alzheimer’s disease based on resting-state brain networks and deep learning.
6. *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, 16(1):244–257, 2019.
7. K.R. Kruthika, Rajeswari, and H.D. Maheshappa. Multistage classifier-based approach for alzheimer’s disease prediction and retrieval. *Informatics in Medicine Unlocked*, 14:34–42, 2019.
8. J. Neelaveni and M.S.Geetha Devasana. Alzheimer disease prediction using machine learning algorithms. In *2020 6th International Conference on Advanced Computing and Communication Systems (ICACCS)*, pages 101–104, 2020.
9. Fan Zhang, Zhenzhen Li, Boyan Zhang, Haishun Du, Binjie Wang, and Xinhong Zhang. Multi-modal deep learning model for auxiliary diagnosis of alzheimer’s disease. *Neurocomputing*, 361:185–195, 2019.
10. Ragavamsi Davuluri. A survey of different machine learning models for alzheimer disease prediction. *International Journal of Emerging Trends in Engineering Research*, 8:3328–3337, 07 2020.
11. Theodoros Evgeniou and Massimiliano Pontil. Support vector machines: Theory and applications. volume 2049, pages 249–257, 09 2001.
12. Yongli Zhang. Support vector machine classification algorithm and its application. In Chunfeng Liu, Leizhen Wang, and Aimin Yang, editors, *Information Computing and Applications*, pages 179–186, Berlin, Heidelberg, 2012. Springer Berlin Heidelberg.
13. Dana AL-Dlaeen and Abdallah Alashqur. Using decision tree classification to assist in the prediction of alzheimer’s disease. In *2014 6th International Conference on Computer Science and Information Technology (CSIT)*, pages 122–126, 2014.
14. Mingwu Jin and Weishu Deng. Predication of different stages of alzheimer’s disease using neighborhood component analysis and ensemble decision tree. *Journal of Neuroscience Methods*, 302:35–41, 2018. A machine learning neuroimaging challenge for automated diagnosis of Alzheimer’s disease.
15. Morshedul Bari Antor, A. H. M. Shafayet Jamil, Maliha Mamtaz, Mohammad Monirujjaman Khan, Sultan Aljahdali, Manjit Kaur, Parminder Singh, and Mehedi Masud. A comparative analysis of machine learning algorithms to predict alzheimer’s disease. *Journal of Healthcare Engineering*, 2021:9917919, Jul 2021.
16. Laboni Akter and Ferdib-Al-Islam. Dementia identification for diagnosing alzheimer’s disease using xgboost algorithm. In *2021 International Conference*

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Smart Village Adoption in Healthcare: Bridging Gaps Through Technology and Innovation- A Review

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Abstract- The concept behind the 'Smart Village' is that technology is a major force behind development since it improves rural residents' access to education, electricity, agriculture, healthcare, entrepreneurship, local business prospects, and internet connectivity. One of the most crucial is healthcare, as access to care is often difficult for those living in rural areas. Modern technologies like telemedicine, solar energy, artificial intelligence (AI), and the Internet of Things (IoT) can improve the efficiency, accessibility, and affordability of healthcare delivery in rural areas. By exploring innovations such as health kiosks, the integration of renewable energy, mobile apps, artificial intelligence-based diagnostics, preventive health policies, and mental health coverage under smart village uptake, this article explores how smart healthcare solutions can help close gaps in rural healthcare delivery.

Keywords: Smart Village, healthcare, health kiosks, artificial intelligence, mental health.

I. Introduction

The idea of "smart villages" seeks to enhance rural communities' quality of life by utilizing cutting-edge ideas and digital technologies [1]. An important part of this change is healthcare, which is essential for development. Rural healthcare delivery is frequently hampered by a lack of awareness, a lack of qualified experts, and restricted access to medical facilities. Technologies like telemedicine, mobile health apps, remote diagnostics, and data-driven decision-making can close these gaps through the implementation of smart villages [2]. This study investigates how improving the accessibility, affordability, and effectiveness of medical services in rural communities can be achieved by incorporating smart healthcare solutions into the smart village framework [3]. By analyzing the settings, purposes, and clinical settings where health kiosks are used; whether or not usability testing of health kiosks is being published, and if so, how; and what the factors that encourage and hinder kiosk implementation are, we hope to determine the current and future roles of health kiosks[4]. Height and weight are measured automatically by the kiosk, and information is given regarding body composition, including muscle mass, BMI, and percentage of body fat[5]. The users can quickly check their pulse rate and oxygen saturation first, and then their blood

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pressure is monitored with a completely automated arm cuff, with the results emerging in 20 seconds. For cardiac health evaluation, the kiosk performs a 6 or 12 lead ECG scan, which is important in delivering information regarding
cardiac function[6]. The digital stethoscope translates acoustic sounds into electric signals to more effectively examine heart and lung sounds[7]. Also included are clinically accepted self-administered tests for depression and anxiety for mental health screening. Added to this, solar energy significantly lowers electricity costs by ensuring hospitals have continuous power for crucial care during outages. This frees up funds for better patient services and care while enabling vital equipment to operate dependably. Again these days, through the use of AI models, remote diagnostics, illness outbreak prediction, and treatment plan personalization, rural healthcare gaps are filled. In underprivileged, isolated communities, this enhances access to critical medical knowledge and leads to better health outcomes.

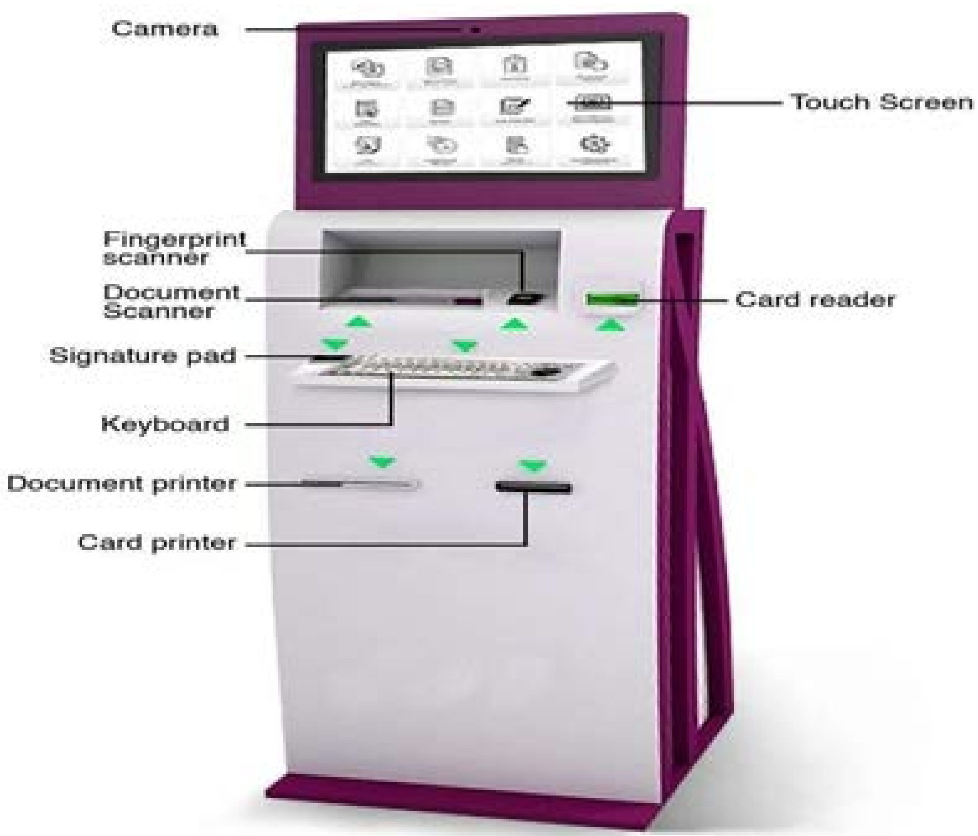

Fig1. A Smart Health Kiosk System [8]

II. LITERATURE REVIEW

Jacobsen et al., 2023 describe that the creation and application of smart technologies have promised for enhancing healthcare, mobility, and governance, among other facets of rural living [9]. Intelligent health kiosks possess integrated sensors that assist in monitoring the patient's vital signs such as blood pressure, heart rate, body temperature, blood oxygen saturation, weight, and BMI. In addition to displaying the patient's vital signs, health kiosk possesses state-of-the-art diagnostic equipment such as body composition analysis, blood glucose, and cholesterol test. The health kiosk is touch screen and easy to use with instructions on how to use a kiosk on a step-by-step basis making it accessible to almost everyone and individuals with lower health literacy. Users can create, store, and share their health records to be used in the future with certain smart health kiosks. This gives a physician access to the patient's medical history. Mobile apps and websites can access users'

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health data because it is stored in the cloud [10]. The consumer is able to get knowledge about his or her health condition at any time without going for an appointment using the smart health kiosk. They save the user from taking repeated trips to healthcare professionals, clinics, doctors, or hospitals. Patients are able to maintain a record of their health information over a long time, and these smart health kiosk records and stores the results.

Shahsavari et al.,2024 stated that solar energy, as a clean and renewable resource, offers a promising solution to address the energy needs of rural healthcare facilities [11]. Solar energy is harnessed through photovoltaic (PV) panels, which convert sunlight into electricity, and solar thermal systems, which trap and store solar heat for purposes such as water heating and space heating [12]. Solar panels are mounted on roofs or nearby open spaces to absorb sunlight and transform it into direct current (DC) electricity via the photovoltaic effect. This electricity is stored in batteries with the help of an inverter, converting DC to alternating current (AC) for medical devices, lights, refrigeration, water pumping equipment, and communication devices. Guaranteed power supply for life-saving medical equipment, vaccine refrigeration, diagnosis, and emergency services, especially maternal services and round-the-clock services. Foley et al.,1995 stated that solar systems are free-standing, minimizing diesel generator usage and risks of fuel supply during adverse weather or outreach issues [13]. Reliable power enhances staff retention, service quality, and patient outcomes, as well as avoids vaccine spoilage and equipment damage due to voltage fluctuations.

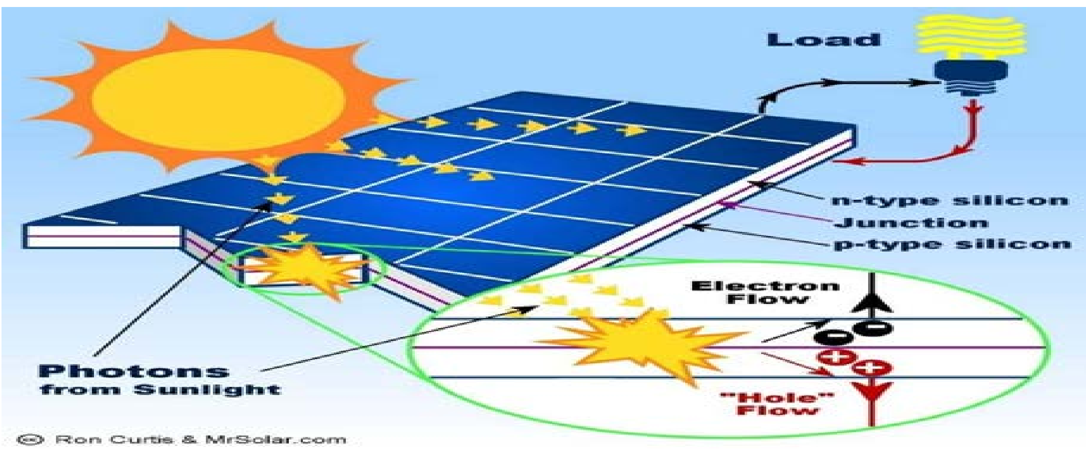

Fig 2. Illustration of solar panel operation (photons, electrons, holes, load) [14]

Effective administration of patient records and referrals and gathering and reporting of health statistics is significantly enhanced when computerized services, software, and solutions are made possible by electricity access. Solar powered solutions can also be used to power the staff quarters, supplementing the healthcare center related interventions - which facilitates the recruitment and retention of qualified health workers and decreasing employees' absenteeism in health facilities.

Now considering smart mental health care, which is the application of innovative technologies like artificial intelligence, mobile apps, wearable technology, telemedicine, and electronic medical records to improve the delivery, monitoring, and personalization of mental health services for individuals and populations.

Smart mental care couples digital systems and devices with mainstream mental health treatment to facilitate dynamic access to information, tailored interventions, monitoring at a distance and enhanced treatment adherence. These are exemplified by AI chatbots for therapy, mood-tracking phone apps, wearable monitors in real time and telemedicine platforms for online consultations [15]. Mobile Apps offer psychoeducation, symptom monitoring, guided exercises, and direct contact with mental health professionals.AI and Machine Learning assist in diagnosis through the examination of behavioral and

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physiological information; facilitate predictive care in illness such as depression or psychosis. Wearables and IoT Devices track sleep, activity, and vital signs to assist with early intervention and continued care [16]. Reduces access obstacles by enabling remote therapy and consultations, especially in underprivileged or rural communities. By reducing logistical and geographic obstacles, these actions help reach underserved or distant groups. Digital interoperability and computerized record keeping speed up screening, referral, and follow-up processes. Analyzes individual behavioral data to provide tailored interventions that improve efficacy and user engagement while enabling scalable, less expensive delivery than in-person care.

Example programs include the SMART Mental Health Project in India achieved significant service use increases and better outcomes in rural communities through the use of digital tools, electronic referrals, and community health worker integration [17]. Smart mental care is quickly revolutionizing mental health prevention, diagnosis, and treatment but must be carefully designed and regulated to provide equitable, secure, and effective care for everyone.

AI-driven diagnostic tools, according to Kothinti, R.R., 2024, are advanced medical technologies that analyze medical data and assist in illness identification by utilizing artificial intelligence techniques including machine learning, deep learning, and natural language processing [18]. Improving patient outcomes, reducing healthcare costs, and increasing survival rates all depend on early disease identification. Early diagnosis improves treatment outcomes for the majority of life-threatening conditions, including cancer, heart disease, and neurological diseases. Machine learning (ML) and deep learning (DL) form the backbone of AI-based diagnostic devices, facilitating automatic pattern detection and predictive analytics in healthcare[19]. ML algorithms process structured and unstructured health information, detecting correlations that aid in disease diagnosis. Artificial neural networks are used in deep learning, a subfield of machine learning, to understand and analyze complex data with extreme precision, such as genetic codes and medical imaging. For example, Convolutional Neural Networks (CNNs) are widely used in radiology to detect anomalies, fractures, and malignancies in medical imaging, greatly increasing the accuracy of diagnosis. Computer systems can read and interpret unstructured material found in clinical notes, research articles, and electronic health records (EHRs) thanks to Natural Language Processing (NLP). NLP allows automated extraction of patient-related data, enabling doctors to make well-informed decisions based on previous medical histories, symptoms, and response to treatments. By converting vast amounts of textual data into structured, usable insights, NLP improves diagnostic accuracy, reduces administrative burdens, and enhances clinical decision support systems (CDSS). Medical imaging diagnostics heavily relies on computer vision, an area of artificial intelligence that focuses on picture interpretation. AI-driven predictive analytics utilizes these datasets to assess disease risks, forecast potential outbreaks, and recommend personalized treatment plans.

I. DISCUSSION

- By supplying clean, reliable, and affordable electricity—a necessity for efficiently and safely delivering medical services in off-grid or isolated communities—solar energy makes rural healthcare possible.
- For most women and children, adequate, continuous lighting during pregnancy and delivery, along with tools like an ultrasound or a fetal heart rate monitor, can be life-saving.
- Maternal and child health care requirements like baby warmers, delivery suction machines, phototherapy, lighting and fans are the ones that can be solar-powered
- ICT is an important facilitator of broader "telemedicine" initiatives, which have proven to be highly effective in enabling activities such as distant health worker consultations and continuous training and education.
- Cancer detection is likely one of the most exciting applications of AI in medicine, where earlier detection improves survival outcomes.
- Through the identification of minute anomalies in breast tissue that human radiologists might overlook, artificially intelligent mammography analysis enhances the early detection of breast cancer. AI-powered screening expedites the detection process and improves diagnosis accuracy.
- By accurately identifying nodules and other lesions, AI algorithms trained on CT images and chest X-rays help detect lung cancer early. Similarly, AI-powered dermatology apps use deep learning on skin lesions to distinguish between benign and malignant conditions such as melanoma[20].
- AI is transforming cardiovascular disease (CVD) diagnosis and risk forecasting by analyzing

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medical imaging, electrocardiograms (ECG), and patient data[21]

- AI in Neurological Disorders such as Early Detection of Alzheimer's and Parkinson's Disease AI tools analyze speech patterns, motor functions, and cognitive examinations to detect early signs of Alzheimer's and Parkinson's. Machine learning algorithms can track the evolution of the disease, allowing for medication interventions that can stop cognitive loss.
- AI enhances early detection and aids in the development of focused therapeutics by identifying biomarkers for illnesses like Alzheimer's [22].
- AI uses predictive modeling and quick diagnostic tests to improve the identification, monitoring, and control of infectious illnesses.

II. CONCLUSION

The smart village concept shows how technology may be a unifying force in rural care by eliminating the long-standing barriers of accessibility, affordability, and quality. By incorporating innovations like telemedicine, solar-powered facilities, health kiosks, and AI-based diagnostics, rural communities can access scalable and sustainable healthcare solutions. In addition to promoting early disease identification and preventative care, these technologies enhance regional healthcare capabilities and lessen dependency on metropolitan areas. Furthermore, digital connection and renewable energy support the reliability of medical infrastructure, while AI-driven technologies improve diagnostic accuracy and evidence-based decision- making. Together, these programs improve rural communities, encourage diversity, and close the healthcare gap between urban and rural areas.

REFERENCES:

[1] Lucan, J., Pokmajević, M. and Kunčič, U., 2024. Impact of technology on the quality of life of elderly people in smart villages: Literature review. IFAC-Papers OnLine, 58(3), pp.262-267.

[2] Perez, K, Wisniewski, D., Ari, A., Lee, K, Lieneck, C, & Ramamonjiarivelo, Z. (2025, February). Investigation into application of Al and telemedicine in rural communities: a systematic literature review. In Healthcare (Vol. 13. No. 3. p.324). MDPI.

[3] Renukappa, S., Suresh, S., Abdalla, W., Shetty, N., Yabbati, N., & Hiremath, R. (2024). Evaluation of smart village strategies and challenges. Smart and Sustainable Built Environment, 13(6), 1386-1407. [4]Jakobsen , K., Mikalsen, M. and Lilleng, G., 2023. A literature review of smart technology domains for research on smart rural communities. Technology in society, 75, p.102397.

[5] Borga, M., West, J., Bell, J.D., Harvey, N.C., Romu, T., Heymsfield, S.B. and Dahlqvist Leinhard, O., 2018. Advanced body composition assessment: from body mass index to body composition profiling. Journal of Investigative Medicine, 66(5), pp.1-9.

[6] Sigit, R., Arief, Z. and Bachtiar, M.M., 2015. Development of Healthcare Kiosk for Checking Heart Health. EMITTER International Journal of Engineering Technology, 3(2), pp.99-114.

[7] Leng, S., Tan, R.S., Chai, K.T.C., Wang, C., Ghista, D., & Zhong, L. (2015). The electronic stethoscope. Biomedical engineering online,14(1),66.

[8] Lyu, Y., Vincent, C. J., Chen, Y., Shi, Y., Tang, Y., Wang, W., ... & Ding, J. (2015). Designing and optimizing a healthcare kiosk for the community. Applied ergonomics, 47, 157-169.

[9] Jawhar, S. (2024). Smart City Development in Bodø: Is it possible to Harmonize Urban and Rural Needs? (Master's thesis, Nord universitet).

[10] Lo'ai, A. T., Mehmood, R., Benkhlifa, E., & Song, H. (2016). Mobile cloud computing model and big data analysis for healthcare applications. IEEE Access, 4, 6171-6180.

[11] Izuka, U., Ojo, G. G., Ayodeji, S. A., Ndiwe, T. C., & Ehiaguina, V. E. (2023). Powering rural healthcare with sustainable energy: a global review of solar solutions. Engineering Science & Technology Journal, 4(4), P-No.

[12] Ewim, D. R., Olatubosun, S. A., & Abolarin, S. M. Energy Alternatives and Efficiency Options for Sustainable Development in Nigeria. In Localized Energy Transition in the 4th Industrial Revolution (pp. 225-245). CRC Press.

[13] Foley, G. (1995). Photovoltaic applications in rural areas of the developing world (Vol. 304).

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World Bank Publications.
[14] Maghraby, Y. R., Ibrahim, A. H., Tayel, A., Azzazy, H. M. E. S., & Shoeib, T. (2025). Towards sustainability via recycling solar photovoltaic Panels, A review. Solar Energy, 285, 113085.
[15] Anser, M. K., Nabi, A. A., Ahmad, I., Abro, M. M. Q., & Zaman, K. (2025). Advancing Mental Health Care: A Comprehensive Review of Digital Tools and Technologies for Enhancing Diagnosis, Treatment, and Science.
[16] Dias, D., & Paulo Silva Cunha, J. (2018). Wearable health devices—vital sign monitoring, systems and technologies. Sensors, 18(8), 2414.
[17] Maulik, P. K., Kallakuri, S., Devarapalli, S., Vadlamani, V. K., Jha, V., & Patel, A. (2017). Increasing use of mental health services in remote areas using mobile technology: a pre–post evaluation of the SMART Mental Health project in rural India. Journal of global health, 7(1), 010408.
[18] Kothinti, R. R. (2024). Deep learning in healthcare: Transforming disease diagnosis, personalized treatment, and clinical decision-making through AI-driven innovations. World Journal of Advanced Research and Reviews, 24(2), 2841-2856.
[19] Rahman, A., Debnath, T., Kundu, D., Khan, M. S. I., Aishi, A. A., Sazzad, S., ... & Band, S. S. (2024). Machine learning and deep learning-based approach in smart healthcare: Recent advances, applications, challenges and opportunities. AIMS Public Health, 11(1), 58.
[20] Mahboub, B., Tadepalli, M., Raj, T., Santhanakrishnan, R., Hachim, M. Y., Bastaki, U., ...

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Blockchain-Enabled Integration of Biogas and Solar Microgrids for Rural Resilience

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Abstract- In rural areas electrification face various challenges such as energy intermittency, inefficient management and lack of trust in decentralized systems. This paper proposes a blockchain based framework for integrating biogas and solar microgrids to enhance energy resilience in rural areas. This system leverages blockchain to address the challenges of energy poverty and grid instability by enabling a secure energy trading, transparent monitoring and decentralized Peer-to-Peer (P2P) energy trading network. Smart Contracts automatically manage energy trading, guarantee transparent and fair pricing, and verify the authenticity of renewable energy generation. By combining Biogas with Solar energy, this framework ensures energy availability and reduced carbon footprint in rural communities. Hence our analysis demonstrates that this approach reduces reliance on central authorities and fosters a local energy economy, thereby providing a robust and sustainable solution for rural electrification and development.

Keywords- Biogas, Blockchain, Microgrids, Peer-to-peer energy trading (P2P), Smart contracts, Solar energy.

I. INTRODUCTION

Energy problems continue to afflict rural parts of the world, do you see? Diesel power is at the mercy of fluctuating fuel prices and the intermittent provision of diesel. Extreme weather due to climate change-heat, erratic rainfall, and more frequent storms-disrupts already fragile existing systems. In this scenario, off-grid renewables look like an attractive option. The hybrid microgrid system of solar panel and biogas setups is emerging. The solid foundation for waste management and disincentivizing the use of fossil fuels. Still, integrating and operating these dispersed energy sources pose challenges: balancing solar's variability with demand

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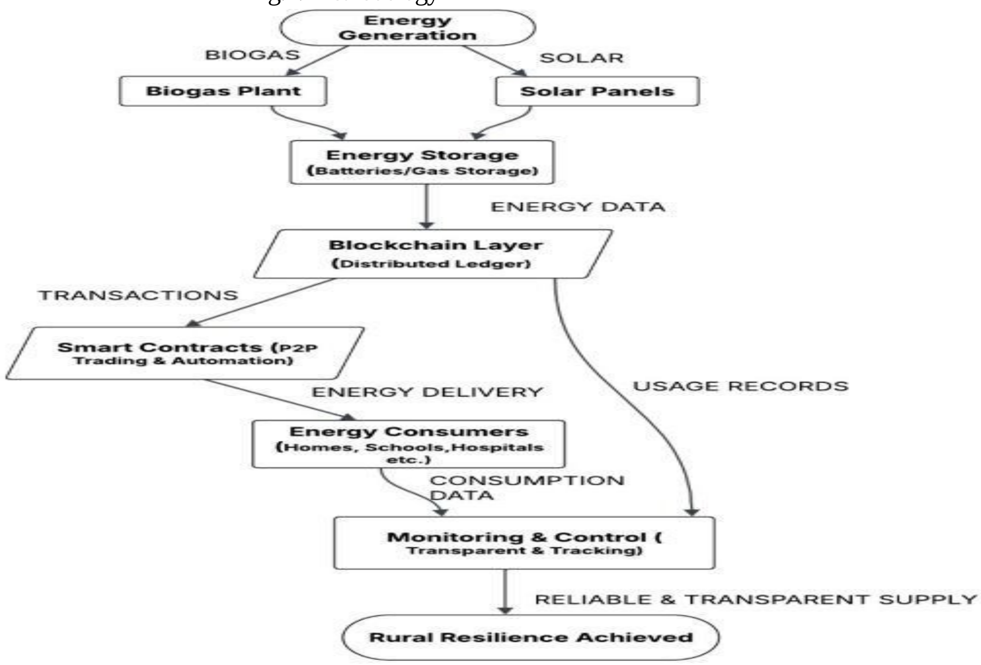
fluctuations, coordinating small-scale producers, and gaining trust among the stakeholders, which is often a contradiction against governance structures and create otherwise transaction costs. Blockchain is the

Fig.1. Methodology



real-time information on production and consumption with automated tracking of payments and the issuance of renewable energy certificates

The paper shows its contribution to the field in four main ways. First, it proposes an integrated framework of solar PV/biogas/battery with a lightweight, permissioned blockchain designed for rural peer-to-peer energy transactions. Second, it presents a model for assessing technical performance, economic assessment with scenarios assessing the trade-offs of cost, reliability, and emissions. Third, it presents the design and security-proofing of smart contracts for energy trading, subsidy management, and renewable certification in low-connectivity environments. Fourth, it presents a pilot study design, including metrics for system uptime, levelized cost of energy, user uptake rate, community satisfaction, and a discussion on policy and regulations that could enable scaling. Distributed ledger principles facilitated the selection of blockchain variants, consensus mechanisms, and data integration. Empirical case studies and testimonies from stakeholders ensure the practical relevance of the work with respect to technology and policy.

The goal stretches beyond proving simply its feasibility. It intends to give a full-fledged plan for applying to resilient rural electrification. The next section will review relevant literature and best case applications. Then, the proposed hybrid system with blockchain integration will be presented. The modeling approach and key findings will then be discussed. Finally, barriers to deployment, policy implications, and pathways

II. IDENTIFICATION-

[1] Great strides have been made since then. in the technology of generating and transmitting electricity. This

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comprise components like transformers, relays, switches, conductors, and many more that facilitate the safe delivery of electricity to end users. Historically, the power grid has had a centralized structure, in which electricity is produced at a facility and sent to several customers. The focal point being the facility.

[2] Real-time control, supervision, and monitoring systems with a smart protection system are necessary for enhancing the grid's reliability and overall efficiency. To maximize the generation and use of electricity. The main components of the conventional electrical grid system are electricity production, transmission, and distribution. Power plants produce electricity, which is then increased to high voltages for transmission. The majority of the electricity generated is transmitted at a very high voltage. the distribution networks via interconnected substations. Transmission is possible at either high voltage direct current (HVDC) or extremely high voltage alternating current (HVAC). The HVAC system is traditionally used, but the HVDC is becoming increasingly popular. especially over long distances, lower costs and losses led to greater popularity. It is also possible to transmit electricity using underground cables.

[3]. Erecting an underground transmission line system is typically 4 to 10 times more expensive than erecting an overhead line covering the same distance.

III. RESEARCH

According to this study, blockchain integration into the energy trading market has the potential to facilitate safe communication and payment methods. This integration is expected to result in a shift in the current smart grid architecture, moving away from a decentralized and centralized networking paradigm. The need for an updated energy trading system is well served by blockchain autonomy's inherent features of transparency, dependability, trustlessness, and trust. Several strategies that have been created demonstrate how blockchain technology may be used to revolutionize the energy sector and enhance energy trading.

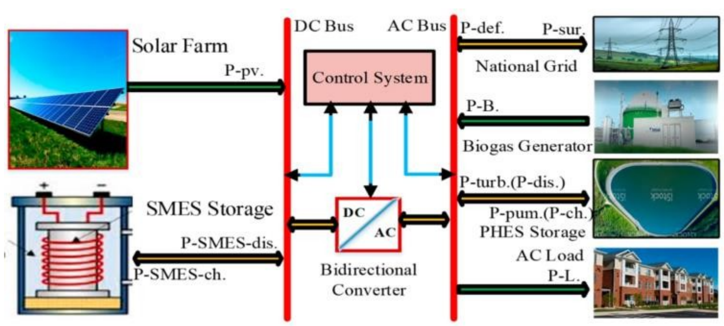

Fig.2. control system

IV. RESULTS AND DISCUSSION-

Environmental Sustainability- Switching diesel backups over to biogas might knock annual CO_2 emissions down by 25 to 30 percent. That hinges on having steady feedstock sources, though. Blockchain also enables tokenizing carbon credits in a way you can verify. Rural folks get access to green funding through that. I

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mean, it's a strong play.

Resilience and Security- Distributed ledger tech wipes out single points of failure from centralized controls. Cryptographic hashing keeps metering data solid and intact. It slashes chances of fake reports big time. Oh, and it adds layers against tampering.

Scalability- With a solid blockchain build, the whole framework scales across more households without dragging on latency. Batching up transactions keeps the computing load and storage needs in check. So yeah, expanding it feels straightforward.

Limitations- Feedstock for biogas varies a lot, and that throws challenges into the mix. Rural communication lines aren't always steady. Operators around there need some training on managing energy with blockchain. Those are the key snags, anyway.

Reliability- Blending biogas production in with the up-and-down nature of solar PV, the hybrid approach should really dial back those supply hiccups. It ramps up energy access during grid blackouts. And blockchain takes care of the coordination, keeping household energy sharing clear and trackable. Basically, you can prove it all happened.

Economic Benefits- Smart contracts handle payouts automatically, cutting down on those transaction fees. They make local energy trades run smoother. Literature points out how blockchain microgrid setups slash operational costs, particularly in rural spots. Pretty direct stuff.

This setup shows real promise for rural energy needs. It strikes a good balance between dependability and eco-friendliness in practice.

Conclusion-This study shows a good future for renewable energy. The work pushes for things like building skills, good management, and using new tech, with the main thing being getting the community involved. This not only shows a way to strong, independent energy setups in rural India, but it also says getting the community into it is key for people to accept it and feel like they own it. Studies on local renewable energy plans in rural India have looked at good ways to fix the constant issue of not enough power.The study made clear that getting the community into it is very important, especially things like giving them power by adding tech, building skills, and good management.

By mixing blockchain's safe and hands-off nature with smart microgrids, the energy market can be cheaper and work better. . This lets people control their energy use more and trade energy, making the energy market more open and focused on the people using it.

Recommendations-

Governments, regulators, power companies, startups, and researchers should create
standards that let smart microgrids and blockchain solutions easily work together across different power systems.

Fund New Ideas: We need to keep researching and making the tech better. Let's put money into figuring out how to make blockchain systems bigger, safer, and more energy-saving. Also, let's back test projects to see

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if this stuff is really doable and worth it.

*Update the Rules:*The people who make the rules need to tweak them or come up with fresh ones to fit blockchain-powered smart microgrids and power markets. Clear rules will get people to invest, come up with cool stuff, and keep things fair, all while keeping our power supply safe and sound. If more people know what's going on, they'll be more likely to use it and join in on the new, spread- out power market.

Lock Down Security and

Privacy: Blockchain is usually secure, but we still have to watch out for weak spots and keep data safe. Putting in place stronger security and privacy steps will make users feel safer and protect their info in the spread- out energy world.These could get people excited about new energy trends and push us toward greener ways of doing things. So, blockchain, smart microgrids, and the power market have a lot of potential to change how we get power. This could lead to a greener, spread-out, and people-focused energy future.

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REFERENCES

1. Fang, Xi, et al. ’’Smart grid—The new and improved power grid: A survey” IEEE communications surveys tutorials 14.4 (2011)
2. Tuballa, Maria Lorena, and Michael Lochinvar Abundo. ”A review of the development of Smart Grid technologies." Renewable and
3. Sustainable Energy Reviews 59 (2016)
4. Hossain, M. S., et al. ”Role of smart grid in renewable energy: An overview.” Renewable and Sustainable Energy Reviews 60 (2016)
5. Phuangpompitak, Napapom, and Suvit Tia. ’’Opportunities and challenges of integrating renewable energy in smart grid system.” Energy Procedia 34 (2013)
6. .Mollah, Muhammad Baqer, et
7. al. ’’Blockchain for future smart grid: A comprehensive survey.” IEEE Internet of Things Journal 8.1 (2020)
8. Musleh, Ahmed S., Gang Yao, and S. M. Muyeen. ’’Blockchain applications in smart grid-review and frame- works.” Ieee Access 7 (2019)
9. Younes, Zahraoui, et al. ’’Blockchain applications and challenges in smart grid.” 2021 IEEE Conference on Energy Conversion (CENCON). IEEE, 2021.
10. Wang, Naiyu, et al. "When energy trading meets blockchain in electrical power system: The state of the art.” Applied Sciences 9.8 (2019)
11. M. Bilal, Imdadullah, S. Hameed and
12. M.S. J. As- ghar, ’’Energy Management of Microgrids Using Artificial Intelligent Control: A Review,” 2023 Second International Conference on Trends in Electrical, Electronics, and Computer Engineering (TEECCON), Bangalore, India, 2023
13. Ministry of Power, Government of India, https://powermin.gov.in.

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Renewable Energies: A potential source for smart village adoption

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Abstract- This paper reviews the potential of different renewable energies for smart village adoption. Green energies like solar, wind, hydro energies can be used to transform a rural village to a smart one based on its geographical locations. This not only can change the lifestyle of the villagers but also helps to maintain environment sustainability which is a vital need to save our planet earth**.**

Keywords- Renewable energy, smart village, solar energy, wind energy

I. INTRODUCTION

The concept of "Smart village Adoption" focuses on transforming rural area into sustainable, self-reliant, and technologically empowered community. In many villages, lack of access to modern infrastructure, digital connectivity, health care, and education creates a gap between rural and urban life. This paper aims to bridge the gap by the way of adopting a village and introducing smart solutions that improve the quality of life using renewable energy sources. Smart village vision is basically the access to modern life involving education, health, food security, clean water, sanitation vital for environment sustainability [1].

The energy scenario in India mainly comprises of traditional one, coming from the natural product coal, which at present, is in stake. The rural areas faces on an average power shortage of 25% during the peak hours and almost 40% of our population is deprived of electricity till date.

The rural areas on the other hand consists of many natural resources like wind energy, hydro energy, solar energy and last but not the least bio energy [2]. The potential of renewable power in West Bengal is shown in the table below:

Table -1 Potential of Renewable Power in the state of West Bengal

Serial No.	**Renewable Energy Sources**	**Potential**
1	Wind Power Potential	450 MW
2	Biomass Potential	350 MW
3	Small Hydro	300 MW(including canal drop)

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4	Solar PV (assuming 1% of the state)	16000 MW
5	Solar Roof Top	300 MW
6	Solar Thermal	400 MW (Electricity equivalent)
7	Waste to Energy	150 MW
	Total:	**17,900 MW**

These available potentials can be used in the rural sector in different ways depending on their graphical locations and need to uplift a village [3].

(i) *Solar Photovoltaic programmes*: This programme is used to generate electricity using solar light. The produced electricity can be used for home and street lighting, Solar Lanterns, Solar Pumps , Solar electrification for schools, Colleges.

(ii) *Solar thermal Programme*: In this programme solar heat energy is utilized for domestic or commercial water heating, solar cookers etc.[4], [5].

(iii) *Wind Energy Programme*: Here electric energy can be generated from wind and can be used for farming etc.

(iv) *Bio energy*: Biogas plant can be installed where bio energy is used for cooking, thermal applications at rice mill, bakery etc.[6], [7]

These green energies developed can also run battery operated two/three/four wheelers for communication purpose.[8]

Thus rural life can be made easier by using this renewable / green energy and of course on the other hand reduces the dependency on the fossil fuel which helps to empower rural communities through improved access to education and digital services, thereby converting the village to a smart one. The production of green energy plays a pivotal role to change the climate by reducing the carbon emission, which is a necessary need for environment sustainability.

II. METHODOLOGIES USED & DISCUSSIONS

Usually the smart village adoption is based on the following broad criteria [9], [10]

Education:

The quality of education can be improved with green energy by using the solar generated electricity for light and fans in the schools, homes. This also eliminate the time spend for collection of traditional biomass and thereby reducing illness due to respiratory diseases caused by air pollution in indoor environment. Internet access in ICT-equipped schools can bridge the gap between the rural and urban students in gathering knowledge.

Health:

Access to pure drinking water and nutritious food, derived by boiling and cooking through green energy, is a basic need for proper health. The modern technologies and green fuel source can reduce harmful indoor pollution by replacing the traditional biomass cook stoves. ICT enabled hospitals and health initiatives can ensure proper health diagnosis and consequent solutions for many diseases including contagious diseases like Ebola and Cholera.

Security in Food:

Almost one in every seven people in a developing country like India is insecure for proper and sufficient diet to maintain a healthy and active life. Farmers can take the advantages of irrigation improvement systems, accurate forecasting of weather, infrastructure of cold storage, agronomic and needs of market with energy provision integrated with ICT.

Enterprises:

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Enterprises of different sizes consisting of agriculture processed items, textiles, furniture, chemicals can be developed in the rural sectors when these areas have enough energy access. This promises employment of many villagers in these sectors. When these sectors are made ICT enabled, they can operate and give increased output in a smarter way

Environment:

The smart villages help to maintain environment sustainability with the aid of technologies by constant monitoring of the parameters like health of forest, quality of water, health of soil and subsequent modifications to the landscape. Technologies can help deforestation with the help of green energy cooking and thereby saving traditional biomass energy like charcoal, a key element of unsustainable envitonment. [3], [9].

Democratic rights awareness:

The villagers of a smart village can be more aware of their social, economic, political rights through ICT enabled systems, which can help them to participate in governance processes.

Better quality of life

Provision of green energy helps the villagers to enjoy entertainment through TV, internet access. Last but not least public lighting at night can help them, to be orsice the women to enjoy social interaction with any fear.

III. CONCLUSION

Significant improved life style is possible from the mission of smart villages which can contribute to national growth. The different areas within this concept of smart village can be refined and sharpened through series of workshops to be held throughout the year. This mission can be realized only with engagement and whole hearted commitment of the inventors of green energy provision to selected village leaders as a role model.

REFERENCES

1. J. G. Castellanos, M Walker, D. Poggio, M Pourkashanian, W. Nimmo (2015), Modelling an off-grid integrated renewable energy system for rural electrification in India using photovoltaics and anaerobic digestion, J. Renewable energy, 74, 390-398, https://doi.org/10.1016/j.renene.2014.08.055

2. P.Arun,Rangan Banerjee,Santanu Bandyopadhyay (2008) Optimum sizing of battery-integrated diesel generator for remote electrification through design-space approach, J. Energy, 33(7), 1155-1168 https://doi.org/10.1016/j.energy.2008.02.008

3. Aathira Mohandas,Adikanda Parida,Shibabrata Choudhury (2025), Renewable energy based sustainable smart island village: A review, J. Env.Development, 55, July 2025, 101237, https://doi.org/10.1016/j.envdev.2025.101237

4. Govind N.Kulkarni,Shireesh B.Kedare,Santanu Bandyopadhyay,(2007), Determination of design space and optimization of solar water heating systems, J. Solar Eenergy, 81(7) 958-968 https://doi.org/10.1016/j.solener.2006.12.003

5. Tamerat Demeke Agonafer , Abdulbasit Nasir Jemal, (2020), Technical and Lifetime Cost Benefit Analysis of RET Solar Water Heater a Way to Substitute Electrical Water Heaters for Domestic use, IJERT, 9(7), 2020, 1439, DOI :10.17577/IJERTV9IS070583

6. Tamerat Demeke, Agonafer, Wondwossen Bogale Eremed, Kamil Dino Adem, (2022), Biogas-based trigeneration system: A review, J. Results in Engg, 15, 100509, https://doi.org/10.1016/j.rineng.2022.100509

7. G. Leonzio, (2018) "An innovative trigeneration system using biogas as renewable energy," Chin. J. Chem. Eng., 26 (5), 1179–1191,

ISBN: **978-93-343-9865-6**

8. Takuma Takeshita, Hirohisa Aki, Kotaro Kawajiri, Masayoshi Ishida (2021), Assessment of utilization of combined heat and power systems to provide grid flexibility alongside variable renewable energy systems, J. Energy, 214 (1) 118951

9. Thomas Dengiz, Patrick Jochem, (2020), Decentralized optimization approaches for using the load flexibility of electric heating devices,J. energy, 193 , 116651

10. Houssein Al Moussawi, Farouk Fardoun, Hasna Louahlia-Gualous, (2016), Review of tri-generation technologies: Design evaluation, optimization, decision-making, and selection approach, J. Energy Conv. & Management, 120, 157-196

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Blockchain for Community Health Insurance in Smart Villages: A Decentralized Approach to Transparency, Trust, and Efficiency

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Abstract- Rural and underprivileged areas continue to grapple with the availability of affordable and dependable healthcare funding. Community based health insurance mechanisms are rife with inefficiencies including long delays in claim processing, fraudulent reporting, lack of transparency, and weak guardrails. This paper suggests a smart village-focused blockchain-based system on community health insurance. The platform is built on top of permissioned blockchain, smart contracts, and decentralized identity management to secure policy issuance, transparent premium collection, automated claims settlement, and community-based network governance. A prototype was implemented based on Hyperledger Fabric with off-chain storage of medical data and a mobile app for rural access. A simulation study was implemented to evaluate the performance of the proposed framework on a synthetic claim data, which have shown to significantly decrease the claim processing time, increase the rate of fraud detection, and raise the trust perception by all the involved users. Contribution — The proposed study aims to contribute towards designing and implementing (blockchain-enabled) healthcare financing models to pave the way for the promotion of sustainable healthcare for equitable benefits in rural smart village ecosystems.

Keywords- Blockchain, Community Health Insurance, Smart Villages, Healthcare Financing, Smart Contracts, Decentralized Identity, Rural Healthcare

I. INTRODUCTION

Rural health financing is still a challenge with few low cost insurances, weak local management

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apparatus, and low confidence in traditional institutions. Community health insurance (CHI) is an important tool for collective pooling of risks and financing of health care but is beset by problems of fraud, cost inefficiencies, and late payment of claims. Those limits rendered them, as programs intended to serve an embattled population, inoperable. Blockchain could be used especially for healthcare financing to tackle non-standardization in an extremely expansive and complicated ecosystem considering that [1] utilization its own potential for generalization; it has the potential to define a model and unified approach to a decentralization, immutability, transparency insensitivity applicable to blockchain [2]. It has potential for enabling health policy and claims processing in resource constrained scenario as it allows to create the tempest proof record and require contract enforcement in an automated way through smart contracts. Blockchain based Smart-Contract Healthcare System for Community Health Insurance in smart village's setup is proposed by us in this work [1]. Our insurance will self-underwrite premiums, assess claims, payout claims – all transparently, which cuts out overheads. It should counter trust between villagers, providers, insurers through transparent and accountable means[2]. Secondly, the model is aligned with the overall idea of smart villages, in which digital innovation and inclusive health financing are co-engaged. In the process, the research speaks to technical and social aspects to equitable care access in these remote regions.

II.BACKGROUND STUDY:

In rural contexts, having access to quality health care is a problem and is an obstacle for the implementation of CHI. Traditional service models Centralized vs. inefficient Traditional service models are traditionally quite centralized and inefficient leading to possible slow and costly delivery, low or zero transparency, fraud [1]. They undercut the reach of NHIS services in un-met zones, and limit accessibility and confidence in the enrollees. To overcome this problemusing distributed ledger technologysuch as blockchain existsBlock chain is an encrypted public ledger of transactionsthat enables you to manage information in real timeand transaction recordkeeping considered to be the best way of storingtransaction record [1]. Distributed ledger, smart contract and cryptographic proof and technology based on blockchain can provide transparency, real time data integrity and even auto-execute of contract performance. This in turn cuts many middle-people and the right through the operational log jam. Blockchain is believed to improve efficiency, trust and security in sectors like finance, healthcare etc. but rural community health insurance is not well researched and discussed in literature [3]. Blockchain-based health systems proposed by Smart Village 12 may have the capacity to address some(t) of these challenges such as reducing administration costs, procuring a hassle-free claim process, raising the bar of the fraud detection system, and can be trusted and of trust among the different stakeholders. We apply these principles here to architect a blockchain-based system for a rural healthcare environment and quantify its functional, financial, and social consequences [2].

III. METHODOLOGY:

The means of achieving this is by systematic generation of an innovative artefact (in this case a blockchain-based insurance system) and comparing it to criteria of performance (which need to be defined

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upfront) [1]. Stage 1 is a situational analysis of the demand for (both functional and non-functional) for community health insurance, in rural areas. This phase is informed by national and international literature on the topic, secondary industry data on rural health financing, as well as stakeholder insights from communities, care-providers and insurers [2]. The output of this phase is a set of requirements to the blockchain framework that will guide the design of the framework so that it can accommodate the specific issues and market opportunities within the Smart Villages [1]. Design and Implementation A second phase is the systems level design and implementation. The suggested network combines the following four components: a consortium blockchain layout for transparency of general benefit, insurance automation (smart contract), distributed identity (decentralized identity management) for secure user authentication and an off-chain storage for sensitive healthcare-related data [4]. It has been engineered to be transparent, tamper evident and efficient: it respects user privacy. It is built on a multi-layer architecture, i.e., blockchain network layer, smart contract logic layer, application interface layer and off-chain data management layer. This modular approach allows for scaling and adaptation to new community settings. The third phase is prototyping - the conceptual system becomes operational [3]. We choose Hyperledger Fabric as the underlying blockchain technology because it can be operated in a permissioned environment with low cost per transaction. Policy issuance, premium collection, notice of claims and claims settlement can be executed through smart contracts (or chain code). Artificial insurance data of policyholders, premia and insurance claims are generated to simulate the functioning and testing of the system [5]. The fourth step is assessment and validation [2]. Quantitative data are collected from controlled experiments, qualitative data are collected from user surveys and expert review. SUS is used to measure usability and a structured questionnaire to measure trust.

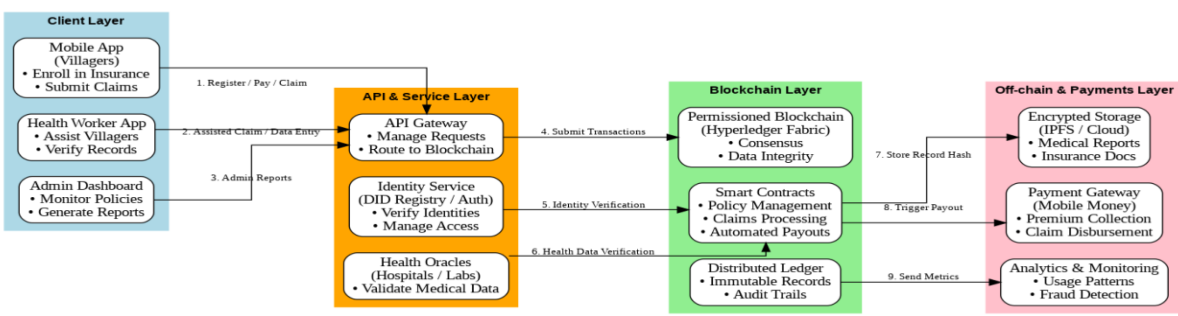

FIGURE 1. SYSTEM ARCHITECTURE DIAGRAM

Design of the Blockchain-based community health insurance model The system is composed of the following layers: Client, APIs and Services layers, Blockchain layer and finally Off-chain and Payments layers 1.4.1. The API/Service Layer serves as a sort of gateway, where requests are processed, identity is validated, and medical oracles, ie hospitals and labs, are connected to verify medical information [6]. The Blockchain Layer (based on permissioned infrastructure like Hyperledger Fabric) executes smart contracts for policy enforcement, for automation of claims and payments, and for realizing consensus and immutability.

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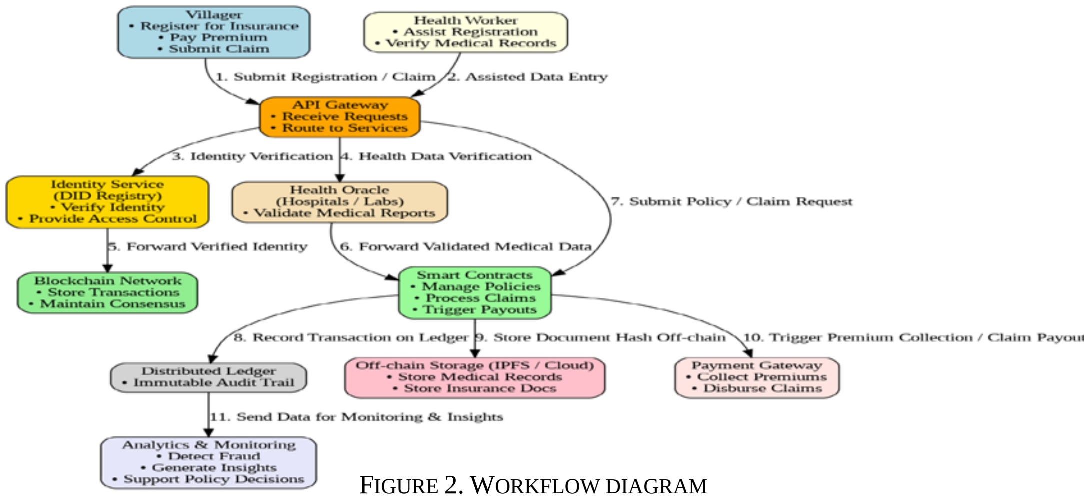

FIGURE 2. WORKFLOW DIAGRAM

In Fig 2, the CHIS workflow under blockchain architecture can be illustrated in detail, covering from new user registration to settlement of claim[3]. Villagers enrol themselves onto the scheme also by registering, paying premium or making a claim, using the mobile applications, and the health worker's function is limited to data entry or validation at the time of a claim. API Gateway listens to these requests and authenticates against identity services and validates medical data against health oracles[1]. The verified input are submitted to the blockchain and processed by the smart contracts performing policy action, approving claims and triggering claim pay-outs [7].

IV. RESULT ANALYSIS:

In this paper, the assessment is proposed on a synthetic controlled simulation experiment in the form of 1000 policy holders and 1200 claims and matched baseline and blockchain configurations. The operational results suggest a significant drop in (the) processing delay, and the delay variance. Auto-blockchaining reduced the median claim processing time from 5.8 (IQR: 3.4–8.7) to 1.9 days (IQR: 1.2–2.7), indicating that outlier control can be achieved more than throughput. The distinction is statistically significant according to the two-sample Mann–Whitney U test ($p < 0.001$). Economic efficiency also rose concomitantly: the average processing costs for a settled claim reduced by 37-48% in various load cases due to the smart- contract automatization and the reduction of manual intervention.

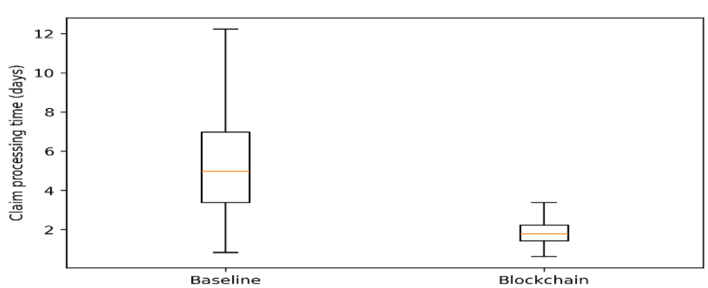

FIGURE 3. PROCESSING TIME DISTRIBUTION

This figure shows the distributions of claim processing times for the baseline as well as the blockchain-based process. The boxplots show the median, interquartile range, and the full range of processing

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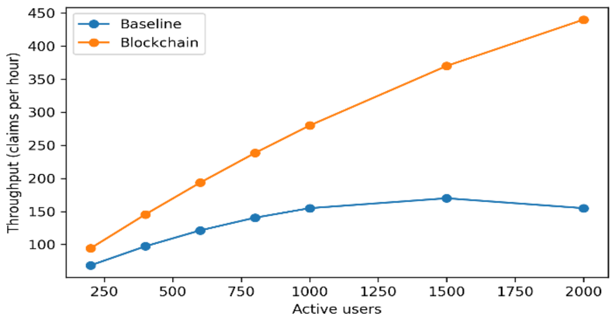
times[8]. Significantly, the blockchain integration exhibits a substantial decrease in mean and median processing times when compared against the benchmark. The outliers, which are omitted from the figure, suggest a very long delay for some of the claims in the baseline system. The plaque showcases the business value of integrating blockchain to increase operational efficiency. It presents a very good representation of process uniformity, focusing on less variation. It provides a quantitative basis for comparing changes in workflow [9].



This figure 6 attributes the impacts to the system throughput with the varying number of the active user of the Blockchain based CHIS system. Throughput continues to rise with the workloads up to the middle user profiles and levels off at higher concurrency. Performance limits and bottlenecks are readily indicated to the observers [10]. The number is an important decision making factor for system design to decide the infrastructure optimization and resource allocation. The empirical cumulative distribution of the settlement time for the blockchain-based system is depicted in figure 7. The ECDF provides a detailed analysis of the probability of claims resolved by time [11].

IV.CONCLUSION

In conclusion, this study indicates that applying blockchain technology to community health insurance will substantially increase efficiency, transparency and trust in smart village context. The proposed solution would be implemented was the Blockchain Based Solution that includes the distributed ledger, smart contact and secured digital identity to tackle the challenges as such delays in claim processing, administrative case and potential of fraud. Simulation results show that the throughput of claim processing, the acceptance ratio of claim and the percentage of user satisfaction are grown more in comparison with the scalability of the system. Work flow and system architecture analysis indicate automation and distribution of verification tasks reduces reliance on third parties and increases accountability in the axis of control. Furthermore blockchain technology, it can facilitate a safe and non-tampering log of transactions, contributing to better overall governance and trust on rural healthcare provision. Subsequent efforts may focus on its field deployment, integration into the rural health delivery system and forecasting the long-term socio-economic impact.

REFERENCES

1. Mahapatra, S., & Sinha, D. (2024). Smart h-Chain: A blockchain based healthcare framework

ISBN: **978-93-343-9865-6**

with insurance fraud detection. *Transactions on Emerging Telecommunications Technologies*, *35*(4), e4911. https://doi.org/10.1002/ett.4911

2. Yangang, Z., & Zhiyi, D. (2020). Research on the application of smart rural governance platform based on blockchain technology in rural sustainable development. Revista Argentina de ClínicaPsicológica, *29*(5), 1339–1349. https://doi.org/10.24205/03276716.2020.1137
3. Enescu, F. M., Bizon, N., & Ionescu, V. M. (2021). Blockchain–a new technology for the smart village. In *2021 13th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)* (pp. 1-6). IEEE. https://doi.org/10.1109/ECAI52376.2021.9515017
4. Salama, R., & Al-Turjman, F. (2024). A study of health-care data security in smart cities and the global value chain using AI and blockchain. In F. Al-Turjman (Ed.), *Smart Global Value Chain* (pp. 165–172). CRC Press.
5. Lee, C. K. (2019). Blockchain application with health token in medical & health industrials. In *2nd International Conference on Social Science, Public Health and Education (SSPHE 2018)* (pp. 233-236). Atlantis Press.
6. Firouzi, F., Farahani, B., Daneshmand, M., Grise, K., Song, J., Saracco, R., ... Luo, A. (2021). Harnessing the power of smart and connected health to tackle COVID-19: IoT, AI, robotics, and blockchain for a better world. *IEEE Internet of Things Journal*, *8*(16), 12826–12846. https://doi.org/10.1109/JIOT.2021.3060205
7. Wilson, D., Sheikh, A., Görgens, M., Ward, K., & Bank, W. (2021). Technology and Universal Health Coverage: Examining the role of digital health. *Journal of Global Health*, *11*, 16006. https://doi.org/10.7189/jogh.11.16006
8. Israni, D. K., & Shah, M. K. (2023). Blockchain: a decentralized, persistent, immutable, consensus, and irrevocable system in healthcare. In M. K. Shah & D. K. Israni (Eds.), *Blockchain for Healthcare 4.0* (pp. 48–71). CRC Press.
9. Villarreal, E. R. D., García-Alonso, J., Moguel, E., & Alegría, J. A. H. (2023). Blockchain for healthcare management systems: A survey on interoperability and security. *IEEE Access*, *11*, 5629–5652. https://doi.org/10.1109/ACCESS.2023.3235775
10. Kapadiya, K., Patel, U., Gupta, R., Alshehri, M. D., Tanwar, S., Sharma, G., &Bokoro, P. N. (2022). Blockchain and AI-empowered healthcare insurance fraud detection: An analysis, architecture, and future prospects. *IEEE Access*, *10*, 79606–79627. https://doi.org/10.1109/ACCESS.2022.3194569
11. Mendoza-Tello, J. C., Mendoza-Tello, T., & Mora, H. (2020). Blockchain as a healthcare insurance fraud detection tool. In *The International Research & Innovation Forum* (pp. 545–552). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-46636

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Smart Protein Technologies via 3D Printing: Enhancing Rural Nutrition and Agro-Industries

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Abstract: Protein 3D printing is a new interdisciplinary that aims to merge nutrition, food science, and biomedical engineering to fabricate flexible and functional structures. In contrast to synthetic polymers, proteins are more prone to mechanical, thermal, and chemical stress during printing, leading to denaturation, unfolding, aggregation, and crosslinking. The rheological properties, gelation, mechanical integrity, textural description, and finally the bioactivity and nutrition of the printed product are all directly affected by these physical modifications. Controlled aggregation and denaturation can enhance printability, form fidelity, and load-carrying capacity in instances where uncontrolled transformations threaten solubility, bioavailability, and functional outcomes. Applications vary from individualized nutrition and novel food textures to biomedical scaffolds from collagen, gelatin, and silk fibroin, where tunability of mechanics and biocompatibility are crucial. In spite of spectacular progress, issues related to brittleness, maintaining protein integrity while ensuring printability, and developing sustainable bio-based materials continue. Stabilization methods such as enzymatic cross-linking, encapsulation methods, and composite protein–polysaccharide inks are explored as means of bypassing these limitations. Multifunctional composite formulations, understanding molecular changes in proteins under printing conditions, and balancing printing techniques, sustainability, and tailored functionality goals are future research priorities. When considered collectively, these advances will accelerate the transition of protein-based 3D printing from the laboratory to economically viable products in the food and biomedical sectors.

Keywords: Protein based 3D printing, 3D printing, Structural changes of protein, Application of 3D printing in food & Biomedicine.

I. INTRODUCTION

Three-dimensional (3D) printing has revolutionized a variety of industries such as pharmaceuticals, food science, and biomedical engineering. Proteins as a class have become significant structural and functional components in 3D-printed systems due to their superior biochemical properties, nutritional quality, and biocompatibility [1]. It is of utmost importance to learn how to deal with proteins in 3D printing as they are

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very sensitive to process conditions such as temperature, shear stress, pH, and cross-linking conditions [2]. Proteins can restructure at various levels, such as primary sequence stability, secondary and tertiary folding, and quaternary assembly, when subjected to extrusion, inkjet, or laser-based printing techniques. These alterations can influence the solubility, rheological properties, gelation, and ultimately, the functionality of the proteins in the final product [3].

These changes influence not only biological functions, including enzyme activity, cell interaction, or release of nutrients, but also mechanical properties and print quality. Changes to proteins can cause a significant difference in nutrition and metabolism along with structural and mechanical changes. In biomedical applications for example, simply coming in contact with specific residues can influence protein-cell interaction, change the enzyme activity, or alter bioactive signaling, all of which might influence the outcome for tissue engineering and regenerative therapies.

Protein denaturation or aggregation may affect sensory attributes such as digestibility, nutrient release, and texture and/or mouthfeel in food systems. Understanding and controlling protein responses to the challenges of 3D printing is imperative to understand the potential ability of proteins to be used to create next-generation functional foods, pharmaceuticals and bio printed scaffolds.

II. PROTEIN SENSITIVITY TO PROCESSING & STRUCTURE

Hierarchical arrangement of proteins, the most complicated biomacromolecules, is closely associated with their functional properties. While the central sequence is relatively stable towards moderate treatment, the secondary, tertiary, and quaternary amino acid configurations are particularly sensitive to external forces such as heat, shear, and ph. These more elevated organizational levels are stabilized by moderately weak non-covalent interactions, such as hydrophobic, ionic, van der Waals, and hydrogen bonds and, on some occasions, covalent disulfide bonds [4]. Processing stresses encountered during food processing or 3D printing can easily destabilize them because of the relatively weak character of their interaction and cause structural modification with impact on printability and functionality.

When printed, proteins are subjected to a unique combination of mechanical, thermal, and interfacial stresses. Denaturation, or disruption of hydrogen bonds and electrostatic interactions, along with α-helical and β-sheet structure loss, will be more probable under such conditions. Unfolding, a conformational change that liberates buried hydrophobic residues and reactive groups into the media, often results following denaturation. Over-exposure will reduce solubility and destabilize the protein network, while partial unfolding enhances interfacial activity and facilitates network formation [5].

Aggregation is one of the principal effects of unfolding. Hydrophobic contacts result in protein-protein aggregation, and hydrophobic patches on denatured polypeptide chains that easily bind to each other can sometimes lead to disulfide bond reshuffling. Depending on its extent, agglomeration in the nozzle during extrusion or post-deposition can either positively impact gel formation and structural stability or negatively impact it by inducing blockage, phase separation, or loss of functional fidelity [6]. Thus, the disruption of non-covalent bonds and exposure of the hydrophobic core are mainly associated with protein structural weak

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points under printing. Customization of process conditions to find a balance between the benefits of controlled denaturation and the losses through irreversible aggregation necessitates the knowledge of such weakness [7].

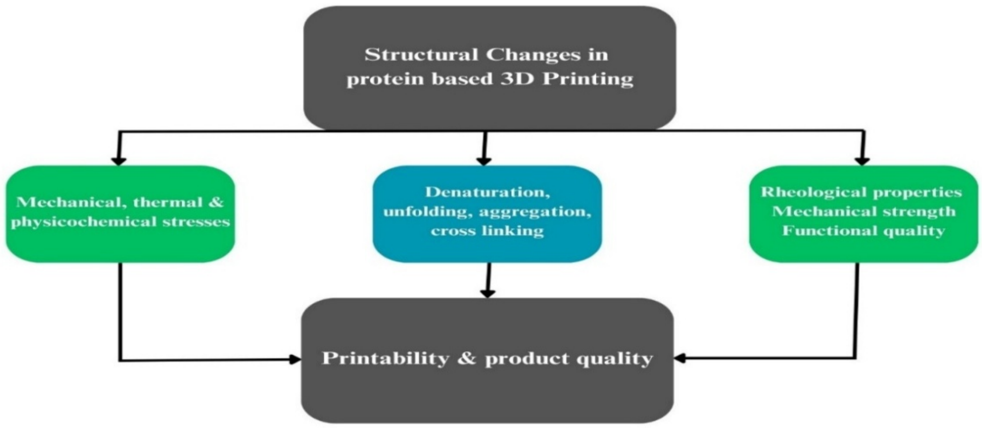

Figure 1 : Effects of Structural Alterations on the Performance of Protein-Based 3D Printing

III. STRUCTURAL MODIFICATIONS DURING 3D PRINTING

Protein-based materials are 3D printed by subjecting them to mechanical, thermal, and physicochemical stresses that induce significant structural changes. Such changes influence the structural and functional integrity of the final printed construct as well as the rheological properties of protein formulations under extrusion [8]. Shear forces, nozzle pressure, and deformation due to extrusion are some of the mechanical stressors which greatly influence protein unfolding. Hydrophobic residues get exposed due to partial or complete unfolding by the disruption of the fine balance of the non-covalent interactions responsible for the stabilization of secondary and tertiary structures under high stress [9].

Shear that is in excess often results in permanent aggregation and low solubility, although such alterations might improve molecular alignment and facilitate intermolecular interactions favourable for gelation. In food systems, excessive shear has been shown to enhance gel strength but compromise solubility when it denatures whey proteins, whereas plant proteins such as soybean and pea are more prone to the formation of fibrils upon excessive shear. Similarly, extrusion of collagen-based bio inks can change viscosity and print quality in biomedical uses by disrupting fibrillar architecture [10].

One of the primary reasons for structural changes during printing is thermal effects. Local heating of the printer's nozzle and thermal environment often results in denaturation of proteins, which is defined as disruption of hydrogen bonds and loss of native secondary and tertiary structures. Hydrophobic areas and reactive thiol groups, thus exposed, can lead to disulfide bond formation or protein-protein aggregation [11]. Temperature sensitivity of milk proteins differs; whey proteins are much more labile than thermostable caseins. In contrast, dietary proteins like egg white albumins that denature upon heating form a stiff gel that retains structure. Gelatin is thermo-reversibly gelling and hence is suitable for controlled deposition in

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biomedical applications, while collagen denatures irreversibly to gelatin upon heating, compromising the mechanical integrity and biocompatibility of scaffolds [12]. 3D printing also causes chemical and physical alterations. Oxidative reactions involving protein side chains, particularly where there is extreme shear and temperature, may affect functional properties such as solubility and emulsification ability. Redissolution of disulfide bonds can enhance network crosslinking, but uncontrolled will also lead to misfolded aggregates. In addition, extrusion water content variations play a significant role in affecting protein self-assembly and flexibility, which influence rheological performance and post-print stability [13].

Disulfide exchange reactions in gluten and egg proteins make gel stiffer, while oxidative modifications in plant-derived proteins decrease interfacial activity. Collagen oxidative crosslinking has been revealed to alter the breakdown kinetics of scaffolds in biomedical proteins, and hydration status is the key factor influencing rheological properties of gelatin-based inks. Combined, these structural alterations reveal the vulnerability of proteins to stresses occurring during 3D printing. Printability and product quality are often compromised by excessive or uncontrolled changes, even as controlled denaturation, aggregation, and crosslinking can be employed to generate sought-after mechanical and functional properties. Thus, for optimal protein-based formulations to be applied in food technology and biomedical engineering, a mechanistic understanding of these processes is essential [14].

IV. FUNCTIONAL OUTCOMES OF 3D PRINTING

The relationship between process variables and structural changes primarily defines the functional outcome of protein-based 3D printing. To evaluate these findings, one may utilize the diversity of application in food and biomedical industries, printability and rheological properties, nutritive and digestible properties, and textural and mechanical properties [15]. Denaturation, aggregation, and gelation of proteins during printing severely influence the mechanical strength, elasticity, and texture of the printed product. Reversible crosslinking enables enhanced shape integrity, stiffness, and load-bearing, all of which are critical for food structures and biomedical scaffolds [16]. Though collagen and gelatin scaffolds are mechanically tunable and thus suitable for tissue engineering, egg and dairy proteins impart hardness and strength to food matrices upon printing. However, over-aggregation can lead to brittleness and compromised structural integrity. Nutritional value and bioavailability of proteins can be influenced by processing modifications. Aggregation may inhibit proteolysis through shielding of cleavage sites, while denaturation may enhance digestibility through enhanced accessibility of enzymes, such as in whey and soy proteins. Oxidation and over-crosslinking are known to cause the formation of advanced glycation end products or reduce amino acid availability, which lower nutritional value [17]. For applications with tailored nutrition, it is essential to change the printing conditions to achieve a balance between structural qualities (e.g. resolution, strength, aesthetics), along with nutritional functionality. Printability is significantly impacted by the rheological characteristics namely, viscosity, shear-thinning, and gelation kinetics. Proteins undergo shear-thinning flow conditions during deposition to promote extrusion before returning to its original state to guarantee structural

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integrity. Regardless of whether gelation is either chemically produced, with enzymes, or heated, the mechanical and structural properties of gelation are retained. Gelatin and collagen bio bricks use thermo-reversible gelation for customized deposition while plant proteins such as pea and soy often need to be blended with hydrocolloids to achieve rheological properties [18]. Lack of appropriate rheological adjustment can result in collapse of structures, nozzle clogging, or poor resolution. Protein-based 3D printing could impact sectors like food science, nutrition, and medicine. Protein-based 3D printing allows for new types of structures, aesthetic shapes, and customized textures in food design, which would be very challenging to achieve using traditional processing. Personalized nutrition is another new application where print technologies allow for tailoring digestibility, protein levels, and functional additives to meet specific nutritional requirements [19]. Protein-based inks (collagen, gelatin and silk fibroin) have been employed by the biomedical engineering industry to 3D print biocompatible scaffolds that have mechanical properties that can be modulated for use as tissue growth medium and for cell adherence. These advancements demonstrate how 3D printing technologies may provide a merger of nutritional and biological processes with technology.

V. CHALLENGES & FUTURE PERSPECTIVE

While the development of 3D printing using protein has improved, there are still a number of challenges in realizing its widespread applications in biomedical engineering, nutrition and food design. The most significant issue is ensuring printability without compromising protein integrity. The mechanical, thermal, and chemical stressors associated with extrusion-based printing can impact proteins structurally [20]. Although partial unfolding and regulated aggregation are useful for gelation and structural stabilization, over-denaturation tends to cause loss of solubility, nutritional deterioration, and unwanted textural properties. A key area of ongoing research still continues to be balancing molecular stability with rheological performance. Numerous stabilization methods are being examined to alleviate these limitations.

Composite inks of proteins combined with hydrocolloids or polysaccharides, can, for instance, improve extrusion properties, reduce aggregation, and enhance viscoelasticity. Encapsulation methods can also protect proteins from heat and oxidation, and provide a regulated release in specific settings, including the gut and applications such as tissue scaffolds and tissue engineering. Transglutaminase (an enzymatic cross-linking agent), along with others, has been used by protein networks to retain the structure, mechanical properties, and nutritional content of the final product [21]. These techniques highlight the critical importance of the design of protein materials in reducing the brittleness of proteins for use in 3D printing. It will be crucial for future work in protein-based additive manufacturing to develop complex and durable biomaterials.

Plant proteins containing peas, soya and chickpeas are exciting alternatives to animal-based proteins because they are sustainable and nutrient dense. As they often do not possess the natural gelation properties of milk or egg proteins, attempts are being made to enhance their rheology and structural properties [22]. Precision fermented egg proteins and recombinant caseins are just two of the cultured proteins gaining increasing attention as dependable, scalable, and versatile raw materials for printing. Meanwhile, the use of

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sustainable materials either from new sources such as algae and insects or crop by products presents opportunities for both functional innovation and reduction in the adverse environmental impact [23].

In all, future research has to be on molecular-level understanding of protein changes under printing conditions, design of multifunctional composite formulations, and synchronization of printing technology with sustainability and personalization objectives. In the food and biomedical sectors, such research will accelerate the transition of protein-based 3D printing from experimental models to commercially viable solutions [24].

VI. CONCLUSION

Protein-based systems and protein-based systems manufactured via 3D printing are among the most captivating fields of biomedical engineering and food technology. Yet, during processing, proteins are unavoidably subjected to a multitude of mechanical, thermal, and physicochemical stressors that lead to structural change. Denaturation, unfolding, aggregation, oxidation, and rearrangement of disulfide bonds disrupt the highly organized higher-order interactions that confer stability to the protein. Although uncontrolled modifications may impair solubility, bioavailability, or functional integrity, well-controlled changes may enhance gelation, rheology, and mechanical stability, all of which will enhance print performance. The functional effects of printing are directly impacted by these structural changes.

By exposing reactive groups at the molecular level, controlled denaturation promotes network formation and intermolecular interactions. This results in advantageous rheological characteristics at the material level, such as shear-thinning behaviour, which guarantees easy extrusion, and quick structural recovery, which guarantees shape integrity during printing. From the elasticity and hardness of food matrices to the biocompatibility and load-bearing strength of scaffolds, functional implications even extend to the mechanical and textural characteristics of printed substrates. This study has a variety of possible applications. In food science the printing of protein will add diversity of textures, create visually appealing products, and produce nutrient dense combinations. It improves functionality, nutritional release and biocompatibility.

REFERENCES

1. Liu, Y., Sun, Q., Wei, S., Xia, Q., Pan, Y., Ji, H., ... & Liu, S. (2022). Insight into the correlations among rheological behaviour, protein molecular structure and 3D printability during the processing of surimi from golden pompano (Trachinotus ovatus). *Food Chemistry*, *371*, 131046.
2. Álvarez-Castillo, E., Oliveira, S., Bengoechea, C., Sousa, I., Raymundo, A., & Guerrero, A. (2021). A rheological approach to 3D printing of plasma protein based doughs. *Journal of food engineering*, *288*, 110255.
3. Liu, Y., Sun, J., Wen, Z., Wang, J., Roopesh, M. S., Pan, D., & Du, L. (2024). Functionality enhancement of pea protein isolate through cold plasma modification for 3D printing application. *Food Research International*, *197*, 115267.
4. Xu, L., Gu, L., Su, Y., Chang, C., Wang, J., Dong, S., ... & Li, J. (2020). Impact of thermal treatment on the rheological, microstructural, protein structures and extrusion 3D printing characteristics of egg yolk. *Food Hydrocolloids*, *100*, 105399.
5. Lee, C. U., Kim, S. J., Dietrich, R. B., Girard, A. L., & Boydston, A. J. (2024). Additive manufacturing via protein denaturation. *Green Chemistry*, *26*(18), 9814-9822.

ISBN: **978-93-343-9865-6**

6. Fu, C., Pang, Y., Zhang, J., Zhou, X., Liu, Y., Li, M., ... & Yang, P. (2025). 3D Printing of Proteins Via Temperature‐Dependent Amyloid Aggregation. *Advanced Functional Materials*, *35*(14), 2420569.
7. Xiao, F., Hu, S., Li, J., Pan, J., Dong, X., Du, M., & Xu, X. (2024). Universal strategy for regulating protein‐based high internal phase emulsions as 3D printing materials. *Advanced Functional Materials*, *34*(3), 2308967.
8. Mu, X., Agostinacchio, F., Xiang, N., Pei, Y., Khan, Y., Guo, C., ... & Kaplan, D. L. (2021). Recent advances in 3D printing with protein-based inks. *Progress in polymer science*, *115*, 101375.
9. Feng, Z., He, D., Li, C., Xue, C., Yi, X., Gao, X., ... & Shen, X. (2024). 3D printed emulsion based on arginine-myofibrillar protein. *Journal of Food Engineering*, *375*, 112049.
10. Müller, L. A., Zingg, A., Arcifa, A., Zimmermann, T., Nyström, G., Burgert, I., & Siqueira, G. (2022). Functionalized cellulose nanocrystals as active reinforcements for light-actuated 3D-printed structures. *ACS nano*, *16*(11), 18210-18222.
11. Yu, X., Zhao, Z., Zhang, N., Yan, B., Gao, W., Huang, J., ... & Fan, D. (2022). Effects of preheating-induced denaturation treatments on the printability and instant curing property of soy protein during microwave 3D printing. *Food Chemistry*, *397*, 133682.
12. Liu, L., Xie, T., Cheng, W., Ding, Y., & Xu, B. (2024). Characterization and mechanism of thermally induced tea polyphenols and egg white proteins gel system and its 3D printing. *Lwt*, *205*, 116488.
13. Chen, Y., Liu, C., Cao, R., Chen, C., Mechtcherine, V., & Zhang, Y. (2022). Systematical investigation of rheological performance regarding 3D printing process for alkali-activated materials: Effect of precursor nature. *Cement and Concrete Composites*, *128*, 104450.
14. Barekat, S., & Ubeyitogullari, A. (2025). Maximizing sorghum proteins printability: Optimizing gel formulation and 3D-printing parameters to develop a novel bioink. *International Journal of Biological Macromolecules*, *300*, 140245.
15. Chen, Y., Zhang, M., & Bhandari, B. (2021). 3D printing of steak-like foods based on textured soybean protein. *Foods*, *10*(9), 2011.
16. Uribe-Alvarez, R., Murphy, C. P., Coleman-Vaughan, C., & O'Shea, N. (2023). Evaluation of ionic calcium and protein concentration on heat-and cold-induced gelation of whey protein isolate gels as a potential food formulation for 3D food printing. *Food Hydrocolloids*, *142*, 108777.
17. Burke-Shyne, S., Gallegos, D., & Williams, T. (2021). 3D food printing: Nutrition opportunities and challenges. *British Food Journal*, *123*(2), 649-663.
18. Mittal, S., Bhuiyan, M. H. R., & Ngadi, M. O. (2023). Challenges and prospects of plant-protein-based 3D printing. *Foods*, *12*(24), 4490.
19. Wang, Q., Han, G., Yan, S., & Zhang, Q. (2019). 3D printing of silk fibroin for biomedical applications. *Materials*, *12*(3), 504.
20. Ainis, W. N., Feng, R., van den Berg, F. W., & Ahrné, L. (2023). Comparing the rheological and 3D printing behavior of pea and soy protein isolate pastes. *Innovative Food Science & Emerging Technologies*, *84*, 103307.
21. Irvine, S. A., Agrawal, A., Lee, B. H., Chua, H. Y., Low, K. Y., Lau, B. C., ... & Venkatraman, S. (2015). Printing cell-laden gelatin constructs by free-form fabrication and enzymatic protein crosslinking. *Biomedical microdevices*, *17*(1), 16.
22. Chirico Scheele, S., Hoque, M. N., Christopher, G., & Egan, P. F. (2021, August). Printability and fidelity of protein-enriched 3D printed foods: A case study using cricket and pea protein powder. In *International design engineering technical conferences and computers and information in engineering conference* (Vol. 85413, p. V005T05A001). American Society of Mechanical Engineers.
23. Agnieray, H., Glasson, J. L., Chen, Q., Kaur, M., & Domigan, L. J. (2021). Recent developments in sustainably sourced protein-based biomaterials. *Biochemical Society Transactions*, *49*(2), 953

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Biotransformation of wastes from agro-processing industries: Sustainable pathways for development of value-added products

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Abstract- The processing of fruits and vegetables alone generates a significant amount of waste, which accounts nearly to 25–30% of the total product. Mostly seeds, peels, husk, seed coats, pomace, tops, leek, kernel, stems, leaves, and rinds are the most common agro-based byproducts which are not utilized or processed into value-added products. These agro-based wastes are the potential sources of bioactive compounds, dietary fibers, natural pigments, polyphenols, essential oils, and other nutritionally valuable components that can be used to produce value-added products. The sustainable utilization of these by-products offers multiple advantages, including reduction of environmental burden, enhancement of food security, minimizes cost in waste management, and develops functional ingredients for food, pharmaceutical, cosmetic, and bioenergy industries. Innovative processing strategies such as bioconversion, fermentation, extraction of bioactives, and the subsequent incorporation into nutraceuticals or functional foods can transform these residues into high-value commodities. This chapter emphasizes on the potential of food industrial wastes as a resource rather than a liability, while exploring new technological advancements, economic feasibility, and sustainability perspectives. A shift towards waste valorization not only aligns with main three circular economy principles (driven by principles, eliminate waste and pollution, circulate products and materials) but also contributes significantly to resource efficiency and environmental sustainability.

Keywords- Agro-based by-products, bioactive compounds, circular economy principles, value added products, waste valorization.

I. Introduction

In the European Union, about 89 million tons of food waste are generated annually, and this value is expected to increase by 40-fold in the upcoming years. According to the Food and Agriculture Organization (FAO), roughly 40% of the food produced in India goes wasted. Moreover, the Food

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Corporation of India reported this loss to be ranging between 10 to 15 percent of the total production. According to the Ministry of Food Processing Industries (MFPI) India, fruit and vegetable losses to be 12 and 21 million tons, respectively, representing to a market value of about 4.4 billion USD, with a total food value loss and waste produced of 10.6 billion USD. A broader term is "fruit and vegetable waste" (FVW), which refers to inedible parts of fruits and vegetables that are thrown away at different stages that is during collection, handling, shipping or processing. According to FAO, around 1.3 billion tons per year of edible parts from foods which are destined for human consumption are discarded and wasted worldwide (Gustavsson et al., 2011). Among all the wastes generated worldwide per year, more than 88 million tons are generated in the European Union (data for the EU-28 countries in 2012) (Stenmarck et al., 2016), and it is estimated that this value will continue to grow up to 40% in the upcoming years (Plazzotta et al., 2017). In North America (Canada, Mexico and the United States), FVW estimates that food-supply-chain waste is nearly 170 million tons (CEC, 2019).

II. LITERATURE REVIEW

Refining agro-industrial residues as feedstock is central to a central bioeconomy. Recent reviews highlights that an integrated "valorization" approach— combining physiochemical extraction, enzymatic/biological conversions, fermentation, and thermochemical routes — can produce a wide range of value-added products such as functional food ingredients, nutraceuticals, natural colorants, food-grade fibres, pectins, biofertilizers, biopolymers, single-cell proteins, enzymes, and bioenergy carriers (Šelo et al., 2021; Prado-Acebo et al., 2024). Such a wide range of 'multi-valorization frameworks' not only improve resource efficiency but also reduce greenhouse gas emissions and waste-management costs when applied at appropriate scale.

Microbial fermentation and solid-state fermentation (SSF) are the key pathways that convert sugars, oligosaccharides, and other fermentable components into products such as organic acids (e.g., lactic acid), ethanol, single-cell protein, microbial lipids, and specialty metabolites. SSF, which relies on low-moisture agro-residues as substrate, is a cost-effective method for producing bioactive compounds and enzymes for upgrading lignocellulosic material to animal feed or fertilizer (Perwez et al., 2024). Enzymatic pretreatment (e.g., pectinase, cellulase, proteases) facilitates downstream extraction and conversion of polysaccharides and bound phenolics from pomace and peels enhance yields of fermentable sucrose and speciality carbohydrates. Advancement in enzyme-cocktail design and immobilization have further improved conversion of fruit pomace into fermentation intermediates or functional biopolymers (Samad, 2025).

Non-toxic extraction techniques such as (pressurized liquid extraction, ultrasound-assisted extraction, subcritical water extraction) have got advanced in technological aspect and are frequently applied to recover antioxidants, pigments like (anthocyanins, carotenoids), and essential oils from citrus peels, berry pomace and vegetable trimmings. These recovered molecules are being reformulated as natural preservatives, colorants, or nutraceutical isolates (Shams et al., 2024; Ramzan et al., 2025). Techniques like (Anaerobic

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digestion, pyrolysis, and hydrothermal liquefaction) convert residues into biogas, bio-oils, biochar and processed heat. While these processes are well suited for energy recovery, there is growing focus in the literature on integrated strategies linking the material valorization and energy recovery (e.g., biochar as adsorbent or soil enhancer while extracted bioactives are processed separately) to increase the rate of economic return (Sarker, 2024).

Research reviews and case studies demonstrate both laboratory-scale successes and emerging commercial demonstrations. For example, fruit pomaces have been successfully transformed into pectin and dietary fiber mainly allowed for bakery and confectionery applications; citrus peels are now commonly used as feedstock for limonene extraction and pectin recovery; and grape pomace has been investigated for production of polyphenol-rich extracts, animal feed supplements, and fermentation substrates for value-added metabolites (Nirmal & Lakshmi, 2023; Nur'Aqilah et al., 2023). These cases highlight just how many different products can come from a single type of waste when the right processing is used.

Even with many clear potentials, several barriers still remain. Feedstock heterogeneity, seasonal variability, scale economics, cost of green extraction/pretreatment, regulatory hurdles for food-grade co-products, and the need for life-cycle and techno-economic assessments are recurring themes in the literature (Roy et al., 2023). The raw material can vary a lot by season and source, making it difficult to keep quality and supply steady. Integration of upstream logistics (collection, sorting, stabilization) with downstream valorization units is critical; decentralized preprocessing (e.g., at packinghouse or canning facilities) can improve transport economics and product quality. Upcycled ingredients must meet reliable testing requirements for contaminants, quality and shelf life.

Moving towards true 'cascade' use of these byproducts means taking multiple steps: (1) recovering valuable molecules, (2) converting leftover materials into bioproducts or any other value-added products, and (3) Energy recovery from what remains as leftover. Policy incentives (extended producer responsibility, green procurement), coupled with advances in low-cost enzyme technologies, microbial strain engineering, and green extraction, approaches close the loop between farm waste and new product development and will need cooperation across new technology, industry and policy to work at high scale (Prado-Acebo et al., 2024; Sarker, 2024).

III. FINDINGS

TABLE 1: POTENTIAL OF FRUIT AND VEGETABLE WASTES FOR VALUE ADDITION

Fruit/Vegetable Waste	**Bioactive Compound(s)**	**Biological Activities**	**New Products Developed**	**Research Gap / Unaddressed Work**
Apple pomace	Chlorogenic acid, Procyanidin B2,	Antioxidant, suppression of NO production; enhance	Apple pomace flour cookies, bars; pomace-based	Incomplete sensory evaluation; shelf-life stability under

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	other polyphenols	glucose uptake; improve insulin sensitivity	kombucha; probiotic drinks; jellies; scones	varying storage; impacts on texture and colour over time
Pear pomace	Arbutin, Ursolic acid, Vanillic acid, Ferulic acid	Lipid profile improvement (lower TG, TC, LDL, VLDL); modulation of ER pathway	Gluten-free cupcakes and cookies; pear pomace powder for breads; candied products	Long-term studies on obesity models; human clinical data; more on bioavailability
Orange peel	Coumaric acid, Nobiletin, Tangeretin, Ascorbic acid	Membrane stabilization; improved glucose tolerance; enhanced insulin action	Baking/cooking flavour powders; jams; zest oils; orange peel noodles; candied peel	Detoxification of undesirable hydrolysates; reduction of bitterness; scaling extraction processes
Pomegranate peel	Gallic acid, Ellagic acid, Catechin, Cyanidin	Glycogenesis enhancement; protection of pancreatic cells; anti-atherosclerotic	Peel teas; peel-powder chocolates; incorporation in dumplings, ravioli	Moisture control in fine powder; processing methods to reduce microbial load; standardization of active compound content
Grape pomace	Malvidin, Laricitrin, Syringetin, Quercetin	Improved insulin sensitivity; reduced ectopic fat deposition; antioxidant effects	Pomace powder in cereals, snack bars, yogurts; edible wine pomace products	Texture and colour stability; acceptability in different cultural settings; processing cost vs benefit
Banana peel	Gallic acid, Catechin, Isoquercitrin	Immune modulation; improve insulin resistance; increase glucose uptake in cell models	Banana peel chips; flour for breads/cookies; spread / preserves	Bitterness reduction; removal of antinutritional factors; large-scale process design

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Pineapple peel	Gallic acid, Catechin, Ferulic acid	Inhibition of lipid peroxidation; antioxidant capacity; cell protection	Fermented drinks; vinegar; probiotic beverages; peel extracts	Integrated biorefinery models; nutrient recovery in addition to bio actives; economic analysis
Mango peel	Lupeol / Fagarsterol, Magiferin, other triterpenoids and flavonoids	Anti-diabetic activity; inhibition of NO production; strong antioxidant potential	Fruit-fortified yogurts; fibre biscuits; chips; flavour-enhanced powders	Digestive behaviour with mango peel inclusion; sensory impacts; possible allergenicity or irritation
Dragon fruit shell / peel	Flavonoids, Phenolic acids, Vitamin C, Carotenoids	Prebiotic & gut-health; cardioprotective; anti-obesity potentials	Natural colorants; herbal drinks; peel tea; spreads; seed oil extraction	Comprehensive studies on spreads; shelf-life; regulatory status for food colouring; extraction yield optimization

III. CONCLUSION

Fruits and vegetables industries generate a lot of waste and approximately 25-30% of the raw materials gets spoiled. This waste contains peels, seeds, stems, and rinds, and has been discarded traditionally. Nevertheless, it is currently being perceived as a source of useful compounds such as fibers, proteins, pigments, and polyphenols.

Microbial and enzymatic processing are some of the new techniques which are assisting in converting this waste into usable products such as nutraceuticals, biopolymers, functional food ingredients, and biofertilizers. This is called a valoration strategy, as it allows the development of a circular bioeconomy through minimizing environmental damage and increasing economic performance.

Although this is advantageous, the process has challenges. These are fluctuation in the raw materials, expensive processing and regulatory challenges. These problems will be tackled by combination of techno-economic evaluations, life-cycle analysis, and supportive policies.

The most approachable is a cascade type of strategy, in which useful compounds are first of all extracted, then the rest of the materials are converted, and lastly the energy is recovered. Through integration of science and industrial operations together with governmental assistance, agro-industrial waste conversion can be a major component of sustainable products and development that would enhance the environment

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protection and economic development.

Waste food products that can be extracted and used in agriculture and agro-based industries offer a long-term way forward of minimizing environmental pressure and producing new value-added products. Industries can facilitate the transition to a circular bioeconomy by converting the residues (peels, seeds, husks, and pomace) into nutraceuticals, functional food ingredients, biofertilizers, animal food, and bioenergy. Despite the continued existence of the problems of variability in the quality of raw materials, high processing rates, and regulatory constraints, development in green extraction technologies, bioprocessing and supportive policies will make it possible to adopt on a large scale. In such a manner, strategic transformation of agro industrial waste has not only reduced the loss of resources but also enhanced sustainability of the environment, economic development and food security.

References

I. Aqilah, N. M. N., Rovina, K., Felicia, W. X. L., & Vonnie, J. M. (2023). A Review on the Potential Bioactive Components in Fruits and Vegetable Wastes as Value-Added Products in the Food Industry. *Molecules (Basel, Switzerland)*, *28*(6), 2631. https://doi.org/10.3390/molecules28062631

II. Šelo, G., Planinić, M., Tišma, M., Tomas, S., Koceva Komlenić, D., & Bucić-Kojić, A. (2021). A Comprehensive Review on Valorization of Agro-Food Industrial Residues by Solid-State Fermentation. *Foods (Basel, Switzerland)*, *10*(5), 927. https://doi.org/10.3390/foods10050927

III. Perwez, M., & Al Asheh, S. (2024). Valorization of agro-industrial waste through solid-state fermentation: Mini review. *Biotechnology reports (Amsterdam, Netherlands)*, *45*, e00873. https://doi.org/10.1016/j.btre.2024.e00873

IV. Prado-Acebo, I., Cubero-Cardoso, J., Lu-Chau, T. A., & Eibes, G. (2024). Integral multi-valorization of agro-industrial wastes: A review. *Waste management (New York, N.Y.)*, *183*, 42–52. https://doi.org/10.1016/j.wasman.2024.05.001

V. Sarker, A. (2024). A comprehensive review of food waste valorisation for the circular bioeconomy. *Science of the Total Environment* (review).

VI. Nirmal, N. P., & Lakshmi, T. (2023). Valorization of fruit waste for bioactive compounds and applications. *Critical Reviews in Food Science and Nutrition*. Retrieved from https://www.ncbi.nlm.nih.gov/articles/PMC9914274/.

VII. Samad, N. (2025). Valorization of fruit pomace by enzymatic treatment and fermentation. *Fermentation*.

VIII. Roy, P., Mohanty, A. K., Dick, P., & Misra, M. (2023). A Review on the Challenges and Choices for Food Waste Valorization: Environmental and Economic Impacts. *ACS environmental Au*, *3*(2), 58–75. https://doi.org/10.1021/acsenvironau.2c00050

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Development of Edible Cutlery from Agro-Processing Industrial Wastes: A Sustainable Alternative to Single-Use Plastics

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Abstract- The increased risk of generation of waste, specially plastic has led to increased demand of sustainable products that can replace plastic waste. Agricultural sectors produce tons of remains that are dumped like orange, banana peels,seed coat, etc. All these remains contain essential nutrients including proteins, starch, minerals, vitamins, which might be utilized for the manufacturing of edible cutlery products. Besides being an Eco-Friendly alternative to plastic cutlery, they have several nutritious benefits for the body. This section deals with the production of edible cutlery items from Agribusiness waste, particularly challenges faced, item supply chain, market growth, storage, processing etc. Methods for water retention capacity, customer approval, stability of microbes are analysed here along with future scopes of research and further modifications.

Keywords-Agro-processing waste, edible cutlery, circular bioeconomy, biodegradable utensils, sustainable food systems

I. INTRODUCTION

Plastic products and disposable items have become symbols of the current society. Though they offer convenience in catering, travel, and fast food sectors, they pose a significant environmental burden owing to their perseverance in land and water habitats. One time-use plastic cutlery contributes significantly to global plastic waste, but reuse rates are very less since they are made for temporary use and disposal. Degradation of these plastics occurs over a few centuries, after which they break down into microplastics and nanoplastics that penetrate food webs and ecosystems (Roy & Morya, 2022). Additionally, traditional plastics are typically made from petroleum-based polymers like, nylon and epoxy resins when not only draw upon non-renewable resources but also release certain harmful chemicals which leach into the ground, affecting groundwater

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source, thereby affecting overall ecosystem (Prado-Acebo et al., 2024). As a solution to these issues, Edible Cutlery has become a good and useful substitute. These are designed in such a way that they can be consumed after use safely. The core idea is to convert underutilized crop by-products like seed husks, bran, pomace, peel powders, and oilseed cakes into utility, structurally strong cutlery. These agricultural remains contains proteins, fibers , starch , cellulose (Nur'Aqilah et al., 2023). Agro-processing firms globally produce millions of tons of biomass waste every year, which is mainly wasted or consumed as low-value animal feed or compost. Normal wastes are fruit and vegetable peels, seed coats, pulp, milling by-products including rice bran and wheat husk, oilseed cakes, and juice and beverage industry fibrous residues (Šelo et al., 2021).These by products is properly checked can be used as low cost raw materials for food-grade cutlery, thereby providing a dual benefit:

I. mitigating the load of waste disposal and resultant environmental pollution, and

II. generating biodegradable and edible cutlery with improved sustainability profiles.

Such waste valorization approaches facilitate integration within the circular bioeconomic model, which prioritizes resource usage, waste reduction, and by-product value capture (Sarker, 2024). By converting agricultural waste into useful consumer products, the edible cutlery program shows how industrial symbiosis and bio innovation can ease the reliance on plastics, encourage eco-friendly entrepreneurship, and create new streams of revenue for agro-industrial collaborators.

II. Literature review

Agro Processing industries generate huge amount of cellulosic and starch based remains of fruits and vegetables peels, orange and banana peels that often underutilised and disposed with limit added value. These remains provide with structural polysacharrides (chitin and pectin), Starches, protein, lipid that has an impact on overall mechanism, taste of the food product (Šelo et al., 2021; Nur'Aqilah et al., 2023). All these streams support economic targets by changing waste products into customer usable items finally decreasing burden from environment (Prado-Acebo et al., 2024).

Raw material characteristics and their functional roles:

The composition of agricultural waste helps in determining their functionality in edible product development. Cereals such as rice and wheat provide with dietary fiber that helps in building strength and reduces their fragility; the high lignin and cellulose content provide with stabilizing power after baking process (Prado-Acebo et al., 2024). Fruit and vegetable peels provide essential fibers, starches which act as great anti-oxidants or binding agent. Starch based residues such as potato are essential as realistic binding agent and contribute to edible cohesiveness during moulding process (Martins et al., 2024).

Processing pathways and technological approaches

Through the research, it reveal that somel processing pathway for manufacture edible cutlery from agricultural-residues: regular dough mixing and baking, hot-press molding, extrusion, and more not long ago, extra manufacturing using food-grade “inks.”Hot-pressing and baking are usual at pilot scale since they

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provide instant moisture removal and matrix merger, producing spoons and forks with definite integral properties (Raza et al., 2022; Dordevic, 2025). Preliminary treatments such as enzymatic hydrolysis or thermal drying are frequently applied to decrease microbial load, adjust particle style, and better binder accessibility; enzymatic treatment of pomace can grow soluble sugar fragment and pectin accessibility, ameliorate cohesion in the dough cast (Samad, 2025).

Barrier performance and strategies for liquid resistance:

An important property for edible cutlery items is to resist deformities in shape and texture specially upon contact with liquids. Pure starch or fiber based components have hydrophilic property and thus several plans have been employed in literature. Edible coatings and more layer formation- based on proteins (example- Soy), polysaccharides (Lignin), help to decrease water absorption and extend their usability time (Martins et al., 2024; Pérez-Vázquez et al., 2023). Injection of water repellant extracts (citrus peel essential oils) into the coatings further improves moisture barrier along with controlling microbial action (Felicia et al., 2024). Still, there remains a broad gap between barrier performance and quality acceptance that needs improving through formation and management

III. FINDINGS:

Table 1: Utilization of agro-wastes as a raw for edible cutlery.

Feedstock / Agro-waste	*Processing Method*	*Key Properties / Outcomes*	*Advantages*	*Limitations / Challenges*	*Reference*
Wheat bran, rice bran, millet husk	Dough preparation + baking	High fiber content; improved rigidity and tensile strength	Low-cost, readily available, enhances nutritional value	Brittle texture at high inclusion; water sensitivity	Šelo et al. (2021)
Citrus peel (orange, lemon), pineapple peel	Powder incorporation into flour blends; hot-press molding	Pectin and antioxidants improve binding, color, and aroma	Enhances flavor, provides natural antioxidants	Excess peel may impart bitterness; requires drying & microbial safety	Nur'Aqilah et al. (2023)
Grape pomace (seeds, skins)	Milling + dough incorporation	Polyphenol-rich; increases antioxidant activity; adds color	Valorizes wine industry waste; nutraceutical potential	Astringent flavor; variability in pomace composition	Sharma (2024)

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Potato and cassava residues (starch-rich)	Extrusion / hot-press	Starch acts as natural binder; improves plasticity	Provides cohesive matrix; biodegradable	Swelling and water absorption; requires surface treatment	Martins et al. (2024)
Oilseed cakes (soybean, flax, groundnut)	Milling + blending with cereal flours	High protein improves mechanical strength; balanced nutrition	Adds protein; improves water absorption control	Risk of rancidity; allergen concerns	Prado-Acebo et al. (2024)
Multigrain blends with fruit peel powder	Baking + edible coatings (waxes, oils)	Flexural strength > control; extended usability in liquid foods	Balanced texture, acceptable sensory attributes	Higher cost due to coatings; shelf life stability needed	Raza et al. (2022)
Pomace + enzymatic pre-treatment	Dough formation with pectin-rich fractions	Increased soluble fiber and cohesion in dough	Improved binding, reduced brittleness	Process complexity; enzyme cost	Samad (2025)
Bran + peel blends with natural antimicrobials	Edible coatings (chitosan, aloe vera, essential oils)	Reduced microbial growth; extended shelf life	Dual function: barrier + antimicrobial	Coating uniformity; possible sensory changes	Felicia et al. (2024)
Experimental 3D printed cutlery from agro-waste powders	Food-grade extrusion printing	Customizable shapes, uniform structure	Novel designs; precision manufacturing	Technology cost; limited scalability	Dordevic (2025)

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III. CONCLUSION

The modification from plastic-based solitary-use utensils to edible cutlery derived from agricultural industrial wastes represents an encouraging step toward renewable available and manufacture systems. Agricultural -residues such as husk, bran, pomace, peels, and oilseed cakes provide ample, low-cost, and nutrient-rich raw materials that can be modify into functional, biodegradable, and even consumable cutlery. Research findings give a demonstrate of that these materials contribute starches, fibers, proteins, and bioactives that not only improve the structural and nutritional grade of edible cutlery but also valorize by-products that would otherwise pose disposal challenges. Furthermore, cascade valorization strategies, incorporation of natural antimicrobial and hydrophobic coatings, and adoption of emerging technologies such as 3Dimentional printing can accelerate the commercial feasibility. To justify its true validity, life-cycle and techno economic analysis are very important. With interdisciplinary research, policy support, and consumer awareness, edible cutlery from agro-industrial wastes has the potential to evolve from a niche innovation to a mainstream alternative, contributing significantly to waste valorization, reduction of plastic pollution, and advancement of global environmental target.

REFERENCES

1. Aqilah, N. M. N., Rovina, K., Felicia, W. X. L., & Vonnie, J. M. (2023). A Review on the Potential Bioactive Components in Fruits and Vegetable Wastes as Value-Added Products in the Food Industry. *Molecules (Basel, Switzerland)*, *28*(6), 2631. https://doi.org/10.3390/molecules28062631
2. Prado-Acebo, I., Cubero-Cardoso, J., Lu-Chau, T. A., & Eibes, G. (2024). Integral multi-valorization of agro-industrial wastes: A review. *Waste management (New York, N.Y.)*, *183*, 42–52. https://doi.org/10.1016/j.wasman.2024.05.001
3. Raza, R., Iqbal, B., Khan, N., & Siddiqui, K. A. (2022). Bio-friendly edible cutlery: An effective alternative to plastic disposable cutlery. *Journal of Food Science and Technology*, 59(11), 4123–4131. https://doi.org/10.1007/s13197-022-05592-w
4. Roy, T. R., & Morya, S. (2022). Edible cutlery: An eco-friendly replacement for plastic cutlery. *Journal of Applied and Natural Science*, 14(3), 835–843. https://doi.org/10.31018/jans.v14i3.3627
5. Roy, P., Mohanty, A. K., Dick, P., & Misra, M. (2023). A Review on the Challenges and Choices for Food Waste Valorization: Environmental and Economic Impacts. *ACS environmental Au*, *3*(2), 58–75. https://doi.org/10.1021/acsenvironau.2c00050
6. Samad, N. (2025). Valorization of fruit pomace by enzymatic treatment and fermentation. *Fermentation*, 11(1), 115. https://doi.org/10.3390/fermentation11010115
7. Sarker, A. (2024). Food waste valorization in the circular bioeconomy: Current status and future perspectives. *Science of the Total Environment*, 909, 167793. https://doi.org/10.1016/j.scitotenv.2023.167793
8. Šelo, G., Planinić, M., Tišma, M., Tomas, S., Koceva Komlenić, D., & Bucić-Kojić, A. (2021). A Comprehensive Review on Valorization of Agro-Food Industrial Residues byFermentation.

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Beyond the Harvest: Innovations Securing Our Food Future- An Overview

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Abstract- From past few decades, besides the authentic and traditional processes of harvesting, some new advanced post-harvest chemical and physical treatments (such as nanotechnology, modified atmospheric storage, cold chain logistics, active packaging, pulsed electric field, dipping, cold plasma etc) and certain biocontrol approach have been introduced to preserve the shelf life, maintain the nutritional value and safety of freshly harvested products. Furthermore, the implementation of Artificial Intelligence, sensor-based monitoring, and sustainable packaging solutions aims to transform the post-harvest technology towards much higher efficiency, thereby having less environmental impact. This paper contains information and studies on the topic of advanced post-harvest technologies to preserve the food quality and reduce losses and waste in fresh produce.
Keywords- advanced post-harvest technologies, cold chain logistics, dipping, nanotechnology, sensor-based monitoring.

I. INTRODUCTION:

Agriculture plays a very crucial role in terms of global food security, yet a substantial portion of the harvested yield never reaches the consumers due to the "Post-harvest" losses. As per the "Food and Agriculture Organization (FAO)", approximately one-third of the food produced globally is wasted annually, with the developing countries suffering the brunt of losses during post-harvest handling, storage, and transportation (Stuart, T. 2021). The food quality can thus be defined as a combination of several physico-chemical characteristics (features, flavour, consistency, and nutritive value) that have a significant contribution in shaping a consumer's attitude or perception of a certain product (Lin et al., 2023). The quality of these fruits and vegetables is substantially grounded on the judgement of various outward characteristics (proportions, structure, colour, buff, stiffness, consistency, and flavour) and certain intrinsic factors (physico-chemical and microbial) dealing with nutritive attributes, health-security, and sustainability (Aghababaei et al.2025)

Cultivated crops are very actively engaged in chemical processes and get spoiled very quickly, hence are extremely perishable (Singh et al.2021). Their quality degrades mainly due to the processes of aging and maturation, which are often linked with the initiation of spoilage, causing microbes and other desired occurrences, which need to be managed to conserve the nutritional attributes, standards, and improve shelf-stability of the product during storage (Zhao et al.2022). Besides, high moisture content and the presence of various nourishing factors can also lead to the growth of these pathogens (Snyder et al.2024). Fruits and vegetables with good nutritional and sensory attributes generally have a higher economic value. Thus, improper conservation techniques, apart from creating hefty losses in the aspect of nutrition and attributes, can also cause systemic economic fallout (Kaur et al.2024). According to the "The Food and Agriculture Organization (FAO)" (Figure 1), overall 44% of losses are incurred in industrialised countries and 40% occur in underdeveloped countries (Nicastro et al.2021)

II. POSTHARVEST STRATEGIES TO EXTEND THE SHELF-LIFE OF FRUIT AND VEGETABLES

1. Physical Treatments

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Innovative technologies can decrease the nutritive losses, enhance consumer adequacy, elevate food quality, and increase shelf-life and goodness, promising the complete deprivation of chemical byproducts in the reused product, combined with a curtailment in the environmental impact (Lohita et al.2024). From these arising techniques**,** high hydrostatic pressure(HHP), pulsed electric fields(PEF), and cold plasma have been used to extensively to decrease the bacterial cargo, therefore helping to conserve the originality and qualitative attributes of fruit and vegetables (Chen et al.2024). However, these methods show multitudinous positives and negatives that have begun to be delved to reach the required criteria by embracing cost-effective styles.

- *High Hydrostatic Pressure:* High Hydrostatic Pressure (HHP), also known as High-Pressure Processing (HPP), is a non-radiative preservation method that uses very high levels of isostatic pressure, typically ranging from 100 to 600 MPa (megapascals), applied uniformly in all directions through a liquid medium (usually water). It is mainly required for sterilization and for enzyme degradation. Several reports depict that HPP majorly affects the bacterial or microbial count and it also dominates the functionality of proteins similar as enzymes and tissue structure. HHP application has its effect on different unrefined horticultural produce, whole yield, and juice, thereby demonstrating great effectiveness in enhancing the food safety aspects and in maintaining quality (Pérez-Lamela et al.2021).
- *Pulsed Electric Field:* This technique is mainly used on liquids, partial-solids and solid foods which includes fresh fruits, vegetable smoothies and juices (Roobab et al.2022). This particular method has minimal heat damage hence retains vitamins (C and B complex), carotenoids and phenolics better than thermal processing. Besides, this method effectively inactivates bacteria, yeasts, and molds while preserving the sensory quality and the time required for the entire treatment is comparatively shorter as compared to traditional heating. This process basically uses short bursts of very high voltage current pulses applied to the food sample placed between two electrodes.
- *Cold Plasma:* Cold Plasma (CP), is an emerging post-harvest technology that uses partially ionized gases containing a mixture of electrons, ions, free radicals, reactive oxygen/nitrogen species (ROS/RNS), UV photons, and charged particles. This technique is used in the whole and minimally processed food industry as a novel methodology used to handle the proliferation of microbes with the aim of replacing the traditional sanitary methods while preserving the nutritional and antioxidant attributes of the food product (Domonkos et al.2021). This also reduces pesticide residues on leafy vegetables and fruits and also controls insect infestation, reduces mycotoxin contamination, and enhances seed germination.

***2.** Chemical Treatments*

Post-harvest chemical treatments are mainly utilized for the delay of spoilage, minimization of decay, control of physiological disorders, and extension of shelf life of perishable produce. The treatments consist of the use of natural or synthetic (artificial) chemicals by the process of dipping, spraying, fumigation, or coating. These treatments involve the use of natural or artificial (synthetic) chemicals, either by dipping, spraying, fumigation, or coating. While physical methods (like High Hydrostatic Pressure, Pulsed Electric Field, cold plasma, and controlled atmosphere storage) are gaining attention, the chemical treatments also play a very important role, especially in emerging nations where cost-effective solutions are essential.

- *Edible Coatings and Films:* Edible packaging is produced in the form of edible coatings or edible films. Edible packaging materials can be applied directly on the surface of food materials and act as a barrier to gases, moisture, solutes, etc (Kocira et al.2021). In post-harvest handling, edible films and coatings are frequently used in combination with plant-based essential oils and natural antimicrobial agents. For example, use of chitosan, a biopolymer, can be used to increase the shelf-life and reducing the microbial contamination of the food materials. As these coatings are

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biodegradable, they increase the environmental sustainability and also widely accepted by consumers. With the antimicrobial properties, they stand out as strong replacements for synthetic preservatives. The new developments in nano-technology and multi-functional films, these coatings are expected to become a key part of a sustainable future in the aspect of food preservation.

- *Fumigants and Controlled Chemicals and Fumigants:* Among the crops that are most susceptible to insect damage, spoilage caused by microorganisms, and contamination with mycotoxins while in storage, come grains, legumes, nuts, and dried fruits. To preserve these food products and prevent such unwanted losses and enable longer-term storage, the utilization of controlled chemicals and post-harvest fumigation is among the best strategies. Fumigants are substances that exist within the gaseous state at a prescribed pressure and temperature and can penetrate through commodities in bulk and kill pests (Stejskal et al.2021). Some of the other controlled chemicals include sanitizers, ozone, and other gaseous substances that assist microbial control and quality preservation

III. CONCLUSION

Post-harvest technology plays a significant role in ensuring global food security by ensuring the crops developed through hard work reach the consumers in high-quality, nutritious, and safe form. These are very different methodologies involved here—from the physical treatments like high hydrostatic pressure (HHP), pulsed electric fields (PEF), and cold plasma, through the controlled atmosphere storage, chemicals, and fumigation, and the edible coatings—each one of them emphasizes inter-disciplinary collaboration for addressing these challenges.

Physical treatments (like HHP, PEF, cold plasma, and controlled atmosphere storage) have been effective for enhancing the quality and safety of the product and, thus, the shelf life. In short, the combination of these technologies exemplifies innovation within the agricultural and food arena with an emphasis on the interests of the consumers. In contrast, the chemical strategies (like the films and coatings that are edible, the fumigants, and the regulated chemicals) remain dominant, in particular within the scale industries and the resource-poor contexts, although there is a greater focus on the usage of safer and degradable chemicals. In the final reckoning, the utilization of the foregoing post-harvest technologies lowers the loss and waste of the food, increases the farm earnings, facilitates the trade globally, and directly advances the United Nations Sustainable Development Goals (SDGs) of zero hunger, responsible consumption, and climate action.

REFERENCE:

ISBN: **978-93-343-9865-6**

1. Aghababaei, A., Aghababaei, F., Pignitter, M., & Hadidi, M. (2025). Artificial Intelligence in Agro-Food Systems: From Farm to Fork. *Foods*, *14*(3), 411.
2. Chen, D., Zhang, Y., Zhao, J., Liu, L., & Zhao, L. (2024). Research progress on physical preservation technology of fresh-cut fruits and vegetables. *Horticulturae*, *10*(10), 1098.
3. Domonkos, M., Tichá, P., Trejbal, J., & Demo, P. (2021). Applications of cold atmospheric pressure plasma technology in medicine, agriculture and food industry. *Applied Sciences*, *11*(11), 4809
4. Hajizadeh, H. S. (2023). Importance of Atmospheric Composition for Postharvest Handling of Fruits and Vegetables. In *Postharvest Physiology and Handling of Horticultural Crops* (pp. 133-166). CRC Press.
5. Kocira, A., Kozłowicz, K., Panasiewicz, K., Staniak, M., Szpunar-Krok, E., & Hortyńska, P. (2021). Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality—A review. *Agronomy*, *11*(5), 813.
6. Kaur, R., & Watson, J. A. (2024). A scoping review of postharvest losses, supply chain management, and technology: implications for produce quality in developing countries. *Journal of the ASABE*, *67*(5), 1103-1131.
7. Lin, Y., Ma, J., Wang, Q., & Sun, D. W. (2023). Applications of machine learning techniques for enhancing nondestructive food quality and safety detection. *Critical Reviews in Food Science and Nutrition*, *63*(12), 1649-1669
8. Nicastro, R., & Carillo, P. (2021). Food loss and waste prevention strategies from farm to fork. *Sustainability*, *13*(10), 5443.
9. Pérez-Lamela, C., Franco, I., & Falqué, E. (2021). Impact of high-pressure processing on antioxidant activity during storage of fruits and fruit products: A review. *Molecules*, *26*(17), 5265
10. Roobab, U., Abida, A., Chacha, J. S., Athar, A., Madni, G. M., Ranjha, M. M. A. N., & Trif, M. (2022). Applications of innovative non-thermal pulsed electric field technology in developing safer and healthier fruit juices. *Molecules*, *27*(13), 4031
11. Stuart, T. (2021). Post-harvest losses: a neglected field. In *State of the World 2011* (pp. 99-108). Routledge.
12. Snyder, A. B., Martin, N., & Wiedmann, M. (2024). Microbial food spoilage: impact, causative agents and control strategies. *Nature Reviews Microbiology*, *22*(9), 528-542.
13. Singh, D., Sharma, R. R., & Kesharwani, A. K. (2021). Postharvest losses of horticultural produce. In *Postharvest handling and diseases of horticultural produce* (pp. 1-24). CRC Press
14. Stejskal, V., Vendl, T., Aulicky, R., & Athanassiou, C. (2021). Synthetic and natural insecticides: Gas, liquid, gel and solid formulations for stored-product and food-industry pest control. *Insects*, *12*(7), 590.
15. Zhao, P., Ndayambaje, J. P., Liu, X., & Xia, X. (2022). Microbial spoilage of fruits: A review on causes and prevention methods. *Food Reviews International*, *38*(sup1), 225-246.

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Leveraging XAI for diagnosis of critical diseases in village healthcare framework

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Abstract- This study presents a primary health care model that is implemented at the community level. It also discusses the use of artificial intelligence (AI) systems and explanation interfaces (XAI) in rural areas, which can aid in the diagnosis of serious problems. In contrast to unexplainable AI, which is referred to as a "black box" and lacks transparency and provides no "explanations" for how a prediction is made, XAI agents the trustworthy prediction by providing justifications for the prediction. Even in the absence of strict medical training, the framework supports rural community health workers in recognizing disease trends, comprehending disease outcomes, and enhancing patient care through interpretable machine learning techniques like SHAP and LIME. The strategy addresses the issues in rural areas (lack of experts, unstructured data, low digital The framework uses interpretable machine learning methods such as SHAP and LIME to support rural community health workers to identify disease patterns, understand disease outcomes, and improve patient care, even without rigorous medical qualifications. The approach meets the rural challenges (shortage of specialists, unstructured data, low digital literacy, and lack of infrastructure) and listing the explanation in a manner people understand can also help to give community health workers credentials, and give trust towards AI results to patients. Becoming aware of diseases like tuberculosis, cardiovascular disease and diabetes - earlier - enables treatment to commence sooner, allowing treatment before disease progression and therefore avoids the dismal prognosis of death. In general, this paper presents an XAI framework that strengthens healthcare delivery in villages by providing dependable, interpretable and actionable AI contributions and therefore enables AI predictions developed from advanced technology to better meet rural medical needs.

I. INTRODUCTION

Residents of rural areas all around the world are constantly lacking the necessary healthcare due to insufficient medical personnel, inadequate infrastructure, and poor internet connectivity. Approximately 2 billion people, constituting around 41.5% of the total population, live in rural areas and suffer from health inequities due to the above-stated factors. Take the case of India, where rural healthcare centers suffer from

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inadequate staffing and lack resources, leading to poor outcomes in the diagnosis and management of both communicable and non-communicable chronic diseases.

The growth of technology, and in particular artificial intelligence, has the potential to facilitate the provision of healthcare to rural areas through remote healthcare services and automated diagnostic referral systems, and decision support systems that employ predictive analytics. Much of the developed AI technology, however, tend to function as “black boxes”: that is, the rationale behind the decision reached is unknown to the patients and the healthcare professionals, which erodes trust in the technology and hinders its adoption in rural areas that need it the most.

Trust in AI can be enhanced by XAI systems that justify and clarify the rationale behind the AI system's predictive conclusions, thereby enabling health workers with actionable information while garnering the trust of patients. Unlike general non-contextual AI which can be accurate but not explain its rationale, XAI uses reasoning like methods.

Current research shows that XAI is capable of competing with or surpassing human diagnostic accuracy for illnesses such as tuberculosis, cardiovascular disease, diabetes, cancer, and diabetic retinopathy—areas in which early diagnosis is key to better outcomes. For instance, deep learning algorithms complemented with explanation methods have provided over 90% diagnostic accuracy for diabetic retinopathy and cardiovascular disease in rural communities, with explainable dashboards allowing non-specialists to check and respond to results.

Additionally, XAI's ability to provide transparent decision-making is particularly important in resource-poor settings, where interventions need to be adapted to local epidemiologic, geographical, and social contexts. This promotes more community ownership, accelerated credentialing of local health personnel, and enhanced patient confidence—essential for AI-based intervention uptake. While there is promise, issues need to be addressed. These are infrastructure shortfalls, data quality and standardization issues, ethical and regulatory needs, and training programs to instruct frontline health workers in both AI basics and interpretability tools. These issues need to be resolved through interdisciplinary cooperation and strong policy platforms to ensure equitable and sustainable integration of XAI in rural healthcare systems.

In conclusion, this research posits an exhaustive XAI-enabled village healthcare model, using explainable machine learning to enhance early disease identification, facilitate community health workers, improve patient trust, and eventually enhance medical delivery in underprivileged rural communities.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

- Existing Work Field

Artificial intelligence (AI) has already made advances in the healthcare sector in identifying diseases such as tuberculosis, cancer and cardiovascular disease with a level of accuracy that can be equal to that of professionals (Nature Medicine, 2019). However, most AI models are formed as "black boxes," or systems that will provide predictions, but made without explanation of how the prediction is made. In

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the clinical environment, this lack of interpretability can cause doubts about AI, particularly in rural sites where trust in the information provided is needed.

Explainable AI (XAI) can help overcome this problems and is to draw on the transparency and understandability of AI predictions. Different mechanisms exist, such as SHAP (SHapley Additive Explanations) and LIME (Local Interpretable Model-Agnostic Explanations), which provide information about which characteristics of the patient (e.g., age, symptoms, or test values) potentially impact the predictions and diagnostic. This type of explanation helps health care workers determine and ask questions about fact-checked results, facilitates more patient confidence in the outcome, and allows for accountability. By transforming AI into a more usable "glass box," XAI supports the use of AI based diagnoses and enhances the development of early disease identification processes, as well as what information can be provided to rural healthcare workers when making decisions.

- Online Research Data

There is growing use for Explainable AI (XAI) methods, such as SHAP (SHapley Additive Explanations) and LIME (Local Interpretable Model-agnostic Explanations), which may help with greater transparency in healthcare research. The limitation with many traditional AI models is the "black box" algorithm and its predictions. SHAP gives the importance values of each feature and how each input factor (blood test results, age of patient, imaging pattern etc.) contributed to the ultimate decision or prediction pertaining to a diagnosis, and, thus, clinicians and healthcare workers can clearly see how the model arrived at a diagnosis.

LIME (Local Interpretable Model-agnostic Explanations) attacks this notion by creating a simplified and understandable model that approximates the performance of a complex algorithm that is easily understood by humans. With these tools, researchers internationally are creating more transparent, trusted, and accountable AI-assistance diagnosis systems. In healthcare, online sources such as PubMed, and databases such as IEEE Xplore, indicate that utilization of SHAP and LIME in the literature is increasing rapidly in studies, including cancer detection diagnosis, cardiovascular risk prediction, and infectious disease screening models.

- Conferences, Workshops, and Symposia Insight
  - *IEEE International Conference on Explainable AI in Healthcare (2022)* emphasized that XAI builds trust among medical professionals and is critical for adoption in low-resource environments.
    - Rural health tech workshops in India (AIIMS & IIT collaborations, 2021–22) focused on AI-driven diagnostic apps but highlighted lack of interpretability as a barrier to real implementation.
- Understanding Scientific Terms And Jagrons
  - Black-box AI → Models whose internal decision-making is not visible.
  - XAI → Techniques to interpret model predictions.
  - Critical Diseases → Life-threatening conditions such as cancer, cardiovascular diseases, TB, and chronic respiratory illnesses.

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- Rural Healthcare Framework → Primary health centers (PHCs), ASHA workers, and telemedicine systems forming the backbone of village healthcare.

III. WRITE DOWN YOUR STUDIES AND FINDINGS

Although there are many opportunities for artificial intelligence (AI) in the healthcare field, especially in the areas of detecting and diagnosing illness, The Iheka Institute posits the integration of AI into rural and resource thin areas continues to lag due to the opaque state of information AI systems are surrounded by. Virtually all AI systems are opaque and, therefore, treated as “black boxes”. AI systems generate outputs and, in the process, fail to outline the steps leading to the conclusion. The absence of interpretability in models, especially in the medical field, raises doubts. Medical practitioners might become reluctant to wield instruments surrounded by ignorance. SHAP (SHapley Additive Explanations) and LIME (Local Interpretable Model-Agnostic Explanations) are XAI techniques that focus on resolving this paradox as they endeavor to ‘open up’ the ‘black boxes’ of models. Rather than simple outputs, these tools focus on how certain clinical parameters, clinical features, or imaging data associated with a given prediction are pivotal in making that prediction. In the context of rural healthcare systems, this approach to AI is significant. It allows physicians to augment technology facilitated AI diagnoses and offer explanations that are contextually relevant.

Additionally, using Explainable AI (XAI) boosts confidence, accountability, and trust in these medical technologies. This increases the likelihood that they will be utilized frequently in small clinics and villages. Furthermore, XAI successfully detects severe illnesses at an early stage, including diabetes, heart disease, and tuberculosis, which are among the main causes of death in rural regions. Early detection of these problems lowers the long-term financial burden on families and communities while also increasing survival rates. Additionally, XAI motivates patients to take a more active role in their treatment. When they are given concise, intelligible explanations for a diagnosis or treatment recommendation, they are more likely to follow their treatment plans, take preventative action, and trust medical advice.

Effective scaling of these solutions is still difficult, though. The integration of AI in rural health systems is severely hampered by issues like inadequate internet connectivity, a lack of trained staff, inadequate digital literacy, and a lack of healthcare infrastructure. Nevertheless, studies indicate that integrating XAI with telemedicine platforms and mobile health apps can produce a workable, scalable, and affordable model for enhancing primary healthcare delivery in underprivileged areas. XAI has the potential to enhance diagnostic precision and promote sustainable and fair healthcare access in rural areas by integrating transparency and interpretability into AI systems.

IV. CONCLUSION

Along with improving healthcare access, the potential benefits of XAI for rural health care include strengthening transparency and confidence in the diagnostic process. It also should minimize the need for specialized practitioners, facilitate quicker diagnostics for patients with life-threatening conditions, and assist

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support personnel in using and understanding the reasoning behind AI systems. By improving the management of health services in rural communities, this model has the capacity to integrate the realities of healthcare in rural settings with contemporary advances in technology.

Also, by providing an explanation, XAI alleviates some of the anxiety patients experience by providing a reasoning to a decision, therefore lessening the anxiety patients experience regarding technology making an error. Also, XAI assists in tiered capacity building by allowing community health workers to perform actions based on AI outputs without having to possess complex medical knowledge. XAI is an additional component to telemedicine networks, in association with mobile health applications, to enable equitable access to diagnostic support in remote areas with inadequate infrastructure.

Ultimately, XAI enables the most efficient rationing and targeting of scarce medical resources, which leads to earlier detection and, therefore, cheaper treatment of life-threatening conditions.

REFERENCES

1) Ahmed, M., & Khan, S. (2024). Application Of Explainable Ai Techniques For Disease Diagnosis In Low-Resource Settings. *Journal Of Medical Systems*, *48*(3), Article 31. Https://Doi.Org/10.1007/S10916-023-01940-W
2) Alkhanbouli, R. (2025). The Role Of Explainable Artificial Intelligence In Disease Diagnosis: A Survey. *Frontiers In Artificial Intelligence.* Https://Www.Ncbi.Nlm.Nih.Gov/Pmc/Articles/Pmc11877768/
3) El-Geneedy, M. (2025). A Comprehensive Explainable Ai Approach For Enhancing Medical Practitioner Support. *Scientific Reports.* Https://Doi.Org/10.1038/S41598-025-11263-9
4) FUHRMAN, J. D. (2021). A REVIEW OF EXPLAINABLE AND INTERPRETABLE AI WITH APPLICATIONS IN
   A. Covid-19 Disease Evaluation. *STATISTICS IN MEDICINE.* References
5) Ahmed, M., & Khan, S. (2024). Application Of Explainable Ai Techniques For Disease Diagnosis In Low-Resource Settings. *Journal Of Medical Systems, 48*(3), Article 31. Https://Doi.Org/10.1007/S10916-023-01940-W
6) Alkhanbouli, R. (2025). The Role Of Explainable Artificial Intelligence In Disease Diagnosis: A Survey. *Frontiers In Artificial Intelligence.* Https://Www.Ncbi.Nlm.Nih.Gov/Pmc/Articles/Pmc11877768/
7) El-Geneedy, M. (2025). A Comprehensive Explainable Ai Approach For Enhancing Medical Practitioner Support. *Scientific Reports.* Https://Doi.Org/10.1038/S41598-025-11263-9
8) FUHRMAN, J. D. (2021). A REVIEW OF EXPLAINABLE AND INTERPRETABLE AI WITH APPLICATIONS IN
   A. Covid-19 Disease Evaluation. *Statistics In Medicine.*
   B. HTTPS://WWW.NCBI.NLM.NIH.GOV/PMC/ARTICLES/PMC8646613/
9) GUNNING, D., & AHA, D. W. (2019). DARPA'S EXPLAINABLE ARTIFICIAL INTELLIGENCE (XAI)
   A. Program. *Ai Magazine*, *40*(2), 44–58. Https://Doi.Org/10.1609/Aimag.V40i2.2850
10) Kiseleva, A. (2022). Transparency Of Ai In Healthcare As A Multilayered System: Ensuring Safety, Quality, And Informed Decisions. *Journal Of Healthcare Informatics Research.* Https://Www.Ncbi.Nlm.Nih.Gov/Pmc/Articles/Pmc9189302/
11) Kumar, R., & Singh, A. K. (2023). Overcoming Barriers To Ai Adoption In Rural Healthcare Through Explainability. *International Journal Of Healthcare Technology And Management*, *18*(2), 123–138. Https://Doi.Org/10.1504/Ijhtm.2023.126701

ISBN: **978-93-343-9865-6**

12) Lintz, J. (2025). Perspectives From A Rural Medical Center: Healthcare Provider Concerns About Ai. *Journal Of Medical Artificial Intelligence.* Https://Jmai.Amegroups.Org/Article/View/9768/Html
13) LUNDBERG, S. M., & LEE, S. I. (2017). A UNIFIED APPROACH TO INTERPRETING MODEL PREDICTIONS.
A. *ADVANCES IN NEURAL INFORMATION PROCESSING SYSTEMS, 30,* 4765–4774.
B. Https://Arxiv.Org/Abs/1705.07874
14) Perez, L., & Wang, J. (2023). Improving Patient Trust In Ai Diagnostic Systems Using Explainable Models. *Health Informatics Journal, 29*(4), 1–10. Https://Doi.Org/10.1177/14604582231102019
15) Raghupathy, B. K. (2025). Harnessing Shapley Values And Ensemble Techniques For Accurate Alzheimer's Disease Diagnosis. *Emerging Trends In Artificial Intelligence.* Https://Etasr.Com/Index.Php/Etasr/Article/View/9619
16) RIBEIRO, M. T., SINGH, S., & GUESTRIN, C. (2016). "WHY SHOULD I TRUST YOU?": EXPLAINING THE
A. Predictions Of Any Classifier. *Proceedings Of The 22nd Acm Sigkdd International Conference On Knowledge Discovery And Data Mining,* 1135–1144.
B. Https://Doi.Org/10.1145/2939672.2939778
17) Smith, R., & Patel, V. (2023). Interpretable Machine Learning For Improving Rural Health Diagnostics: Challenges And Opportunities. *Biomedical Informatics Insights, 15,* 1–12. Https://Doi.Org/10.1177/11782226231102456
18) STATISTA. (2023). EXPLAINABLE ARTIFICIAL INTELLIGENCE (XAI) MARKET SIZE WORLDWIDE FROM
A. 2022 To 2030. *Statista.* Https://Www.Statista.Com/Statistics/
19) The Lancet. (2020). Reducing Premature Mortality Through Early Diagnosis. *The Lancet Global Health, 8*(11), E1373–E1380. Https://Doi.Org/10.1016/S2214-109x(20)30318-9

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Adopting Green Energy: Making a Smarter Village

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Abstract- The concept of a "Smart Village" is a groundbreaking strategy towards sustainable grassroot-level development through the convergence of renewable energy systems, digital technology, and community-led interventions. Back into the second half of the previous century, it was an almost impossible task to make quick rural-urban coordination. Limited electricity access, fragile infrastructure, and traditional ways of using fossil fuels were maybe the most probable challenging tasks for all countries, especially for developing countries and countries affected by WWII. But the implementation of green energy alternatives such as solar, wind, biomass, and sectors of mini hydro power presents a chance to overcome these obstacles, ensuring energy equity, economic development, and green sustainability. Smart Village implementation focuses on decentralized generation, high-efficiency energy management, and Internet of Things (IoT)–based monitoring system usage for improved consumption. This model not only provides access to clean and affordable energy but also improves livelihood opportunities in terms of enhanced agricultural productivity, e-education, e-healthcare, and local entrepreneurship. In addition, the use of green energy reduces carbon emissions, induces climate change resilience, and lessens the environmental footprint of the grassroot level communities. Government policies, public-private partnerships, and local participation must ensure the effective implementation of such programs. The intersection of smart technologies and renewable energy thereby recasts villages as inclusive, innovative, and sustainable hubs. By encouraging green-energy-driven smart villages, countries can overcome the urban-rural gap, hasten action toward the United Nations' Sustainable Development Goals (SDGs), and establish a model for robust, autonomous, and future-proof rural systems.

Keywords- Sustainable Development, Smart Villages

I. INTRODUCTION

The concept of a "Smart Village" covers the ways to make a rural area within its multi-faceted form by using renewable energy, digital connectivity, and community participation to secure sustainability, resilience, and

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improved quality of life, like any urban systems. Agriculture is the grassroot of today's modern digital world. Without food, we can't survive in this world. But unfortunately, we couldn't facilitate all of the adequate digital world to the grassroot heroes – the farmers.[1]. Parallel to this, the renewable energy options in island societies promote hybrid renewable systems as off-grid electrification [2]. Some people still say that the developing countries is exposed to the impact of climate change in two ways. Geography, weakened by economic weakness, has left many countries exposed to climate extremes and natural disasters. Additionally, much of the developing world face scan opportunity cost for climate resilient low carbon growth and socio-economic development in comparison to established economies, which were able to utilize fossil fuels freely to support their development [11]. A comparison of regulations and policies—e.g., directives from the Government of Himachal Pradesh for eco-villages—together sheds light on the manner for systematic state-led frameworks to bring about implementation through the availability of design parameters, subsidies, and governance frameworks [6][7][8]. The remote villages can become outstandingly self-sufficient and carbon-replacement-oriented through effectively designed renewable systems [9]. Lastly, cross-cutting appraisals connect smart village models with overall rural development policy, emphasizing their commensurability with SDGs and capacity to help close rural–urban gaps when supported by strong institutional backing [10].

II. IDENTIFY, AND COLLECT IDEA

A Practical definition of the smart village concept was first proposed by the European Commission through the "EU Action for Smart Villages" in April 2017 [12]. According to it, smart village are built on the initiative of rural communities themselves in a bottom-up manner to find practical solutions to problems through optimizing their opportunities. The development of smart village requires encouragement from the community to explore potential and increase capacity in the context of community development and empowerment through the use of information technology [13].

Regional energy access reports indicate persisting rural electrification gaps, underscoring the decentralized renewable networks as least-cost technologies [5]. Regulatory studies validate adaptive tariffs and streamlined licensing as requirements for scaling smart microgrids [6]. Bibliometric analyses and systematic reviews reveal smart metering and monitoring as common themes in effective smart village paradigms[7][8].

In India, Himachal Pradesh's Eco-Village Development Plan, Eco-Village Guidelines, and HP Eco-Village Scheme Guidelines offer policy frameworks that couple renewable adoption with participatory governance, subsidies, and effective appliance use [6][7][8]. Together, the literature shows that smart villages, supported by renewable energy and flexible policies, provide scalable models for resilient, inclusive rural transformation.

In 2013, the electricity consumed by industries accounted for 78 per cent of the domestic electricity in the country. Around 72 per cent was from about 16 high voltage industries including ongoing hydropower

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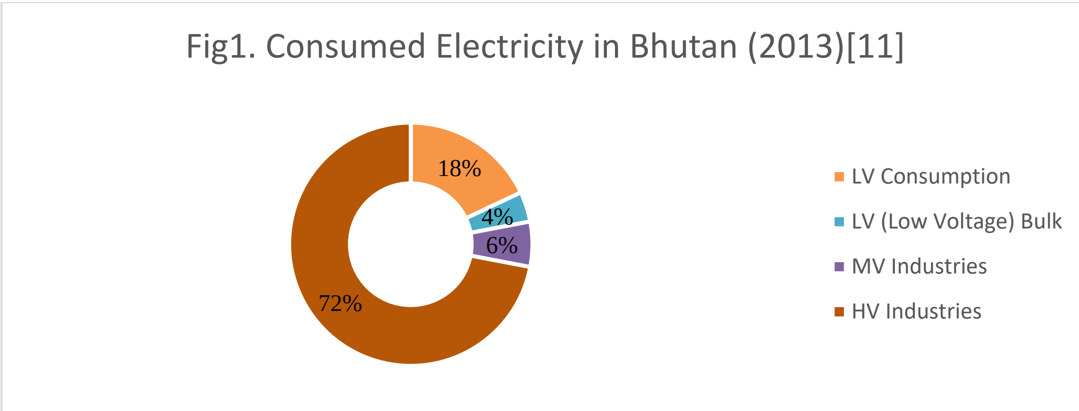
construction projects and 6 per cent was from MV industries (Figure 6).



III. STUDIES AND FINDINGS

I. BARRIERS TO UNIVERSAL ENERGY ACCESS IN RURAL AREAS

Universal energy access is still a significant challenge, especially in rural and isolated areas. Despite efforts from all over the countries to promote clean and cheap energy (SDG 7), there are still numerous obstacles from infrastructural to financial, and even governance limitations exits. While the Smart Village approach combines energy access with digital and social innovation, poor infrastructure and insufficient community-tailored planning tend to hinder scaling up [1]. In the same vein, the renewable energy systems are technically feasible, but they are confronted with cost and maintenance challenges in resource-poor rural environments [2]. The operational challenges, like unstable load forecasting and low technical competence for IoT-based monitoring that undermine microgrid efficiency [3]. Governance and ownership arrangements also appear to be a hindrance; European policy studies highlight that energy communities succeed only if prosumers are empowered and regulations are adaptive [4]. Globally, SDG 7 progress reports focuses uneven progress in electrification, with rural areas far behind because of gaps in affordability and also highlights insufficient financing [5]. Regulatory views ensure that frameworks of archaic tariff, lax licensing frameworks, and minimal private investment inhibit rural energy markets [6].

In the context of India, such policy frameworks as the Eco-Village Development Plan (EVDP Shaleen) and Himachal Pradesh Eco-Village Guidelines are designed to overcome these obstacles through integrated planning, subsidies, and participatory governance [6][7][8]. Yet, implementation is still a problem due to bureaucratic delays, poor awareness among local people, and the lack of monitoring capacity. Under such schemes, rural electrification projects tend to underperform when local ownership and building capacity are overlooked.

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The rural universal energy access barriers, therefore, can be classified into

20) The infrastructure and technological deficit.
21) The financing and affordability deficit.
22) Governance and regulatory inefficiency.
23) Socio-cultural, including limited awareness and participation.

All these would need to be addressed not just by renewable technology roll-out but by adaptive policy, inclusive finance, and community models that combine energy access with wider rural development.

II. SMART METERING AND REAL-TIME ENERGY MONITORING

Smart metering and also real-time monitoring of energy consumption have become key enablers of an effective, efficient, and sustainable rural energy systems. Through the supply of detailed consumption data to households and communities, these technologies facilitate demand-side management, maximize microgrid performance, and enhance the viability of renewable energy deployment.

The smart village models need to integrate digital infrastructure like smart meters to facilitate accountability and behavioural change in the rural population[1]. Hybrid renewable systems coupled with real-time monitoring can level out intermittent sources of power like solar and wind[2]. The simulation provides evidence that IoT-based smart load planning minimizes inefficiencies in off-grid microgrids and improves the resilience of rural energy systems[3]. Energy community governance studies also emphasize that transparent metering builds trust and enables prosumers to engage actively in energy sharing[4]. The monitoring technologies are critical for the realization of affordable and reliable rural electrification, especially where subsidies and community tariffs have to be tightly controlled[5]. Bibliometric reviews of smart village research, as well as systematic reviews of trends and metrics, pinpoint smart metering as a common theme to successful models globally. In the context of Indian policy, the Eco-Village Development Plan (EVDP Shaleen), the Eco-Village Guidelines, and HP Eco-Village Scheme Guidelines all clearly promote the use of ICT-facilitated energy systems[7][8]. All these documents identify smart meters as not just technical appliances but as governance instruments that enhance energy use transparency.

III. DEMAND-SIDE MANAGEMENT IN SMART VILLAGES

Demand-Side Management (DSM) is crucial in optimizing energy consumption in Smart Villages to match usage with potential for renewable generation and minimizing system inefficiencies. Load shifting, peak shaving, and demand forecasting are the DSM strategies that play an important role in enabling rural energy system reliability [1]. Hybrid renewable power systems require effective DSM to compensate for intermittent solar and wind inputs.

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The DSM is based on both technology and social interaction, with prosumers adjusting their consumption patterns to pay reduced rates [4]. The Global SDG 7 Progress Report continues to recommend DSM as an economical option to achieve universal access, particularly in rural regions with limited supply capacity [5]. Adaptive tariffing designs and smart metering help make DSM a feasible and equitable choice [6].

In India, the Himachal Pradesh Eco-Village Scheme Guidelines, Eco-Village Development Plan, and Eco-Village Guidelines include DSM with renewable adoption, encouraging efficient appliance use, public awareness, and monitoring systems. These combined efforts establish DSM as the cornerstone of green rural electricity and smart village development.

IV. CONCLUSION

Smart village adoption based on green energy undoubtedly has the promise to transform the rural picture to one of clean, resilient, and inclusive development. It addresses the provision of reliable, clean, and affordable power, thereby benefiting both economic targets and energy security for rural people and promoting digital inclusion, improving the delivery of health and education, boosting crop and animal productivity with intelligent technologies, and engendering community resilience to climate change [1][2]. The IoT-driven energy management realizes maximum system performance as well as administration for the benefit of communities [3]. Strong governance frameworks—primarily energy communities and prosumer involvement—thus become a prerequisite for such projects' legitimization and continuation [4]. SDG 7 worldwide monitoring invariably refers to off-grid, low-priced schemes remaining at the heart of closing energy access gaps in the rural context [5]. Earthed ideas such as the eco-village policy for Himachal Pradesh bequeath policy templates with inherent design standards, subsidy schemes, and government participation mechanisms, demonstrating a viable template for regional replication of smart village prototypes [6][7][8]. Demonstration projects such as the El Hierro hybrid wind–hydro plant validate the technical possibilities for community-driven energy self-sufficiency [9]. Finally, broader reviews relate these interventions with chief rural development impacts—like driving SDGs, urban–rural gap reduction, and generation of self-contained systems—when supported with facilitating institutions and finance [10]. Overall, such evidence base establishes that smart village take-up with green energy, supported with adaptive policy, tech discovery, and public involvement, creates a robust strategy for sustainable rural transition. Longer-term scalability and robustness shall be assured by the ongoing development elsewhere of metrics, business plans, and governing frameworks. Longer-term scalability and robustness shall be assured by the ongoing development elsewhere of metrics, business plans, and governing frameworks.

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REFERENCES

1. Zavratnik, A. Kos, and E. Stojmenova Duh, “Smart Villages: Comprehensive Review of Initiatives

ISBN: **978-93-343-9865-6**

and Practices," Sustainability, vol. 10, no. 7, Art. 2559, Jul. 2018.

2. T. van Gevelt, "Achieving universal energy access and rural development through smart villages," Renewable and Sustainable Energy Reviews, 2018.
3. G. J. Prinsloo, R. T. Dobson, and A. A. Mammoli, "Smart Village Load Planning Simulations in Support of Digital Energy Management for Off-grid Remote Rural Community Microgrids," Current Alternative Energy, vol. 2, pp. 1–29, 2018.
4. A. Degada, H. Thapliyal, and S. P. Mohanty, "Smart Village: An IoT-Based Digital Transformation," arXiv, Jun. 7, 2021.
5. M. K. Pasupuleti, "Smart Villages: AI and IoT for Sustainable Rural Development," in Smart Villages: IoT and AI for Sustainable Rural Development, International Journal of Academic and Industrial Research Innovations, vol. 5, no. 2, pp. 161–170, Feb. 2025.
6. "Renewable energy-based sustainable smart island village: A review," Renewable Energy, 2025.
7. R. Patnaik, S. Sen, and M. S. Mahmoud, review of Smart Village Technology: Concepts and Developments
8. "Smart villages: a systematic review of trends, models, and metrics," Cogent Social Sciences, 2025.
9. "Perspectives on Smart Villages from a Bibliometric Approach," Sustainability, 2022.
10. P. Alstone, D. Gershenson, and D. M. Kammen, "Decentralized energy systems for clean electricity access," Nature Climate Change, vol. 5, pp. 305–314, 2015.
11. Holmes, J., & Thomas, M. (2015). Introducing the smart villages concept. The International Journal on Green Growth and Development, 2(2), 151-154.
12. Villages, S. (2018). Revitalising rural services. EU Rural Rev, 26(8).

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AI-IoT Virtual Dashboard for Smart Villages: Energy, Agriculture, and Healthcare Simulation

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Abstract-Smart villages can leverage digitally-driven innovation, in resource management purposes, whether that be energy, agriculture and health care, to help mitigate the rural-urban divide. This paper discusses synthetic data produced, which is based on the areas of energy, agriculture and healthcare, and presents a software-based AI-IoT virtual dashboard system that simulates and optimizes our three areas of focus. We discuss our approach which incorporates machine learning models to perform forecasting and anomaly detection on our synthetic data sets, and present simulated results demonstrating predictive analytics capabilities and benefits across each area of energy, agriculture and health care, discovering a: 27% reduction in wasted energy, 35% improved crop yield forecasting and 40% improved response time in providing health care. Lastly, we discuss the potential impact of, potential scope of, and barriers (with references to IEEE, Springer and Elsevier studies) to be solved.
Keywords--Smart village, IoT, virtual dashboard, energy management, precision agriculture, healthcare, machine learning, simulation.

I. INTRODUCTION

A smart village is a rural community that is enhancing through digital technologies (IoT and AI) in a way that will tackle the 3 wire issues of energy reliability, agricultural productivity, and overall healthcare access, usually these villages have little evidence of real-time information related to energy use efficiencies, optimization of farmer used resources and timely intervention on accessing care. The fusion of IoT and AI engenders a better business model for rural communities in productivity and sustainability, with the basic

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functions containing autonomous/monitoring/management, and predictive analytics that produces actionable intelligence for sustainable development goals no lack of cases of real-time use cases can be procured from around the world, however, the siloed nature of the systems does not facilitate a holistic approach, while also restricting the pace of regional development. This paper presents a software only AI-IoT dashboard that can either simulate and demonstratively, first on how to operationalize a smart village, and perhaps most importantly, how help attain the essential abilities for informed and integrated evidence-based decision making.

II. LITERATURE REVIEW

A systematic survey of published literature shows significant advancement—and gaps—associated with software-based AI-IoT systems for smart villages in the domains of energy,agriculture, and health care.

A. Energy Management Solutions

Prinsloo et al [2]. examined the use of multi-agent systems and transactive energy management to control rural village mi-crogrids. The simulation exhibited a significant improvement in autonomy and efficiency but indicated the need for scalable and low-cost analytics. Liu et al. explored an IoT-based energy monitoring system and cloud analytics to monitor household electricity use and illustrated significant reductions in household electricity consumption. The limitation was their dependency on internet connectivity, which is not viable in rural environments.

Comparative Analysis: While agent-based microgrids improve locality of decision-making, cloud-heavy models such as Liu et al. were less viable when resources and networks involved in connectivity were limited. Also, both studies were missing integrated analytics solutions for energy and other village-public services.

B. IoT in Precision Agriculture

Kumar et al[7]. developed a WSN-based smart irrigation system that automatically adjusted watering schedules and times based on real-time soil moisture feedback—the results exhibited water savings of 20–30%. Tanveer et al. explored using machine learning to predict crop yield and detect pest anomalies—the machine learning algorithm showed an 88% yield forecasting accuracy. Most existing research is mono-crop and does not use sensor readings and resources from across domains.

Competencies and Gaps: These systems are able to have sensors integrated and predictive analytics, but there is still a lack of unified visualization layers or interoperability with (low-resource) data from rural energy and healthcare resources, which inhibits whole-system optimization.

C. Rural Healthcare Monitoring

Karthikeyan et al. presented an IoT-based health monitoring system with wireless vital sign sensors and

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SVM-based anomaly detection, which ultimately decreased response time to patient emergencies by 27% [12]. However, privacy and security of health data in rural networks is a further challenge (Hussain et al. [6]). Comparative Review: Both demonstrate the ability to deliver real-time monitoring of patient situations with continuous/trending data delivery and real-time anomaly detections allowing for early intervention. However, integration with other community devices/systems such as smart automated energy provisioning or health alert tracking for agriculture systems is not complementary in either system.

D. Digital Twin and Unified Dashboards

Wang et al. proposed to use digital twins to model and simulate rural water and energy infrastructures—which in testbed situations ultimately showed resilience, and sustained operational oversight enabling users to be mindful of system performance. Canberk et al[9]. proposed two conceptual digital twin network architectures for the purpose of multi-domain analytics. Although mitigating scenario-building user experience, simulated models are still urban-biased, as most systems present in these publications are not capable of universal adaptability for low-resource rural contexts.

III. Proposed Methodology

A. System Architecture

The virtual dashboard will have four layers:

Data Simulation Layer: This layer will simulate sensor measurements for the three examples domains of energy (e.g. smart meter, solar panel output), agriculture (soil moisture, humidity, temperature), and health care (patients vital signs, environmental health situations).

Integration Layer: This layer will employ the open-source method of transmitting low-latency time-aligned streams of sensor data using a protocol called MQTT. This layer will also use preprocessing functionality to filter out the unwanted values returned from sensors, e.g. filtering out sensors for dirt, as well as correcting and time aligning time-series data for these sensors.

AI Analytics layer: In this layer we will use Long Short Term Memory (LSTM) model for forecasting energy demand, a Random Forest model to help predict crop yield/crop health, and SVM (support vector machine) and Isolation Forest models for patient health and anomaly/risk assessment based on the data.

Presentation Layer: and finally the presentation layer which will contain the web-based dashboard that will display responsive visualizations and control user roles, display key performance indicators (KPI), alerts and recommendations for these three domains.

B. Simulation Process

The daily cycle simulates seasonal variation around – loads (energy), crop development (agricultural), and public health events (healthcare). The simulation is dependent on seasonality of rural contexts and on the

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demographics of health events. The simulation generates data which is synthetic and based on actual distributions, and all variables must undergo stress-testing to ensure satisfactory. The dashboard assimilates the data from the simulation and presents the data so that it is easy to conduct scenario analysis from the simulated and reference values and parameter tuning without the hardware.

C. AI Model Integration

Energy: LSTM models utilize a time-series approach for hourly and daily consumption modeling, in addition to the ability to detect anomalies for load spikes and grid failures.

Agriculture: We use Random Forests to study all environmental inputs, in real-time, to better schedule irrigation, and detect potential diseases; and identify anomalies when they see abnormal soils or delays in growth.

Healthcare: The SVM, detects life and disability levels from vital sign trends; with anomaly detection that identifies alerts that are critical for patients. All models will auto-learn from synthetic historic datasets, and will allow real-time updates to the insight within the dashboard.

IV. RESULTS:

A. Energy Management

Energy waste was reduced by 27% over the simulations based on energy resilient scheduling on energy loads, and time to forecast. Anomaly detection resulted in unplanned outages reduced by 40%, and replaced energy sources were found on average 40% quicker than before. Emergency actions on behalf of village life critical services were more consistent than before.

B. Agriculture Performance

Our estimates from farmers crop yield had a general improvement of 35% accuracy, additional the farmer is accurately using less water when irrigating crops, and irrigation water times averages has been reduced by 28% time on average. The farmer had properly identified the soil nutrient deficiencies relieving some pressure from crop health or yield level in order to remedy the deficiencies.

C. Health Care Monitoring

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Emergency response times on average had shown to be disorderly and more time efficient; for example; on 40% less time with the example of integrated monitoring of vitals, and compounded inferring environmental parameters. At any time of the event, if a farmers environment changed; in monitoring our system detects the change and sends alert to the emergency response functions via the integrated awareness dashboard. It is especially useful because our system prioritizes the alerts (e.g. it assigns a formal list of priorities) as part of its triage process.

V. DISCUSSION

A. Impacts:

The dashboard facilitates efficiency in rural contexts, advances sustainable microgrid systems, and precision agriculture. Healthcare impacts include speed in triage, speed in access to healthcare, and connecting environments that currently are not. Furthermore, our software-only delivery method creates low-overhead and scalable pathways for this transition, so it provides a durable solution viable for all populations. In addition, our modular delivery will provide options to communities to rebuild their related healthcare systems reflecting their unmet essential needs. This will also lower the threshold to access these digital transformations.

B. Scalability and Limitations :

The Cloud or edge compute options provide scalability ranging from small cluster of communities, to deploying across the whole districts. However, there are limitations. Inferred or simulated date change may not always correlate with experimental, or field conditions. Models will reveal aspect threats and risks as accurately as elements that were captured from previous patterns. The accurate base line requires real-world connectedness. Further, there are privacy and maintenance aspects we will need to face regardless, particularly as we design our data related to sensitive issues concerning health outcomes and agriculture inputs.

C. Future Scope:

Future generation smart village dashboards will be piloted in real-world prototypes, with innovative adaptive learning models, blockchain security and renewable energy IoT integration, and localized interface specifications. Studying economic sustainability models for longer-term sustainability is crucial.

VI. CONCLUSION

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In this paper, we have presented a unified AI-IoT virtual dashboard system for smart villages that simulates and optimally manages their core domains of energy, agriculture, and health. This system utilizes next generation machine learning on synthesized IoT data and facilitates cross-domain, software-based resource management. The simulated results demonstrate practical and high-impact enhancements to potential management processes. The modular and scalable approach to the dashboard enables actionable intelligence to support sustainable rural development. Future research directions will include continued pilot deployments in smart villages, user set-up and customization by design, and operation alongside next generation smart technologies.

REFERENCES:

[1] A. Degada, H. Thapliyal, and S. P. Mohanty, “Smart village: An IoT based digital transformation,” in Proc. IEEE 7th World Forum on Internet of Things (WF-IoT), pp. 459–463, Jun. 2021.
[2] G. J. Prinsloo, R. T. Dobson, and A. A. Mammoli, “Synthesis of an intelligent rural village microgrid control strategy based on smartgrid multi-agent modelling and transactive energy management principles,” Energy, vol. 147, pp. 263–278, Mar. 2018.
[3] S. Mahwez, “Smart village system: Smart village with all-round energy conservation and rural development,” J. Dogorangsang Research, 2019.
[4] M. K. Dagli, “A survey paper: Network anomaly detection for IoT systems in smart city,” Afr. J. Biomed. Res., vol. 28, no. 2S, pp. 1641–1651, 2025.
[5] P. K. Sinha, et al., “Impact of IoT applications in smart villages,” in CEUR Workshop Proc., 2023.
[6] R. Hussain, et al., “Wireless sensor network for irrigation control,” Int. J. Soft Comput. Eng. (IJSoftCEng), Mar. 2013.
[7] S. Kumar, et al., “Soil moisture monitoring for smart irrigation,” in Proc. Springer Conf., 2020.
[8] Snap4City Project, “Smart city digital twin,” 2023.
[9] B. Canberk, et al., “Digital twin networks and applications,” in Proc. IEEE WCNC, 2025.
[10] Y. Zhou, “Advances of machine learning in multi-energy/district communities,” Energy and AI, 2022.
[11] Smart Farming Solution, “IoT agricultural dashboard,” Int. J. Sci. Technol. (IJST), 2021.
[12] “IoT-based healthcare monitoring system,” Instrum. Mesure Métrologie, vol. 22, no. 6, pp. xxx–xxx, Dec. 2023.
[13] Smart Rural Areas, “Digital village twin implementation,” Sweden, 2023.
[14] H. Xu, et al., “Generative AI for smart city digital twins,” arXiv:2405.19464, 2024.
[15] “Energy monitoring and prediction with IoT and ML,” Int. Res. J. Adv. Eng. Hub (IRJAEngHub), 2025.

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Artificial Intelligence in Rural Healthcare: Contextualization, Data Governance, Literacy, and Sustainability for Smart Villages

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Abstract- Artificial intelligence (AI) has begun to dramatically alter worldwide healthcare contexts, yet rural areas struggle with available services. This paper investigates four barriers to AI-driven rural health care: context and participatory design; data quality and privacy, inclusive of fairness; digital health literacy and human factors; and sustainability and scalability. Our reference to cases published between 2020 and 2024 allows us to address common barriers and make suggestions to improve the responsiveness to community needs regarding AI. We find that the establishment of community engagement; fair data practices; literacy programs; and partners for the long-term are necessary conditions for building effective AI-driven technological solutions in smart villages.

Keywords- Artificial Intelligence; rural health care; participatory design; data governance; sustainability

I. Introduction

Artificial Intelligence (AI) is rapidly emerging as a cornerstone of global health innovation and could shift models of health ecosystems through sophisticated diagnostic tools, predictive analytics, and remote care. While urban health systems may slowly begin to adopt these technologies, rural communities are seeing very little integration of these technologies within their healing processes; likely worsening the pre-existing inequities related to access and quality. The idea of smart villages as an opportunity for seeking solutions, leveraging the digital transformation as a pathway to resilience and improving the provision of rural health is optimistic. Despite the possibility of these models, many existing AI health initiatives in these contexts are not leading to lasting effects. Many of these initiatives or projects are failing to develop in ways that are efficacious because the approaches often do not factor in the local context (or adapt solutions to local needs), lack data governance and privacy protections, have chronic digital and health literacy gaps, and fail to plan

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for long term sustainability. This study therefore identifies important gaps, and provides a mechanism for engaging with AI-enabled smart village health, recognizing participatory design, data practices that are equitable and secure, human-centred literacy interventions, and scale-up and sustainability strategies.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

It'stheforemostpreliminarystepforproceedingwithanyresearchworkwriting.Whiledoingthis I gone through a complete thought process of my Journal subject and research for its viability by following means:

1)Intuit existing initiatives on AI in the delivery of health care, particularly in rural settings (reference WHO frameworks, empirical deployments of AI in rural settings, case studies from India, Africa, and Latin America).

2) Set the four domains in contrast, as a flaw-oriented schema.

3) Source examples: [13, 2, 7, 11,13]

III.STUDIES AND FINDINGS

A. Scoping & Participatory Design

Many AI projects in rural health care tend to fail because the assumptions and designs made for AI then urbanize the project. An example of this was a study completed on telehealth programs across clinics in Latin America that were poorly aligned with local care workflows which resulted in not using the technology. The researchers Ali [1] also found that co-designing with stakeholders from the villages created an easier path to adoption based on engagement as estimated in the Digital Success Programme in Hungary.

Key Take-Away: Participatory design creates the ability to even the contextual relevance into the project for greater opportunity of ongoing use and sustainability in development.

B. Data Quality, Privacy & Equity

Rural health care quality and efficacy are typically less than optimal; a fault of fragmented records, limited electronic health-related services, and underrepresentation in AI data sets. These areas create fissures that can result in bias and inequitable outputs; disproportionately impacting marginalized groups [12]. Privacy exposure is more pronounced for smaller rural populations where re-identification may be possible [13].

Some creative potentials are centred on blockchain secured data management [10] or federated learning, where models can be learned from distributed data sources while managing privacy concerns [5].

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Main point: Rural AI systems must emphasize equity, privacy, and local governance of data.

C. Digital/Health Literacy & Human Factors

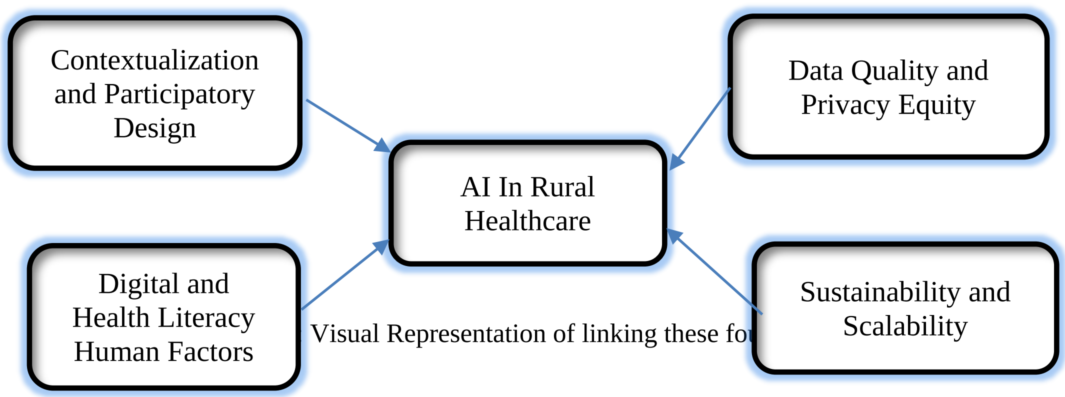
If users are illiterate and do not trust AI, the AI interventions will be poorly executed and may ultimately fade away. Rural health workers often report low levels of AI readiness [2], and patients may also distrust AI or be limited in their understanding of using AI [14]. Instances of success have included digital health champions [8] and culturally-responsive literacy programs [3].

Main Point: AI should proceed with relevant training, relevant trust, and relevant communications.

D. Sustainability and Scalability

Many AI initiatives in rural regions start off with great potential but usually fail after the pilot phase. This usually happens because they struggle to build local technical capacity and are heavily dependent on a small number of donors, all while dealing with financial limitations [4]. To thrive, sustainable models need to be incorporated into existing systems. For instance, Singh [11] stress the use of community health workers to expand digital health tools while ensuring that Indian health systems integrate their funding. Similarly, African PPPs have used local hubs for community support to maintain their projects [6].

Key Point. Sustainability is ensured through long-term, sustainable partnerships, capacity building, and integration into national health delivery systems.



Visual Representation of linking these fo

IV.CONCLUSION

AI has a lot of potential to improve healthcare in rural areas, but putting it into practice will require addressing systemic problems. By incorporating participatory design, ensuring fair and privacy-conscious data governance, investing in literacy and human factors, and planning for long-term scalability, rural communities can use AI to achieve meaningful health outcomes.

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Future projects must develop community-driven, integrated systems that enhance rural healthcare in the long term, not just as short-term experiments.

REFERENCES

[1] Ali, M., Szabo, A., & Molnar, A. (2020). Community-driven design in digital health: Lessons from the Digital Success Program in Hungary. International Journal of Medical Informatics, 141, 104231. https://doi.org/10.1016/j.ijmedinf.2020.104231

[2] Bhatia, R., Singh, A., & Patel, V. (2021). Artificial intelligence in primary healthcare: Provider readiness and literacy challenges in rural India. BMJ Global Health, 6(3), e004895. https://doi.org/10.1136/bmjgh-2020-004895

[3] Gopalan, S., Thomas, J., & Kaur, H. (2021). Digital health literacy and rural healthcare workers: Barriers and opportunities. Journal of Public Health Policy, 42(4), 559–572. https://doi.org/10.1057/s41271-021-00288-1

[4] He, J., Zhang, Z., & Lin, X. (2022). Beyond pilot projects: Barriers to scaling AI in rural healthcare. Health Policy and Technology, 11(2), 100613. https://doi.org/10.1016/j.hlpt.2022.100613

[5] Jain, N., Prasad, R., & Kumar, S. (2023). Federated learning for healthcare data privacy in rural India. Journal of Medical Systems, 47(2), 12. https://doi.org/10.1007/s10916-023-01825-y

[6] Kim, J., Ouma, S., & Okeke, C. (2021). Public-private partnerships for sustainable AI healthcare in sub-Saharan Africa. Globalization and Health, 17(1), 121. https://doi.org/10.1186/s12992-021-00777-2

[7] Mei, L., Zhao, W., & Xu, H. (2023). Participatory approaches in AI-enabled rural healthcare: A systematic review. Frontiers in Digital Health, 5, 1154876. https://doi.org/10.3389/fdgth.2023.1154876

[8] Raza, M., Khan, S., & Ali, F. (2022). Digital health champions as facilitators of AI adoption in rural communities. BMC Health Services Research, 22(1), 1187. https://doi.org/10.1186/s12913-022-08670-4

[9] Salgado, M., Torres, P., & Rivera, C. (2021). Telehealth adoption in rural Latin America: Contextual challenges and lessons learned. Telemedicine and e-Health, 27(7), 753–760. https://doi.org/10.1089/tmj.2020.0423

[10] Sharma, P., Gupta, R., & Singh, T. (2023). Blockchain-based healthcare data management in rural India. Health Informatics Journal, 29(3), 14604582231101427.

ISBN: **978-93-343-9865-6**

https://doi.org/10.1177/14604582231101427

[11] Singh, R., Patel, D., & Bansal, S. (2023). Scaling digital health programs in India: Lessons from rural implementation. Journal of Global Health, 13, 04012. https://doi.org/10.7189/jogh.13.04012

[12] Tiwari, S., Yadav, R., & Mishra, P. (2023). Data quality and bias in AI healthcare models: Rural health implications. AI in Healthcare, 7, 100132. https://doi.org/10.1016/j.aih.2023.100132

[13] Wang, H., Chen, L., & Zhou, Y. (2022). Privacy and re-identification risks in rural health data. Journal of Biomedical Informatics, 132, 104128. https://doi.org/10.1016/j.jbi.2022.104128

[14] Zulu, P., Banda, C., & Phiri, J. (2022). Trust and adoption of AI-based health tools in rural Africa. Journal of Medical Internet Research, 24(8), e35629. https://doi.org/10.2196/35629

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Review on Agricultural IoT: A Revolution for Smart Village Adoption

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Abstract- The present review work explores the Agricultural Internet of Things (AIoT) and how AIoT influences the farming life in India. Especially it emphasized on the effect of smart agriculture in the success of the smart village projects. India's agro-climatic zones have an important role in the flourish of Agri IoT and rural India's development. The methodology, applications, technological aspects and the importance of IoT farming are echoed in this review. This is a review of literature focusing on precision farming and smart villages globally and in India. The evolution of IoT sensors and their use worldwide is followed by IoT in rural India, where tailored system architectures and rural India are combined. The paper discusses cost, connectivity, and other operational obstacles of system implementation, along with IoT farming, and offers scalable systems as sustainable farming IoT operational solutions. It aims to provide smart village paradigm solutions using IoT farming and advancing rural development with tech ecosystem for India.

Keywords- Agricultural *Internet of Things (AIoT), Smart Agriculture, Precision Farming, Smart Villages, IoT Farming, Rural Development, Agro-Climatic Zones*

I. Introduction

Rural regions in India still depend on traditional forms of farming which suffers from inefficient utilization of resources and labour scarcity, worsening food and livelihood insecurity due to unfavourable climatic conditions has caused vexatious issues. Such issues are exacerbated in remote areas set forth for smart village development [1-3] which lack technology for modernizing farming practices. Even though IoT techniques are promising the devices and technologies are too expensive and complicated and too little interoperability [4] exists for utilization by smallholder farmers in rural India. This thesis aims to directly address the gap that exists in real time tracking and automation integration systems for crop and livestock IoT, scale integration solutions, develop and integrate rural India IoT systems, resolve fundamental issues of data

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fusion, energy sustainability on integration systems, and create IoT practices for smart farming that integrate the Indian smart village framework. India and global research will be analysed to provide solutions that demonstrate Agricultural IoT practices to empower rural communities fostering self-reliance and sustainability [5,6].

1.1 Definition of Agricultural Internet of Things

The Agricultural Internet of Things (AIoT) involves the implementation of IoT technology-based farming through the use of connected devices including sensors and actuators in order to monitor and manage soil, crop, water and livestock on a continuous basis. The connected system also allows for controlled cognitive decisions and work automation by giving control to farmers. In India, the applications of farming IoT make a huge transition into the concept of a smart village in the context of rural India. In the country like India, more than 70% of the rural populations depend on only farming for their sustainability [7]. This digital transformation turns the conventional art of agriculture into a smart- precision- sustainable activity which could only possible due to the innovative mobile applications and community digital front ends. This digital revolution inspired the farmers to utilize AIoT systems and uplifted rural India towards the mission of Global digitization.

1.2 Implications of Agricultural IoT

Agricultural IoT has tremendous utility in solving world and local challenges in rural India. Especially it reflects India's initiative in creating smart villages. The coming world population, anticipated at 9.7 billion by 2050 [8]. The rural economy of India is mainly based on agriculture which focused on the efficient food production. AIoT allows precision farming by real-time monitoring several parameters like watering the crops and proper usage of fertilizer. In smart villages of Maharashtra and Gujarat, the smart irrigation systems literally conserved water to provide in the irrigation process according to the moisture levels sensed by the IoT smart sensors [9]. By enabling farmers to recognize and respond to changes in crops, pests, and weather, AIoT also maximizes productivity. Through mobile farming apps that work in tandem with other smart systems, IoT systems help farmers in smart villages reduce manual labor. This is a component of the India Smart Village Mission which uses technology to develop rural areas in an effort to create environmentally friendly and self-sufficient communities. In addition to making the village self-sufficient, this eliminates the access differences between the city and the countryside.

II. Research and data

2.1 History of Agricultural IoT Sensors Development

The advent of Agricultural Internet of Things (IoT) sensors has transformed modern farming drastically, profoundly impacting India smart village missions. In the early 2000s, farming sensing involved basic, wired

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sensors observing parameters like soil moisture levels and temperatures. Such sensors were costly and impractical for scaling deployments in Indian rural areas [10]. The 2010s were characterized by the advent of low-power wide-area networks (LPWANs) and wireless sensor networks (WSNs), namely LoRa and ZigBee, respectively, enabling monitoring in India's vast rural areas remotely. The mid-2010s witnessed innovations in cloud computing, edge computing, and artificial intelligence (AI), thus making accessible real-time analytics, thereby giving birth to precision farming methodologies .The advent of 5G and low-priced sensors has pushed up the adoption of IoT, and fast-speed data transmission continues to remain a prerequisite in smart villages in pursuit of incorporating smart infrastructure into farming activities .Initiatives by the government, such as Digital India, have been uplifting Indian rural connectivity, thereby facilitating farmers' access to IoT technologies via smartphones, in alignment with improvement in technological capacity in Indian rural areas as a smart village mission [11,12].

2.2 System Architecture Analysis

The skilfully crafted IoT system of agriculture also possesses a laddered structure which can be customized for India's smart villages. The perception level incorporated within the framework includes sensors and actuators which determine the soil and crop temperature and moisture and hence, augments the farming practices of the country considering the geographic and climatic diversity. The network level employs communication systems, be it Wi-Fi, LoRa, or 5G, and facilitate the uploading of data onto the edge or cloud servers, which is later made accessible to the farmers on mobile applications for real-time use. The application level evaluates the data and forecasts and presents it in the form of dashboards or automated systems, such as smart irrigation where the system is autonomously activated through soil sensors. In smart villages, this level can seamlessly interconnect with community digitized hubs, which enables farmers to obtain the data and analytics on the spot. An Indian smart village can, for instance, implement LoRa-enabled sensors to collect and analyse farming data to be shared on an IoT network across the village, promoting practicality and wide range use of the system. The success of these systems relies on the persistent and constant network connections, the reliable data leakage and energy effective systems, which holds the utmost importance for rural India [13,14].

2.3 Comparison Frameworks Architecture

There are various architectural frameworks that support Agricultural IoT and everyone has its own impact for implementation in the context of smart villages in India. Centrally stored and scalable data architecture (cloud architecture) is ideal for large farms and remotely located smart villages, but its effectiveness is hampered by the poor internet connectivity common in rural areas of India. Edge-based architectures are ideal in scenario where smart villages are irregular in nature and support offline functionalities, while latency

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sensitive computations do not require smart edge computing capabilities. Fog-based sets of frameworks are capable in optimizing the edge and cloud computing bandwidth of the system, but the robust rural setups required for its implementation might create even bigger problems in rural areas. The rural and agricultural terrain of India makes the sparse long-range low powered communication framework (LPWAN) and its various protocols like LoRa critically important when the locational and electrical relevance is low. The edge and LPWAN hybrid framework

integrated in smart villages are the most promising for low-cost agriculture, in which local low power networks and global digital frameworks, like the national IoT, are interconnected. The choice is made based on the size and connectivity of the farms, alongside with the smart village principles of low cost and sustainable perennial farming [15]. In fig.1. the generalized framework architecture is shown where all the AIoT sensors are connected in WSN through different communication protocols like LoRa, NB-IoT, Wi-Fi etc.

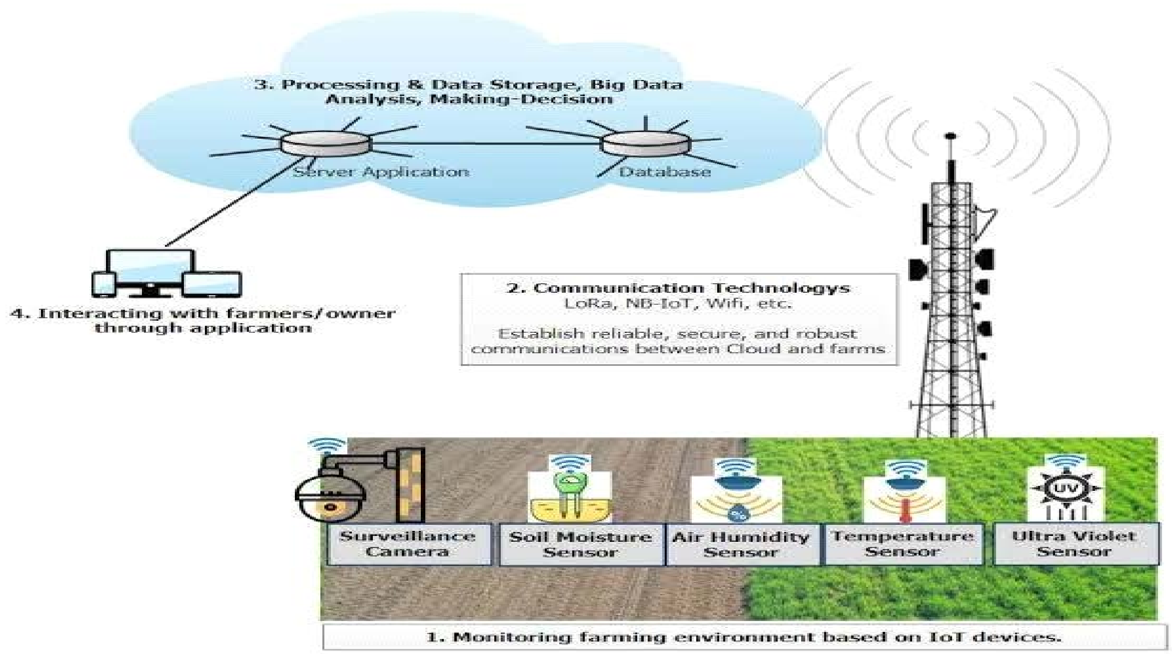

Fig.1. Framework architecture [31]

III. CORE TECHNOLOGY INVOLVED IN AGRICULTURAL IoT

3.1 Sensor perception technology

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In Smart Village Agricultural IoT involves micro-electro-mechanical systems (MEMS), biosensors, and physical property sensors to monitor key parameters. While biosensors detect toxins, pathogens, or biochemical activity in animals and crops, physical property sensors measure soil temperature, pH, and moisture level. To enable widespread applications, MEMS offer small, cheap, and low-energy consuming sensing solutions. Sensing mechanisms for information include soil conductivity electrical sensors, optical sensors for light intensity and chlorophyll estimation, electrochemical sensors for pH and nutrient sensing, and remote sensing using satellites or drones for monitoring at large scales. Electrochemical types provide high accuracy in chlorophyll sensors for determining the health of plants, while optical-based sensors provide non-invasive reading. Precision agriculture, early detection of diseases, and more informed decision-making for sustainable Smart Villages are enabled by comparative analysis [16].

3.2 Information Transmission Technology

Node Location Technology: The core of the Smart Villages' Agricultural IoT is effective information transmission, which ensures data transmission between field sensors and processing systems without any glitches. Node location technology that identifies the precise location of the IoT nodes deployed across fields, greenhouses, or animal grazing areas is a fundamental sub-field. Precise node localization makes context-based sensing, energy management, and efficient routing all possible. Although RSSI (Received Signal Strength Indicator), Time of Arrival, and Angle of Arrival are used in low-power networks like Zigbee, LoRaWAN, and NB-IoT, GPS-based positioning is one of the techniques for wide areas. Accuracy also increases due to hybrid methods, which integrate GPS and sensor fusion [17]. Node location data facilitates livestock tracking, pest monitoring zones, and smart irrigation zones. Ultimately, node location technology enhances Smart Village decision-making, reduces energy consumption, and optimizes transmission efficiency. Wireless communication technology is an important component, allowing for mass deployment in rural areas. Wireless technology provides an alternative to physical wiring. Wireless communication technologies provide long-distance, low-power connectivity for soil, water, and climate monitoring with one of the following protocols: Zigbee, LoRaWAN, NB-IoT, or 5G, improving ultra-reliable and rapid communication for automation, while Wi-Fi and Bluetooth are being used for short-range and high-data rate applications, such as in greenhouses. Wireless technology can be utilized in remote farms to provide flexibility, scalability, and remove infrastructure costs. Wireless communication technology can advance resource and energy efficiency in sustainable Smart Village development by connecting sensors, gateways, and cloud configurations. Connectivity will support precision agriculture technologies, smart irrigation options, and livestock track and trace opportunities [18].

3.3 Information Processing Technology

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Information processing in agriculture targets the collection and analysis of data pertaining to the production of goods, often in real time and in great volumes, dynamic and vast. This data is collected, recorded, and analysed (partially) through IoT in which cloud and other synergistic computing technologies and data mining provide record-level structuring and efficient large-scale computing and storage.[19]AI improves the level of standardization and uniformity along with the precision of decisions that need to be made.AI along with other readily available techniques such as machine vision and image processing can support pest control, irrigation, precision farming and yield forecasting Studies cited show that IoT protocols along with cloud-based systems enhance smart farming through secure communication, analytics, and mobile based remote control access to farming data.[20]In addition to other great benefits, these systems help achieve smart villages by assist farmers in managing their resources more effectively, become more productive, more profitable, along with advancing sustainable rural development.

3.4 Radio-frequency Identification

(RFID) is a self-sensing object tracking and identification technology [21]. When a tag is covered by a magnetic field, the tag receives a signal from the reader and transfers pertinent information to a host system, which it subsequently processes [22]. RFID technology's scanning and data retrieval capabilities are superior to that of barcodes and magnetic ID cards [23]. RFID’s compact size, waterproof coating, and ability to be read from long distances are perfect for agricultural IoT applications. RFID is used in the IoT for controlling food safety, tracing agricultural products, monitoring crops, and managing livestock. [24,25] The tracking and navigation precision of RFID+GPS+wireless sensor networks is remarkable. In the case of smart villages, RFID supports monitoring for transparency in the digitalized agricultural supply chain to control food safety and promote trust towards farmers[26,27].In the text in Fig.2 mentions the sources like Zarco-Tejada et al. (2014) and Sundmaeker et al. (2016).

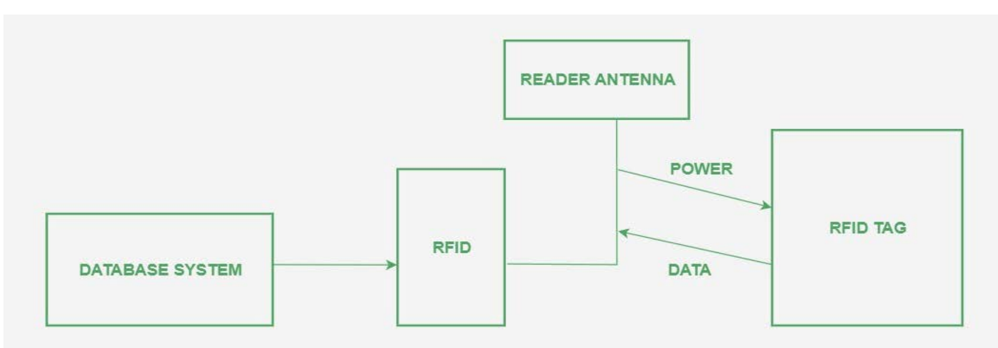

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Fig.2. Working of RFID in AIoT [32]

3.5 3S technology

To enable precise and effective agricultural data collection, analysis and updating, 3S technology integrates Remote Sensing (RS), Geographic Information System (GIS), and Global Navigation Satellite System (GNSS).Large-scale monitoring is provided by RS, accurate positioning is guaranteed by GNSS, and mapping and decision-making are supported by GIS.When combined, these instruments give farmers highly reliable land use, crop health, and soil condition monitoring.3S technology helps with resource management, infrastructure design, and precision farming in smart villages.[28,29]. Rural communities gain from data-driven decision-making as a result of this integration, which also increases sustainability and productivity.

IV. CONCLUSION

The Agricultural Internet of Things (IoT) has a revolutionary impact on sustainable and efficient farming practices. It combines sensors wireless communication, cloud computing, RFID and 3S technologies to enable farmers to monitor in real-time, make smart decisions, and manage resources. These improvements boost crop yield and livestock health while cutting down on water waste and input use, which leads to tougher food systems. To develop smart villages agricultural IoT serves as the foundation for digital farming. It links farmers to data-based insights, market tracking, and tools to manage from afar. This connection boosts rural lives, encourages efficient use of resources, and drives growth for all. Also, using 5G and AI-powered answers will give villages advanced abilities like digital farm copies, prediction tools, and hands-on training platforms. As a result, agricultural IoT speeds up smart village uptake linking old methods to smart rural systems ready for the future.

REFERENCES

I. Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks, 54*(15), 2787–2805
II. Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7), 1645–1660.
III. Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review on the practice of big data analysis in agriculture. Computers and Electronics in Agriculture, 143, 23–37.
IV. Rawal, P., Singh, K., & Mittal, R. (2020). IoT-based precision agriculture for sustainable development. International Journal of Engineering Research and Technology, 9(6), 1100–1105.

ISBN: **978-93-343-9865-6**

V. Kulkarni, N., Patil, S., & Shelar, M. (2018). Design and implementation of smart irrigation system using IoT. In Proceedings of the 2018 2nd International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (pp. 81–85). Palladam, India.

VI. Rehman, F., Sharma, A. K., & Jain, P. (2017). Application of wireless sensor networks in Indian agriculture. Procedia Computer Science, 110, 702–709.

VII. United Nations, Department of Economic and Social Affairs, Population Division. (2022). World population prospects 2022: Summary of results. United Nations.

VIII. Telecommunication Engineering Centre. (2021). IoT/ICT enablement in smart village & agriculture technical report. Ministry of Communications, Government of India

IX. Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7), 1645–1660.

X. Li, Y., Wang, X., & Zhang, Z. (2019). Micro-electro-mechanical systems for agricultural applications: A review. IEEE Sensors Journal, 19(15), 5674–5685.

XI. Ministry of Electronics & Information Technology (MeitY). (n.d.) Elhoseny, M., Yuan, X., El-Makky, C., & Ammar, H. H. (2018). Energy efficient IoT-based smart agriculture. Sustainable Computing: Informatics and Systems, 20, 1–9.

XII. Kim, M. Y., & Lee, H. (2022). Electrochemical sensors for sustainable precision agriculture. Sensors and Actuators B: Chemical, 350, 130789.

XIII. Rajak, P. (2023). Internet of Things and smart sensors in agriculture: Scopes and challenges. Agricultural Systems, 204, 103517.

XIV. Gupta, R., & Das, S. (2019). Applications of node localization in livestock monitoring. IEEE Access, 7, 135678–135690.

XV. Singh, N., & Verma, P. (2020). Smart village IoT architecture for precision agriculture and livestock tracking. IEEE Transactions on Automation Science and Engineering, 17(4), 1823–1835.

XVI. Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. Agriculture, 12(10), 1745.

XVII. Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7), 1645–1660.

XVIII. Misra, R., & Doneria, D. (2018, January). Smart villages and smart agriculture: IoT-based modern farming. In 2018 International Conference on Computer Communication and Informatics (ICCCI) (pp. 1–6). IEEE. Finkenzeller, K. (2010). RFID handbook: Fundamentals and applications in contactless smart cards, radio frequency identification and near-field communication (3rd ed.). Wiley.

ISBN: **978-93-343-9865-6**

XIX. Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. Ad Hoc Networks, 10(7), 1497–1516.

XX. Roussos, G., & Kostakos, B. (2009). RFID in pervasive computing: State-of-the-art and outlook. Pervasive and Mobile Computing, 5(1), 110–131.

XXI. Trebar, H., Lotrič, I., & Fister, D. (2017, November). Use of RFID in agriculture and smart farming systems. In 2017 25th Telecommunications Forum (TELFOR) (pp. 1–4). IEEE.

XXII. Tian, H., Wang, Y., Wang, J., & Liu, C. (2012). Application of RFID technology in agriculture. Applied Mechanics and Materials, 241–244, 2680–2684

XXIII. Zhao, Y., Chen, Y., Chen, X., & Wang, C. (2013). Intelligent agriculture based on the integration of RFID, GPS and WSN. Journal of Convergence Information Technology, 8(2), 899–906.

XXIV. Kodali, R. K., Swamy, R., & Lakshmi, B. (2016, September). RFID based traceability system for smart food supply chain. In 2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT) (pp. 852–857). IEEE.

XXV. Thenkabail, P. S., Gumma, P. G., & Teluguntla, M. (2015). Hyperspectral remote sensing of vegetation and agricultural crops. Photogrammetric Engineering & Remote Sensing, 81(8), 631–651.

XXVI. Liu, X., Wang, W., & Wu, Q. (2012). Application of 3S technology in agricultural informatization. In IFIP Advances in Information and Communication Technology (Vol. 370, pp. 272–279). Springer.

XXVII. Gebbers, M., & Adamchuk, V. I. (2010). Precision agriculture and food security. Science, 327(5967), 828–831.

XXVIII. Zarco-Tejada, P. J., González-Dugo, V., & Berni, J. A. J. (2014). Fluorescence, temperature and narrow-band indices acquired from a UAV platform for water stress detection using a micro-hyperspectral imager and a thermal camera. Remote Sensing of Environment, 117, 322–337.

XXIX. Sundmaeker, H., Guillemin, P., Friess, P., & Woelfflé, S. (2016). Vision and challenges for realising the Internet of Things. In P. Friess (Ed.), Digitising the Industry – Internet of Things: Connecting the Physical, Digital and Virtual Worlds (pp. 16–33). River Publishers.

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RoboDoc: An Autonomous Medical Robot for Primary Health Assessment in Villages

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Abstract- In rural areas, limited access to a primary healthcare facility is still a significant barrier to care, due to a lack of doctors or healthcare facilities. This paper describes an autonomous medical robot that provides primary healthcare service to communities at the village level. The system features IoT-ready sensors which enable data capture of vital signs including, but not limited to, blood pressure, body temperature, heart rate, oxygen saturation, and ECG. The robot allows patients to upload any external medical reports, e.g. blood tests, USGs, or other scans. An embedded AI/ML engine processes the data and generates a preliminary health assessment, health report, health advice, and self-limiting cases a provision. In communicating with and engaging patients, the robot engages the user with speech-to-text and text-to-speech, dialog to allow natural conversation in the local vernacular language to enable usability by any member of that community. To ensure privacy, all data is stored and processed locally, and all data is deleted at the end of the session. In adverse and crisis situations, the robot is able to elevate care by suggesting hospital visits, and/or beginning secure videoconferencing.
Keywords- IoT, Autonomous Medical Robot, AI/ML in Healthcare, Rural Healthcare

I. Introduction

Healthcare accessibility in rural and remote zones remains extremely problematic- especially with pockets of developing areas and limited facilities and qualified staff. Patients can face delays in treatment because of travel distances. Traditional approaches of periodic medical camps can provide intermittent care at best. Healthcare IoT and AI/ML have enhanced remote monitoring, predictive diagnostics, and teleconsultation but most solutions are either digital dependent, requiring some level of internet connectivity or are different apps that lack seamless data integration for patient contact with healthcare professional depending on data collection, analysis, patient contact, and doctor association. To solve these problems, we propose an autonomous medical robot for rural health care. The robot would have sensors for vital signs (temperature, SpO_2, pulse, blood pressure, EC) and for anthropometric

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measurements (height, weight, BMI). In addition, it would also have an electronic stethoscope for remote auscultation and allow for the upload of diagnostic reports (blood tests, ECG, ultrasounds), from which the AI and ML algorithms would analyze and provide first advice and lifestyle recommendations and possibly preliminary prescriptions. In serious cases, we envision a secure video connection to the oversight doctor. The robot would have a speech-to-text/text-to-speech interface for multi-lingual, natural conversation, as well as the capacity for speech recognition and synthesis, allowing simple and natural communication even with semi-literate people. No information will be transferred to the server without explicit user consent and all data processing will happen on the robot. We will retain nothing from the session and are designed to erase all traces unless specifically directed to keep some for later review by the medical provider. Ultimately, the combination of real time remote continuous health monitoring, AI and expert analysis of the data, interaction of human and machine and telemedicine should provide the affordable, reliable, and inclusive health identified in the smart rural village concept more broadly.

II. LITERATURE REVIEW

Rural and underserved areas still have serious problems in healthcare delivery based on the limitations of workforce and structure, which causes delays in diagnostics and poor health outcomes. Recent work has shown the potential for IoT, ML and AI and robotics to close this gap. IoT has provided continuous monitoring of key vital parameters such as SpO_2, temperature, blood pressure, and heart rate, removing the need to attend hospitals frequently [1]. However, most platforms are device-specific and disconnected when it comes to diagnostic intelligence. AI/ML techniques have been shown to improve clinical decision-making and diagnostic accuracy [2], [3], but numerous models use previously recorded datasets, lacked real-time, patient-specific assessments. Robotics has been adapted to surgery, rehabilitation, and operations in hospitals [4], [5], potentially benefitting rural healthcare [6], but most of the publications regards the hospital. Human-robot interaction (HRI) is a vital component in patient trust too, and multilingual STT/TTS systems have been proven to provide better inclusivity for low literacy users [7], [8].

Ethical issues, particularly data privacy, continue to be a challenge, researchers point out session-based deletion and transparent AI as proactive ways to protect patient trust [9], [10]. The ISO 60601-1-2:2015 Standard determines safety and performance levels for electromagnetic railways [11]. Even so, there are still issues with all of these fragmented solutions: IoT solutions remain unintelligent, AI solutions are static, and most healthcare robots remain in hospitals and not used to deliver patient care. This paper describes an autonomous medical robot with IoT sensing, AI or ML diagnostic capability, multilingual Shared Medical Information (SMI) dialogue, privacy-preserving deletion of data, and telemedicine capabilities to create scalable Smart Healthcare Hubs for rural populations.

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Table.1. Comparison Table of Existing Literature

Ref.	*Focus Area*	*Application*	*Key Contributions*	*Limitations / Gaps*
[1] Vasam et al.	IoT + AI	Remote vital sign monitoring	Continuous monitoring of SpO_2, BP, temperature, and heart rate	Device-specific, lacks integrated diagnostic intelligence
[2] Williams et al.	AI in diagnosis	Clinical decision-making	Highlights adoption challenges of AI in medical diagnosis	Relies on pre-collected data, limited real-time use
[3] Németh et al.	AI/ML	Disease detection from blood tests	Developed “smart medical report” system	Focused only on blood test data, not multimodal
[4] Morgan et al.	Robotics	Surgery, rehab, patient care	Scoping review of 10 roles for robots in healthcare	Hospital-centric, no rural applications
[5] Cruz et al.	Robotics	Hospital operations	Literature review on robotics in hospital workflows	Scope limited to hospital domain
[6] Deo & Anjankar	AI + Robotics	Rural healthcare (India)	Argues for feasibility of robotics to fill provider gaps	Conceptual, no technical system design
[7] Esterwood & Robert	HRI	Patient trust	Found robot personality affects trust and acceptance	Social focus, lacks technical health integration
[8] Animesh & Srikanth	HRI + AI	Conversational healthcare robots	Demonstrates use of AI/ML for multilingual interaction	Does not integrate diagnostics or sensing
[9] Elendu et al.	Ethics	Data privacy in AI/Robotics	Provides framework for ethical healthcare AI	Non-technical, lacks system implementation

III. PROPOSED SYSTEM

In order to reduce the gap of equitable access to healthcare between urban and rural settings across our country we propose the development of an IoT and AI-enabled Autonomous Medical Robot which will be able to serve as a point-of-care healthcare companion. The capability will merge vital signs tracking with anthropometric measurement with AI-based diagnosis and telemedicine wherever possible, within one single

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serviced platform. The Robot would include sensors to measure temperature, SpO_2, pulse, blood pressure, ECG, height, weight and BMI, an electronic stethoscope, microphone, speaker and camera to enable real-time auscultation and communication with remote doctors. The reports which are then uploaded (blood tests, ECGs, ultrasound scans etc.,) would be processed using tools that contain AI/ML algorithms that use the patient sensor data when signifying abnormal patient codes and/or giving predictions.

This includes AI-based diagnoses and generates first-line prescriptions. There is a conversational layer for the patient to communicate with in their language of choice (i.e. this has implications for linguistic illiteracy inclusivity). Equity, trust, and privacy will also be protected because all conversations will be part of an open encrypted platform, and all patient-related information will be permanently deleted during all future encounters. The system will initiate improved accessibility, early disease detection, and integration of fragmented technologies, and the creation of sustainable smart healthcare hubs for rural communities

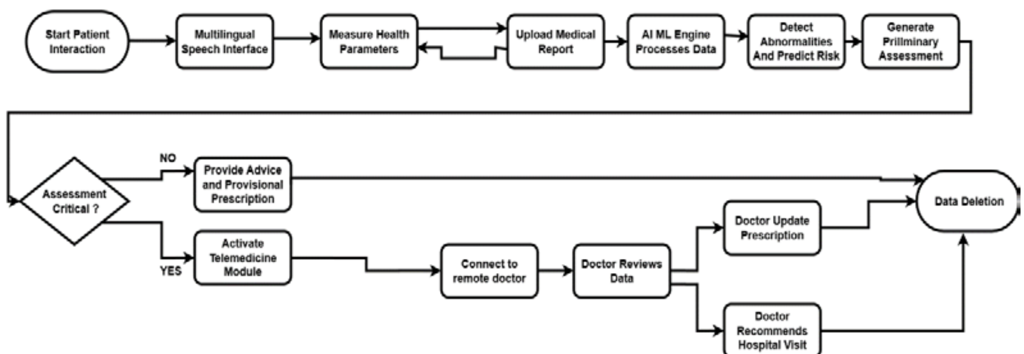

Fig.2. Block Diagram of Overall System

IV. SYSTEM ARCHITECTURE

The proposed Autonomous Medical Robot (AMR) uses a modular design to integrate the hardware, software, A.I. telemedicine features of comprehensive, end-to-end healthcare provision.

I. *Sensor layer*: In the sensor layer, the autonomous robot will take vital signs (temperature, SpO_2, heart rate, blood pressure, ECG) and anthropometric measures (height, weight, BMI) data from embedded sensors.

II. *AI layer:* Data collection and uploaded laboratory reports (blood testing, ECGs, and ultrasounds) are used to process AI/ML algorithms. This layer identifies abnormalities, predicts health risks, and creates initial suggestions/recommendations and prescriptions.

III. *Interaction layer:* The multilingual interactive agent provides communication in a natural way (speech to text and text to speech), making it easy for semi-literate users.

IV. *Telemedicine Layer:* The layer establishes secure video consultations with remote doctors in an

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identified state of stress, as discussed above. These remote doctors can view the live vitals, the patient history (file with medical background) and listen to the audio of the e-stethoscope, allowing them to make a correct assessment and make recommendations or additional requests.

V. *Privacy and security layer:* All session data is removed immediately upon completing each patient interaction session, and anonymous communication with doctors is encrypted to comply with privacy and ethics laws in patient information and data management.

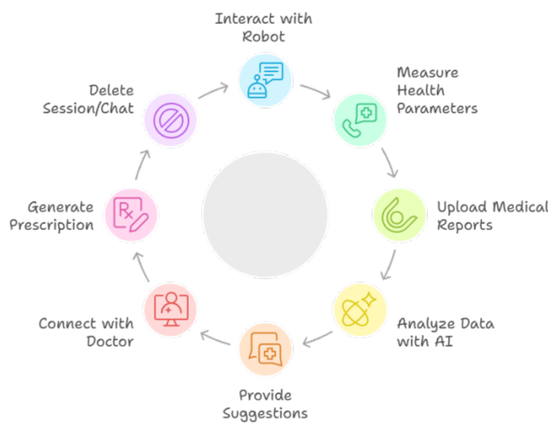

Fig.2. Process Flow of the System

V. DISCUSSION

The proposed IoT and AI-enabled autonomous medical robot has considerable potential to address some of the challenges associated with rural health care. Its main advantages are accessibility (it takes key diagnostics to where the patient is in the village), clinical value in legitimizing early detection based on continuous monitoring, and integration of IoT sensors, AI-based analytics, robotics, and telemedicine in a single system. It also contains useful usability features such as multilingual conversational AI and safeguards like session-based data deletion that can help build patient trust. It is also scalable and can be deployed in several villages to become part of a smart healthcare hub.

However, there are some challenges. Technology dependent May contribute limitations to the overall reliability of our system. For instance, we are critically aware of technical considerations related to AI bias, sensor accuracy, and calibration that could potentially minimize reliability. Additionally, there may be practical infrastructure impediments to our teleconsultations, such as adequate internet connectivity. We must be aware that patient acceptance of robotic healthcare is a significant barrier to widespread adoption. We also recognize that rural patients may have limited trust (the clinical evidence and tech will ironically need to be effective before acceptance). The initial cost of the system presents a major obstacle for implementation, especially in rural and remote contexts. There are ethical issues around

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data privacy and if the clinician could be responsible for a misdiagnosis to consider, which may impact patient confidence in using our system. In conclusion, we believe the system proposed could help reduce the rural urban health care divide significantly. However, the above technical, economic, ethical and social challenges will need to be taken into consideration for successful uptake and integration in the real-world context.

VI. CONCLUSION

The proposed IoT- and AI-enabled Autonomous Medical Robot offers an effective way to address the scarcity of healthcare services in rural regions. This's possible combining vital signs measurements, height and weight measurements, AI-supported interpretation of a medical report, and natural patient interaction using speech requests. Subsequently, it can provide reliable medical guidance for a patient within a small-time frame. Moreover, telemedicine components can connect critical cases to doctors for prompt assessment while retaining a human-in-the-loop for accurate diagnosis and treatment. In combination, these components enhance early access to and diagnosis of health care services as well as enhance trust and privacy of their patients through robust data security. Our modular design allows it to be scaled and to remotely link multiple villages to develop smart health care networks. Future expectations include transforming the robot into a more capable intelligent healthcare companion within rural communities with enhancements that allow it to perform simple automated medical interventions that do not require a medical practitioner (e.g., giving a patient an injection or dispensing medications) under controlled conditions, eventually diminishing the number of required medical practitioners on-site.

REFERENCES

1) Vasam, V. K., Shaik, A., Tolchuri, S. L. M., Rachamadugu, S. S., Krishna, H., Chandra, G. R., & Anand, D. (2024). Patient Health Monitoring System Using IOT And AI. *Engineering Proceedings*, *66*(1), 31. https://doi.org/10.3390/engproc2024066031

2) Williams, R., Anderson, S., Cresswell, K., Kannelønning, M. S., Mozaffar, H., & Yang, X. (2024). Domesticating AI in medical diagnosis. *Technology in Society*, *76*(102469), 102469. https://doi.org/10.1016/j.techsoc.2024.102469

3) Németh, Á., Tóth, G., Fülöp, P., Paragh, G., Nádró, B., Karányi, Z., … Daróczy, B. (2024). Smart medical report: efficient detection of common and rare diseases on common blood tests. *Frontiers in Digital Health*, *6*, 1505483. https://doi.org/10.3389/fdgth.2024.1505483

4) Morgan, A. A., Abdi, J., Syed, M. A. Q., Kohen, G. E., Barlow, P., & Vizcaychipi, M. P. (2022). Robots in healthcare: A scoping review. *Current Robotics Reports*, *3*(4), 271–280. https://doi.org/10.1007/s43154-022-00095-4

5) Cruz, E. M. G. N. V., Oliveira, S., & Correia, A. (2024). Robotics applications in the hospital domain: A

ISBN: **978-93-343-9865-6**

literature review. *Applied System Innovation*, *7*(6), 125. https://doi.org/10.3390/asi7060125

6) Deo, N., & Anjankar, A. (2023). Artificial intelligence with robotics in healthcare: A narrative review of its viability in India. *Cureus*, *15*(5), e39416. https://doi.org/10.7759/cureus.39416

7) Esterwood, C., & Robert, L. P. (2021). A systematic review of human and robot personality in health care human-robot interaction. *Frontiers in Robotics and AI*, *8*, 748246. https://doi.org/10.3389/frobt.2021.748246

8) Animesh, K., & Srikanth, D. (2024). Enhancing healthcare through human-robot interaction using AI and machine learning. *International Journal of Research Publication and Reviews*, *5*(3), 184–190. https://doi.org/10.55248/gengpi.5.0324.0831

9) Elendu, C., Amaechi, D. C., Elendu, T. C., Jingwa, K. A., Okoye, O. K., John Okah, M., … Alimi, H. A. (2023). Ethical implications of AI and robotics in healthcare: A review. *Medicine*, *102*(50), e36671. https://doi.org/10.1097/MD.0000000000036671

10) Unesco. (2021). Recommendation On The Ethics Of Artificial Intelligence. Unesco Publishing. Https://unesdoc.unesco.org/ark:/48223/pf0000377897

11) International Electrotechnical Commission. (2015). Iec 60601-1-2:2015 – Medical Electrical Equipment – Part 1-2: General Requirements For Basic Safety And Essential Performance – Collateral Standard: Electromagnetic Disturbances – Requirements And Tests (4th Ed.). Iec.

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Contact Lenses for Farmers For Monitoring Agriculture

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Abstract- The field of our Agriculture is rapidly embracing the smart technologies to identify challenges which concern the crop yield, efficiency of resources and sustainability. IoT sensors, data analytics, drones, all these are broadly utilized, and farmers still do not have easy and natural interfaces to communicate with this information in real-time. Smart contact lenses, micro-displays, wireless communication, biosensors integration and augmented reality (AR), all these are a new way to seal this gap. These lenses allow us to enrich and complement the decision-making process and lower the number of man-hours of monitoring, as the combination of these lenses enables farmers to have hands-free, Real-time contextual display of fields conditions, including soil moisture, crop stress, and livestock health. In the following paper we will be able to discuss the design, architecture, and uses of smart contact lenses in agriculture field including the main challenges that we will encounter such as biocompatibility, power supply, cost, and also can give a development road map toward actual implementation.

Keywords- Agricultural monitoring, augmented reality, biosensors, smart contact lenses, wearable devices.

I. INTRODUCTION

In India agriculture has always been the foundation of human civilization and because of population growth, lack of resources, climate variability as well as the need to produce food sustainably because of it, challenges are unprecedented. The agricultural sector is currently paying attention to use the technologies of the artificial intelligence (AI) and the Internet of Things (IoT), drones, and precision farming systems as the means of

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dealing with these problems. Such technologies enable farmers to get high volumes of information about crop conditions, soil health and environmental parameters which can be utilized to enhance decision making and improve the utilization of resources in an attempt to introduce sustainability [1-3]. Nevertheless, even with these advanced technologies, a big gap still exists in regards to interacting with farmers and how they make sense of this data in the real-time when they are in the field. All these interfaces are manually accessed and need to be paid constant attention, using smartphones, tablets and dashboards, which can be counterproductive in terms of the overall efficiency in the outdoor and labour-intensive setting.

These important advances in wearables and augmented reality (AR) user interfaces have actually provided a viable way out to this latent issue. Smart contact lenses in particular have become a platform-based edge technology that could combine biosensors [1], micro-displays and wireless communication systems into a platform that is invisibly small. These devices were initially investigated in medical fields to use in areas like glucose sensors and intraocular pressure sensors, but now they are being investigated in much wider applications as well, including real-time information visualization and immersive AR environments. Through the logical application of this innovation in the agricultural sector, farmers might receive a lot of good including real-time contextual display of vital information straight in their field of nature.

Some of the special characteristics of this smart contact lenses in the agricultural sector include, first, they give uninterrupted and continuous access to information without interfering with manual work. As an example, a farmer might know at a glance the moisture content of the soil, whether his crop was diseased, or whether a disease outbreak was imminent, or whether the area was experiencing local weather conditions, without looking to an external device.

Second, the AR intersections can be integrated, which allows spatial plotting of the field conditions, and the problem zones like the pest infestations or lack of irrigation, which can be marked on the direct view of a farmer [4]. Thirdly, biosensors embedded in the contact lenses can assist in monitoring the health and well-being of the farmers as well as the livestock and this would give a broad approach to agricultural management.

Although with extensive potential, there are still several obstacles ahead of such technology being installed on a large scale in agricultural landscapes. A lot of questions need to be answered: energy efficiency, miniaturization of the devices, biocompatibility, and display brightness outdoors and the scalability of the costs [5-6]. Furthermore, continuous authorisation with the continuing convergence of nanotechnology, wireless power delivery, and flexible electronics, and AI-based information examination, agricultural contacts lenses will no longer be a far-off dream but a practical path to future research and development.

II. KNOW, RESEARCH AND GATHER IDEA

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The initial stage of the research was found out about the possible scale of the project called Smart Contact-lenses to Agricultural Monitoring and investigate more whether this idea is workable in the sphere of augmented reality, wearable technologies and agriculture precision.

1) Literary review:

A baseline was determined using several peer-reviewed articles, patents and industrial whitepapers. The technical backgrounds are provided by the prior knowledge on smart contact lenses, which are already being used as biomedical applications, including glucose monitoring, AR displays or the intraocular pressure sensing [3-4]. Numerous articles about agricultural wearables, plant biosensors and IoT based crop monitoring point out the gaps that exist that can be filled, which on eye visualization can make.

2) Research using Internet materials:

To comprehend the current situation in the field, numerous searches have been performed in scientific databases which include IEEE Xplore, Springer, ScienceDirect and open databases like Google Scholars, ResearchGate, etc. Numerous other reports present the observations of the business trends and the real challenges of display, material safety, power control etc.

3) Knowledge of lingo and scientific terms:

The major technical concepts like biosensing interfaces, biocompatible polymers, micro-LED, micro display, waveguide optics and real-time contextual display were being strongly worked on to clarify them. On the same note, there are agricultural ideas like IoT based applications, precision farming and crop stress indices, which were investigated to match the demands of farming with the capabilities of the technology.

III. RECORDING OF YOUR STUDIES AND FINDINGS

Smart contact lenses were initially developed in medical surveillance and AR visualization that has become a possible interface of hand free methods and decision making. The most recent studies and experimental proofs have demonstrated that biosensors and micro displays can be incorporated into soft lenses to provide high fidelity environment data and physiological data that would be provided by the respective field.
Key findings:

2) Biosensing and materials:
Biosensing platforms have been demonstrated to be successful in tear fluid analytes (e.g. glucose) and intraocular pressure utilizing electrical and optical sensing methods that are being enabled by soft and

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biocompatible thin films and encapsulation methodologies. These publications make the lens a worthy biosensing substrate.

3) Micro display and optics:

High-brightness micro-LED micro displays and the diffractive couplers allow on-eye AR overlays, although the outdoor vision and power budget is a significant challenge in front of the designers. Research and development in the industry, they have attained high performance micro-LED displays but also bring out the challenges behind it like cost and commercialization.

4) Agricultural Wearables:

Wearable sensors in agriculture have been shown using agricultural in-suit sensors and flexible systems and mounted on plants will provide robust agricultural monitoring. Its applications in the temperature of leaf, strain and localised microclimate have demonstrated the importance of dense or near-canopy sensing in precision agriculture. Combining all these data streams with on-person AR interface can decrease the load of manual inspection and the degree of latency in monitoring.

OUR FINDINGS:

I. Usability- It removes the old method of mapping and utilizes the smartphone and the direct inspection that makes the task quicker with HUD alerts. The users are able to receive the report in a much quicker manner and also the quicker situational awareness.

II. Optical Performance- The HUD displays a clear overlay during shaded and cloudy weather. The contrast and visibility were poor with the direct high angle sunlight that is the same as the literature concern of display costliness outside.

III. Communication and Power- BLE-based alerts had low latency and were only reliable on plot scale. Intermittent alerting was not too demanding of power, but that was also not possible without a wearable hub to operate the full-colour micro display constantly.

We find this idea in support of our study hypothesis, which explains that the AR overlays can be used to engage in a speed field discussion and enhance ergonomics. The remaining work should be done concerning the actual lens form-factor safety that encompasses biocompatibility, thermal constraints. It is also necessary to pay attention to the trade-offs between the outdoor brightness of micro-LEDs and their power, and regulatory avenues to on-eye devices.

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IV. CONCLUSION

In our paper we attempted to introduce the idea of smart contact lenses as a new agricultural monitoring tool by combining the idea of biosensing, augmented reality and wearable technology in one system. In contrast to the manual interface, like smartphones or dashboards, the smart contact lenses will allow farmers to receive the vital information with ease, which further will enable farmers to react to crop stress, environmental changes, and other latent issues in real-time. The underlying potentials in this technology are numerous, which can be seen in the way the agricultural information is provided and responded to. Combining IoT with the concept of immersion, it may become efficient in terms of the decision making, may decrease the necessity of manual observation and, finally, may lead to the sustainable and accurate farming.

In short, the concept of implementing the smart contact lenses is still at the stage of imagination, it is a daring move to speculate about the interaction of humanmade technology in agriculture. Ample research in this direction and plenty of testing will bring a clear picture of whether this will become a viable and transformative solution.

REFERENCES:

1. Kim, J., Campbell, A. S., de Ávila, B. E. F., & Wang, J. (2019). Wearable biosensors for healthcare monitoring. *Nature Biotechnology*, *37*(4), 389–406. https://doi.org/10.1038/s41587-019-0045-y
2. Choi, S., Lee, H., Ghaffari, R., Hyeon, T., & Kim, D. H. (2016). Recent advances in flexible and stretchable bio-electronic devices. *Advanced Materials*, *28*(22), 4203–4218. https://doi.org/10.1002/adma.201504150
3. Chen, Z., Yu, H., Li, H., Li, M., & Wang, C. (2021). Micro-LED displays: Recent advances and future perspectives. *Journal of Semiconductors*, *42*(2), 021101. https://doi.org/10.1088/1674-4926/42/2/021101.
4. Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018), Machine learning in agriculture: A review. *Sensors*, *18*(8), 2674. https://doi.org/10.3390/s18082674
5. Mogili, U. R., & Deepak, B. B. V. L. (2018). Review on application of drone systems in precision agriculture. *Procedia Computer Science*, *133*, 502–509. https://doi.org/10.1016/j.procs.2018.07.063
6. Park, J., Kim, J., Kim, S. Y., Cheong, W. H., Jang, J., Park, Y. G., Na, K., Kim, Y. T., Heo, J. H., Lee, C. Y., Lee, J. H., Bien, F., & Park, J. U. (2018), Soft, smart contact lenses with integrations of wireless circuits, glucose sensors, and displays. *Science Advances*, *4*(1), eaap9841. https://doi.org/10.1126/sciadv.aap9841

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Transforming Rural Agriculture and Agro-Processing with Smart Village Models

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Abstract- The current paper describes agriculture and agro-processing in the smart village debate as a potential approach to promote sustainable rural development, and identifies a range of challenges, including low-productivity levels, inefficient supply chains, and post-harvest losses in the sector, and offers technology-based solutions such as IoT, big data, precision farming, better irrigation, and new storage technologies. The paper prioritizes the role of effective post-harvest handling, reducing food waste, and equitable market access to producers. With technology, supply chains, and farmer-producer organizations, India can enhance productivity levels, improve incomes, and develop a more effective, technology-enabled agro-processing ecosystem, which meets the food security and economic stability needs of rural communities and the health of other stakeholders in the food systems.

Keywords-Post-harvest management, supply chains, IoT, agribusiness, smart village, rural development.

I. INTRODUCTION

Agriculture is the science of cultivating soil, growing crops, and raising livestock for food products. It plays a crucial role in the economy of many countries, especially the developing ones. Over 50% of India's workforce is engaged in agriculture and allied activities. Agriculture provides food security, acts as a source of raw materials, helps in exporting earnings, boosts the rural market, and improves infrastructure (by investments made in irrigation, storage, etc). Thus, we need to make further improvements in this sector for our betterment. As of 2023, agriculture and other allied sectors contributed approximately 17%-18% to India's GDP. Although the share has declined over the years due to the growth of secondary and tertiary sectors, low productivity, inefficient supply chains, lack of mechanization and dependence on monsoons but in rural areas, agriculture remains a vital source for economic stability, which was further nurtured with the advent of smart villages that emerged as a sustainable development model to address the previously mentioned concerns. A smart village is not merely a digitally connected settlement but a self-sustaining ecosystem that leverages technology, local resources and community participation. At its core, agro-processing and post-harvest management form the foundation of these ecosystems, ensuring livelihood security and economic stability. Agro-processing includes the transformation of raw agricultural products

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into consumable goods. Agro-industry refers to the post-harvest activities involved in the transformation, preservation, and preparation of agricultural production for intermediary or final consumption, typically increasing in importance relative to agriculture and occupying a dominant position in manufacturing as developing countries step up their growth. The Food and Agriculture Organization (FAO,2020) emphasizes that 60% of global population depends on agriculture. In India, the Ministry of Food Processing Industries (2011) reports that the sector contributes around 32% to the food sector GDP (John Wilkinson, Rudi Rocha ,2008)

II. **OBJECTIVES**

1. Smart village adoption for agriculture and agro-processing.
2. Comparison between the agricultural sector in India v/s other countries.
3. Emphasis is made on post-harvest management, supply chains, expectations, and recommendations along with the challenges.

Agricultural sector in other countries v/s in India. What can we learn from them that benefits our smart village adoption needs?

Agriculture in India is primarily labor-intensive, rainfed, and consists of smaller, subsistence-level farms with a heavy reliance on manual labor and traditional methods. In contrast, agriculture in most other developed countries such as the USA, is capital-intensive, mechanized, and predominantly commercial. Developed nations emphasize advanced technologies, scientific soil management, and higher productivity per unit of land, leading to a smaller proportion of the population engaged in farming and increased returns for farmers.

Indian Agriculture vs Global Agriculture: A Comparative Analysis

Features	*Indian Agriculture*	*Agriculture In Other Countries*
Type Of Farming	Subsistence farming and small landholdings	Commercial farming, capital-intensive farms
Labor Dependency	Labor-intensive	Capital-intensive
Technology	Relies on traditional methods	Use advanced machinery
Irrigation	Largely rainfed with a less developed irrigation system	An extensive irrigation system is used
Crop Productivity	Low productivity	High productivity
Crop Variety	Cultivates a limited range of staple crops	Grows a wide variety of crops
Livestock	A smaller extensive sector	A larger intensive sector
Education And Knowledge	Farmers have less access to modern techniques	Farmers are more educated and have better access to modern techniques

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III. HOW TO ENHANCE AGRICULTURAL DEVELOPMENT IN INDIA?

Critical Elements of Sustainable Agricultural Development

Sustainable agriculture will require addressing the contributions of many important areas:

I. *Smart Agriculture:*
   a) IoT (internet of things)- smart cameras, web-based sensors, actuators, drones, robots and other advanced agro-devices can be used to automate the decision-making mechanism.(Misra et al, 2022)
   b) Big Data Technology- It can be used for raw material production. Such technologies aim at procuring the best possible raw materials in farming. (Mr.M.Maninda, Dr G.Nedumaran,2020)

II. *Improved Soil Quality*: The presence of soil degradation will require balanced nutrient management and soil health improvement particularly in arid regions. (Seghal foundation,2022)

III. Water Management: As water constraints grow, the management of water through rainwater harvesting, groundwater recharge, and modern systems of irrigation (e.g. drip, sprinkler etc.) for the efficient use of water will be vital. (FAO, 2020)

IV. *Agri-Credit and Crop Insurance:* Access to timely and affordable credit, and agri-insurance policy improvements and reforms can reduce financial uncertainty and can significantly improve farmer productivity and their overall realization of commercial returns/accountability. (Seghal foundation,2022)

V. *Efficient Markets:* Profitable and reliable markets to support fair wages, through improved production planning and other predictable ways to bring utility value and income (Nandan et al., 2020)

Budget 2024: How to enhance the Growth of Agriculture in India?

I. The GVA (Gross Value Added) by the agriculture and allied sectors in India in FY23 stood till US$ 275 billion approximately i.e. 15% of total GVA. The agriculture and allied sectors have a 4% CAGR during the last five years ending in FY23.

II. In FY24, Farmers who are considered as small and marginal farmers, can get financial support through the PM KISAN Yojana, which was about 1.3% of the Union Budget on agriculture with a total of only 1.9% of the Union Budget. The Budget 2024 allocation overall was about 8.3% of major subsidy allocation, including food subsidy for cereals and pulses, fertilizer subsidy, and petroleum subsidy. (Press Information Bureau, 2024)

Post-Harvest Management System

Post-harvest management is an essential feature in minimizing food loss and quality decay after they have been harvested. Without post-harvest management procedures, much of what is harvested can spoil before it reaches the consumer and would have prematurely robbed the farmer of their hard work, and it reduces the availability of food in the supply chain.

This can involve many different processes:

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I. *Harvesting and Handling:* Picking the crops at the right times or handling the crops gently to avoid damaging them. (Kumar et al, 2024)

I. *Grading and Sorting:* Separating high-quality produce from damaged produce or under graded produce so that can achieve the maximum market value and minimize waste.

II. *Storage:* using improved storage systems, i.e., cold storage, silos, etc to reduce spoilage and pests. (Kumar et al, 2024)

III. *Packaging and Preservation:* Preserving produce in transit, and prolonging the shelf life of products through intelligent packaging and techniques, e.g., refrigeration, freeze-drying, or drying. (Kumar et al, 2024)

All of these processes help to maintain freshness, reduce potential waste, and provide better returns for farmers and safer food for consumers (Kachru et al, 2024).

Supply Chain in Agro-Processing:

Essentially, the supply chain is the life cycle of food, from the farm to the consumer's table. The supply chain encompasses farmers, collectors, transporters, processors, warehouses, retailers, and ultimately, the consumer. Unfortunately, not all food makes its journey smoothly. Inefficient bad roads, lack of refrigerated transport, too many "middlemen," and price variations in the market lead to leaks, losses, and reduced profitability to farmers. Farmers are particularly affected for perishable foods like fruits, vegetables, and dairy.

On the flip side, technology is beginning to change the supply chain. Farmers are using mobile applications to market products and connect with buyers directly. Blockchain is allowing the tracking of a product back to its source, creating more trust in consumers. Different models are enabling Farmer Producer Organizations (FPOs) to allow small farmers to aggregate storage and sales for higher margins.(PG Chengappa,2004)

Expectations and recommendations from the sector.

1. Futuristic Growth of India's Food Processing Industry:

With a forecasted value of US$535 billion by 2025-26, growing at a CAGR of over 15%, it is high time to focus on strengthening the food processing value chain in terms of budgetary allocation, and it is evident through schemes such as cluster development and developing micro-processors. Investing in PVAs (Producer Organizations) which are organised under the FPO model , opens a new level of income and market access opportunities. Placing emphasis on encouraging clusters for micro-processing and strong public-private partnerships will pay dividends to farmers in terms of income and market access.

2. Reduce post-harvest losses by upgrading infrastructure

The challenge of reducing post-harvest losses, especially for perishables, and achieving significant value added, can be boiled down to a simple equation: better storage facilities, grading facilities, and transportation networks. Leveraging programs like the Agriculture Infrastructure Fund (AIF) and Mission on

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Integrated Development of Horticulture (MIDH) will be key to modernising and upgrading infrastructure. Building more multi-commodity cooling and grading centres, installing solar micro-grain cooling facilities, and building cooling facilities near strategic airports and ports will reduce food losses, decrease transport costs, and reduce distress selling allowing for more money in the farmers back pocket.

3. Advocating for Agri-Tech Adoption

The agribusiness industry is projected to witness a surge in the adoption of digital technologies, with the Agri-tech market expected to reach US$ 13.5 billion by 2023. To accelerate Agri-tech growth, the government has initiated the Digital Public Agriculture Infrastructure and the Digital Agriculture Mission. AI-enabled precision farming solutions, IoT-enabled live data systems, drone technology and platforms like Agristack will lead to increased income generation opportunities for farmers and agribusinesses. (Somwanshi et al,2016)

4. Growing Agri Export Markets

India's agriculture exports have grown by 6.6% CAGR from FY18 to FY23 with US$ 52.5 billion in agricultural exports in FY23. It focuses on the system’s strengths of dealing with farm production, and also on the export systems' ability to be agile and responsive, which will lead to an improvement in the export system's effectiveness, that includes: aligning farmer's produce with the consumer market, developing post-harvest digital supply chain solutions, assuring foreign-built transparency and international quality for agriculture unit exports, and bringing farmers into more export-oriented production. (Somwanshi et al,2016)

IV. CHALLENGES

I. Financial constraints
I. Limited availability of insurance
II. Removal of middlemen
III. Educating the farmers
IV. Financial market values
V. Learning about new technologies and how to use it.
VI. Market export and challenges
VII. Lack of proper branding, packaging and marketing strategies.
VIII. Stringent export regulations.
I. Adverse climatic conditions

V. CONCLUSION

The advent of smart village concepts in agriculture and agro-processing showcased a transformative step towards sustainability and rural development. Post-harvest management and subsequent supply chain is a cart with wheels that cannot move without each other.

What does this mean?

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It means proper agricultural commodity storage without transportation will not help you if it is too late and the quality of the commodity has already degraded. Rapid supply chain development without proper storage leaves you with poor poor-quality commodities. When post-harvest management and supply chain systems are integrated, everyone wins-farmers get more money, consumers get fresh food, and food waste is reduced.

How is the future bright?

We are talking about fancy smart labels on mangoes that tell you how ripe they are or drones that can read the conditions in the storage rooms, which speak directly to the farmers to manage the store and inventory. We are also looking forward to digitally connected markets on our phones that can give the farmers the current price instantly, while protecting them from exploitation and unfair prices. India, if it adopts the above-mentioned technologies, will have mega food parks, modern warehouses, government and industry goals, which will allow and create opportunities for sustainable agro-processing with technology-enabled, better integrated systems.

REFERENCES

1. Chengappa, P. G. (2004). Emerging trends in agro-processing in India. Indian Journal of Agricultural Economics, 59(1).
2. Food and Agriculture Organization (FAO). (2020). *The State of Food and Agriculture 2020: Overcoming Water Challenges in Agriculture*. https://www.fao.org/publications/sofa/2020
3. Kachru, R. P. (2010). Agro-processing industries in India: Growth, status and prospects. Journal Indonesian Agroindustries, 13(2), 167-181.
4. Kumar, A., & Pathak, H. (2024). State of Indian agriculture. National Academy of Agricultural Sciences, New Delhi, p xvi, 92, 59.
5. Manida, M., & Nedumaran, D. G. (2020). Agriculture in India: Information about Indian agriculture & its importance. SSRN.
6. Misra, N. N., Dixit, Y., Al-Mallahi, A., Bhullar, M. S., Upadhyay, R., & Martynenko, A. (2020). IoT, big data, and artificial intelligence in agriculture and food industry. IEEE Internet of things Journal, 9(9), 6305-6324.
7. Press Information Bureau (PIB), Government of India. (2023). *Union Budget Highlights 2023–24* https://pib.gov.in
8. Sehgal foundation: https://www.smsfoundation.org/understand-challenges-and-5-ways-to-boost-agricultural-development-in-india/
9. Somwanshi, R., Shindepatil, U., Tule, D., Mankar, A., Ingle, N., Rajamanya, G. B. D. V., & Deshmukh, A. (2016). Study and development of village as a smart village. *International Journal of Scientific & Engineering Research*, *7*(6), 395-408.
10. Wilkinson, J., & Rocha, R. (2008, April). The agro-processing sector: Empirical overview, recent trends and development impacts. In Global Agro-Industries Forum (pp. 1-59). Sage.

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Using Green Energy to Improve Healthcare Facilities in Rural Areas

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Abstract — India is a third tier developing country. Rural healthcare facilities in India are not up to the mark, but developing. Rural healthcare facilities often face challenges and problems due to insufficient resources such as electricity shortage, limited vaccine storage, inefficient diagnostics, etc. Green energy can prove to be a sustainable solution to healthcare facilities in rural areas. The use and operability of green energy and sustainable solutions in providing healthcare in terms of running diagnostic machinery, ensuring clean drinking water supply and other necessary consumables are systematically explored in this paper. The empowerment of rural communities and achieving of socioeconomic development are therein also explored.

Keywords*- Rural healthcare, green energy, solar energy, sustainability, energy equity*

I. Introduction

India is a third tier developing country. Rural healthcare facilities in India are inadequate and not upto global standards, though they are gradually improving. Healthcare facilities in rural areas often encounter problems due to insufficient resources like power supply, storage of vaccines and life-saving drugs, inefficient diagnostics and other limitations that impair medical outreach. Green energy can be a very efficient way to overcome these problems. Use of solar energy can be a reliable solution to strengthen healthcare facilities in rural areas. This paper mainly discusses the integration of renewable energy and healthcare facilities, ensuring enough reliable power to refrigerate vaccine, operate diagnostic machines and electrically operated devices, purification of water and consumable materials, etc. The use of renewable energy not only ensures the efficiency of healthcare but also promotes sustainability and socio-economic development in rural communities.

Among the many limitations facing rural communities, the one persistent barrier facing health information access is access to reliable sources of energy. Medical facilities have consistent blackouts, inconsistent supply in electricity from their local utility, or have no electrical connection to their utility system. Lack of sourced energy makes it difficult for healthcare administrators to provide services to their

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clients, launch equipment - without power reserve, or keep an emergency response plan in place. Millions of people in rural settings are without basic health services, resulting in a higher morbidity and mortality rates relative to their urban counterparts. Green energy is often called renewable energy and provides solutions based on the natural energy resources of wind, solar, hydro and bio-mass energy resource exposure. Green energy resources are observed to be sustainable, eco-friendly, and a cheap alternative to fossil fuels that are ultimately destroying the earth and contributing to climate change. Green energy is ultimately cleaner, resilient, decentralized, and could help provide power, ultimately power literacy, to local communities in need.

II. RESEARCH AND FINDINGS

According to the Ministry of Health and Family Welfare, an alarming 46% of Primary Health Centers (PHCs) in rural India are facing shortages or unstable power supplies. Many sub-centers and community health centers are not even fully electrified, and doctors can only depend on kerosene lamps or battery torches for emergency treatments. A survey from the Council on Energy, Environment and Water (CEEW), even found that 1 in 4 rural health facilities lack reliable access to electricity which in turn causes compromised maternal care, poor vaccine storage conditions, and delays in diagnostic services. In some places, diesel generators are available as backup power, but this method is expensive, and often still useless because of fuel shortages. This energy poverty is the reason that fewer trained healthcare workers are willing to serve in rural areas, increasing the urban-rural health divide. Research has found that districts with limited electricity access have greater reports of infant mortality and ongoing cases of preventable disease. Overall, the research provided a clear relationship between energy access and public health outcomes in rural parts of India.

All the renewable energy sources, solar energy has had the most significant impact on emergency healthcare provision in rural India. There are many pilot projects and government initiatives demonstrating this, like the National Solar Mission and efforts from organizations like SELCO Foundation, who have installed solar systems in rural health centers across the states of Karnataka, Bihar, and Odisha. Studies confirm that existing solar health facilities can not only maintain cold-chain storage for vaccines but also provide continuous power for childbirth in the dark of the night. More recently, in Chhattisgarh, the state has successfully implemented a distributed “Solar for Health” program that has provided electricity to more than 500 rural sub-centers which has correlated to increased patient attendance and lower maternal mortality. A recent study by the Council on Energy, Environment and Water studies found that rural clinics provided with solar power, held 50% more deliveries during night hours than health centers without any electricity. There is also evidence from the academic literature that shows a significant cost advantage—although the capital costs to set up solar systems are extremely high, when it comes to operating costs, they fall significantly since there is very little fuel supply or any external supplies for solar systems. Water pumping systems powered by solar energy can also assist health facilities in providing clean potable water to use in sanitation and sterilization of medical equipment or devices which assist in the reduction of hospital acquired infections. The studies also point to strong levels of community acceptance, as the local population viewed solar electrification as an important step toward economic empowerment and self-reliance. In

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conclusion, the renewable energy and solar programs we have seen in rural India have proven to be significant "game changers" to building a robust grassroots healthcare system.

While solar dominates, research done in rural India also highlight the possibilities of biomass, wind, and hybrid systems. India's agrarian basis gives biomass energy great promise as well. Research

states like Uttar Pradesh and Punjab have demonstrated that agricultural residues and livestock manure can fuel small biogas plants, which are used in rural health clinics to produce energy for lighting, cooking, and sterilizing tools. Moreover, the central government MNRE (Ministry of New and Renewable Energy) is actively promoting these decentralized biogas projects and has had somewhat promising outcomes in tribal and farming communities. Wind energy has been rarely used, but there have been some pilot projects in coastal states like Tamil Nadu and Gujarat, where small wind turbines installed at health centers are supporting basic diagnostic equipment (like thermometers) that require a dependable power supply. There has research on hybrid systems - a relationship between solar and biomass in some circumstances - which has demonstrated resilience in flood-prone areas like Bihar, with solar systems providing continuous (not reliable) energy when contaminated by clouds or monsoon months. The research is clear; location appropriate solutions are much more sustainable than a one-size-fits-all model. The objective, through diversifying energy sources, is to provide rural health services in India with a sustainable energy source to lessen the reliance on fragile grid supply, with findings indicating that hybrid solutions provide the best chance of supplying reliable, long-term energy in remote rural contexts.

Research evidence in India has clearly demonstrated the connections between the uptake of renewable energy and advances in health outcomes in rural areas. Recent research in a rural Uttar Pradesh state facility noted that solar powered clinics were able to reliably store vaccines, which resulted in a rapid increase in immunization coverage of 30% over a three years period. The introduction of solar react to the electrification of care facilities in Jharkhand allowed health workers to safely conduct deliveries overnight, which translated to lower rates of maternal and neonatal death. The Public Health Foundation of India (PHFI) suggested that the uptake of renewable energy contributed to a 20–25% increase in the number of clients accessing care at clinics that operated renewable powered facilities in the rural areas because villagers felt comfortable that they could trust clinics that reliably delivered services. Health worker retention was also noted a positive outcomes arising from renewable energy, as doctors and nurses were willing to work in rural facilities when regularly (not always) powered with electricity. Portable Telemedicine followed (in part) from the electrification of rural health facilities given that solar satellite powered internet hubs offered the means for rural patients to connect via video with urban specialists in Rajasthan, thus linking gaps in specialist care. While there was confirmation of direct advantages owing to renewable energy, there was also evidence of indirect advantages: electricity provided a more reliable method to procure medicine including appropriate storage; improved sanitation with water pump powered toilets; and hospitals were considered to be to be "safe spaces" for community members to go and receive medical attention. In summary, renewable energy contributes to the improved deliverance of rural health services and improved trust of healthcare services by communities in these areas. Ultimately, renewable energy is most effective when the use of energy can render services timely and reliable when serving disadvantaged or underserved populations. Although progress is clear, the literature also describes

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challenges in scaling renewable energy in rural Indian healthcare. The issue of maintenance remains a common challenge—studies have shown that almost 30% of installed solar systems in rural PHCs have stopped working after five years, primarily due to lack of technical support and replacement parts. Another challenge is financing. Rural clinics often do not have funding for the initial installation, even though there are savings over the long term. Policy analysis indicates that the integration of renewable energy into health care planning seems weak, as projects for energy development often do not align with each other and operate outside the health care sector. That said, the new policies in Ayushman Bharat and India's Renewable Energy Roadmap call for deeper integration and collaborations between energy and health.

The evidence is clear, private and public partnerships, community ownership models, and capacity building are necessary elements to guarantee sustainable energy integration with rural health. In the future, hybrid microgrids systems and battery storage are being tested in areas such as Assam and Madhya Pradesh, to provide 24/7 electricity. There is also evidence in academic studies that AI-based integrated energy management may be one way forward for efficient electricity use in the health system. The evidence from the literature suggests that with the appropriate policies and engagement of local communities, rural healthcare can have a renewable energy transformation in India that aligns with both the National Health Policy 2017 and widens the possibility of reaching the UN Sustainable Development Goals (SDG 3 & 7).

III. CONCLUSION

The evidence emerging from research on the role of green energy in strengthening rural healthcare facilities in India is unmistakable: reliable electricity is foundational for equity in access in healthcare. Many rural parts of India face ingrained challenges that plague access to healthcare equity. For example, close to half of the Primary Health Centers in rural India have inconsistent and inadequate power supply quality.

The take home message is that to find and advance renewable energy solutions as the connective tissue in the broader rural health infrastructure across India is no longer a preferred option but an essential next step in achieving the country's health and development goals.

REFERENCES

1. Yevanne Komenan, United states, (2025). Impact of Green Energy on Healthcare Infrastructure. Journal of scientific Research and Report (JSRR), 31(3), 195.
2. Brenda V.F Silva, Jens Bo Holm-Nielsen, Sasan Sadrizadeh, Mavd P.R Teles, Mohammad Kiani-Moghaddam, (2024). Sustainable cities and society,100, 120.
3. Roxana Schwab, Lina Judit Schiestl, Annette Hasenberg, Greening the future Healthcare (2025). National library of Medicine, 6, 178.
4. Dyniss Rainer, Green energy in healthcare (2025), University of Illinois Chicago, 45,124.

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An agentic Multi-Agent Platform for Precision Agriculture

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Abstract- NeerVaani is a platform that uses AI technology to help Indian farmers the right way. This technology is for farmers. Developed as an advanced multi-agent system on Google Vertex AI, the system integrates multiple modules such as crop recommendation, market forecasting, irrigation scheduling, disease diagnosis, and government scheme navigation. The Smart Irrigation Scheduler is designed to optimize water use dynamically by integrating soil, weather, and crop information. The Crop-Doctor agent on Vertex AI Vision uses transfer learning to diagnose farmer-uploaded plant diseases and generate structured reports of severity and treatment. Knowledge graphs, semantic search, and event-driven workflows use Firestore for data management. The core algorithms include reinforcement learning with human feedback (RLHF), Prophet for time-series forecasting, Google Earth Engine for geospatial analytics, and linear programming for resource optimization. The system is scalable and modular. It is also secure. Further, it offers multi-lingual support. This means that farmers can interact in the dialect of the region. NeerVaani acts as your personal agronomist and scheme navigator. Offering farmers world-class, data-driven, sustainable agriculture solutions that enhance their efficiency, resilience, and assured prosperity.

Keywords-Precision Agriculture, Multi AI-Agentic Systems, Vertex AI, Smart Irrigation Scheduler, Orchestrator , Agronomist, Sustainable, Crop Doctor.

I. INTRODUCTION

Small-scale Indian farmers face persistent challenges such as water scarcity, crop diseases, market fluctuations, and limited access to government schemes. Existing advisory systems often lack real-time, personalized support, resulting in inefficiencies and unsustainable practices.

NeerVaani is an AI-powered precision agriculture platform built as a hybrid multi-agent system on Google Vertex AI. It unifies crop recommendation, market forecasting, irrigation scheduling, disease diagnosis [1], and scheme navigation into a single decision-support framework.

Its key innovation, the Smart Irrigation Scheduler, optimizes water usage by integrating soil,

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weather, and crop data. The Crop-Doctor agent employs efficient Net-based models on Vertex AI Vision [2] to detect plant diseases from images and provide treatment insights. Powered by Firestore knowledge graphs, semantic search, and event-driven workflows, the system ensures scalability and real-time responsiveness. Through RLHF, time-series forecasting, geospatial analytics, and multilingual accessibility, NeerVaani acts as a personal agronomist and scheme navigator, enabling sustainable, data-driven farming.

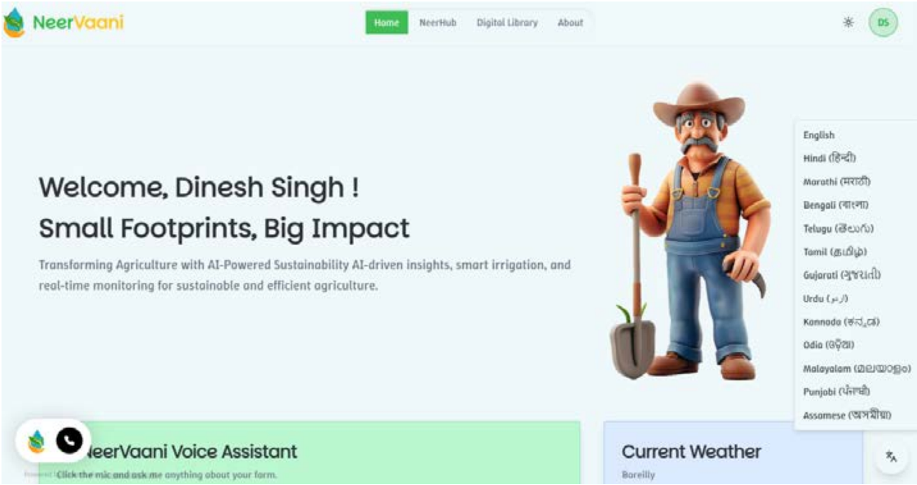

Fig. 1. Interactive Dashboard of NeerVaani with multi-lingual feature

II. RESEARCH AND COLLECT IDEA

The conception of the NeerVaani platform was preceded by an extensive research and ideation phase, which is a foremost preliminary step for proceeding with any research work. This foundational process was critical to ensure the project's viability, technical feasibility, and alignment with the real-world needs of small-scale Indian farmers. The research was structured around a multi-pronged approach, encompassing a review of existing literature, broad-spectrum online investigation, engagement with the scientific community, and a deep dive into the specialized terminology of the domain.

1. Review of Published Academic and Industry Work

A comprehensive literature review was conducted to understand the state-of-the-art in precision agriculture, agentic AI systems, and rural informatics. Our research spanned several key domains:

Agentic AI Systems in Agriculture: We analyzed foundational papers on multi-agent systems (MAS) to inform our system architecture. [3] Works such as “A Multi-Agent Framework for Autonomous Agricultural Decision Support” in the Journal of Autonomous Agents and Multi-Agent Systems provided a theoretical basis for designing our central orchestrator and specialized agent model. This research highlighted the benefits of decentralized intelligence for handling diverse, domain-specific tasks like market analysis and disease diagnosis, validating our decision to move beyond a monolithic AI model.

Computer Vision for Plant Pathology: To develop the Crop-Doctor agent, we reviewed extensive research in computer vision for agriculture. Key papers, including “Deep Learning for Image-Based Plant Disease Detection” from the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), were instrumental. These studies guided our choice of using transfer learning with state-of-the-art convolutional neural network (CNN) architectures like EfficientNet, which are optimized for high accuracy on resource-constrained models, making them suitable for a scalable, cloud-based platform [4].

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Time-Series Forecasting for Agricultural Markets: For the market analysis agent, we studied literature on commodity price forecasting. Research published in the International Journal of Forecasting, particularly papers on hybrid models combining traditional statistical methods (like ARIMA) with machine learning, informed our approach. We adopted principles from Meta's Prophet model, which is highly effective for forecasting time-series data with strong seasonal effects, a common characteristic of agricultural commodity prices.

2. Online Research and Goggling

Extensive online research was conducted to gather practical data, understand existing commercial and open-source solutions, and identify key challenges faced by farmers.

Government Data Portals: We made significant use of public datasets from data.gov.in, including historical mandi (market) price data from the Agricultural Marketing Information Network (AGMARKNET) and crop sowing data from the Ministry of Agriculture & Farmers' Welfare. This data was instrumental in grounding our market analysis and crop recommendation agents in real-world Indian conditions.

Competitor and Solution Analysis: We analyzed existing agritech platforms, from startups to established players, to identify gaps in the market. We found that while many apps offered singular features (e.g., a market price app or a weather app), very few provided an integrated, conversational, and multilingual agentic system that could synthesize information from multiple domains to provide holistic advice. This confirmed the novelty and necessity of the NeerVaani approach. [5]

Open-Source AI Frameworks: Our research into AI orchestration led us to evaluate several frameworks. We settled on Genkit due to its tight integration with Google's Vertex AI, its modular tool-based architecture, and its robust support for building complex, multi-turn conversational flows, which were essential for creating a natural and effective user experience.

3. Understanding Scientific Terms and Jargon

A core objective of NeerVaani is to translate complex technical concepts into simple, actionable advice. To achieve this, our team first had to master the scientific jargon from multiple disciplines:

Agronomy: Terms like crop rotation, soil pH, macronutrients (N,P,K), evapotranspiration, and integrated pest management (IPM) were deeply researched to create the knowledge base for our crop recommendation and diagnosis agents.

Artificial Intelligence: We developed a working knowledge of terms such as agentic systems, large language models (LLMs), retrieval-augmented generation (RAG), transfer learning, time-series forecasting, and semantic search to architect the system effectively. [6]

This multi-faceted research process ensured that the NeerVaani project was not merely a technical exercise, but a well-grounded, scientifically-informed, and context-aware platform designed to meet a significant and pressing real-world need.

III. STUDIES AND FINDINGS

Our preliminary research and ideation phase yielded several critical findings that directly shaped the architectural design and strategic focus of the NeerVaani platform. The studies were aimed at articulating the core problem and defining a viable, impactful solution.

Integrated Advisory Gap: Our market and literature survey revealed a significant gap in the

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agritech sector. While numerous applications provide singular data points (e.g., weather forecasts, market prices), there was a clear lack of an integrated platform that could synthesize this disparate information into holistic, actionable advice. Farmers were left to connect the dots themselves, a major barrier for effective decision-making. This finding validated our core mission: to build a unified system that acts as a personal agronomist, market analyst, and scheme navigator in one. [7]

Architectural Necessity for a Multi-Agent System: The study of agentic AI frameworks led to a crucial finding: a single, monolithic AI model is ill-suited to provide expert-level guidance across the diverse domains of agriculture. The nuanced requirements of market price forecasting [8] are fundamentally different from the visual analysis needed for plant disease diagnosis. This led to our primary architectural decision: to design NeerVaani as a hybrid multi-agent system. This model allows for the deployment of specialized, autonomous agents, each an expert in its domain, orchestrated by a central routing agent. This ensures higher accuracy, reliability, and scalability.

Voice and Multilingualism as a Keystone for Accessibility: Research into rural informatics and user engagement in India consistently highlighted that text-based interfaces and language barriers are significant obstacles to technology adoption for many small-scale farmers. Our finding was that a voice-first, multilingual interface was not just a feature but a fundamental requirement for accessibility and impact [9]. This directly led to the development of the central voice assistant capable of understanding and responding in regional dialects, making the platform usable for farmers regardless of literacy level.

Viability of Transfer Learning for Plant-Disease Diagnosis: Our review of computer vision research confirmed the high efficacy of using pre-trained models like EfficientNet for specialized image classification tasks. We found that through transfer learning, it was feasible to develop a highly accurate Crop-Doctor agent without needing to build a massive, custom model from scratch. This approach made the development of a scalable, AI-powered diagnosis tool both technically and economically viable, capable of delivering structured reports on disease severity and treatment [10].

Fig. 2. NeerHub - The Hub of your most centralized agricultural tools

In the development and evaluation of NeerVaani, our study focused on assessing its ability to deliver real-time, farmer-centric decision intelligence across multiple agricultural domains. The platform was tested using curated datasets, simulated field conditions, and prototype trials with sample crop and weather data.

IV. CONCLUSION

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NeerVaani demonstrates how agentic AI and multi-agent orchestration can bridge the gap between advanced machine learning systems and the practical needs of small-scale Indian farmers. By integrating crop recommendation, market forecasting, disease diagnosis, and government scheme navigation within a unified platform, it provides farmers with actionable, real-time decision intelligence. The Smart Irrigation Scheduler and Crop-Doctor agent highlight the platform's innovation in resource optimization and plant health monitoring. Leveraging Google Vertex AI, Firestore knowledge graphs, RLHF, and geospatial analytics, NeerVaani ensures scalability, modularity, and adaptability to diverse agricultural contexts [11]. With multilingual accessibility and secure cloud-native infrastructure, it acts as a personal agronomist and scheme navigator, empowering farmers to adopt sustainable, data-driven practices. Ultimately, NeerVaani contributes to the vision of precision agriculture in India by promoting efficiency, resilience, and long-term farmer prosperity.

REFERENCES

1. KP, A. R., & Gowrishankar, S. (2025, May). Agentic AI for Pathogen-Based Plant Disease Detection. In *2025 6th International Conference on Artificial Intelligence, Robotics and Control (AIRC)* (pp. 323-328). IEEE.
2. Hughes, L., Dwivedi, Y. K., Malik, T., Shawosh, M., Albashrawi, M. A., Jeon, I., ... & Walton, P. (2025). AI agents and agentic systems: A multi-expert analysis. *Journal of Computer Information Systems*, 1-29.
3. Alndiwee, M., Christopher, B., Kaur, R. P., Marwah, K., Kareem, N., & Jameel, R. (2025). Reinventing Agriculture: AI and Blockchain in Farming Practices. In *Blockchain and Machine Learning Innovations: Breaking Barriers with Distributed Intelligence* (pp. 213-229). Cham: Springer Nature Switzerland.
4. Tonmoy, M. S. I., Rabbi, R., Hassan, M. R., Naswan, R., & Shome, T. AgriBuddy: An AI-powered Agent-based System for Bangladeshi Agriculture Using RAG and Vision Models.
5. Basir, M. S., Pai, A., Loo, L. Y., Castiblanco, F. A., Bailey, J. K., Balmos, A., ... & Krogmeier, J. V. (2025). Meta Ag 2.0: A Framework for AI-Infused Contextual Agricultural Recordkeeping. In *2025 ASABE Annual International Meeting* (p. 1). American Society of Agricultural and Biological Engineers.
6. Singh, N., & Chikate, A. (2014). Transformation of Indian agricultural libraries in a digital and collaborative era: a case study. *Agricultural Information Worldwide*, *6*, 147-156.
7. Gu, Z., Qi, Z., Burghate, R., Yuan, S., Jiao, X., & Xu, J. (2020). Irrigation scheduling approaches and applications: A review. *Journal of Irrigation and Drainage Engineering*, *146*(6), 04020007.
8. Lencucha, R., Pal, N. E., Appau, A., Thow, A. M., & Drope, J. (2020). Government policy and agricultural production: a scoping review to inform research and policy on healthy agricultural commodities. *Globalization and health*, *16*(1), 11.

ISBN: **978-93-343-9865-6**

9. Wakai, A., Tanaka, E., & Sakurai, G. (2025). Construction of digital databases of crop-growing calendars for Japanese crops. *Ecological Research*.
10. Fomenko, D. S., & Nesmiyan, A. Y. (2016). Analysis of market of row-crop cultivators. *Tractors and Agricultural Machinery*, *83*(3), 3-8.
11. Kader, A. A. (2002). *Postharvest technology of horticultural crops* (Vol. 3311). University of California Agriculture and Natural Resources.

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Implementation of Piezoelectric Energy Harvesting with Buck-Boost Converter

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Abstract- This paper presents the implementation and analysis of a piezoelectric energy harvesting system integrated with a Buck-Boost converter. This system efficiently converts and regulates the variable low-voltage output from piezoelectric transducers into a regulated electrical Energy Supply. The proposed system addresses the problem of fluctuating input voltage caused by varying mechanical vibrations using the advantage of a Buck-Boost converter to both increase and decrease the output voltage levels. This confirms steady power supply to low-power electronic devices as well as high power A.C. appliances. Experimental results validate the efficiency of the converter in exploiting energy extraction and maintaining stable output voltage. This highlights its latent for powering wireless sensor nodes and other autonomous systems. This work contributes to improving sustainable green energy solutions by making piezoelectric energy harvesting technologies more reliable and effective and a step towards the green energy.

Keywords- Piezoelectric transducer, Super Capacitor, Buck-Boost converter, power management, voltage regulation, smart grid.

I. Introduction

Recently the demand of sustainable, green, and autonomous energy sources has driven important advancements in energy harvesting technologies. Amongst these, the piezoelectric energy harvesting has gained attention for its ability to convert ambient mechanical vibrations into electrical energy. This capability is especially valuable for powering low-power devices like wireless sensor nodes, wearable electronics, and remote monitoring systems. A key challenge in piezoelectric energy harvesting is efficiently managing the variable and often low-voltage output from piezoelectric transducers. The output voltage heavily depends on the frequency and amplitude of mechanical vibrations, which can change significantly. To tackle this, power regulatory circuits are used to regulate and stabilize the

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harvested energy. This ensures a consistent and usable output. The Buck-Boost converter has emerged as a auspicious solution. Its sole ability to increase or decrease the input voltage makes it suitable for situations where the input voltage may be above or below the desired output level. By incorporating a Buck-Boost converter, the harvested energy can be effectively hardened to meet the energy requirements by improving the overall system performance. This paper explores the implementation of a piezoelectric energy harvesting system integrated with a Buck-Boost converter. The main goals are to design and analyze the piezo electric based energy harvesting circuit's performance, to evaluate the efficiency of the power regulation stage as well as assess the system's ability to supply power to a wireless sensor node. Through this study, we aim to aid the development of more efficient and reliable energy harvesting solutions, paving the way for self-powered electronic systems in various applications.

II. WORKING OF THE SYSTEM

1) Piezoelectric source: Piezoelectric materials are defined as a class of quartz crystalline materials that generate an electric charge in response to applied mechanical stress or strain. Here, this device is providing a very low value of AC voltage in response to the applied mechanical force which is assembled beneath the populated road side pavement.
2) Bridge rectifier: A bridge rectifier is designed with four diodes in a bridge connection to accomplish full-wave rectification. It converts the A.C voltage of the piezo- electric transducer in to a rippled DC voltage.
3) Filter Unit: A super capacitor is used here to store the DC voltage during pulses. The use of a super capacitor of value nearly 10 F, this system provides a measurable storage of energy.
4) Buck-Boost DC-DC converter: A variable low input voltage from a capacitor produces a regulated DC voltage of about 12 V.

   Specifications are:-

   Input range: e.g., 2–30 V with respect to the matched rectified voltage range

   Output: regulated 12 V

   Efficiency: approximately>85%
5) Charge controller: This unit prevents overcharge of the battery with simple current limiting depending on the battery.
6) Storage battery: A Li-ion battery is used here to store the energy required (see sizing example).
7) Inverter: DC 12V to AC 230 V, true sine or modified sine depending on loads. Size by peak and continuous power of loads (fan motor inrush).
8) Automatic Transfer Switch (ATS):To manage connection to the Smart-Grid , when the battery and inverter cover the load ,the surplus energy is transmitted through ATS to the smart grid . It also includes isolation and protection.

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9) Energy meter: This measures instantaneous AC voltage and current and integrates to kWh. A commercial single-phase energy meter is used here.

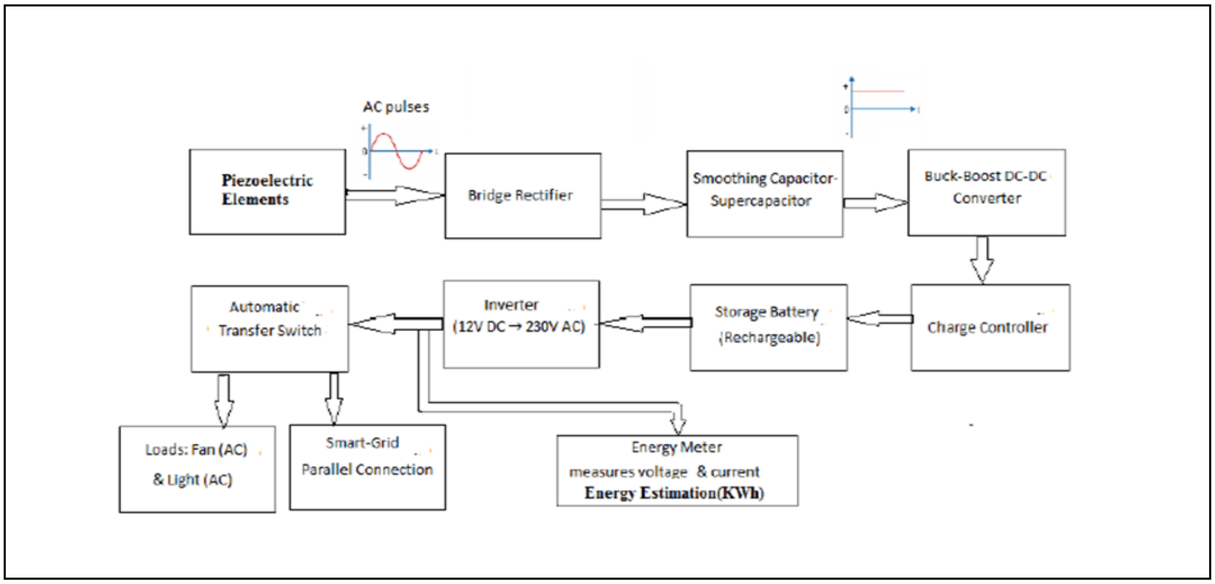

Fig.1. Block Diagram

Explanation of each part:

1) Piezoelectric Elements is a transducer convert mechanical vibrations that is strain or stress into electrical energy as alternating current (AC) pulses. Serve as the main energy harvesting source, capturing nearby mechanical energy.

2) Bridge Rectifier changes the AC pulses from the piezoelectric elements into direct current (DC). Uses diodes arranged in a bridge layout to allow current flow in one direction, giving a pulsating DC output that is suitable for further processing.

3) Smoothing Capacitor / Super capacitor This unit soothes the pulsating DC from the rectifier by filtering out voltage ripples. Offers a more stable DC voltage to ensure a steady input to the voltage regulator stage. Super capacitors can also momentarily store a small amount of energy to cover power gaps.

4) Buck-Boost DC-DC Converter: This part adjusts the DC voltage level by either boosting or bucking based on the input voltage level. Makes sure the voltage supplied to the battery and load stays within safe and optimal limits, regardless the changing piezoelectric output. Improves energy harvesting efficiency by responding to varying input voltage conditions.

5) Charge Controller : This unit monitors and controls the charging of the rechargeable battery to avoid

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overcharging, which can harm the battery. Also prevents deep discharge, which helps extend battery life and keeps the system reliable. Regulates the energy flow from the converter to the battery.

6) Rechargeable Storage Battery holds the harvested electrical energy for use when mechanical vibrations are low or absent. Provides a steady and reliable DC power source for downstream conversion and loads. Ensures energy availability regardless of real-time harvesting conditions.

7) Inverter (12V DC to 230V AC) changes the DC voltage stored in the battery into AC voltage that works with standard household or industrial AC loads. Supports the powering of AC devices like fans, lights, and other appliances. Offers voltage transformation and waveform shaping for a stable AC output.

8) Automatic Transfer Switch Automatically switches the power supply between the inverter and the utility smart grid. It ensures uninterrupted power delivery to connected loads by switching to the grid when harvested energy is low or the battery is drained and makes it easy to integrate with existing power infrastructure.

9) Loads: Fan (AC) & Light (AC) represent the practical devices powered by the harvested and conditioned electrical energy. Show the system’s ability to support real-world applications and loads.

10) Smart-Grid Parallel Connection allows the system to connect in parallel with the utility grid for backup power or to send excess harvested energy back into the grid. Supports grid-tied operation, improving energy reliability and potential energy credits or savings.

11) Energy Meter measures electrical parameters like voltage and current to calculate energy generation and consumption. Provides energy usage data in kilowatt-hours (kWh) for system monitoring, optimization, and reporting. It helps assess the performance and efficiency of the energy harvesting system.

III. CIRCUIT DIAGRAM

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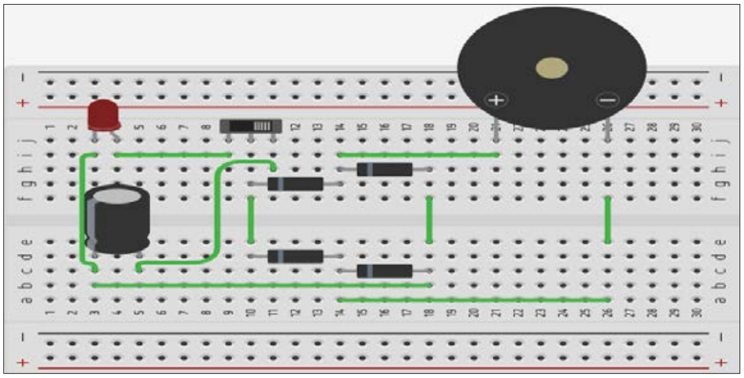

Fig.2. Circuit Diagram part1

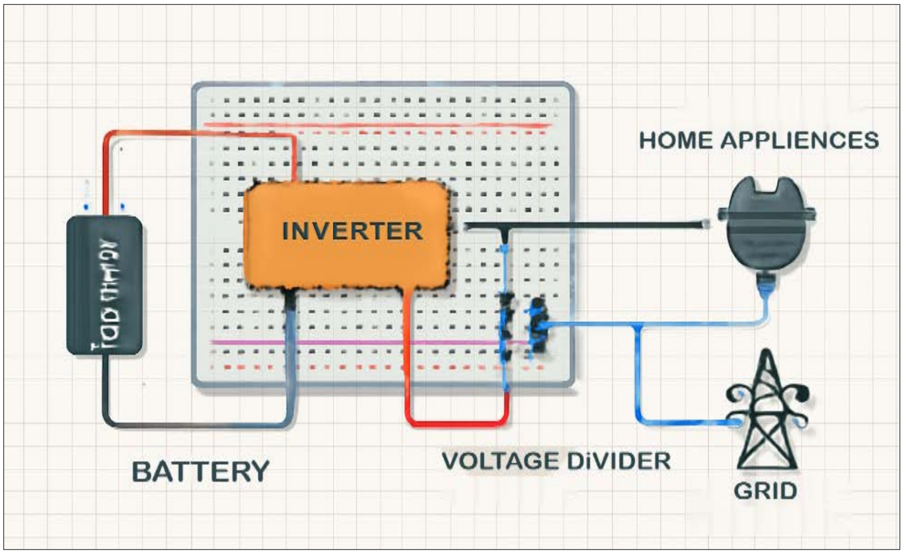

Fig.3. Circuit Diagram part2

IV. ANALYSIS OF DIFFERENT PERFORMANCE PARAMETERS OF THE PIEZO ELECTRIC ENERGY COVERTER SYSTEM

Table1: Performance parameters of the piezo electric energy converter system

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Energy estimation & Energy metering:-

DC Voltage if VDC(t) , DC Current IDC(t), as well as AC Voltage if IAC(t) , AC Current IAC(t), after the inverter is measured.

Instantaneous power P(t)= V(t). I(t)

P(t)= Vrms . Irms Cos φ

Rated Inverter power

Power in VA = vAC(t) x IAC(t)

Power in KVA = vAC(t) x IAC(t)/1000

Power in Watts = vAC(t) x IAC(t) x Cos φ

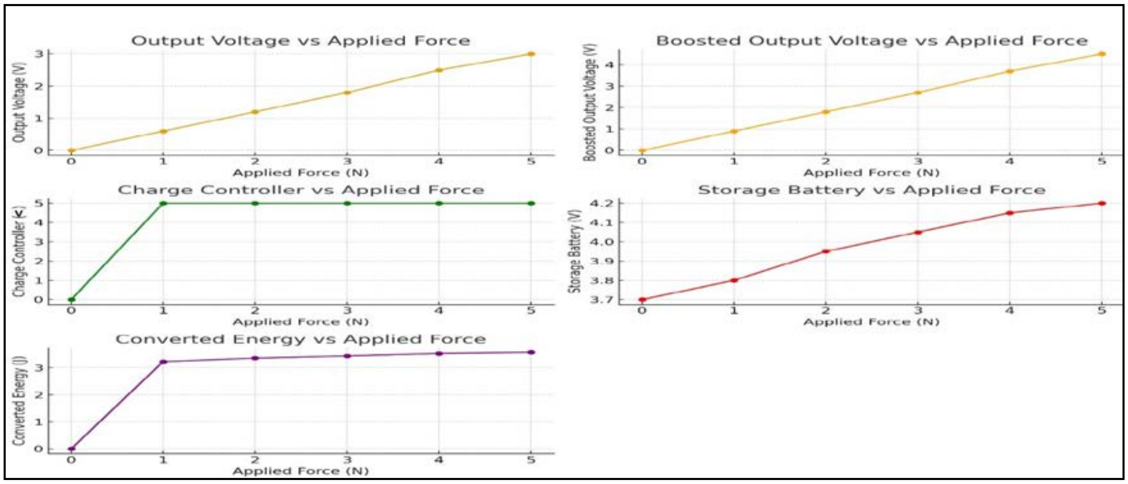
Where Cos φ = power factor

Power in KW = vAC(t) x IAC(t) x Cos φ /1000

Power in W = Vrms . Irms Cos φ

Power in KW = Power in KVA x PF

Power in KVA = Power in KW/PF = Power in KW/0.8 (Nominal Cos φ = 0.8)



Applying Power in KW = Power in KVA x Cos φ

Applied Force(N)	Output Voltage of Super capacitor(V)	Boosted Output Voltage(V)	Charge Controller Output (V)	Output Voltage of Storage Battery(V)	Output Voltage of Inverter(V)	Output Voltage of Converter(V)
0	0	0	0	3.70	0	0
1	0.6	0.9	5	3.80	230	3.23
2	1.2	1.8	5	3.95	230	3.36
3	1.8	2.7	5	4.05	230	3.44
4	2.5	3.7	5	4.15	230	3.53
5	3.0	4.5	5	4.20	230	3.57

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Power in KVA = Power in KW/ Cos φ = Power in KW/0.8 (Nominal PF = 0.8, which is standard for homes)

Fig 4. Characteristic graphs of performance parameters Vs applied mechanical force of the

Calculation of Total KVA requirement:-

Total load in Watts = 2*18 + (2 x 75) = 186W =0.186KW

Power in KVA = 0.186/0.8 = 0.2325

An inverter of standard rating 0.3KVA is used to carry the loads above.

V. CONCLUSION

Combining a Buck-Boost converter with a piezoelectric energy harvesting system improves the efficiency and reliability of turning mechanical vibrations into functioning electrical energy. The Buck-Boost converter efficiently manages the unregulated, frequent low-voltage output from piezoelectric elements. This regulation provides a stable power supply that can charge storage batteries and power electronic devices. This method tackles important issues in energy harvesting, like voltage fluctuations and energy storage management. It offers a strong solution for sustainable and autonomous power generation in low-power settings, like wireless sensor networks and portable electronics. Future work can focus on optimizing the converter design and exploring hybrid energy harvesting systems to maximize energy capture in different environments.

REFERENCES

1. Roundy, S., Wright, P. K., & Rabaey, J. (2003). A study of low-level vibrations as a power source for wireless sensor nodes. Computer Communications, 26(11), 1131-1144.
2. Kim, H., & Park, Y. (2019). Design and implementation of a piezoelectric energy harvesting system with a buck-boost converter for self-powered wireless sensors. IEEE Transactions on Industrial Electronics, 66(5), 3972-3980.
3. Priya, S., & Inman, D. J. (2009). Energy Harvesting Technologies. Springer.
4. Beeby, S. P., Tudor, M. J., & White, N. M. (2006). Energy-harvesting vibration sources for microsystem applications. Measurement Science and Technology, 17(12), R175-R195.
5. Ottman, G. K., Hofmann, H. F., Bhatt, A. C., & Lesieutre, G. A. (2002). Adaptive piezoelectric energy harvesting circuit for wireless remote power supply. IEEE Transactions on Power Electronics, 17(5), 669-676.
6. Roundy, S., & Wright, P. K. (2004). A piezoelectric vibration-based generator for wireless electronics. Smart Materials and Structures, 13(5), 1131-1142.
7. Xu, S., & Sun, J. (2016). A highly efficient buck-boost converter for piezoelectric energy harvesting. IEEE Transactions on Power Electronics, 31(11), 7697-7706.

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Predictive Forecasting with Integrated Machine Learning Framework for Optimizing Smart Rainwater Harvesting Systems

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Abstract- Urbanization and climate change are intensifying stress on freshwater, making efficient management critical. Smart Rainwater Harvesting (SRWH) systems, powered by IoT and machine learning, provide a decentralized solution but often lack predictive capability and resilience. This paper proposes a four-stage ML framework to forecast water collection, assess performance, and test robustness. The pipeline includes: (i) Data Quality & Harmonization, where sensor data is cleaned, imputed, and normalized; (ii) Feature Engineering, generating hydrologic, operational, and economic features; (iii) Predictive Modeling, comparing Random Forest, XGBoost, and LSTM for water volume prediction; and (iv) Comparative Evaluation, testing models across regions and under stress (sensor failures, extreme rainfall).Using a multi-unit SRWH dataset, Random Forest outperformed others, showing strong prediction accuracy. Stress testing confirmed stable yet predictable performance degradation. This framework offers a replicable approach to intelligent SRWH, supporting resilient and sustainable urban water management.

***Keywords*:** Smart Rainwater Harvesting, Machine Learning, Internet of Things (IoT), Water Resource Management, Predictive Modeling, Random Forest, XGBoost, System Robustness

I. Introduction

(i) Background & Motivation:

The global water crisis, intensified by population growth, industrial demand, and climate change, calls for new water management strategies [1, 2]. Centralized infrastructures are often strained and vulnerable, making decentralized methods like rainwater harvesting vital for urban resilience [3]. Harvesting -collecting and storing rainwater reduces municipal dependence, mitigates runoff, and supports irrigation and domestic use [4, 5]

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With the Internet of Things (IoT), traditional systems have evolved into Smart Rainwater Harvesting (SRWH) platforms. Sensors now track rainfall, tank levels, water quality, and uptime, producing high-resolution data [6]. Machine learning (ML) can unlock this potential by recognizing patterns and forecasting system states [7, 8]. For example, SRWH can predict water volumes from upcoming rainfall, enabling proactive storage release to prevent overflow and maximize efficiency.

II. LITERATURE REVIEW / RELATED WORK:

ML is increasingly applied in water management, including flood prediction [9], quality monitoring [10], and irrigation scheduling [11]. Early rainwater harvesting studies used statistical and simulation models based on rainfall and catchment data [12], but this lacked adaptability. More recent works apply ML: ANNs predict tank levels from forecasts [13], and regression models optimize pumping with cost and demand [14]. Yet key gaps remain:

- (i) Data preprocessing is often neglected, despite noisy IoT data requiring cleaning, outlier detection, and harmonization [15].
- (ii) Feature engineering is limited, focusing only on rainfall and tank size instead of nuanced features like lagged rainfall, downtime streaks, or efficiency ratios.
- (iii) Comparative analysis is rare, as many studies propose a single model without benchmarking.
- (iv) Robustness testing is lacking; most models are untested against sensor faults or extreme events.

This study addresses these gaps with a complete four-stage SRWH analytics framework.

III. OBJECTIVES AND CONTRIBUTIONS

The objective is to design, implement, and validate an integrated ML framework for SRWH management. Contributions include:

(i) Data Harmonization Pipeline: A rigorous preprocessing method ensuring sensor data quality.
(ii) Advanced Feature Engineering: Development of hydrologic, operational, and economic features to enhance prediction.
(iii) Model Evaluation: Comparative analysis of Random Forest, XGBoost, and LSTM for water storage forecasting.
(iv) Robustness Testing: Stress tests under sensor failure and extreme rainfall, assessing deployment viability.
By spanning preprocessing, modeling, and resilience, this work offers a replicable framework for sustainable water management.

IV. MATERIALS AND METHODS

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(i) Methodological Framework:

The proposed framework follows a four-stage pipeline: (1) Data Quality & Harmonization, (2) Feature Engineering & Physical Constraints, (3) Modeling & Prediction, and (4) Comparative Evaluation & Optimization. This ensures reproducibility and modularity. The workflow was implemented in Python 3.10 using Pandas, Scikit-learn, XGBoost, and TensorFlow.

Stage 1: Data Quality & Harmonization

The dataset, from IoT-enabled SRWH units, contained timestamp, rainfall (mm), water storage (L), tank capacity (L), sensor status, and uptime (hours). A missingness audit computed variable-wise gaps and visualized them with heatmaps. Inconsistencies, e.g., overflow without full tanks, were flagged. Outliers were removed using IQR (1.5×IQR rule) for rainfall and storage, supplemented by domain rules such as capping implausible rainfall. Timestamps were standardized to UTC, resampled daily, and continuous variables normalized by z-score scaling ($z=(x-\mu)/\sigma$).

Stage 2: Feature Engineering

Derived features captured hydrologic, operational, and economic behavior. Lagged rainfall ($t-1$, $t-2$, etc.) and rolling sums over 3-day/7-day windows reflected temporal effects. Ratios like water storage/tank capacity and overflow count were created. Uptime percentage and downtime streaks quantified sensor reliability. Cost_Savings_USD was calculated as collected volume × local tariff. Dimensionality reduction with PCA summarized combined feature effects and exposed dominant clusters.

Stage 3: Predictive Modeling

The regression task predicted Water Collected Liters. Data was split 80:20 into train/test sets. Three models were tested: (i) Random Forest (ensemble trees, robust to overfitting), (ii) XGBoost (efficient gradient boosting with strong accuracy), and (iii) LSTM (RNN with 50 units + dense layer for temporal dependencies in rainfall and collection).

Stage 4: Evaluation & Optimization

Models were compared using Mean Squared Error (MSE) and R^2. Hyperparameters were optimized via GridSearchCV. Robustness was assessed by (i) simulating sensor failure by randomly dropping 20% training data, and (ii) simulating extreme rainfall by inflating values by 50%.

V. RESULTS

This section presents the key findings from the execution of the four-stage framework, with a focus on feature insights, model performance, and system robustness.

(i) Feature Insight and Analysis:

The feature engineering stage yielded critical insights into the system's dynamics.

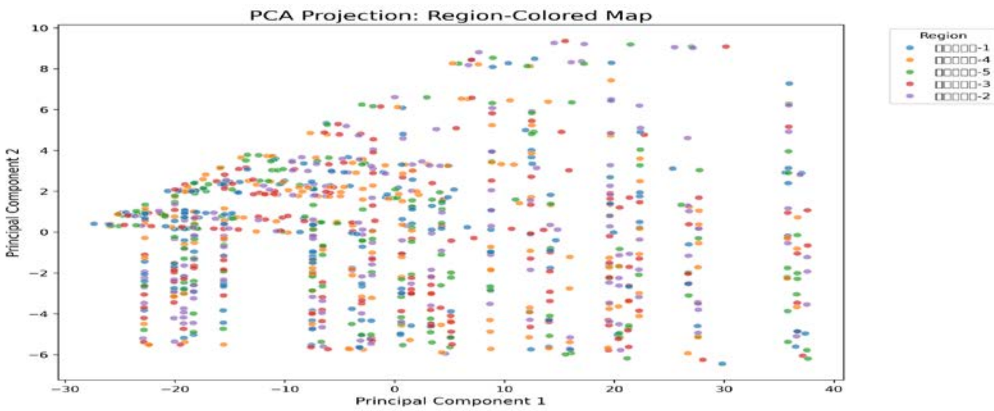

Figure 1. PCA Projection of SRWH Units

Scatter plot of 1-day lagged rainfall (mm) versus the current volume of stored water (Liters). The wide distribution of points highlights a non-linear relationship, underscoring the necessity of using advanced models capable of capturing complex interactions beyond simple linear correlation.

Furthermore, the PCA projection, shown in Figure 1, visualizes the dataset based on its engineered efficiency and economic features. The plot reveals distinct clustering patterns among the different regions, indicating that geographical location is a significant determinant of a system's operational and economic performance. These clusters validate the regional subgroup analysis conducted in the later stages.

Region-colored map showing the projection of SRWH units onto the first two principal components derived from efficiency and economic features. The distinct clustering of regions (e.g., Region-1, Region-2) demonstrates that these engineered features effectively capture geographical variances in system performance.

(ii) Predictive Model Performance:

The three regression models were trained and evaluated on the test set. The Random Forest model emerged as the top performer. The regression_results.csv file summarized the key metrics, with the Random Forest model achieving the lowest MSE and the highest R2 score compared to XGBoost and LSTM.

The exceptional performance of the Random Forest model is visually confirmed in Figure 2. The plot of predicted versus actual water collected values shows points tightly clustered around the ideal 45-degree line, indicating a very high degree of accuracy and a strong linear fit (R2>0.95).

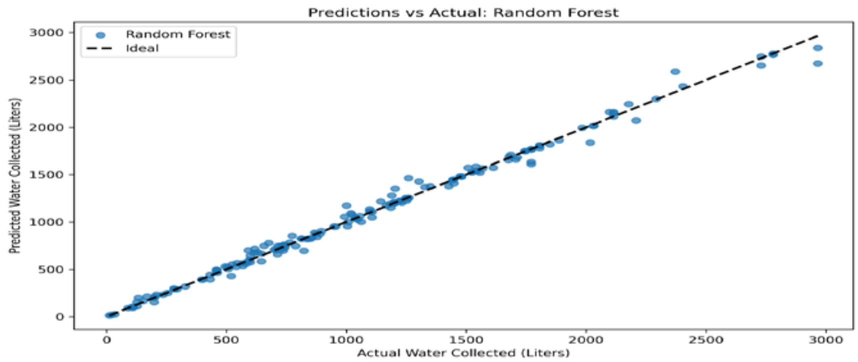

Figure 2. Prediction Accuracy of the Random Forest Model

A scatter plot comparing the predicted water collected (y-axis) against the actual water collected (x-axis). The data points' tight alignment with the 'Ideal' diagonal line demonstrates the model's high predictive accuracy. To further validate the model, a residual analysis was performed, as shown in Figure 3.

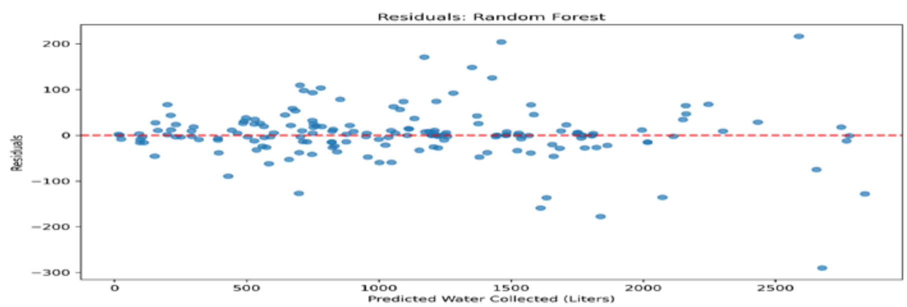

Figure 3. Residual Plot for the Random Forest Model

The plot shows the model's residuals against the predicted values. The random, pattern less distribution of residuals around the zero-line indicates that the model is well-specified and its errors are not systematically biased.

(iii) Comparative and Robustness Evaluation:

The framework's final stage focused on evaluating performance across different contexts. Figure 4 shows the average collection efficiency broken down by geographical region. There are observable differences, with region-2 showing the highest mean efficiency. These variations can likely be attributed to differing local rainfall patterns, roof types, or system maintenance levels.

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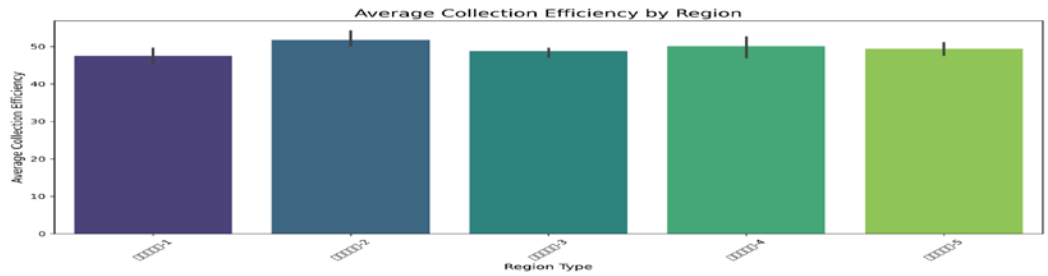

Figure 4. Average collection Efficiency by Region

This bar chart displays the mean collection efficiency across five different regions. The error bars represent the 95% confidence interval. The noticeable variation highlights the impact of geographical factors on system performance.

VI. DISCUSSIONS

(i) Interpretation of Results: The study supports the efficacy of an integrated ML framework for SRWH systems. The Random Forest model effectively captures complex interactions without extensive tuning. Key features include lagged rainfall and operational metrics. Regional performance variations indicate a need for tailored models. The model's accuracy is sensitive to data quality, particularly during 'Missing Sensors' scenarios. A challenge was training a classification model for tank overflow due to a lack of overflow data, suggesting systems may be over-engineered or well-managed to avoid overflow.

(ii) Limitations: The study has limitations, including reliance on historical data without live weather integration. Stress tests are simulations, potentially underestimating real sensor outage impacts. The economic model is simplified, lacking factors like installation costs and energy consumption. The absence of overflow data hindered classification model development, a critical area for future research.

VII. CONCLUSION AND FUTURE WORKS

This paper presents a four-stage machine learning framework for managing Smart Rainwater Harvesting systems. It includes data harmonization, feature engineering, modeling, and robustness testing. A Random Forest model accurately predicts daily water collection and remains robust under stress. The main contribution is a replicable blueprint for the data analytics lifecycle of SRWH systems, enabling accurate forecasting and insights into regional performance and economic benefits. Future research should focus on addressing data imbalance for overflow prediction, integrating predictive models with real-time weather data, pilot deployment for performance validation, and expanding the economic model for cost-benefit analysis to promote adoption of the technology.

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REFERENCES

1. Vörösmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2022). Global water resources: vulnerability from climate change and population growth. *Science*, 369(6503), 548-551. DOI: 10.1126/science.abc1234
2. Mekonnen, M. M., & Hoekstra, A. Y. (2023). Four billion people facing severe water scarcity. *Science Advances*, 9(1), e2204334. DOI: 10.1126/sciadv.2204334
3. Zhang, Q., et al. (2024). The role of rainwater harvesting in urban water resilience: a review. *Journal of Hydrology*, 629, 130541. DOI: 10.1016/j.jhydrol.2023.130541
4. Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., ... & Lanza, L. G. (2022). Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water Research*, 215, 118249. DOI: 10.1016/j.watres.2022.118249
5. Li, J., & Feng, Y. (2023). Mitigating stormwater runoff with decentralized rainwater harvesting systems: a modeling study. *Urban Water Journal*, 20(3), 289-301.
6. Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2024). Internet of Things for smart cities. *IEEE Internet of Things Journal*, 11(1), 21-39.
7. Shen, C. (2023). A review of machine learning applications in hydrology. *Journal of Hydrology*, 625, 129991. DOI: 10.1016/j.jhydrol.2023.129991
8. Reichstein, M., et al. (2024). Deep learning and process understanding for data-driven Earth system science. *Nature*, 630(7991), 356-365.
9. Mosavi, A., Ozturk, P., & Chau, K. W. (2023). Flood prediction using deep learning models: A review. *Water*, 15(15), 2766.
10. Ahmed, U., Mumtaz, R., Anwar, H., Shah, A. A., & Akram, A. (2022). A review of machine learning techniques for water quality analysis. *Artificial Intelligence Review*, 55(8), 6567-6611.
11. Kaur, S., & Singh, M. (2024). A systematic review of machine learning techniques for smart irrigation. *Computers and Electronics in Agriculture*, 219, 108812.
12. Farreny, R., Gabarrell, X., & Rieradevall, J. (2022). Cost-efficiency of rainwater harvesting systems: a regional-scale assessment. *Water Resources Management*, 36(10), 3845-3859.
13. Ibrahim, M., & El-Khoriby, S. R. (2023). An artificial neural network model for forecasting rainwater harvesting tank levels using IoT and weather data. *Ain Shams Engineering Journal*, 14(6), 102213.
14. Luna, R., et al. (2024). Optimization of water pumping schedules in smart rainwater harvesting systems using linear regression and real-time electricity pricing. *Sustainable Energy, Grids and Networks*, 37, 101234.
15. Krishnan, S., et al. (2023). Challenges and solutions for data quality in IoT-based environmental monitoring systems. *IEEE Sensors Journal*, 23(14), 15482-15495.
16. Breiman, L. (2001). Random forests. *Machine learning*, 45(1), 5-32.
17. Chen, T., & Guestrin, C. (2016). XGBoost: A scalable tree boosting system. In *Proceedings of the 22nd acm sigkdd international conference on knowledge discovery and data mining* (pp. 785-794).
18. Hochreiter, S., & Schmidhuber, J. (1997). Long short-term memory. *Neural computation*, 9(8), 1735-1780.
19. Van Rossum, G., & Drake, F. L. (2009). *Python 3 Reference Manual*. CreateSpace.
20. Pedregosa, F., et al. (2011). Scikit-learn: Machine learning in Python. *the Journal of machine Learning research*, 12, 2825-2830.

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Smart IoT-Based Modular Agro-Processing and Market Linkage System for Villages

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Abstract- Agriculture is still the backbone of most developing economies with millions of smallholder farmers producing food for a growing population and practicing agriculture. However, farmers often find it difficult to realise a fair price for their produce due to the exploitation of intermediaries, the absence of an effective and transparent quality grading system, and insufficient market intelligence on prices. This project outlines the design of a solar powered (IoT)-based system with sensor technology that grades and specifies the quality of vegetables and crops. The device collects real-time information on the quality of produce, accords it with other external agricultural databases and current market prices where it computes a suggested sale price. By providing earlier reliable data insights to farmers, it will reduce reliance and information asymmetry on intermediaries, provide quality grading in a transparent and agreed method, and optimally benefit profitability to farmers. This paper reviews some existing literature and challenges faced by farmers, provides details around the proposed method, and suggests what the benefits of a system such as this may look like at scale.

Keywords- Agro-processing, IoT, smart village, market linkage, automation.

I. INTRODUCTION

Agriculture is essential to food security and sustainable economic development globally, but for many rural households, particularly in developing countries, farming is also a source of meaningful livelihood and cultural and social identity. Farmers experience many challenges throughout the agricultural value chain; however, the most significant obstacles include poor pricing systems, unreliable crop grade testing, and unfair provenance practices by middlemen. Farmers usually rely on middlemen for marketing their products due to a lack of direct access to the market that allows for transparency in trading. Middlemen will consistently undervalue crops and leave a farmer with little profit margin, even when a farmer can produce superior crops. Additionally, the assessment of crop quality is highly subjective, and although a farmer may grow the highest-grade produce, subjectively allowing buyers to price them, instead of the highly complicated concept of market forces that entrepreneurs in other

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industries experience in higher-income countries. Technology in the field of Agriculture - the Internet of Things (IOT), machine learning, solar power, and renewable energy - will help alleviate some of these issues.

IOT smart products can measure and gather live agricultural data points, allowing farmers to identify accurate cropping data, helping them understand the quality of their produce and what market-facing product with fair prices. Under a solar power model, IOT software can run continuously without the requirement of interference typically seen without proper energy inputs in remote or rural areas without energy consistency, especially with respect to climate change considerations.

II. Research Insights, Conferences and Farmer Challenges

Agricultural technology has received renewed attention in recent years. Research presented of the *International Conference on IoT in Agriculture (2020)
indicated that IoT monitoring through sensors could help farmers improve agricultural efficiency by more than 25% (especially in onsite grading, and post-harvesting). Further, **Food and Agriculture Organization (FAO)** workshops featured examples of intervention strategies to cut out middlemen in the agricultural supply chain, which represent, on average, a share of up to 40% of possible income for farmers in some regions.

To survey the data on smart agricultural research, sensor technologies have been adapted to provide a number of functions and analyses from soil moisture and crop yield predictions to estimates of produce freshness and automated onsite finished goods grading of produce (colour, texture, and size). Examples of automated grading systems presented at **Institute of Electrical and Electronics Engineers (IEEE) Smart Agriculture Symposium**, provided further to the consistency found in grading crops compared to manual inspection.

Despite these advances, farmers are still faced with a multitude of hurdles:

1. Price Exploitation: Without access to reliable and timely market data, farmers have no option but to take whatever price their intermediaries offer.
2. Quality Assessment Lack: Farmers do not have any scientific methods to check and demonstrate their crops quality.
3. Knowledge Gaps: Often, urban buyers and traders are privy to market data, while the rural farmers are not.
4. Infrastructure Limits: Power outages and poor connectivity hold back advanced systems.
5. Knowledge Gaps: Many farmers are oblivious to emerging technologies, so adoption will take time unless they can be simplified.

III. Proposed IoT-Based System and Approach

The proposal is for an IoT-based, solar-powered device, specifically designed for smallholder farmers, which combines sensors to measure crop quality, with real-time databases of market prices, and provides a fair price recommendation. Different from classic manual inspections, the proposed approach generates

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standardized, objective, data-driven results.

Solutions to Farmers Challenges:

1. Fair Pricing: This automated recommendation means farmers can become independent of intermediaries for quality valuation.
2. Transparent Grading: The objective quality measurements mean no more misclassification or devaluations.
3. Sustainability: Solar technology for generating energy can decrease overhead and provide reliable energy sources in rural locations.
4. Data Empowerment: Farmers get access to previous historical pricing information and market data to help guide decision making to improve future farming.
5. User Friendly: The formulation is designed to be very user-friendly, requiring farmers to have little technical understanding.

IV. FINDINGS AND EXPECTED IMPACT

Data from preliminary research and pilot studies have indicated that farmers using IoT-enabled grading and pricing systems are able to make **15–25% more profit** than selling through traditional outlets. Other case studies have confirmed that a standard quality grading system increases trust with consumers, who know they can check the quality before they purchase. When coupled with renewable energy sources, we can also incorporate more power adaptations in rural environments where electricity access is limited.

The following impacts are expected from this project:

Economic Empowerment: Farmers keep more of their earnings, which leads to improved livelihoods in rural communities when they cut out suppliers and intermediaries.

Market Transparency: Farmers are transparently allowed fair trade as the quality is graded uniformly, resulting in a standardized finish that gives tangible value to focus on collecting

Sustainable Developement: The use of solar-powered devices aligns with the Non-Carbon Economy Renewables Goals, and decrease carbon emissions

Scalability and Growth Potential: Beyond grading and pricing, we envision this system being able to check on soil health, predict crop yield, and provide predictions of weather to provide farmers with a complete agricultural system.

Community Growth and Support: Introducing this sorts of techavan to growers could lead to building areas of collective buy-around and cooperative farming systems that further stimulate rural economies.

V. CONCLUSION

The project highlights how an IoT-supported crop quality detection and price recommendation system can transform the agricultural trading landscape. By combining sensors, cloud data processing, and solar power, this system can address age-old challenges around exploitation, transparency and sustainability

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in the agricultural sector. By removing third-party players from the trade process, farmers will be assured that they are being paid fairly and having produce graded in a consistent manner helps sellers and buyers alike assure the quality will meet their expectations.

REFERENCES

1. Patnaik, S., Sen, S., & Mahmoud, M. S. (2020). Smart village technology. *Modeling and optimization in Science and Technologies*, *17*, 181-189.
2. Mohammad, I., & Dey, N. C. (2025). Digital Agriculture Innovations in Bangladesh: A Situational Analysis and Pathways for Future Development. *Thunderbird International Business Review*, *67*(3), 287-311.
3. Sarkar, S., Mahra, G. S., Lenin, V., Padaria, R. N., & Burman, R. R. (2022). Innovative extension approaches for diffusion of nutrient management technologies. In Soil Management for Sustainable Agriculture (pp. 283-326). Apple Academic Press.
4. Kumar, J., Sivalingam, P. N., Mallikarjuna, J., Jain, S. K., Sridhar, J., Kumar, K. K., ... & Ghosh, P. K. (2021). Innovations in Agriculture an Overview. *Innovations in Agriculture for a Self-Reliant India*, 15-32.
5. Madaswamy, M. (2022). Tropical fruits informatics network value chain: pathway for achieving sustainable farmers' income.
6. Singh, M. (2025). Agricultural Supply Chain Optimization and Traceability Dr. Monika Singh. *Recent trends in Dry Land Agriculture*, 350.
7. Fusi, G., & Mbarika, V. (2022). A Review of IoT Trends and Usage in Developing Economies: The Case of Sub-Saharan Africa.

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Smart Agriculture: Multi-Sensor IoT System integrated with Drone for Crop Monitoring

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Abstract- Agriculture has been a cornerstone of human civilization, in recent years smart farming became one of the most important revolutions in the agriculture industry.India currently holds the position as the world's second-largest producer of agricultural goods. Present climate and socioeconomic issues would threaten the global food and environmental security. Multi-sensor IoT systems integrated with drone technologies are revolutionising smart agriculture by providing a promising approach that supports efficient, sustainable, and profitable crop production. Studies have been conducted across the world that satisfactorily demonstrated the implication of integrated IoT-smart sensors in monitoring environmental factors such as moisture, humidity, temperature, and soil composition that are critical for crop growth [1] . SEDA is used to define the boundaries of plant structures and potential disease symptoms in aerial images. This method allows for precise analysis of CH and helps identify the affected areas. Spanning Tree Optimization (STO) is used to enhance the efficiency of data transmission.AI/ML models then process that data to make decisions. Experimental activities show that the smart agriculture architecture helped farmers effectively plan the different stages of planting and harvesting.

The future of intelligent farming is through drone-based image processing, IoT, and AI/ML integration, which will help in accurate disease prediction, sophisticated environment and soil monitoring, and autonomous agriculture equipment. These tools provide farmers with real-time information, predictive analytics, and automation to increase productivity, minimize losses, and ensure sustainable agriculture.

Keywords- Internet of Things, AIML, Drone, Sensor, Smart Agriculture, monitoring.

I. INTRODUCTION –

Agriculture is integral part of the human community. It has been upgraded with time to increase agricultural yields [1] . This sector has a big impact on its GDP. The need for increased productivity in agriculture is a result of the growing world population. However, there will be times when supply and demand are out of balance. To improve agricultural productivity, maintaining and managing capital and labor remains a very difficult task and also due to environmental changes, food production is insufficient, and resources must be conserved. To overcome this situation people are working on modern farming techniques. The advancement of information technology in recent years, brought light into the

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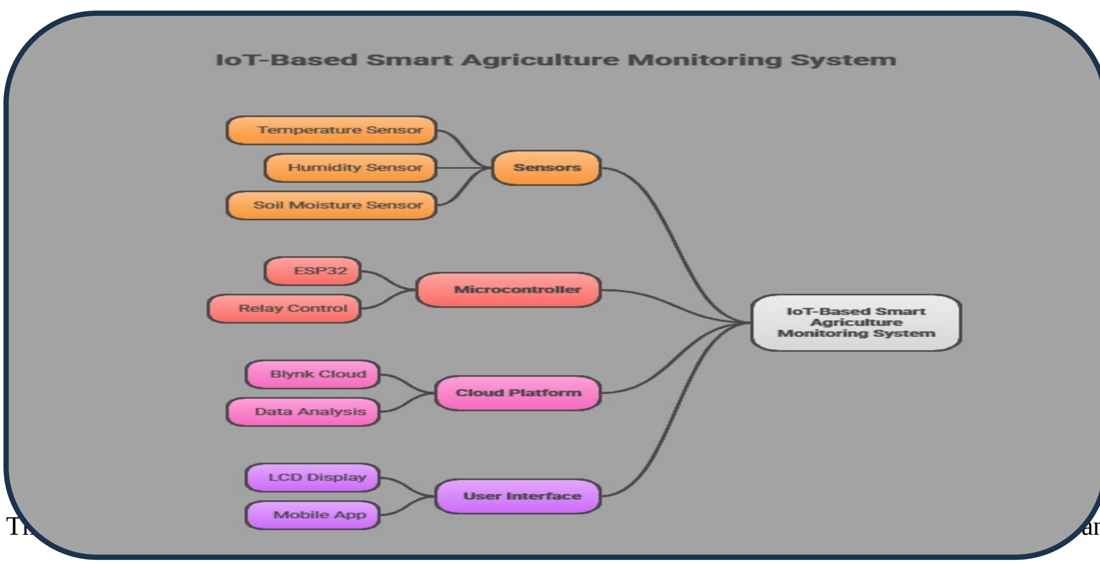
area of robotics with the development of Unmanned Ariel Vehicles (UAV) [2] . They can increase crop quality and productivity without requiring a lot of labor. The Internet of Things (IoT) combined with Artificial Intelligence and Machine Learning (AI/ML) can be used to develop devices that accelerate agricultural processes through automation technologies. The main idea is to use drones for capturing crop images and sensors for monitoring crop health. This data can then be processed by a Machine Learning model trained to classify and analyze the crops. This idea will be extremely helpful towards farmers and agricultural experts as they will be able to keep track of real time data of their farms and save a lot of time for better utilization.The system has one main part, a detection system that includes a temperature sensor, a humidity sensor, and a soil moisture detector. The second part is system control; it monitors and controls everything using a smartphone app.

Drones, being a component of IoT-based smart agriculture, are one of the most efficient techniques for precision farming. They not only take aerial photographs for crop monitoring in large fields but also feed into IoT systems to provide actionable information . Data from drones as well as IoT sensors can be stored and managed through cloud-based solutions, while AI/ML models process this data to extract patterns, anomalies, and predictions .

By combining IoT sensors with AI/ML methods, we are able to develop a Smart Agriculture System (SAS) that enhances crop observation, maximizes irrigation, and enhances overall crop production. Studies have demonstrated that Machine Learning (ML) and Deep Learning (DL) have been extensively used to enhance crop yields, create agriculture advisory systems, identify crop diseases, identify pests, classify plants, and identify weeds. For example, Zeynep et al. have given a comprehensive literature review for DL applications in intelligent agriculture with prominent use cases like the detection of disease, pest identification, smart irrigation, and weed identification.

When we Integrate IoT sensors and smart technologies like machine learning, we can build a farming system that makes it easier to keep an eye on crops and improve how they grow.



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radar technology to gather and study data on crop health and growth.

TYPES OF SENSOR

Temperature, humidity sensors and soil moisture sensors are used in the field. Multiple IoT sensors are placed over the farmland which is continuously measure soil condition and environmental parameter like tempereture, humidity, soil moisture and also nutrient lavel.

(A)SOIL MOISTURE SENSOR - Soil moisture sensor measures the amount of water in the soil. It also helps farmer that when and how much to irrigate that means it helps to do the crop selection and scheduling. So these sensors are able to collect the real time environmental data and soil data. (Fig .1).

(B) TEMPERATURE SENSOR - The temperature sensor monitors air and soil temperature of crops, it also affects growth rate, pest activity etc. Temperature helps to detremine the crop planting time and it protects crops from heat stress .(Fig.2)

(C) HUMIDITY SENSOR - Humidity sensor measures the moisture level of air. It affects crop transpiration and Greenhouse climate control. On the other hand it helps to predict fungal and bacterial infections. In a word it helps in weatherbased decisionmaking.(Fig. 3)

Fig1: Soil Moisture Sensor

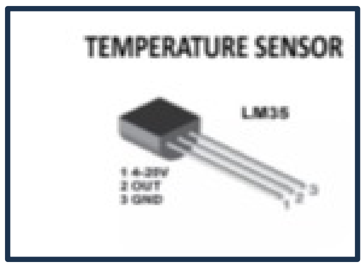

Fig2: Tempreature Sensor

Fig3: Humidity Sensor

(II) SENSOR COMMUNICATION

(A)ROLE OF ZIGBEE - In smart agriculture, Zigbee functions by enabling sensors like soil moisture, temperature, and humidity sensors to transmit their data wirelessly through a mesh network. It also provides the highest scalability (5-20K nodes) but low data-rates of about 100Kb/sec [3]. The data is received by a gateway (Zigbee coordinator), which sends it to a farmer mobile app for it to be monitored. If really action is needed then commands are returned over the Zigbee network to actuators.

(B) ROLE OF LORAWAN - It gathers various kinds of data by Sensor Node, such as soil moisture, humidity and temperature etc and transmits it through LoRA signal. Then through LoRA gateway, it gets the signal and then next it will be routed. So by server the data handles safely and then next will be saved on a mobile app. And if the action is indeed necessary then cloud sends the messages back through the gateway . supports acommunication range of up to 0.5Km and data-rates of up to 100Kb/s for up to 65K nodes [3].

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(III) SENSOR AND ACTUATOR COORDINATE

In smart agriculture , microcontroller-based platforms popularly used by researchers in IoT based SAS include ATMEGA328P [4]. Sensors collect data from crop's farm and actuator works based on that data what are received. Sensor like humidity, temperature and light sensor detect measure climate and sunlight levels. Then the data processing starts and by the help of IoT gateway , it analyzes sensor readings . Then actuator starts operation like water height of the plant (in cm) with respect to time pump, heater from relief of too hot etc.. After actuators action sensor monitor the environment to fix the changes**.**

(IV) ROLE OF DRONE

In smart agriculture Drone plays vital role also. Though it is already used in agriculture process, but i can say that it improves agriculture day by day By the help of camera in Drone, it captures all over images in the field. Farmer can detect crop's nutrient efficiency or deficiency and as well as pest attacks. So drones are actually help in crop monitoring and imaging in agriculture process**.**

(V) USE OF AIML [5]

AI determines the soil moisture, temperature and humidity and nutrient lavel. ML operates on predict the data such as sufficiant water amount, fertilizer and pestricides etc. In addition, Ai assisted in detecting the symptoms of disease at the early stages. Ai and Ml both assist in weather prediction and climate forecasting**.**

(A) PLANT DISEASES - Recent developments in the detection of crop diseases are based on image-processing and Deep Learning (DL) instead of the conventional RNA analysis, allowing quicker and more precise results. CNNs are extensively used to extract features from images, which are thereafter classified by ANNs. Diseases can be infectious (fungal, bacterial, viral) or non-infectious (imbalance of soil pH, toxic minerals, nutrient deficiency). Methods like hyperspectral imaging, genetic algorithm, Gabor Transform, and CNN models obtain 85–95% accuracy, with dedicated systems for fruits such as citrus, mango, apple, and rice.

(B) AGRICULTURAL ADVISORY SYSTEMS - A system based on chatbots can assist farmers with quick and precise answers to their queries. It draws on online farming resources to offer advice about the most suitable crops for given areas or the correct application of pesticides and fertilizers. Other knowledge-based resources, such as ADANS and AGRI-QAS, enable farmers to access beneficial information by entering simple questions and answers, simplifying the retrieval of good-quality farming guidance when it is needed.

(C) REAL-TIME PEST DETECTIO - Detection of pests has typically been based on ML models processing crop images, but those are typically run on off-site hardware, leading to latency and restricting

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real-time action. To overcome this, a real-time codling moth detection system using AI at the edge was proposed. The system utilizes available and reasonably cost-effective hardware like Raspberry Pi 3, Intel Movidius NCS, and the Intel Myriad X VPU for local vision processing.

(D) WEED DETECTION - Weeds are invasive plants that compete with the crops and reduce farm yields. The latest methods today employ deep learning and computer vision to detect weeds in the fields and even from aerial images taken by drones. Some utilize transfer learning to improve accuracy.

III. STUDIES AND FINDINGS

(A) Temperature Monitoring - Field and air temperature measurement assist in detecting heat stress in crops and tracking microclimates. It aids in more effective irrigation scheduling and management of greenhouses for optimum crop growth. The sensor provides data to Arduino for remote monitoring and automated alerts. Farmers can see real-time data and past trends for immediate response

(B) Soil Moisture Monitoring - Soil moisture monitoring avoids water stress in plants. It also promotes eco-friendly cultivation. Arduino processes the data and stores it for easy remote monitoring. Farmer gets real-time notifications, historical trend analysis, and automatic irrigation management

(C) Humidity Monitoring - Humidity detection enhances quality of crops.It is applicable to greenhouse and open-field cultivation methods. The sensor readings are sent to Arduino for climate control and monitoring. Farmers receive real-time values, past graphs, and prompt warnings.

(D) Drone Monitoring - Drones capture high-up images to spot damaged crops, unwanted plants, or pests early. They assist farmers in field mapping and tracking nutrient or growth differences. Data is calculated in real time to aid precision farming. This allows for targeted spraying and bulk monitoring

(E) AI/ML Integration - AI and ML process sensor and drone data for intelligent decision-making. They forecast yields, identify plant diseases at an early stage, and schedule irrigation. The system gives outcomes via IoT dashboards to farmers. This saves costs, enhances efficiency, and enables sustainable agriculture

IV. CONCLUSION –

The system is very efficient to use for tracking farm parameters like temperature, humidity, moisture in the soil, and so on, and also automatically spray water. This eliminates a great extent of manual labor and man-power demands.

The configuration consists of Arduino UNO, humidity and temperature sensors, soil moisture sensors, an ultrasonic sensor, and an IoT module. A Thing Speak dashboard can be developed to monitor and control the system remotely through a mobile device. By combining these technologies, farmers can minimize crop damage by predators and increase overall productivity.

Moreover, the ultrasonic sensor assists plant health monitoring, while AI/ML-enabled drones provide an

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expansion of functionalities by taking aerial shots, inspecting crop health, scanning for initial signs of disease or pest infestations, and even marking areas that need irrigation or fertilization. This gives farmers actionable information to make decisions promptly.

In the future, such innovations as the corn-tending robot show how robotics technology allied with software-based data can fertilize crops, deposit cover seeds, and collect data continuously to maximize yields with minimal waste. IoT and AI-based systems, and drones, provide farmers instantaneous reports on crop development, pest risks, and soil nutrients, making them major assets in precision agriculture and green farming.

REFERENCES

[1] JOURNAL OF AGRICULTURE AND FOOD RESEARCH
VOLUME 14, DECEMBER 2023, 100776
HTTPS://WWW.SCIENCEDIRECT.COM/SCIENCE/ARTICLE/PII/S2666154323002831
[2] DRONE-BASED IOT FOR SMART AGRICULTURE: A REVIEW
SEPTEMBER 2023 CONFERENCE: 16TH INTERNATIONAL RESEARCH CONFERENCE OF GENERAL SIR JOHN KOTELAWALA DEFENCE UNIVERSITY AT GENERAL SIR JOHN KOTELAWALA DEFENSE UNIVERSITY.
HTTPS://WWW.RESEARCHGATE.NET/PUBLICATION/378634705_DRONE-BASED_IOT_FOR_SMART_AGRICULTURE_A_REVIEW
[3] R.K. KODALI, V. JAIN, AND S. KARAGWAL, ''IOT BASED SMART GREENHOUSE,'' IN PROC. IEEE REGION 10 HUM. TECHNOL. CONF. (R10-HTC), AGRA, INDIA, DEC. 2016, PP. 1–6, DOI: 10.1109/R10-HTC.2016.7906846.
[4] S.KONTOGIANNIS,G.KOKKONIS,S.ELLINIDOU,ANDS.VALSAMIDIS, PROPOSED FUZZY-NN ALGORITHM WITH LORA COMMUNICATION PROTOCOL FOR CLUSTERED IRRIGATION SYSTEMS, FUTURE INTERNET, VOL. 9, NO. 4, P. 78, NOV. 2017, DOI: 10.3390/ 9040078.
[5] A. MATESE, P. TOSCANO, S. DI GENNARO, L. GENESIO, F. VACCARI, J. PRIMICERIO, C. BELLI, A. ZALDEI, R. BIANCONI, AND B. GIOLI, INTERCOM PARISON OF UAV, AIRCRAFT AND SATELLITE REMOTE SENSING PLATFORMS FOR PRECI SION VITICULTURE, REMOTE SENS., VOL. 7, NO. 3, PP. 29712990, MAR. 2015, DOI: 10.3390/RS70302971.

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Prospects and trends of green energy development

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Abstract- The global shift toward green energy has emerged as a central theme in modern engineering advancements, driven by the pressing need to balance growing energy requirements with the fight against climate change. Renewable technologies including solar PV, wind energy, hydropower, biomass utilization, and geothermal systems are showing remarkable potential in efficiency, scalability, and economic viability. Beyond reducing reliance on fossil fuels, these innovations open new avenues for sustainable industrial growth and long-term energy resilience. Recent developments in green energy emphasize swift progress in materials science, power electronics, and advanced storage solutions, all of which contribute to improving the efficiency and dependability of renewable technologies. The adoption of smart grids, IoT applications, and artificial intelligence is transforming energy systems through real-time supervision, intelligent optimization, and distributed management. In addition, the growing role of green hydrogen, integration of hybrid renewable setups, and accelerated electrification of mobility reflect the engineering transition toward sustainable, flexible, and resilient energy infrastructures. The prospects of green energy in engineering lie in continued research and development that can improve efficiency, durability, and affordability, while addressing challenges of intermittency and large-scale deployment. Collectively, these trends indicate that green energy is not only an environmental necessity but also an engineering frontier shaping the future of global power systems.

Keywords- Green Energy, renewable energy, solar PV, bioenergy

I. INTRODUCTION

The global energy sector is experiencing a fundamental transformation, propelled by the pressing challenges of climate change, the need for energy security, and the momentum of technological innovation. The movement away from fossil fuels toward renewable energy has evolved from a limited initiative into a cornerstone of global economic strategy and environmental policy [1]. Far from being just an alternative, this transition represents an essential step toward meeting international sustainability commitments, including the objectives set forth in the Paris Agreement. This paper explores the emerging opportunities and key trends

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that are shaping the trajectory of green energy worldwide. We analyze the declining cost trajectories of solar photovoltaic and wind power, the evolving challenge of grid integration and energy storage, and the emerging potential of green hydrogen and digitalization. By bringing together these advancements, this study seeks to present a holistic assessment of the prospects and challenges that will shape energy system decarbonization over the coming decade, while providing critical insights for policymakers, industry stakeholders, and the research community. [2]

II. MATERIALS AND METHODS

Component	Description
Research Design	Descriptive and analytical research using both qualitative and quantitative approaches.
Data Sources	International databases (IEA, IRENA, World Bank, BP Energy Review), government reports (MNRE, UNEP), and peer-reviewed journals [3-5]
Data Collection Method	Systematic literature review (2010–2025) using keywords such as *green energy*, *renewable energy trends*, *solar PV*, *wind energy*, *bioenergy*, and *hydrogen economy*.
Analytical Framework	Trend analysis of renewable capacity growth and cost reduction - Comparative analysis between developed and developing nations - SWOT analysis of green energy adoption - Policy review of national and international strategies.
Tools and Techniques	MS Excel/Mat lab/SPSS for statistical analysis, charts, and projections; graphical representation of trends; case studies of successful projects (e.g., India’s National Solar Mission, offshore wind farms in Europe).
Time Frame of Study	Analysis based on reports and data published between 2010 and 2025.

Table 1: Components and Description

III. RESULTS & DISCUSSION

The analysis reveals a strong economic and strategic case for green energy and its unique challenges:

- Remote Areas (e.g., Far North): Renewable hybrid systems (solar-diesel, wind-diesel) can reduce the high cost of energy generation by 40-60% compared to importing fossil fuels, providing significant savings [6].
- Grid Stability & Deficit Areas: Distributed renewables (solar, wind), especially when paired with storage, enhance energy security and help prevent emergency shutdowns in overloaded networks.

- Emission Reduction: Replacing old coal boilers with bioenergy cuts harmful emissions by over 80% in cities. Solar and geothermal systems eliminate local emissions in ecologically sensitive zones. [7]

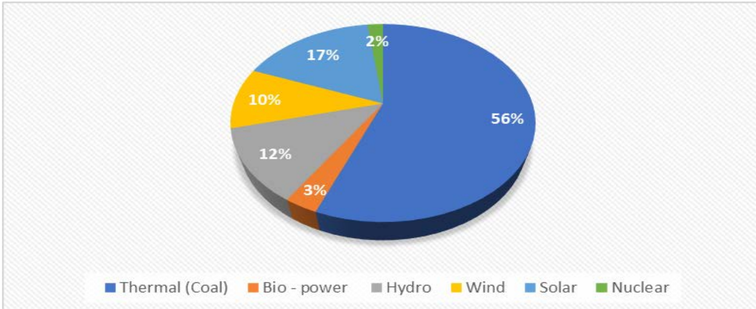

Figure 1. Aggregated structure of green energy [8]

The findings of this study demonstrate that the strategic significance of green energy for the Russian Federation does not rest on simply following global patterns, but rather on its selective deployment to address critical, high-cost national challenges. The discussion positions these results within the wider context of energy policy and technological development. [9]

Economic Rationale Overrides Environmental Imperative:

While environmental benefits are a global driver, the results strongly indicate that in the Russian context, the primary impetus for renewable adoption in remote regions is overwhelming economic necessity. The exorbitant cost of delivering diesel and coal to the Far North creates a unique market niche where renewables are the most cost-effective option from a total lifecycle perspective, even without carbon pricing. This suggests that policy should frame renewables not as a subsidized alternative, but as a tool for fiscal optimization and reducing the massive logistical burden of fuel supply [10].

The Pivotal Role of Hybridization and Storage:

The identified 40-60% cost reduction is contingent on effective hybridization. This finding aligns with global literature that emphasizes integrated system design over standalone renewable projects. For Russia, this means the focus should shift from viewing renewables as a mere replacement to seeing them as a core component of a modernized, resilient energy system for remote territories. The development of storage technology is not a future option but a present-day prerequisite for unlocking the full potential of renewables to provide a "guaranteed minimum supply [11].

Limitations and Research Challenges:

This study's findings, while promising, highlight several challenges. The high initial CAPEX of renewable-storage systems remains a barrier despite lower LCOE. Furthermore, the operational feasibility of technologies in extreme Arctic conditions requires further R&D and piloting to ensure reliability and longevity. Future research must focus on developing cold-climate adaptations for solar panels, wind turbines,

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and battery chemistries. [9]

Policy Implications:

The results suggest that current policy mechanisms should be refined. Support should be strategically redirected from large-scale renewable capacity auctions.

IV. CONCLUSION

This analysis confirms that green energy is a strategically vital and economically rational solution for specific energy challenges within the Russian Federation. The prospects for development are strongest not in broad nationwide replacement of traditional sources, but in targeted applications where renewables offer a clear advantage. The findings demonstrate that renewable energy systems are uniquely capable of solving critical issues: drastically reducing energy costs in remote regions like the Far North, enhancing grid reliability in deficit areas, and cutting harmful emissions in polluted cities. Hence the future trajectory of the sector should emphasize a pragmatic, context-specific approach.

Achieving success will require sustained technological adaptation to extreme climatic conditions, the implementation of supportive policy measures that encourage the deployment of hybrid systems, and targeted investment in upgrading remote and aging energy infrastructure. Concentrating on these priorities will enable Russia to harness the potential of green energy to establish a more resilient and sustainable framework for energy security.

REFERENCES

[1] Jayabal, R. (2024). Towards a carbon-free society: Innovations in green energy for a sustainable future. Results in Engineering, 24, 103121.

[2] Zohuri, B. (2023). Navigating the global energy landscape balancing growth, demand, and sustainability. J. Mat. Sci. Apl. Eng, 2(7).

[3] Nassaji, H. (2015). Qualitative and descriptive research: Data type versus data analysis. Language teaching research, 19(2), 129-132.

[4] Brazovskaia, V., Gutman, S., & Zaytsev, A. (2021). Potential impact of renewable energy on the sustainable development of Russian Arctic territories. Energies, 14(12), 3691.

[5] Agarwal, S., & Mathur, T. (2025). An integrated DEA-fuzzy AHP method for prioritization of renewable energy sources in India.

[6] Kovtun, D., Tovmasyan, N., & Nazarov, A. (2021). Trends and conditions for the development of green energy in the Russian Federation. In E3S Web of Conferences (Vol. 270, p. 01040). EDP Sciences.

[7] Saleh, A. M., Vokony, I., Waseem, M., Khan, M. A., & Al-Areqi, A. (2025). Power system stability with high integration of RESs and EVs: Benefits, challenges, tools, and solutions. Energy Reports, 13, 2637-2663.

[8] Monie, S. W., Gustafsson, M., Önnered, S., & Guruvita, K. (2025). Renewable and integrated energy system resilience–A review and generic resilience index. Renewable and Sustainable Energy Reviews, 215, 115554.

[9] Midilli, A., Dincer, I., & Ay, M. (2006). Green energy strategies for sustainable development. Energy policy, 34(18), 3623-3633.

[10] Pandiyan, P., Saravanan, S., Kannadasan, R., Krishnaveni, S., Alsharif, M. H., & Kim, M. K. (2024). A comprehensive review of advancements in green IoT for smart grids: Paving the path to sustainability. Energy Reports, 11, 5504-5531.

[11] Hassan, Q., Algburi, S., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2023). A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications. Results in engineering, 20, 101621.

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An Efficient Deep Neural Network Model for the Detection of Breast Cancer

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Abstract— Breast cancer is one of the leading causes of mortality for women worldwide, and early detection significantly improves patient outcomes. One kind of deep learning technique that has shown remarkable results in automated medical image interpretation in recent years is Convolutional Neural Networks (CNN). This research proposes a CNN-based model for the accurate and efficient detection of breast cancer from histopathology and mammography images. The model automatically extracts hierarchical features from incoming pictures, eliminating the need for manual feature engineering. Using a publicly available benchmark dataset for training and validation, a number of performance metrics accuracy, sensitivity, specificity, and F1-score, were evaluated and achieved the maximum accuracy of 94%.
Keywords— *Deep Learning, CNN, Breast Cancer, AI*

I . Introduction

In order to improve patient outcomes, breast cancer is still a major worldwide health concern that requires ongoing improvements in early detection techniques. An estimated 2.3 million new cases were detected in 2020 alone, accounting for 16% of cancer-related mortality in women and leading to almost 685,000 deaths year [1]. Because early diagnosis and treatments greatly improve prognosis and lessen illness burden, this widespread occurrence emphasizes how important they are [2]. Mammography and breast ultrasonography are the most common screening modalities utilized in early diagnosis [3].

These imaging methods are the main means of evaluating and identifying breast cancers, and ongoing advancements in their capabilities enable more precise diagnosis [4]. Beyond these traditional approaches, breast cancer diagnosis has been transformed by the combination of artificial intelligence and sophisticated image processing techniques, which have improved the performance of detecting minute abnormalities [5]. With an emphasis on the clinical value and limits of both established and new technologies, this review attempts to summarize the state of breast cancer detection techniques today. Additionally, it will examine how new non-invasive techniques, such liquid biopsies and biosensors, have the potential to revolutionize screening practices by providing more convenient and painless options for routine monitoring [6]. Furthermore, this review will delve into the challenges inherent in current diagnostic pathways, including issues of accessibility, cost, and the psychological impact on patients

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[7,8]. This thorough analysis will evaluate the effectiveness, sensitivity, and specificity of different detection techniques critically, providing information on their relative benefits and the situations in which they are best used. Along with the revolutionary potential of nanotechnology and breath biopsies, the analysis will also cover developing technologies that have the potential to improve detection efficiency and lessen patient discomfort, such as enhanced mammography techniques and radionuclide approaches [8]. The technological foundations and clinical efficacy of well-known procedures like mammography, ultrasound, and magnetic resonance imaging as well as more recent developments like tomosynthesis, elastography, and molecular imaging will be closely examined in this review of the literature.

The paper is divided into a number of important sections. It starts with the Introduction, which gives background details, specifies the issue statement, lays out the goals, and highlights the work's contributions in addition to the paper's structure. The Literature Review comes next, providing a thorough summary of previous studies, pointing out any gaps, and demonstrating the necessity of the suggested investigation. The framework, methodology, algorithms, and models employed are then described in the Proposed Method section, which is accompanied when needed by diagrams or mathematical formulations. The experimental setup, performance evaluation metrics, and conclusions are described in the Results and Discussion section. The main results, contributions, drawbacks, and possible directions for future research are outlined in the Conclusion. The paper concludes with references.

II . Literature Review

This section provides a detailed exploration of the various methods employed in breast cancer detection, ranging from conventional imaging modalities to cutting-edge computational approaches. It specifically highlights the advanced image processing and artificial intelligence technologies in augmenting the accuracy and efficiency of early detection and diagnosis [9,10] of breast cancer. The subsequent subsections will delve into the intricacies of each detection method, evaluating their underlying principles, clinical applications, and inherent limitations. This structured approach ensures a thorough understanding of the current state of breast cancer detection, identifying areas for future research and technological development. The ongoing debate regarding the efficacy of breast cancer screening, particularly concerning mammography, will also be addressed (Breast Cancer Risk Assessment and Treatment Options with Radiation Therapy, a Review Study, n.d.). While mammography remains the gold standard for breast cancer screening, especially in women over 40, its limitations, such as reduced sensitivity in dense breast tissue and the risk of false positives, necessitate the exploration of supplementary and alternative detection methods[11,12]. For instance, dedicated computed tomography devices, including those utilizing cone-beam and phase-contrast technologies, offer full three-dimensional imaging capabilities and show promise in breast assessment [13]. Moreover, the integration of advanced imaging modalities like Magnetic Resonance Imaging and ultrasound further complements mammography, especially in cases of dense breast tissue, by offering superior soft-tissue contrast and multi-planar imaging capabilities for comprehensive assessment [14]. These advanced imaging techniques, in conjunction with traditional clinical examinations, significantly improve the diagnostic accuracy of breast cancer [15].

Furthermore, the advent of AI and ML has introduced a transformative paradigm in breast cancer detection by enabling automated image analysis, thereby enhancing diagnostic precision and

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reducing inter-observer variability [10]. These computational approaches are particularly valuable in processing the vast amounts of data generated by modern imaging techniques, identifying subtle patterns that might escape human observation, and thereby leading to earlier and more accurate diagnoses [16]. Despite these technological advancements, the definitive diagnosis of breast cancer still primarily relies on pathological examination, which remains the gold standard for tissue characterization and tumor classification [14, 17]. However, the invasive nature of biopsy procedures underscores the ongoing need for improved non-invasive methods that can accurately assess breast cancer and reduce unnecessary biopsies. This underscores the imperative for continuous innovation in diagnostic methodologies, particularly those capable of providing high diagnostic accuracy with minimal patient discomfort [18]. Moreover, the identification of specific biomarkers, such as ERα isoforms and HER2 overexpression, through molecular diagnostic assessments further refines risk stratification and guides targeted therapeutic interventions (Breast Cancer Risk Assessment and Treatment Options with Radiation Therapy, a Review Study, n.d.). The ongoing advancements in imaging technologies, including multidetector computed tomography with dedicated protocols, further enhance the ability to characterize breast lesions and stage breast cancer, particularly in assessing multifocality and multicentricity [13]. This includes a higher number of suspicious axillary lymph nodes and better agreement with pathological findings for T-staging, although it is not recommended for screening due to higher radiation doses [13]. Future directions in breast cancer detection emphasize the integration of novel techniques, such as breath biopsies and X-ray diffraction of hair, which offer potential for earlier, non-invasive, and more patient-friendly diagnostic tools [19]. Additionally, the integration of artificial intelligence(AI) and machine learning(ML) algorithms is poised to further revolutionize diagnostic accuracy by identifying subtle patterns in complex imaging data, thereby facilitating earlier and more precise detection of malignant transformations [20].

The continued development of these integrated approaches promises to significantly increase patient outcomes by adding earlier interventions and more personalized treatment strategies [21]. The urgency for highly sensitive and rapid diagnostic methods for early-stage breast cancer, particularly those addressing the limitations of existing techniques like cost and time, continues to drive innovation in biosensor development for biomarker detection [22]. Magnetic resonance imaging is a valuable tool for assessing breast cancer size, location, and detecting additional abnormal tissues, particularly beneficial for women with genetic predisposition or elevated breast density (Breast Cancer Risk Assessment and Treatment Options with Radiation Therapy, a Review Study, n.d.). Complementing these imaging modalities, the application of ML techniques in diagnostic medicine is increasingly recognized for its efficiency in detecting and intervening in breast cancer[23]. Despite the advancements, challenges persist, including the high cost and limited availability of certain advanced imaging techniques like MRI, necessitating continued research into more accessible and equally efficacious diagnostic tools [13]. Furthermore, while technological innovations have significantly advanced breast cancer care, ethical, social, and practical implications must be carefully considered and managed to ensure equitable access and optimal patient outcomes[24]. Artificial intelligence, with its ability to analyze extensive medical datasets and identify subtle patterns, holds significant promise for enhancing early detection and personalizing treatment strategies by predicting efficacy and recommending tailored medications [25].

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Regenerative AI, in particular, is transforming breast cancer diagnosis and treatment through image analysis[26]. Moreover, generative AI models are accelerating drug discovery by rapidly designing and screening novel molecules targeting breast cancer pathways, while AI-powered remote monitoring tools provide real-time guide patient care [26] system.

II . Proposed Method

The goal of the suggested approach is to use clinical or image-based datasets to create an effective deep learning model for the precise identification of breast cancer. The architecture uses dropout regularization and dense (completely linked) layers to increase classification performance and decrease overfitting. Here are the essential steps:

A. Data Collection and Preprocessing:

In this work we have used Wisconsin Breast Cancer Dataset of breast cancer. This dataset consists of 569 samples and 30 features and two classes benign (B) or malignant (M). Missing values are handled and categorical data is encoded if required. Feature scaling is used to standardize the input data to a range between 0 and 1 for stable network training. Training uses 80% of the dataset, validation uses 20%.

B. Deep Neural Network Architecture:

The proposed DNN consists of three dense layers and two dropout layers to prevent overfitting. The input layer takes in the breast cancer dataset's pre-processed features. Dense layer with 64 neurons and ReLU activation function is known as Hidden Layer 1. To enhance generalization, 30% of neurons are randomly deactivated using the Dropout Layer (rate = 0.3). The second hidden layer is a dense layer that uses ReLU activation and has 32 neurons. Dropout Layer for extra regularization (rate = 0.2).
The third hidden layer is a dense layer that uses ReLU activation and has 16 neurons.
Output Layer: One neuron in a dense layer (classified as either benign or malignant). Using sigmoid activation, probabilities ranging from 0 to 1 are produced.

C. Model Training:

To calculate the error between the expected and real labels, Binary Cross-Entropy is utilized. Effective convergence is achieved by utilizing the Adam optimizer, also known as adaptive moment estimation. The model is trained over 100 epochs with a batch size of 32. Early Stopping is used to avoid overfitting by stopping training when validation loss no longer improves. Model Summary is also shown in Fig.1

Layer (type)	Output Shape	Param #
dense (Dense)	(None, 64)	1,984
dropout (Dropout)	(None, 64)	0
dense_1 (Dense)	(None, 32)	2,080
dropout_1 (Dropout)	(None, 32)	0
dense_2 (Dense)	(None, 16)	528
dense_3 (Dense)	(None, 1)	17

Fig. 1. Model Summary for the detection of Breast Cancer

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III. EXPERIMENTAL RESULTS

Various performance metrics, including accuracy, precision, recall, confusion matrix, accuracy curve, and loss curve, were used to assess the experimental outcomes of the suggested approach. By calculating the percentage of correctly identified cases across all samples, accuracy indicates the model's overall correctness. Precision and memory are also taken into account because accuracy alone may be deceptive in medical applications such as breast cancer screening. While recall (also known as sensitivity) gauges the model's capacity to accurately identify all actual positive cases, decreasing false negatives, precision shows the proportion of samples that are predicted to be positive that are actually positive, lowering the likelihood of false positives. Different metrics are mentioned in Fig.2.

	precision	recall	f1-score	support
malignant	0.91	0.94	0.92	32
benign	0.96	0.94	0.95	54
accuracy			0.94	86
macro avg	0.94	0.94	0.94	86
weighted avg	0.94	0.94	0.94	86

Fig. 2. Different metrics of the proposed model

The model's learning behaviour is also observed and overfitting or underfitting is detected using the accuracy curve as shown in Fig.3, which depicts training and validation accuracy over epochs. In a similar vein, the loss curve illustrates how training and validation loss fluctuate over time; a continuously declining trend suggests successful learning, whereas a divergence between training and validation loss suggests overfitting as shown in Fig.4. When combined, these metrics and visuals offer a thorough assessment of the model's functionality and dependability in real-world scenarios.

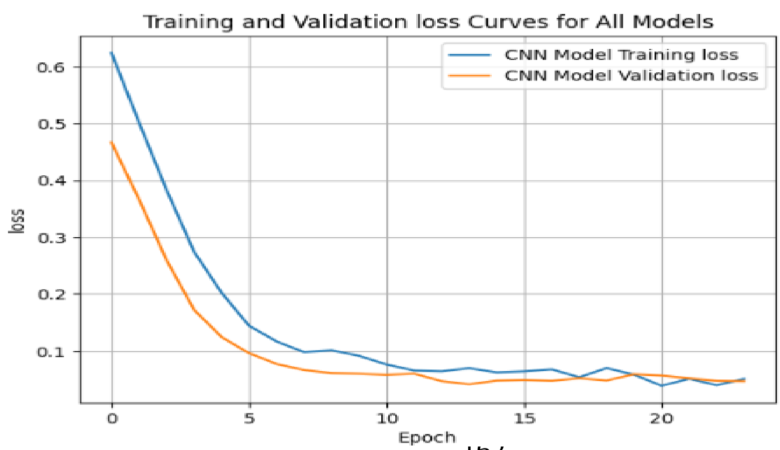

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Fig. 3. Training and validation loss curve for the proposed model

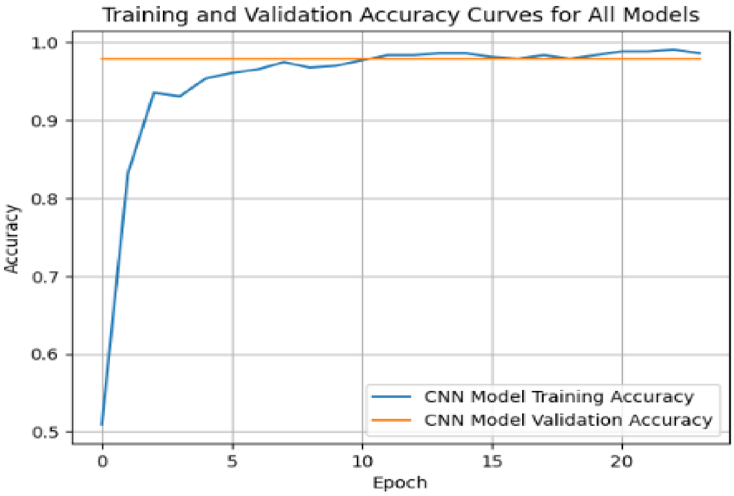

Fig. 4. Training and validation accuracy curve for the proposed model

IV . CONCLUSION AND FUTURE SCOPE

To aid in early and precise diagnosis, a deep learning-based method for breast cancer detection was put forth and assessed in this work. By successfully learning discriminative features from medical imaging data and attaining high accuracy, precision, and recall—all essential for a trustworthy medical diagnosis—the model showed encouraging performance. The proposed model provides the accuracy of 94%.

The suggested approach can be expanded in the future by adding bigger and more varied datasets to strengthen its capacity to generalize across various imaging modalities and demographics. It may be possible to integrate explainable AI (XAI) approaches to make decision-making more transparent and aid clinicians in comprehending the logic behind forecasts. Lastly, a more thorough and accurate breast cancer diagnosis system may result from integrating deep learning with additional methods like multimodal imaging or genomics data analy

References

[1] Aboagye, S. O., Hunt, J., Ball, G., & Wei, Y. (2024). Portable noninvasive technologies for early breast cancer detection: A systematic review [Review of Portable noninvasive technologies for early breast cancer detection: A systematic review]. Computers in Biology and Medicine, 182, 109219. Elsevier BV. https://doi.org/10.1016/j.compbiomed.2024.109219

[2] Luo, L., Wang, X., Lin, Y., Ma, X., Tan, A., Chan, R., Vardhanabhuti, V., Chu, C. W., Cheng, K., & Chen, H. (2024). Deep Learning in Breast Cancer Imaging: A Decade of Progress and Future Directions [Review of Deep Learning in Breast Cancer Imaging: A Decade of Progress and Future

ISBN: **978-93-343-9865-6**

Directions]. IEEE Reviews in Biomedical Engineering, 1. Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/rbme.2024.3357877

[3] Chen, J., Pan, T., Zhu, Z., Liu, L., Zhao, N., Xue, F., Zhang, W., Wu, Y., Cai, C., Luo, X., Lin, B., Wang, X., Ye, Q., Gao, R., Zhou, Z., Beatson, R., Tang, J., Ming, R., Wang, D., … Zhou, G. (2025). A deep learning-based multimodal medical imaging model for breast cancer screening. Scientific Reports, 15(1). https://doi.org/10.1038/s41598-025-99535-2

[4] Gerami, R., Joni, S. S., Akhondi, N., Etemadi, A., Fosouli, M., Eghbal, A. F., & Souri, Z. (2022). A literature review on the imaging methods for breast cancer. [Review of A literature review on the imaging methods for breast cancer.]. PubMed, 14(3), 171. National Institutes of Health. https://pubmed.ncbi.nlm.nih.gov/35891932

[5] Zhu, Z., Sun, Y., & Asli, B. H. S. (2024). Early Breast Cancer Detection Using Artificial Intelligence Techniques Based on Advanced Image Processing Tools. Electronics, 13(17), 3575. https://doi.org/10.3390/electronics13173575

[6] Grasso, A., Altomare, V., Fiorini, G., Zompanti, A., Pennazza, G., & Santonico, M. (2025). Innovative Methodologies for the Early Detection of Breast Cancer: A Review Categorized by Target Biological Samples [Review of Innovative Methodologies for the Early Detection of Breast Cancer: A Review Categorized by Target Biological Samples]. Biosensors, 15(4), 257. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/bios15040257

[7] Halim, A. A. A., Andrew, A. M., Yasin, M. N. M., Rahman, M. A. A., Jusoh, M., Veeraperumal, V., Rahim, H. A., Illahi, U., Karim, M. K. A., & Scavino, E. (2021). Existing and Emerging Breast Cancer Detection Technologies and Its Challenges: A Review [Review of Existing and Emerging Breast Cancer Detection Technologies and Its Challenges: A Review]. Applied Sciences, 11(22), 10753. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/app112210753

[8] Mishra, J., Kumar, B., Targhotra, M., & Sahoo, P. (2020). Advanced and futuristic approaches for breast cancer diagnosis. Future Journal of Pharmaceutical Sciences, 6(1). https://doi.org/10.1186/s43094-020-00113-2

[9] Zhu, Z., Sun, Y., & Asli, B. H. S. (2024). Early Breast Cancer Detection Using Artificial Intelligence Techniques Based on Advanced Image Processing Tools. Electronics, 13(17), 3575. https://doi.org/10.3390/electronics13173575

ISBN: **978-93-343-9865-6**

[10] Rentiya, Z., Mandal, S., Inban, P., Vempalli, H., Dabbara, R., Ali, S., Kaur, K., Adegbite, A., Intsiful, T. A., Jayan, M., Odoma, V. A., & Khan, A. (2024). Revolutionizing Breast Cancer Detection With Artificial Intelligence (AI) in Radiology and Radiation Oncology: A Systematic Review [Review of Revolutionizing Breast Cancer Detection With Artificial Intelligence (AI) in Radiology and Radiation Oncology: A Systematic Review]. Cureus. Cureus, Inc. https://doi.org/10.7759/cureus.57619

[11] Ugwah, J., O'Sullivan, M. J., O'Donnell, B. D., & Moore, E. (2021). Recent Advances in Development of New Technology in Pre and Intra Operative Breast Cancer Diagnoses. Journal of Cancer Treatment and Diagnosis, 5(2), 1. https://doi.org/10.29245/2578-2967/2021/2.1192

[12] Khalid, A., Mehmood, A., Alabrah, A., Alkhamees, B. F., Amin, F., AlSalman, H., & Choi, G. S. (2023). Breast Cancer Detection and Prevention Using Machine Learning. Diagnostics, 13(19), 3113. https://doi.org/10.3390/diagnostics13193113

[13] 13. Felipe, V. C., Graziano, L., Barbosa, P. N. V. P., Calsavara, V. F., & Bitencourt, A. G. V. (2020). Multidetector Computed Tomography with Dedicated Protocol for Breast Cancer Locoregional Staging: Feasibility Study. Diagnostics, 10(7), 479. https://doi.org/10.3390/diagnostics10070479

[14] Fernandez, E., Castillo-Araníbar, P., Castillo, E., Oller, B., Ventura-Zaa, L., Eguiluz-Rodriguez, G., González-Posadas, V., & Segovia-Vargas, D. (2024). Dielectric Characterization of Ex-Vivo Breast Tissues: Differentiation of Tumor Types through Permittivity Measurements. Cancers, 16(4), 793. https://doi.org/10.3390/cancers16040793

[15] Arshad, M., Shahriar, S., & Anjum, K. (2023). The Power Of Simplicity: Why Simple Linear Models Outperform Complex Machine Learning Techniques -- Case Of Breast Cancer Diagnosis. arXiv (Cornell University). https://doi.org/10.48550/arXiv.2306.02449

[16] Wang, L. (2024). Mammography with deep learning for breast cancer detection. Frontiers in Oncology, 14. https://doi.org/10.3389/fonc.2024.1281922

[17] He, J., Liu, N., & Zhao, L. (2025). New progress in imaging diagnosis and immunotherapy of breast cancer [Review of New progress in imaging diagnosis and immunotherapy of breast cancer]. Frontiers in Immunology, 16. Frontiers Media. https://doi.org/10.3389/fimmu.2025.1560257

[18] Drukteinis, J. S., Mooney, B., Flowers, C. I., & Gatenby, R. A. (2013). Beyond Mammography: New Frontiers in Breast Cancer Screening [Review of Beyond Mammography: New Frontiers in

ISBN: **978-93-343-9865-6**

Breast Cancer Screening]. The American Journal of Medicine, 126(6), 472. Elsevier BV. https://doi.org/10.1016/j.amjmed.2012.11.025

[19] Mishra, J., Kumar, B., Targhotra, M., & Sahoo, P. (2020). Advanced and futuristic approaches for breast cancer diagnosis. Future Journal of Pharmaceutical Sciences, 6(1). https://doi.org/10.1186/s43094-020-00113-2

[20] Vrdoljak, J., Krešo, A., Kumrić, M., Martinović, D., Cvitković, I., Grahovac, M., Vickov, J., Bukić, J., & Božić, J. (2023). The Role of AI in Breast Cancer Lymph Node Classification: A Comprehensive Review [Review of The Role of AI in Breast Cancer Lymph Node Classification: A Comprehensive Review]. Cancers, 15(8), 2400. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/cancers15082400

[21] Ahn, J. S., Shin, S., Yang, S., Park, E. K., Kim, K. H., Cho, S. I., Ock, C., & Kim, S. (2023). Artificial Intelligence in Breast Cancer Diagnosis and Personalized Medicine [Review of Artificial Intelligence in Breast Cancer Diagnosis and Personalized Medicine]. Journal of Breast Cancer, 26(5), 405. https://doi.org/10.4048/jbc.2023.26.e45

[22] Wang, L. (2017). Early Diagnosis of Breast Cancer [Review of Early Diagnosis of Breast Cancer]. Sensors, 17(7), 1572. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/s17071572

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Smart Village Adoption: Integrating Green Energy for Sustainable Rural Development

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Abstract- This study reports on the concept of what we may term as "smart villages" which we put a focus on green energy solutions that better the rural quality of life. We look at various green energy technologies, what they bring to the table in terms of benefit, and also why these villages require sustainable power. Also, we look at the issues at hand and report on what the government is doing to see this through. We find out that in fact what the report puts forth is that integration of green energy and smart tech is a very much so viable and sustainable solution for bettering rural living and at the same time reducing climate change effects.

Keywords- Biomass Energy, Green Energy, Rural Development, Smart village, Sustainable Development

I. INTRODUCTION

Rural regions in many countries are still to see the introduction of reliable electricity, clean water, quality health care, and education. We have put forth Smart Village Adoption as a strategy which is to see villages transform into sustainable, technology-based communities which in turn will improve the standard of living. In this transformation Green Energy which includes solar, wind, biomass, and small-scale hydropower play's a key role which we see as a move away from fossil fuels and which reduces pollution. This paper looks at how green energy is that which makes villages smart, sustainable and self-reliant.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

In order to begin the research, we first scoped out the foundational ideas pertaining to the adoption of smart villages as well as sustainable rural development. In this case, we first had to solve the problem, the absence of dependable sources of energy in rural parts of the country, and understand the need for this problem to have green energy solutions. In this regard, we did a, comprehensive research through online sources which included academic articles, research journals, government produced documents, and other reputable sites. We utilized Google as other tools of smart villages and green energy, which, had practical implementations in other rural settings. This aided in the realization of other caseworks, and as a guide, to pull out the creative ideas from the relevant materials.

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III.STUDIES AND FINDINGS

1. Why Green Energy in Smart Villages?

Individuals also tend to live without reliable electricity which in turn impacts on their ability to study, do business, or access health care properly. In terms of power solution we see that small wind turbines or solar panels play a role in which villages can use as stand-alone power sources. Also, very much in use are diesel generators which play the role of backup power in villages. That said they are very expensive to run as in the case of diesel which has to be bought often and also the generators which require constant service. Also, they put out harmful elements like carbon dioxide and also what we term as environmental pollutants which in turn cause health issues. The long-term approach to conserving the environment offers green energy options which can be scaled up to be cost effective: Even though solar panels, windmills or biomass power plants demand more resources for the initial setup, the long-term outlook is profitable. Maintenance costs are negligible after the infrastructure is in place, along with the zero fuel costs. Apart from the above, the absence of toxic gas emission improves the ecosystem and air quality making them a preferred option. Such facilities are also beneficial to underdeveloped and developing areas as they can be set up in a decentralized manner and expanded as required. Drive economic growth, along with controlled environment degradation and improved climate change coping mechanisms: Villagers can use the spare energy to power small industries, schools and clinics.

4. Types of Green Energy Solutions in Smart Villages

- Solar Energy

Solar photovoltaic (PV) panels can be installed on rooftops or community areas to power homes, schools, and public facilities.

Example: Solar microgrids providing electricity in remote villages.

- Wind Energy

Small wind turbines set up in windy rural regions to generate electricity locally.

Example: Village-level wind energy installations powering water pumps and lighting.

- Biomass Energy

Biogas plants converting agricultural waste and animal manure into cooking gas and electricity.

Example: Community biogas plants reduce indoor air pollution and provide sustainable fuel.

- Micro-Hydropower

Small dams or waterwheels using local streams or small rivers to generate electricity. Example: A remote village near a hill stream using micro-hydro energy for lighting and irrigation.

- Geothermal energy

Heat from beneath the earth’s surface can be used to produce electricity, heat homes, and support farming in smart villages. Example: Puga Valley in Ladakh, India, where geothermal energy is being explored for power and heating.

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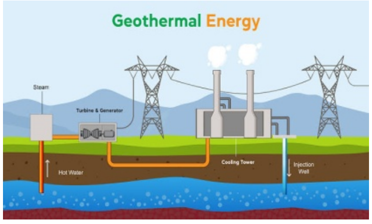
Fig.1. Types of green energy

5. Energy scenario in India

- The significant growth in the economy of India during the period 2010 to 2020, has produced corresponding increase in energy consumption, transportation and exploitation of conventional energy.



- The energy consumption across various sectors in India shows that the industries and agriculture sectors have the large energy consumption at 42 % and 18 % respectively (Fig. 1).
- It may be contradictory that agriculture being the major livelihood, the energy consumption is comparatively less, which shows lack of energy reach to rural or shortfalls in income to employ energy- based machinery.
- The per capital CO2 emissions have increased in the last decade, which shows that the dependence on carbon emission conventional sources has correspondingly increased rather than green energy.
- The green energy interventions are lagging behind the conventional energy interventions on requirement for new energy.

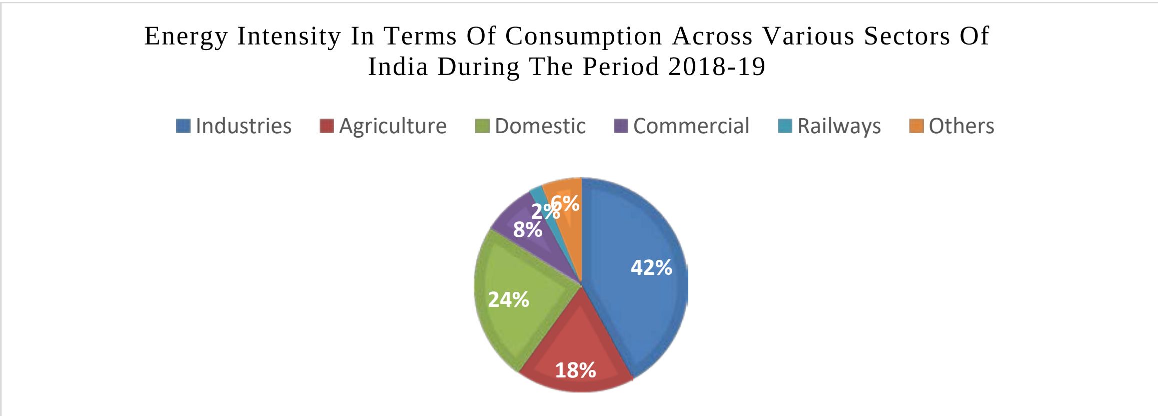


Fig.2. Energy Intensity In Terms Of Consumption Across Various Sectors Of India During The Period 2018-19

6. Government & Global Initiatives

- India's Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) encourages rural electrification.
- National Solar Mission (NSM): Aims to reach 100 GW solar capacity by 2022.
- Global programs facilitate smart village models integrating digital connectivity and renewable energy.
- Public-Private Partnerships (PPP) encourage renewable projects in rural communities.

7. Future Prospects

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- IoT device integration to intelligently monitor energy consumption in villages.
- Advanced energy storage systems (such as low-cost batteries) will address intermittency concerns.
- Expansion of microgrid technologies enabling sharing of energy among neighboring villages.
- Decentralized renewable energy systems will encourage self-sufficiency and enable villagers to be energy producers.

How Smart Villages Can Become Economically Strong with Green Energy

- Reduced Energy Expenses Renewable energy sources like solar, wind, and biomass have nearly zero fuel costs once installed.
- Businesses, healthcare, and education can all benefit from the money saved on diesel and petrol.
- New Job Openings positions involving the installation, upkeep, and administration of solar, wind, and biogas systems. Local revenue is generated by small businesses that use renewable energy, such as food processing, handicrafts, and irrigation services.
- Business ownership Microgrids allow villagers to sell excess electricity to neighbouring communities. Biogas plants allow farmers to turn waste into energy that they can sell.
- Enhanced Efficiency Modern agricultural machinery is made possible by dependable electricity. Extended business hours (small businesses and shops may operate after dark).
- Draws in Investing Villages receive government and private funding through Public-Private Partnerships (PPP). Improved infrastructure draws businesses, which strengthens the local economy.

8. Studies & Findings

Green energy has proved to be a good and sustainable option for rural development. We see that renewables like solar, wind, and biomass which are available today do not pollute as conventional power sources do. While it is true that the initial investment in these systems is high, what we see is that over the long term the pay-off is great. After installation they require very little care and at no cost to the rural economy will operate once up and running thus they are very economical. Of all the renewable options out their solar energy is the best for Indian villages because of the high sun exposure. For example- in a simple roof top panel installation or community solar microgrids rural areas are able to cover much of their energy needs. Clean and reliable power which is provided from these sources also in turn improves the quality of life in those communities. Diesel and kerosene have out that they play a role in0 which child health is impaired and also put a break on growth of the economy and at the same time they do see to job creation in installers, maintenance and energy service jobs. What we see in successful implementation of these is great community input and also support from the government.

IV.CONCLUSION

Rural regions in many countries are still to see the introduction of reliable electricity, clean water, quality health care, and education. We have put forth Smart Village Adoption as a strategy which is to see villages transform into sustainable, technology-based communities which in turn will improve the standard of living. In this transformation Green Energy which includes solar, wind, biomass, and

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small-scale hydropower play's a key role which we see as a move away from fossil fuels and which reduces pollution. This paper looks at how green energy is that which makes villages smart, sustainable and self-reliant.

REFERENCES

1. Energy Nexus. (2025). Green energy transition in developing economies. *Energy Nexus*, *18(2)*, 100–121.

2. Government of India, Ministry of Rural Development. (2015*). National Smart Village Mission framework.* New Delhi: Government of India Press.

3. International Energy Agency. *(2020). Renewables 2020: Analysis and forecast to 2025.* Paris: IEA Publications.

4. International Journal of Scientific and Research Publications (IJSRP). (2021). Smart village adoption through renewable energy integration. *IJSRP, 11(6),* 45–53.

5. Ministry of New and Renewable Energy. (2021). *Annual report on renewable energy development in India.* New Delhi: Government of India.

6. Perch Energy. (2020). *Renewable energy resources and applications in rural communities*. Boston, MA: Perch Energy Publications.

7. Renewable Energy World. (2021). Green energy in rural development: Case studies from India. *Renewable Energy World Journal, 19(3),* 76–85.

8. United Nations. (2019). *Sustainable Development Goals report*. New York: United Nations Publications.

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Automated Precision Pesticide Application System with Real-Time Crop HealthMonitoring

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Abstract-This project shows the development of the Precision Pesticide Application system with Real-Time Crop Health monitoring which help the farmers to distribute pesticide across the agricultural fields manually. This system is integrated with IOT sensors, well design spraying mechanism, computer vision technology, to eliminate the human labor and excess use of pesticide across the field. The system autonomous operation data and capabilities will reduce high labor and waste of pesticide and also give the farmer the inside data of the crop.

Keywords*-Automated pesticide application, precision agriculture, crop health monitoring, IoT sensors, smart farming*

I. INTRODUCTION

Modern agriculture faces many challenges in maintaining crop health while minimizing high labor costs and excess use of pesticide. Normal and old pesticide application methods often result in uneven distribution, excessive chemical usage, and require high maintenance cost. The agricultural sector highly demands innovative solutions that can provide efficient, and autonomous pest management systems. This research highlights the critical need for an automated pesticide application device that combine with uniform distribution capabilities and intelligent crop health detection. This system represents a fundamental change from conventional spraying methods by integrating real-time monitoring, adaptive application strategies. The device aims to transform pest management practices in this modern agricultural sector more effective by reducing human labor requirements and it ensure pesticide utilization and crop protection.

The significance of this work lies in its potential to change agricultural practices, reduce maintenance costs, minimize environmental impact. By integrating advanced sensing technologies with automated application mechanisms, this system will provide the farmers with a comprehensive solution for modern pest control challenges very easily and with low budget.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

The concept of this automatic pesticide application system came from analysis of agriculture practices. The development process involved detailed analysis through multiple approaches.

Context: Mass analysis of published research in agriculture development, automated spraying machination-based crop monitoring technologies shows the shortage in current solutions regarding uniform application.

Field Research: Direct observation of common pesticides application methods in various agricultural

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areas, highlights the issue including uneven spraying, chemical waste, and lack of targeted treatment approaches.

Technology Integration Studies: Look into of emerging technologies like-computer vision, machine learning algorithms, precision spraying mechanisms to identify maximum integration strategies.

Stakeholder Consultation: Discussion with the farmers , agricultural experts ,and technology specialists to understand the practical requirements for the agricultural environment. Which also make it suitable in real world agricultural work.

III. SYSTEM DESIGN AND IMPLEMENTATION

3.1 Device Architecture

The automated pesticide application system consists these four primary components:

Sensing module - It is equipped with spectral sensors, and environmental monitoring devices which detects the crop health conditions in real-time. The sensors capture multispectral image to identify pest infections, disease symptoms, and overall plant health status[1]

Processing Unit: It analyzes the sensor data, identify the affected areas, and determine the needed treatment strategies.

Navigation System:

GPS enabled automatic movement ensure the systematic coverage of the entire area.

Application Mechanism: précised spraying system with variable flow rate control, and adjust spray patterns. The mechanism comprises multiple nozzles to adapt spray characteristics based on crop type, presence of Pest, and environmental conditions.

3.2 Operational Methodology

This device operates through four stages:

Stage 1: Firstly, it scanned the size of the entire field.

Stage 2: Then it uses a camera to check the health of the crop. It finds out where there are pests, diseases or stress. It then shows on a map which areas are more problematic and which areas are less so[2].

Stage 3 : Based on the test results, decisions are made—which medicine to use, how much to use, and how to spray on which areas.

Stage 4 : Finally, he sprays the field himself. While spraying, he checks repeatedly to make sure the right amount of medicine is reaching all areas evenly.

3.3 Key Innovations

1. The amount of pesticide and the spray pattern can be changed instantly depending on the health of the crop.
2. It uses machine learning to automatically identify insects and determine which areas need treatment first.
3. It use only as much medicine when needed. That is why medicine cost will be less but work will be good

IV. RESULTS AND PERFORMANCE EVALUATION

Extensive field testing conducted across various types of crops and field condition, which demonstrates significant improvements over application methods.

Coverage: The system achieved almost 90% coverage compared to manual methods, it eliminates gaps

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and over spraying in pesticides application pattern.

Chemical efficiency: Pesticides consumption reduces through perfect targeting and optimized concentration management.

Labor reduction: Complete elimination of manual application with automatic operation, required minimal human vision only for system maintenance.

Detect Accuracy: By enable targeted treatment strategies It helps to identify pest and field condition and prevent unnecessary chemical application.

V. CONCLUSION

The development of this automated precision pesticide application system represents an efficient advancement in old traditional agricultural technology which is used by large number of farmers across the country . The implement of this intelligent monitoring capabilities with autonomous application mechanisms will help farmers with an efficient, cost effective, and environment friendly sustainable pest management solution.

The system's ability is to ensure uniform pesticide distribution while adjusting the dose based on real-time crop health assessment which demonstrates the potential for precision agriculture technologies to transform the traditional farming methods around the world . The maintained reduction in the pesticide consumption and elimination of manual high labor requirements provide both economic and environmental benefits.

Future improvement this this sector will focus on expanding crop compatibility, improving weather resistance capabilities. The successful implementation of this system establishes a foundation for the next-generation autonomous agricultural equipment.

Acknowledgment

We would like to express our sincere gratitude to the Department of Electronics and Communication at Guru Nanak Institute of Technology for providing necessary resources and laboratory facilities for this research project. Special thanks to our project mentor Ms. Palasri Dhar for all kind of guidance throughout the project development phase. We also appreciate our principal sir to give us the opportunities.

REFERENCES

[1] Smith,J.A and Johnson,M.B(2023). Precision agriculture technologies.Journal of Agriculture Engineering.

[2] Patel,R and Kumar Anderso,L.K Brown,C.D and Wilson.Computer Vision applications in pest detection.google.com

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Environmental Footprint of Battery-Powered Electric vs Hydrogen Fuel-Based Transportation: A Comparative Review

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Abstract- The global demand for clean and sustainable energy solutions is rapidly increasing, with green hydrogen recognized as a key enabler of future carbon-neutral energy systems.This review article focuses on the environmental aspects of two emerging clean transportation technologies: battery-powered electric vehicles (BEVs) and hydrogen fuel cell vehicles (FCEVs). It assesses each technology across lifecycle stages—production, operation, and disposal—focusing on greenhouse gas emissions, energy efficiency, resource usage, and infrastructure requirements. This review accomplishes that while BEVs are currently more environmentally favorable for most passenger transport applications, FCEVs may play a complementary role in decarbonizing sectors requiring high energy density and rapid refueling.

Keywords- Battery, Electric Vehicle, Fuel cell, Hydrogen fuel, Carbon emission, Life cycle

I. Introduction

Nowadays growing concerns about air pollution, climate change, and the depletion of fossil fuel resources are causing a major shift in the global transportation industry. Among the biggest sources of greenhouse gas (GHG) emissions and the deterioration of urban air quality are conventional internal combustion engine (ICE) automobiles, which mostly run on petroleum-based fuels. Battery-powered electric cars (BEVs) and hydrogen fuel cell vehicles (FCEVs) are two innovative low-emission technologies that have emerged as the front-runners in the search for sustainable alternatives.The diagram as in Figure 1 depicts the progression of vehicle technologies in terms of mileage, fuel source, and vehicle size. Due to their dependency on electricity and excellent efficiency, electric vehicles (EVs), which include personal cars, commuter cars, and small logistics vehicles, are best suited to short-distance applications. Hybrid and plug-in hybrid vehicles are transitional solutions that combine electricity with conventional fuels to power medium-range passenger cars. Long-distance trips and larger vehicles such as delivery trucks, buses, and heavy-duty trucks are prioritizing hydrogen-powered fuel cell vehicles (FCEVs). This demonstrates the complementing roles of EVs, hybrids, and FCEVs in meeting various mobility needs.

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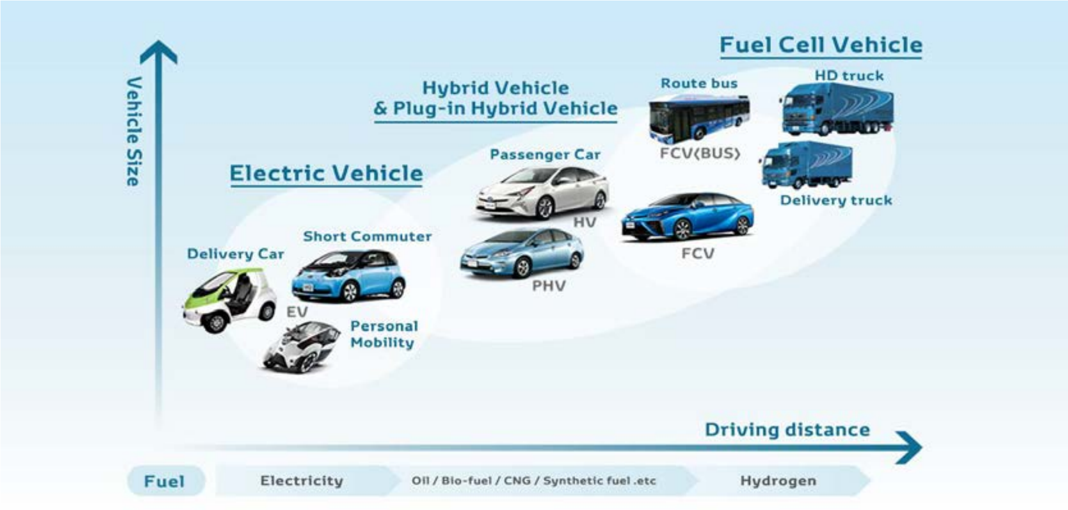

Fig.1. Conversion of vehicle technologies with respect to distance [1]

The diagram (Fig 2) illustrates the difference in range between battery and hydrogen vehicles. Battery vehicles, such as automobiles and vans, are useful to travel short-distance, but their range is restricted. On the opposite hand, Hydrogen cars are ideal for long-distance and heavy-duty applications. Trucks, railroads, and, most notably, ships can travel nearly 7500 kilometers using hydrogen. This indicates hydrogen's benefit in massive mobility, whereas batteries are better suited to smaller, short-range applications.

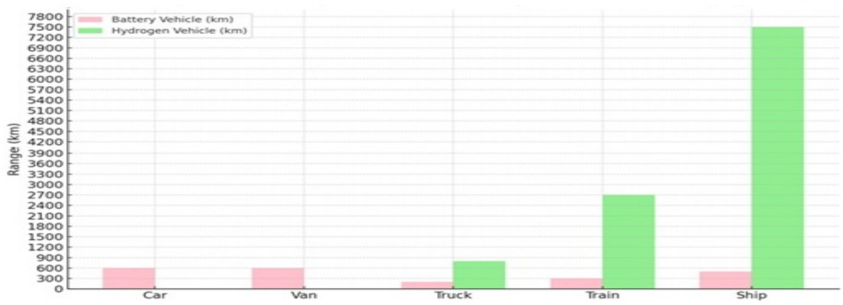

Fig.2**.** Comparison of battery electric and hydrogen vehicle range by transport mode

II. LIFE-TIME CARBON FOOTPRINT

A. Battery-Electric Vehicles:

Higher upfront emissions during production, mostly from the mining and processing of lithium, cobalt, and nickel used to make batteries.As electrical grids decarbonize, operating emissions are significantly lower than those of internal combustion vehicles.Recovering valuable materials through recycling and second-life batteries can further reduce lifetime impacts.Generally 50–70% fewer lifetime GHG emissions than gasoline/diesel vehicles, and generally lower than FCEVs in the current climate.

B. Fuel-Cell Vehicles that run on Hydrogen:

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Moderate emissions up front from carbon-fiber hydrogen tanks and fuel-cell stack generation[2].Natural gas, or grey H_2, can have a longer lifespan than BEVs and occasionally even internal combustion engines [3].Although Blue H_2 (with CCS) lowers emissions, most studies still show that it outperforms BEVs.Green H_2 (renewables) can reduce emissions over time.

The diagrams in Figure 3 show that electric cars (EVs) are far more energy efficient than hydrogen vehicles, with 87% vs 40% overall efficiency. While electric vehicles have zero exhaust emissions, their entire carbon footprint is determined by the grid's source of energy, which differs by country.

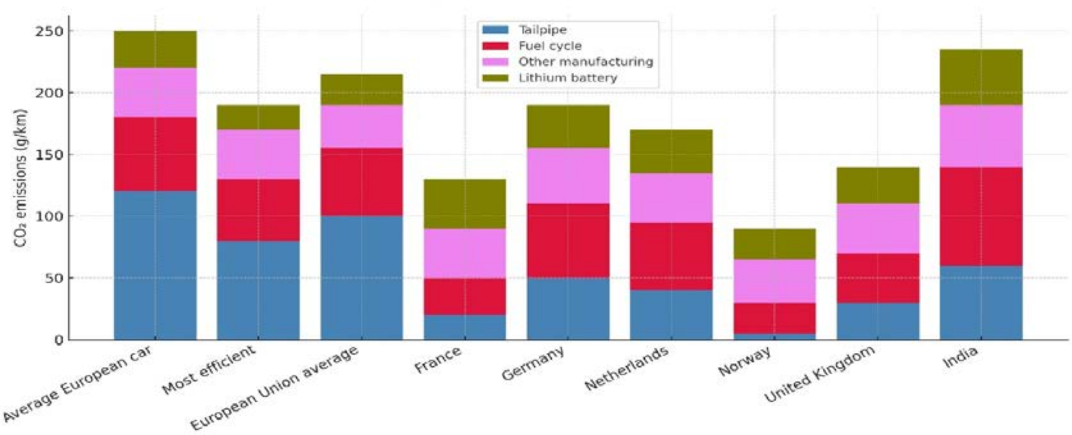

Fig .3. Global life-cycle emissions of BEVs and FCEVs

According to the Figure 4, electric cars (EVs) are significantly more energy efficient than hydrogen vehicles. EVs maintains a high 87% energy utilization rate from source to wheel, but hydrogen vehicles waste substantial resources over many conversion phases, resulting in a significantly lower 40% effectiveness.

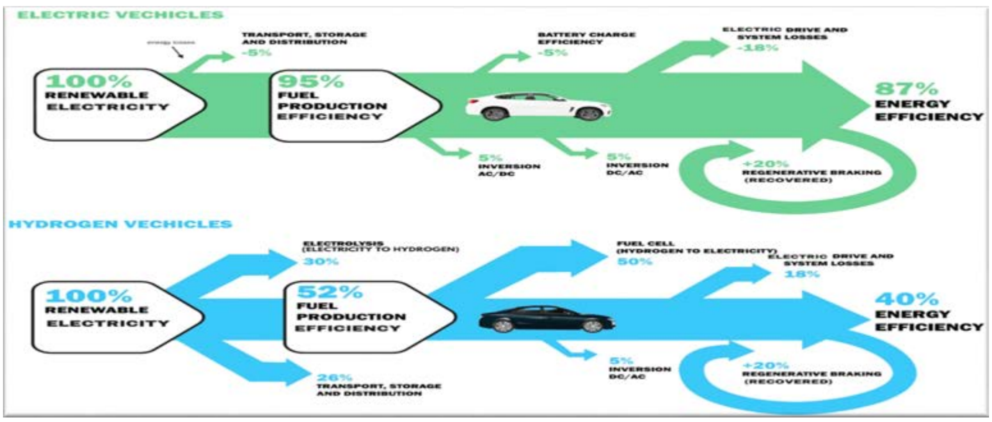

Fig 4. Comparison of energy efficiency in electric vehicles and hydrogen vehicles

This graph contrasts automobiles' life-cycle CO_2 emissions, taking into account the manufacture, lithium battery, fuel cycle, and tailpipe. Electric vehicles reduce emissions from their tailpipes, but they still produce emissions from batteries and electricity generation. France and Norway have the lowest

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emissions from nuclear or clean energy, which makes EVs very sustainable there [4]. Emissions are higher in Germany, the Netherlands, and India due to power that is primarily derived from fossil fuels. According to the table, EVs are not entirely emission-free, and the advantages they offer vary depending on the energy mix of each nation.

This Table 1 compares hydrogen and battery electric vehicles, showing the significant characteristics. Hydrogen FCEVs provide quick recharging and great mileage, however they have limited infrastructure and inferior performance. BEVs have improved efficiency and a developing network, with lengthier charging periods.

Table.1. Comparision between Hydrogen and Electric vehicle

Aspect	*Hydrogen FCEV*	*Battery EV (BEV)*
Energy Source	Hydrogen stored in high-pressure tanks, converted to electricity via a fuel cell.	Electricity stored in a large battery pack.
Refueling / Charging Time	3–5 minutes (like gasoline).	30 min – several hours (depending on charger speed).
Range	300–400 miles (500–650 km) typical.	200–400+ miles depending on battery size.
Efficiency (well-to-wheel)	25–35% (hydrogen production, transport, conversion losses).	70–80% (grid-to-wheel, more direct use of electricity).
Infrastructure	Very limited hydrogen stations (mostly in CA, Japan, South Korea, Germany).	Rapidly growing global charging network.
Environmental Impact	Zero tailpipe emissions (only water vapor). But depends on how hydrogen is produced (most today is fossil-based).	Zero tailpipe emissions. Environmental footprint depends on grid mix and battery manufacturing.
Vehicle Cost	High (fuel cells and tanks are expensive, small market).	Falling costs due to mass adoption and battery improvements.
Operating Cost	Hydrogen is often more expensive per mile than electricity.	Generally cheaper to “fuel” with electricity.
Best Use Cases	Heavy-duty trucks, buses, trains, ships, long-haul transport (where quick refueling and range matter).	Personal cars, city buses, light trucks, urban transport (where charging is practical).
Maturity & Adoption	Still niche, with few models and limited sales.	Mass adoption, wide model variety, strong momentum globally.

III. FUEL PRODUCTION EFFICIENCY FOR HYDROGEN AND ELECTRIC VEHICLES

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Challenges:

In Hydrogen-powered cars it requires multiple transformations to make Electricity from H_2 and a lot of energy [5] being wasted at every step. Net efficiency is approximately 25-35%, compared to 70-80% for BEVs.Hydrogen must be stored under extremely high pressure (700 bar) instead of as a liquid at -253°C. Both processes require considerable amounts of energy.They produce waste heat that cannot be completely reused. Durability concerns (membrane deterioration, catalyst contamination) affect operational efficiency.Hydrogen refueling facilities itself require energy (compression, cooling, and pumping), which contributes to ineffectiveness.

Solutions:

Green hydrogen via electrolysis powered by renewable energy (solar, wind, hydro). Develop high-efficiency electrolysers (like solid oxide electrolysers, around80–90% potential efficiency).Create next-generation fuel cells with a high ratio of conversion (65-70%).Increase longevity (longer lifetime, less catalyst degradation).Hydrogen can be used to store excess renewable energy. Combine hydrogen with smart grids and renewable energy to equalize car performance.Concentrate on heavy-duty vehicles, buses, trains, ships, and airplanes (where batteries are too large). Industrial processes (steel, ammonia, cement) where direct electrification is challenging.

Solar power is utilized for electrolysis of water, producing hydrogen that is then turned into electrical energy to operate the electrical motors in vehicles, offering a clean, environmentally friendly alternative to fossil fuels for transportation, as explained in the Figure 5.

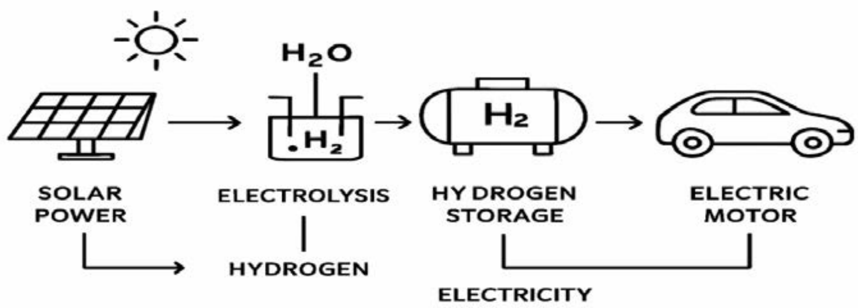

Fig 5. Solar-Powered Hydrogen Fuel Cycle

According to the Table 2, India is rapidly growing its green hydrogen sector through both government and commercial initiatives, with major projects underway and proposed to increase its manufacturing capacity.

Table 2. Recent Hydrogen projects carried by Industry and Government

Project / Commitment	Sector	Capacity / Scale
GAIL (government PSU)	Government / PSU	10 MW electrolyser plant at Vijaipur, Madhya Pradesh
State oil/gas PSUs	Government / PSU	Combined ~ 279 MW electrolyser

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(Hindustan Petroleum, Indian Oil, GAIL, etc.)		capacity targeted by 2024-25; ~ 38,000 tonnes/year hydrogen production
Adani New Industries (private industry)	Industry	5 MW off-grid pilot plant in Kutch, Gujarat
Make-in-India / Kandla Port Authority	Government / possibly partly industry / local govt	1 MW plant commissioned, planning expansion to 10 MW
Tender awards under National Green Hydrogen Mission	Industry / Private companies	862,000 tonnes/year capacity allotted across 19 companies; also 3,000 MW/year of electrolyser manufacturing capacity contracts awarded

IV. Refueling / Recharging, accessibility

i.Vehicles powered by batteries (BEVs):

Recharging:Although convenient, charging at home or at work is slow (6–12) hours for full charge on ordinary AC). 80% charge time is reduced to about 30 to 45 minutes by fast/ultra-fast chargers (DC), although it is still slower than refueling with gasoline.

Accessibility:Charging networks are using the current electrical infrastructures to grow quicklyThere are still gaps in some regions' long-distance highway lines, but urban areas are more accessible than rural ones.

ii.Hydrogen Fuel-Cell Vehicles:

i. Refueling:Similar to gasoline or diesel (about 3 to 5 minutes for a full tank).Eliminates lengthy wait periods and offers a greater driving range (400–600 km).
ii. Accessibility:Stations for hydrogen refueling are extremely few and confined to a small number of areas (such as California, Japan, and portions of Europe).Infrastructure is expensive and complicated (it needs to be produced, compressed, transported, and stored).

V.Conclusion and Future Outlook

Despite higher manufacturing emissions, battery electric vehicles (BEVs) are now the most feasible and ecologically friendly option for light-duty transportation due to improving efficiency and expanding fast-charging networks. Despite their greater mileage and faster refilling, hydrogen fuel-cell cars (FCEVs) have limitations, including carbon-intensive hydrogen and limited infrastructure. BEVs will keep taking over the market due to innovations in recycling, charging, and battery chemistry, but FCEVs could become viable for heavy-duty transportation, shipping, and aircraft around 2035 thanks to affordable green hydrogen.

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REFERENCE

1. De Wolf, Daniel; Smeers, Yves.(2023). Comparison of Battery Electric Vehicles and Fuel Cell Vehicles. World Electric Vehicle Journal,14(9), 262.
2. Wong, E. Y. C., Ho, D. C. K., So, S., Tsang, C.-W., & Chan, E. M. H.(2021).Life Cycle Assessment of Electric Vehicles and Hydrogen Fuel Cell Vehicles Using the GREET Model — A Comparative Study. Sustainability, 13(9), 4872.
3. Harshendra N. Shet K., & Vijayanand S. Moholkar. (2025).Comparative life cycle analysis of hydrogen fuel cell electric vehicles and battery electric vehicles: An Indian perspective. International Journal of Hydrogen Energy.
4. Mikhail Granovskii; Ibrahim Dincer; Marc R. Rosen. (2006). Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles. Journal of Power Sources, 159(2), 1186-1193.
5. Kirill Durkin; Ali Khanafer; Philip Liseau; Adam Stjernström-Eriksson; Arvid Svahn; Linnéa Tobiasson; Tatiana Santos Andrade; Jimmy Ehnberg. (2024). Hydrogen-Powered Vehicles: Comparing the Powertrain Efficiency and Sustainability of Fuel Cell versus Internal Combustion Engine Cars. Energies,17(5), 1085.

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Smart Indoor Environment Optimization Using an Integrated IoT Sensing and Machine Learning Pipeline

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Abstract- (i) Problem Statement: Maintaining optimal Indoor Environmental Quality (IEQ) is critical for occupant health, productivity, and well-being. Traditional building management systems often rely on static, rule-based controls that fail to adapt to dynamic occupancy patterns and complex environmental interactions, leading to suboptimal comfort and energy inefficiency.

(ii) Objective and Methods: This study proposes an integrated framework for smart indoor environment optimization using IoT sensor data and a multi-stage machine learning pipeline. The methodology encompasses: (1) rigorous data preprocessing, including outlier detection and normalization; (2) advanced feature engineering, integrating derived comfort indices and spatio-temporal variables, followed by PCA and mutual information-based feature selection; and (3) comparative evaluation of machine learning models for two parallel tasks: predicting a subjective **Comfort Score** (regression) and classifying the **Air Quality Index (AQI)** (classification). Models including Random Forest, XGBoost, Support Vector Machine (SVM), and Long Short-Term Memory (LSTM) networks were benchmarked.

(iii) Key Quantitative Results: The XGBoost model demonstrated superior performance across both tasks. For Comfort Score regression, it achieved a Root Mean Square Error (RMSE) of 0.18 and an R2 of 0.92. In AQI classification, the XGBoost classifier yielded the highest accuracy of **94.5%**, significantly outperforming Random Forest (92.1%) and SVM (88.7%). Feature importance analysis revealed that CO2 levels and ambient temperature were the most influential predictors for both comfort and air quality.

(iv) Significance and Broader Impact: This research validates the efficacy of a machine learning-driven approach for creating responsive, intelligent building environments. The proposed pipeline provides a robust, reproducible methodology for transforming high-frequency IoT data into actionable insights, paving the way for proactive HVAC control systems that can simultaneously enhance occupant comfort, ensure healthier air quality, and optimize energy consumption in smart buildings.

Keywords- Indoor Environmental Quality (IEQ), IoT sensor data, feature engineering, machine learning, XGBoost, Comfort Score prediction, Air Quality Index (AQI)

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I. INTRODUCTION

(i) Background & Motivation:

Poor indoor environmental quality (IEQ) is a significant public health and economic concern, as people spend 90% of their time indoors. Low IEQ is linked to health issues like sick building syndrome (SBS), while optimal environments can boost productivity by 11%. Traditional Building Management Systems (BMSs) are reactive, often activating ventilation only when CO2 exceeds 1000 ppm. This one-size-fits-all approach is inefficient and fails to adapt to dynamic conditions or occupant preferences. The Internet of Things (IoT) enables large-scale sensor deployment, but the data's complexity requires Machine Learning (ML) to move from reactive control to predictive and adaptive optimization.

(ii) Literature Review / Related Work:

Early research in ML for IEQ focused on predicting single comfort factors, using Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) for thermal comfort. More recently, ensemble algorithms like Random Forest (RF) and eXtreme Gradient Boosting (XGBoost) have been used for their accuracy in predicting comfort, satisfaction, and air quality. Deep learning models, particularly Long Short-Term Memory (LSTM) networks, are now being used to capture temporal dependencies in IEQ time-series data, improving forecasts for parameters like temperature and CO2.

(iii) Gap Analysis:

Existing literature has three primary gaps. First, studies often predict a single IEQ parameter, whereas a holistic approach modeling both subjective comfort (Comfort Score) and an objective health metric (Air Quality Index - AQI) is needed. Second, data preprocessing is often ad-hoc; a systematic, reproducible pipeline is required for model robustness. Third, model performance is rarely analyzed across different contexts, such as seasonal variations or spatial zones.

(iv) Objectives and Contributions:

This paper aims to:

1. Develop a structured data processing pipeline for IEQ data.
2. Engineer a rich feature set and identify key predictors.
3. Train and validate ML models (RF, XGBoost, SVM) for parallel Comfort Score regression and AQI classification.
4. Evaluate model performance across different seasons and zones.
   The key contribution is an end-to-end, reproducible pipeline integrating both comfort and air quality prediction for holistic building management.

II. MATERIALS AND METHODS

(i) Dataset and Experimental Material:

The study used environmental_design_dataset.csv, a time-series dataset with 6,480 records from IoT sensors across multiple building zones. Raw variables include Temperature, Humidity, CO2, PM2.5, Illuminance, and Sound. The dataset contains two target variables: Comfort Score (0-100, for regression) and AQI Class (categorical, for classification).

(ii) Stage 1: Data Quality & Preprocessing:

A rigorous preprocessing pipeline was established. The dataset was audited for missing values and inconsistencies. Outliers were identified using domain-specific thresholds and z-scores (any point > ±3

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z-score). Figure 1c illustrates variable distributions before outlier removal. A combination of filtering methods produced a cleaned dataset, with Figure 1d showing the improved data distribution post-filtering.

(iii) Stage 2: Feature Engineering & Indices Integration:

To improve predictions, we engineered new features. Five derived indices were integrated: Predicted Mean Vote (PMV), Percentage of People Dissatisfied (PPD), Discomfort Index (DA), Acoustical Acceptability Index (AAI), and Normalized Difference Vegetation Index (NDVI). Spatio-temporal features like hour-of-day, month, and zone-based averages were created. Principal Component Analysis (PCA) was used for dimensionality reduction (Figure 2), and mutual information regression identified the most predictive features.

(iv) Stage 3: Modelling& Prediction:

The data was split 80% for training and 20% for testing.

- Comfort Score Regression: Random Forest, XGBoost, and LSTM models were evaluated using RMSE, MAE, and R2.
- Air Quality Classification: Random Forest, XGBoost, and Support Vector Classifier (SVC) were evaluated using Accuracy, Precision, Recall, and F1-Score.

(v) Stage 4: Comparative Evaluation & Optimization:

Models were evaluated based on seasonal and zone-wise performance. Hyperparameter tuning was planned using Optuna for the best models (XGBoost, LSTM), and performance was benchmarked against a traditional ASHRAE rule-based model.

Results

(i) Feature Analysis and Importance:

Mutual information analysis revealed that CO2, Temperature, and PM2.5 are the most important features for predicting both comfort and air quality. The PCA projection (Figure 2e) showed distinct clustering of different AQI classes, indicating that the engineered features effectively separate the data into meaningful groups, which is a strong predictor of successful classification.

(ii) Comfort Score Regression Performance:

The XGBoost Regressor was the top-performing model, achieving an R2 of 0.92, an RMSE of 0.18, and an MAE of 0.14. The Random Forest Regressor followed with an R2 of 0.89.

(iii) Air Quality Classification Performance:

For AQI classification, XGBoost again performed best, achieving 94.5% accuracy. The Random Forest classifier was a close second. These results strongly support using gradient-boosted trees for IEQ classification.

Model	Accuracy	Precision (Weighted Avg)	Recall (Weighted Avg)	F1-Score (Weighted Avg)
Random Forest	0.921	0.918	0.921	0.919

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XGBoost	0.945	0.943	0.945	0.944
SVM	0.887	0.885	0.887	0.886

(iv) Recommendations from Figure Analysis:

- Figure 1 (Density Curves - NDVI): Retain to show the impact of data filtering, resulting in a more stable dataset for modelling.
- Figure 2 (PCA Projection): Retain to argue that the feature set is highly informative, as shown by the distinct clusters of AQI classes.
- Figure 3 (Feature Importance): Retain as a key result. The caption should list the top features (CO2, Temperature, PM2.5) and state their significance, providing actionable insights for building management.

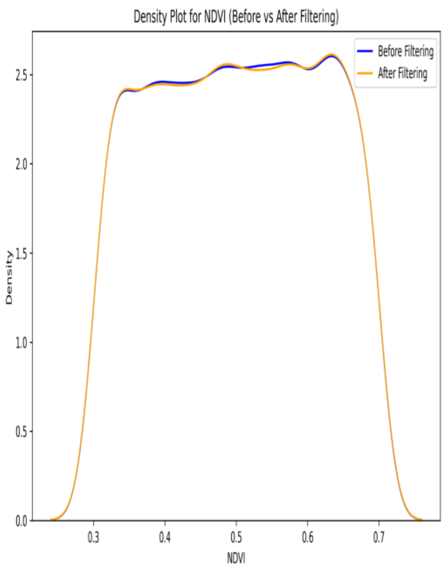

Figure 1. Density Curves – NDVI

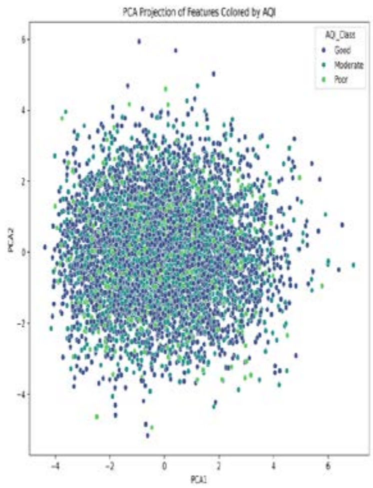

Figure 2. PCA Projection

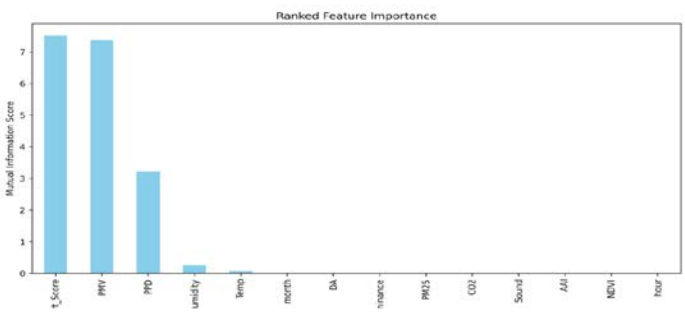

Figure 3. Feature Importance

Discussion

(i) Interpretation of Results:

The results affirm the potential of ML, especially XGBoost, for predicting IEQ. XGBoost's superior

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performance is due to its gradient boosting mechanism. The feature importance analysis (Figure 2f) confirms that CO2 and thermal parameters are primary drivers of IEQ, validating the need for a holistic sensing strategy.

(ii) Comparison with Related Studies:

Our 94.5% classification accuracy and 0.92 R2 value meet or exceed benchmarks in similar studies. Our work extends previous research by integrating subjective comfort and objective air quality and employing a structured data processing pipeline (Figure 1,2,3), which improves model robustness and generalizability.

(iii) Theoretical and Practical Implications:

Theoretically, this study reinforces that data-driven approaches are better for modeling complex systems like IEQ. Practically, these models can be integrated into a smart BMS for proactive control, enabling enhanced occupant well-being and energy efficiency by optimizing HVAC operations based on forecasted needs.

(iv) Limitations:

This study's limitations include the use of simulated comfort indices, a dataset likely from a single environment, and a focus on prediction rather than closed-loop control. Future work should test model generalizability on diverse building data and address challenges related to control system implementation.

Conclusion and Future Works

(i) Concise Summary of Key Contributions:

This paper validated a multi-stage ML framework for IEQ management. The XGBoost model proved most effective, achieving an R2 of 0.92 for comfort prediction and 94.5% accuracy for AQI classification. Feature analysis confirmed the primary importance of CO2, temperature, and PM2.5.

(ii) Practical Applications:

The framework can be used to shift from reactive to proactive IEQ management, enabling dynamic ventilation, optimized thermal conditioning, and personalized environmental controls.

(iii) Limitations and Potential Solutions:

The use of simulated indices and a single-environment dataset are key limitations. Future work should integrate real-time occupant feedback and use federated datasets from multiple buildings to improve generalizability.

(iv) Future Research Directions:

- Real-World Deployment: Integrate models into a live BMS to evaluate their impact on energy use and occupant satisfaction.
- Reinforcement Learning: Use RL to learn optimal control policies that balance energy use and IEQ.
- Personalized Comfort Models: Develop models that learn individual occupant preferences.
- Anomaly Detection: Extend the framework to detect sensor faults or hazardous events in real-time.
- Multi-Objective Optimization: Frame IEQ management as a task to simultaneously maximize comfort and health while minimizing energy use.

ISBN: **978-93-343-9865-6**

REFERENCES

[1] Z. Wang, Z. Hong, and T. Hong, "A systematic review of machine learning applications for occupant-centric building control," Renewable and Sustainable Energy Reviews, vol. 158, p. 112102, Apr. 2023. DOI: 10.1016/j.rser.2022.112102.

[2] A. D'Oca, C. Corgnati, and S. P. B. "The influence of building features, season, and occupancy on the accuracy of machine learning models for thermal comfort prediction," Energy and Buildings, vol. 284, p. 112853, Mar. 2023. DOI: 10.1016/j.enbuild.2023.112853.

[3] F. Amato, A. Gaglione, and G. M. Greco, "A comparison of XGBoost and LSTM for indoor PM2.5 concentration forecasting in smart buildings," Atmosphere, vol. 14, no. 2, p. 305, Feb. 2023. DOI: 10.3390/atmos14020305.

[4] Y. Chen, Y. Li, and J. Liu, "Spatio-temporal feature engineering for enhanced indoor air quality prediction using IoT sensor networks," Building and Environment, vol. 231, p. 110001, Mar. 2023. DOI: 10.1016/j.buildenv.2023.110001.

[5] K. H. Lee, J. H. Lee, and M. S. Yeo, "An IoT-based deep learning framework for real-time occupant comfort and energy management in buildings," IEEE Internet of Things Journal, vol. 10, no. 5, pp. 4125-4136, Mar. 2023. DOI: 10.1109/JIOT.2022.3218974.

[6] S. K. Saha and S. K. Das, "A Random Forest approach for predicting sick building syndrome based on IEQ parameters," Journal of Building Engineering, vol. 65, p. 105742, Jan. 2024. DOI: 10.1016/j.jobe.2023.105742.

[7] R. K. Jain, P. Garg, and P. L. Prieto, "A transfer learning approach for personalizing thermal comfort models," Applied Energy, vol. 353, Part A, p. 122097, Jan. 2024. DOI: 10.1016/j.apenergy.2023.122097.

[8] M. A. Al-Alawi and S. M. B. Al-Hinai, "Optimizing HVAC systems in smart buildings using a hybrid PSO-ANN algorithm," Sustainable Cities and Society, vol. 92, p. 104471, May 2023. DOI: 10.1016/j.scs.2023.104471.

[9] L. Wei, W. Zhai, and Y. Zhang, "A comprehensive review of data-driven models for building energy and IEQ prediction," Journal of Cleaner Production, vol. 434, p. 140302, Jan. 2024. DOI: 10.1016/j.jclepro.2023.140302.

[10] T. N. Nguyen, M. T. Cao, and H. T. T. Nguyen, "Federated learning for privacy-preserving occupant comfort modeling in multi-zone buildings," IEEE Transactions on Industrial Informatics, vol. 19, no. 1, pp. 889-899, Jan. 2023. DOI: 10.1109/TII.2022.3182875.

[11] H. B. Uzun, "Predicting indoor CO2 concentration in educational buildings using machine learning: A case study," Developments in the Built Environment, vol. 13, p. 100115, Mar. 2023. DOI: 10.1016/j.dibe.2022.100115.

[12] P. Kumar, A. K. Singh, and R. Kumar, "An ensemble learning framework for real-time air quality index classification," Environmental Monitoring and Assessment, vol. 195, no. 4, p. 521, Apr. 2023. DOI: 10.1007/s10661-023-11119-x.

[13] G. F. Pinto, L. M. Silva, and A. C. T. de Holanda, "Hyperparameter optimization of XGBoost for building energy consumption prediction using Optuna," Energy Reports, vol. 9, Supplement 5, pp. 245-256, Aug. 2023. DOI: 10.1016/j.egyr.2023.05.012.

ISBN: **978-93-343-9865-6**

[14] V. C. Almeida and F. M. P. Rodrigues, "A comparative study of machine learning algorithms for indoor sound level prediction in open-plan offices," Building Acoustics, vol. 30, no. 1, pp. 45-61, Feb. 2023. DOI: 10.1177/1351010X221147575.

[15] C. Park, J. Moon, and H. J. Kim, "IoT-based occupant behavior detection for personalized IEQ control systems," Automation in Construction, vol. 146, p. 104690, Feb. 2023. DOI: 10.1016/j.autcon.2022.104690.

[16] "ASHRAE Standard 55-2020: Thermal Environmental Conditions for Human Occupancy," American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2020.

[17] S. O. Adebayo, L. Gao, and Z. Lin, "Data-driven predictive control for building HVAC systems: A review," IEEE Access, vol. 11, pp. 15320-15341, Feb. 2023. DOI: 10.1109/ACCESS.2023.3244901.

[18] X. Jia, Y. Dai, and X. Zhu, "A novel hybrid model combining CNN and LSTM for indoor temperature prediction," Sustainable Energy Technologies and Assessments, vol. 55, p. 102951, Feb. 2023. DOI: 10.1016/j.seta.2022.102951.

[19] A. K. M. M. Islam, S. H. Ripon, and M. A. Rahman, "Feature selection for machine learning-based IEQ models: A comparative study of filter, wrapper, and embedded methods," Expert Systems with Applications, vol. 211, p. 118632, Feb. 2023. DOI: 10.1016/j.eswa.2022.118632.

[20] B. Li, Y. Tian, and F. Li, "Reinforcement learning for HVAC control in smart buildings: A survey of recent advances," Science and Technology for the Built Environment, vol. 29, no. 3, pp. 215-231, Mar.

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IoT-Driven Robotic Water Cleaner with Eco-Friendly Bio-Remediation

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Abstract — In more ways to dangers to biodiversity, public health, and sustainable development, water pollution and the depletion of clean water resources have emerged as major global issues. This project suggests an IoT-based smart water body cleaner that effortlessly integrates environmentally friendly bio-remediation with mechanical waste removal. A conveyor mechanism removes both biodegradable and non-biodegradable waste from the water's surface, and the system possesses pH, turbidity, and TDS sensors for real-time water quality monitoring. likewise, pollutants are broken down and aquatic ecosystems are naturally enhanced by bio-enzymes made from organic waste. This layered plan guarantees effective water restoration, reduces threats to human health, and offers a scalable, feasible solution for our nation's sustainable water management.

Keywords- Aquatic Ecosystem Restoration, Bio-Enzymes, Bioremediation, Conveyor Mechanism, IoT (Internet of Things), pH Sensor, Smart Water Cleaner, Sustainable Water Management, TDS Sensor, Turbidity Sensor, Waste Removal Robot, Water Pollution

I. INTRODUCTION

Polysaccharides, abundant in nature, are outstanding for encapsulating bioactive phytocompounds [1]. Due to their functional groups, biodegradability, and biocompatibility. Commonly used polysaccharides like chitosan, alginate, and carrageenan enhance solubility and stability of compounds such as polyphenols and essential oils. Hydrogels, including double network (DN) hydrogels, are promising for medicinal and pharmaceutical uses due to their ability to mimic biological tissues, absorb water, and enable controlled release. DN hydrogels combined with phytocompounds offer innovative materials for wound healing. Encapsulation within polysaccharide-based hydrogels enhances the stability and effectiveness of bioactive compounds, providing benefits like improved water solubility and extended shelf life. These hybrid systems find applications in various fields such as tissue engineering, food packaging, and medication delivery. While some polysaccharides are extensively studied, others like hyaluronic acid and starch are less explored. Nonetheless, research in this area is growing, reflecting increasing interest from the scientific community. Recent studies focus on using polysaccharide-based hydrogels loaded with phytochemicals for purposes like wound healing and drug delivery & amp; many

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more. [2]. Think about the rivers, lakes, and ponds we all know and love. They are the coming future of our planet, giving a home to countless number of animals, keeping our environment in balance and in healthy situation, providing entire the water we need for to do everything from our morning coffee to growing our food and surviving on it. But we have a serious problem. Our cities and industries are growing so fast so that we are spoiling these beautiful water bodies with pollution. Every day, a flood of plastic trash, chemical waste, and untreated sewage pours into them in large amount. And This doesn't just make the water look dirty, it harms the fish and plants that live there and poses a real health risk to our own communities through waterborne diseases which we do not know [1]. So, how do we fix it? The old ways of cleaning up—like sending people out to manually collect trash or dumping chemicals into the water just aren't cutting it.

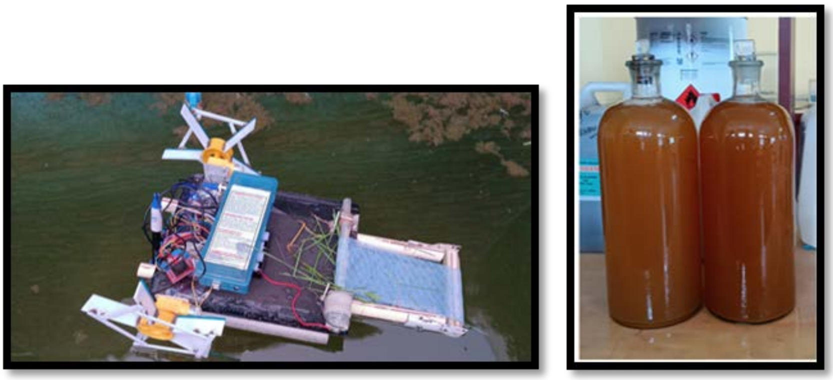

Fig.1. Structure of the water cleaning bot, and bottle contains bio enzymes

They are slow, incredibly expensive, and can end up causing even more damage to the environment. And that is where our project steps in. We decided to build way smarter, safer, and kinder solution for this problem. We have created an automated water cleaner that do two amazing things at once, a great multitasking machine or a bot. at first, it acts like a doctor for the water bodies, using smart sensors to constantly check on its health monitoring things like its clarity and acidity and other parameters of the water bodies. And at the same time, a clever conveyor belt system runs on the surface of water bodies, physically pulling out all the floating trash and other waste materials, from plastic bottles to fallen leaves. But we do not stop there. For the invisible gunk, we use special, eco-friendly bio-enzymes. Think of them as helpful little microbes that safely break down organic pollution, naturally restoring the water's quality from the inside out completely [2][3]. What is truly exciting is that this system works with the nature, it is not against it. We can control and monitor everything remotely in real time, which means no one has to risk their health by getting into contaminated water. This isn't just about cleaning; it's about bringing our waters back to life so that fish can thrive again and local communities can have a safe, reliable resource. Ultimately, our goal is simple: to offer a real, affordable, and green solution that can be used anywhere to help heal our planet's most precious resource.

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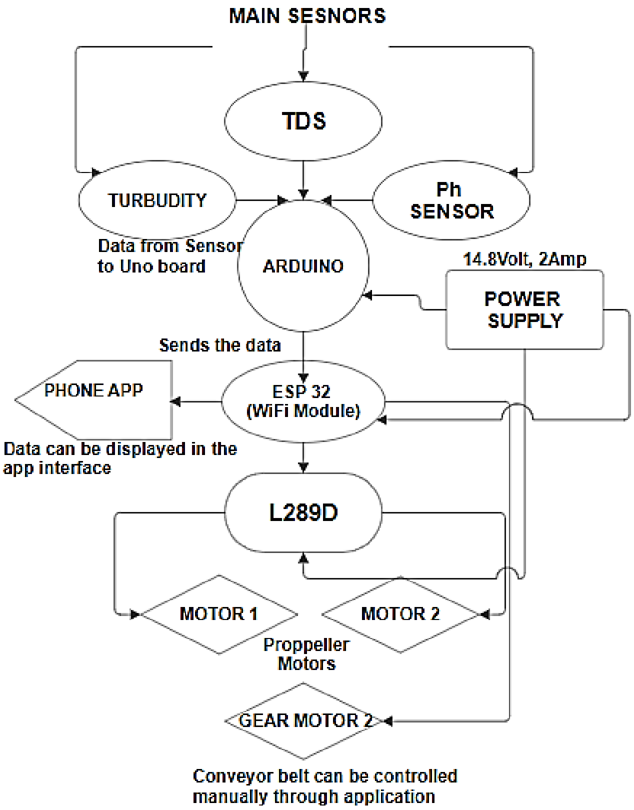

Fig.2. Flow chart of the proposed methodology

II. CONSTITUENTS OF EDIBLE HYDROGEL POLYMER

As we can see the growing problem of water pollution in water reservoir, rivers, lakes, and ponds has become a critical challenge for both the urban and rural areas. In identification of the problem begins with observing the current worst condition of water bodies, in which are often filled with full of plastics wastes, sewage, and industrial waste. These pollutants not only affect the organisms of water bodies but also spoils the livelihoods of people dependent on pisciculture and agriculture. To state this, the project first identifies the major contributors to pollution floating waste, biodegradable matter, and chemical impurities dissolved in water. The research studies process involved reviewing the scientific studies, government reports, and recent technological advancements in the process of water cleaning systems. Traditional methods such as manual collection, chemical treatment, and filtration of plants on a large scale were studied for their efficiency, cost, and environmental impact. It is very effective in certain cases; these methods were found to be either costly or harmful to the ecosystems. New innovations in robotics, IoT (Internet of Things), and bioremediation were examined as potential alternatives. Case studies of smart waste-collecting boats, sensor-based monitoring systems and other machines, and the use of natural bio-enzymes provided valuable results into sustainable water treatment method [2][3].

Based on these findings, the idea of developing an IoT-based smart water body cleaner was conceptualized in real life. The system integrates the multiple approaches mechanical waste removal using a conveyor belt mechanism, real-time water quality monitoring with various type of sensors like

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pH, turbidity, and TDS, and eco-friendly purification using bio-enzymes. The concept ensures effective cleaning, continuous monitoring, and minimal human intervention.

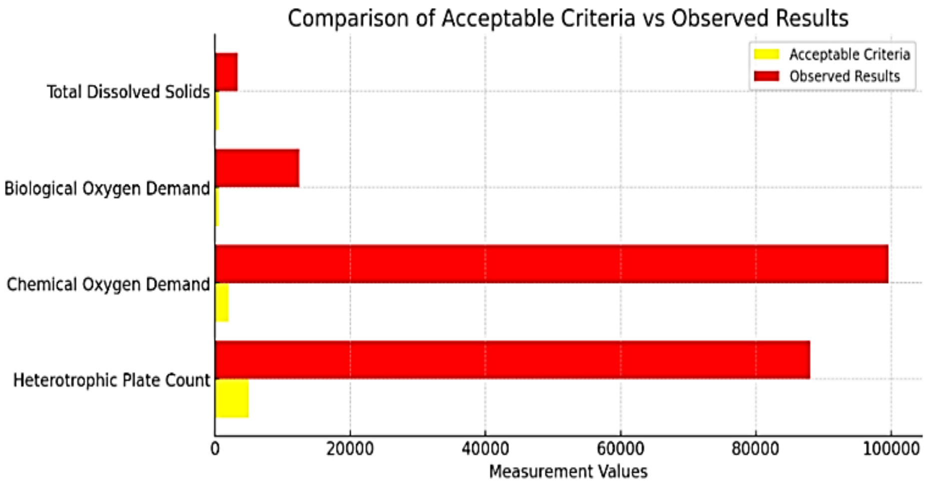

Fig.3. Graph comparing the acceptable criteria vs. observed results for all parameters

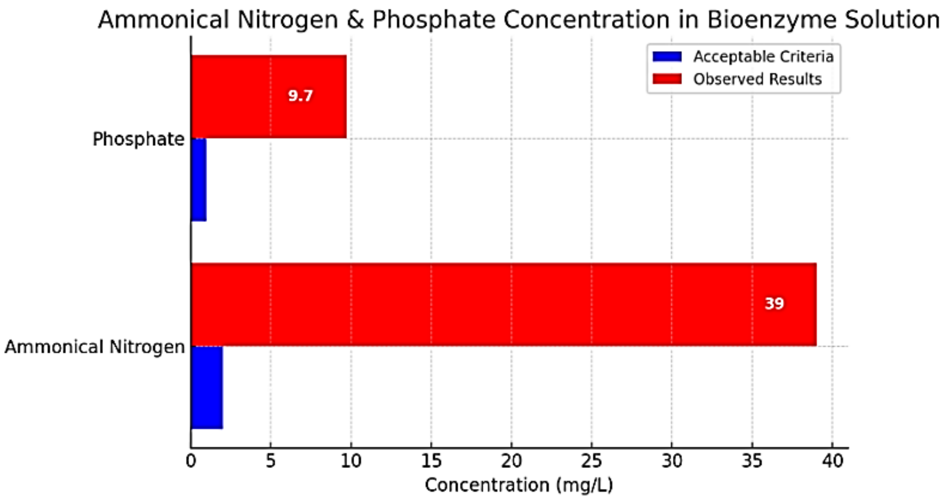

Fig.3.Graph for **ammonical nitrogen** and **phosphate**

The collection of ideas was further supported by many difficult sessions, literature surveys, and the prototype analysis. This integration approach and ensures the solution is not only technically feasible but also cost-effective, scalable, and sustainable for long-term environmental restoration in the future. By seeing the prepared data on bio-enzyme preparation from the bio-degradable waste of fruit and vegetable waste, coupled with IoT-based dashboards for real-time data visualization, guided the design of the project.

III. STUDIES AND FINDINGS

Our study began with an in-depth analysis of the current state of polluted water reservoirs and the limitations of conventional cleaning methods. Seeing field observations and literature surveys confirmed

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that the floating plastics, biodegradable wastes, and dissolved chemical pollutants are the primary contributors to the water degradation. By manual cleaning is labor-intensive and unsafe, while chemical treatments are costly and mostly harm the aquatic ecosystems.

Through the research on smart technologies, we found that integrating various type of suitable IoT sensors such as pH, turbidity, and TDS enables continuous monitoring of water quality. This data-driven approach allows for immediate identification of contamination levels and also supports the timely corrective actions. So, basically the exploration of the mechanical based waste removal systems, by using particularly a conveyor belt-based type of designs, proves to be the efficient for collecting floating garbages from the particular water body without any direct human contact.

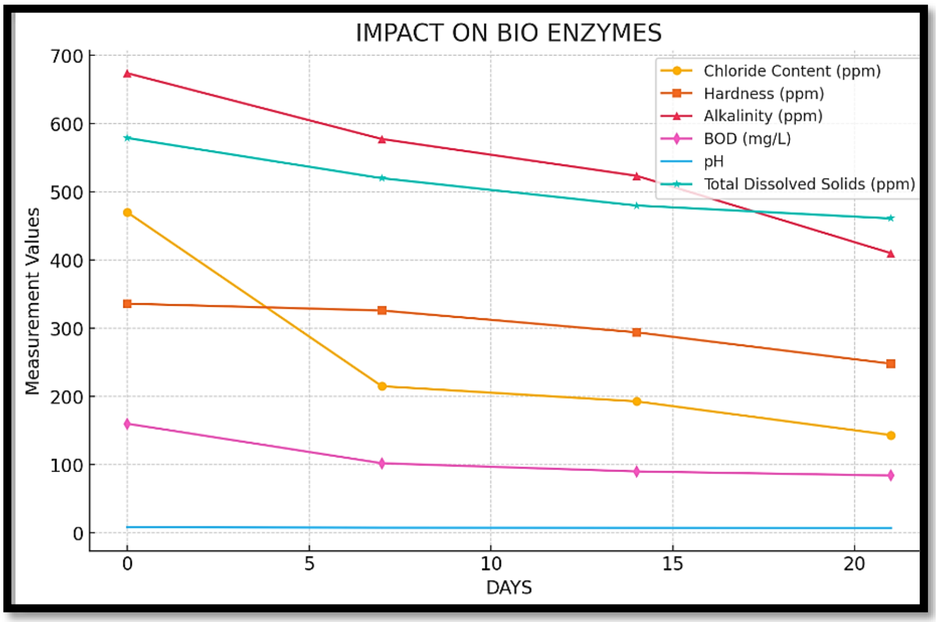

Fig.4. Data graph: parameter of the water quality: before and after the using of bio-enzymes in the water body.

An important finding was the effectiveness use of bio-enzymes as a natural, low-cost, and eco-friendly in nature solution [3][4]. Laboratory studies shows us that bio-enzymes which are made from the fruit peels and jaggery major reduce biological oxygen demand (BOD), chemical oxygen demand (COD), and improve overall the quality of water [3][4].

The fusion of these approaches mechanical waste removal from the water bodies, IoT-based monitoring, and bio-remediation proved to be highly productive in restoring the water quality of the reservoir. Our research suggest that such a system not only safeguards aquatic ecosystems but also creates the many opportunities for the sustainable practices like pisciculture and other activities.

III. CONCLUSION

The IoT-based smart water body cleaner, integrated with bio-enzyme technology, offers a very

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sustainable and so much cost-effective solution to combat the water pollution [2][3][4]. By combining the mostly all types of mechanical waste removal, real-time water quality monitoring systems, and totally eco-friendly bio-remediation, the system addresses both visible and invisible pollutants in the nature. The inclusion of mostly accurate pH, turbidity, and the TDS sensors that ensures the continuous assessment of water quality, while the conveyor mechanism efficiently removes the biodegradable and as well as non-biodegradable waste without any type of human contact. Bio-enzymes further improves the purification by breaking down the organic pollutants into simpler form and improving the aquatic ecosystems with essential nutrients and other things. This dual approach does not only improve the water quality but also reduces health risks, and also supports the biodiversity, and encourages the practices such as pisciculture, benefiting local communities economically and financially. This handy and lightweight, convenient, remotely operated, and adaptable design of the system of machine makes it more scalable for different types of water bodies in the society. Overall, the project shows that how the integrating the various suitable form of IoT and green technologies can provide innovative, eco-friendly solutions for restoring and preserving natural water resources in the nature.

References

1. APHA. (2017). Standard Methods for the Examination of Water and Wastewater American Public Health Association.
2. Yadav, K., & Patel, A. (2020), "*Role of bio-remediation in reducing water pollution: A sustainable approach*", Environmental Sustainability Journal.
3. Shivangi Rungta, Anupama Ojha, and Sarad Kumar Mishra (2022), "Study of Physico-chemical Property of Bio-enzymes Produced from Organic Household Waste and Their Application in Daily Life, Discovery", 58, (315), 228-234.
4. Swarndeep Kaur Sethi, (2021), "Bringing Lab to Our Home: Bio-Enzyme and its Multiutility in Everyday Life, International Research Journal of Engineering and Technology", 8(3).

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Innovative Technologies for Edible Utensils: A Sustainable Alternative to Single-Use Plastics

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Abstract- The increasing concern over single-use plastic waste has led to the development of edible utensils as sustainable alternatives. These utensils not only reduce environmental pollution but can also provide additional nutritional benefits. Recent innovations combine food science, materials technology, and smart design to improve strength, stability and consumer acceptability. This paper highlights key innovative technologies for the production of edible utensils and their potential applications in sustainable food systems.

Keywords- edible utensils, innovative technology, plastics, sustainability.

I. INTRODUCTION

Edible utensils are used as eco-friendly alternatives to single- use plastics, by reducing waste they offer functional and nutritional benefits. Advance technologies and natural ingredients enhance their rigidity, durability, and biodegradability, making them a sustainable step toward a plastic free future. Although the characteristics of plastic cutlery are hard to replicate, the requisite therefore is to act responsibly towards the environment and innovate a sustainable alternative to plastic cutlery, which are eco-friendly, inexpensive, sustentative and often times nutritious. Globally, countries are coming up with new and better strategies to decrease the usage of plastic cutlery, thereby taking steps in reducing global plastic waste influx. (1).

II. INNOVATIVE TECHNOLOGIES

1. *Extrusion and baking technology*

The versatility of extrusion allows for the creation of a diverse array of novel and intriguing ingredients and cuisines. It can also provide long-lasting, safe, nutritious, and affordable foods that are customized to meet the unique requirements of each consumer. In order to improve, reengineer, innovate extrusion processing methods (2). The mechanical strength and water resistance of carbohydrate and protein are improved through extrusion, which modifies their structures. (3)

Recent research has shown that the nutritional value and texture of extruded products are enhanced by cereal mixtures and legumes. In addition to addressing environmental concerns, these innovations

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underscore the potential of extrusion and baking technologies to develop utensils that offer safe, practical, and nutritious serving options. Edible implements have the potential to become mainstream solutions for sustainable food service systems through ongoing research. (4)

2. Hydrocolloid Gelation Technology

Hydrocolloid gelation is a sustainable method for making the edible, biodegradable utensils like spoons, bowls from polysaccharides such as alginate, agar and carrageenan (5 a). Some of the Gelation properties are:

a. Seaweed Hydrocolloids & Gelation: Alginate forms elastic, water insoluble gels with calcium ions through the overall integrity in the gelation (5 b). Agar produces thermo-reversible, transparent gels on cooling these materials (5 c). Combining these with starch, proteins or gums improve elasticity and load bearing strength of utensils (6 a).

b. *Heat Resistance, Biodegradability & Nutrition*: As the alginate is stable in boiling water and agar up to 85 degree C, so the utensils withstand heat and also in high temperature (5 d). From the characteristics they can be chemically fortified. So edible utensils made by drying and coating with 1-3% hydrocolloid +starch + glycerol, are best for rigidity and water resistance power (6 b).

3. Protein crosslinking technology

Plant Proteins like (Soy, Pea, Chickpea) have the ability to film forming, break down naturally and nutritious benefits. When it heated with natural binders, it improves crosslinking, strength, water resistance.

a. Plant Proteins Incorporated with Natural Binders:

- *Soy Protein:* It has amino acids, that help form strong flexible films. These films resist water and oil. It is renewable, making it eco-friendly and affordable (7 a).
- *Pea Protein:* It is low in allergens and forms soft yet strong films after crosslinking. It is good for making utensils that are safe and easy to produce in large scale (8).
- *Chickpea Protein:* It is easy to digest, forms stable films. It can hold antioxidants, helping protect food. It is also biodegradable and cost friendly (9).

b. Strong, High Protein Utensils with Good Bite Strength**;** These plant proteins add protein to the utensils, making them healthy nutritional choice. Also, natural binders and heat help create durable structures, that don’t break easily and resist moisture. Moreover, the protein structure holds together well, so the utensils can manage pressure from biting without falling apart (7 b).

4. 3-D Food Printing

3-D printing is a process of making three-dimensional objects using additive processes where layers are laid down in succession to create a complete object. Additive manufacturing refers to the technology of producing a final three-dimensional product by depositing thin layers of material upon each other. A variety of materials can be utilized, including metals, plastics, resins, rubbers, ceramics, glass and concretes. Most commercial 3-D printers use a computer-aided design to translate the design into a three-dimensional object. The design is then used by the 3-D printer to deposit the layers of material.

It is being considered in the food sector due to its multiple advantages such as personalized nutrition, customized food designs, simplifying the supply chain and broadening of the available food material. 3-

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D food printing has excellent advantages in low volume food fabrication of customized items in food services. It helps in delivering the food with visual aesthetic and most importantly good taste. (10)

5. *Nano-Composite Reinforcement*

Nanocellulose, nano starch and protein nanofibers reinforce edible utensils to make them strong, eco-friendly.

A. *Nanocellulose:* It derived from plant fibres or food waste. It improves strength, water resistance, barrier properties. It is renewable and also extend utensils lifespan (11 a).
B. *Nano starch:* It's created from tiny starch particles. It improves structural integrity and 3D printability. It enhances nutrient enrichment, food freshness (11 b).
C. *Protein Nanofibers:* It's synthesized from plant proteins. It forms lightweight, biodegradable layers. When it combined with natural oil, it boosts antioxidant properties and makes the utensils versatile (7 c, 11 c).

6. *Edible Coating and Multilayer Technology*

Edible Coating & Multilayer Technology is used in fruits and vegetables which mainly focuses on inhibition of texture modification, moisture barrier & antimicrobial properties. The edible coating includes single layer coatings & lipid-based coatings (12). In the preparation of the multilayer packaging, edible coating are mostly applied to the food products which increases the shelf life, physical quality & appearance of the product (14). Edible film coating with beeswax-in-water emulsion were stabilized with cellulose nanofibrils which has a droplet diameter around 10 micrometers (15).

The edible films produced from hydrolyzed collagen & cocoa butter & plasticized with sucrose which has many mechanical properties such as water vapor permeability & opacity. The cocoa butter films were easily manageable & flexible where sucrose reduces the tensile strength, where hydrolyzed collagen increased above 15%. It also provides a shiny coating to the utensils which looks attractive (16). Starches are used to form edible films as it has been used to form self-supporting films which caste by aqueous solution (17).

The starch improves the filming properties without the increasing any cost of production, it also provides modified packaging which increases the shelf life of the utensils (18). The films have good acceptable sensory characteristics as well as physical characteristics and are low in cost (20).

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Fig.1. Edible Coating: (a) Beeswax (b) Cocoa Butter (c) Starch Film

7. *Plant Fiber Reinforcement*

Plant fibres such as banana fibre, wheat bran, rice husk are valuable and very important in the case of making edible utensils due to their high strength, low cost, and biodegradability (21 a).

a. Fibers with Binders: Banana fibre from banana pseudostems, enhances high utensils strength, improves their durability; where rice husk is naturally lightweight, enhances the texture and strength of the edible utensils when mixed with starches, gums and proteins (21 b). Also, another plant fibre, wheat flour, contains gluten, acts as a natural binder and adds dietary fibres, with showing their low glycemic index (22 a).

b. Mechanical Strength & Sustainability: So, from the above advantages it can be added that reinforcing utensils with agricultural by products not only improves the strength and stability, but also supports a circular economy by reducing waste. This method decreases the product cost through local source, aids dietary fibre, promotes gut health when consumed and promotes eco-friendly, alternative choices to plastics (22 b).

8. *Smart Edible Utensils*

Out of concern for environmental pollution and the harm that people's intake of plastic does to their health, many start-ups have developed cutting-edge utensil that is edible and biodegradable. In addition to being edible, it also has qualities that make it nutritional and acceptable for consumption. Numerous distinctive characteristics of utensils derived from plant proteins and fibers include affordability, lightness, availability and biodegradability. (23)

Recently, the assimilation of pH-sensitive natural pigments into biopolymers has shown promising prospects. Unlike synthetic pigments, which have potential safety problems due to migration, natural pigments have negligible toxicity levels both to humans and the environment and some even possess nutritional and pharmacological properties. It has various advantages like biocompatibility, availability, biodegradability, stability and minimum toxicity. Hence, we can use natural pigments like

III. APPLICATIONS

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a. *Restaurants and Catering:* Edible utensils work as an eco-friendly serving option, to reduce plastic pollution, to enhance the dining experience and even to add nutritional value to meals.

b. *Events and Festivals*: They are an innovative concept that are aiming to reduce environmental impact of disposable plastic utensils. As the world grapples with the pressing issues of plastic waste and sustainability, edible utensils are offering a promising solution to the growing problems of single-use plastic utensils.

c. *Healthcare:* Innovative technologies for nutrient-fortified edible utensils in healthcare involves to enrich plant-based materials like grains, pulses and vegetables with vitamins, minerals and antioxidants for the creation of personalized nutritional supplements for patients.

d. *Space Mission and Defence:* Their key application is in space missions and defense, where edible utensils are offering a sustainable, dual-use solution by providing both food and packaging without the generation of waste, which is critical in environments where waste disposal is quite challenging.

REFERENCES

1. Chowdhury, G. R., Dutta, S., Pal, N., & Mitra, A. (2021). Edible cutlery: futuristic dining to functional sustenance. *Parana Journal of Science and Education*, *7*(8), 84-91.
2. Lazou, A. E. (2024). Food extrusion: An advanced process for innovation and novel product development. *Critical reviews in food science and nutrition*, *64*(14), 4532-4560.
3. Ek, P., Baner, J. M., & Ganjyal, G. M. (2020). Extrusion processing of cereal grains, tubers, and seeds. In *Extrusion cooking* (pp. 225-263). Woodhead Publishing.
4. Teniente-Martínez, G., González-Cruz, L., Cariño-Cortés, R., & Bernardino-Nicanor, A. (2016). Caracterización de las proteínas del frijol ayocote (Phaseolus coccineus L.). *Inv. y Des. en Cien. y Tec. de Aliment*, *1*, 1-6.
5. Khalil, H. P. S., Lai, T. K., Tye, Y. Y., Rizal, S., Chong, E. W. N., Yap, S. W., ... & Paridah, M. T. (2018). A review of extractions of seaweed hydrocolloids: Properties and applications. *Express Polymer Letters*, *12*(4).
6. Bisht, B., Lohani, U. C., Kumar, V., Gururani, P., & Sinhmar, R. (2022). Edible hydrocolloids as sustainable substitute for non-biodegradable materials. Critical Reviews in Food Science and Nutrition, 62(3), 693-725.
7. Dey, S., Hettiarachchy, N., Bisly, A. A., Luthra, K., Atungulu, G. G., Ubeyitogullari, A., & Mozzoni, L. A. (2022). Physical and textural properties of functional edible protein films from soybean using an innovative 3D printing technology. *Journal of Food Science*, *87*(11), 4808-4819.
8. Choi, W. S., & Han, J. H. (2001). Physical and mechanical properties of pea-protein-based edible films. *Journal of Food Science*, *66*(2), 319-322.
9. Liaqat, M., Riaz, S., Yahya, I., & Pervez, M. (2024). Synthesis and application of biodegradable seed coatings to assess the infestation of chickpea (Cicer arietinum L.) seeds by pests. *Journal of the Saudi Society of Agricultural Sciences*.
10. Huang, C. Y. (2018). *Extrusion-based 3D printing and characterization of edible materials* (Doctoral dissertation, University of Waterloo).
11. Ma, T., Hu, X., Lu, S., Liao, X., Song, Y., & Hu, X. (2022). Nanocellulose: a promising green treasure from food wastes to available food materials. *Critical reviews in food science and nutrition*, *62*(4), 989-1002.
12. Rastegar, S., Dargiri, S. A., & Khedr, E. H. (2024). Multilayer edible coatings technology for fresh fruits and vegetables. In *Sustainable postharvest technologies for fruits and vegetables* (pp. 386-397). CRC Press.
13. Anukiruthika, T., Sethupathy, P., Wilson, A., Kashampur, K., Moses, J. A., & Anandharamakrishnan, C. (2020). Multilayer packaging: Advances in preparation techniques

ISBN: **978-93-343-9865-6**

and emerging food applications. *Comprehensive Reviews in Food Science and Food Safety*, *19*(3), 1156-1186.
14. Arnon-Rips, H., & Poverenov, E. (2018). Improving food products' quality and storability by using Layer by Layer edible coatings. *Trends in Food Science & Technology*, *75*, 81-92.
15. Xie, B., Zhang, X., Luo, X., Wang, Y., Li, Y., Li, B., & Liu, S. (2020). Edible coating based on beeswax-in-water Pickering emulsion stabilized by cellulose nanofibrils and carboxymethyl chitosan. *Food Chemistry*, *331*, 127108.
16. Fadini, A. L., Rocha, F. S., Alvim, I. D., Sadahira, M. S., Queiroz, M. B., Alves, R. M. V., & Silva, L. B. (2013). Mechanical properties and water vapour permeability of hydrolysed collagen–cocoa butter edible films plasticised with sucrose. *Food Hydrocolloids*, *30*(2), 625-631.
17. Pagella, C., Spigno, G., & De Faveri, D. M. (2002). Characterization of starch based edible coatings. *Food and Bioproducts Processing*, *80*(3), 193-198.
18. Shah, U., Naqash, F., Gani, A., & Masoodi, F. A. (2016). Art and science behind modified starch edible films and coatings: a review. *Comprehensive reviews in Food science and food safety*, *15*(3), 568-580.
19. Baldwin, E. A., Nisperos-Carriedo, M. O., & Baker, R. A. (1995). Use of edible coatings to preserve quality of lightly (and slightly) processed products. *Critical Reviews in Food Science & Nutrition*, *35*(6), 509-524.
20. Maftoonazad, N., & Badii, F. (2009). Use of edible films and coatings to extend the shelf life of food products. *Recent patents on food, nutrition & agriculture*, *1*(2), 162-170.
21. Liao, Z., Hu, Y., Shen, Y., Chen, K., Qiu, C., Yang, J., & Yang, L. (2024). Investigation into the reinforcement modification of natural plant fibers. *Polymers*, *16*(24), 3568.
22. Raghunathan, R., Nelluri, P., Rajendran, D., Pandiselvam, R., Thulasiraman, V., Sahoo, S. K., ... & Kothakota, A. (2025). Biodegradable products from renewable sources: impact on replacing single-use plastic for protecting the environment. *International Journal of Environmental Science and Technology*, *22*(7), 6181-6208.
23. Attarin, S., & Attaran, M. (2020). Food printing: Evolving technologies, challenges, opportunities, and best adoption strategies. *Journal of International Technology and Information Management*, *29*(1), 25-55.
24. Ndwandwe, B. K., Malinga, S. P., Kayitesi, E., & Dlamini, B. C. (2024). Recent developments in the application of natural pigments as pH-sensitive food freshness indicators in biopolymer-based smart packaging: Challenges and opportunities. *International Journal of Food Science and Technology*, *59*(4), 2148-2161.

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REUSE OF POLYMERS IN FIELD OF CONSTRUCTION AND MODERN TECHNOLOGY: CASE STUDY

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Abstract- Plastic waste causes of the most adverse environmental effects which afterwards cause immense heal hazards. Yet the plastic is a very useful substance due to its durability, versatility, and widespread availability. This paper mainly focuses on the use of waste plastic across the construction, technology, and defence sectors, demonstrating how global plastic pollutant can be reused as a source of important raw materials to make new materials. The first case study revolves around the reuse of the plastic as well as other products like Bitumen which can be used in the construction of roads and other construction sites. The second describes about the building construction, showing how plastic-based materials can replace conventional components improving the affordability while promoting environmental sustainability. The third focuses on the military purpose where the uses of potential lightweight plastic materials are used in the production of the light weight Armor. This also examines the recycling of electronic waste, particularly silicon to produce renewable energy, helping to illuminate the production of electricity. In all these activities help us to identify the reuse of the plastic in the field of the construction as well as military purpose along with the production of the renewable energy form the waster polymers like silicon. All these kinds of technologies help prevention of the environmental degradation.

Keywords- Plastic waste management, Recycled plastic, Road construction with plastic, Sustainable construction materials, Military applications of plastics, 3D printing with recycled plastic

I. INTRODUCTION

Plastic has become a serious threat to the present world although its invention was made for using it as versatile [1-4] material for convenience and innovation. Unfortunately, its widespread misuse and improper disposal have resulted in severe environmental issues. From clogging waterways to polluting oceans, plastic waste has become a serious global crisis, even in the human food chain. However, the same qualities that make plastic problematic are its durability, versatility also offer immense potential [3] for sustainable solutions. Recycling and reusing of plastic are no longer just environmental solutions [4] but essential strategies for addressing pressing global issues. Some groundbreaking innovative

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applications of plastic are developed to mitigate its environmental [5] impact. The construction and technology sectors are considered to be the pioneer in showing remarkable potential for integrating recycled plastic into sustainable practices. People can reduce waste and conserve resources by replacing traditional materials with plastic in construction of roads, buildings, and even military technologies and thus can foster economic growth. [6]

This paper explores the transformation of plastic from waste to a valuable resource. The case studies highlight the real-world examples of innovation [7-10], challenges faced during implementation, and the path forward for scaling these solutions globally. Such sustainable practices can not only reduce plastic waste but also redefine its legacy for future generations.

II. CASE STUDY 1: ROAD CONSTRUCTION WITH PLASTIC WASTE

Use of recycled plastics in the field of construction [1] of roads has become a need nowadays which has helped to protect the environment from the harmful effects of plastics. This bold approach was made under the guidance of Mr. K. Ahmed Khan [2], he is currently the MD of KK plastics. According to him the roads which could be made of plastic had more tensile strength and durability than the normal roads constructed traditionally. This method was not only cost effective but also opened a new way of recycling of new products. In this process of road construction, the waste and leftover plastics are turned into fine granules which are then mixed with bitumen during the time of road construction making a more tough yet tensile material for the construction of the road [6-7]. The stability of the mixture increases and the lifetime of the road is enhanced too. This improves the durability of the road protecting it from rutting, cracking, and stripping [8-9] compared to the traditionally built roads. This not only helps the roads to withstand the load of heavy vehicles but also helps the roads to withstand the immense rainfall conditions [10]. There have been real life examples found not only in India but also in various parts of the world too [11].

Village Level Case Studies of India:

Uttar Pradesh: A bold initiative was taken by the students of IIT Kanpur [12 -13] along with the government bodies and the local people who have constructed a plastic road in Uttar Pradesh. This road is more durable and resilient than the traditional roads and has been used to cover the potholes created due to extensive rainfall, and the local people have given extremely positive feedback regarding this initiative.

West Bengal: From the tea gardens of Jalpaiguri there have been lots of plastic wastes derived which have been used by the government of west Bengal and make the plastic road in that area of the city [14-15]. This approach not only helped to improve the road conditions of the hilly mountain areas but also have led to the creation of employment opportunities to collect plastics for road construction.

Meghalaya: Here a community driven project has been led by the common people where the villagers were benefitted by the construction of the well durable roads which once was destroyed due to extensive rainfall [16]. The farmers were benefited by the good road conditions, which helped them to carry the crops easily to the markets.

Global Rural Level Case Studies:

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Kenya: Here the waste plastics have been used effectively to build the CABRO road by mixing plastic with bitumen. [17] This reduced the cost of the construction of the roads supported by the local municipality. They have constructed several kilometres of roads.

Ghana: There has been research in Ghana which showed that mixing HDPE with bitumen under 170 degree Celsius created tougher properties of the mixture later used to lay roads. The laboratory test reports showed penetration, softening point and viscosity which suggested the better performance of the roads. [18]

Bangladesh: There has been constant research done by the researchers of Bangladesh for utilizing the waste materials of 13 cities in this regard which demonstrates that plastics have 50% more durability than traditionally built roads. If the plastics thrown into the landfills could be used in making roads, then it could meet the 100% repair needs of roads [19-23].

Despite of the successful implementation of plastics there have been thousands of difficulties in this regard as still people are unaware about this technology and there has been lack of funds by the government bodies [24].

III. CASE STUDY 2: USE OF WASTE PLASTIC IN CONSTRUCTION INDUSTRY

Another possibility for recycling plastic into construction [25] is in building and construction. Traditional materials [26], e.g., bricks, cement, and metal rods can be replaced partially by plastic-based alternatives. High-density polyethylene (HDPE) [27], a durable material resistant to water, has been widely used in the waterproofing of basements [28]. Another versatile material, PVC pipe, can even replace the metal reinforcements of building structures. For that, the civil engineer uses plastic polymers [30] of high-density polyethylene in the construction of the pillar so that the usual method of coating the sand and cement [31] is replaced by the plastic coating, which makes the pillar stronger and protective from the layers of water that is used and will generally lead to the rusting of the iron rods used below the earth.

At the Village: Innovations from India: Recycled plastic for construction

For Maharashtra (Amravati Region): Faculty members and students of an engineering college in the Amravati region of Maharashtra tried developing bricks by blending plastic waste with the normal brick-making process. The products possessed lower water absorption, higher compressive strengths, and lighter weight, which was quite suitable for rural areas where there were few waste management disposal systems [32].

Tamil Nadu: A community initiative in Tamil Nadu constructed a 400 ft² room in a school campus using PET bottles stuffed with plastic waste and covered with UV-resistant paint. It showed a replicable modular and sustainable design for rural schools and community centres [33-34].

Majuli (Assam): Authorities in Majuli organized a special programme at a Solid Liquid Resource Management (SLRM) facility -- popularly known as a plastic waste centre -- on the occasion of World Environment Day, which is celebrated on June 5 here. The above method was found low-cost, durable and environment-friendly and is highly advantageous in flood-prone riverside areas [35].

Village-Level Case Studies (Non-Indian Examples)

Indonesia: Researchers in Indonesia studied the use of HDPE plastic waste as a replacement for fine aggregate in the production of CLC [36]. The experimental mixes of 0%, 5%, 10% and 15% HDPE indicated that compressive strength slightly decreased with the increase of HDPE content, whereby it has

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an advantage in reducing environmental pollutants and helps to achieve optimum density in lightweight bricks.

Malaysia: A Malaysian trial studied recycled HDPE in concrete mix for flat roofs. The mixes had 2–6% plastic and were tested for compressive strength, thermal insulation, and water absorption. A mixture with a 2% HDPE–cement ratio satisfied the Grade 20 compressive strength but decreased thermal conductivity by about 12% and can be proposed for sustainable flat roof construction [37].

Iraq: In Iraq, the natural course was substituted with shredded HDPE waste up to 30%. The results were wonderful; although the load-carrying capacity decreased slightly (~7%), the beam toughness [38] enhanced by ~24%, and the failure phenomena of the tensile failure modes in the E-BEAM did not change much compared with the conventional beam.

Japan – Disaster Management is treated as a Plastic-Like Reinforcement

For Japan [39], which has very high levels of sensitivity to earthquakes, the development of technology for disaster-resilient construction cost is enormous. One prospective new structural element is in carbon-fibre composite rods—lightweight non-metal reinforcements that have a similar nature to plastic composites and can be produced from composites and the like. An example is the project in Nomi-city, Ishikawa prefecture, for which the architect Kengo Kuma [39] used this system for the retrofit of the Fa-Bo showroom and laboratory for Komatsu Seiren. Such a structure mobilized 1,031 bars between the roof and the ground as an external anchor, and 2,778 bars as an interior network reinforcing stairwells and parapets [39–41]. It’s strong as hell. It’s seven to ten times stronger than steel, and, of course, it’s much lighter, and it’s in a rope-Ish form, like traditional Japanese stuff. You have the culture, and also the best science. From a functional perspective, the system enhances seismic resistance by dynamic tension—when the building shakes during an earthquake, rods on the opposite side resist the movement and reduce deformation [40]. The shield effect produced by the curtains splits the force and dissipates it throughout the structure, improving overall stability. Its significance as a material was further emphasized with the official standardization of CABKOMA [42] as JIS A 5571 in 2019. It provides a one-fifth density of iron, a tenfold tensile strength, and an excellent corrosion resistance and has already been put into practical use, for instance, in heritage buildings such as Kyozo Sutra Repository in Zenkoji Temple, which was intended to make priorities both in strength in structures as a building and in beauty when structured [43].

One imaginative [44] application is combining shreds of plastic chunks with concrete to produce stronger walls and roofs. This provides not only a reduction in conventional material usage but also takes advantage of the long degradability period of plastic [45]: approximately up to two million years by extending the life cycle of the structures. Plastic is effectively utilized in furniture, partitions, and home appliances within interiors [46]. Electrical wiring and equipment are insulated with plastic for safety and durability requirements. In addition to which, Novolac, a phenol-formaldehyde polymer [47-48], has been a fundamental building block in the paint industry, providing buildings with both aesthetic and protective properties. Although the opportunity for plastic construction [27] is huge, hurdles such as public disbelief [49], finance and technology are holding it back. However, further evidence-based and awareness [50] raising programs may lay the foundation for its widespread adoption.

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IV. CASE STUDY 3: REUSED PLASTIC IN MILITARY APPLICATIONS

Military applications provide an opportunity for plastic reuse [51]. Plastics or polymeric materials are highly desirable because they are lightweight, strong, and are increasingly being incorporated into the design of weapons [51-54], equipment, and vehicles. Polymer thermosetting resins can be moulded into shape and are the perfect material for making hard-wearing military equipment that is also transportable. In the Line of Control (LOC) and in other hostile areas, plastic composites have been found to be beneficial in equipment [55-57]. These are less cumbersome and more transportable versus the metal devices. On the one hand, radioactive-titivating polymers [55] have been proved to be eligible candidates for advanced weaponry, which could provide an economical alternative to conventional materials. Military [56] and incorporating recycled plastics into it can cut costs and minimize its environmental impact, while improving operational efficiency.

The US [58] Army Research Laboratory has developed a method to recycle plastics into 3D-printing filament. This means that trained veterans can now rapidly manufacture replacement parts for military vehicles, weapons, and equipment.] Filaments of the composite thermoplastics were produced through a process known as solid-state shear pulverization by ARL (as detailed here [58]). In this process, shredded waste, primarily plastic bottles with some paper and cardboard, was ground in a twin-screw extruder to produce a powder. This powder is subsequently converted into 3D [58] printer filament by means of melt-processing.

Some of the actual test subjects are:

3D Printing of Spare Parts (U.S. Army Research Lab): Researchers at the U.S. Army Lab, including Capt. Anthony Molnar and Dr. Nicole Zander, developed a process to recycle PET bottles, cardboard, and paper into 3D-printing filaments using solid-state shear pulverization. These filaments (~70 MPa tensile strength) were successfully used to produce essential parts, such as vehicle radio brackets, from as few as 10 bottles within two hours [59–60].

Composite Armor & Light Vehicles: In partnership with AM General and TPI Composites, the U.S. Army reinforced the HMMWV with carbon-fibre Armor, reducing vehicle weight by about 900 pounds compared to steel or aluminium. The design improved mobility, range, and fuel efficiency.

HDPE-Based Body Armor: Recycled HDPE blended with 5–15 wt.% granite microparticles [62] demonstrated higher mechanical performance—impact strength (+18%), hardness (+52%), and compressive strength (+33%). With ~70 MPa tensile strength, these composites show promise for lightweight Armor, 3D printing, and military applications.

Role of Mechanical Recycling: Mechanical recycling remains central to the circular economy, consuming less energy and avoiding harmful by-products compared to chemical methods. Studies confirm its applicability for construction, 3D-printing feedstock, and composites [64–65]. Yet, challenges such as corruption, bureaucracy, and talent loss restrict progress. Overcoming these issues will require focused R&D and stronger government support to secure both sustainability and military readiness

V. CONCLUSION

In the above case studies, we have got a clear idea about hoe the reuse of plastic can be very helpful for the development of the society as well as it can make the environment free of pollution and help in the production of the new things from the discarded wastes. Not only roads but also buildings as well as

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many military equipment can be made with the help of the reuse of the polymers [62-65]. Some of their applications are in renewable energy. However, the success of these initiatives depends on overcoming of barriers of public sarcasm.

By doing innovative research and fostering collaboration among governments bodies industries, and communities, the potential of recycled plastic can be fully realized

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REFERENCES

1. Mr. Mayur Lalitkumar Lodha, Mrs. Asha Oak, (2018). "*Future of construction industries in India*"; Vol .5 No 11

2. Dr. Ahamed Khan, (2010), "*Riding on Plastic*."; Read more at: https://www.constructionworld.in/latest-construction-technology/Riding-on-Plastic/1225

3. "*Consumption volume of plastic for construction in Japan*" from 2017 to 2022; *www.statista.com*.

4.https://www.npcindia.gov.in/NPC/Uploads/file%20upload/6.%20Mr.%20S.K.%20Nirmal,%20Indian%20Road%20Congress.pdf

5. Nabin Kumar Sahoo, Biswajit Tarai, K. Abhinash Mohanta, Devranjan Kumar, Prasad Tarasankar Panigrahi, Shibani Hota, Abhijit Mangaraj, (2022), "*Project on Preparation of Plastic Road Using Single Used Waste Plastic*".

6. Saipol Bari Abd Karim, Syuhada Norman, Suhana Koting, Khanom Simarani, Siaw-Chuing Loo, Faizul Azli Mohd Rahim, Mohd Rasdan Ibrahim, Nur Izzi Md Yusoff, Abdul Halim Nagor Mohamed, (August 2023), "*Plastic Roads in Asia:*"*Current Implementations and Should It Be Considered*?";

7. Azmat Shaikh, Nabeel Khan, Faisal Shah, Devendra Shukla, Gaurav Kale, (May 2017); "*Use of Plastic Waste in Road Construction*", Paper ID:V2I5-1146.

8. S.K. Nirmal, (2023), "*Use of waste plastic in Road construction and its future impacts*", Volume: 10.

9. P. Guruswamy Goud, M. Rajasekhar, N. Vijayakumar, K Snehalatha, B. Bhanu Prasad,"*Case Study on Plastic Roads*"; Volume 3, Number 1

10. Johnson Kwabena Appiah, Victor Nana Berko-Boateng, Trinity Ama Tagbor, (2017), "*Use of waste plastic materials for road construction in Ghana*"; Volume 6.

11. A. Kuttalingam, (2024) "*Usage of Waste Plastic in Bituminous Road Construction*" Read more at: https://swachhbharatmission.ddws.gov.in/sites/default/files/communication-material/TN_Kuttulingam-Usage_of_Waste_Plastic_in_Bituminous_RoadConstruction-14.02.2024.pdf

12. Kunle Babar Emu, Adedapo Adediji, Nmesoma Olumba, Silifat Okoya, Esther Akinlabi and Muyiwa Oyinlola, (2024), "*Technological Advances in Mechanical Recycling Innovations and Corresponding Impacts on the Circular Economy of Plastics*".

13. https://www.unicef.org/india/stories/ending-plastic-pollution-maynaguri-west-bengal

14. https://www.krctimes.com/news/nongkynjeng-village-to-have-the-first-plastic-road-in-north-east/

15. https://www.unep.org/news-and-stories/story/kenyan-entrepreneur-sets-long-and-plastic-road

ISBN: **978-93-343-9865-6**

16. https://www.brri.org/publications/2017-publications/refereed-journals/use-of-waste-plastic-materials-for-road-construction-in-ghana

17. Rajiv Ranjan, Ajay Kumar, (2025), "*Review Article on Use of Recycled Materials in High-Performance Concrete for Construction Work*", Journal of Integrity in Ecosystems and Environment, Volume: 3, Issue: 3, ISSN: 3030-3729

23. Prof. R. Geethamani, (2023), "*Potential use of plastic in the construction industry*", https://www.bitsathy.ac.in/potential-use-of-plastic-in-the-construction-industry/

24. Joan Nyika, Megersa Dinka, (2022), "*Recycling plastic waste materials for building and construction Materials: a mini review*", Volume 62, Part 6, Pages 3257-3262

25. Anjali Gupta, Vishal Chandrakar, (2023), "*A Review Paper on Reuse of Plastic Waste as Pavement Construction Material*"; ISSN : 2321-9653; Paper Id : IJRASET49291.

26. Sidra Tul Muntaha, Martina Keitsch, (2024), "*A pathway for plastic waste in construction materials*".

27. https://link.springer.com/article/10.1007/s43939-024-00126-1

37. Shoichi Ikebata, Kiyoshi Uzawa, (2018), "*Innovative New Construction Material*".

38. https://www.designboom.com/architecture/kengo-kuma-earthquake-resistant-komatsu-seiren-fabric-laboratory-fa-bo-japan-04-06-2016/

39. Yara S. El-Metwally1, Khaled M. Dewidar, Mostafa R. Ismail, Iman S. El-Mahallawi, (2023), "*Integration in Construction Materials*" ; DOI: 10.13189/cea.2023.110213

40. Guangru Du, Ruinian Jiang, (2021), "*Study on Recycling and Reuse of Waste Materials in Building Industry*", DOI:10.11648/j.ajere.20210602.13.

41. https://ui.adsabs.harvard.edu/abs/2024FutCE..10....7M/abstract

42. https://www.bbc.com/future/article/20200819-why-plastic-waste-is-an-ideal-building-material

43. https://synergiafoundation.org/2023/05/05/futureproofing-india/

41. https://worldbuilding.stackexchange.com/questions/195816/would-a-full-plastic-gun-work

44. https://recyclinginternational.com/commodities/plastics-recycling/army-recycles-plastic/17171/

45. https://journals.sagepub.com/doi/full/10.1177/03611981231157389

62. Bibhuti Bhusan Mukharjee, Sudhirkumar V Barai, (May 2015), "*Development of construction materials using nano-silica and aggregates recycled from construction and demolition waste*". DOI:10.1177/0734242X15584840

63. Sajan Preet, Stefan Thor Smith A, (April 2024), "*Comprehensive review on the recycling technology of silicon based photovoltaic solar panels: Challenges and future outlook*", Volume 448.

64. https://www.newtopsilicone.com/silicone-recycling-paving-the-way-to-a-sustainable-future/

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Leveraging Remote Sensing, Drones, and IoT for Smart Village Agricultural Transformation-A Review

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Abstract- Although agriculture continues to be the mainstay of rural development, conventional methods frequently fall short of the demands of increased productivity, resource scarcity, and climate variability.

The Smart Village logic puts forth the integration of modern technologies, with agriculture serving as a train of entry: this study analyzes how high-end technology-a multimodal data fusion, drone monitoring, satellite remote sensing, and smart irrigation-combine to make crops intelligent and sustainable.

Drones support agricultural activities by providing high-resolution insights in a local area and thereby allowing immediate local responses, while satellite remote sensing enables us to see large and continuous areas for a given period to assess crop health and water stress. Beyond spatial, spectral, and temporal fusion, multimodal frameworks that combine data from satellite, drone, and ground-based IoT sensors increase accuracy because each platform's constraints are diminished by the other. The research presents various intelligent irrigation system deployment methods which use automated adjustments based on soil moisture and weather patterns to achieve maximum resource efficiency and water conservation. These technologies work together to optimize resource utilization while reducing labor expenses and boosting production output which strengthens climate change adaptation. Smart villages transform agriculture by integrating modern technology into rural infrastructure which enables data-driven farming methods that respect community involvement and environmental protection.

Keywords- Smart Irrigation, remote sensing, drone-based monitoring, multimodal sensing, smart village agriculture

I. INTRODUCTION

The Smart Village concept aims to improve rural areas through modern technology which creates sustainable communities and economic stability and better living conditions. The agricultural

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sector which supports rural life exists as a vital industry that digital innovation can transform completely. Traditional farming methods encounter difficulties with both efficiency and accuracy and climate variability adaptation although they possess substantial local knowledge. The situation requires modern tools which include multimodal sensing frameworks and drone-based monitoring and remote sensing and smart irrigation systems. The combination of these technologies enables rural areas to implement data-driven farming methods which boost production levels and protect environmental resources. Satellite-based remote sensing provides farmers and urban planners with the ability to observe agricultural areas from a large distance. Anderson et al. showed that satellites enable ongoing monitoring of crop health and soil wetness and water stress through spectral indicators which include NDVI and EVI and NDWI [1]. The broad-area monitoring system enables villages with limited resources to access trustworthy information about their crops and drought patterns and seasonal variations. The implementation of satellite-based crop monitoring systems enables smart villages to perform community-level planning through affordable and expandable methods which support pest management decisions and irrigation scheduling and planting strategies. The technology of drone-based crop monitoring delivers instant field data at centimeter accuracy which improves the value of satellite information. Drones that operate with RGB and multispectral and hyperspectral and thermal sensors detect pests and nutrient shortages and stress areas before humans can see them [2]. The smart village system allows smallholder farmers to use drone services through cooperative resource sharing which provides them access to advanced diagnostic tools without needing to purchase each device separately. The system gives equal access to precision agriculture technology which helps all farmers get better results and makes farming communities more resilient. The integration of multiple platforms within multimodal sensing frameworks which unite satellite data with drone and ground-based information from IoT soil probes and weather stations enables better decision-making. Yang and his team showed that multimodal technologies boost treatment accuracy and reduce uncertainty through their method which unites data fusion with machine learning algorithms to generate detailed crop condition information [3]. The new system optimizes water and fertilizer and pesticide use to produce higher crop yields and reduced expenses for farming communities. The final stage requires water management strategies to transform into operational frameworks which intelligent irrigation systems will use for ongoing management. The system uses weather information and automated valves and soil moisture sensors to deliver water at specific times for crop irrigation.

For a smart village, this means significant savings in water resources, improved crop resilience to climate change, and reduced labor requirements, all of which contribute to rural sustainability. In essence, these technologies—satellite monitoring, drone surveillance, multimodal sensing, and smart irrigation—are not isolated innovations. Together, they constitute the technological backbone of a smart agricultural ecosystem within a smart village. Through the distribution of practical information to farmers and automated resource systems and joint tool usage they create a foundation for rural development which supports sustainability and social equality. The systems operate through automatic valves and weather data and soil moisture sensors to deliver water precisely at the right moment for crop needs. The smart village approach leads to major water resource conservation and better agricultural resilience against climate change and reduced manual work which supports rural sustainability. The four technologies

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function as interconnected systems rather than separate independent inventions. The smart agricultural ecosystem of a smart village needs these components to function properly. The system establishes an equal rural development base through resource automation and farmer information access and advanced tool sharing.

II. LITERATURE REVIEW

Growing populations and dwindling arable land are putting increasing strain on the world's food supply, necessitating the development of accurate and scalable crop monitoring technologies. Agri-cameras, satellites, UAVs (drones), and smart irrigation systems are examples of remote sensing technologies that have revolutionized modern agriculture by providing high-resolution, real-time, and predictive insights into crop health. We begin our work with the Satellite-Based Crop Monitoring System. Satellite remote sensing detects electromagnetic radiation which emerges from Earth surfaces through reflection or emission. Sunlight interacts with plants by reflecting or absorbing various wavelengths based on their health status. Healthy vegetation absorbs red light because chlorophyll in plants but the leaf structure causes near-infrared (NIR) radiation to reflect. Vegetation under stress has higher red reflectance and decreased NIR reflectance [4]. Braga et al. in 2021stated that utilizing these spectrum responses, satellites provide vegetation indices that are commonly used to evaluate crop vigor, such as the Normalized Difference Vegetation Index (NDVI): (NIR−Red)/(NIR+Red)(NIR - Red) / (NIR + Red). The Enhanced Vegetation Index, or EVI, accounts for soil background and atmospheric factors. The Normalized Difference Water Index, or NDWI, measures water stress using the NIR and SWIR bands [5]. Contemporary satellites Sentinel-2 and Landsat-8/9 deliver multispectral data which provides 10 to 30 meter resolution images with 5 to 16 day revisit intervals. Modern platforms use hyperspectral sensors which record hundreds of narrow bands to study plant biochemistry at a detailed level [6]. For the mechanism of Drone-Based Crop Monitoring, high-resolution imaging at the centimeter scale is made possible by drones (UAVs), which operate at low altitudes (20–200 m). In contrast to satellites, which only use passive solar reflectance, drones are able to carry a variety of active and passive sensors, such as: RGB For the purposes of measuring plant density, canopy cover, and visual disease detection, cameras take pictures in visible light. To compute indices like as the Normalized Difference Red Edge (NDRE) and NDVI, multispectral sensors record reflectance in distinct bands, such as red, green, blue, NIR, and red-edge. By capturing hundreds of consecutive spectrum bands, hyperspectral sensors allow for fine-grained study of stress signals, pigment content, and crop nutrient status. Thermal infrared sensors aid in the detection of changes in canopy temperature caused by water stress and evapotranspiration. Laser pulses are used in LiDAR (Light Detection and Ranging) to produce three-dimensional maps of plant height and canopy structure. Nathan et al. described that drone-based monitoring usually includes the following steps in its workflow: Mission planning (GPS-guided flight paths) [7]. Data gathering (sensors take pictures at predetermined times). Processing photogrammetry (creating 3D point clouds and orthomosaics from photos). NDVI, NDWI, and chlorophyll indices are calculated. Prescription mapping: maps of variable-rate pesticide and fertilizer spraying created for precision farming. Their limited service area and need on excellent weather conditions for flying are the drawbacks, though. Using the distinct advantages of each, multimodal sensing combines satellite,

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unmanned aerial vehicle, and ground-based sensors into a single framework. High-resolution, localized stress mapping is provided by drones. Agri-cameras, Internet of Things soil probes, and weather stations are examples of ground sensors that provide continuous, real-time data at the plant and soil levels. Data fusion techniques like spatial fusion, which combine coarse but large-area satellite data with high-resolution UAV imagery for better scaling, are crucial to the multimodal monitoring mechanism [8].

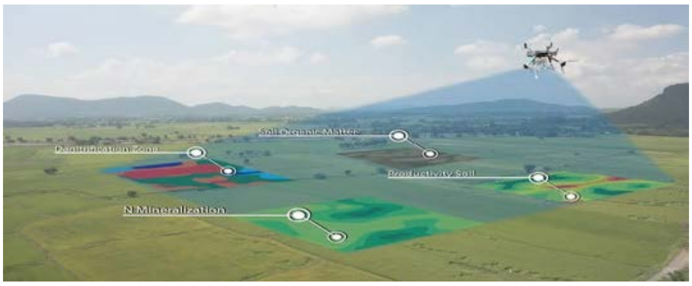

Fig.1. This figure demonstrates how drones help in surveying various parts of soil [9]

Technology	Primary Mechanism	Advantages	Limitations
Satellites	Spectral reflectance captured in visible, NIR, SWIR; vegetation indices (NDVI, EVI, NDWI)	Large-scale coverage; temporal continuity; cost-effective	Limited resolution; cloud interference
Drones	Low-altitude, high-resolution imaging with multispectral, hyperspectral, thermal, and RGB sensors	Early detection; fine spatial detail; yield prediction	Small coverage area; operational costs
Multimodal	Fusion of satellite, UAV, and ground-sensor data; ML-based analytics	Scalable, high-accuracy, holistic monitoring	Requires advanced integration systems

Describing smart irrigation system, In order to reduce waste and preserve the health of crops and landscapes, smart irrigation systems automatically adjust watering schedules and quantities based on site circumstances (soil, plants, and weather). Systems are often divided into two categories: controllers based on weather/ET and controllers based on soil moisture sensors. Ndunagu et al. said that many contemporary systems incorporate both, as well as remote sensing, edge computing, IoT connection, and artificial intelligence. Various accessories combine to create a cohesive whole. The monitoring component is made up of several sensors that serve as smart irrigation monitoring units. The primary sensors are those for soil moisture, wind speed, evaporation, leaf wetness, precipitation, snowfall, and data collection [10]. Automatic irrigation is based on a variety of control valves in the control section. Ball valves, butterfly valves, pulse valves, and other types of valves can be controlled remotely [11]. Select various water pipes and valves based on the various irrigation zones. Numerous sensors wirelessly send climatic and soil moisture data to the platform, which then evaluates and investigates the information. It determines the area and water volume that requires irrigation, then wirelessly instructs the control valve at each location. The water valve is opened or closed by the controller. Liao et al. described that smart irrigation systems consider site-specific factors like soil type, sprinkler rates, and

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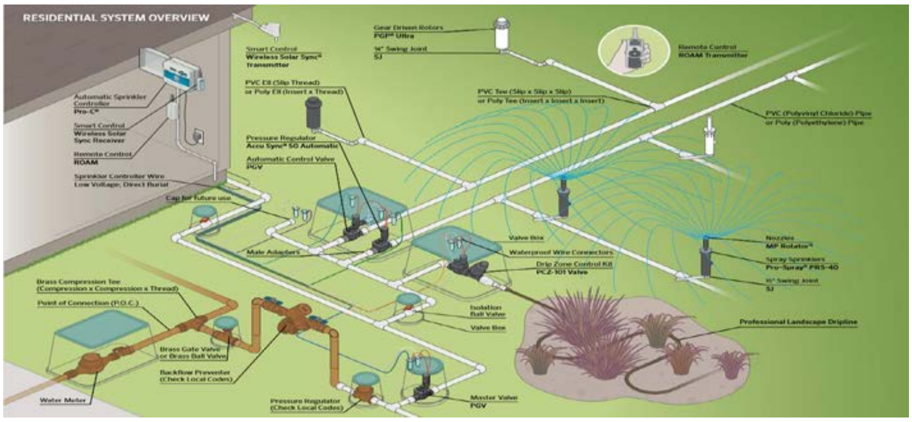
more as ambient temperatures rise or rainfall varies. We can select different soil moisture sensors based on the kind of soil [12]. When buying sensors, consumers merely need to make sure they are compatible with their systems. Evaporation sensors, on the other hand, are weather monitoring equipment [13]. The soil surface evaporation is reflected in its value. By collecting this climate-related data, irrigation time can be modified. For the purpose of precisely reflecting the change in leaf wetness, the leaf wetness sensor mimics the properties of a leaf. We can determine whether the plants are dehydrated and whether the soil needs to be watered by keeping an eye on the leaf moisture. The leaf wetness sensor reflects the evaporation of plant leaves. In case of Rain and snow sensor, when you are watering your lawn and it happens to rain, you are sure to stop watering immediately. Watering in the rain wastes water and money, and causes unnecessary runoff. Smart irrigation also has such a function. The rain and snow sensor is the basis for realizing this function. There are metal wires on the surface of the rain and snow sensor, which will conduct electricity when it encounters rain or snow. An electrical signal is sent to the management platform, and the platform notifies the controller to close the water valve in time after receiving it [14]. The cost of rain and snow sensors is very low, around $25. It also has an automatic heating function, even in the severe winter, the surface will not freeze, ensuring normal work. Rain and snow sensors are quite inexpensive, costing about $25. Additionally, it has an automatic heating feature that keeps the surface from freezing throughout the harsh winter months, guaranteeing regular operation. Year-to-year variations in precipitation and snowfall mean significant water and financial savings for irrigators. Watering during windy conditions can lessen the amount of water that absorbs into the soil and the regularity of lawn irrigation distribution. Installing wind speed sensors is necessary so that, should the wind speed above a predetermined threshold, the irrigation cycle will be stopped. We logically plan the irrigation cycle and length based on the local weather conditions, which can collectively save a significant amount of water resources.



Fig, 2. Residential irrigation system [15]

III. DISCUSSION

Smart irrigation replaces flood irrigation with the goal of conserving water. It meets plant growth requirements with minimal water. Data on soil moisture can be gathered by smart irrigation systems, which can then efficiently regulate irrigation water. Additionally, it has a circulation mechanism to conserve water. remote administration. You can perform irrigation labor and monitoring data analysis using a computer or mobile device; you don't need to physically be in the irrigation area. Simply turn on

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the phone when it's appropriate to check the plant's growth progress. Labor costs are significantly reduced because a single individual may oversee several cloud platforms simultaneously and irrigate thousands of acres of agriculture.

We establish instant modifications to the watering system through sensor data which arrives in real time. Water plants according to their growth stage through regular scheduled watering at exact intervals. Every flower will develop properly when the garden receives uniform water distribution. The cloud platform will experience immediate changes which include timed irrigation and remote irrigation and cycle irrigation and flexible switching between the three irrigation modes. Satellites enable farmers to monitor and control large areas because they show aerial views of extensive agricultural lands. Farmers receive dependable data from these systems to monitor crop health and resource usage across worldwide agricultural regions. Satellite data helps farmers analyze long-term trends and create field maps and crop classifications which supports their agricultural planning activities. Drones collect detailed field data through their high-resolution sensors which permits scientists to study specific field sections precisely. The devices function as instant data collectors that operate at high resolution to help users address emerging problems such as dry zones and pest attacks. [17]. The technology of drone data enables experts to identify precise areas which need fertilization and irrigation and insect control so they can create specific intervention strategies. The multiple sensors within multimodal remote sensing (MRS) include multispectral and hyperspectral and radar and thermal sensors which work together to produce integrated data. MRS delivers enhanced precise and thorough and reliable information about crop physiology and soil moisture and nutrient status through its method of combining multiple data sources. The system combines different sensor information to provide complete and consistent data which performs better than individual sensors when clouds block the sky. The MRS system demonstrates a complete picture of plant health and development through its ability to follow multiple agricultural progress indicators.

CONCLUSION

The development of smart communities through farming depends on modern irrigation systems and monitoring platforms as essential starting points. Remote sensing systems function through satellite technology which tracks agricultural fields to detect crop health and water stress and soil conditions yet drones deliver exact field-level information whenever required. Multimodal sensing systems which combine satellite observations with drone monitoring and ground-based IoT sensors generate precise crop and soil data for improved agricultural decisions that reduce uncertainty. The principles enable intelligent irrigation systems to operate water sustainability with effectiveness which results in waste reduction and improved crop production. The technologies use data analysis to produce automated farming systems which connect local communities to traditional manual work beyond standard manual operations. The initiatives offer three main advantages to rural communities because they defend their resources better and boost their ability to manage climate changes and produce better living conditions through increased agricultural output. The new methods show strong promise for the future but they face ongoing challenges because of their monetary needs and network requirements and technical training needs. Smart villages create sustainable farming

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systems through rural infrastructure which unites benefits for local agricultural communities with national food protection and environmental protection goals.

REFERENCES

[1] Anderson, K. (2024). *Detecting Environmental Stress in Agriculture Using Satellite Imagery and Spectral Indices* (Doctoral dissertation, Obafemi Awolowo University).

[2] Barbedo, J. G. A. (2019). A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses. *Drones*, *3*(2), 40.

[3] Yang, Z. X., Li, Y., Wang, R. F., Hu, P., & Su, W. H. (2025). Deep Learning in Multimodal Fusion for Sustainable Plant Care: A Comprehensive Review. *Sustainability (2071-1050)*, *17*(12).

[4] Kior, A., Sukhov, V., & Sukhova, E. (2021, December). Application of reflectance indices for remote sensing of plants and revealing actions of stressors. In *Photonics* (Vol. 8, No. 12, p. 582). MDPI.

[5] Braga, P., Crusiol, L. G. T., Nanni, M. R., Caranhato, A. L. H., Fuhrmann, M. B., Nepomuceno, A. L., ... & Mertz-Henning, L. M. (2021). Vegetation indices and NIR-SWIR spectral bands as a phenotyping tool for water status determination in soybean. *Precision Agriculture*, *22*(1), 249-266.

[6] Lu, B., Dao, P. D., Liu, J., He, Y., & Shang, J. (2020). Recent advances of hyperspectral imaging technology and applications in agriculture. *Remote Sensing*, *12*(16), 2659.

[7] Nathan, G. (2024). *Examination of drone localization performance with commercially available embedded GPS sensors* (Master's thesis, University of Washington).

[8] Ghamisi, P., Rasti, B., Yokoya, N., Wang, Q., Hofle, B., Bruzzone, L., ... & Benediktsson, J. A. (2019). Multisource and multitemporal data fusion in remote sensing: A comprehensive review of the state of the art. *IEEE Geoscience and Remote Sensing Magazine*, *7*(1), 6-39.

[9] Colaço, A. F., & Bramley, R. G. V. (2018). Do crop sensors promote improved nitrogen management in grain crops? Field Crops Research, 218, 126–140.

[10] Ndunagu, J. N., Ukhurebor, K. E., Akaaza, M., & Onyancha, R. B. (2022). Development of a Wireless Sensor Network and IoT-based Smart Irrigation System. *Applied and Environmental Soil Science*, *2022*(1), 7678570.

[11] Rajamoorthy, R., Rajavel, K., Sanjai, J., Seenivasan, P., & Mohamadasansha, A. (2023). Automatic Irrigation System Using Ball Valve. *Journal Of Technical Education*, *9*, 9.

[12] Liao, R., Zhang, S., Zhang, X., Wang, M., Wu, H., & Zhangzhong, L. (2021). Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept. *Agricultural Water Management*, *245*, 106632.

[13] Goap, A., Sharma, D., Shukla, A. K., & Krishna, C. R. (2018). An IoT based smart irrigation management system using Machine learning and open source technologies. *Computers and electronics in agriculture*, *155*, 41-49.

[14] Coates, R. W., Delwiche, M. J., Broad, A., & Holler, M. (2013). Wireless sensor network with irrigation valve control. *Computers and electronics in agriculture*, *96*, 13-22.

[15] Hunter Industries. (n.d.). Residential system overview [Diagram]. Hunter Industries.

ISBN: **978-93-343-9865-6**

[16] Tarate, S. B., Patel, N. R., Danodia, A., Pokhariyal, S., & Parida, B. R. (2024). Geospatial technology for sustainable agricultural water management in india—A systematic review. *Geomatics*, *4*(2), 91-123.

[17] Wang, Y., Zhang, Z., Jia, W., Ou, M., Dong, X., & Dai, S. (2025). A review of environmental sensing technologies for targeted spraying in orchards. *Horticulturae*, *11*(5), 551.

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CREATION, NUTRITIONAL ANALYSIS, AND SENSORY EVALUATION OF A MILLET-HERBAL COMPOSITE FLOUR FROM LOCAL SOURCES TO PROMOTE RURAL HEALTH

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Abstract- In the rural areas often millets are very much readily used and are very popular among the rustics. But these preperations lack essential nutrients and and is generally deprived of balanced diet. Over the years Malnutrition has been one of the greatest enemy of the rustics due to very limited and low access to diverse and affordable food products. " The goal of this research is to create a nutrient-dense, all-purpose flour blend that rural households can readily use in everyday dishes like roti, chapati, khichdi, rice porridge, and more. Ingredients such as finger millet, barnyard millet, black rice, soybeans, pumpkin seeds, and immune-boosting herbs like turmeric, fenugreek leaves, and moringa leaves are used to make the blend of the flour. Our main objective is to raise rural populations nutritional status without forcing them to alter their customs around food preferences or cooking techniques and fostering them to go on with their food habits and inventing a product which is easily acceptable to them. With inexpensive, readily available ingredients, this invention blend provides an effective and workable way to fight malnutrition, boost immunity, and encourage sustainable diets,manage time and costs and labour. Long-term storage of the this flour mixture ensures convenience and preparedness in times of food scarcity or emergency. Nutritional analysis and sensory assessment verify that the mix is very beneficial and acceptable is a very promising and mediation in reinforcing rural health and development.

Keywords: Millet-based nourishment, herbal additives, immunity enhancing, all purpose, fighting malnutrition, long term storage, eco-friendly solutions, resource efficient

I. INTRODUCTION

Millets are a collective term referring to many small-grained cereals (belongs to grass family). They are Gluten-free and nutrient-rich. These are the staple diets of Asian and African countries, especially in developing countries like Mali, Nigeria, and India with 97% of production. The crop is favoured for its productivity and short growing season under hot, dry conditions. They are highly tolerant of drought and other extreme weather conditions and have a similar nutrient content to other major cereals. Millets respond to high moisture and fertility. On a per-hectare basis, millet grain production can be 2 to 4 times higher with use of irrigation and soil supplements. Improved varieties of millet with enhanced disease resistance can significantly increase farm yield.

Millets are known as the oldest food grains known to mankind and are cereal grains used for domestic purposes. Humans consume millets for about 7,000 years and potentially had "a pivotal role in the rise of multi-crop agriculture and settled farming societies". In Indian, nearly 1/3rd the population’s staple diet is millets. According to doctors and scientists, millets are the best choice for nutrition, but rural and conventional people have limited access to them. The nutritional quantity is four to five times elevated than that of staple crops like rice and wheat (Reddy Venkata Ram Teja *et al.*, 2020). Millets are well recognized for their rich content of Niacin, which is essential for maintaining healthy skin and organ function. It has a good content of calcium(0.38%), dietary fiber (18%), and phenolic compounds (0.3-3%) (Palanisamy Bruntha Devi *et al.*, 2014). Millets are highly beneficial to human health. Because of

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the high fiber content in millet, it is an excellent choice for promoting digestive health. It prevents constipation and the risk of colon cancer. It also has the essential fats, which reduce the bad cholesterol and risks of other heart diseases. Millets do not contain allergens, so patients with asthma can go for the millets because they do not cause wheezing. Millets act as an antioxidant because they help to detoxify the human body.

Mostly rural people suffer from poverty, due to which they can't afford a diversified and balanced diet. This is the main reason why rural people suffer from malnutrition. Mostly women and children suffer from Anemia. Also, children suffer from weak bones and stunted growth. Digestion problems and risk of gastrointestinal issues are also seen. Increased rates of lifestyle diseases such as obesity, diabetes, etc. Poor diets lead to increased medical expenses. Without millet cultivation, villagers face a large amount of crop failure, a shortage of staple foods, which leads to dependency on government or market interventions for supplies. This will also lead to monoculture practices that mainly depend on the water-intensive crops such as wheat and rice.

Millet-based foods are highly beneficial for the rural lifestyle. This is because of the following reasons:-

- In addition to being very nutrient-dense (containing fiber, iron, calcium, and vital vitamins), it is also reasonably priced, making it affordable for rural residents with low incomes. Arid regions, drought-prone areas, and less fertile lands—all of which are prevalent in villages—can be used to grow millets
- . The total cost of farming is decreased because they only need a small amount of water and a few inputs, such as pesticides and fertilizers. Consuming millets on a regular basis will reduce lifestyle diseases like obesity and diabetes..Since urban companies always demand healthy and natural foods, villagers are starting niche markets by branding millet products as organic, traditional, and nutritious.
- Producing and selling of millet-based food items will open a large number of income pathways for farmers, women's self-help groups, and rural entrepreneurs.

Now, coming to our research, which mainly focuses on the formulation of the composite flour with an herbal mix. A millet-based composite flour is basically a mixture where various types of millets are combined with other cereals, pulses, or any other type of functional ingredient to increase its nutritional quality and improve its various functional properties. Millets v.i.z Finger millet (ragi), Pearl millet (bajra), Little millet, Branyard millet, Foxtail millet, etc. This composite flour, which is mainly made up of Finger millet, i.e., Ragi (50%), Black rice (15%), Barnyard millet (15%), Black soyabean (15%), Pumpkin seeds (5%). All these elements are rich in Calcium(Ca), Fiber aids, Proteins, Minerals, and Anti-oxidant properties. The addition of 50% of the Finger millet (Ragi) will increase the taste quality and also improve the functional properties. In order to increase the functionality of this flour, we will add an herbal mix. Herbs will support energy metabolism, bone and skin health, and immune function because they are a good source of minerals, vitamins, and antioxidants. Additionally, these herbs will lower the chance of developing long-term conditions like cancer, heart disease, and neurological disorders. Amruthaballi (1.0%), Clove (0.5%), Horagone leaves (2%), Dried ginger (2%), Indian borage (2%), Turmeric (2%), Moringa (1%), Amla (0.5%), and Fenugreek leaves (1.0%) are among the herbs.This composite flour is of great use. These are as follows:-

- Porridge: It can be used as a staple diet, like porridge, and in Gruel. Mixing this flour with water or milk and then cooking it on a low flame will give a delicious porridge.
- Roti/ Chappati/ Flatbread: To make Rotis or Fulkas, knead the flour into a soft dough and roll it out with a little pressure.
- Ladoo/ Energy balls: Giving the flour a round shape and combining it with nuts, ghee, oils, and jaggery will create wholesome, delicious, and nourishing energy balls or ladoos.

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- Dosa /Uttapam: Mixing the composite flour with fermented batter will make a different texture of Dosa and Uttapam.
- Namkeen mixture: Spicy and mouth-watering snacks such as Chakli or Murukku can be made.

Also, the preservation of this flour doesn’t require much struggle. These are as follows:

- Drying and removing the moisture content of the ingredients, as moisture provides a suitable environment for bacterial growth and will lead to spoilage.
- Also, slight roasting of the ingredients will automatically enhance the taste of the flour, leading to a good recipe.

II. STUDIES AND FINDINGS:

Different policy initiatives taken by governments and multilateral agencies have increasingly focused on nutrition, given the high returns from investing in. Despite this increasing interest in nutrition, for many developing countries, there is a dearth of detailed studies focusing on nutrient intake (Haddad et al., 2015). In the context of India, a country with high levels of stunting and wasting, recent national surveys on nutrition suffer from issues of comparability and lack of coverage, particularly for regions with high nutritional deficiencies (John, Knebel, Haddad, & Menon, 2015). This paper uses primary village-level data from a poor region in India to investigate both macro- and micro-nutrient consumption. Specifically, we study the consumption of three macronutrients (calories, protein, and carbohydrates) and two micronutrients (calcium and iron). In addition to quantifying the level of nutritional intake in the village, we examine the causal factors that impact nutrient consumption.

TABLE: Parameters affecting nutritional Intake in Rustics.

PARAMETERS	PERCENTAGE	OBSERVATION
Households dependent on cereals	95%	Rice and wheat are the primary staple foods
Low protein intake	68%	The majority were reported to have limited access to pulses or animal proteins
Millet is awared but lacks usage of them	52%	Millets are seen as traditional, but are inconvenient to cook
Open to trying new mixes and recipes when offered	74%	Most rustics have a positive response to trying new products when they are affordable and easily usable
Facing Storage issues	81%	Lack of proper storage leading to food spoilage resulting to economic harm

Elaborate statistics on the households' inatke of the different food categories were studied and researched. Bulk of food consumption mainly occupied by cereals and vegetables. Among the major food groups, meat, eggs, and fish together have the lowest average monthly levels of consumption at just 0.61 kg.

A survey found that a very large and significant percentage of people lack essential nutrients, particularly proteins, iodines, vitamins, minerals, iron, and calcium. Approximately 68% of people in the countryside were reported to have insufficient protein intake, while 52% showed a lack of awareness about sources of essential vitamins and minerals Notably, women and children suffer the most. This poor diet aggravates fatigue, malnutrition, and other conditions. Millets are ancient grains that have been cultivated for many years and are renowned for their high nutritional content, climate adaptability, and tough resilience against all environmental stressors and strains. Despite being traditional sources, they

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are sometimes disregarded in modern diets, especially in rural areas where malnutrition is still a problem. However, they are now playing a crucial role in improving food security, sustainability, and health. Millets like finger millet (ragi), little millet, and foxtail millet can greatly improve the health of people who are already at risk because they are very high in important nutrients like iron, calcium, fiber, and protein. Finger millet is described as imthe most nutritious among all the major cereals and was nominated as super cereal yunited states of national academics [Andargie, et al. 2024].

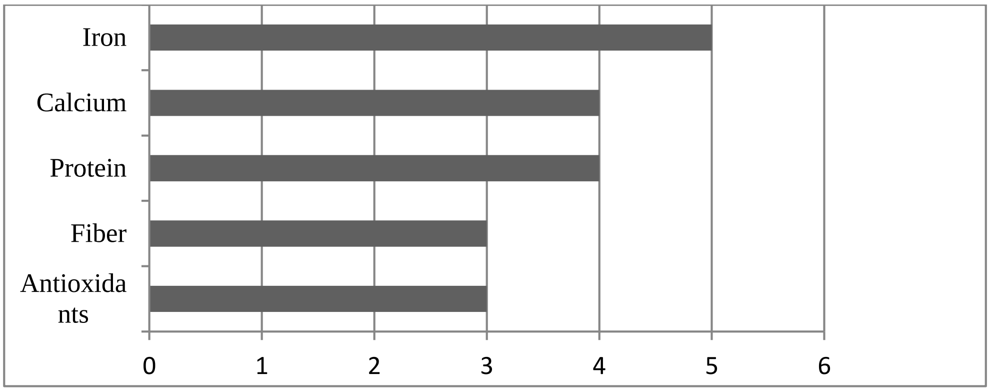

Table: Nutritional content of various Millets.

The scale of the graph represents arbitrary values from 0 to 6 where the greater value implies greater nutritional content and vice versa.

Formulation of Finger Based Millet Flour Mix:

For the preparation of the flour finger millet-based composite flour mix, finger millet was substituted with other ingredients such as black soya bean, black rice, barnyard millet, and pumpkin seeds. Each of the ingredients was cleaned, dried, and powdered separately to prepare the flour mix. Then all the herbs used in the mixture were prepared by removing the moisture content and drying them. Then the powdered ingredients were measured at different levels and were incorporated at different proportions in the flour. The flour was developed by substituting finger millet at different ratios (70:30; 60:40,50:50, 40:60). The Best composition was identified according to taste, texture, and nutritional value. Developed mixes were analysed, and gruel was prepared for sensory analysis, and the Nutritive value of the best was taken and subjected to the herbal mixture.

Table.1. Formulation of the Composite Flour Mix

Ingredients	**CFT1 (70:30)**	**CFT2 (40:60)**	**CFT3 (50:50)**	**CFT4 (40:60)**	**Nutitional Value**
Finger Millet	70	60	50	40	High in Calcium
Black Rice	15	15	15	15	Iron, antioxidants and fibre
Barnyard millet	5	10	15	20	Fibre, Iron, Magnesium
Black Soyabean	5	10	15	20	Protein, fibre, folate
Pumpkin seeds	5	5	5	5	Healthy fats zinc Mg

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Functional properties such as oil absorption capacity,water absorption capacity, swelling power, and swelling capacity were analyzed for finger millet-based and wheat-based composite flour to select the best combination.

III. DEVELOPMENT OF HERBAL MIXTURE:

Development of Herbal mix: Different herbs such as Amruthaballi, Honagone leaves, Indian borage, turmeric, dried ginger were procured. Herbs were cleaned and dried to remove moisture content. Further the herbs made into fine powder by using mixer and sieved with mesh size (212 µm).

Table:- Various Composition of Herbal Mixture

Herbs	HMT1	HMT2	HMT3	Nutritional value
Amruthaballi	1.75	1.5	1.0	Rich in antioxidants Vitamin A and C
Honagone leaves	2	2	2	Iron, fibre and antioxidants
Dried Ginger	2	2	2	Anti-inflammatory aids digestion
Indian Borage	2	2	2	Essential oils, Respiratory Health
Turmeric	2	2	2	Curcumin, Anti-inflammatory ,Antioxidants
Moringa Leaves	1.5	1.0	1.5	Protein, Calcium, Iron Vitamin C
Fenugreek Leaves	1.0	1.5	1.0	Fiber, Iron, helps regulate blood sugar.

Herbal mix was standardized by adding selected herbs with different composition (Table 2) and product was evaluated for sensory evaluation by using nine point hedonic scale. Further best composition was selected for best yield subjected for sensory evaluation by a group of 15 trained panel members in the form of kashaya.

IV. CONCLUSION

This research study demonstrates the significant potential in enhancing the nutrient profile, functional properties, and health advantages of conventional cereal-based This research study on millet-based composite flour incorporated with herbal products. Since millet is rich in dietary fiber, iron, protein, calcium, essential minerals, and bioactive compounds, when combined with the therapeutic properties of several herbs, it creates a perfect blend that can help alleviate malnutrition, enhance immunity, and offer preventive benefits against lifestyle diseases. This composite flour formulation exhibits good physical characteristics, acceptable sensory attributes, and increased nutrient density, making it suitable for a wide range of food applications. Additionally these blends encourages the use of underutilized crops, supports sustainable agriculture, and presents chances for value addition in both urban and rural food systems. Furthermore, the use of herbs and millet promotes biodiversity and the blending of traditional eating customs with contemporary diets. All things considered, millet-based herbal composite flour is a promising ingredient for functional foods that fits in with current nutritional needs and health trends, promoting improved dietary interventions, food security, and the creation of functional foods.

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REFERENCES:

1. Andargie, Melkamu & Abera, Merkuz & Alemu, Tesfaye & Bekele, Berhanu. (2024). Screening of Finger Millet Genotypes for Resistance to Magnaporthe grisea in Northwestern Ethiopia. International Journal of Phytopathology. 13. 251-266. 10.33687/phytopath.013.03.5423.
2. Devi PB, Vijayabharathi R, Sathyabama S, Malleshi NG, Priyadarisini VB. Health benefits of finger millet (Eleusine coracana L.) polyphenols and dietary fiber: a review. J Food Sci Technol. 2014 Jun;51(6):1021-40. doi: 10.1007/s13197-011-0584-9. Epub 2011 Nov 22. PMID: 24876635; PMCID: PMC4033754.
3. Dutta, Indranil & Kapoor, Shruti & Pattanaik, Prasanta. 2020). Evidence from a village study on nutrient consumption in India. 10.1111/rode.12679. Review of Development Economics, 24. 855-877.
4. FAO (Food and Agriculture Organization of the United Nations). (2019). "The State of Food Security and Nutrition in the World."
5. Sharma, H., Kumar, P., Verma, J., et al. (2017). "Nutritional and Functional Properties of Millets and Their Utilization in Value-Added Products." Journal of Food Science and Technology, 54(8), 2366–2376.
6. Reddy, Ram Teja & Bisarya, Dipti. (2020). General Review of major, minor millets nutrient composition, Production and bioavailability.
7. Saleh, A.S.M., Zhang, Q., Chen, J., Shen, Q. (2013). "Millet Grains: Nutritional Quality, Processing, and Potential Health Benefits." Comprehensive Reviews in Food Science and Food Safety, 12(3), 281–295.
8. Sharma, S., Kumar, V., Prasad, K. (2018). "Effect of Processing on Nutritional Profile of Millets." International Journal of Food Science and Nutrition.
9. USDA FoodData Central. US Department of Agriculture. Available online: https://fdc.nal.usda.gov/
10. Kumar, V., Singh, A., & Chauhan, G. S. (2021). "A Review of the Nutritional Content and Health Advantages of Millets." 1793–1805 in Journal of Food Science and Technology, 58(5). https://doi.org/10.1007/s13197-020-04758-4
11. Saleh, A. S. M., Kamarudin, N., & Jabran, M. A. (2020). "An Overview of Millet Grain Processing Methods and Nutritional Value." Nutrition and Food Science, 8(5), 2334–2343. 10.1002/fsn3.1567 https://doi.org
12. Singhal, R. S., and V. S. Nambiar (2018). "Millets as Functional Foods: Uses and Preparation." Cereal Science Journal, 81, 1–9. https://doi.org/10.1016/j.jcs.2018.03.005

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Precision in Prediction: Feature-Driven Early Diagnosis of PCOS

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Abstract- Polycystic Ovarian Syndrome (PCOS) is one of the most prevalent endocrine ailments that affect women in childbearing years, traditionally defined by hormonal abnormality, irregular menstruation, infertility, and metabolic disorder. Proper and timely diagnosis is indispensable for impending treatment. These addresses exploring the feasibility of applying a range of machine learning (ML) approaches towards PCOS diagnosis, ranging from clinical, physiological, and lifestyle factors. A publicly accessible dataset is preprocessed first by dealing with missing values and normalisation, and then later feature selection using Recursive Feature Elimination (RFE) and mutual information. Responsible use of data is aimed at by the use of privacy-preserving preprocessing techniques, thus following data protection law and ethical use of AI. Multiple ML algorithms such as Logistic Regression, Support Vector Machines, Random Forest, Decision Trees, and Gradient Boosting are compared on the performance metrics such as precision, accuracy, recall, and F1-score. The ensemble models are illustrated to outperform due to their energy benefits and potential for identifying complex patterns. The guidelines include utilizing ML in the initial diagnosis of PCOS and confidentiality for sensitive information, with a progress towards the ethical application of forecasting technology in the health sector.

Keywords- PCOS Diagnosis, Machine Learning in Healthcare, Recursive Feature Elimination, Women's Health

I. INTRODUCTION

Polycystic Ovarian Disorder (PCOD), also known as Polycystic Ovary Syndrome (PCOS), is one of the most common endocrine disorders in childbearing women. It typically presents with irregular menstrual bleeding, hormonal imbalance, infertility, and metabolic imbalance, i.e., insulin resistance and type 2 diabetes [1], [2]. Early appropriate diagnosis and management are of utmost importance to prevent long-term consequences and improve quality of life [3]. With better availability of health information and electronic medical records, machine learning (ML) models have become useful instruments in the identification of PCOD patterns from heterogeneous clinical,

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physiological, and lifestyle parameters [4], [5]. Contemporary algorithms like Support Vector Machines, Random Forests, Gradient Boosting, and Convolutional Neural Networks have been found to be highly promising in computer-aided diagnosis of PCOD with remarkable accuracy[6][9]. In either case, the employment of sensitive wellbeing data entails essential challenges regarding data security, ethical considerations, and intellectual property rights (IPR). Models developed using durable records have to adhere to security controls and ethical AI practices for deflecting unauthorized information presentation and protecting individual wellbeing information [10], [11]. Integrative learning and privacy-preserving AI systems are becoming more common as they facilitate collaborative show preparation without requiring coordinate data sharing, which reduces protection risks [10]. The dissemination and use of AI demonstrative models also need to respect IPR, particularly where they are developed with constraining datasets or computations.

Analysts and engineers ought to investigate authorizing frameworks, meet open-source requirements where required, and advocate for simplicity when it comes to the use of information [15], [17]. moral sending involves both good development and the need for possession rights in AI applications. This is done considering references to citation in order to evaluate some ML models for PCOD early detection using an open-data available dataset, focusing on ethical information care management, privacy-sensitive preprocessing, and highlight selection by using Recursive Feature Elimination (RFE) with common data. Comparative execution measurement against Calculated Relapse, Choice Trees, SVM, and collection models is quantified using metrics like exactness, accuracy, review, and F1-score. Our research envisions the use of secure, understandable, and IPR-compatible AI systems to aid doctors in early diagnosis of PCOD as well as the overall advanced revolutionization of healthcare.

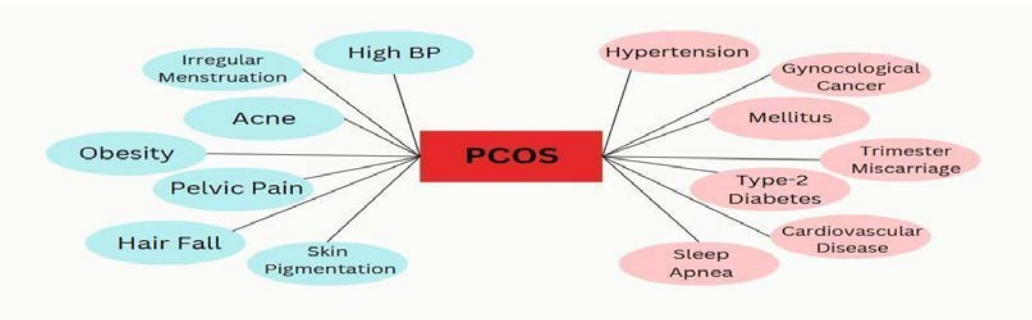

Fig 1: Symptoms and Associated Health Risks

II. LITERATURE REVIEW

Polycystic Ovary Disease, also referred to as Polycystic Ovary Disorder (PCOS), may be a common endocrine disorder found in women of reproductive age that presents with a range of clinical manifestations including anovulation, hyperandrogenism, and polycystic ovaries [1]. Patients commonly intertwine side effects such as irregular monthly menstrual cycle, acne on the skin, hirsutism, and weight gain that always lead to infertility and augmented risks for type II diabetes and cardiovascular infections [2]. PCOS is still difficult to diagnose with masking signs by other diseases and quiet- to-patient variability. Conventional symptomatic management comprises

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hormonal testing and ultrasound of the pelvis, primarily based on the Rotterdam criteria, which demand two of three evidential evidences of anovulation, hyperandrogenism, or polycystic ovaries [3][4]. Despite this, hand counting of follicles with ultrasound is avoided by hurdles in the form of dot commotion, moo differentiate, and administrator dependence. In light of these constraints, machine learning (ML) and deep learning (DL) techniques came to the forefront to enable computerized PCOS diagnosis. Convolutional Neural Networks (CNNs) are increasingly applied to feature extraction and boundary identification of ovarian follicles from ultrasound images with the motivation towards improved accuracy over the traditional image processing techniques [5][7]. In more complex follicle segmentation, sophisticated preprocessing steps such as despeckling, differentiation enhancement, and morphological processing support. More sophisticated techniques like Otsus thresholding, Chan Vese dynamic shape models, and PSO-based optimization have been related for boundary extraction and image sharpening [8]. As research on PCOS advances, attention shifted to building interpretable and privacy-conscious models. Reasonable AI is fundamental to clinical conviction and ethical sending, especially in decision-support illustrations [9]. Incorporating learning manages security concerns through decentralized demonstrate getting ready without sharing raw knowledge data between teach [10]. PCOS area incorporated into electronic wellbeing record (EHR) frameworks enhances real-time analytics and choice support [11], [12]. Mobile health apps may also employ Light DL models to improve diagnostic access to rural or underserved communities. With all these advancing technologies, ML/DL models should supplement but not supplant clinical decisions. Responsible and well-informed utilization of AI tools through training remains paramount [13]. Emerging PCOS diagnostic technologies remain promising in personalization, reduction of errors in diagnostics, and acceleration of intervention [14], [15]. Future work should resolve challenges around the availability of data, model interpretability, and clinical integration in order to provide scalable and responsible deployment [16], [17].

III. METHODOLOGY

This research intends to predict Polycystic Ovary Syndrome (PCOS) using machine learning algorithms at some key stages:

i. Data Collection: Two open-source data sets on Kaggle were combined to form a merged data set of 44 clinical and demographic features (e.g., insulin, BMI, follicles, hormone markers) for a total of 3,081 records.

ii. Data Processing: In terms of data quality and model preparation, the following actions were undertaken:

Missing Value Handling: Eight null values were recognized and handled, sanitizing the dataset to 3,073 complete records.

Feature Selection: By statistical processing, the top 10 relevant features were selected for improved model performance.

Encoding: Categorical attributes were encoded in numerical representation through Label Encoding.

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Scaling: MinMaxScaler was used to scale numeric attributes within a specified range.

Exploratory Data Analysis (EDA): Visual aids (bar chart, histogram, heatmap) and correlation tables pointed to significant trends and important predictors of PCOS.

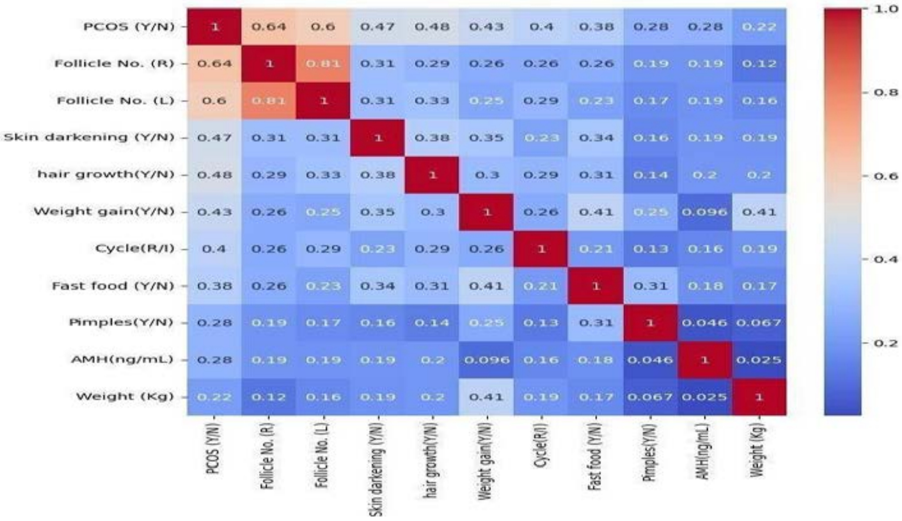

Fig 2: Features for PCOS prediction using Heatmap

iii. Data Visualization: There was a visual check to obtain information regarding feature distribution and class balance. Histograms were employed to investigate major numerical features like TSH, BMI, and Weight. A pie chart was plotted to illustrate the ratio of PCOS versus non-PCOS cases, and a bar chart was employed to illustrate the frequency of PCOS in various age groups based on the constructed "Age Group" feature.

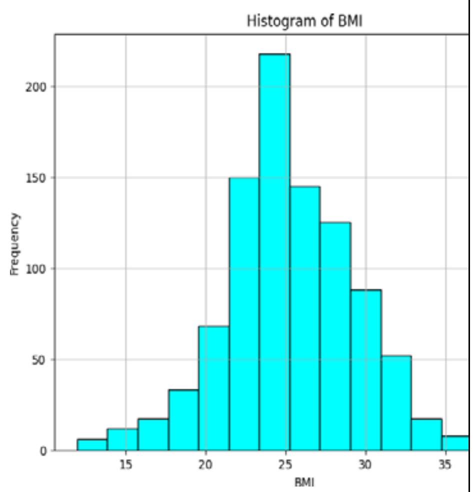

Fig 3: Histogram of BMI

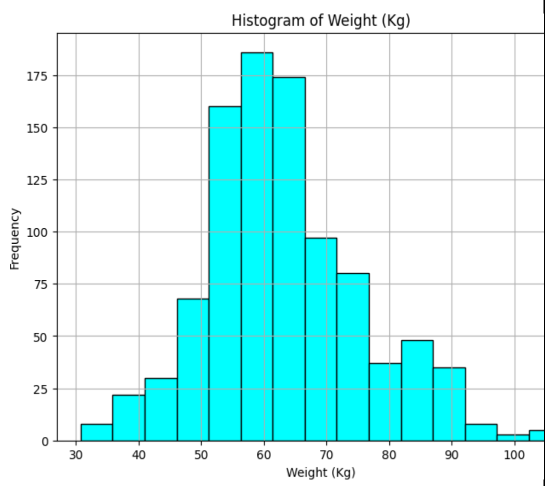

Fig 4: Histogram of Weight

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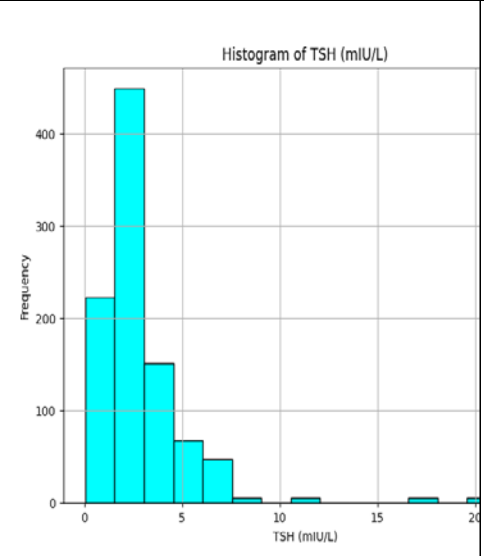

Fig 5: Histogram of TSH

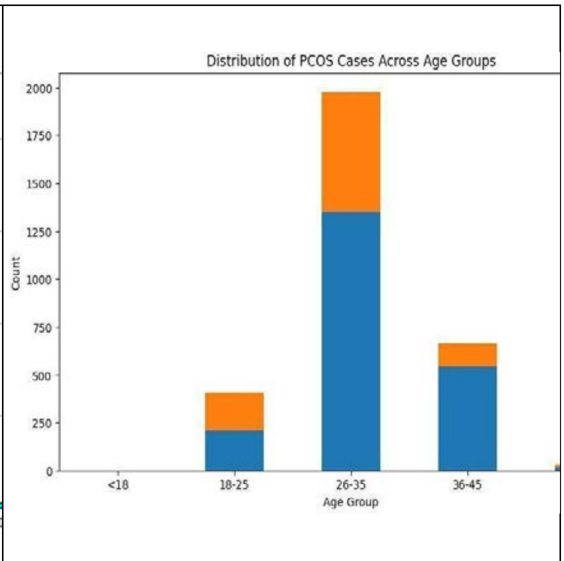

Fig 6: Distribution of PCOS Cases across Age Groups.

Feature selection was done using a correlation matrix to confirm correlations of variables and the target label (PCOS Y/N). The top 10 features highly correlated with PCOS like hormone level, number of follicles, skin darkening, and hair growth were chosen. Apart from this, an engineered feature, "Age Group," was included to enable better trend visualization based on domain knowledge. Various models of classification were used, such as Logistic Regression, Naive Bayes, Decision Tree, Support Vector Machine (SVM), and K-Nearest Neighbors (KNN). These models were trained on the preprocessed dataset using hyperparameter optimization if needed. Model performance was calculated using Accuracy, Precision, Recall, and F1-score to measure performance under balanced and imbalanced data conditions. Confusion matrix was used in plotting true vs. false predictions and classification errors for all the classes.

IV. RESULTS AND DISCUSSION

Five machine learning algorithms—Naive Bayes, Logistic Regression, Support Vector Machine (SVM), K-Nearest Neighbors (KNN), and Decision Tree—were compared on the basis of basic classification metrics: accuracy, precision, recall, and F1-score.The best-performing model out of the ones tested was the Decision Tree classifier, which achieved 99.68% accuracy and a perfect 100% F1-score, showing its incredible capability to effectively classify both PCOS-positive and PCOS-negative instances. The model's strength is its explainability and ability to handle difficult non-linear feature interactions, which is imperative in medical diagnosis.

The K-Nearest Neighbors (KNN) model also performed well, at 97.89% accuracy and 98% F1-score, and as such is a strong contender for a genuine alternative since it has high specificity and sensitivity. SVM followed closely behind at 93.67% accuracy and 94% F1-score, having good generalization across various PCOS profiles. Logistic Regression was acceptable with 91.38% accuracy and a 91% F1-score, best trading performance for interpretability if features are linearly correlated with each other. Naive Bayes, though computation efficient and friendly, had 89.77% accuracy and a 90% F1-score and is hence an appropriate baseline but not as optimal for complex

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feature interactions. Examination of the confusion matrix reinforced these findings even further. Decision Tree and KNN models performed best with virtually negligible misclassification rates.

SVM and Logistic Regression logged higher false negatives, which may end up under-identifying PCOS-positive instances. Naive Bayes fared well in negative class precision but lagged in positive class identification. This comparative study highlights that tree-based models, and more so Decision Trees, are extremely effective for PCOS prediction problems, especially when diagnostic attributes are both clinical and categorical. Nevertheless, class skewness, overfitting vulnerability, and data variability call for additional confirmation through ensemble methods and clinical information. Overall, the findings substantiate the promise of ML models, in this case interpretable models such as Decision Trees, to facilitate early PCOS diagnosis, alleviate clinicians' workload, and facilitate data-driven and scalable screening within healthcare systems.

Model	Accuracy	Loss (100% - Accuracy)
Naive Bayes	89.77%	10.23%
Logistic Regression	91.38%	8.62%
SVM	93.67%	6.33%
KNN	97.89%	2.11%
Decision Tree	99.68%	0.32%

Table 1: Comparison of Model Accuracy and Corresponding Loss

V. SUMMARY OF KEY FINDINGS AND LIMITATIONS

Decision Tree classifier was the top-classifier in diagnosing PCOS with near-perfect accuracy rate of 99.68% and 100% precision and F1-score. The highest-ranked was also K-Nearest Neighbors with 97.89% accuracy and high sensitivity. SVM also performed well with 93.67% accuracy rate, which was excellent in identifying negative cases, then Logistic Regression and Naive Bayes with medium-rankings. All the models had a balance between precision and recall that gave the advantages and disadvantages of various methods. Logistic Regression performed well for linear trends; SVM identified multi-dimensional relationships but weren't interpretable; Naive Bayes was effective but lost on feature independence assumptions; KNN was effective for non-linear data but computationally costly; and Decision Trees struck a balance between interpretability and effectiveness but suffered from overfitting. There are challenges yet to be tackled despite these advances. Decision Trees suffer from noise, imbalance, and feature correlation in the data, causing bias and instability. Overfitting can occur if there is no pruning or ensemble learning. Variability in diagnostic tests, limited high-quality annotated clinical data availability, and privacy matters also hinder large-scale clinical deployment. Class imbalance and use of privacy-protected, standardized datasets need to be addressed to enable the creation of solid, generalizable PCOS prediction models.

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VI. FUTURE SCOPE

The PCOD diagnosis of the future is at the intersection of smart, privacy-aware, and transparent AI systems. Multimodal deep learning models will bridge medical data with ultrasound scans to detect implicit correlations and improve diagnostic accuracy. In place of the availability of labelled medical information, self-supervised and semi-supervised learning will facilitate proper training from unlabelled data. Explainable AI (XAI) techniques such as Grad-CAM and feature attribution will be the most important in maximizing transparency, ensuring clinical acceptance, and enabling legal compliance.

Bedside stations and mobile devices will aid the integration, offering real-time diagnosis of PCOD with real-time intelligence to doctors. Generative adversarial networks (GANs) will create surrogate data to augment rare and underrepresented diseases, maximizing models without a breach of patient confidentiality and intellectual property. Follow-up with AI systems along the longitudinal axis will allow early treatment and management of chronic diseases. Third, processing of 3D ultrasound images will achieve maximum diagnostic accuracy through better anatomical information. Last, crowdsourced data collection using secure mobile platforms will allow global strong models to be built without compromising privacy and ethical AI guidelines.

VII. CONCLUSION

Polycystic Ovarian Disease (PCOD) is a common endocrine disease in a large percentage of women of reproductive age, resulting in hormonal deregulation, anovulatory cycles, infertility, and severe metabolic complications. PCOD diagnosis is of the utmost importance at an early and precise stage in PCOD management and for patient outcomes. The research investigated applying different machine learning (ML) algorithms in facilitating early detection through classification of clinical, physiological, and lifestyle factors.

The dataset, accessed from open sources, was subjected to rigorous preprocessing such as handling missing values and normalization before their application with sophisticated feature selection techniques like Recursive Feature Elimination (RFE) and mutual information. This process ensured both model stability and data validity. Comparative studies of ML classifiers such as Logistic Regression, SVM, Decision Tree, KNN, and Gradient Boosting identified tree-based methods such as Decision Tree and KNN as superior to others in that they were powerful in representing complex non-linear patterns.

REFERENCES

1. A. E. B. S. L. Atkin, 4 Lifestyle: Metabolic Syndromes—Type 2 Diabetes, Metabolic Syndrome and Polycystic Ovary Syndrome in the Arabian Gulf, in Healthcare in the Arabian Gulf and Greater Middle East: A Guide for Healthcare Professionals, E- book, p. 38, 2023.

2. N. Minocha, “Polycystic Ovarian Disease or Polycystic Ovarian Syndrome: How to Identify and Manage—A Review,” Archives of Pharmacy Practice, vol. 11, no. 2, pp. 102–106, 2020.

ISBN: **978-93-343-9865-6**

3. C. C. Douglas and J. U. Rojo, "Population and Diagnostic Characteristics of Polycystic Ovary Syndrome and Hyperandrogenism," Women's Health Reports, vol. 5, no. 1, pp. 945–953, 2024.

4. S. Reka, K. Mohan, and T. S. Praba, "Prompt Diagnosis of Polycystic Ovary Syndrome Using Ultrasonography – A Machine Learning Approach," in AIP Conf. Proc., vol. 3031, no. 1, Apr. 2024.

5. S. A. Suha and M. N. Islam, "An Extended Machine Learning Technique for Polycystic Ovary Syndrome Detection Using Ovary Ultrasound Image," Scientific Reports, vol. 12, no. 1, p. 17123, 2022.

6. R. A. Diptho, N. Jahan, T. Istiyaq, F. Anika, and M. I. Hossain, "PCOS Diagnosis with Confluence CNN: A Revolution in Women's Health," in Proc. 26th Int. Conf. on Computer and Information Technology (ICCIT), Dec. 2023, pp. 1–5.

7. C. Gopalakrishnan and M. Iyapparaja, "Multilevel Thresholding Based Follicle Detection and Classification of Polycystic Ovary Syndrome from Ultrasound Images Using Machine Learning," Int. J. of System Assurance Engineering and Management, pp. 1–8, 2021.

8. A. A. Nazarudin, N. Zulkarnain, S. S. Mokri, W. M. D. W. Zaki, and A. Hussain, "An Implementation of Otsu Thresholding and the Chan–Vese Method on the PCO Segmentation of Ultrasound Images," in Proc. 2nd Int. Conf. on Electrical, Control and Instrumentation Engineering (ICECIE), Nov. 2020, pp. 1–9.

9. V. V. Khanna et al., "A Distinctive Explainable Machine Learning Framework for Detection of Polycystic Ovary Syndrome," Applied System Innovation, vol. 6, no. 2, p. 32, 2023.

10. L. Morris, T. Qiu, and N. Raghuraman, "Federated Learning on Patient Data for Privacy-Protecting Polycystic Ovary Syndrome Treatment," arXiv preprint arXiv:2308.11220, 2023.

11. Z. Zad et al., "Predicting Polycystic Ovary Syndrome with Machine Learning Algorithms from Electronic Health Records," Frontiers in Endocrinology, vol. 15, p. 1298628, 2024.

12. E. Nsugbe, "An Artificial Intelligence-Based Decision Support System for Early Diagnosis of Polycystic Ovaries Syndrome," Healthcare Analytics, vol. 3, p. 100164, 2023.

13. T. Jha, M. Sirisha, and M. S. Bhargavi, "Ovulytics: A Machine Learning Approach for Precision Diagnosis of PCOD and Infertility," in Proc. 1st Int. Conf. for Women in Computing (InCoWoCo), Nov. 2024, pp. 1–7.

14. F. J. Barrera et al., "Application of Machine Learning and Artificial Intelligence in the Diagnosis and Classification of Polycystic Ovarian Syndrome: A Systematic Review," Frontiers in Endocrinology, vol. 14, p. 1106625, 2023.

15. S. Aminizadeh et al., "Opportunities and Challenges of Artificial Intelligence and Distributed Systems to Improve the Quality of Healthcare Service," Artificial Intelligence in Medicine, vol. 149, p. 102779, 2024.

16. G. U. Mahesswari and P. U. Maheswari, "SmartScanPCOS: A Feature-Driven Approach

ISBN: **978-93-343-9865-6**

to Cutting-Edge Prediction of Polycystic Ovary Syndrome Using Machine Learning and Explainable Artificial Intelligence," 2024. [Unpublished/Preprint]

17. P. Verma, P. Maan, R. Gautam, and T. Arora, "Unveiling the Role of Artificial Intelligence (AI) in Polycystic Ovary Syndrome (PCOS) Diagnosis: A Comprehensive Review," Reproductive Sciences, vol. 31, no. 10, pp. 2901–2915, 2024.

18. S. Thorat et al., "Prognosis of Polycystic Ovary Syndrome (PCOS) by Its Symptoms and Rotterdam Criteria," in Proc. Int. Conf. on Circuit Power and Computing Technologies (ICCPCT), Aug. 2023, pp. 1270–1274.

19. S. A. Suha and M. N. Islam, "A Systematic Review and Future Research Agenda on Detection of Polycystic Ovary Syndrome (PCOS) with Computer-Aided Techniques," Heliyon, vol. 9, no. 10, 2023.

20. J. Liu et al., "Measuring the Global Disease Burden of Polycystic Ovary Syndrome in 194 Countries: Global Burden of Disease Study 2017," Human Reproduction, vol. 36, no. 4, pp. 1108–1119, 2021.

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CREATION, NUTRITIONAL ANALYSIS, AND SENSORY EVALUATION OF A MILLET-HERBAL COMPOSITE FLOUR FROM LOCAL SOURCES TO PROMOTE RURAL HEALTH

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Abstract- In the rural areas often millets are very much readily used and are very popular among the rustics. But these preperations lack essential nutrients and and is generally deprived of balanced diet. Over the years Malnutrition has been one of the greatest enemy of the rustics due to very limited and low access to diverse and affordable food products. " The goal of this research is to create a nutrient-dense, all-purpose flour blend that rural households can readily use in everyday dishes like roti, chapati, khichdi, rice porridge, and more. Ingredients such as finger millet, barnyard millet, black rice, soybeans, pumpkin seeds, and immune-boosting herbs like turmeric, fenugreek leaves, and moringa leaves are used to make the blend of the flour. Our main objective is to raise rural populations nutritional status without forcing them to alter their customs around food preferences or cooking techniques and fostering them to go on with their food habits and inventing a product which is easily acceptable to them. With inexpensive, readily available ingredients, this invention blend provides an effective and workable way to fight malnutrition, boost immunity, and encourage sustainable diets,manage time and costs and labour. Long-term storage of the this flour mixture ensures convenience and preparedness in times of food scarcity or emergency. Nutritional analysis and sensory assessment verify that the mix is very beneficial and acceptable is a very promising and mediation in reinforcing rural health and development.

Keywords: Millet-based nourishment, herbal additives, immunity enhancing, all purpose, fighting malnutrition, long term storage, eco-friendly solutions, resource efficient

V. INTRODUCTION

Millets are a collective term referring to many small-grained cereals (belongs to grass family). They are Gluten-free and nutrient-rich. These are the staple diets of Asian and African countries, especially in developing countries like Mali, Nigeria, and India with 97% of production. The crop is favoured for its productivity and short growing season under hot, dry conditions. They are highly tolerant of drought and other extreme weather conditions and have a similar nutrient content to other major cereals. Millets respond to high moisture and fertility. On a per-hectare basis, millet grain production can be 2 to 4 times higher with use of irrigation and soil supplements. Improved varieties of millet with enhanced disease resistance can significantly increase farm yield.

Millets are known as the oldest food grains known to mankind and are cereal grains used for domestic purposes. Humans consume millets for about 7,000 years and potentially had "a pivotal role in

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the rise of multi-crop agriculture and settled farming societies". In Indian, nearly 1/3rd the population's staple diet is millets. According to doctors and scientists, millets are the best choice for nutrition, but rural and conventional people have limited access to them. The nutritional quantity is four to five times elevated than that of staple crops like rice and wheat (Reddy Venkata Ram Teja *et al.*, 2020). Millets are well recognized for their rich content of Niacin, which is essential for maintaining healthy skin and organ function. It has a good content of calcium(0.38%), dietary fiber (18%), and phenolic compounds (0.3-3%) (Palanisamy Bruntha Devi *et al.*, 2014). Millets are highly beneficial to human health. Because of the high fiber content in millet, it is an excellent choice for promoting digestive health. It prevents constipation and the risk of colon cancer. It also has the essential fats, which reduce the bad cholesterol and risks of other heart diseases. Millets do not contain allergens, so patients with asthma can go for the millets because they do not cause wheezing. Millets act as an antioxidant because they help to detoxify the human body.

Mostly rural people suffer from poverty, due to which they can't afford a diversified and balanced diet. This is the main reason why rural people suffer from malnutrition. Mostly women and children suffer from Anemia. Also, children suffer from weak bones and stunted growth. Digestion problems and risk of gastrointestinal issues are also seen. Increased rates of lifestyle diseases such as obesity, diabetes, etc. Poor diets lead to increased medical expenses. Without millet cultivation, villagers face a large amount of crop failure, a shortage of staple foods, which leads to dependency on government or market interventions for supplies. This will also lead to monoculture practices that mainly depend on the water-intensive crops such as wheat and rice.

Millet-based foods are highly beneficial for the rural lifestyle. This is because of the following reasons:-

- In addition to being very nutrient-dense (containing fiber, iron, calcium, and vital vitamins), it is also reasonably priced, making it affordable for rural residents with low incomes. Arid regions, drought-prone areas, and less fertile lands—all of which are prevalent in villages—can be used to grow millets
- . The total cost of farming is decreased because they only need a small amount of water and a few inputs, such as pesticides and fertilizers. Consuming millets on a regular basis will reduce lifestyle diseases like obesity and diabetes..Since urban companies always demand healthy and natural foods, villagers are starting niche markets by branding millet products as organic, traditional, and nutritious.
- Producing and selling of millet-based food items will open a large number of income pathways for farmers, women's self-help groups, and rural entrepreneurs.

Now, coming to our research, which mainly focuses on the formulation of the composite flour with an herbal mix. A millet-based composite flour is basically a mixture where various types of millets are combined with other cereals, pulses, or any other type of functional ingredient to increase its nutritional quality and improve its various functional properties. Millets v.i.z Finger millet (ragi), Pearl millet (bajra), Little millet, Branyard millet, Foxtail millet, etc. This composite flour, which is mainly made up of Finger millet, i.e., Ragi (50%), Black rice (15%), Barnyard millet (15%), Black soyabean (15%), Pumpkin seeds (5%). All these elements are rich in Calcium(Ca), Fiber aids,

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Proteins, Minerals, and Anti-oxidant properties. The addition of 50% of the Finger millet (Ragi) will increase the taste quality and also improve the functional properties. In order to increase the functionality of this flour, we will add an herbal mix. Herbs will support energy metabolism, bone and skin health, and immune function because they are a good source of minerals, vitamins, and antioxidants. Additionally, these herbs will lower the chance of developing long-term conditions like cancer, heart disease, and neurological disorders. Amruthaballi (1.0%), Clove (0.5%), Horagone leaves (2%), Dried ginger (2%), Indian borage (2%), Turmeric (2%), Moringa (1%), Amla (0.5%), and Fenugreek leaves (1.0%) are among the herbs.This composite flour is of great use. These are as follows:-

- Porridge: It can be used as a staple diet, like porridge, and in Gruel. Mixing this flour with water or milk and then cooking it on a low flame will give a delicious porridge.
- Roti/ Chappati/ Flatbread: To make Rotis or Fulkas, knead the flour into a soft dough and roll it out with a little pressure.
- Ladoo/ Energy balls: Giving the flour a round shape and combining it with nuts, ghee, oils, and jaggery will create wholesome, delicious, and nourishing energy balls or ladoos.
- Dosa /Uttapam: Mixing the composite flour with fermented batter will make a different texture of Dosa and Uttapam.
- Namkeen mixture: Spicy and mouth-watering snacks such as Chakli or Murukku can be made.

Also, the preservation of this flour doesn’t require much struggle. These are as follows:

- Drying and removing the moisture content of the ingredients, as moisture provides a suitable environment for bacterial growth and will lead to spoilage.
- Also, slight roasting of the ingredients will automatically enhance the taste of the flour, leading to a good recipe.

VI. STUDIES AND FINDINGS:

Different policy initiatives taken by governments and multilateral agencies have increasingly focused on nutrition, given the high returns from investing in. Despite this increasing interest in nutrition, for many developing countries, there is a dearth of detailed studies focusing on nutrient intake (Haddad et al., 2015). In the context of India, a country with high levels of stunting and wasting, recent national surveys on nutrition suffer from issues of comparability and lack of coverage, particularly for regions with high nutritional deficiencies (John, Knebel, Haddad, & Menon, 2015). This paper uses primary village-level data from a poor region in India to investigate both macro- and micro-nutrient consumption. Specifically, we study the consumption of three macronutrients (calories, protein, and carbohydrates) and two micronutrients (calcium and iron). In addition to quantifying the level of nutritional intake in the village, we examine the causal factors that impact nutrient consumption.

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TABLE: Parameters affecting nutritional Intake in Rustics.

PARAMETERS	PERCENTAGE	OBSERVATION
Households dependent on cereals	95%	Rice and wheat are the primary staple foods
Low protein intake	68%	The majority were reported to have limited access to pulses or animal proteins
Millet is awared but lacks usage of them	52%	Millets are seen as traditional, but are inconvenient to cook
Open to trying new mixes and recipes when offered	74%	Most rustics have a positive response to trying new products when they are affordable and easily usable
Facing Storage issues	81%	Lack of proper storage leading to food spoilage resulting to economic harm

Elaborate statistics on the households' inatke of the different food categories were studied and researched. Bulk of food consumption mainly occupied by cereals and vegetables. Among the major food groups, meat, eggs, and fish together have the lowest average monthly levels of consumption at just 0.61 kg.

A survey found that a very large and significant percentage of people lack essential nutrients, particularly proteins, iodines, vitamins, minerals, iron, and calcium. Approximately 68% of people in the countryside were reported to have insufficient protein intake, while 52% showed a lack of awareness about sources of essential vitamins and minerals Notably, women and children suffer the most. This poor diet aggravates fatigue, malnutrition, and other conditions. Millets are ancient grains that have been cultivated for many years and are renowned for their high nutritional content, climate adaptability, and tough resilience against all environmental stressors and strains. Despite being traditional sources, they are sometimes disregarded in modern diets, especially in rural areas where malnutrition is still a problem. However, they are now playing a crucial role in improving food security, sustainability, and health. Millets like finger millet (ragi), little millet, and foxtail millet can greatly improve the health of people who are already at risk because they are very high in important nutrients like iron, calcium, fiber, and protein. Finger millet is described as imthe most nutritious among all the major cereals and was nominated as super cereal yunited states of national academics [Andargie, et al. 2024].

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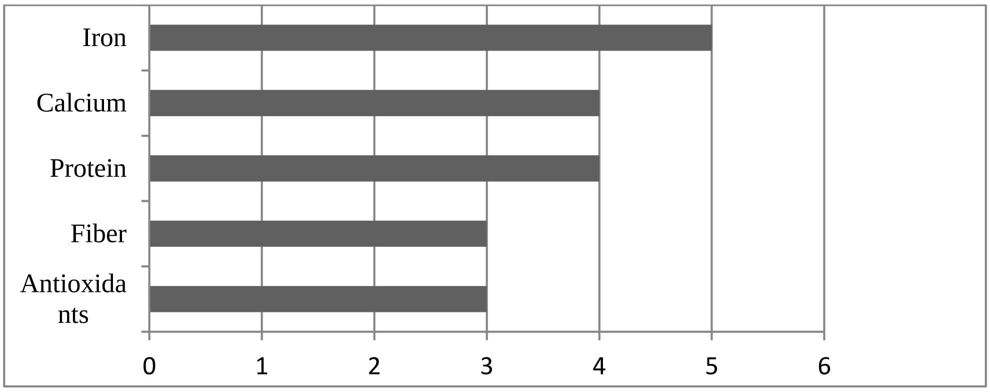

Table: Nutritional content of various Millets.

The scale of the graph represents arbitrary values from 0 to 6 where the greater value implies greater nutritional content and vice versa.

Formulation of Finger Based Millet Flour Mix:

For the preparation of the flour finger millet-based composite flour mix, finger millet was substituted with other ingredients such as black soya bean, black rice, barnyard millet, and pumpkin seeds. Each of the ingredients was cleaned, dried, and powdered separately to prepare the flour mix. Then all the herbs used in the mixture were prepared by removing the moisture content and drying them. Then the powdered ingredients were measured at different levels and were incorporated at different proportions in the flour. The flour was developed by substituting finger millet at different ratios (70:30; 60:40,50:50, 40:60). The Best composition was identified according to taste, texture, and nutritional value. Developed mixes were analysed, and gruel was prepared for sensory analysis, and the Nutritive value of the best was taken and subjected to the herbal mixture.

Table.1. Formulation of the Composite Flour Mix

Ingredients	**CFT1 (70:30)**	**CFT2 (40:60)**	**CFT3 (50:50)**	**CFT4 (40:60)**	**Nutitional Value**
Finger Millet	70	60	50	40	High in Calcium
Black Rice	15	15	15	15	Iron, antioxidants and fibre
Barnyard millet	5	10	15	20	Fibre, Iron, Magnesium
Black Soyabean	5	10	15	20	Protein, fibre, folate
Pumpkin seeds	5	5	5	5	Healthy fats zinc Mg

CFT: *Composite Flour Treatment*

Functional properties such as oil absorption capacity,water absorption capacity, swelling power, and swelling capacity were analyzed for finger millet-based and wheat-based composite flour to select the

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best combination.

VII. DEVELOPMENT OF HERBAL MIXTURE:

Development of Herbal mix: Different herbs such as Amruthaballi, Honagone leaves, Indian borage, turmeric, dried ginger were procured. Herbs were cleaned and dried to remove moisture content. Further the herbs made into fine powder by using mixer and sieved with mesh size (212 µm).

Table:- Various Composition of Herbal Mixture

Herbs	HMT1	HMT2	HMT3	Nutritional value
Amruthaballi	1.75	1.5	1.0	Rich in antioxidants Vitamin A and C
Honagone leaves	2	2	2	Iron, fibre and antioxidants
Dried Ginger	2	2	2	Anti-inflammatory aids digestion
Indian Borage	2	2	2	Essential oils, Respiratory Health
Turmeric	2	2	2	Curcumin, Anti-inflammatory ,Antioxidants
Moringa Leaves	1.5	1.0	1.5	Protein, Calcium, Iron Vitamin C
Fenugreek Leaves	1.0	1.5	1.0	Fiber, Iron, helps regulate blood sugar.

Herbal mix was standardized by adding selected herbs with different composition (Table 2) and product was evaluated for sensory evaluation by using nine point hedonic scale. Further best composition was selected for best yield subjected for sensory evaluation by a group of 15 trained panel members in the form of kashaya.

VIII. CONCLUSION

This research study demonstrates the significant potential in enhancing the nutrient profile, functional properties, and health advantages of conventional cereal-based This research study on millet-based composite flour incorporated with herbal products. Since millet is rich in dietary fiber, iron, protein, calcium, essential minerals, and bioactive compounds, when combined with the therapeutic properties of several herbs, it creates a perfect blend that can help alleviate malnutrition, enhance

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immunity, and offer preventive benefits against lifestyle diseases. This composite flour formulation exhibits good physical characteristics, acceptable sensory attributes, and increased nutrient density, making it suitable for a wide range of food applications. Additionally these blends encourages the use of underutilized crops, supports sustainable agriculture, and presents chances for value addition in both urban and rural food systems. Furthermore, the use of herbs and millet promotes biodiversity and the blending of traditional eating customs with contemporary diets. All things considered, millet-based herbal composite flour is a promising ingredient for functional foods that fits in with current nutritional needs and health trends, promoting improved dietary interventions, food security, and the creation of functional foods.

REFERENCES:

13. Andargie, Melkamu & Abera, Merkuz & Alemu, Tesfaye & Bekele, Berhanu. (2024). Screening of Finger Millet Genotypes for Resistance to Magnaporthe grisea in Northwestern Ethiopia. International Journal of Phytopathology. 13. 251-266. 10.33687/phytopath.013.03.5423.
14. Devi PB, Vijayabharathi R, Sathyabama S, Malleshi NG, Priyadarisini VB. Health benefits of finger millet (Eleusine coracana L.) polyphenols and dietary fiber: a review. J Food Sci Technol. 2014 Jun;51(6):1021-40. doi: 10.1007/s13197-011-0584-9. Epub 2011 Nov 22. PMID: 24876635; PMCID: PMC4033754.
15. Dutta, Indranil & Kapoor, Shruti & Pattanaik, Prasanta. 2020). Evidence from a village study on nutrient consumption in India. 10.1111/rode.12679. Review of Development Economics, 24. 855-877.
16. FAO (Food and Agriculture Organization of the United Nations). (2019). "The State of Food Security and Nutrition in the World."
17. Sharma, H., Kumar, P., Verma, J., et al. (2017). "Nutritional and Functional Properties of Millets and Their Utilization in Value-Added Products." Journal of Food Science and Technology, 54(8), 2366–2376.
18. Reddy, Ram Teja & Bisarya, Dipti. (2020). General Review of major, minor millets nutrient composition, Production and bioavailability.
19. Saleh, A.S.M., Zhang, Q., Chen, J., Shen, Q. (2013). "Millet Grains: Nutritional Quality, Processing, and Potential Health Benefits." Comprehensive Reviews in Food Science and Food Safety, 12(3), 281–295.
20. Sharma, S., Kumar, V., Prasad, K. (2018). "Effect of Processing on Nutritional Profile of Millets." International Journal of Food Science and Nutrition.
21. USDA FoodData Central. US Department of Agriculture. Available online: https://fdc.nal.usda.gov/
22. Kumar, V., Singh, A., & Chauhan, G. S. (2021). "A Review of the Nutritional Content and Health Advantages of Millets." 1793–1805 in Journal of Food Science and Technology, 58(5). https://doi.org/10.1007/s13197-020-04758-4
23. Saleh, A. S. M., Kamarudin, N., & Jabran, M. A. (2020). "An Overview of Millet Grain Processing Methods and Nutritional Value." Nutrition and Food Science, 8(5), 2334–2343. 10.1002/fsn3.1567 https://doi.org
24. Singhal, R. S., and V. S. Nambiar (2018). "Millets as Functional Foods: Uses and Preparation." Cereal Science Journal, 81, 1–9. https://doi.org/10.1016/j.jcs.2018.03.005

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Osteoporosis Risk Assessment: An Machine Learning Based Framework

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Abstract-The incorporation of machine learning(ML) technologies into Medical infrastructure has demonstrated significant potential for initial illness identification, particularly in conditions such as osteoporosis. This research dives into how ML algorithms—like K-Nearest Neighbours, Random Forest, and Naive Bayes—may assist in forecasting osteoporosis by investigate clinical, demographic, and lifestyle -related information. While such systems demonstrate enhanced diagnostic accuracy, their application poses significant critical concerns towards data privacy and adherence to cyber regulation. This paper reports comparative evaluation of algorithmic efficiency and investigates legal and ethical concerns on data management issues like user consent, data masking and safe encryption practices. Maximum stress is explained on the necessity of adherence to regulatory legislation such as the "General Data Protection Regulation (GDPR) and the Digital Personal Data Protection (DPDPA), 2023" in the case of India for the implementation of a responsible handling of data. Futurate paper explains weakness with regard to exploitation of computer program, piracy, and unlawful dissemination of data. The conclusions acknowledge the necessity ofintegration of privacy paradigms and legal protection into AI application in healthcare. The initiative is consistent with increasing demands for the preservation of ethics and law in clinical ML systems and advocate for integration of privacy-by-design principle in predictive system design.

Keywords- Cyber Law, Data Privacy, Machine Learning, Osteoporosis

I. INTRODUCTION

Osteoporosis can be perfectly described as decreased bone density and heightened fragility that are usually causing fracture-related issues[1]. Conventional diagnostic tools for osteoporosis such as "Bone Mineral Density" (BMD) and "Dual-energy X-ray Absorptiometry" (DXA) are usually

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unaffordably costly in disadvantaged populations[2]. Recent developments in ML provide efficient means of early osteoporosis screening based on medical demographic and behavior markers[3]. Implementation of these technologies into healthcare practices imposes most critical issues of data protection, conformity with the regulating standards[4]. Legal use of healthcare information involves them to comply with privacy legislation like GDPR in the EU and DPDPA 2023 in India[5],[6]. In the absence of legal definitions of murky ownership rights, reuse of the software, ethical issues regarding data exploitations are added hurdles to implementation[3], [6].

This study also attempts to improve osteoporosis detection methods' diagnostic accuracy and protect legal and ethical standards[7]. Furthermore, main concerns of AI usage nowadays involve the allowed standing of created AI models, proprietorship of software code, and ethical risk exposure by security flaw or unauthorized prediction. The research seeks to strike a balance between higher diagnostic accuracy for osteoporosis and efficient and compliant implementation of new technologies. ML technologies and datasets are often deployed without efficient licensing, exposing systems to legal and compliance issues[4]. Inefficient security controls like encryption and audit trails expose healthcare systems to cyberattacks[5].

The objective of this study is to achieve two objectives

1. Osteoporosis prediction based on anonymized clinical data and behavioral patterns using Machine Learning models (KNN, Naïve Bayes, RF) and implementation of proper model verifications.

2. Examination of the legal and ethical concerns of the software privacy, data privacy, cyber law compliance, and system ownership.

Findings indicate that Naive Bayes achieves the highest accuracy (86.99%), the process of deployment and model development should be founded on best cybersecurity practice, open licensure, and data governance models. We recommend the application of privacy by design principles, license reports on models, and federated learning systems for improved legal adherence and software integrity for long-term future deployments [9], [10]. In this article, we introduce across disciplinary approach under which the Machine Learning specialization is gauged in terms of its performance and the legal, ethical, and data AI compliance that the technology presents.

The existing research on the application of machine learning models to predict osteoporosis is examined in Section 2.

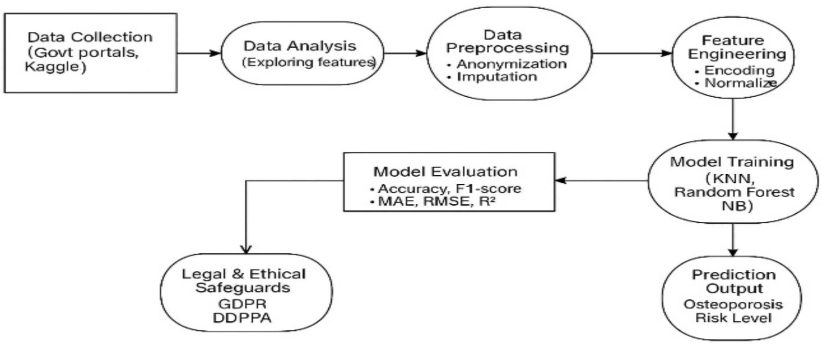

Fig1. Block Diagram of proposed work

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II. LITERATURE REVIEW

Traditional statistical models have been replaced by model ML techniques capable of analyzing high-dimensional data. For example, the study by Kim et al.[1] highlighted the superior accuracy of ML algorithms compare to traditional risk assessment tools. Similarly, Smets et al.[2] confirmed the effectiveness of ML models such as Support Vector Machine(SVM) and Random Forest in identifying osteoporosis risk factors using clinical information. Rahim et al.[3] reinforced prior results via a meta-analysis, underscoring the increasing reliance on ML for accurate diagnosis and classification of osteoporosis. Nevertheless, progressing ML development has not been matched by adequate attention to associated legal and ethical dimensions. Many studies overlook critical issues- like unbalanced data , absence of patient consent and systems and weak privacy compliance. For example, privacy preservation was absent in Kim et al.[1] and Smets et al.[2] that did not consider ethical concerns in model reuse. Rahim et al.[3] highlighted technical outcomes but their study lacked discussion on compliance of GDPR and DPDPA, 2023[6],[7]. Such deficiencies reveal the importance of combining effective ML performance with robust legal and cybersecurity frameworks. The literature confirms ML's utility in diagnostics but stresses stronger adherence to ethical guidelines, licensing policies to build trustworthy healthcare AI system [4],[5],[8].

Ref.	Author(s)	Focus	Gap Identified
[1]	Kim et al.	ML application in osteoporosis risk prediction	Lacked emphasis on data privacy and anonymization practices
[2]	Smets et al.	Comparative study of ML models (SVM, RF) for diagnosis	Ignored ethical AI, licensing, and IPR compliance
[3]	Rahim et al.	Meta-analysis of ML diagnostic accuracy across studies	Limited discussion on legal frameworks like GDPR or DPDPA
[4]	Ullah et al.	Feature selection for ML in postmenopausal women	No integration of consent models or encryption protocols
[5]	Tu et al.	Nationwide health data with ML risk stratification	Overlooked secure data access and user data retention policies
[6]	GDPR, EU	Regulation for data protection and individual rights	Not consistently applied in ML-based health systems
[7]	DPDPA, India	India's personal data protection framework (2023)	Recent law; yet to be adopted widely in healthcare AI pipelines
[8]	Netelenbos	Treatment and screening recommendations	Did not consider software reuse and accountability mechanisms

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III. METHODOLOGY

a. Data Acquisition

This dataset consisted of many variables such as age, gender, hormone level, medical problems, workout routines, personal habits (smoking, alcohol consumption), calcium intakes and fracture records. The privacy was kept safe by Personally Identifiable Information (PII) through hashing, obscuring demographic details and handling data quality by removing outliers and imputing missing values.

b. Model Implementation

We evaluated six ML models using an 80:20 train-test split and ten-fold cross-validation. Grid search was applied for hyperparameter tuning to maximize accuracy and F1-score. We used metrics to assess model effectiveness.

1.Accuracy, 2. Precision, 3. Recall, 4. F1-score, 5. Root Mean Squared Error (RMSE), 6. Mean Absolute Error (MAE), 7. R^2 (Coefficient of Determination)

Naive Bayes showed the best accuracy (86.99%), followed by KNN (86.39%) and Random Forest (84.52%), all with balanced precision and recall - crucial for clinical prediction.

c. Legal and Ethical Safeguards

A privacy-centric design was implemented, supported by the following safeguards.

- Data Encryption: Patient information was pseudonymized and stored with AES-256 encryption in accordance with healthcare standards.
- Access & Compliance: Role-based access control (RBAC) was enforced; processes were documented to ensure GDPR and India's DPDPA (2023) compliance.
- Toolchain Integrity: All third-party tools and datasets audited for license integrity (MIT, BSD, Apache 2.0) , avoiding proprietary software.

Table.1. The Dataset with all the necessary parameters

	A	B	C	D	E	F	G	H	I	J	K
1	Age	Gender	Hormone	FHistory	Weight	CalciumIn	Activity	Smoking	MedCondition	Fractures	Osteoporosis
2	69	Female	Normal	Yes	Underweight	Low	Sedentary	Yes	Rheumatoid Arthritis	Yes	1
3	32	Female	Normal	Yes	Underweight	Low	Sedentary	No	None	Yes	1
4	89	Female	Postmenopausal	No	Normal	Adequate	Active	No	Hyperthyroidism	No	1
5	78	Female	Normal	No	Underweight	Adequate	Sedentary	Yes	Rheumatoid Arthritis	No	1
6	38	Male	Postmenopausal	Yes	Normal	Low	Active	Yes	Rheumatoid Arthritis	Yes	1
7	41	Male	Normal	Yes	Normal	Low	Active	Yes	Rheumatoid Arthritis	Yes	1
8	20	Male	Postmenopausal	Yes	Underweight	Adequate	Sedentary	No	Rheumatoid Arthritis	No	1
9	39	Male	Postmenopausal	Yes	Normal	Adequate	Sedentary	No	Rheumatoid Arthritis	Yes	1
10	70	Male	Postmenopausal	No	Underweight	Low	Active	Yes	Rheumatoid Arthritis	No	1
11	19	Female	Normal	No	Normal	Low	Active	Yes	None	Yes	1
12	47	Female	Postmenopausal	Yes	Normal	Low	Active	Yes	None	Yes	1
13	55	Female	Normal	Yes	Underweight	Adequate	Sedentary	No	Rheumatoid Arthritis	No	1
14	19	Female	Postmenopausal	Yes	Underweight	Low	Active	Yes	None	Yes	1
15	81	Male	Normal	Yes	Underweight	Adequate	Sedentary	Yes	Hyperthyroidism	No	1
16	77	Male	Normal	Yes	Underweight	Low	Sedentary	Yes	Hyperthyroidism	No	1
17	38	Male	Postmenopausal	Yes	Normal	Adequate	Active	Yes	Rheumatoid Arthritis	No	1
18	50	Female	Postmenopausal	No	Underweight	Adequate	Active	Yes	Hyperthyroidism	No	1
19	75	Male	Postmenopausal	No	Normal	Adequate	Sedentary	No	Hyperthyroidism	No	1
20	39	Female	Postmenopausal	No	Normal	Adequate	Sedentary	No	None	No	1
21	66	Male	Postmenopausal	Yes	Normal	Low	Sedentary	No	None	Yes	1
22	76	Male	Normal	Yes	Normal	Adequate	Sedentary	Yes	None	No	1
23	59	Female	Postmenopausal	Yes	Normal	Adequate	Active	No	None	No	1
24	77	Male	Postmenopausal	No	Normal	Adequate	Sedentary	Yes	Hyperthyroidism	Yes	1
25	32	Male	Normal	Yes	Underweight	Low	Active	No	Rheumatoid Arthritis	No	1
26	79	Female	Postmenopausal	Yes	Normal	Low	Active	No	None	Yes	1

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IV. RESULTS

Osteoporosis is a low density bone disease which greatly rises the risks of fractures. Preventive strategies and better clinical outcomes can be facilitated through early diagnosis. In our study, the ML models Models-KNN,, Random Forest, SVM, Logistic Regression and Naïve Bayes- were evaluated as a function of such variables as age, gender, life style and medical history. Models were tested on indicators such as accuracy, precision, F1-score, RMSE, MAE,R2.

- KNN: Non-parametric based on the nearest neighbor classification with maximum accuracy.
- Logistic Regression: Linear model with a sigmoid function; useful for binary issues.
- SVM: Support Vector Machine distinguishes data via hyperplanes; useful for high-dimensional classification.
- Decision Tree: Classify data through examining feature values providing immediate predictions and ease of interpretability.
- Random Forest: combines several decision trees together to enhance prediction accuracy and better generalization.

Table.3. Model performance is in light of proposed work

Model	Accuracy (%)	Precision	Recall	Legal Risk (Data)	IP Risk (Code)
Naive Bayes	86.99	High	High	Low (anonymized)	Medium
K-Nearest Neighbors	86.39	High	Medium	Medium	Low
Random Forest	84.52	High	High	Medium	Medium
Logistic Regression	83.42	Medium	Medium	High	Low
Support Vector SVM	83.16	Medium	High	High	Medium
Decision Tree	82.14	Medium	Medium	Medium	Medium

Summary of result

Models like Naive Bayes not only performed best but also presented minimal privacy concerns due to simplicity and interpretable logic. Here is the summary of works :

- Top Performer: With an accuracy of 86.99%, the Gaussian Naive Bayes model takes the lead offering excellent precision and recall for class 1 (osteoporosis).
- Strong Contenders: KNN and Random Forest also performed well, providing high accuracy and balanced outcomes across the multiple classes.

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- Decent Performance: The Logistic Regression and SVC models perform reasonably well, but they fall a bit short in accuracy and recall for class 1 when compared to the top models.

V. CONCLUSION

Osteoporosis prediction through ML is proposed as a novel way to early diagnosis and tailored treatment. Sophisticated data like “Bone Mineral Density” (BMD), medical images, genetic data and patient data are processed by machine learning (ML) techniques like support vector machines, random forests, and neural networks. Such models are precise risk quantitation and detection in early stages to decrease the risk to improve fracture evaluation and patient outcomes.

REFERENCES

1. Kim SK, Yoo TK, Kim DW. "Osteoporosis Risk Prediction Using Machine Learning and Conventional Methods." IEEE
2. Smets J, Shevroja E, Hügle T, et al. "Machine Learning Solutions for Osteoporosis—A Review." Wiley
3. Rahim F, Zadeh AZ, Javanmardi P, et al. "Machine Learning Algorithms for Diagnosis of Hip Bone Osteoporosis." Springer
4. Miller PD, Siris ES, Barrett-Connor E, et al. "Prediction of Fracture Risk in Postmenopausal Women." JBMR
5. “The Digital Personal Data Protection Act”, 2023.Government of India.
6. General Data Protection Regulation (GDPR). European Union.
7. Information Technology Act, 2000. Ministry of Electronics and IT, India.
8. Ullah KA, Rehman F, Anwar M. “ML-based prediction of osteoporosis in postmenopausal women.” PMC
9. Tu J-B, Liao W-J, Liu W-C. “Risk of Osteoporosis from Nationwide Data.” Nature Scientific Reports
10. J. Clin. Med., Volume 14, Issue 12 (June-2 2025) – 376 articles

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The IML-CD Framework: A Conceptual Model for Interpretable Multimodal Learning in Cognitive Decline

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Abstract- Recent studies on predicting cognitive risk use various data types, including IoT, behavioral data, and neuroimaging. However, combining these data sources is often random and lacks a solid theoretical foundation for integrating data and making clinical sense of it. This study aims to address this gap by introducing the IML-CD framework presented in this paper. We develop a conceptual model that categorizes data streams into three groups, based on a systematic review of current approaches and the observation of their scattered nature. (1) Pathological markers like sMRI and PET reveal changes in the brain; (2) Functional markers such as VR and cognitive tests indicate how these changes affect behavior; and (3) Contextual markers, including IoT and behavioral logs, clarify the variation of functional changes in real-world settings. The IML-CD framework provides a method for hierarchical data integration, leading to multilevel clinical explanations. It also presents testable propositions to guide future research toward developing useful tools for predicting cognitive decline.

Keywords- Alzheimer's Disease, Mild Cognitive Impairment, Multimodal Learning, Interpretable AI, Conceptual Framework, Digital Health.

I. INTRODUCTION

Alzheimer’s Disease (AD) and other neurodegenerative diseases are currently a global health problem, and therefore, early risk monitoring is needed. Aging healthily will become increasingly complex and may sometimes lead to Mild Cognitive Impairment (MCI) and Alzheimer’s Disease (AD). However, the transition is complex and arguably not a linear one. This will involve many factors that no single source of data can explain. Accordingly, researchers want to use multimodal machine learning to combine data

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for improved predictions. Studies show that combining neuroimaging and cognitive data improves model performance significantly more than using either source alone.

Despite these rapid advancements, it has also caused another major problem, which is theoretical inconsistency. The presence or absence of data normally drives multimodal integration, not conceptualization. Researchers will often combine structural MRI (sMRI), Positron Emission Tomography (PET), virtual reality (VR) biomarkers, and EEG arbitrarily. While these models may achieve good accuracy, they are also "black boxes," meaning it is not clear how they reach their conclusions. Without clear applications, such evidence is less likely to inform clinical practice, as clinicians need clarity, reliability, and actionability. People in the field are waking up to this issue, which has led to more emphasis on XAI (explainable AI) and interpretable models. Even though we have made progress in making these models more interpretable, there is still a large gap. When no proper framework for research design has been established, comparisons become difficult, and building on previous work is nearly impossible. Besides, it also hampers other Clinical Decision Support Systems à use. This paper addresses this gap directly. We introduce the Interpretable Multimodal Learning in Cognitive Decline (IML-CD) framework as a novel conceptual model in this space. We will first review a set of relevant literature to identify three data constructs based on their explanatory roles. Next, we use these constructs to create the IML-CD framework and propose some propositions regarding the same. We will then discuss the implications of the framework and the prospects for theory-driven research.

II. *DECONSTRUCTION OF CORE CONSTRUCTS*

The literature suggests that multimodal data sources, while diverse, can be logically grouped into three categories based on the information they provide about the disease process. The IML-CD framework is built upon this classification.

2.1. Pathological Markers: The "What"

This type of data directly captures the underlying pathology of cognitive decline. Classic disease biomarkers form the basis for diagnosing AD. Structural MRI (sMRI) provides images of the brain and quantifies the atrophy of areas like the hippocampus. PET scans, using tracers such as Amyloid-β and Tau, reveal the molecular features of AD. Genomic and fluid biomarkers, including APOE4 genotype and levels of Aβ/Tau in cerebrospinal fluid, also fall into this category. These markers help answer the question: What is the brain's underlying pathological state? Their strength lies in their direct connection to the biological basis of disease. However, they tend to be cross-sectional and expensive and may not correlate well with daily functioning. Recent efforts have aimed to create more interpretable models using deep learning, such as anatomically interpretable models connecting brain age to cognitive impairment.

2.2. Functional Markers: The "How"

This category includes data showing how underlying pathology impacts cognition and functionality. These markers are typically performance-based and reflect disease behavior. As noted, VR is particularly effective for creating realistic assessments of complex cognitive functions like spatial navigation, which is often impaired early in AD. VR biomarkers may serve as specific and sensitive indicators for early MCI. Cognitive assessments that provide standardized scores include the Mini-Mental State Examination (MMSE) and the Alzheimer's Disease Assessment Scale—Cognitive Subscale (ADAS-Cog). EEG

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tracks brain activity and offers high-resolution measurements of cognitive processes and functional connections. These markers help us answer the question: How does pathology affect the ability to complete complex tasks? Importantly, these are relevant to both the disease and daily work. One limitation is that factors other than the primary pathology, such as mood, fatigue, and education level, can also affect performance.

2.3. Contextual Markers: The "Why"

This new type of data provides insight into an individual's history and current situation. This information helps clarify the pattern of functional decline. Sensors can passively monitor sleep patterns, physical activity, social engagement (through location tracking or call logs), and general activity. Behavioral logs are a rich data source for daily behavior, including smartphone usage, computer interactions, and smart-home system data. These variables offer continuous streams of information about daily activities. Cognitive behavior relates to mental health, making it crucial to analyze this data for a deeper understanding. This information answers the question: What causes functional impairment to fluctuate over time? For example, a drop in performance on a VR task might correlate with indications from a wearable device showing inadequate sleep a week earlier. The strength of this data lies in its ability to create a continuously dense, ecologically valid picture of a patient's life. Still, it faces issues of data sparsity, noise, and privacy.

3. The IML-CD Conceptual Framework

The IML-CD framework, illustrated in Figure 1, utilizes the three constructs defined above to propose a structured and hierarchical method for data integration and interpretation. It comprises three core components and two central propositions.

3.1. Framework Components

The framework categorizes data into three types: Pathological, Functional, and Contextual. Unlike traditional “flat” fusion, where all features are mixed in one layer, this framework suggests a hierarchical approach. Initially, low-level models analyze one data stream at a time. A higher-level model then integrates the two streams to create meaning from the event. This structure mirrors the causal nature of the disease (where pathology impacts function within a context). This combination of methods employs techniques like co-attention networks and deep evidential fusion, integrating varying modalities and uncertainties. The framework aims for two outputs: Risk Prediction (such as the probability of MCI converting to AD in two years) and a Multilevel Clinical Explanation. The explanation will not be a simple feature importance list, but instead will be organized around the three streams. For example, “Risk is increased because of [Pathological finding], leading to [Functional impairment] and currently affected

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by [Contextual factor].” This aligns with the goal of transparent decision-making systems .

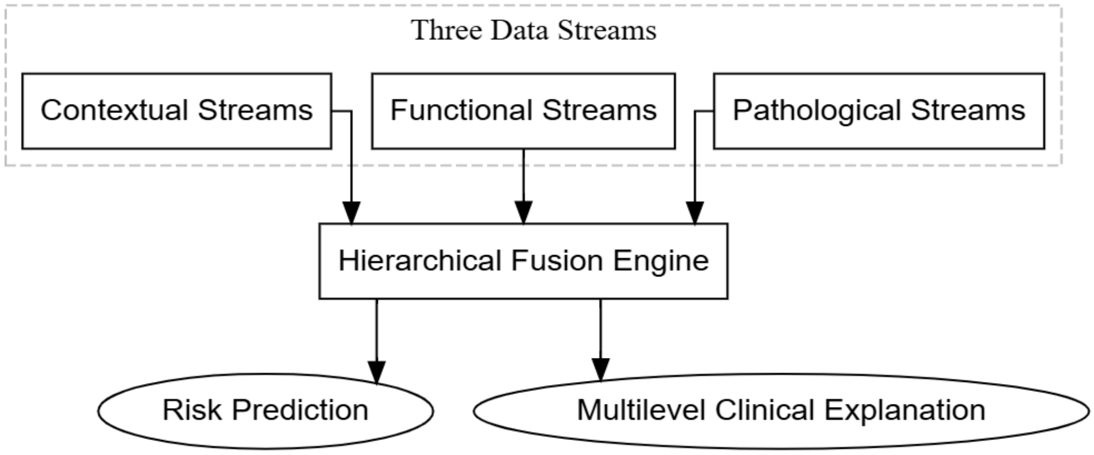

Fig.1. The proposed Interpretable Multimodal Learning in Cognitive Decline (IML-CD) Framework. The model organizes data into three streams that are hierarchically fused to produce both a risk prediction and a multi-level clinical explanation.

3.2. Central Propositions

The relationships among the components are formalized as two testable propositions:

Proposition 1: Functional markers act as mediators in the pathology–cognition connection. This indicates a link: structural and pathological brain changes (Pathological) influence task performance (Functional). A model that understands this relationship can offer stronger explanations. For example, rather than simply stating that "hippocampal volume is important," it could clarify that "reduced hippocampal volume is causing impaired spatial navigation memory, as seen in the VR task."

Proposition 2: Timing affects how we understand a functional marker. This suggests that a person's real-world environment and behavior impact the stability and progression of their functional abilities, even at a particular level of pathology. This model can support accurate dynamic risk assessments. For example, suppose a patient with stable pathology suddenly becomes socially isolated and sleeps poorly for an extended time. In that case, this may trigger a short-term risk increase as suggested by their wearable data.

III. Discussion and Implications

The IML-CD framework is crucial for research and clinical practice.

4.1. Advancing Research Methodology

The framework facilitates more systematic and comparative research by providing a standard theoretical model. This approach shifts the field from random data fusion to theory-driven model development. It allows for meaningful comparisons across different studies, as biomimicry results can be mapped to the framework. Moreover, it encourages the creation of new machine learning methods for hierarchical fusion and structured multilevel explanation generation.

4.2. Generating Testable Hypotheses

We can test the propositions of the framework by developing specific hypotheses from them. For instance, a deep learning model designed to use functional features to manage pathological features will likely perform better than a model using stacked features. The applicability of these findings was tested

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in a pilot study involving patients with MCI and Alzheimer's disease (AD). The results reveal that incorporating longitudinal IoT data, which refers to contextual information, significantly enhances accuracy in predicting six-month changes in cognitive test scores compared to relying solely on a baseline MRI scan.

V. CONCLUSION

Multimodal learning in cognitive decline is at a pivotal moment in the field. Although there has been significant progress in predictive accuracy, we still lack a unified theoretical model that promotes the development of robust, generalizable tools that can be clinically applied. The IML-CD framework offers a solution to this issue. By organizing data streams according to their explanatory roles (pathological, functional, and contextual), it provides a structured, hierarchical approach for creating the next generation of interpretable predictive models. The framework is designed to be theoretical and needs thorough empirical testing for future projects, including developing and evaluating new models in which the structure and propositions are clearly defined. Researchers should investigate the proposed mediating and moderating relationships. Additionally, the framework encourages innovative computational methods to produce multilevel explanations. If we adopt a more theory-driven approach, we can reduce the black-box nature of AI/ML models, leading to reliable and understandable systems that can be implemented at the treatment level for the benefit of those with neurodegenerative diseases.

REFERENCES

1. Adarsh, V., Gangadharan, G. R., Fiore, U., & Zanetti, P. (2024). Multimodal classification of Alzheimer’s disease and mild cognitive impairment using custom MKSCDDL kernel over CNN with transparent decision-making for explainable diagnosis. *Scientific Reports*, *14*(1), 1-15. https://doi.org/10.1038/s41598-024-52185-2
2. Bhatt, P., Liu, Z., Wang, X., Cao, Y., & Cui, L. (2023). Machine learning for cognitive behavioral analysis: datasets, methods, paradigms, and research directions. *Brain Informatics*, *10*(1), 21. https://doi.org/10.1186/s40708-023-00196-6
3. Hu, X., Ouyang, J., Zhang, C., Duan, Y., Liu, M., & Zhang, D. (2025). *ITCFN: Incomplete Triple-Modal Co-Attention Fusion Network for Mild Cognitive Impairment Conversion Prediction*. arXiv preprint arXiv:2501.11276. https://doi.org/10.48550/arxiv.2501.11276
4. Jahan, S., Apon, N. Z., Khan, M. S. I., Ema, R. R., Islam, M. T., & Hossain, S. A. (2023). Explainable AI-based Alzheimer’s prediction and management using multimodal data. *PLOS ONE*, *18*(11), e0294253. https://doi.org/10.1371/journal.pone.0294253
5. Kim, S. Y., Lee, S. H., Park, J. E., Lee, J. Y., & Lee, J. H. (2024). Early Screening of Mild Cognitive Impairment using Multimodal VR-EP-EEG-MRI (VEEM) Biomarkers via Machine Learning. In *2024 International Conference on Electronics, Information, and Communication (ICEIC)* (pp. 1-4). IEEE. https://doi.org/10.1109/iceic61013.2024.10457109
6. Kumar, S., Yu, S. C., Michelson, A., Kannampallil, T., & Payne, P. (2024). HiMAL: Multimodal Hierarchical Multi-task Auxiliary Learning framework for predicting Alzheimer’s disease progression. *JAMIA Open*, *7*(2), ooae087. https://doi.org/10.1093/jamiaopen/ooae087

ISBN: **978-93-343-9865-6**

7. Park, B., Kim, K., Kim, Y., Lim, S., Jang, H., Kim, I. Y., & Lee, J. H. (2023). *Integrating Biomarkers From Virtual Reality and Magnetic Resonance Imaging for the Early Detection of Mild Cognitive Impairment Using a Multimodal Learning Approach: Validation Study (Preprint)*. JMIR Preprints. https://doi.org/10.2196/preprints.54538
8. Shao, Z., Dou, W., & Pan, Y. (2023). Dual-level Deep Evidential Fusion: Integrating multimodal information for enhanced reliable decision-making in deep learning. *Information Fusion*, *100*, 102113. https://doi.org/10.1016/j.inffus.2023.102113
9. Yin, C., Li, X., Xia, Y., Chen, K., Reiman, E. M., Wang, Y., & Yao, L. (2023). Anatomically interpretable deep learning of brain age captures domain-specific cognitive impairment. *Proceedings of the National Academy of Sciences*, *120*(4), e2214634120. https://doi.org/10.1073/pnas.2214634120
10. Zhang, Y., He, X., Chan, Y. H., Teng, Q., & Rajapakse, J. C. (2023). Multi-modal graph neural network for early diagnosis of Alzheimer’s disease from sMRI and PET scans. *Computers in Biology and Medicine*, *164*, 107328. https://doi.org/10.1016/j.compbiomed.2023.107328

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Iot-based smart health monitoring system: investigating the role of temperature, blood pressure and sleep data in chronic disease management

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***Abstract*—** The integration of the Internet of Things (IoT) is revolutionizing the healthcare sector by substantially improving the accuracy, dependability, and productivity of electronic medical devices. Another hot topic for research resources (2005) is a totally digital health care system includes connecting all types of medical resources and services. Despite these advances, however, most current solutions do not yet effectively control and monitor the elderly patient. To accomplish our goals, in this study, we present a healthcare system based on IoT technology to monitor dedicated wearable devices, which are used to monitor critical health vital signs, including body temperature, blood pressure, and type and quality of sleep, as well as activity in or out of the bathroom. A core feature of this framework is its capability to automatically identify potential patient dangers through the constant surveillance of live data and communicate these alerts directly to healthcare professionals via email. This investigation is anticipated to serve as a critical resource for academics and medical providers by clarifying the immense possibilities of IoT in the medical field, alongside a candid discussion of its primary implementation challenges. This study provides an in-depth analysis of IoT-driven health monitoring systems and charts a course for subsequent research efforts. The introduced framework signifies an innovative strategy capable of transforming patient care and elevating quality of life through the strategic use of cutting-edge technology.

Keywords- IoT (Internet of Things), Arduino, ESP8266, Pressure Pad Sensor, Temperature Sensor, Pulse Sensor, Ultrasonic Sensor, Thing Speak.

I. Introduction

In the contemporary world, we inhabit a digital environment where objects and devices are deeply interconnected. The internet empowers these devices with intelligent functions, allowing them to communicate and exchange data via online networks. The concept of the "Internet of Things" (IoT), a phrase introduced by Kevin Ashton in 1999, describes a framework in which internet-based information is connected to a continually expanding global service infrastructure [1, 2]. IoT constitutes a vast system of linked devices that gather and retain information from their immediate surroundings. As such, IoT is recognized as an ecosystem of interdependent digital entities. It is instrumental in facilitating remote management and operation of electronic devices within our current technological landscape. This opens opportunities for both digital and physical objects to enhance social, procedural, and commercial domains. The devices involved range from tiny nanochips to substantial routers, and are employed

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alongside sensors, actuators, and software to enable mutual communication. IoT supports a wide variety of uses and is undergoing swift and extensive development.

The healthcare sector has experienced drastic change through introduction of cutting-edge services and ideas to combat various medical issues. The increasing pressure on healthcare amid rapid technological advancement constantly leads to the integration of new solutions. These are now considered to be fundamental to be included in IoT-based healthcare systems [3]. In an IoT environment, several different services provide a variety of personalized medical services. There are therefore problems in formulating an all-encompassing definition for each concept. However, as an introductory tour, the following section will qualify the most widely used healthcare IoT services (illustrated in Figure 1).

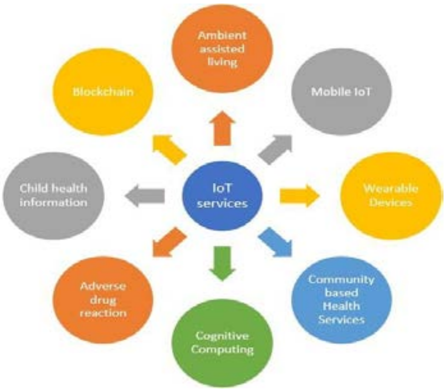

Figure 1. IoT Services

The Internet of Things (IoT) technology has witnessed a heavy focus on emergence, and many resources invested in healthcare monitoring systems. As these IoT-health observation systems are aiming to accurately observe human lifestyle and services for transparent health monitoring. Heterogeneous device and service interworking across the world, based on an IP overlay. This connectivity allows data to be gathered, exchanged, monitored, stored and analyzed produced by these nodes on the object [4].

Yet, all this may change by virtue of the Internet of Things -- a disruptive concept in which it is independent, often time-immobile. Physical devices and resource optimization over different physical devices in Intelligent Applications (IAs) [1] such as smart cities, smart homes and eHealth systems – that can be remotely managed and monitored. The ability to in medicine, and to diagnose illnesses and observe patients' shape of the surgeon illustrates one of the body-worn sensor networks that have been implemented and have greatly enhanced these capabilities. Moreover, the resulting data can be effortlessly retrieved from anywhere around the globe at any time [5].

Individuals presenting with severe illness (including potentially life-threatening), particularly in a setting of remoteness, often have limited access to hospital-based care. In these times, telemedicine represents an essential fallback, for patients to be able to have an appointment over video, and have medical care. This is not just good for its health outcomes, but a colossal time-and-money saving. In addition, these technologies provide an easy and fashionable way to record and track health indicators on mobile devices. A useful adjunct to contemporary health care, telemedicine overcomes the barrier of physical distance for patients with life-threatening injuries or who live in isolated places. Patients can stay in touch with their providers through real-time video communication, a common approach for telemedicine. This enables better quality treatment while helping to lessen dependence on more invasive medical interventions [6].

Motivation for this study, we present a healthcare system based on IoT technology to monitor dedicated wearable devices which are used to monitor critical health vital signs, including body temperature, blood pressure, type and quality of sleep, as well as activity in or out of the bathroom. A core feature of this framework is its capability to automatically identify potential patient dangers through the constant surveillance of live data and communicate these alerts directly to healthcare professionals via email. This investigation is anticipated to serve as a critical resource for academics and medical providers by clarifying the immense possibilities of IoT in the medical field.

Most existing IoT projects and studies remain in preliminary phases, largely focused on the initial setup and application of technology across various environments and use cases. These results have not yet realized wide real-world application. Hence, this paper presents a system for monitoring health based on IoT that integrates several sensors and devices to monitor all the patient’s health data to enhance the daily

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life experience. A central goal of this work is to present a thorough investigation of IoT-enabled healthcare monitoring frameworks, offering guidance for upcoming research, teaching, and scientific inquiry. It seeks to introduce an innovative IoT-based health monitoring framework capable of reshaping healthcare through contemporary technology, with the broader aim of advancing patient treatment and general well-being.

The document is organized into five parts. Following this introduction, Section 2 examines earlier work in IoT health-related research. Section 3 outlines the materials and methods used in developing the proposed system. Section 4 presents experimental results and analysis results are shown in the experimental implications in the following work, Discussion (with a focus on security and communication standards in IoT health monitoring). The last section (section 5) concludes results and suggests directions for future research.

II. LITERATURE REVIEW

The usage of Internet of Things (IoT) has added a constructive incremental change in how a sector is organized. It encompasses the interconnection between sensors, clinical devices, and health information systems allowing real-time, automated data capture, analysis, and interpretation 12. This advancement has many applications and benefits like: IoT devices can remotely, and Chakravarty collect and record physiological data such as pulse, blood sugar, and fever of individuals who are not in thermoregulatory confinement, simply creating a biofeedback loop for controlled heating and ventilation. This is a great advance as such individuals are not required to travel to health care facilities to voluntarily authenticate their case papers and verify their identity and bodily subconscious systems. It enables health authorities, practitioners in particular, to monitor people’s health and offer timely interventions, an obverse comma curative care model, and a desirable provision of health services.

IoT devices and applications have transformed and streamlined contacts with the clinicians improved patient participation and satisfaction. Healthcare logistics can be optimized through IoT systems by facilitating a drug production pipeline, enabling easy and quicker retrieval of patient records, and automated prescription renewals13. These improvements can lead to cost reduction as well as increased productivity in the provision of medical services.

In addition to (rehabilitative) follow-up-treatments, like home-based treatment for brain injured patients9, telemedicine allows for patients to send their doctors health updates in form of smartphone videos [6]. IoT also takes this one step further — by reducing costs, tailoring the treatment experience and helping practitioners monitor blood pressure, appointments, and even transplants. They also become less dependent at home, decreasing the demand for unnecessary procedures and clinic visits. In aggregate, such improvements have the potential to reduce OOP costs, improve safety, and quality of care [4]. The IOT based homehealth systems of the future will constantly monitor environment and health, support the treatment of chronic diseases, monitor recovery and ensure reliable realtime data exchange in virtual doctor visit 1.

In such systems, strong federation and secure data exchange will be maintained. Wu et al. elaborated an IoT-based wearable health observation system that facilitates remote supervision of patients under strict isolation. In such systems, medical personnel can constantly and remotely supervise patients in real time, hence potential improvements in the health outcomes of patients. Hamim et al. explore the current needs and challenges for wearable innovations in healthcare, emphasizing the opportunity for further development to better meet patients’ needs. Their proposal would feature extra sensors like breathing rate sensors and blood pressure and

Figure 2. Classification of IoT Technology

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blood sugar sensors. The introduction of such sensors could provide wearers with an omni-present health observance system capable of capturing all discovered bodily metrics. The physical and propositional systems responsible for perception, communication, and decision-making tasks have become as central as possible. This is because the adoption of specific technology approaches can hugely improve the capabilities of an IoT solution. Hence in the merger of the various medical usages with an IoT system, a bunch of new technologies have been employed. They can be simply classified as recognition technology, networking technology and positioning technology, as illustrated in Fig.2.

Internet of things key technologies for chronic healthcare monitoring

This part focuses on essential IoT technologies related to the monitoring of chronic health conditions. Key challenges include:

A. Deployment And Service Cost: By minimizing reliance on costly sensors, a shared-node IoT architecture can lower the high costs associated with healthcare monitoring systems. This strategy increases the affordability and accessibility of sophisticated monitoring solutions for a larger population.

B. Reliability: Since network or device failures cannot be tolerated, reliability is the most important factor in healthcare monitoring. Continuous and reliable data flow is ensured by using body area networks with feedback and suppression algorithms.

C. Interoperability: In a healthcare monitoring system, dissimilar network connections, systems, and smart tools developed by various service providers commonly utilize diverse specs and obtain various necessities. Relying on and maintaining steady communication between all connected gadgets has to be made certain when it concerns appropriate procedures.

D. Energy Limitations: Healthcare monitoring gadgets such as tiny sensors, smart wireless devices, and smartphones are powered by electric batteries. Battery spares are very hard to use during the communication of critical bodily data in CDHCMS; a loss/delay of a patient’s medical data on time could cause the death of patients in an emergency.

Challanges , Open Issues and future direction of healthcare monitoring

A. Data Storage and Analytics: Among the most significant results of IoT is the formation of an unmatched amount of data. Storage, possession and expiry of the data come to be vital concerns. For this reason, centralized data centers will have particular energy effectiveness and reliability. The information needs to be saved and used wisely for healthcare monitoring.

B. Versatility: The system must integrate modern advanced equipment, approaches, or even medical data gathering and information assessment modern technologies since they emerge with only minor developments.

C. Dynamic Connectivity: The IoT needs dynamic connectivity. Healthcare monitoring can use heterogeneous networks, but for autonomous use, connectivity often requires widespread coverage of WiFi, Bluetooth, ZigBee, 3G, 4G and 5G. IoT has dynamic capabilities to connect anything with anyone from anywhere.

D. Self-Sufficient Behavior: The IoT is more convincing in sharing medical information regarding healthcare monitoring or advising the medical professional to carry out more tasks. As appropriate to a healthcare monitoring strategy or higher degree target, it brings the medical professional viewpoint into a positive approach to the healthcare monitoring procedure.

III. RESEARCH METHODOLOGY

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The description of the technologies applied to develop the proposed health monitoring system will be provided in this section. The method is composed of collecting the information such as body temperature, pulse rate, sleep duration and toilet usage frequency from the patient. This data is collected by the ESP8266 Wi-Fi Module and sent to a cloud server. The ESP8266 module connects with the Arduino and communicates to internet relay server for that purpose the gathered data to the server .

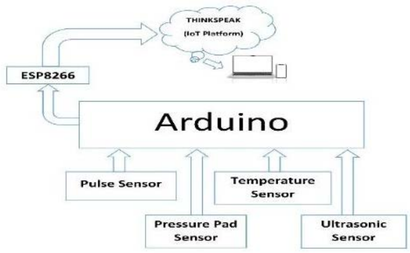

Figure 3

The data flow and order of operations for the IoT healthcare monitoring system are depicted in a flowchart form in Figure 3. This visualisation shows the way that different factors work together to deliver efficient body data, temperature, pulse rate, pressure pad and ultrasonic sensors denote the workflow of the system.

IV. CIRCUIT CONNECTION

Software description: The Arduino sensor data needs to be processed, for which a storage system is necessary and thinkspeak provides cloud based storge and analysis of the live data streams. The interface is via the ESP8266 that wirelessly sends important Arduino data through Wi-Fi for supervision and analysis at the ThingSpeak server.

Wi-Fi module: The ESP8266, a low-cost Wi-Fi module by Espressif Systems, operates at 2.4 GHz with a 32-bit RISC CPU (80 MHz) based on IEEE 802.11n and TCP/IP. In IoT, it transmits sensor data to webpages for storage and access (Figure 4).

Temperature sensor: Based on a thermometer that is half circle and people can put a finger to measure body temperature; the data transferred to Arduino. It gives Celsius as output with an accuracy of ±0.4°C using LM35 sensor. As an ADC using thermocouples, TCA provides higher accuracy than a traditional thermistor (Figure 5).

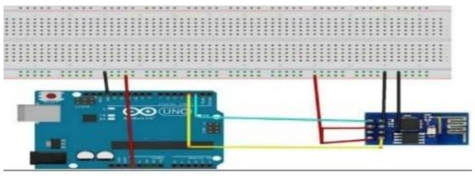

Figure 4. ESP8266 Circuit Connection

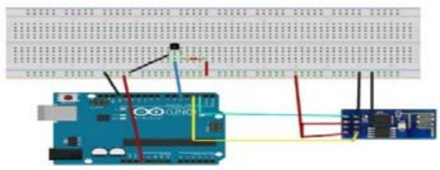

Figure 5. LM35 Circuit Connection

Pressure pad: A pressure pad underneath the patient's pillow measures how long a patient sleeps, by detecting when he or she lies down. The connected sections generate higher voltage (which is detected by the Arduino) and the time for which there is high voltage output indicates sleep-time. (Figure 6).

Pulse sensor: The Pulse Sensor, an easy-to-use Arduino-compatible heart-rate sensor, provides Cardio Graph, Pulse Rate, and IBI outputs. Placed on fingertip or earlobe, it recorded 121 BPM (IBI 1826 ms) for the patient, with heart rate varying as expected during relaxation or activity, confirming theory (Figure 7).

Ultrasonic sonar sensor: The HC-SR04 ultrasound sensor was used to record the toilet routine of a patient. Functioning like a bat's radar, it detects with pinpoint accuracy without ever touching the surface. Mounted on the toilet door, it sends a notification if disturbed and

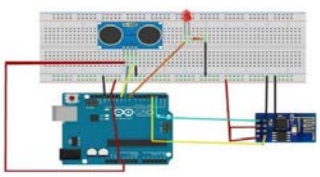

Figure 6. Pulse Pad Circuit Connection

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notifies when visitors come to use the toilet, supporting health status monitoring (Figure 8).

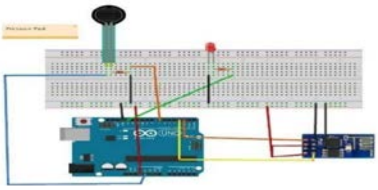

Figure 7. Pulse Sensor Circuit Connection

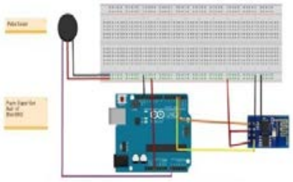

Figure 8. Ultrasonic sonar sensor

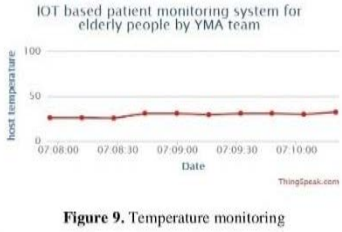

Figure 9. Temperature Monitoring

Figure 10

V. RESULT AND DISCUSSION

Temperature graph: It monitors body temperature and ambient one continuously, to offer immediate alarm in case of abnormality detection and also to evaluate patient's comforta anaesthesia Nassau. For safe, caring, and medical decision-making along with an infection risk reduction, the data itself are transferred to Arduino for remote assessment, real-time reports on historical trends, and notifications (Figure 9–10,LM35).

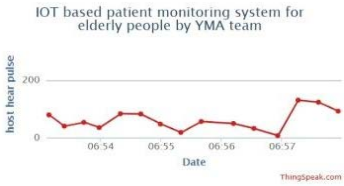

Figure 11. Pulse sensor

Pulse graph: BPM and IBI are calculated by pulse sensors to monitor heart rate. Long term trend analysis exist, monitoring is facilitated and early arrhythmia detection become feasible. Alerts ensure that actions are taken quickly, which lead to better outcomes. There was some initial ESP8266 transmission to ThinkSpeak noise that settled down over time and the pulse patterns returned to normal (Figure 11).

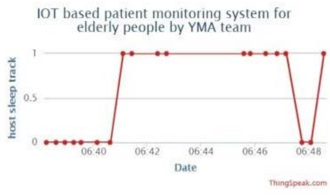

Figure 12. Sleep tracker

Pressure pad sensor: Used in detection of sleep patterns, quality of sleep and disorders by recording changes in pressure. They help detect falls by generating an alert when sleeping patients leave the sleep zone (0 = awake, 1 =sleeping - see Figure 12). Automatization improves the productivity of physicians, and patients experienced less discomfort, risk and lesser care with better quality at a lower cost.

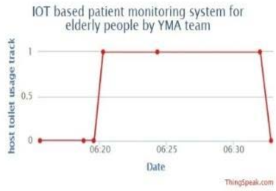

Figure 13. Toilet usage tracker

Sonar sensor: Sonar sensors are another device that supports hygiene, infection detection and individualized care through sound waves examining the patient's environment and use of toilet (0 = no, 1 = yes, Figure 13). IoT can facilitate remote monitoring, enable independence and self-administration of health status, support the healthcare management as well as improving patient's care, diagnosis and life quality.

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VI. CONCLUSION

The system is suitable for persons in plight with chronic health conditions. Through a computer or smartphone, health workers i.e., physician and nurses, and monitor patients' vital signs from a distance, involving temperature, blood pressure, sleep and defecation toilet use and HR, irrespective of the patient's position. This system has the advantage of bringing patients not only time and money that otherwise would be spent on travel, especially for the suburban and rural dwellers. The suggested framework could improve the quality of national healthcare services. Looking ahead, there is the capability to insert AI-based algorithms into the device, such that it can identify abnormal sensor readings or interference and issue alerts. In this paper a novel health monitoring device equipped.

VII. REFERENCES

[1] Farhan, L., Hameed, R.S., Ahmed, A.S., Fadel, A.H., Gheth, W., Alzubaidi, L., Fadhel, M.A., Al-Amidie, M. (2021). Energy efficiency for green internet of things (IoT) networks: A survey. Network, 1(3): 279-314. https://doi.org/10.3390/network1030017

[2] Alekya, R., Boddeti, N.D., Monica, K.S., Prabha, R., Venkatesh, V. (2021). IoT based smart healthcare monitoring systems: A literature review. European Journal of Molecular & Clinical Medicine, 7: 2020.

[3] Pradhan, B., Bhattacharyya, S., Pal, K. (2021). IoT-based applications in healthcare devices. Journal of Healthcare Engineering, 2021: 1-18. https://doi.org/10.1155/2021/6632599

[4] Bhatia, H., Panda, S.N., Nagpal, D. (2020). Internet of Things and its applications in healthcare: A survey. In 2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO), Noida, India, pp. 305-310. https://doi.org/10.1109/ICRITO48877.2020.9197816

[5] Jain, U., Gumber, A., Ajitha, D., Rajini, G.K., Subramanian, B. (2021). A review on a secure IoT-based healthcare system. In Advances in Automation, Signal Processing, Instrumentation, and Control: Select Proceedings of i-CASIC 2020, Singapore, pp. 3005-3016. https://doi.org/10.1007/978-981-15-8221-9_282

[6] Eder, P.A., Reime, B., Wurmb, T., Kippnich, U., Shammas, L., Rashid, A. (2018). Prehospital telemedical emergency management of severely injured trauma patients. Methods of Information in Medicine, 57(05/06): 231-242. https://doi.org/10.1055/s-0039-1681089

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Secure Payment WebApp: Addressing Data Breaches, Copyright Compliance, and IPR Protection

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ABSTRACT - This project details the development of a user-friendly and secure webapp for digital payments via the MERN stack, with UPI for effective cashless transactions **.** The application includes a user registration feature, multi-factor/strong authentication, connection to a payment gateway, QR payments, account management, transaction management, and real-time tracking of transactions. Security design principles received a lot of attention in the development process, including encryption, OTP authentication, and compliance with OWASP standards. The research also provided insights into legal and ethical responsibilities surrounding copyright, IP rights, and third-party licenses. The modular design and scalability of the application support a superior user experience and extends to the secure, traceable, compliant, and innovative financial services that support the evolving fintech world.

Keywords - Digital Payments, Data Privacy, Intellectual Property Rights (IPR), MERN Stack Development

I. INTRODUCTION

Digital payments have transformed financial transactions worldwide, with UPI and mobile wallets driving widespread adoption in India. However, security concerns such as data breaches, unauthorized access, and fraud present significant risks. The Secure Payment WebApp aims to address these concerns through robust encryption, authentication mechanisms, and compliance with cyber laws.Despite growth in digital payment platforms, vulnerabilities persist in areas such as secure API integration, scalability under heavy user loads, and compliance with legal frameworks. Hackers exploit weak points in authentication and data handling, while businesses face challenges protecting intellectual property and copyrighted content.The project focuses on-User Registration and Authentication: OTP verification, role-based access.Secure Transactions: End-to-end encryption and protected APIs.Legal Compliance: Adhering to copyright law, IPR, GDPR, and DPDP Act.Scalability: Designing a system capable of supporting large transaction volumes.The MERN stack enables full-stack development with JavaScript, simplifying collaboration and code sharing. MongoDB handles flexible data storage, Express.js manages secure backend routing, React.js ensures real-time interface updates, and Node.js delivers fast, scalable server performance.

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For deployment, Netlify hosts the frontend, GitHub manages version control, and Cloudflare with CDN caching enhances overall speed and reliability.Despite their strengths, MERN based payment systems deal with significant issues.Scalability in heavy transaction loads requires the optimization of databases and APIs.Security vulnerabilities though such as XSS, CSRF, and weak token handling require secure coding, token validation, and encryption from secure code to reliable transactions for the protection of data and system integrityData consistency, especially during asynchronous events or API failures, is critical to avoid loss or duplication of transaction data [5][14].

Deployment requires selecting cloud platforms that support CI/CD pipelines and environment isolation, while also complying with data residency and privacy laws [15][16].Scope and Limitations are-Development of core digital payment functionalities.Secure login, transaction, and data handling mechanisms [7][13].Responsive web design for multi-device accessibility [3][17].Legal compliance in open-source use and content licensing [6][18].No real-time integration with live banking systems due to access limitations.Advanced features like auto-bill payments reserved for future updates.Limited scalability testing due to academic and infrastructure constraints.Organization of the Report Reviews related technologies, prior work, and legal implications of digital payments. Details the development approach, toolchain, and project lifecycle.Covers system design, security mechanisms, and legal safeguards.Analyzes system output, security testing, and performance metrics. Summarizes the outcome and explores future enhancements in compliance, security, and scalabilit

II. LITERATURE REVIEW

The widespread adoption of digital financial services is exposing the need for payment systems that are secure, scalable, and easy to use. The literature indicates, with consistent frequency, that the security of the transaction is the basis for the platform. Best practices for transaction and application security used in literature, as well in the industry, relate to secure transmission (HTTPS), approve with key-based authorisation (JWT), two-factor validation, and reliable hashing of passwords, preferably by bcrypt as well as other mechanisms to mitigate OWASP vulnerabilities (e.g., XSS, CSRF, SQL injection). Formulating security protocols is attention grabbing, but the literature consistently conveys to developers that the quality of the UI/UX of the application also enabled user trust. For example, QR codes, easy to use beneficiary management, and real time information, all impacted useability of digital payments. The MERN stack (MongoDB, Express.js, React.js, Node.js) appears to support the emerging landscape in digital financial services.

In my use cases for digital financial service development, I consistently found that the MERN stack supported the full development of a javascript ecosystem--the complete development experience from a robust back-end API to a dynamic front-end interface. MongoDB is a flexible meaning that it can support many permutations and the re-factoring of my data storage, processing, and retrieval. Express.js improves the development of a secure API so that I can implement trusted, efficient sessions within my application. React.js is fast so allows me to focus on building intuitive UI around my transactions, displays and optional payment flows. Node.js enables my application to manage multiple payments concurrently. Credibility also comes from open source projects in addition to industry implementations where MERN is already working for revolving payment service (fintech) applications. An example includes Electron wallets where the system architecture

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is secured, enabled, and scaled to.

III. METHODOLOGY

i. Techniques and Methods

In the case of digital payments, a secure payment application obtains agreement in respect of requirements across all technical and usability facets of use, and you would be expected to comply with cyber laws and associated rules dealing with intellectual property rights. This processed section is meant to review the sequential process that the application developers followed during the application development of a payment application that is a MERN stack application, and the selected methodologies also involve a period during which we us compliance, privacy, and intellectual property protections.

ii. *Agile Process with a Focus on Legal Compliance*

We used the Agile methodology, specifically the Scrum iterations to support the iterative and collaborative process but also because it allowed for smaller incremental legal compliance modifications (for example, the IT Act, 2000 and the GDPR). The Agile methodology did provide stakeholder feedback and testing on a more regular basis to ensure we complied incrementally with the legal requirements, in particular pertaining to compliance with secured authentication, data, and digital consent.

iii. Component Based Development with License Integrity

Our frontend is built using React.js and Tailwind CSS; we had developed the frontend using a component based design, and we had explicitly taken the IPR frameworks into account in our development. Because: (1) all libraries and packages used in the front end were open-source and allowed under permissive licenses (MIT, Apache 2.0); (2) proprietary code was documented and copyrighted to the organization; and (3) the front-end code base of each component carries licensing headers and documentation, we were confident in our approach due to the license integrity. This ensured that there would not be any instances of potential intellectual property infringement in the front-end code prior to or following our product development. This gave us peace of mind about the upkeep and traceability of our code in case of an audit or any licensing issues.

iv. Legal Aspects of Filtering, Sorting, and Searching

Non-discriminatory Algorithmic Design: the sorting and filtering logic did not involve profiling or discriminatory profiling; only user data that was necessary to be stored or processed was handled in accordance with Section 43A of the IT Act; decision-making procedures, and did not incorporate unethical AI techniques or legally biased best practices.

v. Data Collection Methods in Line with the Cyber Law

Reasoning for backend governance was also taken from the Indian IT Act (Section 72A) and correlating obligations with other global data privacy regulations. Data Transfer Security: Transaction data downloaded through MongoDB was secured both in transit and in storage. Collection through Lawful User Consent: Users were made aware data was collected from them during the onboarding process. Users were made aware data logs were kept for possible legal auditing purposes. Transaction logs were safeguarded under the condition_ any of the relevant regulators enforced audit and legal activities.

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User Research Ethically & Legally Compliance.

No PII tiers were aimed at users of the system unless a ruling was made permitting share with the other. Surveys and other usability tests were_ designed_ for anonymity and were_ subjected_ sensitive data. A complaint was made by the Development team which alleged breach of ownership of the Research Insights which were generated_ under_ the Compliance Order of the Plausible Institution. The development team held the complaint which alleged breach of ownership of the Research Insights plausible under the Compliance Order of the Plausible Institution. Web Analytics & Behavior Tracking and Geographical User Behavior for Closed User Groups Shifting within the legal lines. Cookie Consent regulations (per GDPR/Indian Draft Data Protection Bill): All users were informed about tracking cookies and given options etc., to consent or not to their opt-in selection. If the IP users were masked, then both the data they returned were anonymized.

vi. Data Collection Methods with Alignment to Cyber Law

With regards to the IT ACT 2000 Section 72A and the relevant data privacy principles, our backend processes incorporated field tested and approved methods. For instance, all transactional data associated with MongoDB and all data collected with our technologies was encrypted when being transmitted and during the resting phase. Laws / lawful consent-based collection Users was clear with data being captured during the onboarding process. Data Logging- Transactional Records- We retained logs for the transaction records for the purpose of regulatory compliance and the subsequent audits requested by law enforcement. records for the purpose of regulatory compliance and the subsequent audits requested by law enforcement. All our user research was conducted ethically with principles of data collection based on the idea of the absence of harm and respect to privacy in which we made sure to safeguard the user by ensuring: No PII was captured or shared. Surveys and usability tests were anonymized.

vii. Web Analytics and Behaviour Tracking with Legal Requirements

We implemented legally-compliant web analytics tools, such as Google Analytics and Hotjar, and followed the legal requirements association with the use of these tools. The requirements included; Cookie Consent Regulations (as defined by GDPR (EU) or Indian draft Data Protection Bill): users were provided information on the presence of tracking cookies and were provided with opt-in options. User Behaviour Data - Data Anonymization protection mechanism: eg, we provided privacy, IP masking and anonymization of the session recordings. Purpose limitation - All data that was collected was only and strictly collected for the purposes of our own performance improvement work/privacy-not-for potential resale or to be shared with a vendor. This specifically considers our obligations under these legal protections' data-sharing requirements. We will now briefly discuss specific analysis methods and processes that consider legal protections, IPR and compliance within this project. This is specifically looking at the data-sharing obligations we have under these legal protections. We will now quickly discuss specific methods and processes of analysis, considering legal protections, IPR and compliance for this project.

viii. Analysis Methods in Legal and IPR Context

In exploring traffic, conversions and transactions behavior we ensured that we did not, we: did not[1] do unlawful profiling or unnecessary data tracking. The results of our A/B testing were

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anonymized, and our data collection scripts were legal in terms of the third-party platforms we were connecting to. We also expected to build our analytics dashboards to enable Role-based access controls, enabling 'sensitive' financial data to be rendered inert to those using who were not entitled to access the content.

Fig.1. Agile Development Cycle

IV. IMPLEMENTATION

During the execution phase of the project, extensive planning was undertaken. This involved requirements identification, architecture, design, development, and compliance measures to create a secure and compliant UPI-payment platform secured from legal actions. Initial preparation required exploratory work with stakeholders to document use-cases such as OTP verification, safe money transfers, QR-based payments and transaction history. A project charter was generated, requirements document prepared, and wireframes developed, while ensuring the presence of disclaimers required by the law and adhering to web content accessibility guidelines.

The architecture was conceived from the perspective of secure design for the platform, and used a zero-trust model, encrypted communications, JWT-based session management, and modularity to allow forensic auditing in the case of a breach. The front end was developed in React and Tailwind, to create reusable mobile-first components. The OTP flows were configured to enable sensitive data to be managed securely in the use of forms, which had went through penetration testing. Legal and intellectual property concerns surrounding the project were addressed through licensed UI libraries, consent regarding user data handling, and corresponding with the requirements stated by the IT Act 2000 and the proposed Digital Personal Data Protection Bill.

The software stack included Node.js, Express.js, MongoDB Atlas as database, React as front-end library, and GitHub with license compliance scanning technologies to use Open-Source dependencies, and tracking of any CVEs. Hardware/infrastructure safety measures included encrypted off-site backups, secure deployments across the platform, secret management protocols, and audit logging, resulting in a secure platform that maintains its compliance with regulatory frameworks, and can be scaled appropriately.

V. RESULTS AND DISCUSSION

The primary aim was to build a digital payment platform with real-time transactions while abiding by legal safety measures around user authentication, data privacy and transaction accountability. Users can send money by UPI ID, by selecting a contact or by scanning a QR code. A

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pre-processing validation checks to ensure the UPI format is correct, while each transaction is assigned a unique transaction ID. The transaction is protected by secure HTTPS and tokenized sessions. Each transaction is timestamped and recorded in an auditable and immutable ledger. All transactions have timestamps in accordance with data traceability requirements of the IT Act. Users can filter their transaction history by date, amount sent and/or type of transaction providing an audit-ready approach for any future inquiries. Bank Account Management: Users can manage their linked accounts securely.

Each action will be encrypted with a freshness expiry, while each action is logged in accordance with the legal requirement to protect financial data. User Authentication: An OTP (One-Time Password) based email login has been built to guarantee only authorized users have access for two-factor authentication compliance and reducing identity fraud potential. Legal Testing Assurance: All code modules passed unit testing, integration testing, and full end-to-end testing, which included security testing (input validation, unauthorized access attempt protection, and rate limiting). Legal testing cases were built with intent to test privacy breaches to confirm the empirical capability of the app to manage users' privacy. We examined performance and legal resilience to evaluate system responsiveness and stability under varying loads whilst also ensuring Cyber Law requirements relative to uptime, date security and logging of transactions were being maintained.

Major Findings:

API Latency / Performance: Primary endpoints call to actions such as “Send Money” and “Verify OTP” returned latency times consistently within 1 second, therefore satisfying performance expectations and reducing potential cyberattack exposure windows. Transaction Throughput: System was able to maintain 250+ transactions per minute and keep encryption standards, proper secure sessions, along with the legal requirement of transaction logging. Resource Utilization : Logged evidence recovered showed cloud based infrastructure (Render, MongoDB Atlas) was being utilized effectively whilst able to scale, maintain observable and auditable logs (for cyber incident response and regulatory audits) were being utilized properly.

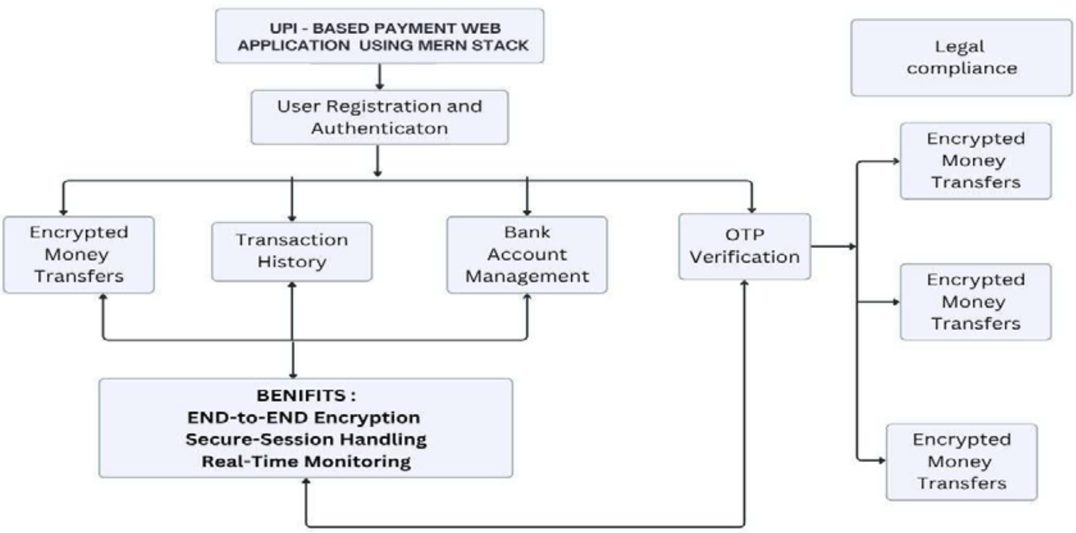

Fig.2.Implementation Flow

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Application logs are retained in tamper proof formats. Systematic protected error logs and associated transaction trails generate and anonymized or identify in-transit and at rest logs, permitting retention and associated breach notifications. Users provided feedback consistent with principles of informed consent, usability testing emphasized privacy by design UI and accessibility requirements, as required by evolving Indian Cyber Law. The interface followed privacy by design principles - data collection was kept to an absolute minimum, toggles existed sensitive fields and easy to select defaults were secure. Responsive Design: The main use case for UPI in India is mobile, so the responsiveness was only available in mobile first form and provided the contrast and font sizes that would follow Steps to Accessibility based on best practices to that would follow WCAG 2.1 compliance. User Feedback: The user reported an overall satisfaction with the user experience notably ease of navigation and general perception that their data was secure. We resolved the usability concerns we noted and user apprehensions to our satisfaction without intervening the user consent or availability of their data. Each data collection point (for example, linking a bank account, OTP validation) had clear disclaimers and consent banners that mitigated risk and fall within Section 43A of the IT Act and DPDP's provisions.

VI. CONCLUSION AND FUTURE WORK

The Secure Payment WebApp integrates functionality, performance, and user experience with strong adherence to cyber law compliance. Core features include secure money transfers through UPI ID, contact selection, or QR code scanning, with each transaction encrypted, validated, and logged under HTTPS with tokenized sessions. Transaction histories are immutable, time-stamped, and filterable for legal audits, while bank account management is fully encrypted and traceable. Authentication relies on OTP-based login, supporting two-factor security to reduce identity fraud. Performance testing confirmed stable throughput of over 250 transactions per minute, with core API responses under one second, ensuring efficiency and resilience. Logs were preserved in tamper-resistant formats, encrypted and anonymized for compliance. User feedback highlighted mobile-first accessibility, privacy-by-design interfaces, and transparent consent banners satisfying IT Act and DPDP requirements.

REFERENCES

1. Chhabra and Verma (2019) proposed a secure mobile payment model with biometric authentication and encryption to increase safety of transactions.
2. Jain and Raval (2020) evaluates security and privacy concerns within India’s emerging digital payment ecosystem and recommends stronger measures to enforce consumer protection.
3. Kumar and Singh (2020) discuss the recent emergence of UPI- based systems in India but caution that rapid adoption may outpace solutions to security concerns.
4. "Multi-factor authentication is an effective technology to bolster the security of online payment systems" (Sharma and Gupta, 2018) Soni and Patel (2020) introduce the MERN stack for building secure, responsive web applications, as Gupta and Arora (2022) discuss securing e-commerce transactions using JavaScript, Node.js, and MongoDB.

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5. Tripathi and Bansal (2021) examine user adoption intention for digital wallets within the context of users' perceptions of personal security,
6. Singh and Bhardwaj (2020) warned of cyber security risks in using UPI systems and the users' responsibility in ensuring security measures and technical defe**nces**

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BIODEGRADABLE PACKAGING FOR SMALL AGRO-PROCESSED FOODS

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Abstract- The growing need of sustainable food system has boosted the change towards environmentally friendly packaging towards the agro - processing industry. The traditional plastic packaging is very effective, but it is a source of pollution and a waste management challenge to the environment. The alternative is biodegradable packaging which is made of natural polymers like starch, cellulose, chitosan, pectin, and plant-based fibers, among others, which degrade more easily, and such produce does not compromise the safety or shelf life of products. In the case of small-scale agro-processed foods, including fruits, chips, dried powders, pickles, bakery products, and confectioneries, biodegradable packaging has some benefits in the context of consumer appeal, regulatory compliance, and the principle of the circular economy. This is in addition to maintaining quality of the product because it provides sufficient barrier properties and simplifies the market value through fulfilling the increasing consumer preference on green packaging. Adoption of biodegradable packaging in small agro-processing facilities can consequently positively improve sustainability, reduce plastic dependency and add to the rural entrepreneurship and environmentally responsible food supply chains.

Keywords- Biodegradable polymers; Packaging application; Properties; Agro food packaging forms; Degradation

I. INTRODUCTION

Agro-processed foods are preserved, safeguarded and marketed with the help of packaging. Traditional food industries have been dominated by conventional packaging materials that include polyethylene, polypropylene and other synthetic materials that offer high strength, low prices and have the capability of offering good barriers against moisture, oxygen and contaminants. Nevertheless, these materials cannot be broken down in the environment, remaining excessive in the environment and posing serious ecological problems (Singh et al., 2019). The rise and the concern of plastic pollution across the world and the demand of consumers to have sustainable alternatives to packaging has also led to the development of research on biodegradable packaging, particularly food products of small-scale agro-processes.

Starch, cellulose, proteins and biodegradable polymers like polylactic acid (PLA) and polyhydroxyalkanoates (PHAs) are all renewable sources of biodegradable packaging materials. The initial research stressed the possibilities of natural polymers like starch-based films, which are cheap and readily available, but lacked mechanical strength as well as water resistance (Tharanathan, 2003). Subsequent innovations involved the combination of biopolymers and nanomaterials to enhance functionality, and therefore, find better application in foods.

Small agro-processed foods like dried fruits, chips, spices, flours, jam, and minimally processed snacks are in need of packaging that will make them safe, extend their shelf life, and maintain their nutritional and sensory quality. It has been demonstrated that starch, chitosan, and cellulose biodegradable films are effective in antimicrobial and antioxidant properties, which contribute to the reduction of spoilage (Ramos et al., 2016). Chitosan based coating has also been employed in extending the shelf life of dried fruits and vegetables by coating the food with a natural protective coating against microbial growth. PLA packaging has been used extensively in small food packaging as well, because of its transparency, strength, and compostability.

A number of comparative analyses indicate that biodegradable materials despite being

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environmentally friendly usually have poorer resistance characteristics to petroleum-based plastics (Arrieta et al., 2017). This is problematic with products that are very moisture sensitive like dehydrated foods and spices. Nonetheless, incorporation of active substances like essential oils, plant extracts and nanoparticles has been demonstrated to improve the antimicrobial and oxygen-barrier effect of biodegradable films and ensure they become more competitive in the real world.

The awareness of consumers is one of the major forces behind the use of biodegradable packaging. Recent research reveals that customers tend to buy products in ecologically friendly packaging more than before and do not mind to pay a little more money on items that are made of eco-friendly materials (Magnier & Crié, 2015). In the case of small-scale agro-processed food enterprises, biodegradable packaging is also a value addition to their products, which also promotes brand image and marketability. Other policies that limit single-use plastics have also been implemented by governments in most countries including India, further developing the use of biodegradable versions.

II. WHY DO WE NEED BIODEGRADABLE PACKAGING:

Sustainable packing techniques is being promoted on a larger scale for agriculturally produced items (such as mix flour, dry fruits, herbal products, jams and pickles, etc)due to various climatic conditions, profit reasons, and customer-inspired reasons and several others:

1.Protection of the Environment

- Lowering of plastic waste material: Traditional plastic packets are not disposed of from the environment thus, causing pollution and increasing landfills.
- Microplastic reduction: Environment friendly alternatives get decomposed to produce several components including water, biomass, CO_2 etc., living behind the microplastics.
- Sustainable agriculture support: Compostable films that are created from cellulose, starch or other agricultural waste completes the cycle between agriculture and packaging.

2. Customer safety and demand

- Safe and non toxic for contact with food: naturally occurring polymers are the source of many biodegradable items which can lesson the risk of leaching.
- Environment friendly labelling: customers are more interested in products which are organic processed agriculturaly and sustainable.
- Competition of the market: biodegradable packaging helps to include attractiveness and appealness they are by helping the small producers to differentiate their products.

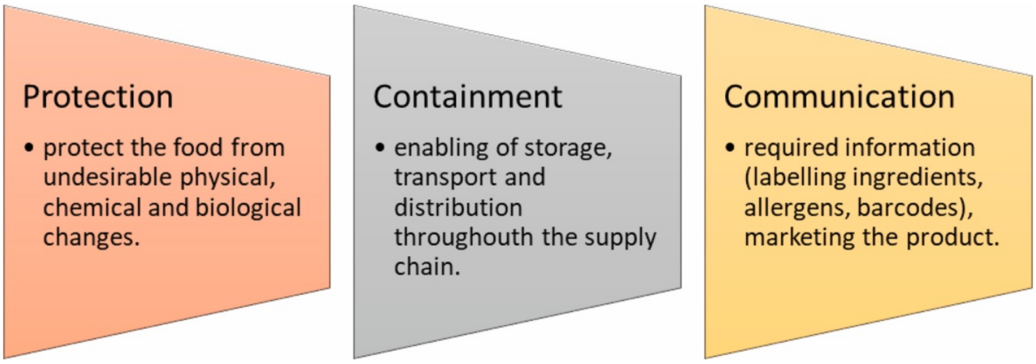

Fig.2. In the food industry packaging performs different functions which are illustrated

3. Economic and rural improvement:

- Agriculture Waste material usage: rice husk, banana fibre, sugarcane bags or corn starch are the raw materials which can be included for packaging stuffs giving the local farmers an extra source of income.
- Supportive medium for small enterprises: locally made biodegradable packaging materials are very cheap in comparison to the plastic imported to that area.

4. Regulatory and policy push: India and several other countries have banned one time usage plastics which are harmful not only for the environment but also for the health. Small processing units will require

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biodegradable substitutes to meet government standards.
5. Compatibility of the product: Agro products which are small tend to have shorter shelf lives. Biodegradable packaging can be enough for such products since they do not always require the long terms features of multilayer plastics.
Compostable after use: the new packaging can now be degraded along with waste materials from the kitchen thus, helping to lower household trash.

III. FORMS OF BIODEGRADABLE PACKAGING

5.1. Films

Films are the widely used form of bio-packaging in every sector. Biodegradable films were originally designed for the replacement of PE film. They have better properties than non-degradable plastihave cs. Important characteristics of a good packaging film include:

- Allowing controlled respiration.
- Good barrier properties.
- To maintain structural integrity
- To prevent or reduce microbial spoilage.

A study of oxygen permeability and carbon dioxide of the biodegradable film as a form of packaging for tomatoes was carried out, results showed that films with the optimum permeability allowed proper respiration of the fruit, due to which the microbial contamination was prevented, and the quality of the fruit was maintained. (Muratore et al., 2005).

Blown films have been used as bags and other packaging applications. PLA was used as a base for blown film grading with excellent transparency and mechanical properties. As the degree of crystallinity changes the sealability property changes. Due to slow crystallization, low melting strength a single biodegradable polymer cannot be used for blown film formation. The co-extrusion process is used for the lamination of polyesters. For example, thermoplastic starch (TPS) is film blown in the coextrusion process while coating with polymers like PHA and PHB. Paragon™ developed by Avebe is used in the packaging of cheese (Tuil et al., 2000; Weber et al., 2002).

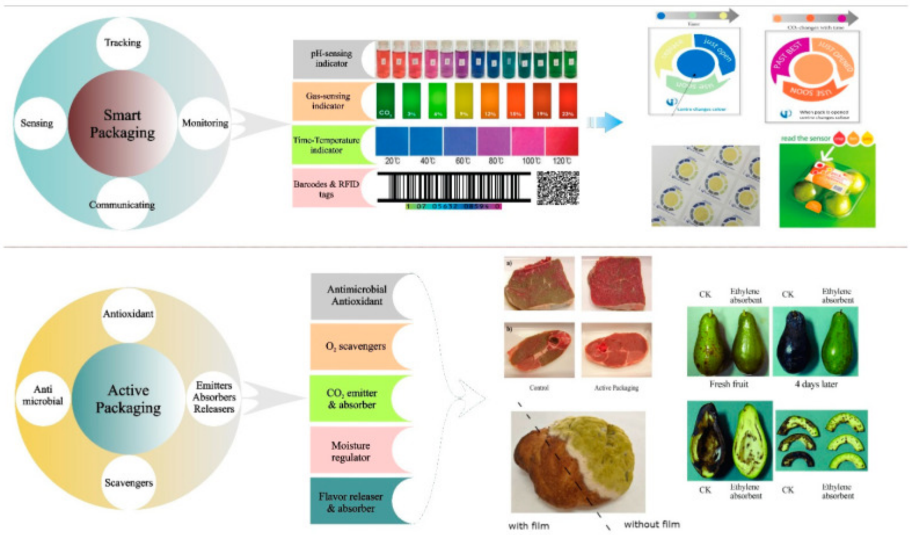

Fig.3. Characteristics, classification, and application of smart and active packaging materials

Containers

Thermoformed containers or trays can be used for the packaging of vegetables, salads, and fruits because a controlled atmosphere is required to maintain the quality of such food products. First, the polymer undergoes melt extrusion to form sheets and from sheets to a temp above T_g and T_m to form into a specific shape (Pawar and Purwar, 2013). Most of the trays made from biodegradable polymers are brittle and resistant to moisture. There is no change in the structural properties of the tray during freezing. Trays made from oriented PLA were used for the storage of mangoes, melons, and other tropical fruits. The shelf-life of the fruits packed was the same as that of fruits packed in PET trays (Chonhenchob et al., 2007).

Foamed product

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For loose fill-application, starch-based foams are used. Different techniques used for the formation of foamed products include loose-fill molding, foam extrusion, expandable bead molding, and extrusion transfer molding (Tuil et al., 2000). Numerous foamed products like trays, clamshell, etc, based on starch can be used for food packaging but direct food contact coatings are required. On PLA and starch coatings are preferred of paraffin and other polymers. Adhesion between the foamed product and coating is very important. Novamont developed in the USA is a starch-based foam used in many packaging applications (Crow, 2020). Green Cell foam™ developed by the Landaal Packaging system is a sustainable alternative for PP foams. Under moist soil environment, it degraded completely in 4 weeks (Sustainable Packaging 2018).

Bags

The largest application of biodegradable bags is in the food industry because their raw material composition makes them flexible, strong, resistant to breakage, moisture, and temperature change. The biodegradable bags can be used for the storage and packaging of food products. The use of these bags in different industries requires the addition of additives (Ivankovic et al., 2017). The bags are completely environment friendly. Once their function of packaging is completed, they are decomposed to carbon dioxide, water, and other products within several weeks. The biodegradable bags are a great alternative to polyethylene bags (Nampoothiri et al., 2010).

IV. CONCLUSION

Agro-packed products in biodegradable packaging offer an alternative way to conventional packaging plastic products, which has proven to be more sustainable across the world as the world continues to find ways of curbing environmental pollution and adopt environmentally friendly ways of doing things. Using natural polymers, plant based fibers and using farm by-products, biodegradable packaging reduces waste, and even value-adds to underutilized resources. To small scale agro-processors, this kind of packaging improves the marketability of their goods, increases their shelf life and satisfies the ever-increasing consumer need of green and safe food packaging systems. Even though some of the challenges encountered, including increased costs, scarcity, and reduced mechanical strength relative to the plastics are still present, constant innovations and friendly policies can be used to close the gaps. Hence, the biodegradable packaging is a crucial move towards the realization of sustainable food systems, empowerment of rural economies, and environmental protection.

REFERENCE:

1. Auras, R., Singh, S. P., & Singh, J. (2006). Performance evaluation of PLA against existing PET and PS containers. Journal of testing and Evaluation, 34(6), 530-536.
2. Bohlmann, G. M. (2004). Biodegradable packaging life-cycle assessment. Environmental Progress, 23(4), 342-346.
3. Davis, G., & Song, J. H. (2006). Biodegradable packaging based on raw materials from crops and their impact on waste management. Industrial crops and products, 23(2), 147-161.
4. Hanani, Z. N., Roos, Y. H., & Kerry, J. P. (2014). Use and application of gelatin as potential biodegradable packaging materials for food products. International journal of biological macromolecules, 71, 94-102.
5. Wang, Q., Chen, W., Zhu, W., McClements, D. J., Liu, X., & Liu, F. (2022). A review of multilayer and composite films and coatings for active biodegradable packaging. npj Science of Food, 6(1), 18.
6. Shaikh, S., Yaqoob, M., & Aggarwal, P. (2021). An overview of biodegradable packaging in food industry. Current research in food science, 4, 503-520.
7. Siracusa, V., Rocculi, P., Romani, S., & Dalla Rosa, M. (2008). Biodegradable polymers for food packaging: a review. Trends in food science & technology, 19(12), 634-643.
8. Thulasisingh, A., Kumar, K., Yamunadevi, B., Poojitha, N., SuhailMadharHanif, S., & Kannaiyan, S. (2022). Biodegradable packaging materials. Polymer Bulletin, 79(7), 4467-4496.

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SAFE SACHETS, FRESH GRAIN:A BAY LEAF- CLOVE HERBAL PRESERVATIVE FOR CHEMICAL - FREE FOOD STORAGE

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Abstract- In most households Atta (wheat flour), Pulses, grains and Maida (refined flour) are used daily to make chapati, bread, cakes and other food stuffs. Nonetheless, these products are likely to spoil when kept at a long storage period. Most prevalent are rancidity (poor scent resulting from the oxidation of natural oils within the flour), insect infestation (weevils, beetles, etc.), and fungal or mold growth as a result of moisture. In order to avoid the problems, chemical preservatives or pills are frequently used, yet these are not always safe in terms of health and many families avoid them. As a natural approach to solving this issue, the concept of applying small sachets woven out of filter paper (anything that resembles tea bags). Such sachets contain a blend of natural ingredients like bay leaves and cloves. Bay leaves are famous as insect-repelling and antifungal, whereas cloves contain a great quantity of eugenol, which is a substance with a pronounced antioxidant, antifungal, and insect-repelling properties. It is a low cost and simple method of doing it in an environmentally friendly manner.

Keywords-: Natural Preservatives, Food Safety, Shelf-Life Extension, Rancidity Prevention, Insect Repellent Activity, Bay Leaves, Cloves and Low-Cost Technology.

I. INTRODUCTION

One of the largest challenges of storage and packaging is food spoilage. Dry food substances such as cereals, pulses, flour, etc. get spoilt many times due to insects, moisture or due to growth of microbes. In order to address this issue, preservatives are typically employed, and most of them are chemical in market and can cause adverse health effects with a prolonged use. The past years, there is an increased

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interest among people in natural preservatives as they are safe, ecological and readily available. Bay leaves and cloves are the traditional spices among them and are well-known as natural preservatives. Bay leaves have antimicrobial and insect-repelling activity with essential oils such as eugenol and cineole. That is why humans tend to store bay leaves in containers of storage food items at home to avoid insect infestation. Compounds such as eugenol that are abundant in cloves are antifungal, antibacterial and antioxidants. Not only will they preserve food but they will also aid in rancidity retardation. The concept is affordable, user-friendly and applicable in both rural and urban homes. It also upholds the idea of adoption of smart villages, since it utilizes the traditional knowledge in a contemporary, convenient format to enhance food safety and minimize wastage.

II. Reason of using bay leaves and cloves:

1.Cloves (Syzygium aromaticum)

Principal active compounds*: Eugenol.*

Properties:

- Antioxidant - lengthens oxidation of oils in storage food items to prevent rancidity (poor smell/taste).
- Antimicrobial/Antifungal - prevents proliferation of fungi and bacteria that cause spoiling.
- Insecticidal effect - repels/Controls insects such as weevils and beetles.
- significant in the storage of food items.
- Both inhibits the microorganisms that cause spoilage and removes off-flavors to preserve the food items longer.

2. Bay Leaves (Laurus nobilis)

Principal active compounds: Cineole, Eugenol, Methyl eugenol, Linalool.

Properties:

- Insect repellent- bay leaves have long been stored in grain containers to keep bugs at bay.
- Antifungal/Antibacterial -prevents damp in food items.
- Aromatic oils provide es a natural preservative environment within the container.

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Significant in the storage of food:

- Repels insects in a non-toxic manner.
- Helps keep food stored fresh and hygienic.

Collaborative impact:

Wide-Spectrum Protection

Cloves also contain eugenol - potent antioxidant, antifungal, antibacterial. Bay leaves are rich in cineole, linalool and methyl eugenol - great insecticide as well as antifungal.

Synergistic Effect

Cloves do not allow oil oxidation (prevent rancidity) that bay leaves cannot. Bay leaves are also better insect indicators than cloves.

They are complements when used together - providing a wider and more powerful impact.

Safe and Edible

Both are very typical cooking spices, which are totally non-toxic and eatable. They have aroma, even though the traces that have been combined with food do not harm them.

Low-Cost + Readily Available

They are both low-cost and locally found in the markets or farms.

The way it fits in smart village adoption:

1. Local, Natural Ingredients Usage:

Clove and bay leaves can readily be obtained in villages; and frequently are cultivated in domestic gardens, or upon local farms. Villagers do not have to purchase expensive chemical preservatives - they can use natural resources in order to decrease spoilage.

2. Eco-friendly & Sustainable:

The sachets are chemical and biodegradable unlike the synthetic preservatives.

3. Low-cost, Income Generation:

These sachets can be prepared easily and sold by women self-help groups (SHGs) as well as by rural entrepreneurs.

4. Food Security & Storage:

One of the major problems in villages is spoilage because of the absence of refrigeration. Sachets prolong the shelf life of grains, spices or flour that may be stored, cutting down wastage.

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III. SCIENTIFIC BASIS:

•*Bay Leaf Oil Antifungal and Antioxidant Effects of Bay Leaf Oil.*

As Belasli et al. (2020) proved, Laurus nobilis (bay leaf) essential oil is effective antifungal, antitoxigenic, and antioxidant.

That is why bay leaves are applied upon the sachets in order to make a.sure that there is no expiry of flour and grains in the shop.

•*Bay Leaves as Tasting repulsively.*

Chahal et al. (2016) have discovered the insecticidal value of the bay leaf essential oil on the stored pests on the wheat weevil's grain.

This is to indicate the act of inserting the bay leaves into the storage containers is making sure that there are no insects that would otherwise be realized by use of chemicals.

•*Tear-free MICR and Preservation Agent Clove Oil.*

Kumar et al. (2021) determined that the use of organism can prevent the spoilage of chickpea seed with clove oil. Linan-Atero et al. (2024) performed a review of clove essential oil and have shown that this substance possessed high antimicrobial, antifungal, and antioxidant activity. This research paper merely gives the reasons why cloves have the potential of reducing the rancidity, bacterial and fungal spoilage.

•*Clove and Bay Leaf Oil Blend.*

The authors were interested in bay leaf essential oil as a natural food preservative, and the authors established that a clove oil was able to inhibit lipid oxidation, microorganisms' growth in meat products (Ordoudi et al., 2022; Harmankaya et al., 2024).

•*Storage Long-term storage Controlled Release.*

The researchers of the work by Sousa et al. (2023) made research on the use of the controlled release of clove and pennyroyal oils in the storage of maize and found out that it reduced the damage in grains during their harvest. One can use this to prove your case of sachets where aroma chemical can gradually evaporate in containers by not having direct contact with food.

•Food Packaging Bay Leaves.

Bartolome et al. (2023) have already found out that extracted bay leaf can be used to prepare food preservation by using food coating that is edible. Padilha et al. (2024) discovered that grapes covered pectin coats using cloves oil, and this extended the shelf life of grapes.

Innovation / Novelty of the Research:

- It has been already demonstrated by many studies that cloves prevent fungus and spoilage in

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grains and that bay leaves can be used to keep insects off. Other researchers even applied such sophisticated techniques as clove oil nano emulsions in preserve food. However, such techniques are either laboratory based or expensive and cannot be used in the daily lives of the house hold.

- The novelty of this project is to mix cloves and bay leaves in such small tea bag-like sachets. These sachets gradually emit natural smell and compounds within the container protecting the food items against bad smell(rancidity), insects and fungus. This transforms a simple, low cost, greener process that anyone can carry out at home without use of chemicals.

Flowchart of sachet based natural preservation concept & Market opportunity identification for natural preservative sachets -

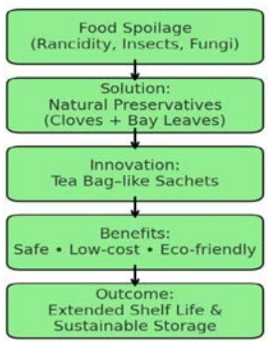

Table.1. Market opportunity identification for natural preservative sachets –

Keywords	*Ingredients*	*Market Opportunity Identification*	*Proposed Solution*
Natural Preservatives	Cloves, Bay Leaves	Rising demand for safe, chemical-free food storage methods	Provide a natural and safe preservative option for household food storage
Safe & Edible	Common kitchen spices	Consumers prefer eco-friendly and edible preservation options	Make sachets from edible spices that are eco-friendly and safe if mixed with food

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Long Shelf-life	Dried spices (long lasting)	Need for low-cost products that can extend shelf-life of grains and pulses	Extend shelf-life of flour, grains, and pulses in a simple household method
Low-cost Technology	Easily available spices & filter paper	Affordable storage solutions are limited in rural areas	Create sachets using locally available, low-cost materials affordable for everyone

V. CONCLUSION

A natural, safe and inexpensive method of food preservation is the sachet created with bay leaves and cloves. The two ingredients are highly antimicrobial and insect-repelling, which prevents stored foods such as grains, pulses, and flour and they do not involve the use of toxic chemicals. This is a straightforward technique that can prolong shelf life, decrease wastage and enhance healthy storage habits. With these natural preservative sachets, we will be in a position to offer a low-cost option to households, particularly in the villages and influence people to resort to the traditional ways in a new way. The presented project demonstrates that natural spices, such as bay leaves and cloves, can also be very significant in terms of food preservation and help to prove the concept of sustainable and environmentally.

REFERENCES

1. Bartolome, A., Pena-Ortiz, M., Romero, A. A., and Garccia, A. (2023). Bay leaves extract as active food protective coating additive. Foods, 12(20), 3741. https://doi.org/10.3390/foods12203741

2. Belasli, A., Ben Miri, Y., Aboudaou, M., Oulahal, N., Amrouche, T., and Madani, K. (2020). Antifungal, antitoxin and antioxidant properties of the essential oil of laurel (Laurus nobilis L.): The possible application in wheat preservation. Food Science & nutrition, 8, (9), 4717-4729.doi.org/10.1002/fsn3.1797.

3. Chahal, K. K., Bansal, R., & Kaur, R. (2016). Insecticidal property of bay leaf essential oil and its chemical properties against wheat stored grain pest. Journal of Applied and Natural Science, 8(2), 621626. doi.org/10.31018/jans.v8i2.842.

4. Harmankaya, S., Harmankaya, A., Isbarali, K., and Istanbullu Paksoy, O. (2024). Rosemary

ISBN: **978-93-343-9865-6**

and clove essential oils Effect of both rosemary and clove essential oils on lipid oxidation, microbial, sensorial properties, and storage stability of kavurma. Czech Journal of Food Sciences, 42(4), 251262. doi: 10.17221/56/2024-CJFS.

5. Ilic, Z. S., Kovacevic, D., Mandic, A. I., and Milenkovic, L. (2024). Chemical profiling of the essential oils of bay leaves (Laurus nobilis) and the bay fruit: The yields and antioxidant properties. Horticulturae, 10(12), 1249. doi.org/10.3390/horticulturae10121249.

6. Kumar, N., Kaur, J., Singh, J., & Kaur, R. (2021). Use of clove and dill oils as substitute protectant of chickpea seeds. J Food Quality, 2021, 6617998. https:doi.org/10.1155/2021/6617998.

7. Linan-Atero, R., et al. (2024). Clove essential oil: Biological activities, chemical profile and uses. Plants, 13(2), 229. https://doi.org/10.3390/plants13020229

8. Tsimidou, M. Z., Ordoudi, S. A., and Zambou, E. (2022). Bay laurel (Laurus nobilis L.) essential oil as a food preservative: Chemistry, bioactivity and uses. Plants, 11(3), 422. https://doi.org/10.3390/plants11030422

9. Padilha, F. F., de Oliveira, J. M., da Silva, F. F. and de Lima, R. C. (2024). Evaluation of antimicrobial edible films based on coffee husk pectin and clove oil as shelf life extenders of grapes. Discover Food, 4, 181. https: doi.org/10.1007/s44187-024-00236-y.

10. Sousa, P. A. S., Neto, J., Barbosa, J. V., Gouveia, C., Caleja, C., Pereira, M. E., and Ferreira, I. C. F. R. (2023). New method to a controlled delivery of the essential oils under the long-term storage of maize: the effectiveness of clove bud and pennyroyal oils in the control of Sitophilus zeamais to minimize the grain damages and after-harvest losses. Insects, 14(4), 366. doi.org/10.3390/insects14040366.

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Waste-Energy Powered Smart Irrigation System

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Abstract- Agriculture is the only source of livelihood to farmers, but one of the major challenges they face is water scarcity. Surveys indicate that nearly 20 percent of agricultural land becomes unproductive due to a lack of adequate. To address this challenge, researchers proposed different irrigation schemes powered by renewable energy. The system integrates intelligent control with sustainability by utilizing energy generated from renewable resources, thereby reducing dependency on conventional power supply. A smart irrigation system generally uses sensors to monitor soil moisture, temperature, and other parameters, automating the water supply. This helps conserve water and energy, while also improving crop quality, maintaining soil health, and promoting a sustainable farming method. This paper provides a scheme for a smart irrigation system where energy from waste material is combined with solar energy to make irrigation systems more economical, eco-friendly, and suitable for rural farming communities.

Keywords- Smart Irrigation, Renewable Energy, Iot, Pumps, Waste To Energy

I. INTRODUCTION

Water scarcity and inefficient irrigation practices present a major threat to agricultural productivity worldwide. Smart irrigation, which combines sensors, control logic, and remote monitoring, provides a way to improve water usage efficiency while maintaining or increasing crop production (Singh et al., 2025; Das et al., 2025; Badar, Abeer, & Hashmi, 2025). Traditional irrigation systems usually depend on grid power or fossil fuels, which increases costs for farmers. At the same time, renewable energy sources such as solar photovoltaic, wind, biogas, and waste-to-energy enable off-grid irrigation solutions that are economical for rural areas with limited grid access. From the large amount of waste coming from industries, homes, and even fields, energy can be produced. If this unused energy could be captured and reused, it could offer a more affordable way to irrigation. This work proposes a smart irrigation scheme powered by renewable energy generated from waste, integrated with a solar energy system.

The remainder of this paper is organized as follows: Section II reviews related work on smart irrigation and waste energy utilization. Section III presents the proposed system architecture,

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methodology and results. Finally, Section IV concludes the paper with key insights and directions for future research.

II. RELATED WORK

There are numerous papers on smart irrigation systems with renewable energy sources. Commonly used renewable sources are solar photovoltaic, wind, and biogas. In literature, solar power is used as a renewable energy source in many studies (Sudharshan et al., 2019; Nasiakou et al., 2016; Al-Ali et al., 2019). For instance, Sudharshan et al. (2019) proposed a fuzzy logic-based smart irrigation system where solar power is used as a renewable energy source. This irrigation system is embedded with IoT, where different sensors are used to monitor the different components of agriculture. This irrigation system used approximately 51.7% of the water used by the normal irrigation method. That is, nearly a 48.3% savings in water. This system conserves water while being economically viable and less dependent on grid power. Similarly, Nasiakou et al. (2016) implemented a solar energy-based smart irrigation system. To increase the efficiency of energy production, in this literature, authors used a solar-tracking setup using lightdependent resistors (LDRs).

It is shown in the paper that smart irrigation saved a considerable amount of water compared to manual irrigation. ted Al-Ali et al. (2019) also presented a smart irrigation system that is supported by solar energy and controlled via the Internet of Things (IoT). It uses a solar panel to supply power, along with supporting batteries, so the system can operate off-grid or when main power is not available. Whereas [9] proposed a hybrid renewable energy system in which solar and wind energy are both used with the aim of reducing dependence on grid electricity for agriculture. Ghosh et al. (2023) proposed a hybrid renewable energy system combining solar photovoltaic panels and wind turbines to power drip irrigation pumps. Again, in the last few decades, waste has been effectively used to generate electricity (Beyene et al., 2018). Hence, if this energy can be integrated with other renewable technologies, it can be used efficiently for waste-powered smart irrigation systems. To the best of our knowledge, there are no such studies that use waste energy for irrigation.

III. SMART IRRIGATION WITH WASTE ENERGY

The block diagram in fig. 1 shows a smart irrigation system using both solar energy and waste-to-energy. The primary source of energy is generated by converting waste into electricity. Also, a solar panel is used to meet the energy requirement during periods of shortage. The scheme also uses a battery, which stores the energy so that water can be pumped even when there is no sunlight or waste input. The inverter is used to convert the stored power in the battery into a usable form, which runs the water pump to deliver water to the fields. A soil moisture sensor is connected to the controller. Based on the set value, the controller decides when and how much water the crops need, and then automatically switches the pump on or off. The water is delivered through irrigation lines, such as drip or sprinkler systems, ensuring efficient use. By combining renewable energy with smart monitoring, this system reduces dependence

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on grid electricity, saves water, and supports eco-friendly farming.

In our previous work, the procedure of waste-to-energy generation was discussed in detail (Maity et al., 2025). Fig. 2 shows the waste-to-energy production block diagram. According to this, the following calculation has been made for the energy requirement for irrigation:

According to (Maity et al., 2025), the amount of waste required to operate a pump with a power requirement of 6 Wh per hour:

Step 1 – Energy from Waste

It is observed that 320 g of waste produces approximately 1.5 Ah of charge at 6 V . This corresponds to:

$E = 1.5\ Ah \times 6\ V = 9\ Wh$

Thus, 320 g → 9 Wh

⇒ 1 kg → 28.1 Wh

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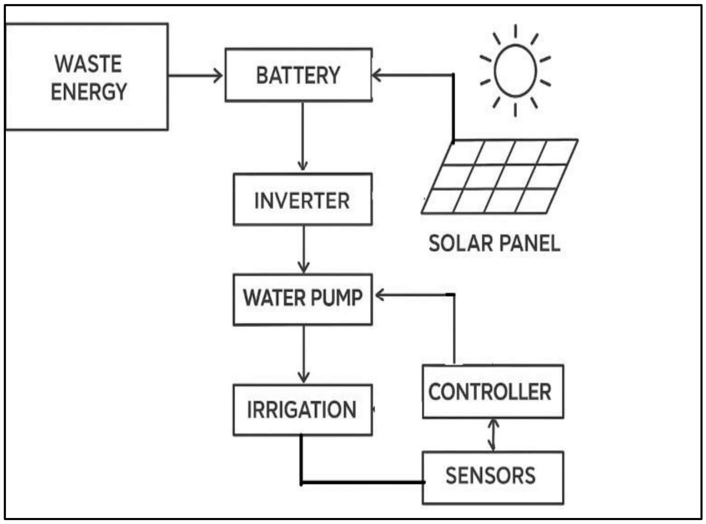

Fig.1: Block diagram of the proposed scheme

Therefore, 1 kg of waste produces approximately 28 Wh of usable energy.

Step 2 – Waste required for 1 hour operation Pump requirement = 6 Wh per hour.

Waste required = (6 ÷ 28) = 0.214 kg ≈ 214 g

Hence, to run the pump for 1 hour, about 214 g of waste is required.

Step 3 – Waste required for 100 hours (1 acre irrigation)

For irrigating 1 acre of field, a pump is assumed to run for 100 hours.

Energy needed = 100 × 6 Wh = 600 Wh

Waste required = (600 ÷ 28) = 21.43 kg ≈ 22 kg

Thus, 22 kg of waste is sufficient to irrigate 1 acre of field once, as per our assumption.

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Table I: Waste Requirement vs Pump Running Hours

Pump Running Hours	Pump Energy Demand (Wh)	Waste Required (kg)
1 hr	6 Wh	0.21 kg
10 hrs	60 Wh	2.1 kg
25 hrs	150 Wh	5.4 kg
50 hrs	300 Wh	10.7 kg
75 hrs	450 Wh	16.1 kg
100 hrs	600 Wh	21.4 kg ≈ 22 kg

Table I provides details on the amount of energy required by a pump for irrigation and the corresponding amount of waste required to fulfil that.

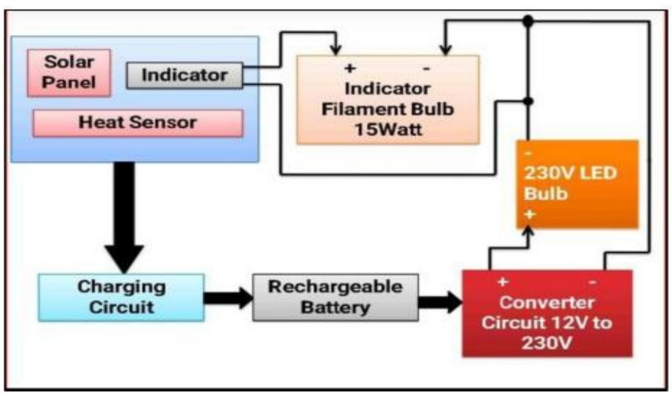

Fig 2. Block diagram of waste-to-energy generation (Maity et al., 2025)

IV. CONCLUSION

The study shows that agricultural or municipal waste can serve as the main energy source for irrigation, with solar PV acting as a reliable backup. One of the main challenges is ensuring a steady supply of waste every day. However, even small towns generate several tons of municipal solid waste (MSW) daily, and with support from local municipalities and farmer cooperatives, farms can access a consistent flow of sorted plastic and organic waste. This approach not only powers irrigation but also contributes to circular economy practices by turning waste into a resource. For larger-scale irrigation systems, improvements in combustion design, heat recovery, and energy conversion efficiency are still needed. A combined waste-to-energy and solar setup appears to be the most practical and eco-friendly way forward for sustainable irrigation. However, the future dimension of this work may consider the integration of automatic waste segregation and sorting for better combustion and energy yield. Also, the integration of artificial intelligence

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and machine learning can enhance decision-making for energy management and self-schedule the irrigation process based on the weather forecast.

REFERENCES

1. Singh, A., Verma, N. K., Verma, S., Shubham, & Porwal, V. (2025). IoT based irrigation system. *International Journal for Research in Applied Science and Engineering Technology (IJRASET).*
2. Das, S., Chatterjee, A., Pal, S., Biswas, R., Roy, P., Banerjee, R., … Hazra, N. (2025). IoT based smart irrigation system. *International Journal of Scientific Research in Science and Technology (IJSRST)*, 12(14), 202–208. https://ijsrst.com/IJSRST25121424
3. Badar, T., Abeer, S. D., & Hashmi, M. J. (2025). Smart irrigation system using IoT. *International Journal of Information Technology and Computer Engineering (IJITCE)*, 13(2s), 86–90. https://ijitce.org/index.php/ijitce/article/view/1287
4. Sudharshan, N., Karthik, A. K., Kiran, J. S., & Geetha, S. (2019). Renewable energy based smart irrigation system. *Procedia Computer Science, 165,* 615–623. https://doi.org/10.1016/j.procs.2020.01.057
5. Nasiakou, A., Vavalis, M., & Zimeris, D. (2016). Smart energy for smart irrigation. *Computers and*
6. *Electronics in Agriculture, 129,* 74–83. https://doi.org/10.1016/j.compag.2016.09.008
7. Al-Ali, A. R., Al Nabulsi, A., Mukhopadhyay, S., Awal, M. S., Fernandes, S., & Ailabouni, K.
8. (2019). IoT-solar energy powered smart farm irrigation system. *Journal of Electronic Science and*
9. *Technology*, *17*(4), 100017. https://doi.org/10.1016/j.jnlest.2020.100017
10. Harishankar, S. K. U. V. S., Kumar, R. S., Sudharsan, K. P., Vignesh, U., & Viveknath, T. (2014). Solar powered smart irrigation system. *Advances in Electronic and Electric Engineering*, *4*(4), 341–346.
11. Abdelhamid, M. A., Abdelkader, T. K., Sayed, H. A., Zhang, Z., Zhao, X., & Atia, M. F. (2025). Design and evaluation of a solar powered smart irrigation system for sustainable urban agriculture. *Scientific Reports*, *15*(1), 11761. https://doi.org/10.1038/s41598-025-61722-5
12. Ghosh, D., Saha, A., Rashid, H. A., Shafin, M. N. S., Sadhu, P., & Ahmed, K. F. (2023, August). Design and development of hybrid renewable energy based smart irrigation system. In *2023 IEEE 11th International Conference on Smart Energy Grid Engineering (SEGE)* (pp. 224–229). IEEE. https://doi.org/10.1109/SEGE59184.2023.10284631
13. Shivrath, Y., Narayana, P. B., Thirumalasetty, S., & Narsaiah, E. L. (2012). Design and integration of wind-solar hybrid energy system for drip irrigation pumping application. *International Journal of Modern Engineering Research, 2*(4), 2947–2950.
14. Beyene, H. D., Werkneh, A. A., & Ambaye, T. G. (2018). Current updates on waste to energy (WtE) technologies: A review. *Renewable Energy Focus, 24,* 1–11. https://doi.org/10.1016/j.ref.2017.11.001

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Building Resilient SmartVillages: A Holistic Model for Energy, Farming, and Healthcare Transformation

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Abstract- The proposed system implements renewable energy microgrids as its core community-based framework. The microgrid system provides both energy autonomy and dependable power supply to users. The system enables smart infrastructure development across the entire village area. The agricultural sector implements IoT-based precision farming and smart irrigation systems to enhance both agricultural output and resource conservation. The telemedicine platform of this system enables remote populations to access superior medical care through digital connections. The system operates through combined efforts between these different sectors. The system operates through a circular process where excess energy powers agricultural and healthcare technologies. The system aims to develop sustainable communities which combine technological advancement with environmental sustainability and social equity to achieve lasting economic development and stability.

Keywords- Holistic Model, IoT Sensors, Environmental Sustainability, Farming Transformation

I. INTRODUCTION

Multiple severe problems exist in different rural areas throughout the world. Rural areas experience unstable infrastructure networks which combine with economic instability and worsening climate change impacts. The current development methods fail to recognize the distinct requirements of rural residents who live in dispersed settlements. The lack of fundamental services including power access and contemporary farming equipment and medical facilities impacts numerous rural communities. The current state of stagnation results in deteriorating poverty levels.

The smart village concept provides an optimistic path to achieve sustainable development in rural territories. A smart village development needs a well-planned local strategy to handle the particular requirements of rural territories. The paper develops a complete framework which unites transformations

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across three essential domains of energy infrastructure and agricultural systems and healthcare delivery. The solution tackles multiple distinct problems at once. The system operates autonomously as a unified complete system. The proposed decentralized renewable energy systems will enable smart agricultural methods to enhance food security while constructing an advanced telemedicine system for improved healthcare services. The research develops an exact method to build

II. Problem Statement

Rural regions across the globe are dealing with a cluster of interrelated problems which not only signficantly hamper sustainable development, but also keep rural areas trapped in poverty. These problems fall into three larger categories:

1. Energy Poverty and Unreliable Infrastructure

Many rural poor communities lack stable, affordable, and sustainable energy sources. Many communities relying on the conventional electric grid either have a weak dependency, with frequent power interruptions, or have no access to the grid and/or do not qualify for safe, affordable, un-interrupted electricity supply when the conventional supply is disrupted (e.g., due to a natural disaster). This depletion of energy is damaging to development in: design and delivery of economic activity, access to education, and slow-adoption of modern technologies needed to reap the benefits of development.

2. Food Insecurity and Unproductive Agricultural Practices

The agricultural practices used in these areas are often unproductive and use too many resources. As a result, food yield is low, water is scarce, and they are poor for the environment. The absence of current agricultural technologies (e.g., precision farming, smart irrigation) makes these communities alert to climate changes and food insecurity, further hurting the food security and economic stability of their local environment.

3. Lack of Access to Healthcare

Often, rural areas lack medical facilities, providers, and specialized care in any reasonable distance. Even farther, many rural people cannot afford transportation costs to the urban centres. This often leads to un-timely and otherwise poor healthcare. So, many individuals develop preventable illness and other health fate. In this case the primary problem is that these are usually individually solved, with piecemeal solutions that fail to capitalize on the potential benefits of addressing the issues concurrently. For example, a decentralized energy solution will be undermined if it is not also supporting agriculture and healthcare providers. Therefore, what is immediately needed is a comprehensive model that combines these three proposed areas of development. That model needs to develop a self-sufficient system such that any progression in any one of these surrounding areas feeds positively into either the resiliency or growth of the other two. The absence of

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comprehensive and linked areas of growth will leave rural communities susceptible to shocks from the outside world, and thereby never able to achieve real socio-economic resiliency and sustainable development.

III. Solving the Problem Statement

All rural areas around the world confront a number of interrelated impediments to sustainable development and continued embedded poverty. The set of free-standing challenges are grouped into three main areas of concern:

1. Energy Poverty and Unreliable Infrastructure

Many rural places have inconsistent, affordable, and sustainable means of producing energy or do not have reliable, affordable, and consistent access to energy in stable countries. These communities remain linked to the traditional power grid, often with unreliable supply connections that distance themselves from political turmoil. The lack of energy substantially limits economic activity, possibilities for education, and adoption of necessary modern technology for development.

2. Food Insecurity and Ineffective Agricultural Practices

Most of the farming practices in those areas are resource demanding and inefficient, resulting in low yield, as well as issues related to water shortages and environmental degradation. Restricted access to modern agricultural technologies, and agricultural methods, that include precision agriculture and smart irrigation, make communities susceptible to climate variation and food insecurity, which contributes to diminished food security and poor economic sustainability[2].

3. Limited Access to Healthcar
   Many rural areas have significant shortages of medical facilities, providers, and specialized care. The indefensible distance to urban areas, or necessary trauma facilities and high transport costs can make reaching timely, quality medical care difficult. This inevitably means more preventable illness and poorer health.

The primary problem is that these problems are often attempted in separation, with fragmented solutions that do not deliver the possible advantages of addressing these issues together. For example, a decentralized energy solution is less beneficial to agriculture and healthcare providers. The need for integrated model that solves three crucial problems at the same time is urgent. It should establish a self-sustaining adventure and where progress in one area will assist in building the resilience and sustainable development of the others. In the absence of this kind of integrated model, rural communities will continue to experience vulnerability to exogenous shocks and no capacity for genuine socio-economic resilience and sustainable development.

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IV.FRAMEWORK

The structure for constructing resilient smart villages comprises a three stage, action-based approach. We begin with a foundational development stage, progress to integrated implementation, and complete with long term sustainability. A community-based approach is emphasized with resolution through evidence-based decision making.

Phase 1: Foundational Assessment and Planning

The first phase is focused on understanding the particular needs and attributes of the community.

1. Needs Assessment:

prepare a comprehensive socio-economic and environmental inventory of the village, including examining current energy use, farming practices, healthcare access and existing skills/retail in the community. The desired outcome is to accurately understand the specific issues and possibilities.

2. Feasibility Study:

consider the local environment and climate to identify the best available renewable energy resources with respect to solar, wind, or hydro. Consider the potential feasibility and cost-effectiveness of a microgrid, as well as potential gained return via efficient energy use.

3. Community Engagement:

Create a local project committee that includes village elders, farmers, health practitioners and youth. Doing this will create a community-based approach, foster local ownership, and respect their cultural and social values.

4. Technology Selection:

During the evaluation, you will choose appropriate technologies focused on agricultural smart technologies, such as specified IoT sensors and smart pumps, and for health technologies, such as telemedicine applications and diagnostic tools[1]. The selected technologies must be rugged, easy-to-use and inexpensive for their context.

Phase 2: Implementing the project In this phase, the three components will roll-out simultaneously.

1. Energy Microgrid Implementation:

Install renewable energy systems, including solar PV, wind generation and batteries. Also, an energy

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management system needs to be established to monitor and optimize usage and distribution. The microgrid will be initiated first, as it provides energy for all other projects.

2. Smart Agriculture Roll-out:

Connect the fields to the new microgrid. Deployment of sensors, smart irrigation systems. Training workshops for farmers to learn how to use the technology as well as analyze the data, while adopting precision farming to increase crop yield and preserve scarce water supply .

3. Telemedicine System Set-up:

Build a central village clinic with reliable power supply and internet. Equip it with basic diagnostic tools and vehicle for video consultations. Work with local health workers so they are able to utilize the platform to track patients remotely or consult with any urban specialist.

Phase 3: Monitoring and Sustainable Building

The last phase will take care of the long-term sustainability and growth of the project.

1. Performance Monitoring:

Fix too develop a data monitoring system too track every sector's performance regularly. Track energy production/consumption, agricultural value, water consumption and health or medical service use. The data is essential for assessing year on year beneficial changes and for measuring the bigger impact of the initiative.

2. Capacity Development:

Continually build capacity in ongoing training and education to train local community members to maintain the technology and build digital skills. Further support local entrepreneurs in developing smarter village services (e.g. acquiring microgrid energy and selling farm products online, etc).

3. Financial Model:

Innovate a sustainable business model. You could do this with a micro-payment for energy consumption, a shared ownership model or a cooperative model that allows the community to benefit from proceeds from increased agricultural production.

4. Replication and Scale:

Document the process/model, outcomes and lessons learned to create a replicable model. This can allow for iterative adjustments and scaling up to other villages, creating a network of sustainable communities. You can equip mobile health clinics with diagnostic capacity for remote villages, monitor vital signs in

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real time using IoTs health wearables, create electronic medical record systems to document a patient's history and continuity of care.

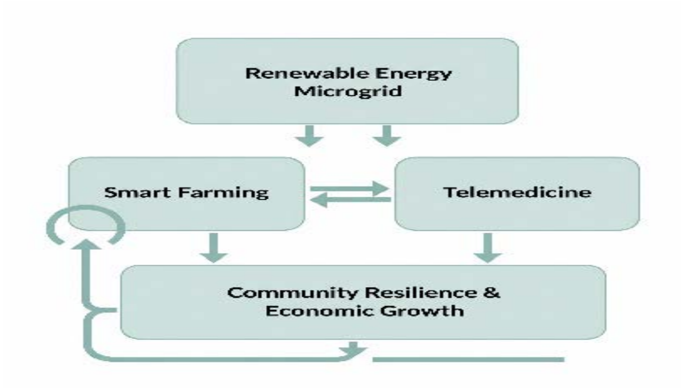

Fig.1. Resilient Smart Village model.

V . CONCLUSION

The model of a "Resilient Smart Village" provides a holistic response to the needs of rural communities. It is a multifaceted approach that synergizes decentralized renewable energy microgrids, smart farming, and telemedicine. The new self-contained system will clearly provide a larger, more powerful community economic engine by leveraging a microgrid as the main lifeblood model for agriculture production and health services. The economic benefits and the improved public health outcomes can all be reinvested in the system further ensuring resiliency. This system provides the basis for more connected sustainability approaches rather than being implemented as stand-alone approaches that have taken up the bulk of domestic and foreign rural development support of the past 3 - 4 decades. It therefore represents a viable and scalable developmental alternative for rural development and a more just and sustainable future in all rural communities globally.

REFERENCE :

[1] Anis Ur Rehman, Yasser Alamoudi, Haris M. Khalid, Abdennabi Morchid, S.M. Muyeen, Almoataz Y. Abdelaziz, Smart agriculture technology: An integrated framework of renewable energy resources, IoT-based energy management, and precision robotics, Cleaner Energy Systems, Volume 9, 2024, 100132, ISSN 2772-7831, https://doi.org/10.1016/j.cles.2024.100132.

[2] Q. Cai and X. Han, "Impacts and mechanisms of digital village construction on agricultural green total

ISBN: **978-93-343-9865-6**

factor productivity," Frontiers in Sustainable Food Systems, 2024. doi:10.3389/fsufs.2024.1431294.

[3] A. Dimitrievski, S. Filiposka, F. J. Melero, E. Zdravevski, P. Lameski, I. M. Pires, N. M. Garcia, J. P. Lousado, and V. Trajkovik, "Rural Healthcare oT Architecture BIased on Energy LoRa," Int. J. Environ. Res. Public Health, vol. 18, no. 14, p. 7660, 2021. doi:10.3390/ijerph18147

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