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Analysis of Contamination of Soil by Sensor Monitoring Systems: A Green Technology

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ABSTRACT

The soil is a significant element of the landscape because it affects the crops, distribution of natural vegetation and human settlements across the landscape. Soil contains organic matter, liquids, gases as well as numerous microbes. Soil quality monitoring plays the most important role in sustainable crop production. Monitoring of soil using traditional methods requires many tests to be conducted in order to predict the soil quality. Soil testing entails the analysis of a soil sample from a specific land that includes estimation of pH, electrical conductivity for moisture content, nitrogen, phosphorus, potassium (NPK) level, temperature, etc. There are many challenges for direct monitoring of soil quality in terms of its chemical, biological and physical characteristics. However, with the advancement in sensor technology, certain sensors for soil quality monitoring have been developed and commercially available too. In this paper, the design and development of available sensor monitoring system for remote monitoring quality of soil has been reviewed. The objective is to explore the different kinds of sensors systems that can be used for predicting soil quality. Internet of Things (IoT) based sensors are efficient, and provide quick results with lesser resources.

***Key words**: Internet of Things, Contaminants, Remote monitoring, Sensor, Agriculture, Nitrogen, Phosphorus, Potassium (NPK)*

Introduction

The soil is an essential natural resource, just like air and water. Soil influences the distribution of crops, natural vegetation and human settlements over the terrain; therefore, it is an important component of the landscape (Osakwe, 2014; Mahajan, 2014; Khan *et al*., 2000). Soil is made up of different components like minerals, gases, liquids, organic matter and the numerous species which support life on earth. These fractions greatly influence soil texture, structure, and porosity which affect the pH, moisture level, nitrogen, phosphorus, potassium (NPK) level, temperature in soil (Shivanna *et al*., 2014; . Chaudhari, 2013).

Maintaining soil quality is the groundwork for sustainable as well productive agriculture and requires regular monitoring of soil followed by appropriate efforts for quality management.

Traditional methods of soil quality monitoring require many chemicals and equipment as well time consuming(Khan *et al*., 2000). There are many challenges for direct monitoring of soil quality in terms of its chemical, biological and physical characteristics. However, with the advancement of technology, various smart systems have been proposed for proper monitoring of soil quality for managing good soil health. Different researchers have proposed innovative ways for assessing soil quality in terms of selected soil quality indicators (Raj, 2016; Hussain, 2013)

Internet of Things (IoT) based technologies consist of virtual and physical elements as well as environmental friendly components which are linked to the internet via devices for perceiving desired information (Gahukar, 2007; Raj, 2016). It is also important to highlight that different set ups required in different regions depending upon the quality and usage of soil as well on the climatic conditions.

In this paper, different types of sensors/systems available for soil quality monitoring have been reviewed and their performance and reliability have been analyzed in terms of their efficiency, characteristics, utility and availability. The study will help the decision makers for resilience of land with good quality soil, good soil productivity and better nutrient cycling.

As per literature, soil monitoring includes collection of soil samples, testing of sample on the field, as well as comparing the results to databases of soil information currently existing (Zhang, 2009). IoT based sensor technology can be utilized for soil monitoring in real time (Patil *et al.,* 2021). The IoT based smart kit is different from conventional methods because lab based technologies are time consuming and costly. It is important for the farmers to know about the quality of soil by keeping track of the precise amount of nutrients present in soil so that a farmer can simply modify fertilizers in accordance with the needs of the crops to be produced. By using farm management software, farmers can be benefitted from receiving fertilizer recommendations based on the data which promotes plant growth for ideal yield.

Lab based monitoring is quite time consuming and require lot of chemicals for complete investigation of soil properties and these chemicals further enter the environment and pose further implications.

Types of Sensors

There are various types of sensors commercially available like NPK sensor, pH sensor, moisture sensor, temperature sensor and many others (Bogena, 2007). These sensors can help in measuring different parameters of soil on the field only (Castañeda-Miranda, 2020). IoT based sensors; soil pH, NPK, moisture, temperature sensors have been studied in this paper to understand its importance uses. They provide real-time information regarding soil moisture content, temperature, NPK and other factors. After measuring the responses to the electrical signals, its being sent into the soil, and the probe transfers the information to a data logger. The advanced technologies will not only profit the farmers but will also be advantageous to the research labs and agricultural institutes.

The pH sensors are very useful for the measurement of soil pH because the soil carries nutrients like Nitrogen (N), Potassium (K) and Phosphorous (P) which plants need in particular amounts to grow, flourish and fight off diseases. If the pH of soil is more than 5.0, nitrogen content of soil increases (Mahajan and Billore, 2014). If soil pH is in between 6.0 - 7.0 then phosphorous is readily available for the plants. Few bacteria are also responsible for conversion of atmospheric nitrogen into another form that can be used by growth of plants. If soil solution is too acidic then plants cannot utilize NPK and other nutrients. Plants are more likely to absorb toxic metals if soil is acidic in nature. Soil pH sensor consists of two electrodes as shown in Figure 1. One electrode is present for pH however another electrode is available for soil moisture. This sensor is analog device and not dependent on power supply to function.

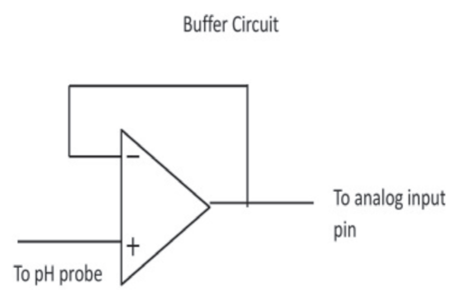

Fig. 1. Soil pH buffer circuit

The calibration of pH sensor was done by Ahmad *et al.*(2016) by comparing with standard lab based pH buffer solutions. (Ahmad *et al.*, 2016). A total of sixteen buffer solutions were prepared by using pH buffer tablets, two each was prepared by keeping range of 3 to 10 pH. The pH electrode was dipped in all these solutions and the corresponding voltage was read by the microcontroller and the obtained calibration curve is shown in Figure 2.

Fibre optic pH sensors-based fluorescence/ab-

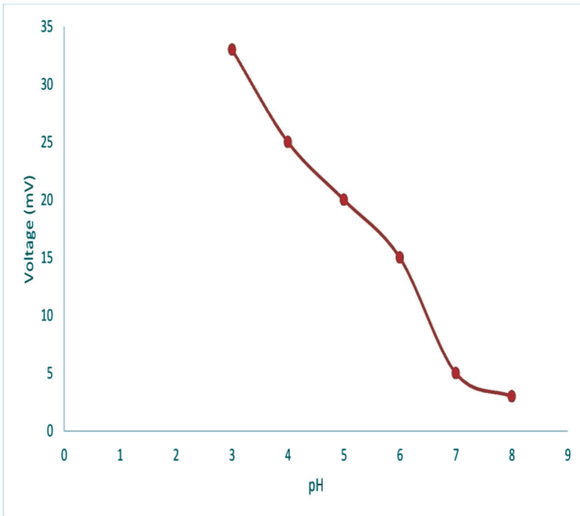

Fig. 2. pH calibration curve (Ahmad *et al.*, 2016).

sorption of suitable chromophore (Wolfbeis *et al.*, 2002) can be used for remote sensing by carrying the optical signal over long distance. These sensors have indicator dyes immobilized on part of the optical fibre that cause pH sensitive changes in the absorption spectrum of the test solution but these sensors have sensitivity issues.

Various metal oxides based electrochemical sensors such as iridium and rutheniumoxide materials have been proposed for pH measurement and they offer quick response, good sensitivity and reliable results over a long period of usage in different environmental conditions (Lobsey *et al*., 2010). These materials are having excellent attributes for wireless and online monitoring system (Manjakkal *et al*., 2020).

Placidi et al in 2020 prepared soil sensor to determine water content in soil for automated irrigation purpose (Placidi *et al*., 2020). The study was aimed to provide ecofriendly, reliable and automated moisture sensor which can sorts out the problem of over- irrigation and helps in optimization of irrigation water and management. The moisture sensor is based on the principle of relation between soil resistance and soil moisture. Soil resistance is inversely proportional to soil moisture (Nagahage *et al.,* 2019). The soil moisture sensor can measures moisture of various kinds of soil efficiently. Ahmad *et al.* prepared moisture soil sensor and used in measuring moisture content of different soils (Ahmad *et al*., 2016). Field test concluded that the moisture sensor error was mostly dependent on the quantity of wetness. Further, error was more likely to occur in the moderate wet soil. However, as the value of moisture content increases in soil, the error decreases and become zero in 100% soil moisture content. Figure 3 shows the soil moisture sensor circuit.

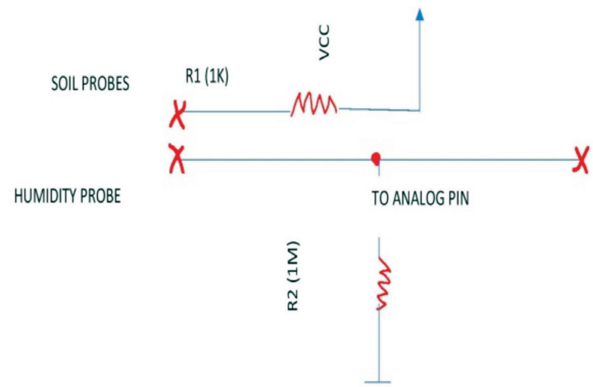

Fig. 3. Soil moisture sensor circuit

Nitrogen, phosphorus, and potassium (NPK) are very significant nutrient source components for soil. These components can be measured in order to find out how much extra nutrient content are required to the soil in order to enhance the fertility of soil. NPK sensors can be of great help to determine whether the soil used to support plant production is nutrition abundant or deficient (Hak-Jin *et al*., 2009). The nutrient content of the soil samples can be obtained in various ways by using mass spectrogram or sensing element. However, the spectral analysis process is not convenient, where results are only 60% to 70% accurate. Hence, to detect soil nitrogen, phosphorous, and potassium, a soil NPK sensor is better option. So NPK sensor is easy to use, economical and transportable. Deepa and *et al.* in 2015 studied about NPK sensor and mentioned that nitrogen(N), phosphorus(P), and potassium(K) deficiencies can all be identified by using it and it is based on the principle of colorimetry (Deepa *et al.,* 2015). It also reduces the unintended amount of fertilizer to be added. With the use of this sensor, a farmer may choose the appropriate amount of fertilizer to be applied to improve the quality of soil in a given field (Guo *et al.,* 2021). As per literature, electrochemical sensors for determination of NPK can be used as a single sensor panel (Lin *et al.,* 2008). Using sensors, the soils can be categorized into either one of the three categories as shown in Table 1. Based on the categorization, quantity of the requisite nutrients can be assessed which can be applied to the soils.

Table 1. Low, Medium and High NPK values range in soil

Nutrient (Kg/ha)	High	Medium	Low
Nitrogen	>480	250-480	<240
Phosphorus	>22	11-22	<11
Potassium	>280	110-280	<110

Temperature affects few vitals processes in soil. So, it is very important to know the temperature of soil at the field. As a result, soil temperature severely affects respiration, photosynthesis, water potential and transpiration of the soil translocation and microbial activity. Soil temperature sensor is also available commercially. They are highly precise, digital, corrosion free and water proof sensors. They are efficient enough to signal slightest variation in soil temperature accurately (Zhu *et al.*, 2019). Temperature sensors can be prepared from one p type and one n type semiconductor materials viz; semiconductor metal oxides as a thin film (Gregory *et al.*, 2010). Many researchers are trying to manufacture temperature sensors from ceramic materials but still no concrete and accurate results could be found in measurement of soil temperature from it (Aniley *et al.*, 2017). However platinum based sensors are giving best results because of its long-term stability, and durability (Fallis, 2013).

Conclusion

The Indian farming sector is in a difficult state due to a lack of automation and mechanical advances. In India, agribusiness innovation needs to be accelerated, whereas cutting-edge agriculture innovation is primarily capital-intensive. Before, the farmer had to check manually how much fertilizer is needed to get a good yield but with the advancement in technology, we can use various methods like IoT based smart sensors to check different parameters to analyze the contaminants present in soil (Figure 4). The Internet of Things is largely concerned with data collecting and single-machine processing, with minimal attention paid to entire application systems.

The system is economical, easier to use, implement and feasible. This will help the farmers get an in-depth knowledge of what is happening in their field and the accurate measurements of different components present in soil.

Future Scope

Although the existing system for different kinds of soil testing sensors operate properly in India but technologist and scientists are trying to find better options by which new concept should be adopted for future development and environmental sustainability. As technologies enhance, so does the requirement for crop production increases due to over population. There is an significant potential in the agricultural field for the application of new technologies.

There is a requirement for novel and inexpensive technique to understand the quality of soil to be used broadly in agriculture, highway engineering, industrial environmental control and green house management.

- Sensors are available for detection of different parameters individually. There is requirement to prepare single kit to measure different parameters. It can reduce the difficulty of using different smart kits for different parameters.
- To improve the agricultural yield and green belt with limited resources, the substantial innovations will be of great help. Low cost soil sensors for estimation of soil NPK, moisture, pH, and temperature sensors are required in developing countries, where small scale farmers cannot afford the costly sensors.
- In future, sensors can be developed for weather satellite downlink and early warning system for cyclone and natural disaster evading for preventing economic losses.

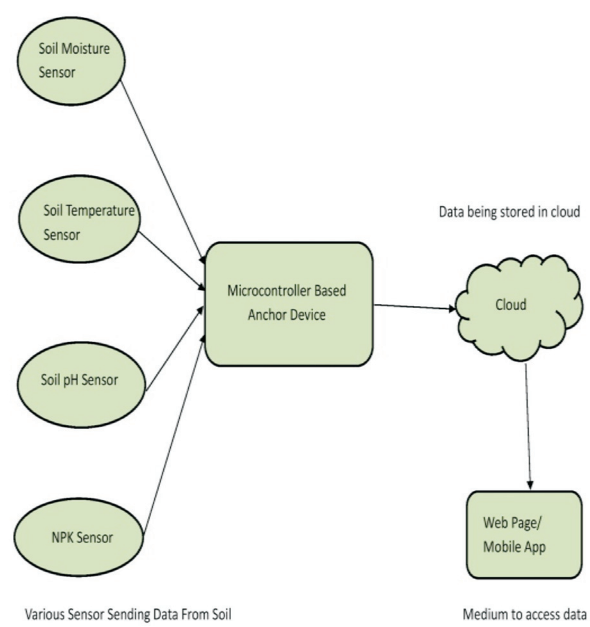

Fig. 4. Proposed kit for simultaneous detection of different parameters

- As per literature available, different sensors have been used for the determination of different parameters. Several new sensors with different functionality can be prepared and exploited in measuring values of heavy metals in different kinds of soil.

Therefore, the need of hour is to have universal package for determination of different kinds of contaminants from various soil. The universal technology will give complete solution about the treatment technology adopted for different kind of soil.

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