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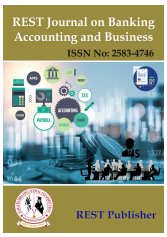

Real Time Tracking Technologies In Biomedical Waste Management: A Systematic Review Using Prisma Guidelines

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ABSTRACT

Biomedical waste (BMW) management has become a critical concern for healthcare institutions due to increasing waste generation and associated environmental and public health risks. Traditional biomedical waste management systems rely heavily on manual documentation and monitoring, which often results in inefficiencies, poor traceability and regulatory compliance challenges. Real-time tracking technologies such as the Internet of Things (IoT), Radio Frequency Identification (RFID), GPS and cloud-based monitoring platforms provide advanced solutions for monitoring biomedical waste from generation to final disposal. This study explores the application of real-time tracking technologies in biomedical waste management, evaluates their effectiveness and highlights their potential benefits in improving safety, efficiency and regulatory compliance. The study adopts a qualitative research methodology through literature review and analysis of existing technological systems used in healthcare waste management. This study followed the PRISMA guidelines for conducting and reporting the systematic review. Findings indicate that real-time tracking systems significantly enhance waste segregation, transportation monitoring and decision-making processes while reducing human error and environmental risks. The paper concludes that integrating digital tracking systems into biomedical waste management frameworks can contribute to safer healthcare environments and sustainable waste management practices. The adoption of digital technologies in biomedical waste management enables healthcare administrators to make data-driven decisions, improve operational efficiency and ensure regulatory compliance through real-time monitoring.

1. INTRODUCTION

Biomedical wastes are wastes that are produced in the process of diagnosis, treatment, or immunization of human beings or animals. This includes sharps, pathological wastes, pharmaceutical wastes and more. If not properly managed, biomedical wastes pose a serious risk of infection, environmental contamination, and occupational health risks to healthcare workers. Across the world, there are a large number of healthcare facilities that are generating a huge amount of biomedical waste on a daily basis. In addition, the rise in the number of hospitals, diagnostic centers, vaccination programs and medical research has led to the rapid increase in the generation of biomedical waste. In the case of global health crises, the amount of biomedical waste is increasing exponentially due to the use of PPE, testing kits and other disposable medical devices. With the increase in healthcare facilities and laboratories around the world, the quantity of biomedical wastes has increased significantly. In fact, it is estimated that every bed in a healthcare facility generates 0.45 to 1.13 kg of biomedical wastes

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every day (Ishaq et al., 2025) Traditionally, the waste management systems in biomedical waste management are based on tracking the waste, using paper-based systems and conducting periodic inspections. However, these systems are not transparent and are error-prone, leading to poor traceability of the waste movement from the time of generation to the time of disposal. The recent technological advancements in the field of IoT devices, RFID tags, GPS tracking and cloud-based monitoring systems have made it possible to track the movement of biomedical waste containers, transportation vehicles and disposal activities in real time (Roy, 2026). Real-time tracking systems are therefore emerging as a critical innovation in modern biomedical waste management. Technological advancements have also provided smart technologies for the efficient management of biomedical waste. Technologies such as real-time tracking systems through IoT sensors, RFID tags, GPS-based transportation tracking systems and cloud-based data platforms provide the means to monitor biomedical waste management processes continuously. The potential of the real-time tracking system in the efficient management of biomedical waste is significant. This research aims to discuss the potential of real-time tracking systems in the efficient management of biomedical waste in the context of modern healthcare waste management practices.

Research Gaps

Current literature lacks real-time monitoring in traditional waste tracking systems and shows limited integration of digital technologies in healthcare waste logistics. These gaps highlight the need for research focusing on real-time digital tracking solutions for biomedical waste management.

Research Objectives

The objectives of this study are:

- To analyze the role of real-time tracking technologies in the management of biomedical waste.
- To examine the technological frameworks such as IoT, RFID and GPS, which are used in waste monitoring systems.
- To assess the benefits of implementing digital tracking systems in healthcare settings.

2. REVIEW OF LITERATURE

The study on IoT-based smart waste monitoring systems showed that sensors placed inside waste bins can monitor waste levels and alert waste collection crews when they have reached maximum capacity (Ishaq et al., 2025). In another study, researchers designed a smart medical waste management system through sensors placed on medical waste trolleys and cloud technology to monitor waste weights, storage and disposal status in real-time, providing dashboards and notifications to medical staff for efficient waste handling (Supriya et al., 2024). Digital systems for tracking biomedical wastes also employ technologies such as barcode technologies, RFID technologies and GPS technologies for transport tracking. These technologies help the authorities to monitor the entire lifecycle of the wastes, starting from their generation to their disposal (Roy, 2026). The wireless technologies like Global System for Mobile Communication (GSM), Low Power Wide Area Network (LPWAN) and cloud computing are used to enhance waste tracking, optimize collection routes to ensure safety and compliance which offer low power consumption, allowing sensors to run for years and long range coverage for large medical facilities or cities. (Akhmetzhanova, et al., 2025) The transportation of biomedical wastes can be tracked with the help of GPS technology. GPS technology can be used with the vehicles that collect biomedical wastes. This technology can ensure that biomedical wastes are transported to appropriate facilities without any unauthorized practices of biomedical waste disposal. This technology can also optimize routes taken by vehicles that transport biomedical wastes and can reduce costs (Rakesh et al., 2024). RFID technology is also used in the tracking of biomedical waste containers during the process of collection and transportation. Using RFID tags on waste containers, healthcare facilities are able to track the movement of waste during the waste management process. A study was conducted on the implementation of an integrated system using the combination of RFID and AI in the management of medical waste, which led to improved efficiency in the waste management process and reduced the mixing of hazardous waste (Ahmed et al., 2025). The system also reduced the time taken in collecting waste by 30%. RFID systems also promote transparency in the waste management process and ensure that the waste is handled and taken to the appropriate facilities. Smart waste bins with sensors have emerged

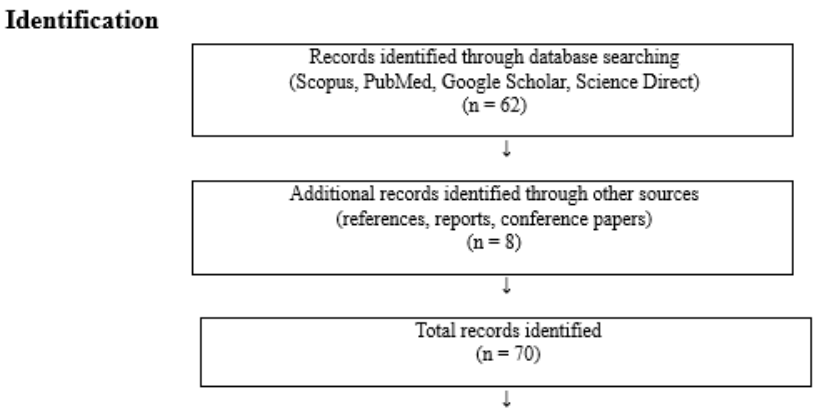
as an important component of modern waste management systems. These waste bins have sensors that monitor waste levels, types and send notifications when they are full. The study on developing an automated system for biomedical waste segregation through sensors and microcontroller showed that it is possible to accurately identify and segregate waste through sensors (Padmapriya et al., 2025). The study showed that it is possible to accurately identify and segregate waste through sensors, which reduces handling hazardous waste, thereby improving safety. Artificial intelligence, along with machine learning, is also being incorporated into real-time waste monitoring systems. AI can predict the patterns of waste generation through the analysis of the generated waste. Recent studies have shown that smart waste management systems can improve the efficiency of the system, reducing the cost of waste management. AI-based systems, along with smart sensors, have the capability to improve the efficiency of the system. AI-based systems have the capacity for predictive analysis for the generation of waste in the healthcare sector (Vasudevan, 2024, Wang, Chen & Zhao, 2023). Effective transportation and collection of biomedical wastes are significant in the efficient management of wastes. In this regard, real-time tracking technologies help healthcare administrators to track the vehicles used in the transportation of wastes. The study conducted to examine the effectiveness of IoT-based smart bin technologies in the efficient management of medical wastes in healthcare facilities showed that real-time tracking technologies could help in the efficient management of medical wastes (Murugan, 2023). This method reduces fuel consumption, operational costs, and environmental impacts. The COVID-19 pandemic has resulted in an increased rate of biomedical waste production globally. According to various studies, the production of healthcare waste has risen significantly due to the increased usage of PPE kits, testing kits and disposable medical equipment during the pandemic. This has resulted in the need for smart waste monitoring technologies and waste management practices (Hossein et al., 2025). The COVID-19 pandemic has resulted in the increased adoption of digital monitoring systems in hospitals. Hospitals and waste management authorities should use cloud platforms to collect, store, and analyze data on biomedical wastes. Cloud platforms help monitor the process of generation, storage, transportation, and disposal of wastes in real-time. Cloud platforms help administrators and regulatory authorities to make decisions and implement policies through the use of centralized dashboards (Zhang, Liu, & Li, 2023).

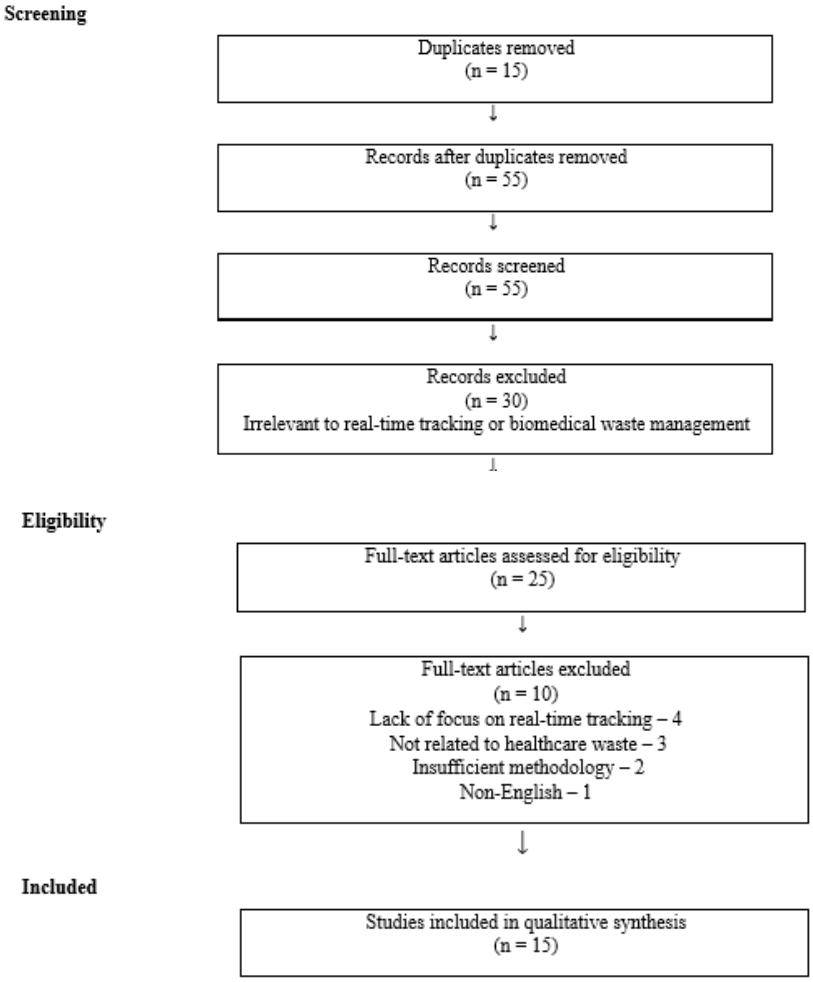
3. RESEARCH METHODOLOGY

The research methodology applied is qualitative research methodology using secondary data sources. The research design applied is a descriptive and analytical research design for the study on technological solutions applied in biomedical waste tracking systems. The data for the research study has been obtained from the Academic Journals, Research Articles, government reports, conference papers, online academic databases. The data for the research study has been analyzed by comparative Analysis of Different Waste Tracking Technologies, Thematic Analysis of Literature and Evaluation of Technological Frameworks Used in Healthcare Waste Management.

PRISMA flow diagram

A Study on Real-time tracking in Biomedical Waste Management (n=15)





Findings & Discussion

Based on the objectives of the study, the findings reveal that i) real-time tracking technologies can improve the traceability of waste from generation to disposal, ii) IoT-based smart bins can improve the monitoring of waste levels to prevent overflows, RFID or barcode-based tagging can improve the accurate identification of biomedical waste containers, GPS-based transportation systems can improve the safe transportation of waste, Cloud-based technology can improve the real-time data visualization for healthcare administrators. iii)These technologies can improve the efficiency of biomedical waste management. This indicates that real-time tracking technologies can change traditional biomedical waste management systems to smart systems. IoT-based monitoring technologies can help track waste containers in real time, which can optimize the schedule of waste collection and minimize the handling of hazardous wastes unnecessarily. In addition, RFID and GPS technologies can offer full traceability of the transportation of wastes to authorized facilities. Real-time data analytics can improve decision-making and resource allocation in the management of health care wastes. However, the implementation of real-time technologies requires investment in infrastructure, staff training, and integration with traditional systems.

Recommendations

Healthcare institutions must employ integrated real-time tracking technologies to enhance the efficiency, transparency and safety of biomedical waste management. Internet of Things technology, usage of RFID tags, GPS technology for transportation monitoring and cloud-based data platforms, can be used to track biomedical waste management from the point of generation to final disposal. This will ensure that healthcare institutions are complying with environmental

regulations. Furthermore, healthcare institutions must invest in staff training to ensure the effective implementation of these technologies. Integration of other emerging technologies such as artificial intelligence will improve the management of biomedical waste. This will be done through the effective allocation of resources in healthcare institutions (Mohamed et al., 2023, Zhang et al., 2023, Wang et al., 2023) also highlighted the importance of staff training to effectively implement these technologies in the health care institutions to prevent infection and contamination of the society to maintain sustainable environment.

Limitations

The study has several limitations. It relies primarily on secondary data sources and there is a limited availability of real-world case studies, particularly from the perspective of developing countries. In addition, technological cost factors were not quantitatively analysed. The research mainly focuses on technological aspects, while policy-related factors were not extensively considered.

Future Research Directions

The future research can include Integration of Artificial Intelligence for predictive waste management, Integration of smart cities with biomedical waste management systems, Development of waste segregation systems using machine learning for efficient waste segregation and classification.

4. CONCLUSION

Biomedical waste management is an important aspect of the operations of health care facilities. However, the existing waste management practices are not transparent, efficient, or traceable. This has been a major source of health and environmental hazards. Technologies such as IoT, RFID, GPS and cloud-based monitoring systems provide a promising solution for the management of biomedical waste. Real-time monitoring is possible using such technologies, which can improve the efficiency of biomedical waste management. The implementation of digital tracking systems has the potential to improve the existing practices of biomedical waste management. From a managerial perspective, the adoption of digital technologies in biomedical waste management can support healthcare administrators in making more informed decisions regarding waste collection, segregation, transportation and disposal. Managers can use real-time data to monitor compliance with waste management regulations, optimize operational processes and reduce the risk of environmental contamination and occupational hazards. Furthermore, integrating digital tracking systems can enhance transparency, improve coordination among different stakeholders and promote sustainable waste management practices within healthcare organizations.

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