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LEGAL IMPLICATIONS OF AI-ASSISTED MEDICAL WASTE MANAGEMENT IN HEALTHCARE FACILITIES

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Abstract:
Medical waste management in healthcare facilities is critical to protecting public health and the environment. Improper handling of medical waste can lead to environmental pollution and pose serious health risks. In Indonesia, Permenkes No. 2 of 2023 provides a regulatory framework for managing medical waste, but its implementation needs to be improved, especially in remote healthcare facilities with limited infrastructure and resources. Technological advances, especially artificial intelligence (AI), offer potential solutions to optimize medical waste management through real-time tracking, sorting, and monitoring.
This study aims to evaluate the role of AI in supporting the implementation of Permenkes No. 2 of 2023 in several health facilities and identify barriers to AI adoption. Using a normative legal approach combined with case studies from health facilities in Indonesia, this study highlights the effectiveness of AI implementation in medical waste management. The results show that AI has the potential to improve compliance with medical waste management standards, optimize waste processing, and strengthen supervision through real-time data collection. However, AI adoption faces high costs, a lack of infrastructure, and limited technical expertise, especially in remote areas.
The implications of this study emphasize the need for investment in technological infrastructure, health workforce training, and supportive policies to address barriers to AI adoption. This would maximize the potential of this technology in more effective medical waste management for public health and a safer environment.

Keywords *: Artificial; Intelligence; Environmental Health; Health Facilities; Medical Waste*

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INTRODUCTION

Medical waste management has become a significant global concern due to its potential to harm the environment and public health. Healthcare facilities, including hospitals, clinics, and laboratories, generate a variety of wastes, some of which are classified as hazardous due to their infectious, toxic, or radioactive nature. If not managed properly, these wastes can cause environmental pollution and pose serious health risks to healthcare workers, patients, and the general public (Jose, 2024). The issue of medical waste management is particularly relevant in developing countries, where infrastructure and regulatory compliance may need to catch up. In Indonesia, these concerns have prompted the introduction of Permenkes No. 2 of 2023, an expansion of Government Regulation No. 66 of 2014 on Environmental Health, which aims to establish clear standards for medical waste management in healthcare facilities nationwide. However, implementing proper medical waste management practices faces significant challenges despite the regulatory framework.

Globally, the volume of medical waste has increased due to expanding healthcare activities, population growth, and medical advancements. According to the World Health Organization (WHO), healthcare activities generate waste that can be divided into two main categories: general waste and

hazardous waste. General waste is similar to household waste and poses minimal risk. In contrast, hazardous waste includes sharps, pathological materials, pharmaceutical waste, and radioactive substances, which can cause serious harm if not handled properly. In developed countries, such as a city hospital in Florida, United States, the rate of biomedical waste generation reaches 10.7 kg/bed/day (Maamari et al., 2015). In Indonesia, hazardous medical waste is generated in significant amounts, so its proper disposal is an urgent problem that must be addressed to prevent environmental contamination and health hazards. In Indonesia, only some hospitals have a policy on medical waste management (Musa, 2014). Some hospitals manage medical waste by burning it using an incinerator. This is because they need a permit from the Environmental Agency (BLH) to use the incinerator. After all, the distance between the incinerator and the buildings around the hospital is less than 50 meters (Maulana et al., 2017).

In response to this growing problem, Permenkes No. 2 of 2023 was designed to fill the gaps in existing regulations and create comprehensive guidelines for medical waste management. The regulation outlines detailed requirements for the handling, sorting, transporting, and disposing of medical waste to ensure that health facilities comply with national environmental health standards. These measures are intended to reduce the risks associated with improper waste management, including environmental pollution, the spread of infectious diseases, and long-term ecological damage. However, the effectiveness of this regulation has been limited by various constraints, especially in remote and underdeveloped areas.

One of Indonesia's significant challenges in medical waste management is inadequate infrastructure to manage hazardous waste. Many health facilities, especially those in rural and remote areas, need access to incineration plants or other waste management technologies to process dangerous materials (Astuti, 2019) safely. With adequate infrastructure, health facilities can avoid unsafe disposal practices, such as open burning or dumping waste in landfills that are not equipped to handle hazardous substances. These methods increase the risk of environmental pollution and disease transmission, highlighting the need to improve waste management facilities across the country (Bokhoree et al., 2014).

Another challenge is the need for more awareness among healthcare workers regarding the importance of proper medical waste management (Pandey, 2016). In many healthcare facilities, waste is not properly segregated, and hazardous materials are often mixed with general waste, increasing the risk of exposure and contamination. In addition, healthcare workers in these facilities usually need more training and knowledge to handle and dispose of hazardous waste according to regulatory standards (Akkajit et al., 2020). This lack of awareness contributes to non-compliance with Permenkes No. 2 of 2023 and perpetuates the risks associated with improper waste management.

To address these challenges, technology has emerged as a potential solution to improve medical waste management practices. In particular, artificial intelligence (AI) offers new opportunities to automate and optimize various aspects of the waste management process, including waste tracking, sorting, and real-time monitoring. Integrating AI into medical waste management systems has the potential to improve compliance with regulatory standards and increase the overall efficiency of the waste disposal process.

Medical waste management is a crucial issue that affects public health and the environment, especially in developing countries like Indonesia. Although Permenkes No. 2 of 2023 provides a regulatory framework for managing medical waste, significant challenges remain, including inadequate infrastructure, financial constraints, weak law enforcement, and low awareness among healthcare workers. The integration of AI offers a promising solution to many of these challenges by automating waste sorting, improving tracking, and optimizing processing processes. However, to fully realize the potential of AI in medical waste management, significant investments in infrastructure, training, and data security are required. Overcoming these barriers will be critical to improving compliance with medical waste management regulations and protecting public health and the environment.

Research on medical waste management shows that its implementation still has many challenges, so it cannot be said to run optimally. In Indonesia, for example, several health facilities, especially in remote areas, still face significant obstacles in implementing medical waste management by regulations, such as Permenkes No. 2 of 2023. Common problems include limited infrastructure, lack of access to adequate waste processing technology, restricted funds, and low awareness and training among health workers regarding the separation and management of hazardous waste.

Meanwhile, although developed countries may have more stringent technology and regulations globally, they still need help implementing wholly safe and sustainable medical waste management. Factors such as high costs, complex technology, and strict compliance with standards often need to be addressed to achieve optimal results.

Therefore, this research still requires various improvement efforts and support, such as investment in waste management infrastructure, increased training for health workers, and the application of new technologies, such as AI, to improve efficiency and compliance. Although several steps have been taken, research and implementation in the field still need improvement to achieve optimal success in medical waste management. This study aims to evaluate the effectiveness of medical waste management in health facilities, especially in implementing applicable regulations, such as Permenkes No. 2 of 2023 in Indonesia.

RESEARCH METHOD

This study was designed with a normative legal approach that focuses on analyzing legal principles, laws and regulations, and relevant legal frameworks in Indonesia's medical waste management context. It specifically examines the effectiveness of implementing Permenkes No. 2 of 2023, a continuation of Government Regulation No. 66 of 2014 concerning Environmental Health, and Law No. 17 of 2023 concerning Health.

This study also seeks to understand the extent to which existing regulations can address the problems faced by health facilities in managing hazardous medical waste safely and effectively, especially in facilities located in remote or less developed areas. This study was conducted in several health facilities, including hospitals, health centers, and clinics, in areas with limited infrastructure to process medical waste. Data were collected over time to reflect the variation in challenges and successes in implementing regulations across geographic and socio-economic conditions.

The main aspects studied in this study include compliance with medical waste management regulations, waste separation and disposal, and challenges in implementing adequate waste management technology or infrastructure. This research strategy emphasizes an approach that combines regulatory analysis and evaluation of practical implementation in the field to provide a comprehensive picture of the effectiveness and weaknesses of the current medical waste management system.

The population of this study consisted of various health facilities in Indonesia that vary in capacity and geographical location. The sample was selected purposively, covering large hospitals in urban areas and health centers in remote areas. The sample selection aims to provide a comprehensive view of the implementation of medical waste management policies in various health facility conditions.

The research instruments used were a study of relevant legal and regulatory documents, structured interviews with health workers and facility managers, and direct observation of the medical waste management process at selected locations. This document study involved an in-depth analysis of applicable regulations, such as Permenkes No. 2 of 2023 and Law No. 17 of 2023, as well as broader environmental regulations.

During the data collection process, structured interviews were used to obtain direct views from health workers and facility managers regarding the challenges they face in medical waste management and their evaluation of the applicable regulations. This is expected to reveal areas that

need improvement or clarification in the rules. These interviews were conducted face-to-face at several health facilities, while in hard-to-reach locations, interviews were conducted online.

Direct observation of medical waste management practices was conducted to see how policies and procedures set out in the regulations were implemented in the field. This observation focused on separating, transporting, and disposing of hazardous medical waste, especially to identify whether more clarity needed to be provided between written regulations and actual practices in the field.

This study's analysis strategy focused on evaluating the gap between regulations and implementation in the field. Findings from observations and interviews were then compared with standards set in rules to identify existing gaps. Data obtained from different health facilities allowed for comparing conditions in facilities with good access to medical waste management infrastructure and those less developed. This was expected to reveal factors that influenced the success or failure of implementing medical waste management.

The research strategy also includes exploring innovative solutions, such as using artificial intelligence (AI), to address challenges in medical waste management. This analysis is conducted through a literature review of technologies that have been used in various countries and discussions with experts and practitioners in the field of medical waste management. In addition, this study assesses the potential and limitations of these technologies in the Indonesian context, where infrastructure and technological capabilities in health facilities may differ significantly.

The results of this study were analyzed using a descriptive-qualitative approach. Data obtained from legal documents, interviews, and observations were analyzed to provide a clear picture of the effectiveness of regulations and the challenges faced in their implementation. The results of this study are expected to identify areas that require special attention in improving regulations or other supporting policies.

With a research strategy that combines regulatory analysis with field data collection and insights from possible technologies, this study aims to provide practical and applicable solutions. This study presents normative analysis and offers a comprehensive understanding of the steps needed to improve medical waste management in Indonesia. Ultimately, this study is expected to be the basis for preparing practical policy recommendations and contributing to efforts to improve environmental safety and public health.

RESULTS AND DISCUSSION

Current Legal Framework and Conditions of Medical Waste Management

A comprehensive set of legal frameworks governs medical waste management in Indonesia to protect public health and the environment. The foundation of this regulatory framework is Permenkes No. 2 of 2023, which outlines standards for the handling, sorting, transporting, and disposing of medical waste generated by healthcare facilities (Ardhani, 2016). This regulation is an extension of Government Regulation No. 66 of 2014 on Environmental Health, which provides a broader legal context for environmental protection and healthcare waste management across the country. In this section, we will delve deeper into the legal aspects of medical waste management, highlighting the regulatory provisions and practical challenges in implementing this regulation in Indonesia.

Fieldwork conducted for this study indicated that compliance with Permenkes No. 2 of 2023 needs to be more consistent across health facilities. Compliance rates were relatively high in larger, more urban hospitals with better funding and infrastructure. These hospitals have invested in waste sorting systems, incinerators, and partnerships with third-party waste management services. In these facilities, medical waste is correctly separated into hazardous and non-hazardous categories, and disposal processes comply with government regulations, with proper handling through incineration or autoclaving. These facilities also demonstrated better awareness among health workers regarding the importance of medical waste management (Rahno et al., 2015).

Ministerial Regulation No. 2 of 2023 was enacted to address growing concerns over improper disposal of medical waste, which poses severe risks to public health and environmental safety. The regulation was developed in line with Law No. 32 of 2009 on Environmental Protection and Management, which mandates the sustainable use of natural resources and prevention of environmental pollution. As healthcare facilities are significant generators of hazardous waste, this legal framework clearly outlines their role in safeguarding the environment. Ministerial Regulation No. 2 of 2023 defines the types of waste generated by healthcare activities, categorizing them into hazardous and non-hazardous categories. The regulation mandates that dangerous waste—such as sharps, infectious waste, toxic chemicals, and radioactive materials—must be separated from general waste at source to prevent contamination and ensure safe disposal. The law also sets out guidelines for treating and disposing of medical waste, including incineration, autoclaving, and chemical disinfection, depending on the nature of the waste.

Other legal instruments play a significant role in shaping the regulatory landscape of medical waste management in Indonesia. Government Regulation No. 101 of 2014 on Management of Hazardous and Toxic Waste (B3 Waste) provides a comprehensive framework for managing hazardous waste across sectors, including healthcare. This regulation emphasizes the importance of safe disposal methods. It outlines the responsibilities of healthcare facilities in ensuring that their waste management practices do not endanger the environment or public health. In addition to this regulation, Law No. 17 of 2023 on Health consolidates various health-related legal obligations, replacing the now-defunct Law No. 44 of 2009 on Hospitals. Under this new law, healthcare facilities' responsibilities for managing medical waste have been expanded to include stricter monitoring and enforcement mechanisms.

Law Number 17 of 2023 stipulates that healthcare facilities must comply with national and international standards for waste management to protect public health. It introduces specific sanctions for non-compliance with environmental and health regulations. This reflects the increasing commitment of the Indonesian government to integrate sustainable practices into healthcare operations, particularly in managing hazardous waste that poses significant health risks if not handled properly. In addition, Law Number 17 of 2023 is closely aligned with Law Number 32 of 2009 concerning Environmental Protection and Management, which mandates sustainable practices across all sectors and emphasizes the need for proper medical waste management (Asrun et al., 2020). This intersection of laws places a clear legal obligation on healthcare providers to ensure that waste is disposed of in a manner that is safe for the environment while protecting public health and safety.

However, the situation differs significantly in smaller health facilities and rural and remote areas. These facilities often need more financial resources to invest in proper waste management infrastructure and are more likely to face logistical challenges related to waste disposal (Axmalia & Sinanto, 2021). Medical waste, including hazardous materials such as sharps and infectious waste, is often mixed with general waste due to inadequate waste segregation practices. Furthermore, some facilities need access to licensed third-party waste treatment companies, leaving them no choice but to use unsafe disposal methods such as open burning or burying waste, increasing the risk of environmental contamination and spreading infectious diseases (Ratu, 2014).

Several challenges were identified in implementing Permenkes No. 2 of 2023, especially in facilities that were found not to comply with the provisions.

- Lack of Infrastructure: One of the significant obstacles to effective waste management is the need for adequate infrastructure, especially in rural and underdeveloped areas. Many facilities need access to incinerators or other waste management technologies to handle hazardous medical waste.
- Financial Barriers: Smaller clinics and community health centers often need more financial resources to invest in proper waste management systems. The costs associated with purchasing equipment, training staff, and contracting with licensed waste treatment facilities are often prohibitive, leading to inadequate compliance with government regulations.

- Limited Government Oversight: Despite regulations, government oversight could be more robust, especially in more remote areas. This lack of oversight results in lower levels of compliance because facilities need to face sufficient consequences for failing to comply. Regulatory bodies responsible for monitoring waste management practices often need more personnel and resources to conduct routine inspections, further exacerbating the problem.
- Awareness and Training Gaps: Healthcare workers in smaller, under-resourced facilities often need more training in medical waste management, resulting in poor sorting practices and an overall lack of regulatory compliance. Awareness of the long-term environmental and health consequences of improper waste disposal is also low, contributing to the ongoing problem.

Potential of AI in Medical Waste Management

The use of AI in medical waste management can be one of the national development efforts. National development is related to tangible things and includes things that cannot be seen concretely because it covers all aspects of Indonesian people's lives (Amelia & Budi, 2022). Medical waste management in health facilities is increasingly becoming a critical environmental and public health issue. The strict requirements set by Permenkes No. 2 of 2023 and Law No. 17 of 2023 concerning Health mandate comprehensive protocols for managing, sorting, and disposing of hazardous medical waste. However, practical implementation challenges require innovative solutions, especially in rural and under-resourced health facilities. In this context, integrating AI technology offers a transformative approach to improving compliance, efficiency, and sustainability in medical waste management. This section discusses how AI can address critical challenges and its potential to revolutionize medical waste management in Indonesia.

Compliance with Permenkes No. 2 of 2023 requires strict adherence to waste sorting, transportation, and disposal protocols. However, healthcare facilities, especially in rural areas, often need more resources, training, and supervision to maintain these standards. AI can address these challenges by automating various aspects of medical waste management, ensuring consistent compliance with legal requirements while reducing the burden on healthcare workers.

AI-Based Waste Sorting and Tracking. One of the most significant challenges in medical waste management is segregating hazardous materials, such as infectious and sharps, from non-hazardous general waste. AI-powered image recognition and machine learning systems can automate this process by identifying different types of medical waste at source (Aggarwal et al., 2022). These systems use advanced algorithms to scan and classify waste based on visual characteristics, ensuring that hazardous materials are correctly separated before disposal.

Radio Frequency Identification (RFID) tags, specific tags assigned to specific bins, have also been used for medical waste and allow for measurement and tracking of waste disposal. Based on the tag information (obtained by mobile operators/handheld devices/scanning devices), different waste materials are disposed of at pre-determined bins. RFID technology can monitor, manage,/and track waste transportation from source to sender and finally to disposal centers; black marketing of medical waste can also be monitored. Any violations can be easily captured, detected, and prosecuted (Namen et al., 2014).

For example, AI-enabled systems can automatically be installed at waste collection points in healthcare facilities to sort waste into appropriate bins. This reduces human error, a common cause of improper sorting and subsequent environmental pollution. Additionally, by ensuring that hazardous waste is isolated from general waste early in the process, healthcare facilities can more easily meet the standards set by Permenkes No. 2 of 2023.

In addition, AI-powered sorting systems can be connected to real-time monitoring platforms that track the amount and type of waste generated by healthcare facilities (Ishaq et al., 2023). These platforms provide administrators with data on waste flows, allowing them to optimize waste management strategies and identify areas of possible non-compliance. Based on 4G/5G-based modules, Bluetooth positioning technology consisting of Bluetooth iBeacon, Bluetooth positioning

terminal, LoRa communication base station, positioning engine and map, deployment inspection + POI information management and calibration application, mobile application, server software, has been used in hospitals in China. Waste collection and transfer vehicles are equipped with Bluetooth positioning terminal tags, continuously monitored and visualized (Zhao & Niu, 2022).

AI systems can also be used to track medical waste from the point of production to final disposal. Real-time tracking and data collection ensure that all waste is accounted for and handled according to proper procedures. This increased transparency in the waste management process allows healthcare facilities and regulatory bodies to monitor compliance more effectively. Additionally, AI can optimize waste disposal logistics, ensuring that waste is transported and treated efficiently, reducing the risk of contamination.

Predictive Maintenance and Waste Processing Optimization. Another key area where AI can improve medical waste management is the operation of waste processing facilities. AI-powered predictive maintenance systems can monitor the condition of incinerators, autoclaves, and other waste processing equipment, allowing for early detection of potential malfunctions (Huang & Koroteev, 2021). This helps avoid equipment breakdowns that could lead to untreated waste or disruptions in waste processing. By ensuring that waste processing facilities operate smoothly and efficiently, healthcare facilities can better comply with medical waste disposal regulations and reduce environmental damage. AI also enables the optimization of the waste processing process itself. For example, AI algorithms can analyze historical data on waste volume and facility capacity, allowing for better planning of waste disposal needs. This can prevent the overloading of treatment facilities and ensure that waste is processed promptly, thereby reducing the risks associated with the accumulation of untreated waste in healthcare facilities.

Blockchain, an innovative technology that started with cryptocurrencies, can now also be applied to medical waste management. To correctly manage, coordinate, and monitor wastewater and medical waste, systems based on blockchain technology and the Internet of Things (IoT) are being designed in a futuristic manner. In hospital waste management, IoT-enabled containers measure the quantity of waste and track and exchange data between entities. These insights are forwarded to the Blockchain via WiFi, 4G, or 5G for real-time processing at specified intervals. The data blocks are collected and validated using DPoS, a consensus algorithm (Kassou et al., 2021). Compared to conventional methods, it seems cost-effective but requires continuous monitoring and lacks decision-making capabilities. Furthermore, additional features such as decision-making algorithms, Bluetooth signals, GPS mapping features with cameras, and height managers can be incorporated (Grace et al., 2023).

AI systems have the ability to process large amounts of data generated by healthcare facilities, thus offering real-time monitoring of medical waste management processes. These systems can continuously collect and analyze waste production, sorting, transportation, and disposal data and ensure that healthcare facilities comply with legal requirements set out in Law No. 17 of 2023. For example, AI can monitor waste disposal systems and ensure that incinerators or autoclaves operate within legally required parameters. If improper waste handling is detected, the AI system can trigger an alert, allowing administrators to take immediate corrective action. This proactive approach helps prevent violations of waste management regulations and reduces the risk of environmental pollution.

Furthermore, AI-based data analysis can provide healthcare administrators and regulatory bodies with insights into waste management trends. By analyzing waste production and disposal patterns, AI systems can identify areas where facilities are at risk of non-compliance or where improvements are needed. This data-driven approach enables healthcare providers to make informed decisions about resource allocation, staff training, and infrastructure investment, ultimately improving their ability to comply with Permenkes No. 2 of 2023 and Law No. 17 of 2023.

They are improving Government Oversight and Regulatory Compliance. A critical component of regulatory compliance in medical waste management involves detailed reporting. Healthcare facilities must keep comprehensive records of their waste management practices, including

information on the type, quantity, and method of disposal of hazardous waste. Ensuring the accuracy and completeness of these records is critical to meeting the legal standards set forth by Permenkes No. 2 of 2023. AI can also play a role in improving government oversight of medical waste management. By collecting and analyzing real-time data from healthcare facilities, AI systems can provide regulatory agencies with a clear picture of waste management practices across the country (Stephina et al., 2020). This would allow for more targeted inspections and enforcement actions, especially in areas with low levels of compliance. AI can also help identify patterns of non-compliance, allowing regulators to intervene before problems escalate.

AI can streamline the reporting process by automatically generating reports based on real-time data collected from waste management systems. These reports can be tailored to meet specific regulatory requirements, ensuring that healthcare facilities comply with legal obligations. Additionally, AI-powered systems can cross-reference waste management data with regulatory guidelines to ensure that all legal requirements are met, reducing the risk of sanctions for non-compliance. For example, AI systems can track when waste is generated, how it is transported, and where it is disposed of (Ahmad et al., 2021). This comprehensive data collection allows healthcare facilities to provide detailed reports to regulators demonstrating compliance with medical waste regulations. By automating this process, AI reduces the administrative burden on healthcare providers and improves the accuracy and reliability of waste management documentation.

Data collected by AI systems can also support policy-level decision-making. For example, by analyzing waste generation and disposal trends, policymakers can identify additional resources or regulatory adjustments that may be needed to improve waste management practices. AI's ability to process large amounts of data quickly and accurately can significantly enhance governments' ability to respond to emerging challenges in medical waste management.

Challenges in AI Adoption. Waste management and maintenance services in cities worldwide are becoming smarter; automation and digitalization can also be realized in medical waste management. AI has the potential to revolutionize waste management and can analyze medical waste. Therefore, AI can help optimize waste collection routes, collection scheduling, and resource allocation, reducing operational costs and energy consumption (Sengeni et al., 2023). Although AI has promising potential in medical waste management, several barriers must be overcome to ensure successful implementation, especially in the Indonesian context.

One significant barrier is the high cost of implementing AI systems. While larger hospitals with more substantial financial resources may be able to afford the necessary technology, smaller clinics, and community health centers, especially those in rural areas, may need help to afford the costs of AI integration. The infrastructure required for AI implementation, including hardware, software, and technical support, presents significant financial challenges for under-resourced facilities. To address this, partnerships between the government and the private sector and subsidies or grants may be needed to help healthcare facilities adopt AI technologies.

Technical expertise is another limiting factor. Implementing AI systems requires specialized knowledge, both in terms of initial setup and ongoing maintenance. Many health facilities, especially in remote areas, may need more technical staff to operate these systems effectively. Extensive training programs will be essential to ensure that health workers can effectively use AI devices for waste management.

The issue of accountability is another crucial aspect that is currently under-regulated. An action is considered legal if it has legal consequences that can be accounted for or recognized by the state (Hernando & Amelia, 2024). Data security and privacy issues are crucial issues that need to be addressed. AI systems rely on large amounts of data, which can include sensitive information in the context of healthcare. Ensuring this data is stored and processed securely is critical to maintaining trust in AI technology and ensuring compliance with national and international data protection laws.

The application of AI in waste management can pose significant challenges and ethical issues. Algorithms learn from data, and biased training data can cause AI systems to amplify biases (Naik et

al., 2022) inadvertently. Addressing bias in AI algorithms ensures fairness. AI relies on extensive data for accurate learning, which raises privacy and security concerns (Camacho et al., 2018). Ensuring data is collected and used ethically, with appropriate consent and safeguards, can compromise patient safety and privacy (Vollmer et al., 2020). Many AI algorithms, incredibly complex deep learning models, can be challenging to interpret and understand. A lack of transparency in decision-making can hinder accountability and the ability to address issues when AI systems make incorrect or harmful predictions (Hörnle, 2019). Transparent AI models and explainable AI techniques are critical to building trust and understanding. While AI has the potential to drive significant progress and improvements in many areas, it is essential to balance this progress with responsible implementation. Rushing into AI without considering potential consequences can lead to unintended adverse outcomes (Gerke et al., 2020). These ethical challenges and considerations underscore the need for a holistic and responsible approach to AI development, where innovation is balanced with social and moral concerns (Li et al., 2023). This approach will help ensure that AI technologies contribute positively to society while minimizing potential risks (Karnavel et al., 2023).

Future directions and potential advancements can be considered to ensure effective and sustainable biomedical waste management. These advancements will improve waste disposal methods and minimize environmental and health risks associated with improper waste handling (Singh et al., 2020). Next-generation biomedical waste management can continuously monitor waste processes by incorporating drones and remote sensing. This entails monitoring generation, collection, transport, and disposal, enabling real-time data-driven resource allocation, interventions, and compliance monitoring (Gade & Aithal, 2021). AI predictive models estimate biomedical waste using population density, disease, and healthcare activity. This helps waste systems anticipate needs, optimize routes, and allocate resources efficiently. Machine learning enhances sorting, recycling, and disposal (Rong et al., 2020). More advancements are needed in autonomous robots with AI and sensors. Futuristic Blockchain technology can generate transparent waste management records, ensuring proper disposal, tracking, and verifiable compliance data (Khosla et al., 2022).

CONCLUSION

The findings of this study also highlight the gap between existing regulations and implementation in the field, where some healthcare facilities still need to be able to safely separate and dispose of hazardous medical waste. To bridge this gap, this study explores the potential use of technology, such as artificial intelligence (AI), which can help automate waste management processes, improve waste separation accuracy, and provide real-time monitoring.

Integrating technology, particularly AI, into medical waste management has great potential to address some of the challenges faced, particularly in improving regulatory compliance, optimizing waste management processes, and supporting government oversight. However, realizing these benefits requires significant investment in technology infrastructure, workforce training, and supporting policies that address cost and data security barriers.

Overall, this study provides recommendations for the government and related parties to strengthen support for health facilities throughout Indonesia in the form of funding, training, and access to technology. With a holistic approach involving regulations, infrastructure support, and technology utilization, Indonesia can improve the effectiveness of medical waste management, maintain public health, and protect the environment from the negative impacts of hazardous waste.

REFERENCE

Aggarwal, K., Maad M. Mijwil, Abdel-Hameed, A.-M., Safwan, A., Murat, G., Anas, MZA, & Safaa, H.A. (2022). Has the Future Already Begun? The Current Growth of Artificial Intelligence, Machine Learning, and Deep Learning. Iraqi Journal of Computer Science and Mathematics, 3(1).

Ahmad, R.W., Salah, K., Jayaraman, R., Yaqoob, I., Omar, M., & Ellahham, S. (2021). Blockchain-Based Advanced Supply Chain and Waste Management for COVID-19 Medical Equipment and Supplies. IEEE Access, 9, 44905–44927. https://doi.org/10.1109/ACCESS.2021.3066503

Akkajit, P., Romin, H., & Assawadithalerd, M. (2020). Assessment of Knowledge, Attitude, and Practice in Medical Waste Management among Health Workers in Clinics. Journal of Public and Environmental Health, 2020. https://doi.org/10.1155/2020/8745472

Amelia, T., & Budi, H. (2022). Dynamics of Investment Law in Indonesia. PT Kaya Ilmu Bermanfaat.

Ardhani, R. (2016). Managing a Hospital. Lambung Mangkurat University Press.

Asrun, AM, Sihombing, LA, & Nuraeni, Y. (2020). Impact of Medical Waste Management Related to Law No. 36 of 2009 Concerning Health and Law No. 32 of 2009 Concerning Environmental Protection and Management. PAJOUL (Pakuan Judicial Law Journal), 1(1), 33–46. https://doi.org/10.1017/CBO9781107415324.00.

Astuti, AP (2019). Study of waste management in public hospitals in West Nusa Tenggara Province (NTB). Public Health, 2(1), 12–20.

Axmalia , A., & Sinanto , RA (2021). Handling of Household Infectious Waste during the COVID-19 Outbreak. Journal of Community Health, 7(1), 70–76.

Bokhoree , C., Beeharry , Y., Makoondlall-Chadee , T., Doobah , T., & Soomary , N. (2014). Assessment of Environmental and Health Risks Associated with Medical Waste Management in Mauritius. APCBEE Procedia, 9, 36–41. https://doi.org/10.1016/j.apcbee.2014.01.007

Camacho, D. M., Collins, K. M., Powers, R. K., Costello, J., & Collins, J. (2018). Next-Generation Machine Learning for Biological Networks. Cell.

Gade, DS, & Aithal, PS (2021). Smart City Waste Management through ICT and IoT-Based Solutions. International Journal of Applied Engineering and Management, 51–65. https://doi.org/10.47992/ijaeml.2581.7000.0092

Gerke, S., Minssen, T., & Cohen, G. (2020). Ethical and legal challenges in artificial intelligence-driven healthcare. Artificial Intelligence in Healthcare, 295–336. https://doi.org/10.1016/B978-0-12-818438-7.00012-5

Grace, C.S., .G., Sreeja, M., & Deepika, M. (2023). Non-Human Intervention Robot in Biomedical Waste Management. International Journal of Health Technology and Innovation, 2(01), 2–4. https://doi.org/10.60142/ijhti.v2i01.75

Hernanto, TS, & Amelia, T. (2024). Omnibus Law Law Enforcement in Indonesia. PT Kaya Ilmu Bermanfaat.

Hörnle, J. (2019). Artificial intelligence in healthcare: A critical analysis of legal and ethical implications. International Journal of Law and Information Technology, 27(2), 142–170.

Huang, J., & Koroteev, D. D. (2021). Artificial intelligence for energy and waste management planning. Sustainable Energy Technology and Assessment, p. 47. https://doi.org/10.1016/j.seta.2021.101426

Ibrahim, J. (2022). Normative Legal Research Theory & Methodology. Bayumedia Publishing.

Ishaq, A., Mohammad, S.J., Bello, A.-AD, Wada, S.A., Adebayo, A., & Jagun, Z.T. (2023). Smart dustbin monitoring using IoT for sustainable biomedical waste management. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-023-30240-1

Jose, R. (2024). Healthcare Waste Management; Its Impact: A Case Study in the Greater Accra Region. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4751230

Karnavel, K., Feroz, A. M., & Fathima, S. S. (2023). Surveillance of Infectious Medical Waste Using IoT. 11(5), 2320–2882.

Kassou , M., Bourekkadi , S., Khoulji , S., Slimani , K., Chikri , H., & Kerkeb , M.L. (2021). Blockchain-based medical waste and water management concept. E3S Web of Conferences, 234. https://doi.org/10.1051/e3sconf/202123400070

Khosla, R., Jha, A., Dua, S., Varmani, S. G., Rajput, N., & Pani, B. (2022). Increased biomedical waste due to COVID-19 in India: Statistical correlation, challenges, and recommendations. Frontiers in Environmental Science, 10. https://doi.org/10.3389/fenvs.2022.1022098

Li, F., Ruijs, N., & Lu, Y. (2023). Ethics & AI: A Systematic Review of Ethical Issues and Related Strategies for Designing with AI in Healthcare. AI (Switzerland), 4(1), 28–53. https://doi.org/10.3390/ai4010003

Maamari , O., Brandam , C., Lteif , R., & Salameh , D. (2015). Levels and patterns of health care waste generation: The case of Lebanon. Waste Management, 43, 550–554. https://doi.org/10.1016/j.wasman.2015.05.005

Marzuki, PM (2019). Legal Research Revised Edition. Kencana.

Maulana, M., Kusnanto, H., & Agus, S. (2017). Solid Waste Processing of Medical Care Father Hazardous and Toxic Material Waste in Private Hospitals in Jogja City. Proceedings of the 5th Urecol, 2 (1) (February), 184–190.

Musa, AE (2014). Assessment of medical, solid waste management in Khartoum state hospitals. Journal of Applied and Industrial Sciences, 2(4), 2328–4609.

Naik, N., Hameed, B., Shetty, D.K., Swain, D., Shah, M., Paul, R., Aggarwal, K., Ibrahim, S., Patil, V., Smriti, K., Shetty, K., Rai, B.P., Chłosta, P., & Somani, B. (2022). Legal and Ethical Considerations in Artificial Intelligence in Healthcare: Who is Responsible? Frontiers in Surgery.

Namen, A. A., Da Costa Brasil, F., Abrunhosa, J. J. G., Abrunhosa, G. G. S., Tarré, R. M., & Marques, F. J. G. (2014). RFID technology for hazardous waste management and tracking. Waste Management and Research, 32, 59–66. https://doi.org/10.1177/0734242X14536463

Pandey, S. (2016). Nosocomial Infection through Hospital Waste. International Journal of Waste Resources, 06(01). https://doi.org/10.4172/2252-5211.1000200

Rahno, D., Roebijoso, J., & Leksono, AS (2015). Management of Solid Medical Waste at Borong Health Center, East Manggarai Regency, East Nusa Tenggara Province. Journal of Sustainable Development and Nature, 6(1), 22–32.

Ratu, WK (2014). Study of Hospital Waste Management and Its Development Prospects in Makassar City. Scientific Scholar.

Rong, G., Mendez, A., Bou Assi, E., Zhao, B., & Sawan, M. (2020). Artificial Intelligence in Healthcare: A Review and Prediction Case Study. Engineering, 6(3), 291– 301. https://doi.org/10.1016/j.eng.2019.08.015

Sengeni, D., Padmapriya, G., Imambi, S.S., Suganthi, D., Suri, A., & Boopathi, S. (2023). Biomedical waste management method using artificial intelligence techniques. Handbook of Research on Safe Disposal Methods of Municipal Solid Wastes for a Sustainable Environment, pp. 306–323. https://doi.org/10.4018/978-1-6684-8117-2.ch022

Singh, A.V., Rosenkranz, D., Ansari, M.H.D., Singh, R., Kanase, A., Singh, S.P., Johnston, B., Tentschert, J., Laux, P., & Luch, A. (2020). Artificial Intelligence and Machine Learning Empower Advanced Biomedical Material Design for Toxicity Prediction. Advanced Intelligent Systems, 2(12). https://doi.org/10.1002/aisy.202000084

Stephina, R., Sushmitha, S., Thanmaya, H.K., Thejaswini, Y.N., & M.S.A. (2020). Innovative Waste Disposal System in Hospitals Using Robots. 3961–3966.

Vollmer, S., Mateen, B. A., Bohner, G., Király, F. J., Ghani, R., Jonsson, P., Cumbers, S., Jonas, A., McAllister, K. S. L., Myles, P., Granger, D., Birse, M., Branson, R., Moons, K. G. M., Collins, G. S., Ioannidis, J. P. A., Holmes, C., & Hemingway, H. (2020). Machine learning and artificial intelligence research for patient benefit: 20 key questions about transparency, replicability, ethics and effectiveness. BMJ, p. 368. https://doi.org/10.1136/bmj.l6927

Zhao, Z., & Niu, M. (2022). Other medical waste treatment and disposal are based on Bluetooth and LoRa Wireless IoT. International Health Review (Online). https://doi.org/10.56226/ihr.v1i2.34