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IoT and GIS Integration for Real-Time Monitoring of Soil Health and Nutrient Status

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Abstract*— This research study proposes an innovative method for enabling real-time monitoring of soil health and nutrient status in agricultural areas by integrating Internet of Things (IoT) and Geographic Information Systems (GIS) technologies. The conventional approach to soil monitoring is more difficult and challenging; it provides the most current data required for making smart decisions. The proposed method makes use of IoT devices configured with a wide range of sensors to continuously monitor essential soil qualities including moisture, pH, temperature, and nutrient concentrations. These sensors are strategically placed around rural areas to provide full coverage and accurate data collection. To process, analyze, and store the information collected by IoT devices, it is sent wirelessly to a cloud database. Using GIS capabilities, data collected is spatially mapped, providing farmers and agricultural specialists with a comprehensive overview of the soil health and nutrient status over the whole farm or field. Monitoring soil health and nutrient status in real-time provides invaluable insights to farmers, allowing them to make data-driven choices about when and how much water and fertilizer should be applied to crops and other crop management methods. In addition, the system may send automatic warnings and messages to farmers when critical circumstances are recognized, reducing the potential of lost crops and making the most efficient use of available resources. The advantages of integrating IoT and GIS in agriculture, with particular emphasis on the potential to revolutionize soil monitoring and nutrients management to increase crop productivity while reducing negative environmental impacts.

Keywords*— *Internet of Things, Geographic information systems, Soil health, Data visualization, Sensors

I. INTRODUCTION

Agriculture supports many rural people in India. Still, the agricultural industry is struggling. Land productivity is an issue. Collecting field data takes time [1]. No machine automatically tests all essential data. It is assessed by collecting samples, submitting them to a lab, waiting days or weeks, and obtaining a picture and report of the field condition from that day. Due to the time-consuming method and lack of soil nutrient knowledge, farmers cannot choose the optimal crop, fertilizer, and irrigation for the soil and needs a portable soil nutrient analyzer.

Soil health assessments often include a lot of field sampling and analysis in a lab [2]. While this method does provide reliable findings, it is often too time-consuming and expensive to be used for real-time monitoring of soil characteristics. With the development of soil sensors and wireless networks, offline measurement and field sampling may soon be obsolete. One of the most significant tools for farmers now is access to reliable and current soil data [3]. Real-time soil sensor data can increase agricultural output and income, sustain and improve product quality, advance food security, and safeguard the environment.

The proposed approach will benefit the next generation of farmers who want to cultivate plants ecologically soundly while effectively using the soil's naturally occurring nutrients [4]. The whole thing can be made into a little package that fits easily in a field next to the crop. In addition to suggesting crop rotations when necessary, the current soil test choices allow for remote management of temperature, humidity, and soil moisture.

This system was developed to send a text message to the user's phone whenever certain conditions are met, such as a certain level of soil moisture, pH, Nitrogen, Phosphorous, or Potassium concentration, as well as the general humidity and temperature of the farm. To get the message to the farmer, a Smartphone is optional [5]. The farmer will profit significantly from this SMS alert since it will give him a general notion of the soil condition of the field even before he sets foot on it.

To assess soil health, the design and implementation of an IoT system for tracking four dynamic soil parameters temperature, moisture, electrical conductivity, and carbon dioxide concentration [6]. Measurements of soil health and location data collecting, long-distance data transfer, data storage, data presentation, and a downlink connection for potential feedback management to enhance crop yield are all crucial components of an IoT system.

Agriculture relies on the soil because it contains essential minerals for plant development. Soil moisture, temperature, and pH represent only a few chemical and physical variables significantly impacting crop output [7]. The open-source hardware may pick up on these characteristics and put them to use out in the field. It is recommended that farmers should be enabled to monitor soil conditions on their smartphones, including humidity, temperature, and pH.

The farmer will benefit from innovative agriculture and effective farming apps since it will have constant access to soil and crop health data and energy use [8]. It describes methods for assessing soil quality, soil type, and moisture levels in light of shifting water availability and climatic conditions. Farmers may save time and money by considering all of these elements before deciding on a crop to grow in a given area and the amount of fertilizer to apply based on the soil's nutritional content.

II. LITERATURE REVIEW

To maximize crop yields, regular soil monitoring is essential. With the help of an IoT-based soil monitoring system, farmers may remotely monitor soil characteristics and get the data required to increase crop or plant productivity [9]. Soil qualities in the field are often diagnosed by laborious, actual testing in the lab. But with the help of the IoT, specific agricultural soil sensors can be used for remote sensing, allowing this to be done in real time. Real-time data monitoring from sensors places a premium on efficient resource use.

The ability to remotely monitor soil conditions is a new development with the potential to revolutionize farming methods and boost crop yields [10]. The soil's fundamental parameters, pH value, temperature, and moisture content help characterize the ground and inform fertilizer application and crop selection decisions. The pH scale is measured using an antimony electrode. It used the inverse relationship between soil resistance and soil moisture to build the matching circuitry to estimate the soil moisture content.

Standard farming uses plant development to sustain and improve human existence. Lack of mystery, insufficient farmland and water, and an abundance of self-interested farmers have all contributed to the event's decline in the nation [11]. However, it also means decreased production because of insufficient water, inappropriate chemical applications, and expensive harvests. The Wi-Fi module relays information between the sensors, the controller, and the computer. The quality of water resources and soil are constantly checked for pollution by this method.

The suggested framework for detecting soil nutrients in real-time in the cloud may be taken everywhere [12]. The proposed system captures soil nutrients and factors, including temperature, humidity, and pH readings, and makes it accessible globally using authentic cloud channel credentials. Soil analysis uses an RGB color sensor and a soil doctor plus kit for the suggested framework. Soil analysis in real-time through the cloud: a demonstration

Food crop production drives Indian agrology. The soil's nutrients affect crop quality. Our country has many fertile soils. Soil nutrients include macro and micronutrients [13]. Fertilizers boost crop quality regardless of weather. This fertilizer may increase crop output or decrease it. Fertilizer is a crucial determinant in yield richness. This IoT-based Android system tests soil minerals and evaluates fertilizer needs. It assesses fertilizer levels efficiently and is known to farmers.

Highly provisioned sensors enhance soil nutrients. This efficient technique educates farmers about fertilizer management. IoT for soil pH, moisture, temperature, and humidity monitoring are discussed in [14]. Crop development relies on pH and soil moisture. Different sensors measure soil characteristics. Plant illness is detected through infrared sensors. For future usage, the cloud server stores discovered values. Farmers may use an application to check soil pH, moisture, and temperature for crop yield.

Wireless sensor networks help analyze soil nutrients because allow for remote soil fertility monitoring, analysis, crop selection, and the construction of irrigation decision support systems, among other applications [15]. Wireless sensors in the suggested system collect data on soil macronutrient levels and upload them to the cloud. The mobile app displays soil fertility data whenever it's most convenient for the user.

III. PROPOSED SYSTEM

The main objective of this work is to develop a system for real-time soil monitoring by combining IoT and GIS technologies. It proposes to improve agricultural output by setting up IoT sensors for data collecting and processing through a central server, then communicating that data in GIS maps to farmers. Using IoT technology, this system can gather and transmit real-time data from various sensors deployed in the environment. Due to the IoT, farmers can rapidly check soil quality and nutrient levels from afar. This information is vital for better decision-making, more efficient use of resources, and longer-term agricultural success.

A. *Working model*

The technique places sensors in the soil at critical locations around the farm. To thoroughly visualize the soil's health and nutrient condition, these sensors are intelligently positioned to collect data from various areas and soil types. Sensors for measuring soil moisture, pH, temperature, nutrients, and compaction have been utilized. Continuous measurements of several soil properties are possible with each sensor.

The sensors are connected to IoT devices like microcontrollers and single-board computers like the Raspberry Pi. The IoT device operates as a data aggregator, gathering data from the sensors and sending it to a centralized data center for analysis. IoT devices may send and receive data without interruptions when connected to a wireless sensor network. These networks provide continuous data flow, which expedites decision-making and reduces the wait time between collecting data and using information.

All the acquired soil data is collected and stored in a cloud-based database, making the central information hub the heart of the system. This component has significant computational capabilities to handle and evaluate the incoming data. Extensive soil data from various IoT sensors are safely stored in the cloud. The cloud's scalability and flexibility ensure that relevant parties can access their data whenever required. The gathered soil data is mapped out geographically using a GIS. By putting this information on computerized maps, farmers and agricultural specialists can visualize the state of the soil and the nutrients across an entire farm or field and spot trends and patterns.

Data analysis methods, such as IoT, are used to the amassed information to develop beneficial inferences. Using visual illustrations and user-friendly dashboards, this knowledge is made more approachable to end-users. The technology is designed to provide immediate warnings and messages to farmers and users when significant soil conditions are identified, allowing for more timely and informed decision-making. For instance, a farmer may set up an automatic alarm to notify them when soil moisture levels fall below a specific threshold; at that moment, it can begin irrigation of the crops.

To facilitate the system's applications by farmers and agricultural specialists, a straightforward interface is designed. Real-time data, visualization implements, and the ability to establish custom alert levels are easily accessible via the user interface. The implemented model works as a decision support system that suggests to farmers how to manage their crops best using current time soil data and expert recommendations.

This established model of continuous soil monitoring allows precision agriculture, reduces wasteful use of resources, and supports environmentally responsible agricultural methods by combining the IoT and Geographic Information System technology. For farmers, this means having access to the data needed to respond swiftly to changing conditions, increase production and protect the long-term viability of their soil. Such systems have the potential to revolutionize agriculture further as technology develops, providing food security and environmental protection in a rapidly changing world.

B. Methods and Materials

Several tools and techniques are used to construct an IoT-GIS integration system to monitor soil health and nutrient level in real time. In the IoT-GIS setup, Raspberry Pi acts as the control unit, collecting sensor data, analyzing it, and transmitting it to the servers. This system improves agricultural soil monitoring and decision-making by providing real-time alarms, integrating with GIS for mapping, and storing historical data for future analysis.

The system's backbone is a network of sensors deployed around the field to monitor soil conditions such as moisture, pH, temperature, nutrients, and compaction. These sensors monitor various soil characteristics in real time throughout an entire farm. Data from the embedded sensors are collected and processed by IoT devices such as Raspberry Pi. At the same time, communication over wireless network modules ensures that data flows freely between sensor nodes and the data hub.

The real-time data is collated at the central data hub, powered by a computer or server with sufficient storage and processing features, and then saved to a database in the cloud. Wi-Fi modules for wireless connection allow data transfer between sensor nodes and IoT devices. The collected soil data is then analyzed using advanced data analysis tools. Soil data is then overlaid on digital maps using GIS software like ArcGIS or QGIS, allowing for spatial visualization and soil health and nutrient status mapping.

Integrating this data allows farmers and agricultural specialists to make more informed choices about irrigation, fertilizing, and effectively managing crops. Utilizing wireless sensor components, power supply options for ongoing operation, beneficial enclosures for sensors and IoT devices, and specific crop sensors are also crucial to the system's success in meeting the particular requirements of real-time soil monitoring in agriculture.

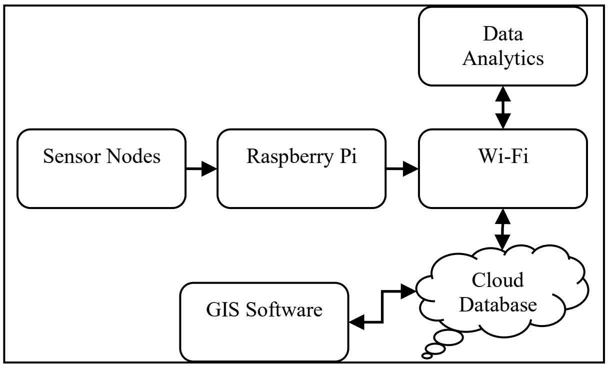

Fig. 1. Block diagram

An IoT sensor for soil monitoring can determine important soil characteristics, including moisture, pH, nutrients such as nitrogen, phosphorus, potassium content, and temperature. As an outcome of these measures, farmers can better determine the optimal watering, fertilizing, and otherwise caring for their crops.

A soil moisture sensor is used to determine the soil's moisture content. Different technologies, such as capacitance, resistance, and Time Domain Reflectometry (TDR), may be used as their foundations. This sensor data is crucial for farmers to decide when and how much to water their crops. Water saving and increased crop yields are two potential outcomes of accurately measuring soil moisture for irrigation management.

Soil pH sensors are used to determine the soil's acidity or alkalinity. The pH of the soil has a significant role in the availability and absorption of nutrients by plants. For crop health and nutrient absorption, the ideal pH level changes from crop to plant. To ensure their crops always thrive, farmers may use pH sensor data to adjust the amount of lime or sulphur to the soil.

Sensors placed underground can monitor the soil's temperature at varied depths. Soil temperature affects plant development, microbial activity, and nutrient availability. Some plants can only be cultivated effectively at very accurate temperatures. Farmers can keep an eye on the soil's temperature have a better chance of making smart choices about when to plant, which crops to grow, and how to adapt their methods to the weather.

Micronutrients such as iron and zinc and macronutrients such as nitrogen and phosphorus are also measured using nutrient sensors. By monitoring soil nutrient levels, these sensors help farmers provide optimal crop growth conditions. Farmers who monitor nutrient levels may better adjust their fertilizer applications and use precision agricultural techniques, resulting in more nutrient efficiency and less waste.

The electrical conductivity of soil is influenced by factors including moisture and nutrient concentration, which may be measured using soil conductivity sensors. Salinity in the soil, measured by conductivity, is a known plant development inhibitor. With the help of these sensors, farmers can identify areas of high salinity and take proper action to address salt-related soil problems.

The soil's density and amount of compaction are measured using soil compaction sensors. Reduced agricultural yields may result from compacted ground, limiting root development and water penetration. To minimize condensation and enhance soil structure, these sensors aid farmers in evaluating soil conditions and implementing suitable soil management strategies, including deep tillage and cover cropping.

With IoT devices and GIS technology, farmers and agricultural experts can receive real-time insights about soil health and nutrient status throughout their fields by integrating data from these multiple sensors. Incorporating these sensors into precision agriculture operations can increase agricultural output and sustainability while decreasing environmental harm.

C. *Geographic Information Systems*

GIS technology integrates soil data from sensor nodes throughout the agricultural field with topography, land cover, and boundary data. GIS provides spatial maps of soil characteristics (moisture, pH, nutrient concentrations) over a farm or field by overlaying soil data on digital maps. This geographical mapping shows soil variability, enabling farmers to assess soil health and nutrient trends. GIS software displays soil data graphically and interactively. Color-coded maps, charts, graphs, and 3D models simplify complicated data for end-users. Visualization helps farmers and agricultural professionals assess soil conditions and make crop management solutions.

GIS allows spatial analysis of soil data, revealing connections and correlations between soil characteristics and other geographic properties. Farmers may examine soil moisture levels and pH levels around their land. The spatial analysis aids agriculture's data-driven decision-making. Farmers may manage sites using GIS technology. It can adjust agricultural actions to soil conditions. For instance, low-moisture areas may need additional irrigation, whereas nutrient-deficient regions may benefit from focused fertilizer treatments. Precision agriculture maximizes input use and minimizes waste.

GIS integrates current data from the centralized data center into geographic maps. The GIS system automatically updates soil health and nutrient status based on sensor data. Farmers can adapt quickly to changing conditions with real-time monitoring, optimizing crop growth and production. Farmers and agricultural professionals may make informed decisions using IoT data, cloud databases, and GIS technologies. Spatial soil data, real-time analysis, and visualization help make data-driven crop management, irrigation, fertilizer, and agricultural practice choices.

IV. RESULT AND DISCUSSION

The soil monitoring system combines IoT and GIS for continuous coverage. IoT sensors collect soil data moisture, pH, and nutrients and transmit it to a hub such as a Raspberry Pi. GIS maps display the processed data, allowing farmers to make quick, informed choices for improved crop management. The advantages of using an IoT-GIS integration system to monitor soil health and nutrient levels in real time for agricultural management are substantial. The increase in farm output and crop production is particularly significant. With this technology, farmers have access to vital information on sensors of nutrients in real time, which aids in irrigation, fertilization, and other essential crop management approaches. Using this kind of precision agriculture, farmers can provide their plants with the precise amount of water and nutrients it need to develop and reproduce.

In addition, the technology helps farmers maximize their use of resources by directing them to precise locations in their fields based on real-time information. Farmers may save money and lessen their effect on the environment if the use irrigation and fertilizer specifically designed for each region. The outcome is less chemical runoff and water use in agriculture, which is more sustainable. Farmers can better understand spatial patterns and connections due to the spatial mapping and display of soil data made possible by GIS integration.

With this image, it can make more informed decisions and personalize its management approach to each farm. In addition, the system's real-time nature allows farmers to quickly adjust to shifting soil conditions, allowing for appropriate interventions to reduce crop losses and increase yields. The system utilizes sensors to collect continuous soil health and nutrient status data. The data collected by these sensors is used to assess the soil and its nutritional quality.

The system sends notifications to farmers or agricultural experts if specific data depart from the suitable range or established thresholds, indicating possible problems that need attention. For fast interventions to be made and crop losses to be avoided, alerts are crucial. Table 1 illustrates sensor parameters will trigger an Alert if their values fall above or below the specified thresholds.

TABLE I. SENSOR VALUES

Sensor Parameter	Current Value	Threshold (Min)	Threshold (Max)	Alert Status
Soil Moisture	32.5%	25%	50%	Normal
Soil pH	6.5	6.0	7.5	Normal
Soil Temperature	25.3°C	-	-	-
Nitrogen (N) Level	25.1 ppm	20 ppm	40 ppm	Alert
Phosphorus (P) Level	12.3 ppm	10 ppm	25 ppm	Normal
Potassium (K) Level	18.5 ppm	15 ppm	30 ppm	Normal
Soil Compaction (kPa)	1000 kPa	800 kPa	1200 kPa	Normal
Soil Conductivity (EC)	800 µS/cm	600 µS/cm	1200 µS/cm	Normal

Table 2 collects a wide range of data regarding agricultural pursuits at various locations. Each row represents a distinct event, complete with information about the date and time, the activity type, and any relevant alerts. The data in this table may be used as part of a continuous initiative to monitor and manage soil nutrients and health.

Soil health and nutrient levels can be optimized by immediately alerting farmers or agricultural professionals to the problem and allowing them to take corrective action. Combining numerous sensors ensures accurate evaluation of soil health and aids farmers in making educated choices for optimal crop development and yield. To ensure its usefulness in today's agriculture, the IoT-GIS integration system's functionality is crucial for real-time soil health and nutrient status monitoring. Since the sensor readings tell farmers the state of the soil precisely, their precision and consistency are essential to the system's effectiveness.

TABLE II. FIELD ACTIVITIES

Activity ID	Location ID	Activity Type	Timestamp	Alerts
1	1	Irrigation	2023-08-01 08:00:00	Watered for 30 minutes
2	1	Soil Sampling	2023-08-01 09:00:00	Collected samples
3	2	Fertilization	2023-08-01 10:00:00	Applied NPK fertilizer
4	2	Irrigation	2023-08-01 11:00:00	Watered for 20 minutes

Figure 2 graphs show the IoT-GIS system monitors soil health and nutrient condition. Over each day of the week, Location A improves with some volatility, Location B remains stable at its peak, and Location C changes while also improving. The graph illustrates how the system may provide timely data for smart farming choices in the present moment.

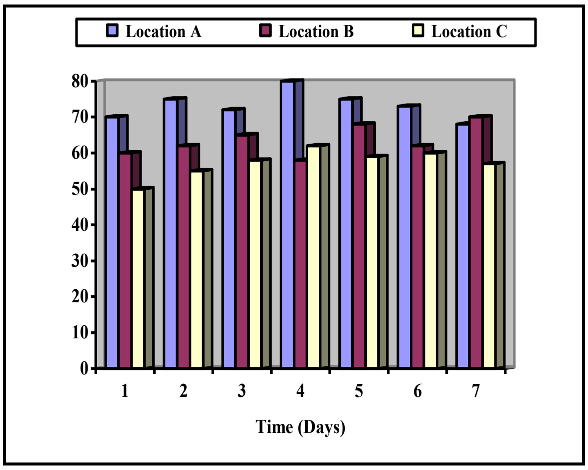

Fig. 2. Overall Performance of IoT-GIS Soil Monitoring System

Farmers may be able to take preventative measures due to real-time data gathering and transmission that enables timely monitoring. To help farmers improve their fertilization, irrigation, and other farming techniques, the system's data processing abilities are crucial in taking raw sensor data and turning it into useful information. As a further benefit, the alerting system instantly alerts farmers of any unfavorable changes in soil conditions, allowing for fast interventions to avert crop losses and ensure optimum plant development. Data understanding is improved by an easy interface with comprehensive graphics, allowing for better decisions.

Due to spatial mapping made possible by GIS integration, an exhaustive overview of regional soil health differences may be created. The system's overall efficiency is enhanced by its scalability, adaptability, connection, and security, making it resistant to data breaches and suitable for the evolving demands of agriculture. Improved agricultural output, longevity, and resource efficiency are all made possible because of the IoT-GIS integration system's real-time insights and support for data-driven operations.

Enhancing data transmission, local the process, predictive methods, storing and data prioritization, optimizing the network, and continuous monitoring to reduce wait times is important. Finally, the results of the IoT-GIS integration system demonstrate outstanding potential for the future of agriculture. The system provides farmers with the information required to make data-driven choices, improve resource management, and boost agricultural output via data in real-time, precise agriculture, and GIS technology. Increased crop yields, lesser environmental impact, and enhanced inter-community communication are all ways this system influences the future of agriculture, maintaining its continuous relevance and successful development.

V. CONCLUSION

In conclusion, the IoT–Geographic Information System integration system for real-time soil health and nutrient status monitoring is a significant step forward for modern agriculture. The system gives farmers useful insights into their fields' constantly evolving conditions. The system's effectiveness relies on the accuracy and stability of the sensor data, which in response, allows farmers to make informed decisions about irrigation, fertilizing, and other critical aspects of crop management. Farmers may be better prepared to manage changing environmental circumstances and optimize crop production by collecting and transmitting real-time data. Soil health data regarding the system's analytical capabilities may be better discussed, helping implement an informed method. Through precision agriculture, this data helps minimize adverse effects on the environment and maximize the use of scarce natural resources. Due to spatial mapping and visualization made possible by GIS integration, farmers now get a complete picture of soil variance throughout their farms. Increased agricultural output directly results from increased spatial knowledge, which enables customized management approaches and more effective resource usage. The system informs farmers when soil characteristics stray from predetermined standards, allowing them to manage risks and prevent crop losses. Adopting this innovative technology will result in a healthier and more efficient agricultural sector, paving the path to a more prosperous and environmentally friendly future for farming and the world.

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