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LITERATURE REVIEW: IOT-BASED GEOGRAPHIC INFORMATION SYSTEM FOR MONITORING SOIL CHEMICAL PROPERTIES IN OIL PALM PLANTATIONS

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Abstract

Oil palm has a crucial role in the National economy, where its productivity depends on the soil chemical properties of the soil. In practice, monitoring methods carried out using conventional methods can be time-consuming and expensive. Therefore, a more efficient approach is needed. By reviewing previous research, this study highlights the latest developments, challenges, opportunities, and future directions in utilising the Internet of Things and Geographic Information Systems for monitoring soil chemical properties in oil palm plantations, thereby supporting more productive and sustainable management. The descriptive method was applied in this literature review research to 26 relevant articles selected from various publication databases, covering the time frame from 2020 to 2024. This study examines the development of IoT sensors for monitoring soil parameters, including humidity, pH, and temperature, in real-time, as well as the application of GIS for spatial analysis and data visualization. The results highlight the significant potential of integrating IoT and GIS to provide efficient real-time data and spatial analysis, thereby supporting more precise land management and informed decision-making, particularly concerning soil fertility and fertilizer use.

Keywords: *GIS, IoT, Oil Palm, Soil Chemical Properties*

LITERATURE REVIEW : SISTEM INFRORMASI GEOGRAFIS BERBASIS IOT UNTUK PEMANTAUN SIFAT KIMIA TANAH DI PERKEBUNAN KELAPA SAWIT

Abstrak

Kelapa sawit memiliki peranan krusial dalam perekonomian Nasional, di mana produktivitasnya bergantung pada sifat kimia tanah. Pada praktiknya, metode pemantauan yang dilakukan menggunakan cara konvensional terkadang membutuhkan waktu dan biaya yang tidak sedikit. Oleh karena itu, perlu adanya pendekatan yang jauh lebih efisien. Dengan menelusuri berbagai penelitian yang telah dilakukan sebelumnya, penelitian ini menyoroti perkembangan terkini, tantangan, peluang, dan arah masa depan dalam pemanfaatan Internet of Things dan Sistem Informasi Geografis dalam hal pemantauan sifat kimia tanah di perkebunan kelapa sawit, guna mendukung pengelolaan yang lebih produktif dan berkelanjutan. Metode deskriptif pada penelitian literature review ini, dilakukan terhadap 26 artikel yang relevan dengan melakukan seleksi dari berbagai basis data publikasi dengan rentan waktu tahun 2020 hingga 2024. Penelitian ini menganalisis pengembangan sensor IoT untuk memantau parameter tanah seperti kelembapan, pH, dan suhu secara real-time, serta pemanfaatan SIG untuk analisis spasial dan visualisasi data. Hasilnya menyoroti potensi besar integrasi IoT dan SIG dalam menyediakan data real-time dan analisis spasial yang efisien, mendukung pengelolaan lahan dan pengambilan keputusan yang lebih presisi, terutama terkait kesuburan tanah dan penggunaan pupuk.

Kata kunci: *IoT, Kelapa Sawit, Sifat Kimia Tanah, SIG*

1. INTRODUCTION

Elaeis guineensis or palm oil, is one of the plantation commodities that has an essential role in the national economy. Palm oil is utilized in various industries, including food, cosmetics, and renewable energy (Alhaji et al., 2024). High palm oil production makes it a primary raw material in the world vegetable oil market, with countries such as Indonesia and Malaysia as major producers. People's oil palm plantations make a significant contribution to Indonesia's economic growth. Additionally, smallholder oil palm plantations play a crucial role in achieving the economic objectives of the Sustainable Development Goals (SDGs) in Indonesia. The SDGs are a global platform with 17 main development goals and 169 target indicators. One of the main goals of the SDGs is to eradicate poverty (Barus & Ernah, 2024). High palm oil production makes it a primary raw material in the world vegetable oil market, with countries such as Indonesia and Malaysia as major producers. Growing global demand is driving efforts to improve the productivity and efficiency of oil palm plantations.

The successful production of oil palm plantations is highly dependent on the chemical properties of the soil, which play a crucial role in determining the availability of nutrients required by plants (Simanjuntak & Hendrawan, 2022). Soil chemical properties are an intangible but testable characteristic of the soil, including pH (potential of Hydrogen), nutrient content (macro and micro), organic matter, Cation Exchange Capacity (CEC), and soil reactions, which fundamentally affect nutrient availability and fertility for plant growth. One of the primary aspects of soil's chemical properties is its pH, which influences the solubility of essential plant nutrients. A comparison of Soil chemical properties between forest land and oil palm plantations shows significant differences in pH, with oil palm plantation land generally having a lower pH, which has the potential to negatively impact plant health (Baihaki et al., 2020). C-organic levels, Al saturation, and CEC are also variables that are positively correlated with palm oil productivity. The high CEC allows the soil to retain nutrients better, thereby improving fertilization efficiency (Farrasati et al., 2020).

In the oil palm plantation system, monitoring soil conditions is a crucial aspect for maintaining land quality. Conventional methods are often time-consuming and cost-ineffective, requiring a more efficient and precise approach. Modern technology enables real-time monitoring of the soil with greater accuracy, assisting farmers and garden managers in optimizing the use of fertilizers and other resources. Monitoring soil conditions can be done in several ways, both conventionally and with modern technology. The use of tools such as soil moisture Sensors, pH meters, and laboratory-based soil analysis devices can help speed up the monitoring process and improve data accuracy (Ginting, 2020). In addition, to improve the effectiveness of monitoring, the use of drones with a broader range and adequate power support, as well as GIS-based mapping systems, is being implemented, allowing for more thorough and efficient monitoring of soil quality over a larger area (Budiharto et al., 2021). Efficient and accurate monitoring of soil conditions can help farmers and garden managers optimize their land management practices, including the use of fertilizers and other resources. Modern technologies such as soil sensors, pH meters, and GIS-based mapping systems simplify the monitoring process, thereby increasing the productivity and sustainability of oil palm plantations.

Geographic Information Systems (GIS) have developed into a valuable tool in agricultural land management. GIS enables the spatial analysis of land parameters (Sirait & Lubis, 2025), providing a visual representation of the distribution of nutrients across various areas of oil palm plantations. Data can be mapped and analyzed using GIS to determine more effective land management strategies (Hegde et al., 2022). With GIS, modeling and predicting land conditions become easier and more accurate (Khawaldah et al., 2020). Through mapping techniques and data analysis, palm oil producers can identify areas that may have problems, such as nutrient deficiencies or increased erosion hazards. Analysis of soil phosphorus fractions can be facilitated with the aid of GIS, which helps determine land suitability and address fertilization issues. In addition, the measurement of relevant climate variables, such as rainfall, from the data integrated into the GIS also contributes to determining the optimal time for applying agricultural inputs, such as fertilization and irrigation (Bilotta et al., 2023; Haj-Amor & Bouri, 2020).

In recent years, the Internet of Things (IoT) has been introduced as a solution in the precision agriculture sector (Kagan et al., 2022; Sharma & Shivandu, 2024). IoT enables the use of connected sensors to automatically collect data from the field, including soil chemical properties parameters (Jenath et al., 2024). The data from the IoT sensor is then sent to the server for further analysis, enabling real-time monitoring of land conditions and faster decision-making. The integration of IoT technology with GIS has brought significant innovations in plantation management (Tan & Lu, 2022; Yang, 2024), which is also true for oil palm plantations. The combination of these two technologies allows for more efficient and responsive monitoring and management of land conditions in the field. IoT provides a variety of sensors that can be used to collect field data in real-time, such as soil moisture, temperature, and crop conditions.

This study aims to comprehensively review the use of IoT and GIS technologies for monitoring soil chemical properties in oil palm plantations. This study highlights recent developments, existing challenges, innovation opportunities, and future directions related to the application of these technologies to support more productive and sustainable oil palm plantation management. Understanding the latest technological developments and best practices in monitoring soil conditions will provide valuable insights for academics, agricultural practitioners, and policymakers in improving the productivity and sustainability of oil palm plantations, a strategic commodity for the Indonesian economy.

2. CURRENT RESEARCH

Monitoring Soil Chemical Properties: In this study, several key components of utilizing IoT technology and GIS for monitoring soil chemical properties in oil palm plantations are discussed. These components include the development of IoT sensors, the integration of Artificial Intelligence (AI) in data analysis, the use of GIS in soil mapping, the benefits and challenges of implementation, as well as future trends and innovations in these technologies.

2.1. Development of IoT Sensors for Soil Monitoring

The development of IoT-based soil monitoring systems is becoming increasingly important in the context of modern agriculture, aiming to improve efficiency and sustainability. Various studies have demonstrated how this technology can be utilized to monitor environmental parameters crucial for plant growth, including moisture, soil pH, and temperature. Soil moisture monitoring systems using sensors, such as the YL-69, have proven effective in providing real-time data that allows for more efficient irrigation arrangements (Hendro Yuwono et al., 2024). The use of this tool is not only helpful in monitoring soil moisture but can also be integrated in an automatic watering system, so that farmers can maintain optimal soil conditions for plant growth (Ramadani et al., 2021). This is reinforced by research showing that the FC-28 soil moisture sensor can provide accurate information on moisture levels, which is very helpful in making watering decisions (Husdi, 2018). Research by Izza et al., (2023), regarding the use of fuzzy logic to improve plant growth efficiency by controlling soil moisture more adaptively. This approach, which combines IoT with intelligent control algorithms, enables the system to adjust watering based on real-time field conditions. Additionally, the same system can account for other variables, such as temperature and light intensity, to create a more supportive environment for plants (Merdekawan & Sari, 2022).

The implementation of this system not only focuses on moisture control but also considers soil quality factors, such as pH and temperature. Research using Arduino shows how a monitoring system can effectively measure and analyze these critical parameters simultaneously, providing a comprehensive picture of the soil conditions required to achieve optimal agricultural yields (Anto & Arie Atwa Magriyanti, 2022). With further developments, such as the integration of sensors for other parameters, farmers can better adapt to climate change and varied weather conditions. In a broader context, the use of IoT in agriculture also shows potential in risk mitigation and resource management. With a network of connected sensors, the data collected can be accessed in real-time, enabling farmers to make faster and more informed data-driven decisions, as well as increase their involvement in managing their farmland (Rouf & Agustiono, 2021). With the continuous development of IoT technology, the application of this system can improve agricultural yields, improve water use efficiency, and reduce the manual workload of farmers in monitoring soil conditions. Projects like this have a significant contribution to agricultural sustainability and increased productivity in the digital age (Lazim & Hidayat, 2022; Munabbih et al., 2020).

2.2. Integration of AI in Soil Data Analysis

The integration of AI in soil data analysis offers numerous benefits, particularly in enhancing the efficiency of soil management and predicting agricultural yields. Use Machine Learning for soil analysis, as described in the study (Motwani et al., 2022; Venkateswara Reddy et al., 2024), allowing a better understanding of soil composition and conditions, which is essential for proper plant recommendations. To develop a system of plant recommendations, machine learning techniques analyze soil and environmental data on a massive scale, allowing for more accurate and relevant results in the local context. In the research carried out (Choudhary et al., 2022), it was shown that AI-based recommendation systems can not only be used for the classification of plant diseases but also to improve food security through smarter and more adaptive agricultural management. In other studies (Zavala Díaz et al., 2024), the analysis of soil moisture estimation also shows a contribution of Machine Learning in monitoring soil conditions, which can predict efficient irrigation needs, thereby reducing water waste.

The combination of machine learning with geographic information systems has become an effective tool for geotechnical analysis. Hamdani et al., (2024), emphasize the importance of geotechnical data in designing building foundations, where AI can play a role in analyzing soil capacity data based on geotechnical testing. The integration of such data through AI opens up opportunities for better risk management of potential structural failures caused by previously undetected soil conditions. The use of AI in soil quality monitoring and analysis is carried out, where soil quality indicators can be measured using data generated through a combination of remote sensing methods and AI-based data analysis, helping in more sustainable land management (Mas'udi et al., 2021). The integration of AI in soil data analysis holds great potential to enhance agricultural productivity and natural resource management, thereby supporting more sustainable and efficient agricultural practices. In a broader context, the integration of AI and soil data through interdisciplinary approaches creates new challenges, such as striking a balance between the use of technology and understanding regulations related to land use (Nuraziza & Sudirman, 2024). This understanding is critical to implementing effective policies in data-driven land and agricultural management.

2.3. The use of GIS in Mapping Soil Chemical Properties

The use of Geographic Information Systems plays a crucial role in mapping soil chemical properties, which can be utilized to enhance land management and informed decision-making related to soil fertility. GIS enables efficient spatial analysis, facilitating the collection and visualization of data required in research on soil characteristics. For example, research in the Bluto District demonstrates how GIS is utilized to analyze Soil chemical properties and support site-specific soil fertility management, particularly in the context of agricultural growth (Rahman et al., 2023).

The use of GIS in conjunction with the Global Positioning System (GPS) can be an effective tool in creating spatial variability maps (Subhasree et al., 2022). These maps facilitate the determination of the spatial distribution of soil chemical properties, which in turn enables more targeted nutrient recommendations to enhance crop productivity, improve yield quality, and mitigate environmental stress. Additionally, this method can reduce operational costs as it requires less soil analysis compared to the analysis approach, plot to plot.

Other research suggests that GIS-based geostatistics and multivariate analysis can be used to estimate the characteristic spatial variability of physico-chemical soil properties with a high degree of accuracy (Arumugam et al., 2022). This study aims to predict the spatial variability of these soil properties by combining GIS-based geostatistics and multivariate analysis, as was done in the Sultan Bateri Block, Wayanad District. This combination enables researchers to analyze and compare soil data, facilitating a more comprehensive spatial assessment.

GIS systems can be efficiently used to map various soil properties, including mechanical content, nutrient status, and salinity characteristics (Bobomurodov et al., 2023). This analysis explores various options for mapping soil properties using GIS systems, offering multiple perspectives on the effective use of GIS in mapping. This study was conducted on sierozem soil in the Parkent District, Tashkent Region, based on research that utilized soil map data analysis from the study area and the generalization of results from soil cartography studies, laboratory analyses, and camera images. The result of this study was the creation of digital thematic maps for the selected areas, including maps of the mechanical composition of the soil, soil nutrient status, and salinity maps.

3. RESEARCH METHODS

This Literature Review research uses a descriptive method to examine the use of the Internet of Things and Geographic Information Systems in monitoring soil chemical in oil palm plantations. The data sources used are obtained from research publication databases, including Scopus, IEEE Xplore, ScienceDirect, Google Scholar, EBSCO, DOAJ, and others. The search for relevant articles used the keywords Internet of Things, Geographic Information Systems, soil chemical properties, and oil palm plantations. The time vulnerability used in searching for research publication articles is 2020-2024.

From the results of the search for research publication articles carried out, these articles will be reviewed and cited in the writing of this research, to be summarized and recorded in the reference list. The stages in this study begin with identifying the research topic. Identification is carried out by determining the focus of the study, namely the use of IoT and GIS in monitoring soil chemical properties in oil palm plantations. The second stage involves searching for relevant research articles using a research publication database and applying pertinent specific keywords. Article search results will be selected based on predetermined criteria, such as time range, article source, and keyword compatibility. After being selected, analysis and synthesis will be carried out by grouping the literature based on its content. The final stage involves summarizing the research results on the application of IoT and GIS technology in monitoring soil conditions in oil palm plantations. An overview of the research stages is illustrated in Figure 1, which presents a chart.

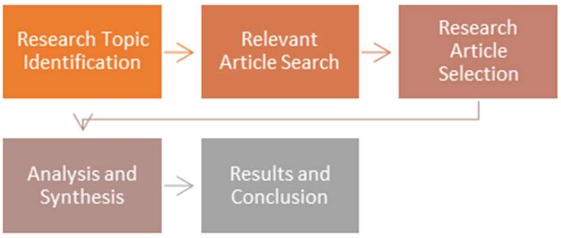

Figure 1. Research Stages

4. RESULTS AND ANALYSIS

4.1. Result

A comprehensive literature review was conducted through a multi-database search, including Scopus, IEEE Xplore, ScienceDirect, Google Scholar, EBSCO, DOAJ, and other relevant databases, as well as specific keywords such as the Internet of Things, Geographic Information Systems, soil chemical properties, and oil palm plantations. The publication time range is 2020-2024. From these results, as many as 26 relevant articles were successfully identified. Through the identification of literature content, three main categories were found related to the use of Internet of Things technology and Geographic Information Systems for monitoring soil chemical properties in oil palm plantations. The categories include the effectiveness of IoT sensors in monitoring soil chemical properties, the role of GIS in spatial analysis of soil chemical properties, and the integration of IoT and GIS in soil monitoring. Table 1 below summarizes the articles based on the three contents.

Table 1. Literature Content

No	Literature Content	Reference
1	Effectiveness of IoT Sensors in Monitoring Soil Chemical Properties	(Kagan et al., 2022), (Sharma & Shivandu, 2024), (Jenath et al., 2024), (Hendro Yuwono et al., 2024), (Ramadani et al., 2021), (Izza et al., 2023), (Merdekawan & Sari, 2022), (Anto & Arie Atwa Magriyanti, 2022), (Rouf & Agustiono, 2021), (Lazim & Hidayat, 2022), (Motwani et al., 2022), (Bobomurodov et al., 2023)
2	The Role of GIS in Spatial Analysis of Soil Chemical Properties	(Budiharto et al., 2021), (Sirait & Lubis, 2025), (Hegde et al., 2022), (Khawaldah et al., 2020), (Haj-Amor & Bouri, 2020), (Bilotta et al., 2023), (Hamdani et al., 2024), (Mas'udi et al., 2021), (Rahman et al., 2023), (Subhasree et al., 2022), (Arumugam et al., 2022), (Bobomurodov et al., 2023)
3	Integration of IoT and GIS in Soil Monitoring	(Yang, 2024), (Tan & Lu, 2022)

The utilization of IoT in monitoring soil chemical properties allows the implementation of systems that can measure various essential parameters such as moisture, temperature, pH, and nutrient content. Technologies commonly used in this implementation include Arduino platforms, NodeMCUs, and cloud computing. Geographic Information Systems also play an essential role in the spatial analysis of soil chemical properties. GIS is used for spatial mapping and analysis, including geostatistical techniques and the use of the GPS. Additionally, there is significant potential in integrating IoT and GIS technologies to enhance the efficiency and accuracy of soil monitoring, thereby facilitating the development of more innovative and more integrated agricultural management systems. Table 2 is an explanation of the benefits of each literature content.

Table 2. Benefits Obtained

No	Literature Content	Benefit
1	Effectiveness of IoT sensors in Monitoring Soil Chemical Properties	Improve agricultural efficiency, *real-time monitoring*, optimization of resource use (water, fertilizer), early detection of soil problems, and more informed decision-making.
2	The Role of GIS in Spatial Analysis of Soil Chemical Properties	Mapping of soil nutrient distribution, identifying areas requiring special attention, analysis of land use changes, visualization of spatial data, and more effective land management planning.
3	Integration of IoT and GIS in Soil Monitoring	More innovative farm management systems, process automation, integrated data-driven decision-making, dynamic spatial data visualization, and higher operational efficiency.

The use of IoT sensors in monitoring soil chemical properties enables farmers to track soil conditions in real-time and with greater accuracy. With the data collected, they can optimize the use of resources such as water and fertilizer, detect soil problems early, and make more informed decisions, ultimately improving crop yields. Geographic Information Systems serve as a powerful tool for mapping and analyzing the spatial distribution of soil chemical properties, enabling the identification of areas requiring special attention and facilitating more effective land management planning. Additionally, the integration between IoT and GIS yields a more intelligent farm management system. Data obtained from IoT sensors can be integrated into GIS for dynamic spatial visualization, enabling integrated data-driven decision-making and improving overall operational efficiency.

4.2. Analysis

Of the 26 research articles found, the utilization of technology for monitoring soil chemical properties is focused on three main areas: the effectiveness of IoT sensors, the role of GIS in spatial analysis, and the integration of the two in soil monitoring. IoT sensors enable the real-time measurement of various soil parameters, including moisture, pH, temperature, and nutrient content, providing accurate and efficient data to optimize farming practices. Meanwhile, GIS enables the practical spatial analysis and visualization of soil data, assisting in the identification of spatial variability and supporting decision-making related to land management and fertilizer applications.

A key contribution of this research is a deeper understanding of how IoT and GIS can be used effectively in monitoring soil chemical properties. The integration of the two enables real-time data collection from IoT sensors and advanced spatial analysis through GIS, resulting in a more comprehensive understanding of soil conditions and more targeted management. These studies offer valuable insights into how these technologies can be effectively integrated into agricultural practices to enhance productivity, sustainability, and resource management, serving as a valuable reference for researchers, agrarian practitioners, and policymakers.

5. CONCLUSION

The use of Internet of Things and Geographic Information Systems technology in monitoring Soil chemical properties in oil palm plantations shows significant potential to improve the efficiency and effectiveness of land management. The integration of IoT sensors for real-time data collection of various soil parameters and spatial analysis using GIS enables more efficient and responsive land monitoring, supporting precise decision-making related to fertilizer applications and land management.

For further research, validation of the effectiveness and sustainability of the system through large-scale field trials is essential. In addition, exploration of economic, social, and potential integration of climate data in GIS is also recommended to ensure comprehensive benefits and more optimal implementation of agricultural inputs.

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