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Agriculture Based on Wireless Sensor Network: Literature Survey

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Abstract

This manuscript provides an extensive review of the existing literature regarding the confluence of Wireless Sensor Networks (WSN) and Internet of Things (IoT) innovations in the field of Agriculture. The investigation delves into a variety of systems and frameworks crafted to elevate agricultural methodologies through immediate surveillance and oversight of ecological factors. Essential elements encompass the deployment of diverse sensors, including those for soil moisture, temperature, and humidity, which are vital for refining irrigation practices and promoting effective water utilization. The manuscript underscores the significance of microcontrollers such as Arduino and Raspberry Pi in managing and relaying information to central hubs or cloud platforms for distant access and governance via mobile interfaces. Furthermore, the study addresses the applications of communication protocols like LoRa, ZigBee, and Wi-Fi, which enable extensive and efficient data relay. The incorporation of machine learning strategies for distinguishing crops and weeds, along with the utilization of solar energy to power sensor units, is also scrutinized. The manuscript wraps up by highlighting the transformative potential of IoT and WSN technologies in modernizing smart agriculture, providing avenues for energy-efficient and automated farming solutions.

Keywords: Wireless Sensor Networks, Internet of Things, Artificial Intelligence, Light Dependent Resistor

الخلاصة:

هذي المخطوطة تقدم مراجعة شاملة للأدبيات الموجودة بخصوص تداخل شبكات الاستشعار اللاسلكية (WSN) وابتكارات إنترنت الأشياء (IoT) في مجال الزراعة. التحقيق يتناول مجموعة متنوعة من الأنظمة والأطر المصممة لتحسين الأساليب الزراعية من خلال المراقبة الفورية والإشراف على العوامل البيئية. العناصر الأساسية تشمل نشر مستشعرات متنوعة، بما في ذلك تلك الخاصة برطوبة التربة ودرجة الحرارة والرطوبة، اللي تعتبر حيوية لتحسين ممارسات الري وتعزيز استخدام المياه بشكل فعال. المخطوطة تؤكد على أهمية المتحكمات الدقيقة مثل أردوينو وراسبيري باي في إدارة ونقل المعلومات إلى مراكز مركزية أو منصات سحابية للوصول البعيد والإدارة عبر واجهات الهواتف المحمولة. بالإضافة إلى ذلك، الدراسة تتناول تطبيقات بروتوكولات الاتصال مثل LoRa و ZigBeeوWi-Fi، اللي تمكن من نقل البيانات بشكل واسع وفعال. كما يتم فحص دمج استراتيجيات تعلم الآلة لتمييز المحاصيل والأعشاب الضارة، بالإضافة إلى استخدام الطاقة الشمسية لتشغيل وحدات الاستشعار. المخطوطة تختتم بتسليط الضوء على الإمكانيات التحويلية لتقنيات IoT و WSNفي تحديث الزراعة الذكية، وتوفير طرق لحلول زراعية موفرة للطاقة وآلية.

1. INTRODUCTION

Innovative farming is a strategy that employs scientific methods and advanced technology to boost agricultural yields, essential for satisfying the rising food needs of an ever-expanding world population [1]. By the 12 months 2050, the speedy boom of urban areas will necessitate a 70% enhance in food manufacturing to fulfill international desires. At present, farming utilizes roughly 70% of the accessible water supply, underscoring the importance of effective resource management. Contemporary agricultural practices, augmented by IoT innovations, have outstripped conventional techniques, presenting answers to these pressing issues [2-6]. The IoT stands proud as a vital innovation for transforming agriculture, allowing devices to engage and share statistics seamlessly while not having direct touch. Fresh improvements which include semi-automated and completely automatic irrigation setups, utilizing tools like Arduino microcontrollers and GSM generation, had been counseled to beautify water conservation and increase crop yields [7-9]. The agricultural sector's IoT landscape is anticipated to expand remarkably, with forecasts suggesting an annualized advancement of 10.2% out of 2022 to 2030 [10,11]. Emerging patterns in agriculture had been fashioned with the aid of improvements in WSNs. The miniaturization and affordability of sensor devices have turned WSNs into a favored choice in precision agriculture. These networks find application not just in conventional farming but also in horticulture, livestock management, and viticulture. The main aim of implementing WSNs in these domains is to enhance quality and yield [1]. The significance of weaving WSN into IoT frameworks to tackle communication hurdles and elevate agricultural practices [12,13]. Merging AI with wireless communication advancements offers smart decision-making assistance for irrigation systems, enabling distant oversight and control [14]. The farming industry has skilled wonderful technological development, incorporating current-day improvements together with the IoT, WSNs, drones, AI, robotics, big statistics analytics, and blockchain era to boost productiveness and performance [10]. The research manuscript unfolds in the following manner. In Section 2, a comprehensive literature review is presented, highlighting prior scholars who have woven technological advancements into their explorations to aid in the metamorphosis of conventional labor-heavy farming into intelligent agriculture. Section 3 delves into the realm of WSN, shedding light on their pivotal influence in agricultural progression and outlines their fundamental components, such as sensors, control units, and communication devices. Additionally, it touches upon the applications of WSN within the sphere of smart agriculture. Concurrently, Section 4 comparisons of technologies, Section 5 the result, Section 6 the conclusions.

2. LITERATURE REVIEW

The integration of WSN technologies with the IoT is of great interest to many researchers due to the significant advancements these technologies have brought about in various fields, including agriculture. Recent research in this area has been summarized and presented in Table 1.

Jindarat and Wuttidittachotti [15] The system transforms traditional chicken farming into a “Smart Farm.” It uses sensors like the Gas Sensor (MQ-2, MQ-135, MQ-136), Photosensitive sensor (LDR), and Humidity Sensor (DHT22) to monitor the environment. An Arduino connects all sensors, sending data to the Raspberry Pi via UART. The camera links to the Raspberry Pi through a Common System Interface (CSI). The system creates a bridge between the Raspberry Pi and smartphones using a server-client model. Data exchange is managed through sockets, referencing IP addresses and ports within the transport layer, employing the TCP protocol. The Raspberry Pi runs on Raspbian Wheezy. Python is used to decode Arduino signals and manage controls like fans and lights based on sensor readings. An Android app lets users remotely manage and modify farm conditions. Kamath et al. [1] The goal is to deploy a wireless network for observing crops and weeds. The paper highlights the surge of wireless sensor networks in farming, driven by IoT innovations. These networks play a pivotal role in the surveillance of fundamental agricultural metrics such as temperature, humidity, soil moisture, and nitrite levels. The research elucidates the utilization of Raspberry Pi devices as visual sensor nodes within the established network. These nodes transmit data to a central base station through Bluetooth 4.0, which subsequently communicates the information to a remote station employing the IEEE 802.11 a/b/g/n protocols. To energize the sensor nodes and the base station, solar cell is employed. At the remote station, the acquired images undergo preprocessing. The study utilizes machine learning classifiers, namely random forest and support vector machine, to categorize paddy crops and weeds. Muhammad et al. [7] The research focuses on an intelligent irrigation system aimed at water conservation. Various IoT middleware platforms like Ubidots, ThingSpeak, and Amazon IoT facilitate device connectivity and data exchange throw Wi-Fi. The Raspberry Pi 4 Model B serves as the microcontroller for the smart agriculture system. The system employs multiple sensors, including the DHT22 for temperature and humidity and soil moisture sensors for soil monitoring. Since the Raspberry Pi lacks built-in analog input, the ADS1115 Analog to Digital Converter is used for accurate signal conversion. The paper emphasizes LoRa technology for long-range communication necessary for environmental monitoring. Suggested improvements include adding sensors for pH levels, light detection, and crop observation via image processing to enhance system efficiency.
Atmaja et al. [12] The study concludes that a communication framework for Smart Agriculture, founded on WSN and the IoT, has been successfully established. This framework proficiently interfaces with a Raspberry Pi to gather data from a variety of sensors, such as ultrasonic, soil pH, and soil moisture sensors, subsequently transmitting this information to servers for remote access. Sensor data is relayed from all sensor nodes to the Raspberry Pi via ESP 01 modules. These sensors accumulate data that is processed locally by Arduino and conveyed to a server utilizing ESP8266. The Raspberry Pi functions as a local server, directing data to a central server and archiving it in an online database. The Raspberry Pi operates on a Linux-based operating system, Raspbian. Khriji et al. [16] This research

explores clever irrigation techniques using a wireless sensor network linked to the Internet of Things. A case study pertaining to the smart irrigation system was executed, which encompassed five components: (sensing, processing, subscriber unit, operation, persistence). The sensing component is comprised of a soil moisture sensor (SEN_13637) and a soil temperature sensor (DS18B20), in conjunction with a wireless node referred to as Panstamp. The processing component consists of receiving nodes that are serially connected to the Raspberry Pi (RPI). The data is transmitted to the gateway (RPI) utilizing the MQTT communication protocol. A MySQL database was employed for direct data storage, which can be accessed through a web interface or a mobile application. The lightweight open-source broker Mosquitto was selected, and an appropriate web server, Flask.

Trihandoyo and Aristawati [17] The research focuses on crafting a super-efficient automation system for ideal plant growth. This cutting-edge system is thoughtfully built with a range of crucial elements, including a versatile breadboard, a sophisticated Arduino R3 microcontroller, an advanced soil moisture sensor, a DHT11 sensor for accurately measuring temperature, a clear and informative LCD display, a reliable water pump to ensure proper hydration, and a fan to facilitate air circulation and temperature regulation. Furthermore, the intricate circuit diagram of the monitoring system was carefully developed to seamlessly integrate all these components, thereby allowing for precise monitoring and adjustment of the environmental parameters crucial for the plants' growth. Jain [18] The paper examines the incorporation of an embedded system that mitigates the limitations of conventional irrigation techniques. By leveraging IoT and web-based technologies, the system seeks to optimize water utilization. A notable benefit of this system is its remote operation and visualization via an Android mobile application. The proposed framework amalgamates several moisture sensors, DHT22 with IoT devices that convey data to a central unit and archive it in the cloud for instantaneous monitoring and management. A mobile application is designed to enable users to remotely access and regulate irrigation data, thereby improving the efficacy and effectiveness of water usage in agriculture. The system utilizes a microcontroller (Arduino YUN) and Node MCU (ESP8266) for data processing and communication, ensuring irrigation is triggered based on real-time soil moisture assessments. Ogunbiyi et al. [19] The research centers on crafting and implementing a self-operating irrigation system linked with a mobile app. This innovative system empowers farmers to oversee irrigation from afar. It comprises an Arduino Microcontroller, an Android smartphone equipped with Wi-Fi, an Esp8266 Wi-Fi Module, soil moisture sensors (YL-69), solenoid valves or a DC water pump, relays, and switches. The Arduino Microcontroller is coded in C, while the mobile app is created using Java for Android devices. This application showcases sensor information and enables farmers to relay commands to the microcontroller via Wi-Fi. The system features an LCD that interacts with the microcontroller to exhibit the moisture levels in the soil. - et al. [20] The manuscript elaborates on the benefits of automated leaf detection in agricultural monitoring, facilitating the identification of foliar diseases. This project includes a self-operating irrigation system. A WSN is utilized to collect real-time information from the field. This network comprises sensors for soil moisture, water level, NPK analysis, PI camera to monitor the leaf disease and ultrasonic detection to track the plant's growth. The information gathered by these sensors is processed by a central unit (Raspberry Pi) that interfaces with the user's device through a Wi-Fi module. Users can track the motor's condition and metrics and the illness of the leaf and the height of the plant via a specialized webpage. Natonis et al. [21] The main objective of this study is to create an innovative greenhouse system that allows for remote and automated management, making it easier for farmers to cultivate their crops. The design phase involves crafting mechanical and hardware schematics using design tools such as Sketchup and Fritzing, as well as programming in the Arduino IDE. The system is built around an Arduino Uno microcontroller, which plays a crucial role in managing different sensors (DHT22 for Temperature and Humidity, GUVA-S12SD for Ultraviolet Intensity, and Soil Moisture Sensor). The Wi-Fi Module (ESP8266) is employed to enable seamless communication between the Arduino Uno and the server (Blynk).

Tang et al. [14] This scholarly inquiry offers an exhaustive examination of the utilization of IoT technology and wireless communication methodologies that facilitate the transition of conventional agricultural irrigation systems towards intelligent irrigation practices. The study elaborates on the hierarchical development within the agricultural IoT framework, emphasizing that the efficacy of this system is fundamentally dependent on the communication technologies employed. It encompasses short-range data transmission methodologies such as Zigbee, Wi-Fi, and 5G, alongside low-power wide-area communication technologies including LoRa and NB-IoT. Furthermore, the research articulates the merits and demerits, as well as the applications of the aforementioned five technologies, while also addressing the challenges encountered in the management of smart agricultural irrigation systems. Effah et al. [22] have proposed an innovative model architecture categorizing sensor networks into static and dynamic clusters. Each cluster comprises a central main node and several subordinate member nodes.Member nodes utilize the DHT22 sensor to collect soil moisture and temperature data, relaying it to the main node. Subsequently, it communicates with a gateway/base station or another cluster coordinator. Both main nodes and the gateway maintain local data copies in CSV format, logging the relevant time, date, and sender MAC address. Each entity, including main nodes, member nodes, and the gateway, represents Raspberry Pi 3B+. BLE 4.2 technology facilitates communication within member node clusters, while LORA technology is employed for base station communications, enabling off-site signal propagation. This system is powered by rechargeable solar energy banks. Hosny et al. [23] The paper offers a comprehensive examination of advancements in IoT applications within greenhouse agriculture. It categorizes IoT-related greenhouse farming into smart greenhouses, hydroponics, and vertical farming, referencing pertinent review articles. The authors identify various resource management challenges in greenhouse farms, such as energy, water, and communication service management, necessitating solutions to enhance IoT technology utilization. Actuators execute directives from the control system, regulating components like irrigation and lighting based on sensor inputs. The paper evaluates multiple communication protocols, such as ZigBee and LoRa, each possessing distinct advantages and disadvantages. It proposes future research avenues to address these challenges, including the creation of a unified architecture and the integration of advanced technologies like AI and 5G.

Kumar et al. [2] The strategy weaves IoT into smart farming, boosting productivity. This paper showcases sensors monitoring vital environmental factors and utilizes drones with tech gear. The IoT system evaluates communication methods for optimal performance. Cloud tech offers farmers swift data insights for prompt choices. Machine learning analyzes data to reveal key agricultural trends. Farmers can detect nutrient issues, diseases, or pests through data insights. IoT controllers are vital for farming automation; Arduino is basic but lacks Wi-Fi, while ESP8266 Node MCU is preferred for connectivity. Raspberry Pi manages larger farms effectively, despite memory limits, while the Giant Board boosts IoT capabilities. Intel Edison simplifies aquaponics and horticulture, marking a shift to modern farming tech. Advanced tools like BeagleBone and ESP32 are crucial for secure and efficient farm IoT systems, balancing speed and security. Mandal et al. [24] The paper explores innovative smart farming techniques like IoT, AI, blockchain, sensors, and mobile tools like chatbots. AI helps tackle agricultural issues using expert systems, fuzzy logic, and neural networks. Sensors are crucial for precision agriculture, gathering key data on the environment and crops.Mobile apps facilitate smart farming with tools for disease identification, fertilizer use, and water needs. The paper outlines various communication technologies for IoT, such as Wi-Fi, Sigfox, LoRa, and ZigBee. Case studies illustrate the real-world impact of smart technologies in farming. Sanz et al. [25] The team of researchers crafted an innovative system aimed at tracking hydrological events. This setup features a robust array of sensors, including those for soil moisture and water levels, all interconnected through Narrowband Internet of Things (NB-IoT) technology. The system employs a Quectel BC660K NB-IoT communication modem, the system relied on IoT devices powered by Li-Ion batteries,along with an ESP-32 processor for optimal data handling. Calibration of the soil moisture and water level sensors was performed through controlled experiments to guarantee precise measurements in real-world settings. The open-source cloud platform Thinger.io was leveraged for data management, facilitating smooth integration and analysis of the sensor information. Et-taibi et al. [26] The research introduces an innovative cloud-driven smart irrigation framework powered by solar energy aimed at linking multiple small-scale intelligent farms. The system employs sensors to collect instantaneous data on environmental parameters (Temperature and Humidity Sensor (DHT 11), Fire Sensor, PIR Motion Sensor, Soil Moisture Sensor). And the NI CompactRIO controller, along with Cloud Computing and Arduino Nanos, programmed with LabVIEW. The findings indicate notable advancements in water preservation. Node RED is utilized for overseeing and visualizing data. The paper emphasizes various communication technologies employed to enable data exchange and device interconnectivity, which include (Wi-Fi, GPRS, Bluetooth, ZigBee, MQTT, LoRa, 4G, and 5G). Ting and Chan [27] The paper emphasizes the importance of LoRaWAN for IoT networks. The system utilizes LoRa technology for long-range communication. The design incorporates strategically placed components including transmitter and receiver nodes, a solar power system, and wiring. An Arduino Uno microcontroller processes data from various sensors. These sensors comprise a DHT22 for temperature and humidity, a raindrop sensor, an FC-28 soil moisture sensor, and a DS3231 real-time clock module. The NodeMCU ESP32 is employed for synchronized data transmission in the smart farm system. An I2C LCD display offers a user-friendly interface for monitoring environmental conditions. The ThingSpeak IoT platform is integrated for real-time data visualization and crop condition monitoring. The Blynk mobile application enables remote management of IoT devices. Yamini et al. [28] The paper uses simulations to assess various wireless sensor network techniques. It compares platforms like Tmote Sky and OpenMote, validating results through simulations and real-world tests. The paper discusses network simulators like NS-2 and OMNET++ for simulating events. These tools are vital for testing network protocols, including TCP, broadcasting, and multicasting. The methodology employs interference models to gather data, crucial for grasping WSN communication dynamics. It mentions communication technologies in IoT systems, such as WSNs, ZigBee, NFC, GPRS, LTE, RFID, and Bluetooth. The research explores simulation tools like Matlab/SIMULINK to enhance IoT modeling speed. The study looks into energy-efficient strategies for WSN-IoT integration, including the Chaotic Whale Optimization Process. Adopting longer encryption key lengths is vital for securing sensor nodes.

Parab [29] The initiative is designed to create a smart agricultural ecosystem powered by IoT technology, and machine learning. It employs a range of sensors, such as the DHT11 for monitoring temperature and humidity, a PIR sensor for detecting movement, and a soil moisture sensor. These devices are meticulously positioned throughout the field to capture essential environmental information. The heart of this system is the ESP8266 microcontroller. This microcontroller plays a vital role in forwarding the information via a Wi-Fi connection to be visualized on an application interface. Additionally, this module features a recommendation algorithm that advises on the best crops to plant and the appropriate fertilizers to utilize, based on the inputs given by the farmers. Furthermore, there's a manual switch to control the water pump, activating or deactivating it according to the soil's moisture levels. Sinha [30] The document delineates a sophisticated irrigation framework that enhances the monitoring and management of water utilization in agricultural methodologies, utilizing six specific sensors that measure water levels, soil moisture, light intensity, temperature, DHT11 humidity, and pH values. It also includes a GSM module, LCD, and a motorized pump as output devices. Furthermore, soil moisture and humidity sensors, among others, are incorporated with an Arduino Microcontroller. Exhaust fans operate as output mechanisms, crafted to eliminate unpleasant scents, excess moisture, smoke, and various airborne pollutants.The system utilizes wireless communication technology to connect the intelligent sensing apparatus with the smart irrigation network. This facilitates the smooth transfer of data from the sensors to the central system for analysis. Ali et al. [31] This research delves into the realm of automated poultry farming through the fusion of sensor networks and machine learning technologies. An array of sensors, including MQ135, LDR, DHT11, and water level indicators, link seamlessly to the RPI3B+ for efficient data gathering. Information is transmitted every minute to the RPI3B+, logged in CSV format for subsequent analysis and enhancement. The RPI3B+ operates a machine learning algorithm to scrutinize user interaction trends within the system. The RPI3B+ serves as a decentralized decision-making entity, fine-tuning settings for fans, heaters, pumps, lights, and exhaust systems to uphold optimal conditions. An evaluation of five machine learning models revealed that the Decision Tree model excelled beyond the others in this context.

Table 1 Survey Summary

cite	Year	Aim of the work	System Capabilities	IoT Devices	Communication Technologies
[15]	2015	The study seeks to create a savvy chicken farming management system that blends embedded tech with smartphone innovation.	Monitoring and Controlling	_Gas Sensor module (MQ-2, MQ-135, MQ-136), Photosensitive sensor module (LDR), and the Humidity Sensor module (DHT22) _Raspberry Pi and Arduino	TCP protocol and UART
[1]	2019	launch a wireless visual sensor network for precision farming, specifically monitoring paddy fields for weed detection.	Monitoring and Controlling	_temperature, humidity, soil moisture, and nitrite levels _Raspberry Pi	Bluetooth 4.0, IEEE 802.11 a/b/g/n
[7]	2020	A smart irrigation system designed for water savings, it curtails excess watering by tracking soil moisture and weather, ensuring optimal water usage while safeguarding plant health.	Monitoring and Controlling	_DHT22 for temperature and humidity and soil moisture sensors _Raspberry Pi 4 Model B	Wi-Fi

[12]	2021	leverage the magic of IoT and WSN to forge a powerful communication network that enhances smart farming, boosting productivity and sustainability.	Monitoring and Controlling	_ultrasonic, soil pH, and soil moisture sensors _Raspberry Pi and Arduino _ ESP8266-01	Wi-Fi
[16]	2021	Craft an ingenious irrigation system that harnesses IoT and WSN to enhance water efficiency and minimize expenses.	Monitoring and Controlling	_soil moisture sensor (SEN_13637) and soil temperature sensor (DS18B20) and Panstamp _Raspberry Pi	MQTT
[17]	2022	crafting a super-efficient automation system that enables meticulous oversight and fine-tuning of essential environmental factors vital for plant flourishing.	Monitoring and Controlling	_soil moisture sensor and DHT11 sensor _Arduino R3	Non
[18]	2023	Harness IoT innovation to craft an intelligent irrigation solution that boosts water conservation, minimizes effort, and fosters eco-friendly farming.	Monitoring and Controlling	_moisture sensors and DHT22 _Node MCU (ESP8266) _Arduino YUN	Wi-Fi
[19]	2023	Crafting an intelligent irrigation system that pairs with a mobile app, enabling farmers to control their watering from afar	Monitoring and Controlling	_soil moisture sensors (YL-69) _Arduino _ ESP8266	Wi-Fi
[20]	2023	empower farmers to optimize their irrigation through a smart system that adapts to soil moisture.	Monitoring, Controlling and prediction	_ PI camera, soil moisture, ultrasonic detection, water level, and NPK analysis _Raspberry Pi	Wi-Fi
[21]	2023	design a cutting-edge greenhouse that enables remote automation for seamless crop management by farmers	Monitoring and Controlling	_DHT22 for Temperature and Humidity, GUVA-S12SD for Ultraviolet Intensity, and Soil Moisture Sensor _Arduino Uno _ ESP8266	Wi-Fi
[14]	2024	Craft an insightful critique and assessment to bolster the evolution and execution of intelligent irrigation solutions, thus improving agricultural efficiency and sustainability.	Boost the productivity, eco-friendliness, and impact of farming water use strategies	Non	Non
[22]	2024	Showcase a practical hardware assessment of an innovative cluster-	Monitoring and Controlling	_DHT22 _Raspberry Pi 3B+	BLE 4.2 and LORA

		based agricultural Internet of Things (CA-IoT) network, crafted to be resilient, cost-effective, versatile, user-friendly, and infrastructure-free, tackling the pressing issues of global food scarcity due to climate shifts and an expanding population via precision agriculture and greenhouse technologies.			
[23]	2024	The document delves into the innovative strides of IoT integration in greenhouse farming.	It classifies IoT-driven greenhouse agriculture into innovative smart greenhouses, soilless hydroponics, and dynamic vertical farming.	Non	Non
[2]	2024	showcase how IoT innovations can transform agriculture by enhancing efficiency, productivity, and sustainability, while tackling implementation hurdles.	Farmers can unveil nutrient deficiencies, illnesses, or pest invasions using data-driven insights.	Non	Non
[24]	2024	The article delves into cutting-edge smart agriculture methods utilizing IoT, AI, blockchain, sensors, and mobile solutions like chatbots.	_AI helps tackle agricultural issues _gathering key data on the environment and crops _Mobile apps facilitate smart farming with tools for disease identification, fertilizer use, and water needs	Non	Non
[25]	2024	craft a dynamic framework to track hydrological phenomena driven by events.	Monitoring	_soil moisture and water levels _ESP-32	NB-IoT
[26]	2024	The study unveils a groundbreaking cloud-based smart irrigation system designed to	Monitoring, Controlling, and Prediction	_Temperature and Humidity Sensor (DHT 11), Fire Sensor, PIR Motion Sensor, Soil Moisture Sensor _Arduino Nanos	GPRS and ZigBee

		connect various small-scale intelligent farms.		_NI CompactRIO	
[27]	2024	craft an innovative and budget-friendly IoT framework employing sensors and accessible apps to revolutionize farming, aiming to boost productivity and growth in small-scale agriculture through the expansive reach of the LoRa protocol.	Monitoring and controlling	_raindrop sensor, an FC-28 soil moisture sensor and DHT22 _Node MCU ESP32 _Arduino Uno	LoRa
[28]	2024	to investigate and dissect cutting-edge (WSN) methods in the realm of the Internet of Things (IoT).	The fusion of IoT and WSNs enhances demand response, load predictions, and grid resilience via smart data insights.	Non	Non
[29]	2024	craft a visionary IoT agricultural platform that monitors field insights and forecasts for eco-friendly farming, delivering tailored guidance to empower local farmers' choices.	Monitoring, Controlling and prediction	_DHT11 for monitoring temperature and humidity, a PIR sensor for detecting movement, and a soil moisture sensor _ ESP8266	Wi-Fi
[30]	2024	crafting an ingenious irrigation system that optimizes water efficiency by tracking consumption and distributing it wisely across farmlands.	Monitoring and Controlling	_measure water levels, soil moisture, light intensity, temperature, DHT11 humidity, and pH values _Arduino	WSN GSM
[31]	2024	Create a smart poultry farm system (CSPF) by harnessing the power of IoT and machine learning.	Monitoring, Controlling and prediction	_MQ135, LDR, DHT11, and water level indicators _RPI3B+	WSN

Table 2 Comparison between studies

Category	Studies	Focus	Innovations	Impact	Top Choice
1. Smart Farming Management and Precision Systems (2015-2020)	[15,1,7]	Managing poultry farms, monitoring paddy fields, and implementing smart irrigation to conserve water	Early integration of IoT with embedded systems, visual sensors, and smartphone interactions focused on efficiency	Significant for niche applications (e.g., poultry, paddy fields), laying groundwork for specialized precision farming.	
2. Advanced IoT and Wireless	[12,16,17]	IoT and WSN frameworks	Improved data communication	Enhanced efficiency and	

Sensor Networks for Broader Applications (2021-2022)		applied to irrigation and environmental control	and real-time monitoring for larger or more complex farming setups	operational savings; serves as a foundation for fully autonomous farming systems.	
3. Next-Generation Smart Irrigation and Remote-Control Systems (2023-2024)	[18,19,20,26,30]	Focused on irrigation efficiency, integrating mobile and cloud-based systems for small farm connectivity	IoT-driven water distribution based on soil moisture and user input, combined with smartphone apps and cloud-based control	Real-time, remote irrigation control, enhancing water conservation, reducing labor, and adaptable to various farming scales.	
4. Comprehensive Smart Agriculture and Greenhouse Management (2024)	[21,22,23,29]	Broad IoT applications in greenhouse management, including remote automation and cluster-based networking for resilience	Focus on climate resilience, user-friendly IoT, and field monitoring for real-time environmental adjustments	Ideal for closed-environment farms, empowering local farmers with data-driven insights for improved crop yield.	
5. Integration of AI, Blockchain, and IoT for Transformative Farming (2024)	[24,25,27,28,31]	AI, blockchain, and IoT combined to create frameworks for data tracking, security, and operational ease	Combines AI for predictions, blockchain for data integrity, IoT for real-time monitoring and control	Holistic, data-rich platforms that optimize yield and sustainability; blockchain enhances reliability and transparency, valuable for larger ecosystems.	Study 24: Integrates IoT, AI, blockchain, and mobile solutions, providing a versatile framework for productivity, efficiency, and sustainability, adaptable across various farming types and scales.

3. VERVIEW OF WSN FOR SMART FARMING

3.1 Components of WSN

The WSNs are a system made up of many components that work together to monitor and collect data on a variety of environments. These components, ‘sensing units, communication units, processing units, and power sources’, all have an essential part to play in WSN’s ability to work in complex ways and fulfil functions such as data collection, processing and relaying, that are crucial for uses ranging from ecological observation to structural integrity evaluations. Refer to Fig. 1.

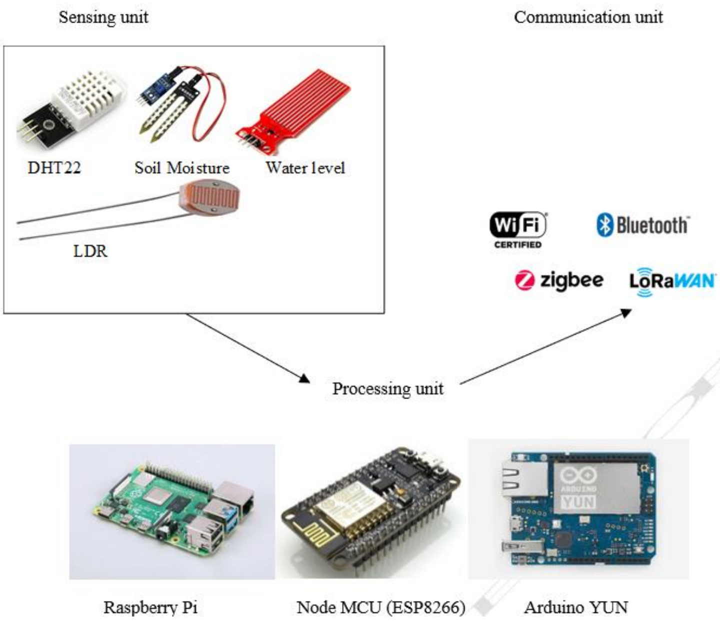

Fig. 1 physical components of wireless sensor network in smart farming

3.1.1 Sensing unit

In the realm of Intelligent Farming, various sensors are deployed to detect and evaluate numerous atmospheric and soil conditions. Below are descriptions of the selected sensors [7].

3.1.1.1 Humidity and temperature sensor (DHT22)

Humidity and temperature detectors are employed to gauge the ambient relative humidity and temperature. To function, they require an input voltage of 5 V [18]. Measurement Range: − 40 ◦C–80 ◦C for temperature, 0%–100% for humidity Precision: ±0.5 ◦C for temperature, ±2% for humidity [27].

3.1.1.2 Soil Moisture Sensor

Soil hydration detectors are employed to gauge the water levels and moisture present in soil for flora [21]. These sensors mainly function based on two distinct concepts: tension-based sensors (Tensiometer, Granular Matrix Sensor) and sensors that measure soil water content (Time Domain Reflectometry, Capacitive sensor) [23,32,33]. There are two categories of soil moisture sensors: (Resistive Soil Moisture Sensor, Capacitive Soil Moisture Sensor) [7].

3.1.1.3 Water level sensor

The water level monitoring device is an instrument designed to gauge the fluid height within a stationary receptacle that may be excessively high or low [30]. This water level monitor consists of three terminals: VCC, Ground, and Data. It operates optimally with a current draw of less than 20 mA and a direct current voltage of 3-5V. Its sensing range spans an area of 40 mm× 16 mm. The liquid level monitor performs best within a temperature range of 10 to 30 degrees Celsius and a humidity spectrum from 10% to 90%, provided there is no condensation present [31].

3.1.1.4 The LDR

Light sensors are frequently employed to monitor illumination within greenhouses. Their main function is to assess the brightness of sunlight and modify automated sunshades as necessary [2,34,35]. The sensitivity of an LDR fluctuates with different wavelengths, peaking at approximately 600 nm [31].

3.1.2 Communication unit

The protocols of WSNs have gained remarkable traction over traditional wired transmission systems, thanks to their efficient communication methods, ease of upkeep, and budget-friendly nature when juxtaposed with cabling solutions. These innovative protocols enable seamless wireless interactions, remote data gathering, and a variety of applications by sending out electromagnetic waves [23,36,37]. Subsequently, a comparative analysis is illustrated in Table 2.

3.1.2.1 Bluetooth Low Energy (BLE)

Is recognized as Bluetooth smart technology. It functions within the 2.4 GHz ISM frequency band. Furthermore, BLE finds its application in various agricultural fields due to its efficiency in power consumption and cost-effectiveness as a wireless communication solution. It facilitates data transmission over short ranges of up to 10 meters and achieves data rates reaching 200 Kbps. In contrast to traditional Bluetooth, BLE accommodates an unlimited number of nodes in a star configuration and features reduced connection times, resulting in diminished power usage. Nonetheless, BLE is limited to one-way communication. Hence, BLE is ideal for scenarios where the longevity of battery life is prioritized over high-speed data transfers [16].

3.1.2.2 Wi-Fi

Is a wireless LAN innovation forged by the IEEE 802.11 standard [38]. As the digital landscape has evolved, Wi-Fi has gained immense traction across numerous sectors. Wi-Fi flaunts impressive communication speeds, robust signal penetration, rapid data transfer, and expansive bandwidth. Nevertheless, the technology heavily relies on bandwidth, and any disruptions in the signal may lead to system failures [14]. Furthermore, Wi-Fi's data protection is lacking, rendering it vulnerable to breaches and potential data loss during agricultural environmental monitoring and data exchanges. Additionally, Wi-Fi is ill-suited for the retrieval and storage of substantial agricultural data volumes. Its networking capacity is limited, allowing only a finite number of devices to connect, typically in the range of dozens, making it inadequate for extensive agricultural irrigation systems [14]. This innovation encompasses a variety of radio wavelengths, ranging from 2.4 to 60 GHz, and meticulously outlines the configuration of data packets. Wi-Fi has gained immense popularity across numerous gadgets, mainly owing to its extensive coverage area, generally between 3–7 km, aided by a robust transmitting antenna, along with its capability to achieve data transfer rates reaching as high as 700 Mbps [10,39,40].

3.1.2.3 ZigBee

ZigBee technology, founded on the IEEE 802.15.4 framework, navigates through various radio frequency spectrums, such as 2.4 GHz, 915 MHz, and 868 MHz, achieving a remarkable data transfer speed of 250 kbps. Impressively, ZigBee is capable of operating in a low-energy sleep mode, allowing battery usage to last for extensive durations [10,41]. It embraces a range of networking methodologies, incorporating star, tree, and mesh configurations, which culminate in three main types of Zigbee networks: star, tree, and wireless mesh network designs [42].

3.1.2.4 LoRaWAN

This technology is grounded in the IEEE 802.15.4 g framework [23,43,44]. The challenges posed by the vast expanse of the farm are addressed through LoRa technology, which enables extensive-range communication via radio frequency. LoRa offers a lot of benefits that make it highly fitted for wireless data transmission in IoT. Long-range is one of the most significant as it allows transmitting data over a considerable distance. This is vital for smart agriculture, in which sensors are spread over a vast area. Low power consumption also contributes to better efficiency of devices with batteries and their enhanced lifespan. The security of the LoRa data transmission helps to guarantee that it is confidential and authentic. The method uses multi-symbol data formats and chirp spread spectrum (CSS) modulation for effective data encoding and transmission, allowing LoRa to operate across various frequency ranges, such as 433 to 435 MHz in Malaysia and 919 to 923 MHz in Asia [27,45].

3.1.3 Processing unit

Are specialized hardware components developed to perform data related operations amazingly fast, offloading these tasks from the Central Processing Unit (CPU). Operations Managers provide the necessary visibility into how data is moved and processed in complex computing landscapes, ensuring optimal performance as well as, maximizing resource efficiency.

3.1.3.1 Raspberry Pi

A low-cost little Linux-powered board, able to drive monitor and keyboard/mouse it provided an inexpensive means of interacting with electronics whilst still being a platform for programming or even hosting simple web services. Remember that it has no analog inputs compared to Arduino, so you need an external ADC or an interface board for those. MySQL could be embedded on the board where a GPIO pin can do duties as Digital Input or Output, both work at 3.3V [15].

3.1.3.2 Node MCU (ESP8266)

Is an open-source IoT framework, which is versatile. It is worth mentioning that its firmware operates on ESP8266 Wi-Fi module. Development language is done in Arduino IDE with C/C++ or Lua programming languages. The device uses 16 GPIO pins for the control of peripheral devices, for example, sensors, LEDs, and switches. In addition, 16 pins can act as PWM outputs. Node MCU has two UART interfaces, and the device works under XTOS OS. The capacity of the device is 4M Bytes. Moreover, the supply voltage is 5V. There exists an L106 32-bit processor, which is powered at a speed of 160 MHz [29].

3.1.3.3 Arduino YUN

ATmega32u4 microcontroller and an Atheros AR9331 are included in the board and are provided with Wi-Fi and Ethernet connectivity options. ATmega operates with a frequency of approximately 16 MHz. This board facilitates the management of systems and mechanisms, provides data exchange across the network. Its power is 5 V DC [18].

3.2 Application of WSN in smart farming

The domain of smart farming has readily adopted WSNs as central instruments, supplying sophisticated methods of managing and improving agricultural domains. They guarantee that data collection and analysis take no time at all, which means more well-informed decisions and better crops. Therefore, the major functions of WSNs in the area of agriculture are as follows, developed further with the help of recent research studies.

3.2.1 Monitoring soil conditions

One of the possible applications of the WSNs is the use of them to gather the soil characteristics of the agricultural land during some time and analyze the data later to predict the most suitable crop to grow there. The sensor networks are used to detect a variety of agricultural parameters such as temperature, humidity, leaf moisture, soil hydration and others [1]. Trihandoyo and Aristawati [17] The research focuses on crafting a super-efficient automation system for ideal plant growth. This cutting-edge system is thoughtfully built with a range of crucial elements, including a versatile breadboard, a sophisticated Arduino R3 microcontroller, an advanced soil moisture sensor, a DHT11 sensor for accurately measuring temperature, a clear and informative LCD display, a reliable water pump to ensure proper hydration, and a fan to facilitate air circulation and temperature regulation. Furthermore, the intricate circuit diagram of the monitoring system was carefully developed to seamlessly integrate all these components, thereby allowing for precise monitoring and adjustment of the environmental parameters crucial for the plants' growth.

3.2.2 Irrigation management

Precise irrigation is a method of water application synchronized with the peculiar needs of the crop. It implies measurement and control of a number of waters given to the foliage using the findings taken in the soil, or the status of the crop, in addition to climatic components illustrating the crop’s fitness. This type of irrigation can be achieved through such key goals as economy of water use, minimum energy cost, and maximum crop yield. It is facilitated by such modern technologies as WSNs, interconnected systems, mobile applications, real-time monitoring, and other [16]. Ogunbiyi et al. [19] The research centers on crafting and implementing a self-operating irrigation system linked with a mobile app. This innovative system empowers farmers to oversee irrigation from afar. It comprises an Arduino Microcontroller, an Android smartphone equipped with Wi-Fi, an Esp8266 Wi-Fi Module, soil moisture sensors (YL-69), solenoid valves or a DC water pump, relays, and switches. The Arduino Microcontroller is coded in C, while the mobile app is created using Java for Android devices. This application showcases sensor information and enables farmers to relay commands to the microcontroller via Wi-Fi. The system features an LCD that interacts with the microcontroller to exhibit the moisture levels in the soil.

3.2.3 Crop health monitoring

Observing flora is a crucial component of farming, gardening, and botanical studies. It encompasses the consistent tracking and evaluation of different physiological, environmental, and growth factors of flora. This practice aids in grasping the plant's vitality, development speed, and overall effectiveness [17]. - et al. [20] The manuscript elaborates on the benefits of automated leaf detection in agricultural monitoring, facilitating the identification of foliar diseases. This project includes a self-operating irrigation system. A WSN is utilized to collect real-time information from the field. This network comprises sensors for soil moisture, water level, NPK analysis, a PI camera to observe foliar ailment, and ultrasonic sensors to overseer grass expansion. The information gathered by these sensors is processed by a central unit (Raspberry Pi) that interfaces with the user's device through a Wi-Fi module. Users can track the motor's condition and metrics, along with the foliar ailment and the plant's extent via a specialized webpage.

Table 3 Comparison Between the Components and its Limitations

Component	Energy Efficiency	Data Accuracy	Scalability	Limitations	Difficulties
Humidity & Temperature Sensor (DHT22)	Moderate power requirement; operates at 5V	High accuracy: ±0.5°C (temp), ±2% (humidity)	Scalable for multiple installations within limited range	Cost: Affordable; Maintenance: Requires recalibration over time; Environmental Impact: Limited to moderate environments	Sensitive to temperature extremes and humidity condensation, which may impact longevity and accuracy
Soil Moisture Sensor	Varies by type (Resistive is less efficient, Capacitive is efficient)	Moderate accuracy, especially for resistive type	Scalable but typically requires close proximity	Cost: Capacitive sensors are more costly; Maintenance: Soil conditions can affect sensor lifespan; Environmental Impact: Not suited for highly alkaline soils	Soil composition affects data accuracy; resistive sensors may degrade in damp soil, requiring frequent replacement
Water Level Sensor	Low power (20 mA at 3-5V)	High accuracy within limited temperature and humidity range	Limited scalability due to optimal range in small setups	Cost: Moderate; Maintenance: Regular cleaning needed; Environmental Impact: Limited to non-corrosive liquids	Sensitive to condensation and extreme temperatures; limited to stationary and moderate environments
LDR (Light Sensor)	Low power consumption	Moderate accuracy, peak sensitivity at 600 nm	Scalable for broader area if light conditions are uniform	Cost: Low; Maintenance: Minimal; Environmental Impact: Stable, limited interference with external conditions	Susceptible to dust or physical obstructions, impacting sensor accuracy
Bluetooth Low Energy (BLE)	Very energy efficient, ideal for battery-operated devices	High accuracy for short-range communication	Limited to small-scale networks (10m range)	Cost: Low; Maintenance: Minimal, but range constraints; Environmental Impact: Minor,	Not suited for long-range communication; limited to one-way communication

				due to low power usage	and small networks
Wi-Fi	High energy consumption	High accuracy, robust signal penetration	Moderate scalability, with limited number of devices per network	Cost: Moderate to high; Maintenance: Higher upkeep due to data security risks; Environmental Impact: High energy use	Limited to areas with good signal, vulnerable to interference, not ideal for large data storage due to bandwidth limitations
ZigBee	Low energy consumption (sleep mode)	Moderate accuracy for low data transfer	Scalable, supports mesh networks	Cost: Moderate; Maintenance: Minimal but requires networking setup; Environmental Impact: Low	Limited data rate of 250 kbps; prone to interference from other 2.4 GHz devices
LoRaWAN	Very low energy consumption	Moderate accuracy over long distances	High scalability for wide area networks	Cost: Higher for initial setup; Maintenance: Periodic firmware updates; Environmental Impact: Low	Limited data rate; susceptible to environmental noise due to large coverage area
Raspberry Pi	Moderate energy efficiency	High accuracy for processing and data handling	Scalable with additional peripherals	Cost: Moderate to high; Maintenance: Requires software management; Environmental Impact: Moderate	Requires external ADC for analog input; limited GPIO pins for multiple sensors
Node MCU (ESP8266)	Low energy consumption	High accuracy for low-power applications	Moderate scalability with limited GPIO pins	Cost: Low; Maintenance: Minimal; Environmental Impact: Low due to power efficiency	Limited processing capacity; may require additional support for extensive applications
Arduino YUN	Moderate energy efficiency	High accuracy in connectivity and data exchange	Moderate scalability, but more complex due to multiple controllers	Cost: Moderate to high; Maintenance: Moderate, requires technical knowledge; Environmental Impact: Moderate	May require external data storage; limited to small to medium-sized applications

4. COMPARISONS OF TECHNOLOGIES

In order to evaluate the technologies' strengths, weaknesses, opportunities, and threats in agricultural systems, the following SWOT table has been created for intelligent farming: humidity and temperature sensors, soil moisture sensors, water level sensors, LDRs, BLE, Wi-Fi, ZigBee, LoRaWAN, Raspberry Pi, Node MCU, and Arduino YUN. Table 4 Comparison between technologies

Technology	Strengths	Weaknesses	Opportunities	Threats
Humidity & Temperature Sensor (DHT22)	High precision; affordable; low power consumption	Limited range and temperature resilience; may require recalibration	Suitable for small and medium-scale farms; potential for weather pattern and humidity data analytics	Potential data inaccuracies in extreme weather; susceptible to environmental wear
Soil Moisture Sensor	Essential for irrigation management; cost-effective options available	Soil type and mineral content affect accuracy; resistive sensors degrade in high moisture	Improved water management; optimized crop yield; applicable for both open fields and greenhouses	Potential sensor damage from extreme soil conditions; higher maintenance for resistive sensors
Water Level Sensor	Low-cost; provides critical data for irrigation reservoirs and water management	Limited operating range; may need regular cleaning	Useful for managing water resources efficiently; reducing water wastage	Susceptibility to corrosion and extreme weather; inaccuracies in high humidity environments
LDR (Light Sensor)	Low cost; essential for greenhouse automation; effective for monitoring sunlight levels	Accuracy depends on exposure and dust accumulation; sensitive to obstructed light sources	Supports crop growth optimization; greenhouse automation for lighting adjustments	Vulnerable to environmental factors like dust and shading
Bluetooth Low Energy (BLE)	Highly energy-efficient; cost-effective; supports multiple nodes	Limited to short-range communication; lacks two-way communication	Useful for small farms; effective for close-range sensor networks	Limited scalability in large fields; subject to interference from other Bluetooth devices
Wi-Fi	High-speed data transmission; broad device compatibility	High power consumption; limited scalability in dense sensor networks; security concerns	Allows real-time monitoring and control; enables data sharing and cloud storage	Vulnerable to network instability and security threats; high power requirements unsuitable for large-scale deployment
ZigBee	Low power consumption; effective for mesh networks; supports multiple topologies	Low data rate; potential interference in the 2.4 GHz band	Well-suited for extensive mesh networks in farms; enables multiple node setups across fields	Limited scalability in very large farms; lower bandwidth limits complex data transmission
LoRaWAN	Long-range, low power; suitable for vast agricultural areas; secure data transmission	Low data rate; higher initial setup costs; susceptible to environmental noise over long ranges	Ideal for remote, large-scale farms; enables long-range monitoring and efficient water usage management	Limited data throughput restricts complex data analysis; potential regulatory issues for spectrum usage

Raspberry Pi	Versatile and powerful; supports complex data processing and storage; suitable for advanced applications	Moderate power consumption; lacks analog inputs; limited GPIO for extensive sensor connections	Enables advanced data processing and decision-making on-site; can host web interfaces for monitoring	Requires external components for analog data; may be costly for small farms or simpler use cases
Node MCU (ESP8266)	Low cost; highly versatile; energy-efficient; compact design	Limited processing power and storage; may need additional modules for extended applications	Great for IoT applications; can serve as a Wi-Fi-enabled controller for multiple sensors	Limited computational capability for large data sets; may not suit long-term, intensive data applications
Arduino YUN	Integrated microcontroller and Linux environment; supports Wi-Fi and Ethernet connectivity	Limited to smaller-scale applications; relatively high cost; lower processing speed compared to other boards	Enables real-time data exchange across networks; ideal for small farms and localized data processing	May not handle extensive data processing tasks; limited expansion capability due to fewer GPIO and lower processing power

The agricultural technologies included in this table include sensors for temperature, humidity, water levels, soil moisture, light detection, and BLE, Wi-Fi, ZigBee, and LoRaWAN communication systems, as well as processing units like Raspberry Pi and Node MCU. Temperature and humidity sensors, soil moisture sensors, water level sensors, light sensors, Bluetooth Low Energy (BLE), Wi-Fi, ZigBee, LoRaWAN, Raspberry Pi, Node MCU (ESP8266), and Arduino YUN are just a few of the technologies and solutions included in the table for a variety of applications. Cost-effectiveness, precision, range, dependability, and device interoperability are just a few advantages that these technologies provide. They do, however, have certain drawbacks, such low data rates and battery usage. It is advised to employ energy-efficient procedures and take into account alternate technology for larger farms in order to improve these solutions. The necessity of routine calibration and maintenance for these systems is also emphasized in the text. By addressing the limitations of these technologies through calibration, material selection, hybrid systems, and optimal configurations, farmers may increase productivity, improve resource management, and ensure sustainability in agricultural operations.

5. RESULTS

The research findings presented in the connected documents highlight the significant advancements and potential of integrating Wireless Sensor Networks (WSNs) and Internet of Things (IoT) technologies in the field of smart agriculture.

Communication Efficiency, Resource Utilization, Irrigation Efficiency, and Management Accuracy

Fig. 2 illustrates the trends and impacts of WSN and IoT technologies on various aspects of agricultural operations. The integration of these technologies has led to substantial improvements in communication efficiency, enabling seamless data transfer between sensor nodes, control units, and remote monitoring platforms. This enhanced connectivity has in turn optimized resource utilization, particularly in areas such as precision irrigation management. The data-driven insights provided by WSN-IoT systems have significantly improved the accuracy and responsiveness of agricultural decision-making. Farmers can now monitor real-time soil moisture levels, environmental conditions, and crop health, allowing for targeted and efficient resource allocation. This has resulted in enhanced irrigation efficiency, reducing water wastage and promoting sustainable farming practices.

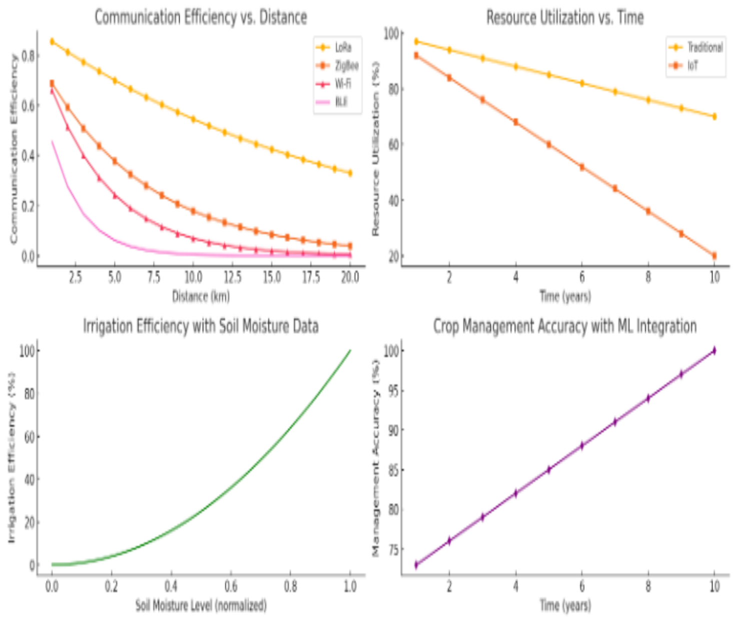

Fig. 2 The Results of Communication efficiency, Resource utilization, irrigation efficiency, and management accuracy

Energy Consumption and Sustainability Index

Fig.3 showcases the impact of WSN and IoT technologies on energy consumption and the overall sustainability index in smart agriculture. The adoption of energy-efficient sensor nodes, communication protocols, and processing units has led to a notable reduction in power requirements for agricultural monitoring and control systems. This improvement in energy efficiency, coupled with the integration of renewable energy sources such as solar power, has significantly enhanced the sustainability of smart farming operations. The sustainability index, which encompasses factors like water conservation, carbon footprint, and resource optimization, has shown a marked increase with the implementation of these advanced technological solutions.

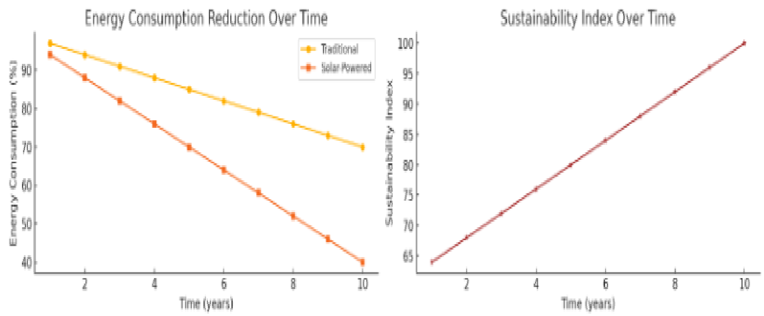

Fig.3 Show the Results of energy consumption and sustainability index

Overall, the research findings demonstrate that the confluence of WSNs and IoT in agriculture has the potential to revolutionize traditional farming practices. By enabling real-time monitoring, data-driven decision-making, and automated resource management, these technologies can contribute to increased productivity, improved resource utilization, and enhanced environmental sustainability in the agricultural sector. However, the successful deployment of these systems requires addressing challenges related to infrastructure costs, data security, and user adoption, which will require further research and strategic investments.

6. CONCLUSIONS

The confluence of (IoT) and (WSNs) in agriculture is examined in this paper, with an emphasis on how these technologies might improve agricultural sustainability and efficiency through automation and resource optimization. The study emphasizes the application of cutting-edge microcontrollers and sensors, machine intelligence fusion, creative energy solutions, and cutting-edge communication technologies like LoRa and ZigBee for real-time monitoring and governance. Smart agriculture, which addresses urgent issues in agriculture such real-time monitoring, data-driven decision-making, and resource efficiency, may be developed through the integration of WSNs and IoT technology. Real-time crop and soil monitoring; automated precision agriculture; AI-driven predictive analytics for crop management; monitoring of livestock health and behavior; improved crop disease detection through computer vision; effective supply chain management; smart irrigation systems with predictive weather integration; greenhouse automation and climate control; crop and weed detection for targeted treatment; and an integrated farmer decision support system (DSS) are some useful ideas for combining AI with 5G networks in smart farming. Nonetheless, there are a number of issues that must be resolved. Using these technologies may be complicated by infrastructure expenses, data protection issues, and farmer training requirements. It can be costly to deploy 5G and IoT infrastructure in rural or isolated agricultural regions, and the growing amount of data exchange raises privacy issues. Furthermore, farmers might need training in order to operate and maintain this sophisticated equipment. To sum up, the combination of 5G and AI presents a revolutionary chance for smart farming, fostering sustainability and production. To overcome real-world obstacles and make these technologies viable and accessible for mass agricultural usage, further study and calculated investments are required. We can optimize crop management, lower risks, enhance agricultural practices, and use less water by integrating these technologies.

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