Original Research Article

Estimation of soil Nitrogen, Phosphorous and Potassium using IOT based Sensor

ABSTRACT

This study developed an IoT-based sensor system to measure soil Nitrogen (N), Phosphorus (P), and Potassium (K) levels. Using an Arduino-based setup, the sensors were installed at different soil locations to provide real-time nutrient data. The collected data was analyzed to determine nutrient levels, and the results were visualized using ArcGIS and the IDW method.The analysis showed significant variability in soil nutrient levels. Nitrogen levels were consistently low, indicating a need for nitrogen fertilization. Phosphorus levels were mostly high, suggesting that extra phosphorus fertilization is not needed in most areas. Potassium levels were generally low, indicating the need for potassium fertilization in several locations.These findings help in understanding soil nutrient management better and demonstrate the potential of IoT applications in precision agriculture.

Keywords: NPK sensor, IoT, IDW

1. INTRODUCTION

Maintaining optimal soil fertility is fundamental to ensuring sustainable agricultural production and global food security. Key nutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K) are essential for plant growth, influencing crop yield, quality, and defence mechanisms. Traditionally, soil nutrient assessment has relied on periodic sampling and laboratory analysis, which can be costly, time-consuming, and often provide delayed results. In recent years, the emergence of Internet of Things (IoT) technology has revolutionized agricultural practices by offering real-time, remote monitoring capabilities through IoT-based sensors. IoT-based soil sensors represent a promising innovation in precision agriculture, enabling continuous monitoring of soil conditions such as nutrient levels, moisture content, and pH. These sensors utilize wireless connectivity to transmit data to cloud-based platforms, where it can be analyzed and accessed by farmers and agronomists in real-time. This real-time monitoring capability allows for timely adjustments in fertilization practices, irrigation schedules, and other management decisions, thereby optimizing resource use and enhancing crop productivity.

Recent literature underscores the transformative potential of IoT-based soil sensors in agriculture. Research by [1] demonstrated the effectiveness of IoT technology in improving nutrient management by providing accurate and timely soil nutrient data. Similarly, studies by [2] highlighted the role of IoT sensors in enhancing soil health monitoring and sustainable agricultural practices. These advancements not only contribute to increased yields but also support environmental sustainability by reducing nutrient leaching and minimizing fertilizer runoff. The integration of IoT sensors with advanced data analytics, machine learning algorithms, and artificial intelligence (AI) holds promise for predictive modelling in agriculture. By analyzing historical data and environmental parameters, IoT systems can forecast nutrient requirements and optimize fertilizer applications based on crop demand and soil conditions [3]. This predictive capability not only enhances efficiency but also reduces the environmental impact of agriculture, aligning with global sustainability goals.

Despite these advancements, challenges such as sensor accuracy, data security, and the cost-effectiveness of IoT deployment remain significant barriers to widespread adoption.

Addressing these challenges is crucial to realizing the full potential of IoT-based soil sensors and ensuring equitable access to technology for farmers worldwide [4]. Moreover, efforts to enhance user interfaces, provide training programs, and promote technology literacy among farmers are essential for successful implementation and uptake of IoT solutions in agriculture.

This research aimed to develop a sensor to estimate soil N, P, and K levels using IoT-based sensors. By summarizing recent literature and presenting important findings, this study seeks to contribute to the IoT applications in agricultural nutrient management. The findings of the study will be useful for agricultural stakeholders in need based nutrient applications and sustainable nutrient management.

2. MATERIAL AND METHODS

2.1 Designing of ardino Based NPK sensor Using IoT Based Technique

2.1.1 Hardware components needed

- Arduino Board
- NPK Sensor
- Communication Module
- WiFi Module
- Cellular Module
- Power Supply

2.1.2Software components needed

- Arduino IDE
- IoT Platform

2.1.3 Circuit Design

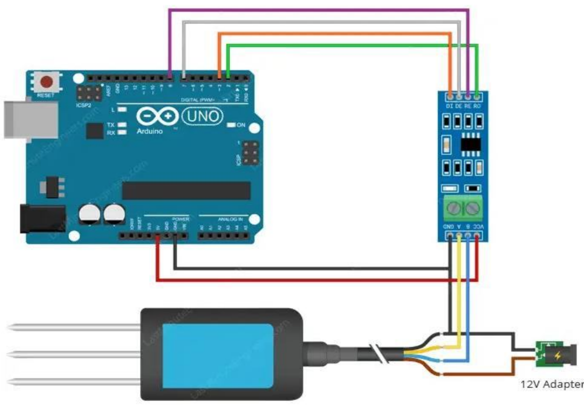
1. The NPK sensors to the Arduino board was connected by following their respective datasheets or guides.
2. IoT module was connected to the Arduino board.
3. Proper power connections were ensured for all components.
4. The soil NPK Sensor: The resolution of this soil NPK Sensor was up to 1mg/l or (1mg/1)
5. Connections:
    - Analogue pins of Arduino i.e. A4, A5 are connected to pins of OLED i.e. SDA, SLC respectively.
    - On Arduino board 5v is positive and GND(Ground) is negative.
    - The jumper wires. Likewise wire from 5V is made into 3 connections by combining 3jumper, GND is also made into 3 negatives using jumper wires.
    - One of the positive jumper wires of 5V and one of the Negative jumper wires of GND are connected to VCC and GND of OLED and Interface module respectively.
    - Similarly, one of the positive jumper wires of 5Vand one of the negative jumper wires of GND are connected to VCC and GND of soil NPK sensor respectively.
    - Digital pin 2, 3 of Arduino board is connected to RO and DI of Interface module.
    - Digital pin 7, 8 of Arduino board is connected to RE and DE of Interface module.
    - The NPK sensor has 2 outputs (RS485_A&RS485_B) are connected with A & Bon Interface module.
    - Arduino board is powered with the help of USB cable which is connected with Laptop or an Adaptor (9V-12V).

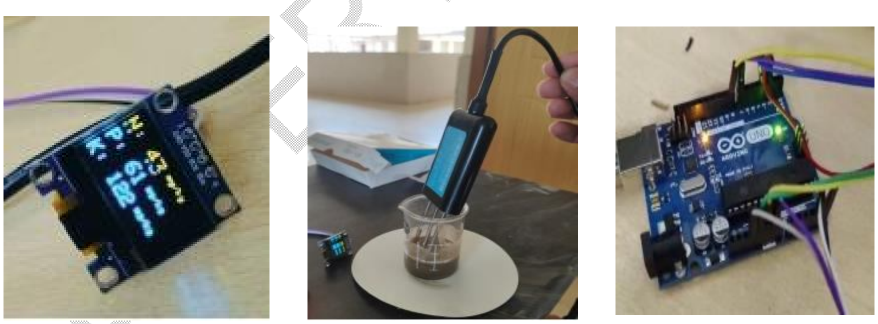
2.1.4 SoftwareDevelopment

1. Arduino Sketch: Arduino sketch was written to read data from the NPK sensors using analog or digital pins.
2. IoT Communication: Code to establish communication with IoT platform was implemented.
3. Data Processing
4. Integration and filed testing was done to validate the accuracy and reliability of NPK sensor system

2.2 Estimation of N, P and K using IOT based NPK Sensor

The NPK sensor probes were installed at various locations in the soil. These sensors are equipped with probes that can measure the levels of N, P, and K in the soil. The sensors continuously collected data on the nutrient levels in the soil. The collected data was then analyzed to determine the concentrations of N, P, and K in the soil. This analysis involved using algorithms to interpret the sensor readings and calculate the nutrient levels based on predetermined calibration curves or models. The analyzed data was visualized as maps using ArcGIS software by utlilizing IDW method.





(a)Arduino Uno board   b) NPK Sensor   (c)IoT Module

After estimating NPK content in soil, the each soil samoles were classified as low, medium and high quantity of NPK based on the classification of ICAR as follows [5].

Caterogy	**N (kg ha^{-1})**	**P (kg ha^{-1})**	**K (kg ha^{-1})**
Low	< 280	<10	<108

Medium	280 - 560	10 - 25	108 - 280
High	>560	>25	>280

Figure 1: Flowchart of IoT based NPK sensor making

3. RESULTS AND DISCUSSION

The developed NPK coding was attached as Appendix I. The estimated content of NPK of various soil samples were represented in Table 1. The analysis of soil samples from various locations revealed notable variations in Nitrogen (N), Phosphorus (P), and Potassium (K) levels, and it was classified according to ICAR standards. The study assessed soil nitrogen (N) levels across various locations using an IoT-based sensor system. The findings revealed that nitrogen levels ranged from 12 to 44 kg ha^{-1}, categorizing all sampled locations as having low nitrogen according to ICAR recommendations, which define low nitrogen as less than 280 kg ha^{-1}. The lowest nitrogen levels were observed at the front of the college (12 kg ha^{-1} and right side of the college (14 kg ha^{-1}), indicating significant nitrogen deficiencies. Other locations, such as in front of the pond (21 kg ha^{-1}for both samples), side front of the college (32 kg ha^{-1}), and various wheat crop areas (ranging from 18 to 36 kg ha^{-1}), also demonstrated low nitrogen levels. The highest nitrogen levels were found in the mango orchard (44 kg ha^{-1}) and left side of the orchard (44 kg ha^{-1}), yet these values still fall within the low nitrogen category.These findings align with recent literature that highlights widespread nitrogen deficiencies in Indian soils. According to [6], nitrogen is often the most limiting nutrient in Indian agriculture, necessitating regular supplementation to maintain soil fertility and crop yields. The observed low nitrogen levels across all sampled locations underscore the need for a targeted nitrogen fertilization program. This is critical to enhance soil fertility and support sustainable agricultural practices.

The study investigated phosphorus (P) levels across various locations using an IoT-based sensor system, with results ranging from 18 to 62 kg ha^{-1}. These values reflect notable variability in phosphorus content within the study area.Among the sampled locations, the lowest phosphorus levels were observed at the front of the college (21 kg ha^{-1}), right side of the college (20 kg ha^{-1} and 24 kg ha kg ha^{-1}), and wheat crop areas (ranging from 18 to 25 kg ha^{-1}), categorizing these areas as having low phosphorus content. Moderate phosphorus levels were found at the front of the boys' hostel (40 kg ha^{-1}), wheat crop areas near the pond (41 kg ha^{-1} and 44 kg ha^{-1}), and coriander field (47 kg ha^{-1}). High phosphorus levels were observed in the mango orchard (62 kg ha^{-1}), left side of the orchard (58 kg ha^{-1} and 62 kg ha^{-1}), and several locations near the girls' hostel (60 kg ha^{-1} for both sides), indicating sufficient phosphorus availability in these areas. These findings are consistent with recent literature emphasizing the variability of phosphorus levels in Indian soils. According to [7] Indian soils generally have adequate phosphorus content, localized deficiencies can occur, necessitating targeted fertilization strategies to optimize crop growth and yield. The observed low phosphorus levels in certain areas highlight the importance of site-specific nutrient management practices to address deficiencies and improve overall soil fertility. Moreover, the high phosphorus levels detected in the mango orchard and orchard areas align with studies indicating that these locations may retain phosphorus from previous fertilizer applications or organic matter decomposition, reducing the need for additional phosphorus supplementation in these [7].

The study then analyzed potassium (K) levels across various locations using an IoT-based sensor system, revealing a wide range of concentrations from 36 to 125 kg ha^{-1}.These findings highlight significant spatial variability in potassium content within the study area.Among the sampled locations, areas with low potassium levels (< 108 kg ha^{-1}) included wheat crop areas near the front of the college (36 kg ha^{-1}), right side of the college (46 kg ha^{-1} and 49 kg ha^{-1}), and front of the college (40 kg ha^{-1}), indicating a need for potassium supplementation to improve soil fertility in these regions. Moderate potassium levels (108 - 280 kg ha^{-1}) were observed in various locations such as the wheat crop areas near the pond (82 kg ha^{-1} and 88 kg ha^{-1}>), coriander field (94 kg ha^{-1}), and around the girls' hostel (75 kg ha^{-1}). High potassium levels (> 280 kg ha^{-1}) were found in the mango orchard (125 kg ha^{-1}), left side of the orchard (117 kg ha^{-1} and 124 kg ha^{-1}), and areas near the girls' hostel (121 kg ha^{-1} for both sides), indicating adequate potassium content in these areas.

These results align with recent literature emphasizing the importance of potassium in crop nutrition and its variable distribution in agricultural soils. Studies by [8] highlight that while potassium deficiencies are common in certain regions, excessive potassium can also occur due to historical fertilizer applications or soil composition, influencing crop productivity and nutrient management strategies.

Table 1: The NPK content of different samples collected from the study area

S. No	Location name	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1	Infront of pond (gram field)- 1	21	29	59
2	Infront of pond (gram field)-2	21	29	59
3	Inside the pond	39	55	110
4	Side front of college	32	45	90
5	Front of college	15	21	40
6	Front of boys hostel	28	40	80
7	Wheat crop (Boys hostel)- 1	29	41	82
8	Wheat crop (Boys hostel)-2	31	44	88
9	Wheat crop (Boys hostel)- side	18	25	51
10	Wheat crop (Boys hostel)- near of pond	36	50	101
11	Coriander field	34	47	94
12	Mango orchard	44	62	125
13	Girls hostel (front) - left	26	37	75
14	Right side of college - 1	17	24	49
15	Right side of college - 2	14	20	46
16	Right side of college - 3	35	49	58
17	Right side of college - 4	37	52	104
18	Wheat crop -1 (front of college)	27	37	75
19	Wheat crop - 2 (front of college)	34	47	95
20	Wheat crop -3 (front of college)	12	18	36
21	In front of girls hostel - right side	43	60	121
22	Side of girls hostel	43	60	121
23	Left side of college	33	46	89
24	Left side of orchard 1	42	58	117
25	Left side of orchard 2	44	62	124

Further the spatial variability of N, P and K were mapped using IDW method. From the maps Fig. 2 to 4 significant spatial variability in Nitrogen (N), Phosphorus (P), and Potassium (K) levels were noticed.Fig:2 represents the spatial variability of nitrogen across the study area. The spatial variability of nitrogen, as visualized using ArcGIS and the IDW method, illustrates the heterogeneity in nutrient distribution within the study area. Such variability necessitates site-specific nutrient management strategies to optimize fertilizer application and improve crop productivity. According to [9], balanced fertilization, including the appropriate application of nitrogen, is essential for maintaining soil health and achieving sustainable agricultural goals.

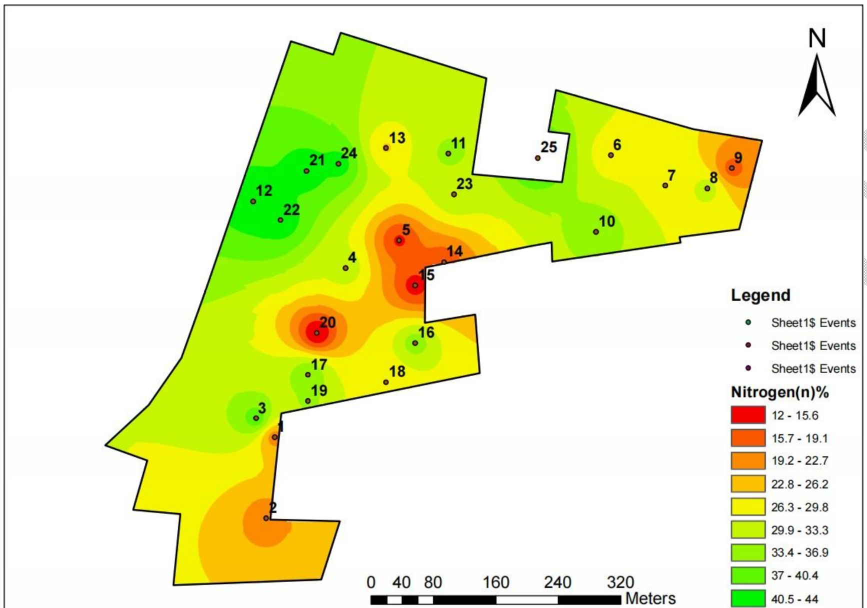


Fig. 2: The nitrogen % map of the college campus

Fig:3 represents the spatial variability of phosphorous across the study area. Phosphorus levels, on the other hand, displayed notable spatial variability but its content was predominantly high. Locations such as Inside the pond, Mango orchard, and Left side of orchard showed high phosphorus content, indicating that additional phosphorus fertilization might not be necessary in these areas. However, a few samples, such as Front of college and Wheat crop had medium phosphorus levels, suggesting that phosphorus fertilization might be needed in some areas

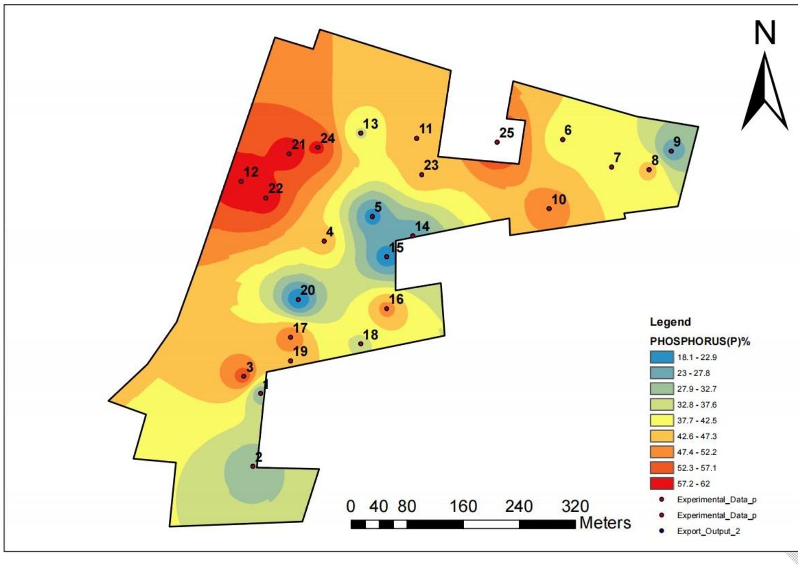


Fig.3: The phosphorus % map of the college campus

Fig.4 represents the spatial variability of potassium across the study area. Low potassium levels were observed in locations such as In front of pond (gram field), Front of college and Wheat crop field -3. These areas require potassium fertilization to improve soil fertility. Medium potassium levels were found in samples like Inside the pond, Mango orchard and In front of girls hostel suggesting a moderate requirement for potassium supplementation in these zones.

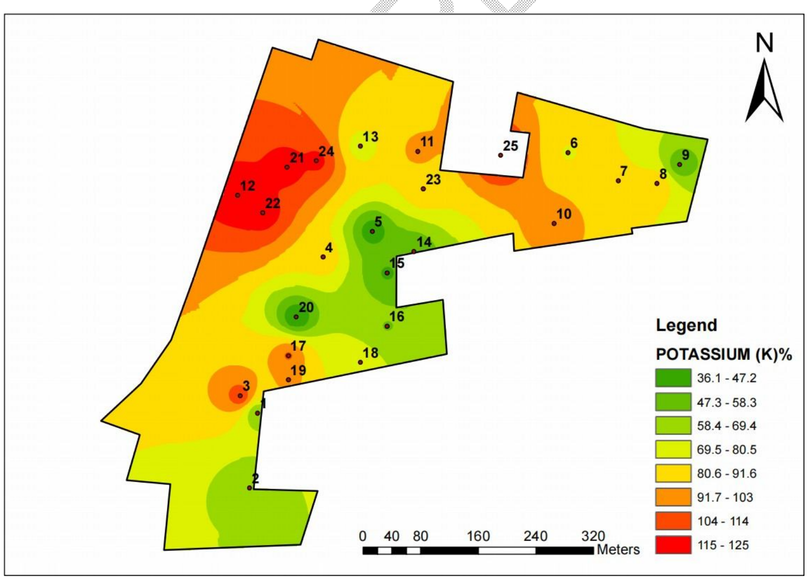


Fig. 4: The potassium % map of the college campus

Similar to this findings, [10] emphasize that while phosphorus and potassium levels may vary, nitrogen consistently requires supplementation due to its rapid depletion from the soil. This study's results corroborate these findings, with all sampled locations demonstrating nitrogen levels well below the ICAR recommended threshold for sufficiency.

4. CONCLUSION

The study utilizing an IoT-based sensor system effectively assessed the spatial variability of nitrogen (N), phosphorus (P), and potassium (K) levels across multiple locations. The findings revealed widespread nitrogen deficiencies throughout the study area, with all sampled locations exhibiting low nitrogen levels according to ICAR standards. This highlights the urgent need for targeted nitrogen fertilization strategies to enhance soil fertility and support sustainable agriculture practices. In contrast, phosphorus levels varied considerably, with some areas showing low levels necessitating supplementation, while others exhibited sufficient or high phosphorus content, potentially reducing the need for additional phosphorus fertilization. Potassium levels also varied significantly, underscoring the importance of tailored nutrient management practices to optimize crop productivity. Spatial mapping using ArcGIS illustrated the heterogeneous distribution of these nutrients, emphasizing the need for site-specific fertilizer applications. These findings contribute to the broader understanding of nutrient dynamics in agricultural soils and underscore the role of IoT technology in precision agriculture for improving nutrient management strategies.

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