

# The Role of Technology in Monitoring Land Pollution in Indonesia

Aisha Putri Khoirunisa<sup>1</sup>, Risha Khaitunnisa Husein<sup>2</sup>, Syaldila Diffa Ramadhan<sup>3</sup>, Gamal Muhammad Adam Ardiansyah<sup>4</sup>, M. Ilham Kumala Zalni<sup>5</sup>, Marningot Tua Natalis Situmorang<sup>6</sup>, Evelyn Hanaseta<sup>7</sup>

<sup>1,2,3,4,5,6,7</sup> Department of Environmental Engineering, Faculty of Engineering, Universitas Sahid Jakarta, Jakarta, Indonesia. Email: [2023339023@usahid.ac.id](mailto:2023339023@usahid.ac.id)<sup>1</sup>, [2023339021@usahid.ac.id](mailto:2023339021@usahid.ac.id)<sup>2</sup>, [2023339053@usahid.ac.id](mailto:2023339053@usahid.ac.id)<sup>3</sup>, [2023339027@usahid.ac.id](mailto:2023339027@usahid.ac.id)<sup>4</sup>, [2023339027@usahid.ac.id](mailto:2023339027@usahid.ac.id)<sup>5</sup>, [natalis\\_situmorang@usahid.ac.id](mailto:natalis_situmorang@usahid.ac.id)<sup>6</sup>, [Evelyn\\_hanaseta@usahid.ac.id](mailto:Evelyn_hanaseta@usahid.ac.id)<sup>7</sup>

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## ABSTRACT

Soil pollution in Indonesia has become a serious environmental issue caused by industrial activities, intensive agriculture, and domestic waste. Technology is crucial in detecting, monitoring, and managing soil contamination more effectively and efficiently. This paper discusses the application of various technologies such as the Internet of Things (IoT), environmental sensors, and Geographic Information Systems (GIS) in monitoring soil pollution in Indonesia, including the benefits, challenges, and implementation recommendations.

**Keywords:** Technology, Soil Pollution, Monitoring, IoT, GIS, Indonesia.

## I. Introduction

Indonesia, experiencing consistent economic expansion since 2005, has encountered substantial urbanization and migration towards major cities, intensifying pressure on its coastal environments (Adyasari et al., 2021). This confluence of factors has precipitated a surge in waste generation, substantially elevating the levels of pollution that infiltrate and degrade critical ecosystems (Fitria et al., 2019). The urgency of addressing environmental pollution and degradation in Indonesia cannot be overstated, given its profound implications for the nation's long-term well-being and sustainable development (Sopian & Pudjiastuti, 2021). Recognizing the gravity of the situation, the Indonesian government has proactively formulated a range of regulations and policies to mitigate the detrimental impacts of pollution on its terrestrial ecosystems (Irharni et al., 2018). These regulatory frameworks are designed to govern pollution control, encompassing measures to prevent, mitigate, and restore environmental pollution, thereby ensuring the preservation of environmental quality (Nihaya et al., 2018). In addition, the government has recognized the importance of transparency in environmental management and has implemented initiatives to enhance transparency and reduce pollution. The escalating levels of air pollution, exacerbated by rapid urbanization, industrialization, and sustained economic growth, have emerged as a prominent concern in Indonesia (Kusuma et al., 2023; Nihaya et al., 2018). This heightened pollution poses significant threats to public health, leading to respiratory ailments and cardiovascular diseases, and engenders ecological damage by disrupting ecosystems and

diminishing biodiversity (Amheka et al., 2015). In response to the pressing need for effective pollution management, technology emerges as a pivotal instrument, offering innovative solutions for monitoring, assessing, and mitigating land pollution in Indonesia. Technological advancements empower stakeholders to gain comprehensive insights into pollution sources, pollutant dispersion patterns, and the overall ecological impact, informing targeted interventions and strategies. The intricate challenges inherent in household waste management within Indonesia's burgeoning urban centers necessitate an integrated and comprehensive approach encompassing diverse stakeholders' active involvement (Amheka et al., 2015). The waste problem is challenging to solve, especially in urban areas, and is compounded by the rapid infrastructure development and industrial growth (Pratiati et al., 2021). Waste management problems in Indonesia include: the large amount of waste produced, the low level of waste management services, the limited number of landfills, waste management institutions, and costs (Muhashiby et al., 2021; Rosesar & Kristanto, 2020).

Technological interventions hold immense promise for revolutionizing land pollution monitoring in Indonesia, from remote sensing and GIS to sensor networks, data analytics, and modeling. Remote sensing technologies, including satellite imagery and aerial surveys, facilitate the extensive and continuous monitoring of land cover, land use changes, and pollution hotspots across vast geographical areas (Maniatis et al., 1987). Geographic Information Systems serve as indispensable tools for spatial analysis, enabling the integration of diverse datasets to map pollution distribution, identify pollution sources, and evaluate potential environmental risks (Maryono & Hasmantika, 2019). Furthermore, sensor networks, strategically deployed across landscapes, offer real-time data on air and water quality parameters, providing timely alerts on pollution incidents and enabling proactive responses (Aboyitungiye et al., 2021). Moreover, integrating Geographic Artificial Intelligence technology and Unmanned Aerial Vehicles presents novel opportunities for efficient and accurate collection, analysis, and visualization of geographic data, further enhancing the effectiveness of environmental monitoring efforts (Pertuack & Latue, 2023). Data analytics and modeling techniques empower stakeholders to discern pollution trends, forecast future pollution scenarios, and assess the efficacy of pollution control measures (Kristyawan et al., 2021). The urgency of adopting sustainable waste management practices cannot be overstated, particularly in light of the failures observed in numerous Indonesian villages stemming from geographical, social, and infrastructural challenges (Adriyanti et al., 2018). The mismanagement of waste poses a significant threat to environmental sustainability in Indonesia, potentially resulting in soil and water contamination, air pollution, and the proliferation of disease vectors. To address these multifaceted challenges, deploying appropriate technologies is imperative to enhance waste management efficiency, promote circular economy principles, and safeguard the integrity of Indonesia's terrestrial ecosystems. Given the limitations of manual surveys in waste detection due to their high workforce demands, remote sensing technologies offer a scalable solution for monitoring potential pollution sources (Magyar et al., 2023). The integration of geomatics, computer science, engineering, and economics enables the utilization of ancillary, satellite, and ground data for investigating areas susceptible to illegal waste disposal, and GIS-based tools can provide continuous and reliable environmental monitoring for companies that support municipalities and regions (Ragazzo et al., 2025). Optimizing waste collection routes through AI algorithms represents a crucial facet of waste management, underscoring the potential of technology to streamline operations and minimize environmental impact (Nwokediegwu et al., 2024). Effective waste management integrates various technologies, such as remote sensing, proximal sensing, ground-based sensing, Geographic Information Systems, and related plugins (Ragazzo et al., 2025). These technologies provide the means to monitor pollution events and analyze the spatial distribution of waste collection sites (Rumung & Dwipayanti, 2021).

Recognizing the pivotal role of technology in addressing environmental challenges, the Indonesian government has undertaken proactive measures to promote the adoption of technological solutions for pollution monitoring and management. These measures encompass policy frameworks, regulatory standards, and financial incentives to foster innovation, encourage technology transfer, and facilitate the deployment of advanced environmental technologies. Furthermore, collaborative initiatives involving government agencies, research institutions, private sector entities, and international organizations are instrumental in driving

technology development, capacity building, and knowledge sharing in environmental management. By prioritizing sustainable waste management practices and integrating technology, Indonesia can effectively mitigate the environmental impact of waste, safeguard public health, and foster a cleaner, healthier environment for present and future generations. The Indonesian government has arranged in detail about waste management as stipulated in Regulation Number 18 of 2008 concerning waste management. The mandate states that waste management is a national problem that must be resolved (Syafii et al., 2020). Law enforcement in waste management reflects the commitment of the government and the regional government to enforce regulations, and producers are required to provide the necessary facilities for waste segregation (Purba & Erliyana, 2020). Waste banks are a practical solution by Law 18 of 2008 and Government Regulation No. 81 of 2012, which outlines the mandate to change the community's paradigm (Utama & Pratama, 2021).

Soil pollution in Indonesia is an increasingly urgent environmental problem that needs to be addressed as agricultural activities, urbanization, and chemical overuse increase. Declining soil quality directly impacts agricultural productivity and national food security. Therefore, monitoring soil quality is important to maintain environmental balance and support a sustainable agricultural sector (Elvera & MSi, 2024). Technological developments, especially the Internet of Things (IoT), remote sensing, and geographic information systems (GIS), have presented a new approach to real-time monitoring of soil conditions. Using sensors to measure soil parameters such as pH, humidity, and temperature, as well as cloud-based data processing, allows the monitoring process to be faster, more accurate, and more cost-effective (Megah Sari, Jumardi, & Rasjid, 2022). This technology-based monitoring system detects changes in soil conditions and helps in more responsive land management decision-making. With this progress, Indonesia can improve the soil monitoring system, especially in the agricultural sector, which is spread across various regions with diverse geographical characteristics.

Previous research in Indonesia has focused chiefly on manually monitoring soil quality through sampling and laboratory analysis, which takes a long time and costs much money. A study by Elvera and MSi (2024) shows that the application of sensor-based monitoring systems in smart agriculture can improve irrigation efficiency and maintain the stability of soil nutrients. This proves that technology integration can be a practical solution to improve conventional monitoring systems. Furthermore, the research of Megah Sari et al. (2022) developed a prototype of an IoT-based system to monitor soil pH in agricultural land, providing convenience in obtaining real-time data. These findings underscore the importance of innovation in monitoring systems to improve the accuracy and speed of decision-making in land management. However, the challenges of implementing this technology in Indonesia are still quite significant, especially related to internet infrastructure in rural areas, the cost of technology adoption, and the low digital literacy of farmers. Against this background, this research is important to examine further the role of technology in monitoring soil pollution in Indonesia, including identifying opportunities for developing systems adapted to local conditions.

## II. Research Method

With a literature review approach, this qualitative research aims to analyze various soil pollution technologies applied in Indonesia in depth, especially those based on sensors and the Internet of Things (IoT).

### 2.1. Data Type

The type of data used in this study is secondary data, obtained through a literature study of scientific journal articles that discuss the application of technology in Indonesia's soil pollution monitoring system. This data is collected without direct interaction with the research object but is sourced from documentation of previous research results that have been officially published and can be scientifically accounted for. The secondary data in question includes technical information about the hardware and software used in the

monitoring system, including the types of sensors, microcontrollers, and GSM and IoT-based communication systems. In addition, the data collected also includes monitored environmental parameters, such as soil pH values, soil temperature, humidity, and heavy metal concentrations. Thus, all types of data in this study are qualitative, focusing on the technical aspects and implementation of soil pollution monitoring technology in various land conditions in Indonesia.

## 2.2. Data collection techniques

The data collection technique in this study was carried out using a literature study method related to scientific articles relevant to soil pollution monitoring technology in Indonesia. Data is collected by studying, reviewing, and recording important information from each journal, such as the type of sensor used, environmental parameters, and the system used. The data included test methods, monitoring results, and conclusions from each study. These data are collected and then analyzed qualitatively to answer the research objectives.

## III. Results and Discussion

Environmental monitoring is essential to understanding the actual condition of the natural environment. Through a systematic and measurable data collection process, we can accurately monitor the dynamics of environmental change and recognize patterns that have the potential to have a significant impact on ecosystems, public health, and human life in general. Understanding these changes allows preventive measures to be taken to reduce the negative impacts that may arise. Environmental monitoring activities also evaluate environmental status and trends, support policy formulation and implementation, and provide information needed for reporting to policymakers at the national level, international forums, and the wider public (United Nations Economic Commission for Europe, 2023).

Environmental monitoring technology uses advanced devices and systems to observe, measure, and analyze various environmental conditions, including air quality, water, soil, noise levels, and meteorological phenomena. The success of technology in monitoring soil pollution in Indonesia can be seen from its ability to detect pollutant parameters with precision and present continuous data. Some of the technologies used include:

### 1. Environmental Sensors

A sensor is a component, device, or tool that detects, measures, and records an environment's specific physical, chemical, or biological parameters. This technology directly measures soil physical and chemical parameters, such as pH, humidity, temperature, and heavy metal content. The sensors are usually permanently installed in strategic locations to obtain data continuously.

### 2. Internet of Things (IoT)

The Internet of Things (IoT) is a concept in which objects can transmit or receive data over a network without the need for the help of computer devices or human intervention (Andaria et al., 2023). IoT plays a crucial role in environmental monitoring by allowing sensors to connect to the network and send data directly to the analytics platform. By leveraging IoT, we can connect thousands to millions of environmental sensors in one centralized network, allowing for continuous data collection and real-time monitoring of environmental conditions. For example, sensors installed at various points in a city can transmit data about air quality, temperature, humidity, and other parameters to a control center, where the information can be analyzed to detect pollution patterns or other environmental changes.

### 3. Geographic Information System (GIS)

A Geographic Information System (GIS) is a system that combines spatial data (maps) with attribute or descriptive data to produce useful information. GIS processes, analyzes, visualizes, and presents

environmental data spatially in environmental monitoring. For example, GIS can be used to create maps that show the spatial distribution of air quality, forest degradation, shoreline changes, and others, which can support better analysis and decision-making.

Various studies in Indonesia have shown the effectiveness of this technology, including through monitoring pH and toxic gases in rice fields with ESP32 and integrated sensors, web-based telemonitoring systems for monitoring EC, pH, and polluted soil temperature, and the use of GIS in mapping areas that are prone to pollution due to industrial and mining activities. In addition, environmental monitoring also has an important role in measuring the success of implementing environmental protection policies and conservation programs. The data collected from this activity is the basis for evaluating the effectiveness of the policies that have been implemented and supports more optimal strategy planning in the future. One of the causes of soil pollution in Indonesia is agriculture. Pesticides are most widely used by farmers in the agricultural sector (Siahaan, 2021). In spraying, the pesticide solution is broken down into nozzles or atomizers that are dispersed in the form of droplets. The picture that can be obtained from soil pollution is the situation where chemicals made by humans enter the soil, causing changes in the soil structure, both physically and chemically. The use of high amounts of pesticides can cause a decrease in pH values, causing a decrease in soil fertility (Siahaan, 2021). The toxic content of pesticides can also cause contamination, which can cause various health problems for humans. In this case, environmental censorship should have started to be applied in Indonesia, especially in the case of soil pollution. This is needed immediately because the soil fertility level and the high level of pollutants are primarily determined by the chemical and physical parameters contained in it (Siahaan, 2021).

Environmental sensors to measure soil pH must be used to maintain soil fertility. The role of IoT must certainly play a significant role in this measurement. For example, the pH value measured automatically from the sensor will later be sent through an application developed for farmers, who will later be able to receive a notification of the soil's pH level.

#### IV. Conclusion

Based on the results of the literature study, it can be concluded that technology plays a vital role in monitoring soil pollution in Indonesia. The application of environmental sensors, the Internet of Things (IoT), and Geographic Information Systems (GIS) has been proven to increase the effectiveness, efficiency, and accuracy in monitoring soil conditions. This technology enables real-time monitoring of critical parameters such as pH, humidity, temperature, and heavy metal content, supporting faster and more precise decision-making in land management. However, there are still challenges such as limited infrastructure, high costs, and low digital literacy among farmers. Therefore, the support of various parties, including the government, the private sector, and academics, is needed to expand the application of this technology evenly and sustainably throughout Indonesia.

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