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Assessing the challenges to medical waste management during the COVID-19 pandemic: Implications for the environmental sustainability in the emerging economies

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ABSTRACT

Emerging economies are struggling with proper and efficient management of waste due to their constrained resources and weak management. In recent days, this crisis has worsened due to the outbreak of the highly contagious COVID-19 pandemic. To avoid building up stockpiles and contaminating communities with potentially contagious medical waste (MW), and to ensure sustainability in the current and post-COVID-19 era, it is a dire need to develop and implement a safe and efficient medical waste management (MWM) system. This research, thereby, aims to identify, assess, and prioritize the key challenges to efficient and sustainable MWM to mitigate the impacts of the disruptions caused by situations like the pandemic in emerging economies. An integrated approach consisting of the Best-Worst Method (BWM), Interpretive Structural Modeling (ISM), and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) has been proposed to achieve the objectives. Based on the literature review and expert feedback, a total of seventeen challenges were identified and later prioritized by using BWM. The top twelve challenges have been further analyzed using ISM-MICMAC to examine their interrelationships. This study reveals that lack of proper law enforcement and insufficient financial support from investors and the government are two crucial challenges for efficient MWM implementation. The research insights can assist healthcare facility administrators, practitioners, and city managers in identifying the associated challenges and shaping strategic decisions for establishing and managing efficient MWM systems to ensure sustainable development in the post-COVID-19 era.

1. Introduction

In response to technological advancement and modern facilities, there has been a significant spike in the generation of MW in healthcare facilities [1]. The MW is considered the second most hazardous waste in the world, after radiation. Sharps, human body and tissue parts, blood, chemicals, pharmaceutical trash, and medical devices, both hazardous and non-hazardous, radioactive materials contribute to the MW generated in healthcare facilities [2]. However, the generation of MW is not limited to hospitals or health centers only. According to the World Health Organization (WHO), diagnosis, treatment, and immunization of humans usually beings at home, which can also be a potential source of MW. Though hazardous MW accounts for only 10–25% of total waste [3], the inappropriate management of this waste can give rise to several issues, including the spread of contagious diseases, contaminated communities, and many sorts of environmental pollution [4,5].

Since the outbreak of the COVID-19 pandemic, this crisis has endangered the global health system along with diverse impacts on the environment, economy, and society [6,7]. The chance of confirmed COVID-19 cases and deaths has increased profoundly due to the constantly changing genomic sequence of COVID-19 and the greater risk of infection. The amount of hazardous MW generated has been exacerbated dramatically as a result of the measures taken to tackle this highly contagious virus [8,9]. As a consequence, the use of disposable personal protective equipment (PPE) such as gloves, surgical masks, air-purifying respirators, as well as plastic syringes and needles, high-flow nasal cannulas, and breathing circuits, etc. have been increased unexpectedly [10]. In Wuhan, China, the MW increased dramatically from 40 to 50

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tons/day to 247 tons/day on March 1, 2020, due to the COVID-19 outbreak [11].

Again, restrictions on recycling, as an action to prevent the spread of the virus, have given a rise to MW generation [12]. Failure to provide environment-friendly treatment for MW can create an alarming situation [13]. In addition, as SARS-COV-2 can survive up to 7 days on MW like facemasks, gloves, etc., emergency disposal of such waste has been of great concern to both physicians and healthcare professionals to safeguard health and environment [14–16]. Otherwise, MW will be a potential transmission source of COVID-19 and other infections beyond the control [17,18].

This pandemic has posed several challenges to the existing MWM regulations and practices worldwide in terms of changes in generated waste amount and composition, disposal frequency and timing, allocation, and risk of infection [19,20]. Managing waste violating the standard guidelines by the WHO poses serious risks of exponential disease transmission to waste collectors, caregivers, patients, and the community in general [2]. Unfortunately, in many emerging economy countries, MW is collected with municipal solid waste and discharged in open landfills that are easily accessible to both the general population and stray animals [21]. As this waste disposal system is not as robust and well-regulated as in developed nations, it expedites the potential risk of spreading the virus to the community [22,23]. Furthermore, MW incineration is often prioritized over recycling. Since it produces several toxic gases that are undoubtedly detrimental to both human beings and environmental sustainability [24]. Different environmentally sustainable disinfection and disposal techniques such as autoclave, pyrolysis, microwave, chemical disinfection, etc. are yet unavailable in emerging economies [25]. For this reason, many researchers have stressed the MWM as a major concern in the emerging economy context [10,19,25]. To this end, emergency disposal of MW is imperative in a timely, orderly, efficient, and harmless manner to ensure good health, well-being, and environmental sustainability.

Bangladesh, being an emerging economy, has been struggling to manage the increased amount of MW during this pandemic. Due to having a vulnerable management system, Bangladesh was already struggling for safe and effective waste management before this pandemic, but now COVID-19 has worsened the case. The common practice in the country is to discard such waste in an unsupervised landfill without segregating them from regular waste [26]. Furthermore, the lack of cleaners and garbage collectors adequate training, open burning of MW, violation of the WHO's guidelines, etc. have exacerbated the spread of COVID-19 drastically and also hampered the environmental stability across the country [26]. It is, therefore, a dire need to adopt safe waste management strategies as soon as possible to avoid building up a stockpile and contaminating communities with potentially contagious MW. Successful implementation of MWM initiatives is not so easy task in the context of emerging economies, and there exist a lot of challenges that may hinder the adoption process.

Thereby, to successfully promote the adoption and implementation of MWM initiatives in the emerging economy context, we must identify those challenges, and examine the interrelationships among them. Recently, several researchers have pointed out the impact of COVID-19 and relevant challenges regarding successful MWM implementation [10,27,28], but research based on qualitative and quantitative methods integrating challenges to implementing MWM program and environmental sustainability in the context of COVID-19 crisis has not been explored yet. To bridge the above-mentioned research gaps, the following research questions (RQs) are investigated in this study:

RQ1: What are the key challenges to implementing MWM in the context of an emerging economy?
RQ2: How can these challenges be evaluated to overcome the impacts of a pandemic like COVID-19?
RQ3: What are the relationships among the identified challenges?

Exploring the aforementioned RQs, this study proposes an integrated approach aiming at identifying, prioritizing, and depicting the interdependence relationships among the most influential challenges. The integrated approach has been formulated with the help of BWM, and ISM-MICMAC methods. In the first research phase, through reviewing previous literature and relevant materials, a preliminary list of key challenges was developed. In the second phase, by incorporating the expert's responses, the relevancy of the identified challenges was checked. After that, based on their optimal weights obtained by BWM, the key challenges were sorted and prioritized. As the identified challenges usually do not hinder the implementation process independently, they might influence other challenges. Hence, it is necessary to check the causal interactions among them as well. In the fourth phase, this analysis was carried out with the help of the ISM method. MICMAC analysis was also performed later to classify these challenges into four clusters based on their driving and dependence power.

Medical waste disposal and management is a very serious issue for any country, especially during a pandemic. If the medical wastes are not properly handled, it can spread the infection even further. This situation is even more serious in emerging economy countries. Their vulnerable healthcare system and constrained resources can hinder sustainable MWM even to a greater extent. The research is one of the first studies that explore sustainable MWM from an emerging economy context to assist managers and policymakers in crucial decision-making using an integrated BWM, and ISM- MICMAC framework. This research is expected to assist the decision-makers and the policymakers to formulate proper strategies based on the identified challenges, which may offer better protection both to human health and the environment.

The study offers several significant theoretical contributions to the literature as well. The integrated BWM and ISM- MICMAC framework used in this study can be utilized in other relevant sectors and provide future researchers, and practitioners with valuable insights. This integrated approach can be used in the identification and exploration of the relevant factors and thus can aid in the adoption of proactive managerial practices to promote long-term sustainability.

The remainder of this paper is structured as follows: Section 2 conceptualizes the theoretical background of the MWM system, the current scenario, and the key MWM challenges. Section 3 discusses the research methodologies. Section 4 delineates the calculations and results obtained from this research. Section 5, discusses the results and the implications of the research. Finally, Section 6 concludes the study, and discusses some future research directions.

2. Literature review

Following the objectives of the study, the MWM system, and the present scenario, significant challenges to implementing the MWM system and the research gaps and contributions have been highlighted in this section.

2.1. MWM system and present scenario

The MW is defined as contagious, poisonous, or environmentally noxious waste created directly or indirectly by medical facilities during medicinal or precautionary treatment and related operations. Medical waste is divided into three major categories: general waste (which includes fluids, foodstuff, and paper), toxic waste (which is mostly made up of various infectious used items or materials), and sharps (which comprises glass waste and needles) [29]. The safe and effective MWM system is one of the most complicated and demanding concerns, as the world's population grows and demand for medical services grows with it. If treated improperly, the disposal of a new kind of MW (COVID--waste) poses a serious threat to human health and environmental sustainability throughout the world [30].

Historically, pandemics and epidemics have always been known to inflict great distress and misery on the human population. COVID-19 was no different since it set its first footstep in Bangladesh on the 8th of March. According to the Institute of Epidemiology, Disease Control and Research (IEDCR), over 2 million people have been infected with COVID-19 as of April 2022 in Bangladesh [31]. Bangladesh's capital, Dhaka, is the world's most densely inhabited metropolis (28,410 people per square kilometer). The people of Bangladesh, like the rest of the world, had a rough time when COVID-19 struck Bangladesh (163 million people in 147.5 square kilometers) in early March 2020, while the city of Dhaka, Bangladesh was the hotspot of COVID-19 infection [28].

The amount of MW generated by families and healthcare institutions is growing exponentially in Bangladesh. There are around 654 government hospitals and 5055 private hospitals and clinics in the country, with a total of 141,903 beds and an additional 9061 diagnostic center beds, all of which can generate a massive amount of MW [28]. COVID-19-related MW from patients was 658.08 tons in March 2020, as per a newly published paper, and had climbed to 16,164.74 tons in April 2021 [32].

2.2. Key challenges to implementing the MWM system

For the past few years, several research has been carried out to explore the challenges to successful MWM adoption. [30]. for instance, found that failure to segregate wastes at the source mix biodegradable and nonbiodegradable waste components makes the disposal process more complex. Singh et al. (2021) found that failure to segregate waste at source as one of the challenges to managing MW effectively and safely. To improve waste recycling, it is critical to concentrate on waste segregation, which aids in the identification of biodegradable and nonbiodegradable waste components [33]. The inability to rapid collection and transportation of wastes cause longer processing time to deal with [27]. It is imperative to transport waste kept in waste storage depots at frequent intervals to guarantee that garbage bins/containers do not overflow, and waste does not pollute the streets [34]. [19] identified inadequate storage space as a potential challenge for successful MWM implementation. With the rapid growth of MW during this pandemic existing capacity of waste storage is falling short to cope [2]. We live in a throw-away consumerist culture. Some landfills make a significant contribution to environmental dangers due to a lack of adequate on-site waste disposal management [28]. Long-term consequences like leaching, subterranean eutrophication, and the discharge of potentially hazardous gases, for example, continue to be a problem in today's landfills [35]. MW recycling is extremely challenging due to a lack of information and assistance, processing costs, and alternative recycling techniques [70]. Difficulties with the proper recycling of waste material may lead to a huge volume of unprocessed waste [13].

For the literature search, Web of Science, Science direct, and Scopus, Google Scholar databases were used, and the search timeline was from 2016 to 2022. While searching for the initial list of challenges to implementing a successful MWM system, Boolean Operators were used. The challenges were searched in previous literature sources with the help of using some key terms: "challenges to implementing medical waste management system" OR "barriers to manage COVID-19 related medical waste" OR "key challenges/barriers/impediments" AND "challenges affecting successful medical waste management initiatives during COVID-19" OR "ensuring environmental sustainability by medical waste management implementation during COVID-19 pandemic", and so on. Table A1 in the supplementary materials provides the initially identified list of main and sub-challenges to implementing the MWM system for ensuring environmental sustainability in the COVID-19 context.

2.3. Research gaps and contribution

The safe and effective MWM has long been a popular issue among researchers, but the recent pandemic has spurred scholars all around the world to scrutinize numerous aspects of MWM. [32]. focused on identifying the potential ways that accumulate the total MW in Dhaka city during the COVID-19 pandemic. Recently, several researchers have pointed out the impact of COVID-19 and relevant challenges regarding successful MWM implementation in emerging economies perspectives [10,27,28]. However, research based on qualitative and quantitative methods, integrating challenges to implementing MWM and environmental sustainability in the context of the COVID-19 crisis has not been explored yet. Moreover, prior studies have not explained the interrelationships among the challenges to implementing MWM, which is a major research gap.

Therefore, the current research intends to fill these knowledge gaps by exploring the relevant challenges and hierarchically modeling those challenges to demonstrate their relationships explicitly using an integrated BWM and ISM-MICMAC framework. Several recent studies have utilized similar integrated approaches, which are presented in Table 1.

3. Methodology

This research proposes an integrated and intelligent approach to identifying, prioritizing, and depicting the interdependence relationships among the most influential challenges to implementing the MWM program in the emerging economy context. The existing literature involves numerous MCDM techniques for prioritizing factors based on their relative weighting.

Pairwise comparison methods like AHP, Fuzzy AHP, and ANP are often considered tedious and time-consuming and often come with a significant risk of incorporating bias in the responses, making the obtained outputs imprecise [51]. On the other hand, as a vector-based approach, BWM needs fewer pairwise comparisons. Thereby, it produces more consistent comparisons, delivering more precise outcomes, compared to methods like AHP or ANP [52]. BWM requires only two reference points (best and worst) in BWM for comparison with others and has achieved the preference of researchers from different domains. The data achieved from unbiased responses and simple analysis result in more consistent output than any other MCDM technique [53]. This way, BWM reduces the decision-makers burden on the importance of pairwise comparisons of factors under consideration. BWM also minimizes the level of inconsistency or uncertainty in the outcomes [54]. Hence, BWM has been adopted in our study to prioritize the identified challenges for its salient feature of providing reliable decisions efficiently with less ambiguity.

Again, since ISM modeling develops a level-by-level fundamental understanding of complicated interactions among the factors in complex situations in both graphical and textual forms, it is more effective at analyzing the interrelationships among the challenges [55], while MICMAC analysis is appropriate for grouping the factors into clusters that will clearly define the factors that are driven and those that are driven by Ref. [38]. Thereby, ISM-MICMAC has been utilized to analyze the interrelationships among the challenges in this study. The key steps of this study are shown in Fig. 1.

3.1. Sampling and data collection

The research consists of collecting data in three phases. At the beginning of data collection, a Google questionnaire form with the identified challenges from the literature was prepared and circulated to the experts for identifying the key challenges to MWM in the context of Bangladesh as an emerging economy. The questionnaire was set in yes-no format to ask the experts to provide their opinion on whether the challenges affect MWM or not (Table A1, Appendix-A). The respondents were chosen from different organizations like hospitals, diagnostic centers, city corporations, academicians, etc. based on the convenience to reach them. The inclusion criteria for expert selection included vast experience in hospital administration, waste management, or academia, more than 10 years of working experience, and knowledge of the MWM system. The purposive sampling technique [56] was used to select the

Table 1
Recent works using similar integrated approaches.

Literature	*Objective(s)*	*Focused area*	*Findings*	*Tools*
[36]	Investigating what drives people to buy electric cars in developing countries.	Electric vehicle industry	Vehicle performance and reliability were identified to be the most significant driver	Principal Component Analysis (PCA), ISM-MICMAC
[37]	Simulating and evaluating Green Lean Six Sigma success elements for the Indian healthcare facilities.	Healthcare industry	Management's commitment and financial availability were the most critical success factors	ISM-MICMAC
[38]	Figuring out what makes an island nation a competitive sports tourist location	Tourism industry	Government support and Destination political stability were found to be the major factors	Fuzzy Delphi, ISM-MICMAC
[39]	Modeling the drivers of solar energy development in an emerging Economy	The solar and renewable energy sector	The favorable geographical location in terms of solar Irradiation was identified to be the most important driver	BWM, ISM-MICMAC
[40]	Evaluating the factors for sustainable supplier selection in the steel industry	Steel industry	Reputation and the supplier position was found to be the most crucial factor	BWM, TOPSIS, ISM-MICMAC
[41]	Analyzing operational Hazards in heavy fuel oil-based power plants	Heavy Fuel Oil-based power plants	Standard Operating Procedure (SOP) and Training were identified as the two most critical hazards	FAHP, FTOPSIS, ISM-MICMAC
[42]	Analyzing barriers to the sustainable supply chain in the apparel & textile sector	Apparel and textiles sector	Poor supplier performance was determined as the most significant barrier	ISM, Fuzzy MICMAC, DEMATEL
[43]	Mapping interactions among green innovations barriers in the manufacturing industry	Manufacturing industry	The lack of enforceable laws regarding returned and recycled products was determined to be the major barrier	ISM-MICMAC
[44]	Assessing the barriers to the adoption of electric vehicles in India	Electric vehicle industry	Shortage of charging stations was found as the most crucial barrier	BWM, ISM-MICMAC
[45]	Constructing a model for agricultural entrepreneurs' propensity to adopt sustainable farming	Agriculture sector	Policies related to agriculture and training and development programs were identified to be the most crucial factor	ISM-MICMAC

Table 2
List of challenges to MWM, after expert validation.

Major Challenges	Sub-challenges	References
Operational challenges (OC)	Failure to segregate wastes at source (OC1)	[30]; Singh et al., 2021)
	Inability to rapid collection and transportation of wastes (OC2)	[34]
	Inadequate storage capacity (OC3)	[2,19]
	Lack of safe disposal site (OC4)	[70]
	Difficulty in recycling (OC5)	[13,70]
Technological challenges (TC)	Unavailability of disinfection and disposal technology (TC1)	[34,46]
	No waste tracking system (TC2)	[47]
	Scarcity of networking and information sharing (TC3)	[33,48]
Government challenges (GC)	Lack of proper law enforcement (GC1)	[48,49]
	Inadequate financial support from investors and the government (GC2)	[47,49]
	Centralized waste management (GC3)	[7]
	No involvement of informal bodies (GC4)	[50]
Managerial challenges (MC)	Lack of knowledge and awareness of operating personnel (MC1)	[28]
	Lack of training (MC2)	(Singh et al., 2021)
	Insufficient skilled manpower (MC3)	[27,28]
	Lack of organizational commitment (MC4)	[27]
	Lack of top management involvement (MC5)	[32]

experts, particularly those who are knowledgeable, informative, and experienced, and can contribute considerably to the study. The willingness and commitment of the experts were reassured [57,58] before collecting the research data. The information was gathered for several weeks. Though the Google questionnaire form link was sent to 20 experts via email, the complete feedback from only 8 experts (40% response rate) was achieved after several emails and phone call reminders. Purposive sampling is a non-probabilistic technique and samples are chosen based on the researcher's opinion rather than a random selection process [59]. As a result, qualitative experts' feedback is gathered which ultimately leads to better results. The initially identified challenges (see Table A1 in the supplementary materials) were placed to the expert for their validation and asked to add new challenges to the list, if necessary. The experts removed three sub-challenges, "Inadequate decision support system (TC4)", "Higher population density (MC6)", and "Reluctance to adopt standard practice (MC7)" and no new challenges were introduced. With the remaining seventeen challenges, as shown in Table 1, we proceed with the BWM survey design.

In the second phase, data were collected to identify and prioritize the most influential challenges to implementing the MWM system using BWM. Here, the identified challenges were sent to eight experts for their opinions. In addition [60], argued that data should be from four to ten respondents to ensure the credibility of data used in the BWM method. Table 3 shows the background of the survey respondents. The respondents used a 9-point Likert scale ranging from 1 (very weakly influential) to 9 (very highly influential) to identify the best (most influential) and worst (least influential) challenge from the list of challenges provided. Subsequently, comparison vectors for both major challenges and sub-challenges were developed from the experts' feedback.

In the third stage, the authors applied the ISM-MICMAC approach to investigate the contextual relations among the key challenges and make clusters for ensuring environmental sustainability. To do so, we collected expert's responses having professional experience of more than 20 years and vast knowledge of sustainability and MWM. The details of BWM and ISM-MICMAC methods are explained in the following sub-sections.

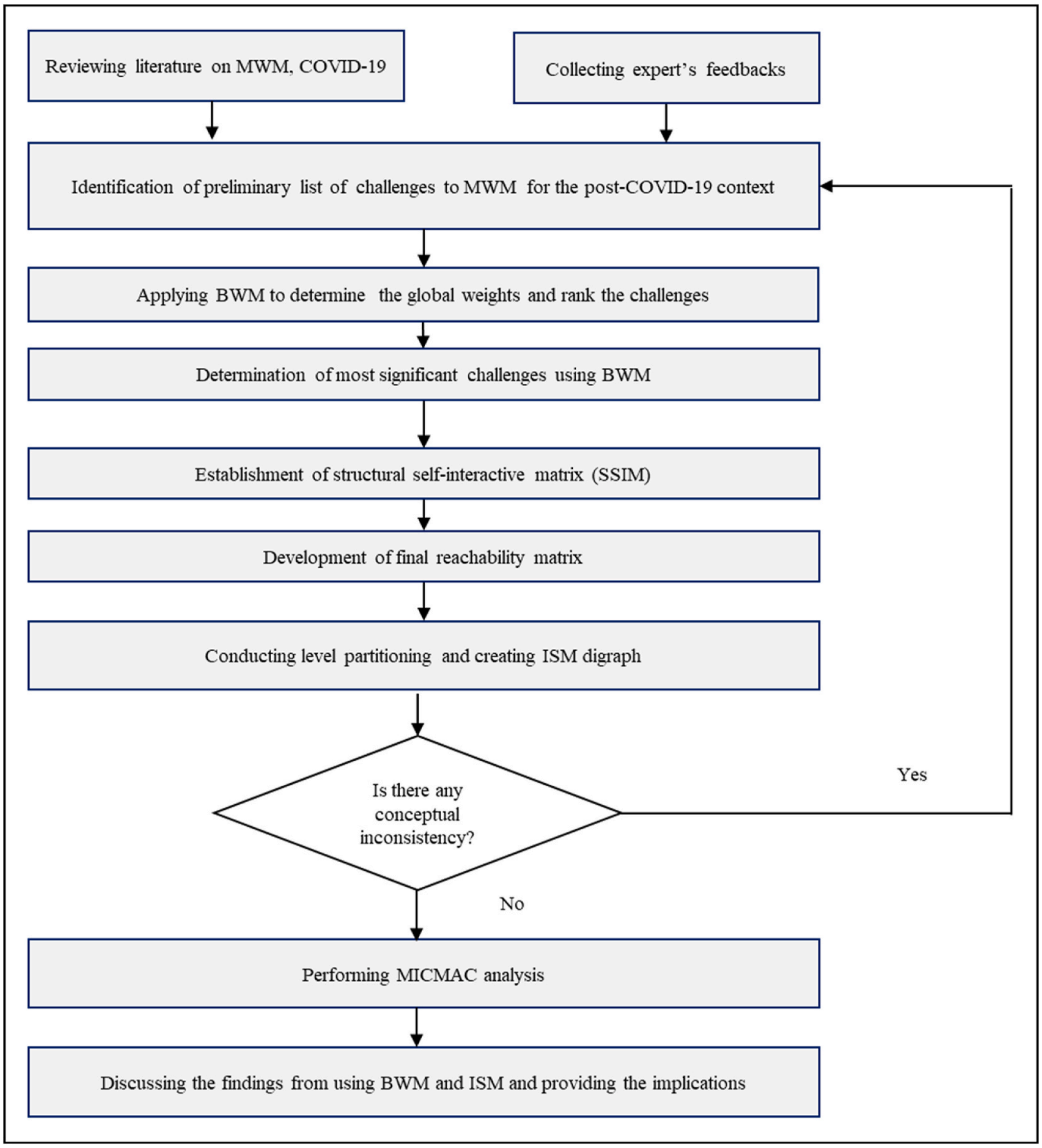

Fig. 1. Proposed research framework.

3.2. Best-Worst Method (BWM)

The BWM formulated by Professor Jafar Razaei in 2015, is one of the recent and exclusive MCDM techniques [61]. This tool has drawn much attention from researchers and practitioners for solving complex real-world problems [39,62]; Vafadarnikjoo et al., 2020). In this method, before preparing pair-wise comparison matrices, the best and worst criteria are identified which gives the decision-makers a clear view of the importance of evaluation. Another important feature is that this method works with small sample data and mitigates the possibility of biases by experts' opinions. These advantages lead us to select this tool for determining the optimal weights and ranking the key challenges to implementing the MWM system successfully. The stepwise procedure of BWM [63] is described in Appendix B of supplementary materials.

3.3. Interpretive Structural Modeling (ISM)

Interpretive Structural Modeling (ISM) is an analytical and directional structuring technique that offers a systematic approach to dealing with complicated real-world problems [64]. It provides a graphic depiction of the scenario (or problem) that may be utilized to get fresh insights and come up with new alternative solutions. In 1974, Warfield invented it to explore complicated socioeconomic relationships [65]. This technique is 'interpretive,' in that expert will interpret parts of a complex system and their interconnection through conversation [41, 66]. Utilizing graph theory and matrix algebra, ISM represents the visual model. Due to its simplistic concept and easy computational steps, it has gained much popularity and is widely used in various areas. The key steps of the ISM methodology are described in Appendix C of supplementary materials.

3.4. Cross-impact matrix multiplication applied to classification analysis

MICMAC involves a direct classification study of system variables, in which the link between variables is directly obtained from the recognition of specialists and stakeholders. This technique is usually applied to calculate the driving power and dependence power of the factors under analysis, which is calculated by adding the entries of interaction possibilities in its row and column, respectively. Based on their dependency and driving power levels, which are shown on the horizontal and vertical axes, variables are mapped onto a two-dimensional grid grouping into four clusters [64]. In Cluster 1 (Autonomous cluster),

Table 3
Background of survey participants.

Experts	Type of the Organization	Designation	Experience	Expertise
Expert-1 (E1)	City Corporation	Chairman of the Waste Management Committee	More than 10 years	Waste Management
Expert-2 (E2)	Medical College	Senior Assistant Surgeon	10 Years	MWM
Expert-3 (E3)	University	Professor	More than15 Years	Waste Management, and sustainability
Expert-4 (E4)	Medical College	Civil Surgeon	More than15 Years	MWM
Expert-5 (E5)	City Corporation	Vise Chairman of the Waste Management Committee	10 Years	Waste Management
Expert-6 (E6)	Diagnostic Center	Manager	More than 10 years	MWM
Expert-7 (E7)	Medical College	Chief Administrative Officer	15 Years	MWM
Expert-8 (E8)	Medical College	Administrative Officer	More than 10 years	MWM

challenges have both poor driving and dependence power, and they play a neutral role in the MWM implementation process. In Cluster 2 (Independent cluster), challenges possess good driving power but poor dependence power. Cluster 3 (Dependent cluster) is the opposite of the independent cluster. Finally, in Cluster 4 (Linkage cluster), challenges have both strong driving and strong dependence power. However, these challenges are relatively unstable, and any change to these challenges has a feedback effect on the other related challenges.

4. Results

This section presents the findings from the implementation of the proposed framework to identify and evaluate the key challenges to implementing the MWM system that may hinder the establishment of sustainable waste management practices and ensuring environmental sustainability in the context of the emerging economy: of Bangladesh. For performing BWM, the set of main and sub-challenges was considered as the alternatives. Then, based on the responses of eight experts including academic experts, city corporations, medical professionals, etc., the most influential (best) and the least influential main challenge (worst one) were identified (Appendix D, Table D1). Then, two types of vectors - *"Best-to-Others (BO)"* and *"Others-to-Worst (OW)"* vectors were formed collecting responses from the experts. Similar steps were followed for sub-challenges to MWM implementation. The sample formats of these vectors from Expert-1(E1) are presented in Appendix D, Table D2-D5. Using these vectors, the weights of the main challenges and sub-challenges were calculated from BWM analysis. Later, the global weights of each sub-challenge are obtained by multiplying the main challenge's weights and the respective weight of sub-challenges (Appendix D, Table D6). In this study, eight sets of weights for each main challenge and sub-challenge were obtained based on eight expert responses. Using the average technique, the overall weights and aggregated global weights for all challenges were calculated. Table 4 shows the weights and ranks of the key challenges to implementing the MWM system.

From the 17 challenges ranked in Table 3, the 12 most significant challenges, whose weights were greater than 0.0250 [39] were

Table 4
Aggregated final weights of challenges using BWM.

Main Challenges	Weight	Sub-challenges	Global Weight	Rank
Operational (OC)	0.2685	OC1	0.0740	5
		OC2	0.0906	3
		OC3	0.0217	15
		OC4	0.0250	13
		OC5	0.0572	9
Technological (TC)	0.1551	TC1	0.0698	6
		TC2	0.0227	14
		TC3	0.0626	8
Government (GC)	0.3306	GC1	0.1149	2
		GC2	0.1230	1
		GC3	0.0556	10
		GC4	0.0370	12
Managerial (MC)	0.2458	MC1	0.0890	4
		MC2	0.0482	11
		MC3	0.0178	17
		MC4	0.0213	16
		MC5	0.0696	7

*The abbreviations are described in Table 2.

considered for further analysis using ISM and MICMAC methods. The five least significant challenges – "Lack of safe disposal site (OC4)", "No waste tracking system (TC2)", "Inadequate storage capacity (OC3)", "Lack of organizational commitment (MC5)", and "Insufficient skilled manpower (MC4)" were excluded in the subsequent ISM-MICMAC analysis.

Now, the interactions and the hierarchical position of challenges were explained with the help of ISM analysis. Following the procedures of ISM analysis, based on the expert's response, a structural self-interactive matrix (SSIM) was constructed. The SSIM for the key challenges to implementing the MWM program is shown in Table 5.

After developing the SSIM, an initial reachability matrix was constructed from the SSIM by replacing V, A, X, and O symbols into binary numbers (1s and 0s). In the next step, by checking transitivity issues, the final reachability matrix was formulated (Appendix E). Then, level partitioning was performed to determine different levels of the key challenges to MWM implementation. To do so, the reachability, antecedent, and interaction set of each challenge were measured. From the three sets, the final level portioning was done. As shown in Table 6, the top-ranked 12 challenges can be divided into six levels.

The final ISM-based model of the challenges is presented in Fig. 2. This digraph helps to represent the hierarchical position among the challenges situated at different levels, forming links with other challenges. Fig. 2 shows that level 1 contains "Centralized waste management (GC3)", "No involvement of informal bodies (GC4)" and "Lack of training (MC2)". Level 2 consists of "Unavailability of disinfection and disposal technology (TC1)" and "Scarcity of networking and information sharing (TC3)" while "Difficulty in recycling (OC5)" and "Lack of top management involvement (MC5)" are located at level 3. "Failure to segregate wastes at source (OC1)" is the lone member of level 4. "Inability to rapid collection and transportation of wastes (OC2)" and "Lack of knowledge and awareness of operating personnel (MC1)" are situated at level 5. Finally, the bottommost level is occupied by a "Lack of proper law enforcement (GC1)" and "Inadequate financial support from investors and government (GC2)".

Now, for performing MICMAC analysis, the driving and dependence power of all challenges were calculated from the final reachability matrix. In this study, the MICMAC analysis clusters the challenges into four groups, which are shown in Fig. 3. From Fig. 3 we can see that "Lack of proper law enforcement (GC1)", "Inadequate financial support from investors and government (GC2)", "Failure to segregate wastes at source (OC1)", "Inability to rapid collection and transportation of wastes (OC2)" & "Lack of knowledge and awareness of operating personnel (MC1)" are in the independent variable cluster (IV) with high driving and low dependence power. "Difficulty in recycling (OC5)" and "Lack of top management involvement (MC5)" are in the linkage variable cluster

Table 5
Development of structural self-interactive matrix (SSIM).

Challenges	OC1	OC2	OC5	TC1	TC3	GC1	GC2	GC3	GC4	MC1	MC2	MC5
OC1		A	V	O	O	A	O	O	V	A	O	V
OC2			V	O	O	O	A	V	V	X	O	O
OC5				O	O	O	A	O	O	A	O	X
TC1					X	O	A	V	V	O	O	O
TC3						O	O	O	O	O	O	A
GC1							X	V	O	O	O	O
GC2								V	V	V	V	O
GC3									O	O	O	A
GC4										O	O	A
MC1											V	V
MC2												A
MC5												

*The abbreviations are described in Table 2.

Table 6
Final level portioning of the final reachability matrix.

Challenges	Reachability set	Antecedent set	Intersection set	Level
OC1	OC1	OC1, OC2, GC1, GC2, MC1	OC1	4
OC2	OC1, MC1	OC2, GC1, GC2, MC1	OC2, MC1	5
OC5	OC5, MC5	OC1, OC2, OC5, GC1, GC2, MC1, MC5	OC5, MC5	3
TC1	TC1, TC3	OC1, OC2, OC5, TC1, TC3, GC1, GC2, MC1, MC5	TC1, TC3	2
TC3	TC1, TC3	OC1, OC2, OC5, TC1, TC3, GC1, GC2, MC1, MC5	TC1, TC3	2
GC1	GC1, GC2	GC1, GC2	GC1, GC2	6
GC2	GC1, GC2	GC1, GC2	GC1, GC2	6
GC3	GC3	OC1, OC2, OC5, TC1, TC3, GC1, GC2, GC3, MC1, MC5	GC3	1
GC4	GC4	OC1, OC2, OC5, TC1, TC3, GC1, GC2, GC4, MC1, MC5	GC4	1

*The abbreviations are described in Table 2.

(III). "Unavailability of disinfection and disposal technology (TC1)", "Scarcity of networking and information sharing (TC3)", "Centralized waste management (GC3)", "No involvement of informal bodies (GC4)" and "Lack of training (MC2)" are in the dependent variable cluster (II). There is no variable in the autonomous variable cluster (I).

5. Discussions

From the BWM result, as shown in Table 4, it is apparent that the "Government challenges (GC)" are prevailing over other main challenges. Taking the current scenario of MWM into account, without the government's policies, support and eagerness, it is nearly impossible to initiate sustainable MWM in an emerging economy context [49]. After that, the operational and managerial challenges have to be overcome during this pandemic to extract the social and environmental benefits. As the application of technology has yet remained far-fetched in our health system, technological challenges are seemed to be less superior to the aforementioned ones. Table 4 contains the weighting of the main challenges where GC has been found the most significant followed by OC, MC, and TC.

As depicted in Table 4, "Inadequate financial support from investors and government (GC2)" is the most influential sub-challenge to a sustainable MWM system. The pandemic has changed the characteristic of MW from the point of view of their formation and treatment. Their management demands the use of particular technology to benefit the health and environment. Installation, operations, and maintenance of the MWM facility will need a significant investment, which the health organization now lacks [47]. Government should declare financial subsidies in the form of tax benefits to encourage and develop MWM [67]. "Lack of proper law enforcement (GC1)" is the second most crucial sub-challenge identified in the current research. Though there are laws and regulations regarding MWM, it is hardly found any institutions in Bangladesh follow the proper ways to deal with MW. No regulatory authority is found during this pandemic to audit and monitor periodically the status of MW. However, it is strictly prescribed to formulate separate policies during this pandemic and promote research & development (R&D) to implement effective MWM [68]. Being highly infectious, COVID-19-contaminated MW can transmit the virus more rapidly in comparison to normal conditions. The spread of the virus can be obstructed provided the MW is collected and transported to a particular place to dispose of as early as possible. For this reason, the "Inability to rapid collection and transportation of wastes (OC2)" is found as the third significant challenge to overcome. [34]. have also emphasized immediate accumulation and carrying away to the disposal site after disinfection or on-site disinfection. "Lack of knowledge and awareness of operating personnel (MC1)" is the fourth influential challenge to take into account while operations or activities are to be performed with MW. Unawareness can cause the worker infected while working with MW and infect others exponentially. [27]. has also acknowledged operators to take necessary precautions and have awareness of MWM. It is a common practice in our country to collect municipal waste and MW together. If done so during this pandemic, the MW will be a potential transmission source of COVID-19 affecting human life. That is why "Failure to segregate wastes at source (OC1)" appears to be the fifth important challenge. The inability to separate MW will spoil the objectives of subsequent activities. Singh et al. (2021) also deliberated to collect the MW in different colored bins based on their types to facilitate further activities.

"Unavailability of disinfection and disposal technology (TC1)" is viewed as the sixth crucial factor. Incineration or land filling is followed by most of the organizations in Bangladesh which are heavily deteriorating the environment transmitting diseases [27]. No adoption of disinfection and disposal technology may also cause the authorities to do so. Therefore, it is imperative to use advanced disposal and disinfection technology during the pandemic to protect both humans and the environment. As these technologies may not be available in our country, it is required to import and install them which is a managerial and also strategic decision. It necessitates having the interest and involvement of top management that the organizations are lacking in this regard. Therefore, "Lack of top management involvement (MC5)" is figured out as the seventh most important sub-challenge. Communication, networking, and information sharing are obligatory in the recent era for effective management of activities. Information regarding the amount of waste, place of origin, vehicle and staff allocation, route planning, etc. are not communicated properly, MWM in the COVID-19 pandemic will be beyond control. Networking and information sharing a dire need in

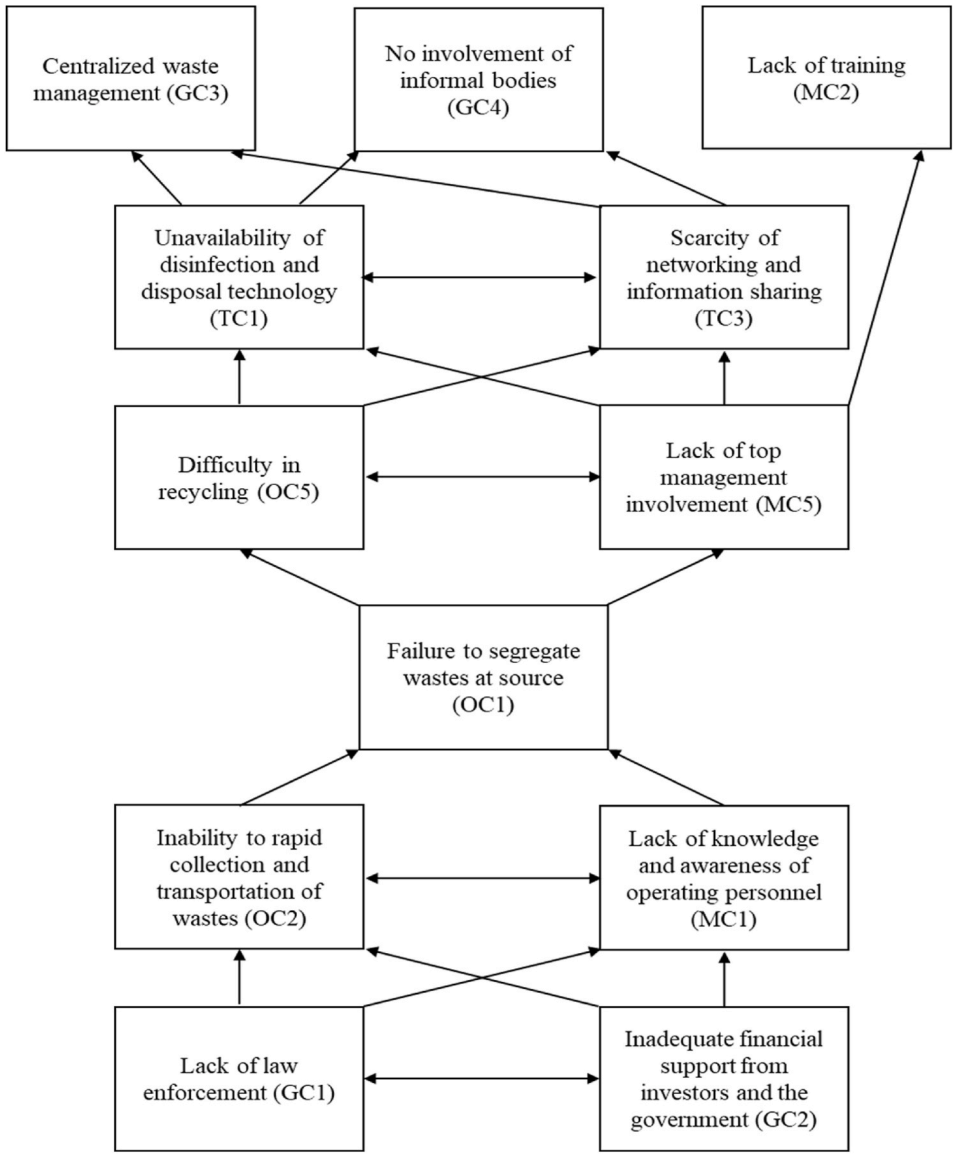

Fig. 2. ISM digraph of the sub-challenges to implementing the MWM program.

our health facility system and this study found that "Scarcity of Networking and information sharing (TC3)" has been found as another significant challenge to deal with. MW generation has risen alarmingly during this pandemic concerning the authorities on how to manage them. It is also risky to recycle the MW and further use them. However, researchers have regarded it prudent to go for recycling after utilizing the advanced disinfection technology [13]. "Difficulty in recycling (OC5)" is another significant challenge to solve to manage this huge amount of MW.

The "Centralized Waste Management (GC3)" system impedes the time and effort required to decide on MWM as practiced in emerging economies. Again, the responsibility only stays with the municipal authority to take care of MW in the current scenario. Decentralizing this waste management system will accelerate the collection, segregation, and disposal of waste during this pandemic in the most effective manner. "Centralized Waste Management (GC3)", therefore, occupies the tenth position in the critical challenge list of our research. [69]. have also advocated this practice as an impediment in the way of MWM. The unusual case of COVID-19 has put the frontlines at threat of being affected by the virus. They must be trained up to date before handling this infectious MW. [27]. have stated labors with no professional training work with MW. "Lack of training (MC2)" is the eleventh challenge identified in the research. As there are numerous numbers of hospitals in Bangladesh, government alone can't track and manage the waste successfully. Informal organizations under the regulation and guidance of the government can help manage MW in a better way. "No Involvement of informal bodies (GC4)" has worsened the situation. [7]. suggested indulging the informal organizations in MWM giving proper incentives and financial benefits.

The current research emphasizes evaluating the challenges that will assist in developing proper strategies for implementing successful MWM in the context of COVID-19 in an emerging economy, Bangladesh. Fig. 2 illustrates that "Inadequate financial support from investors and the government (GC2)" and "Lack of proper law enforcement (GC1)" have possessed the greatest impact on other challenges in implementing a successful MWM system. These two challenges, as shown in Fig. 3, are also in Cluster IV of independent variables, with strong driving power and weak dependency power, indicating that they will influence other challenges. [49]. identified that majority of advancements in MWM have relied on external funding, which is unstable and unsustainable in the long run. Effective MWM will be impossible to accomplish if investors and the government do not provide adequate financial support.

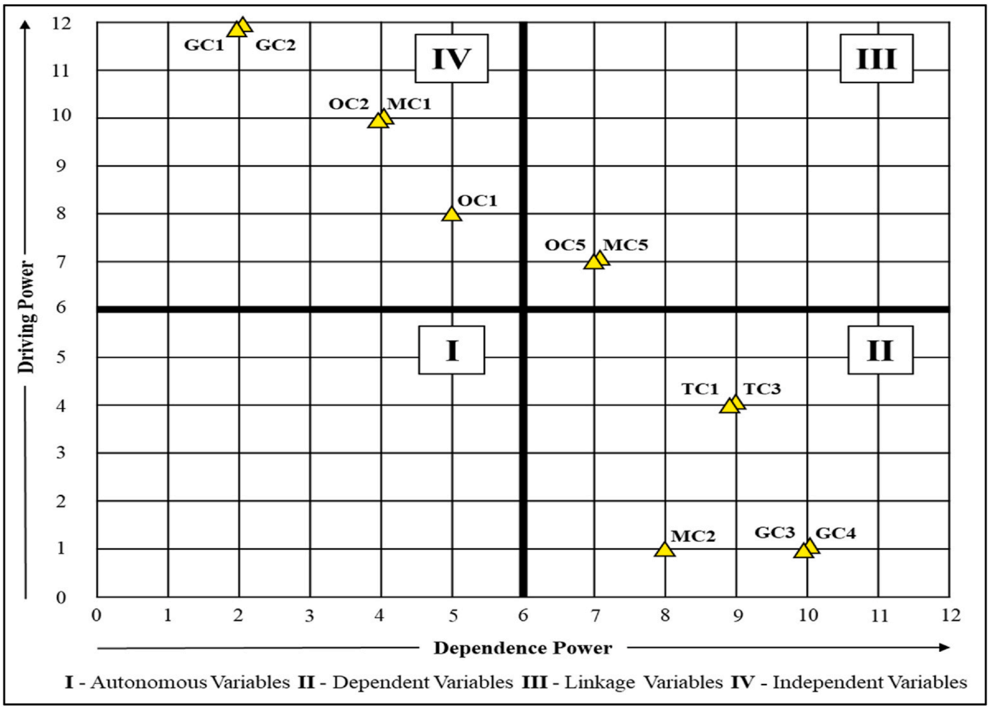

Fig. 3. Clustering of challenges to MWM through MICMAC analysis.

[47]. emphasized on providing effective law enforcement and encouraging government agencies to follow the law will improve the effective monitoring of MW.

The abovementioned two challenges will exert a direct impact on the "Inability to rapid collection and transportation of wastes (OC2)" and "Lack of knowledge and awareness of operating personnel (MC1)" which are positioned on level 5. These two challenges are also detected in cluster-IV of the independent variable (Fig. 3) along with "Failure to segregate wastes at source (OC1)". These challenges possess higher driving power and moderate dependence power. [27]. noted that it is critical to transfer MW stored in waste storage depots at regular intervals to prevent waste bins/containers from overflowing and waste from polluting the streets. [28]. argued that a lack of knowledge and understanding of operational personnel on MWM is the fundamental cause of present human health impairment and ecosystem quality deterioration. To deal with the current scenario regarding MWM, sufficient relevant knowledge and awareness must be improved. [30]. highlighted the need of concentrating on waste segregation, which makes it quicker to distinguish between different types of waste components and aids in the successful implementation of MWM.

Level 3 includes "Difficulty in recycling (OC5)" and "Lack of top management engagement (MC5)". These challenges are part of the MICMAC analysis cluster-III of linkage variables, implying that they are highly unsustainable and that any change in these factors would have an impact on others as well as a reversible causal relationship with themselves. Fan et al. (2021) mentioned that difficulties in recycling will lead to an increased volume of untreated MW, which will possess an adverse influence on MWM. [32]. emphasized the need for top management involvement in MWM implementation since top management is responsible for formulating guidelines, standards, and organizational priorities, as well as providing encouragement and leadership for effective MWM.

"Unavailability of disinfection and disposal technology (TC1)", and "Scarcity of networking and information sharing (TC3)" are placed on level 2 of the ISM model. These two challenges have a driving power of 4 and a dependency power of 9, classifying them as dependent variables in cluster II. For overcoming technological challenges [34], emphasized the importance of efficient MWM disinfection and disposal techniques, worrying that these wastes would eventually end up in wastewater and the environment, exposing the population to danger of infection while [48] addressed the need of having a robust networking and information transfer infrastructure, as a lack of such options will result in poor MWM.

All three challenges including "Centralized waste management (GC3)", "No involvement of informal bodies (GC4)", and "Lack of training (MC2)" are positioned on level 1. All these challenges are present in MICMAC analysis' cluster II of dependent variables, which has weak driving and strong dependence power. These variables have low driving power but high dependability, implying a bad consequence for decision-makers. It's difficult to estimate the amount of MW created across the country during this pandemic because of "Centralized waste management (GC3)'. As a result, decentralization in this area will aid successful MWM. "No involvement of informal bodies (GC4)" makes it increasingly challenging for individuals working in MWM since they lack strategic assistance and involvement from the casual sector, leading the monitoring system to deteriorate. "Lack of training (MC2)" is observed to be having stronger dependence on power. Singh et al. (2021) acknowledged that providing appropriate training on relevant issues will enable MWM to be implemented successfully.

5.1. Theoretical implications

The findings of this study have numerous implications for the researchers from the theoretical point of view. The first aspect of the originality of the study is to bridge the key challenges to sustainable MWM in the complex context of a pandemic. This type of integration has not been suggested or explored in the waste management literature yet. This study is one of the first attempts to develop an intelligent MCDM-based framework by synergically integrating BWM, and ISM-MICMAC methods to identify, rank, and reveal the relationships among the challenges to MWM. The article developed a hierarchical model of the challenges, indicating the significant relationships between them. The proposed framework informs policymakers and industries to recognize the key challenges that may appear during the implementation of a successful MWM system. The framework enables a better decision-making process for overcoming such challenges in a post-COVID-19 context. The proposed framework may provide a new outlook to future researchers to apply such type of integration with other methods to identify the relevance of the challenges and sub-challenges for MWM implementation. Again, these findings proposed by this study may apply to countries from other economical contexts. Second, our findings extend our understanding of the under-investigated domain of MWM. More centrally, the article contributes to the literature on identifying and analyzing challenges to implementing the MWM system to address sustainability challenges. The present research is one of the first attempts to examine these challenges in the context of developing economies. Third, the analysis undertaken has extended the knowledge of the post-COVID-19 context of waste management in developing economies.

5.2. Practical implications

Besides a theoretical contribution, the findings of the study have several important implications for practitioners, researchers, and policymakers. The research findings can provide some support for the conceptual premise that may help sustainability and environmental managers to understand the role of the effective MWM system in emerging economies. This can assist to shape strategic decisions for successful MWM implementation, identify the key challenges that hinder the adoption process, ensure sustainability and human well-being, and maximize the economic value generated from effective MWM practices in both tangible and intangible forms. While fully recovering from this unusual COVID-19 pandemic might be extremely difficult, emerging economies' companies are trying to evaluate what initiatives or strategies they need to take to avoid building up a stockpile and contaminating communities with potentially contagious MW. This study has shed light on the importance of effective MWM to establish operational excellence and sustainable development.

The findings of this study suggest that the government and regulatory authorities in developing countries have a key role in implementing MWM practices across the country to ensure sustainability. Therefore, it is imperative for the government and regulatory authorities to actively take part in the execution process of MWM initiatives and manage enough funding to implement the system successfully. Furthermore, this study has identified that lack of segregation of wastes at source, insufficient recycling, lack of awareness and proper training, weak disinfection and disposal technology, etc., to be responsible for slowing down the MWM implementation. The study insights suggest that the managers of developing countries' medical enterprises must focus on the cognitive factors through talent hunting and regular training of their employees whilst trying to strengthen the technical capabilities of the enterprises through active involvement of the government and regulatory authorities and establish a robust information infrastructure.

5.3. Implications towards environment and sustainability

This research contributes to sustainability and sustainable development in several ways. For instance, the study contributes to environmental sustainability by suggesting separating MW at the source and applying cutting-edge technology for disinfection and disposal. In addition, the adoption of advanced disinfection and disposal techniques will lessen the exposure of infectious viruses and toxic gases into the environment ceasing the practice of landfilling and incineration. The use of advanced disinfection technology like vaporized hydrogen peroxide, dry heat technique, etc. will propel the use of disposable items more than once, resulting in the recycling of medical items. As a consequence, the leftover medical items will be reduced significantly. The lower the MW generated, the lower the effort and expense will be required to dispose of them. This will make medical waste management more economically sustainable. The research has also acknowledged the rapid collection and transportation of MW to the safe disposal site. This strategy will restrict the living environment from being contaminated by MW, safeguarding the human and surrounding environment and society. Thereby, this study will be able to contribute to all three aspects (environmental, economic, and social) of sustainability.

Based on the outcomes of this research, the government must ensure proper enforcement of law considering the environmental issues, adequate financing, and subsidies, and perform audits periodically to make sure that every institution has adopted such strategies to protect the environment from negative impacts. This study can be substantially linked to a variety of attributes that are immensely important for achieving certain pertinent SDGs, especially in emerging economies. For example, the research can support infrastructure improvements and medical sector retrofits to make their operations more sustainable, with improved utilization of resources and ecologically sound technologies, which is closely related to SDG 9 (Industry, Innovation, and Infrastructure). Additionally, effective MWM can contribute to lowering the negative per capita environmental consequence of cities, which can aid in the achievement of SDG 11 (Sustainable Cities and Communities). Additionally, the study promotes the reduction in waste formation through improved management, control, and recycling, which is deeply related to SDG 12 (Responsible Consumption and Production).

6. Conclusions

The COVID-19 pandemic has imposed a lot of uncertainties and disruptions in different sectors worldwide and its scary impact is much more severe in emerging economies. Due to COVID-19, Bangladesh is experiencing an increased amount of MW. Due to having a vulnerable management system, Bangladesh was already struggling for safe and effective waste management before this pandemic, but now COVID-19 has worsened the case. The inappropriate management of this waste raises several issues, including the spread of contagious diseases, and many types of environmental contamination. Thereby, to ensure environmental sustainability and community safety and health, policymakers of emerging economies should develop and adopt an effective MWM system for the current and post-COVID-19 pandemic perspective. Motivated by the current situation, this study presents an integrated approach for identifying, evaluating, and prioritizing key challenges to implementing the MWM program successfully. With the aid of literature reviews and expert feedback, 17 challenges were considered primarily, and then, upon implementing BWM analysis, the five lowest-rated challenges were eliminated. Finally, the remaining top 12 factors were selected for ISM-MICMAC analysis.

The BWM findings imply that "Inadequate financial support from investors and the government (GC2)" and "Lack of proper law enforcement (GC1)" are the two topmost-ranked challenges. These challenges, both independently and interdependently, are found to have a significant impact on the effective implementation of the MWM system. These two parameters are also found to be in the independent variable cluster in MICMAC analysis and at the most influential level in ISM analysis. This finding suggests that these two challenges should be given higher priority to achieve successful implementation of the MWM system. The study offers various significant theoretical, practical, and environmental implications, which have been discussed in detail in subsections 5.1-5.3.

Although this study is one of the initial attempts that integrate quantitative and qualitative methods for assessing challenges to implementing MWM, it does have some limitations, which can be overcome in future research attempts. For instance, the model was developed and verified based on expert opinions. Hence, there are always some risks of subjective bias in the findings. Though the experts are chosen from different domains, the population size still isn't large and diverse enough to avoid ambiguities. Such biases can be overcome in future research endeavors if fuzzy or grey theory-based tools are applied to the study, where the respondents will feel more flexible to provide their opinion. In the future, the proposed framework can also be compared with other popular methods like AHP, SWARA, ARAS, or EDAS to present a comparative analysis. This comparison can provide decision-makers with a clearer view of the strengths and weaknesses of various existing evaluation methods. Again, this study focuses on only 20 major challenges, which might not be exhaustive. More relevant issues can be detected and addressed in future research attempts. Again, the selected list of significant challenges might evolve with the change in technology, government policies, and managerial practices. Hence, the study might need to be redone after 10 years or so to ascertain its validity and relevance. The key challenges examined represent the context of Bangladesh as an emerging economy. Hence, the findings may not be entirely generalizable in the context of other developing economies or developed countries. Therefore, we recommend that more research attempts should be made in the future for countries from other economic contexts.

CRediT authorship statement

Saifur Rahman Tushar - Conceptualization, Methodology, Software, Formal analysis, Investigation, Data Curation, Writing - original draft. Md. Fahim Bin Alam - Conceptualization, Methodology, Software, Formal analysis, Investigation, Data Curation, Writing - original draft. A. B. M. Mainul Bari, Ph.D. – Corresponding Author, Supervision, Conceptualization, Resources, Visualization, Writing - review & editing. Chitra Lekha Karmaker - - Visualization, Writing-reviewing and editing. All the authors participated in the study.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used in this research are provided either in the manuscript or in the supplementary materials file

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seps.2023.101513.

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