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ASSESSING CHALLENGES AND ENABLERS FOR THE AI-ENABLED HEALTHCARE WASTE MANAGEMENT IN INDIA

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Abstract

Healthcare waste management is vital for protecting public health and the environment, yet traditional methods often fall short in handling increasing waste volumes. This study investigates how artificial intelligence can transform Healthcare waste management to enhance efficiency. Through a literature review of 58 papers, 21 challenges and 12 enablers were identified. Using Multi-Criteria Decision-Making Techniques—TOPSIS and DEMATEL—the study prioritized these factors and analysed their interrelationships. Key challenges include inadequate procurement and inventory management, lack of supply chain transparency, and poor logistics optimization. Critical enablers are real-time monitoring, IoT-based sensors, cloud platforms, and data analytics, which support smarter, more sustainable waste handling. The findings highlight that successfully implementing AI requires overcoming technical, organizational, and regulatory barriers while leveraging key technologies. This study provides valuable insights for healthcare administrators and policymakers aiming to modernize Healthcare waste management systems, offering a roadmap for safer, more efficient, and resilient Healthcare waste management through AI integration.

1. INTRODUCTION

The way the environment can maintain itself, how public health can be looked after, and what can be done for it to continue operating effectively depend on efficient waste management in healthcare. Often, traditional practices are unable to cope with the increasing amounts of refuse generated by health care facilities, which may lead to environmental pollution and endanger human lives. This research study looks at how transportation and disposal methods can be improved using artificial intelligence (AI) in transforming healthcare waste management (HCWM). Public health and environmental protection necessitate that HCWM be considered important. All wastes produced by medical activities in hospitals, research institutions, and laboratories are referred to as healthcare waste by the World Health Organization (WHO) (WHO, 2018). To prevent the potential risks of disease spread and pollution of the environment, like infection control, proper health care waste management is a critical requirement (Townend & Cheeseman, 2005).

HCWM is the systematic handling of healthcare waste generated within healthcare facilities for environmentally safe disposal. This comprises different types of wastes such as chemical, pharmaceuticals, sharps, infectious, and pathological wastes (Chartier, 2014) (Figures 1 and 2). Effective procedures are necessary to minimize risks to patient health, healthcare workers' safety, and community members in general.

Figure 1. Solid Healthcare Waste

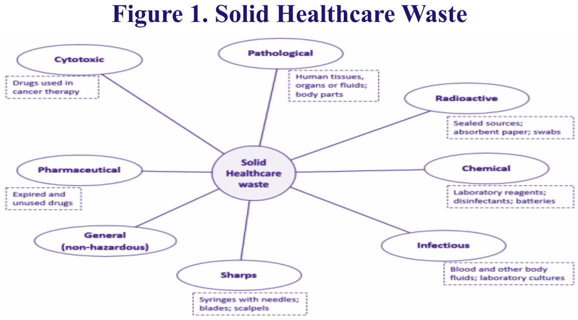
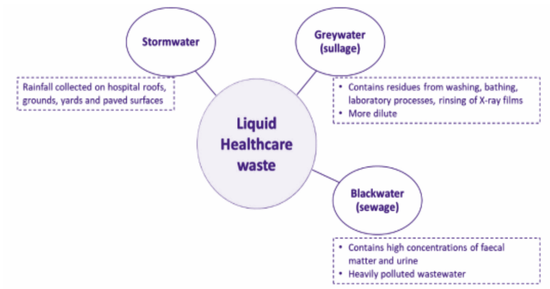


Figure 2. Liquid Healthcare Waste



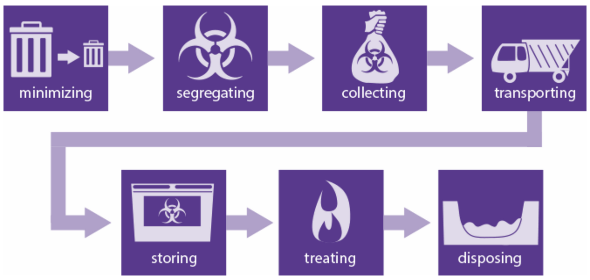
Traditional (HCWM)is collection, segregation, transportation, treatment and disposal. These are manual, labor-intensive, and prone to inefficiencies (Alagöz & Kocasoy, 2008). With the increasing volume of healthcare waste due to population growth and advancement in medical technology (Patwary et al., 2011) waste management systems are facing challenges.

AI is a game-changing technology that can help in waste management in many ways. AI tools that can help in decision making, increase operational efficiency, and reduce cost are machine learning, predictive analytics, and optimization algorithms (Nguyen). AI can offer smart solutions for waste management in the healthcare industry, including automating the waste segregation process, predicting waste generation patterns, and optimizing waste collection routes.

2. LITERATURE REVIEW

HCWM is the methodical processing of waste produced in healthcare organizations. The goal is to guarantee ecologically responsible and safe disposal. This covers a broad spectrum of waste categories. These include chemical, pharmaceutical, sharps, infectious, and pathological waste (Chartier, 2014). Effective management procedures are essential to reduce hazards to the health of patients. It also protects healthcare providers and the general public. HCWM is a multi-step process. It includes collection and transportation (Figure 3) Storage treatment and disposal. Strict regulatory criteria must be followed for each of these procedures to guarantee compliance and safety (Fatta-Kassinos, 2010). To avoid the mixing of hazardous and non-hazardous waste, which can complicate the treatment process and increase disposal costs, proper segregation at source is crucial (Fang et al., 2023). Healthcare personnel's lack of awareness. Limited infrastructure and inadequate training. Logistical problems with waste transportation are the main obstacles in HCWM (Patwary et al., 2011). Furthermore, the growing amount of trash generated by healthcare due to population expansion and technological improvements presents serious difficulties for waste management systems (Mmereki et al., 2017).

Figure 3. Healthcare Waste Management Process



The term AI refers to a wide range of tools and methods. These provide computers the capability to carry out tasks that ordinarily call for human intelligence. AI has the potential to improve waste management through numerous procedures. These include predictive maintenance, Route optimization, Waste sorting (De Luca et al., 2021). Numerous research works have investigated the use of AI in garbage management. In their study (Nguyen) examined how machine learning optimization algorithms work. Predictive analytics may be used by AI to increase waste management efficiency. Similarly, (Lu & Chen, 2022) showed how well AI-powered computer vision systems work. This helps to automate the recycling material sorting process. The implementation of AI in waste management has several benefits, including operational efficiency, cost savings, and better decision making (Figure 5).

AI technologies like computer vision, machine learning and natural language processing are used more and more in waste management to cut costs and increase efficiency. Machine learning algorithms can forecast future waste volumes. This is done by analyzing historical waste generation data (Nguyen) Better planning and resource allocation are made possible. Automation using a Computer vision system can reduce the need for human labor (Lu & Chen, 2022). A few advantages of implementing AI are Enhanced decision making, cutting costs, and increased operational efficiency. Large data sets may be processed in real time by AI-driven systems. This gives rise to insights that can be put into practice. It allows waste management procedures to be dynamically adjusted (Berk & Brown, 2020).

Figure 4. AI in Healthcare Waste Management

2.1 Challenges and Enablers of AI-Enabled Healthcare Waste Management

AI and other cutting-edge technologies cannot be seamlessly integrated into hospital waste management because of a number of obstacles. These difficulties cover a variety of topics. These include worries about data security and privacy. There are also difficulties integrating new systems with the infrastructure that is still in place. Moreover, the low level of digital proficiency among healthcare workers hinders progress. Modernizing hospital waste management is further complicated by interoperability problems, opposition to change, and a lack of precise and trustworthy data. In order to successfully apply AI-enabled solutions, it is crucial to improve the effectiveness, security, and efficiency of these systems. Sustainability of HCWM procedures is imperative. These issues must be resolved. Table 1 shows challenges related to AI-enabled HCWM systems.

Table 1: Challenges Related to the AI-Enabled Healthcare Waste Management System

S. No.	Challenge Name	Description	References
1	Lack of Data Privacy and Security	Protecting data related to patients' hazardous material and ensuring data security measures.	(Kandasamy et al., 2022; Wang et al., 2022)
2	Complexities in integration	Ensuring seamless integration among digital technologies	(Tang et al., 2023)
3	Lack of Data accuracy and quality assurance	Lack of data accuracy, reliability, and completeness, including data entry errors, duplication, and inconsistencies	(Caniato et al., 2016; Lemma et al., 2022)
4	Interoperability with Legacy Systems	Integration of digital tracking systems with traditional approaches can lead to data inefficiencies.	(Ilyas et al., 2020; Zhao et al., 2021)
5	Limited digital skills	Lack of digitally skilled workforce for effective analysis and interpreting waste data for decision-making	(Mohamed et al., 2023)
6	Lack of data integration	Lack of integrating data from various sources and systems to provide a comprehensive view of waste management	(Fitriani et al., 2022; Singh et al., 2022)
7	Lack of scalability of Analytics tools	It ensures that data analytics solutions are scaled to accommodate increasing volumes of waste data as healthcare facilities grow.	(Mazzei & Specchia, 2023; Zamparas et al., 2019)

8	Initial investment cost	Higher investment costs to implement industrial automation and robotics	(Mohamed et al., 2023; Sharma & Sharma, 2019)
9	Resistance to change	Staff resistance to adopting this due to fear of loss of jobs	(Arun Kumar & Wang, 2021; Riek, 2017)
10	Maintenance and repair	Lack of tools for proactive maintenance	(Vichitkraivin & Naenna, 2021)
11	Safety compliance and Lack of Safety focused technologies	It ensures that automated systems are complying with safety standards and regulations to protect workers from hazards.	(Bhubalan et al., 2022; Voudrias, 2024)
12	Workforce redesign	Reengineering existing workflows to align the system with an advanced robotics system	(al-Sulbi et al., 2023)
13	Lack of Digital training and awareness	Lack of training for staff to operate safely alongside automated systems and follow safety protocols	(Mohamed et al., 2023; Wang et al., 2022)
14	Lack of safety documentation	Lack of safety procedures, risk assessments, and incident reporting	(Brindha et al., 2020; Han et al., 2023)
15	Lack of Timely waste collection and disposal	There is a need for efficient scheduling and coordination to prevent waste buildup.	(Fan et al., 2016; Hammond et al., 2023)
16	Lack of Procurement and inventory management	There is a need to ensure an adequate supply of waste containers and equipment.	(Aydın, 2021; Babaee Tirkolaee & Aydın, 2021; Peng et al., 2020)
17	Lack of Transport logistics and route optimization	It deals with reducing transportation costs and carbon footprint through efficient routing.	(Emmanuel & Stringer, 2007; Mahyadin et al., 2013)
18	Lack of Waste disposal facility coordination	It helps to establish contracts and partnerships with appropriate disposal facilities.	(He et al., 2016; Luo & Liao, 2022)
19	Lack of Supply chain transparency	It tracks waste movements and costs for better decision-making.	(Caniato et al., 2016; Mastorakis et al., 2011)
20	Lack of Energy-intensive waste treatment approaches and of energy consumption monitoring	There is a need for efficient scheduling and coordination to prevent waste buildup.	(Ahmad et al., 2021; Le et al., 2022)
21	Lack of Clean and green energy adoption	It deals with reducing transportation costs and carbon footprint through efficient routing.	(Chisholm et al., 2021; Mazzei & Specchia, 2023)

A number of enablers make it easier to implement an AI-enabled HCWM system. These include the use of cloud-based platforms for data storage and accessibility. IoT-based sensors and RFID technology for real-time tracking and monitoring is essential. Enhanced data analytics allow for preventive maintenance and decision-making. Examples of these enablers include effective resource allocation and inventory optimization systems. Blockchain technology is also crucial for safe data storage. By utilizing these enablers, HCWM may be made much more accurate, efficient, and sustainable. This opens the door to new and useful approaches. Table 2 shows enablers related to an AI-enabled HCWM system.

Table 2 Enablers Related to AI-Enabled Healthcare Waste Management System

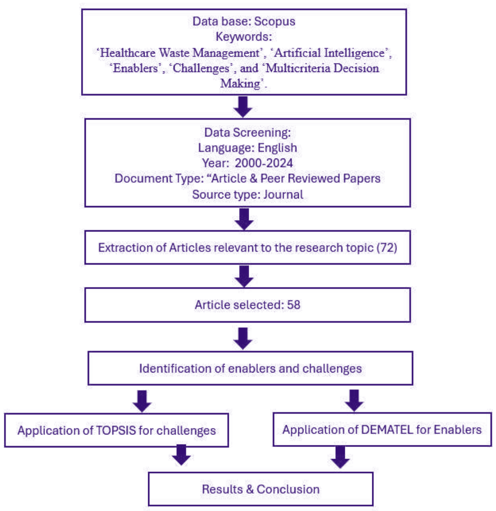
S. No.	Enabler Name	Description	References
1	IoT based sensors and RFID technology adoption	IoT-based sensor and RFID technology adoption helps to provide real-time information on waste levels in the bins and optimize collection and disposal schedules.	(Andeobu et al., 2022; Giakoumakis et al., 2021; Wawale et al., 2022)
2	Waste to energy solutions	Adopting these solutions, i.e., Thermal Depolymerization and anaerobic Digestion of Organic Waste, helps to convert waste into energy, which contributes towards renewable energy production.	(Nolz et al., 2011)

3	Waste Segregation and Categorization Technologies	Digital tools for waste segregation and categorization	(Bujak, 2009; Chen et al., 2022)
4	Cloud-based platforms	It stores the waste management data, enabling efficient collaboration and remote access.	(Rahayu et al., 2021; Sahni et al., 2018)
5	Remote monitoring, Real-time tracking and control	It uses sensors and automation to manage waste collection and disposal	(Akila et al., 2021; Bucătaru et al., 2021; Chisholm et al., 2021)
6	Inventory optimization systems	It ensures efficient management of waste and equipment	(Erdebilli & Devrim-İçtenbaş, 2022)
7	Efficient resource allocation	Better allocation of resources, i.e., staff, containers, and disposal facilities	(Patwary et al., 2011; Perry et al., 2012)
8	Ensuring long-term sustainability	Fostering long-term sustainability initiatives to ensure cost reduction and attract revenues	(Aseweh Abor & Bouwer, 2008)
9	Data analytics and predictive maintenance	Use these approaches to reduce operational disruptions in waste management.	(Mohamed et al., 2023; Wawale et al., 2022)
10	Blockchain technology for data security	Secure patient and waste management data and ensure data privacy	(DRAGAN, 2019)
11	Emergency response system	Digital system for quick responses in waste management emergencies	(Le et al., 2022; Wang et al., 2022)
12	Compliance monitoring and reporting	Use of digital tools for compliance monitoring automation	(Yang et al., 2021; Zhao et al., 2021)

3. METHODOLOGY

The methodology of the research is shown in Figure 3. After screening, about 58 articles were selected for review. The literature study emphasizes the significance of the use of AI technologies in hospital waste management. This allows us to take advantage of enablers and solve current challenges.

Figure 5. Methodology



3.1 Data Collection

A thorough literature analysis was conducted to identify the factors influencing HCWM, and the results revealed 33 important factors—21 challenges and 12 enablers. By removing duplicates and combining related entries into one category, these characteristics were improved. A survey was given to healthcare workers, including physicians, nurses, managers, and support staff, in order to collect data. To transform qualitative data into quantitative form, the survey used a Likert scale (1: Not at all relevant, 2: Slightly relevant, 3: Relevant, 4: Strongly relevant, and 5: Extremely relevant). To guarantee statistical significance and dependability, a minimum of 107 responses were gathered. This method produced a solid dataset for additional examination of the factors found.

3.2 Multi-Criteria Decision-Making in Healthcare Waste Management

HCWM has been using Multi-Criteria Decision-Making (MCDM) methodologies more and more to handle the industry's complex and multifarious problems. These methods support decision-making. They take into account a variety of competing factors. These include cost influence on the environment and operational efficiency. The implementation of several MCDM strategies in HCWM is examined in this review of the literature. A popular MCDM method called Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) assigns a number to each alternative according to how far away it is from the ideal solution. TOPSIS has been used in numerous research. It aims to improve HCWM. In this regard, Beheshtinia et al. (2025) used the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for prioritizing 24 criteria with 'Operation cost', 'Occupational hazards of human resources', and 'The impact of released substances on health'. Similar to this Parashar et al. (2024) have used TOPSIS to evaluate the environmental performance of the medical service supply chain in India, Decision-Making Trial and Evaluation Laboratory (DEMATEL) aids in locating and examining causal connections between various criteria. This approach has been successfully used in HCWM to comprehend relationships between various components. DEMATEL was utilized by Elangovan et al. (2025). They investigated the interplay between diverse obstacles and facilitators in the implementation of AI-driven hospital waste management systems by shedding light on the main causes and obstacles. The study helped people make better decisions.

3.2.1 Fuzzy MCDM Methods

Fuzzy logic is used in fuzzy MCDM techniques to address ambiguity and uncertainty that are part of decision-making. HCWM has seen considerable benefit from the application of fuzzy TOPSIS and fuzzy AHP. For instance, Kharat et al. (2016) evaluated the sustainability of several healthcare waste treatment solutions. They did this in the face of uncertainty using fuzzy AHP. Similar to this. Gupta et al. (2023) used fuzzy TOPSIS to rank waste management plans according to factors like cost, public health risk and environmental impact.

3.2.2 Integrated MCDM Approaches

To take advantage of the advantages of various approaches, integrated approaches that incorporate several MCDM techniques have also been investigated. Govindan et al. (2013) provided a more comprehensive framework for decision making. They did this by combining AHP and TOPSIS to assess and choose the best healthcare waste disposal technique. Furthermore, to evaluate complicated decision issues with interdependent criteria, hybrid models combine DEMATEL with other MCDM techniques. Techniques like ANP (Analytic Network Process) have been employed.

3.3 Application of the TOPSIS Method for Prioritizing Challenges

3.3.1 *Overview of TOPSIS*

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making (MCDM) method developed to identify the best option among a set of alternatives. When decision-makers require a clear preference order, TOPSIS's calculation of the relative proximity to the ideal answer yields a clear ranking of the options. Because TOPSIS is computationally efficient, it can be applied to situations involving a multitude of

criteria and options. While other MCDM techniques just take into account the best or worst case, TOPSIS takes into account both, providing a fairer assessment. It is adaptable to many decision-making situations since it can handle both quantitative and qualitative criteria. It involves the following steps:

Step 1: Create a matrix consisting of M alternatives and N criteria. This matrix is usually called an "evaluation matrix".

Step 2: Normalize evaluation matrix:

$$a_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{M}(a_{ij})^2}} \qquad (1)$$

Step 3: Calculate the weighted normalized decision matrix. (weight=1/107)

$$X_{ij} = a_{ij} * w_j \qquad (2)$$

Step 4: Determine the best and the worst alternative for each criterion.

Step 5: Calculate the Euclidean distance between the target alternative and the best/worst alternative.

$$d_i^b = \sqrt{\sum_{j=1}^{N}(X_{ij} - X_j^b)^2} \qquad (3) \qquad d_i^w = \sqrt{\sum_{j=1}^{N}(X_{ij} - X_j^w)^2} \qquad (4)$$

Step 6: Calculate the Performance Score.

$$S_i = \frac{d_i^w}{d_i^w + d_i^b} \qquad (5)$$

Step 7: Rank alternatives according to the TOPSIS score in descending order.

The ranking of alternatives is shown in Table 3 after the application of TOPSIS with the inputs from the 5 industry experts.

Table 3. Ranking of Challenges using TOPSIS

Challenge	Rank
Lack of Procurement and inventory management	1
Lack of Supply chain transparency	2
Lack of Timely waste collection and disposal	3
Lack of Waste disposal facility coordination	4
Lack of Clean and green energy adoption	5
Limited digital skills	6
Lack of Transport logistics and route optimization	7
Lack of Energy-intensive waste treatment approaches and of energy consumption monitoring	8
Lack of scalability of Analytics tools	9
Lack of data integration	10
Resistance to change	11
Safety compliance and Lack of Safety focused technologies	12
Lack of Data accuracy and quality assurance	13
Interoperability with Legacy Systems	14
Initial investment cost	15
Lack of Digital training and awareness	16
Lack of safety documentation	17
Maintenance and repair	18
Workforce redesign	19
Complexities in integration	20
Lack of Data Privacy and Security	21

3.3.2 Application of DEMETAL Method for Prioritizing Enablers

DEMATEL technique is intended to simulate and assess cause-and-effect correlations between various aspects in complex systems. It facilitates the identification of important issues. Efficient prioritization of them by helping decision-makers visualize the structure of interdependencies. Interactions among elements. Steps in Applying DEMETA are as follows:

Step 1: Construct the Direct-Relation Matrix: Collect experts' opinions to form the direct-relation matrix A=[a_{ij}] where a_ij represents the influence of factor i on factor j.

Step 2: Normalize the Direct-Relation Matrix: Normalize the direct-relation matrix A using the formula:

$$D = \frac{A}{max_i(\sum_{j=1}^{n} a_{ij}} \qquad (1)$$

where D is the normalized direct-relation matrix.

Step 3: Compute the Total-Recommendation Matrix: Calculate the total-relation matrix T using:

$$T = D(I - D)^{-1} \qquad (2)$$

where I is the identity matrix.

Step 4: Determine Prominence and Relation: Calculate the sum of rows and columns to determine the prominence (sum of influences given and received) and relation (difference between influences given and received):

$$r_i = \sum_{j=1}^{n} t_{ij} \qquad (3) \qquad c_j = \sum_{i=1}^{n} t_{ij} \qquad (4)$$

Prominence: $r_i + c_j$

Relation: $r_i - c_j$

Step 5: Cause and Effect Diagram: Plot the r_i+c_j (prominence) on the horizontal axis and r_i-c_j(relation) on the vertical axis to form the cause-and-effect diagram.

Table 4. Ranking of Enablers using DEMETAL

Rank	Enabler name	Cause/effect
1	Remote monitoring, Real-time tracking and control	Cause
2	Ensuring long-term sustainability	Effect
3	Data analytics and predictive maintenance	Cause
4	IoT based sensors and RFID technology adoption	Cause
5	Cloud-based platforms	Cause
6	Efficient resource allocation	Effect
7	Inventory optimization systems	Effect
8	Blockchain technology for data security	Cause
9	Waste Segregation and Categorization Technologies	Effect
10	Compliance monitoring and reporting	Effect
11	Waste to energy solutions	Effect
12	Emergency response system	Effect

4. RESULTS

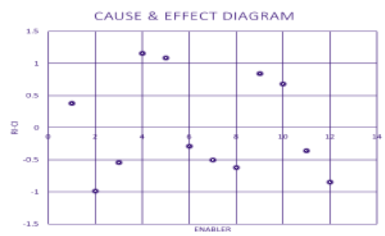
4.1 Ranking of identified challenges

The TOPSIS analysis identifies a number of significant obstacles to the adoption of AI-enabled hospital waste management solutions (Table 3). The absence of inventory and procurement management systems is the biggest obstacle that has been found, highlighting the necessity for efficient and integrated solutions to expedite these procedures. Lack of supply chain transparency, which is essential for maintaining real-time information flow and effective operations, is the second-highest barrier. Using Blockchain technology, which offers a decentralized and transparent ledger, can assist in addressing the issue. Effective coordination between waste disposal facilities and timely collection and disposal of waste was also noted as a significant challenge. These challenges demonstrate the need for real-time tracking systems and Internet of Things-based sensors to improve facility coordination and garbage collection schedule optimization. Another major barrier is the lack of acceptance of clean and green energy, which emphasizes the need for waste-to-energy technology and renewable energy sources to lessen the environmental impact of waste management. Adoption of modern technology is further hindered by a lack of transport logistics, route optimization, and limited digital capabilities. Algorithms for AI-based route planning and training programs can assist in reducing these problems. Adopting energy-efficient technology and real-time monitoring systems is crucial, as evidenced by the absence of energy-intensive waste treatment methods and energy consumption monitoring. There is a need for scalable cloud-based platforms and integrated data management systems that reflect the issues, such as the inability of analytics tools and data integration to scale. Major challenges include safety compliance concerns and resistance to change. It also requires strong leadership. Effective communication is essential in addressing these concerns.Financial obstacles such as the expense of initial investment, maintenance, and repairs underscore the necessity of financing sources. Predictive maintenance programs are also emphasized. Strategic planning and stakeholder participation are needed. Address organizational difficulties like workforce redesign. Integration complications may arise. Finally, the absence of data security and privacy stresses the crucial need for strong security procedures. Encryption technologies are essential to safeguarding private data. In conclusion, a thorough examination of these challenges suggests that a diverse strategy is needed to get beyond these barriers. Stakeholder involvement is key. Strategic planning, infrastructural investment, technical innovation, and ongoing research and development should all be part of this approach. Economic and long-lasting solutions may result from successfully addressing these issues.

4.2 Ranking of the identified enablers

The applications of the DEMATEL technique give the ranking as well as the Cause-and-Effect category of the enablers. Prioritizing enablers for AI-enabled HCWM systems was accomplished using the DEMATEL technique (Table 4). The outcomes show which factors are most important. Facilitating efficient and long-lasting waste management techniques. Real-time tracking, control, and remote monitoring are ranked as top enablers. This emphasizes how crucial it is to have a strong system in place. These systems can monitor waste management operations continually and make modifications in real time to ensure efficiency and safety. This offers knowledge about the advantages of using such techniques to ease the HCWM process. Another important component emphasized is ensuring sustainability over the long run. This highlights how important it is to have procedures and tools that maintain operational and environmental health. Sustainable practices minimize impact on the environment. They guarantee adherence. To legal requirements. Both of these are important for the healthcare industry. The fact that data analytics and predictive maintenance are ranked second indicates how crucial it is to use advanced analytics to analyze large volumes of data. This process helps enhance decision-making and foresee equipment faults. Predictive maintenance lowers maintenance expenses and decreases downtime by resolving problems before they become serious. Another important enabler is the use of RFID technology and IoT-based sensors. These systems enable efficient monitoring and management. Offering comprehensive real-time data on the types, amount, and place of waste. This ensures timely waste collection. Additionally, reduces risks associated with improper disposal. Platforms that are cloud-based score highly. They are flexible and scalable. These systems facilitate sharing and processing. Furthermore, they allow the storage of data. Allowing for thorough analysis as well as efficient operations. They are essential for combining different data sources. It enhances waste management systems' effectiveness. Effective resource management and waste reduction depend on systems for inventory optimization and efficient resource allocation. By ensuring the best possible use of resources, these systems reduce expenses. They also improve operational effectiveness. Waste output in healthcare settings can be unpredictable. Effective resource management is essential. For data security, blockchain technology is very important for maintaining data integrity and privacy. Blockchain ensures regulatory compliance, and it increases stakeholder trust by offering an immutable, secure record of transactions. Technologies for waste segregation and classification make it easier to precisely identify the type of waste. This decreases contamination and increases treatment effectiveness. By ensuring that all actions follow regulations, compliance monitoring and reporting help to lower the risk of non-compliance. This reduces penalties. Waste-to-energy solutions are emphasized. They produce useful energy while also decreasing the amount of waste produced. By turning garbage into a resource, this strategy promotes sustainability. It aligns with environmental objectives. Last to handle waste management-related incidents, the emergency response system is essential. Strong emergency response protocols guarantee prompt resolution of problems. This reduces hazards to public health and safety. The DEMATEL review concludes by highlighting the necessity of using cutting-edge techniques and technologies to improve hospital waste management's sustainability, security, and efficiency. By addressing these facilitators, waste management systems can become more sustainable and efficient while also greatly enhancing operational performance, regulatory compliance, and environmental impact.

Figure 6. Cause-and Effect diagram



The DEMATEL analysis effectively categorized the enablers for AI-enabled HCWM into cause-and-effect enablers, highlighting their interdependencies and importance (Figure 6). Further system advancements are largely driven by these enablers. An efficient waste management system's foundation is real-time data collecting and monitoring, which can only be achieved through the widespread use of RFID technology and Internet of Things-based sensors. Scalable and adaptable solutions for data processing, sharing, and storage are provided by cloud-based platforms, enabling thorough analysis and efficient operations. Overseeing waste management operations and making quick modifications to ensure efficiency and safety requires remote monitoring, real-time tracking, and control. By analyzing enormous volumes of data and foreseeing equipment failures, predictive maintenance and data analytics improve decision-making by cutting down on maintenance expenses and downtime. By guaranteeing data integrity and privacy, blockchain technology for data security fosters stakeholder trust and assures regulatory compliance. These are the results that come about when cause enablers are successfully put into practice. waste-to-energy solutions promote environmental goals by offering a sustainable way to turn waste into energy that can be used. Technologies for waste segregation and classification increase the effectiveness of waste treatment procedures by lowering contamination and improving disposal techniques. Systems for optimizing inventory and resource allocation make sure resources are used wisely. This reduces expenses and boosts operational effectiveness. Adopting procedures and technology that maintain operational and environmental health is necessary. To ensure sustainability in the long run. An emergency response system is essential for waste management incidents. They are handled quickly and effectively while reducing hazards. Compliance monitoring and reporting help lower the risk of non-compliance and the fines that come with it. It does this by ensuring all actions follow regulatory standards.

5. CONCLUSION & LIMITATIONS

This study has been conducted in the Indian HCWM context. The study follows a systematic methodology of review for identifying the challenges and enablers for the AI application in HCWM. The study identified the 21 challenges and 21 enablers that are important for the application of AI in the Indian HCWM context. The study applied the two important MCDM techniques for the analysis. However, the application of the techniques is limited to this level. Further, the study can be extended to the development of a framework for AI-enabled HCWM. Also, further empirical investigations can be extended based on the multiple stakeholders' evaluations based on the findings of this study. A further advanced theory development can be undertaken in the domain of applications of AI in HCWM with a large-scale survey.

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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