ACHSM Asia-Pacific Journal of Health Management

RESEARCH ARTICLE

IDENTIFYING FACTORS AFFECTING BIOMEDICAL WASTE MANAGEMENT IN THE CONTEXT OF UNITED NATIONS' SUSTAINABLE DEVELOPMENT GOALS IN INDIA

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ABSTRACT

OBJECTIVE:

The objective of the study is to capture the perceptions of the variables of knowledge, attitude, practice and compliance-monitoring and their role in biomedical waste management in the context of United Nations' Sustainable Development Goals (SDG).

DESIGN:

The authors used interviews and survey questionnaire to capture perceptions of biomedical waste management. Convenience sampling was employed in the state of Goa, India. The data was analysed using partial least squares, structural equation modelling (PLS-SEM).

SETTING:

Doctors, nurses, pharmacists and other paramedical staff across 10 private hospitals in Goa, India, participated between June 2024 and November 2024 and sample of 85 was obtained.

MAIN OUTCOMES AND MEASURES:

Knowledge, attitude, practice and compliance-monitoring were found to be four factors (variables) that affect biomedical waste management.

RESULTS:

The major challenges to implementation of biomedical waste management were found to be lack of funding (35.3%), competing priorities (23.5%), lack of expertise (17.6%), resistance to change (11.7%). Eighty eight percent of the respondents felt the need for proper training and expected the training to be conducted once a quarter (52.9%), monthly (23,5%) or at least twice a year (17.6%). While the respondents understood biomedical waste management, 70.2% were not aware of United Nations' Sustainable Development Goals (SDG 3, 12, 17). While awareness of SDG was low, 94.1% of the respondents mentioned that impact of biomedical waste on environment was advocated by the hospital and 88.2% felt that the hospital ensures environmentally safe disposal of biomedical waste either themselves or through a partner. Interestingly, only 56.5% of the respondents were aware of any government initiatives promoting sustainability in hospitals, indicting low levels of awareness.

Asia Pacific Journal of Health Management 2026; 21(1):i4297. doi: 10.24083/apjhm.v21i1.4297

CONCLUSION:

Knowledge, attitude, practice and compliance-monitoring positively affects biomedical waste management. Proper training will improve the biomedical waste management and the awareness of UN SDGs.

KEYWORDS

biomedical waste management, sustainable development goals, SDG, PLS-SEM, Hospital, KAP

INTRODUCTION

During and post COVID-19 pandemic developing countries have struggled to manage biomedical waste generated during the pandemic, this raises a lot of questions regarding sustainable disposal of biomedical waste to protect public health and environment. It also mandates a better future preparedness [1]. Improper biomedical waste management continues to plague developing countries like India and there is a need to better manage hospital waste [2] and is revealed to spread infectious disease and cause environmental degradation [3]. Asian developing countries are also densely populated and rapidly urbanizing, this, along with resource constraints make the management of biomedical waste difficult [4].

A healthy society needs a healthy balance between the external macro (ecological) and internal human body (micro) and a healthy inter-relation between these two factors. Any imbalance could have serious effects on the national wellbeing and on an individual [5]. While a healthcare system exists to bring humans back to health, it can also pose a risk to society if it is not able to manage its biomedical waste [6].

Biomedical waste is the waste arising during the diagnosis, treatment or immunization of human beings, animals or research activities related to them or arising during the production and testing of biological material and health camps [7]. This waste needs to be handled properly to avoid harm of healthcare workers and often leads to spread to infectious disease and environmental degradation and can be both hazardous and non-hazardous in nature. [3,8]. India generates approximately two kg/bed/day of biomedical waste which consists of anatomical waste, cytotoxic waste, sharps etc and if not properly treated could lead to deadly infectious diseases like hepatitis B, hepatitis A and human immunodeficiency virus amongst others and can have adverse social, environmental and ecological impact [9]. Understanding biomedical waste management involves studying knowledge, attitude and practice (KAP) of biomedical waste management by the healthcare professionals and is an often used method [10]. There is a need to follow proper guidelines, especially from World Health Organization regrading biomedical waste management to overcome difficulties of proper segregation, handling and disposal [11].

World Health Organization (WHO) estimates that between 75% and 90% of the healthcare waste is non-hazardous, while the balance (10% to 25%) remains hazardous and may pose both environmental and health risk [12]. Due to the nature of the healthcare waste and its potential threat and risk to life and environment it has taken central stage in national health policy in many countries. In developing countries it however has not received much attention since it competes with other priorities [13]. While globally, there is an increased awareness amongst healthcare professionals regarding biomedical waste, the problem with India is the lack of awareness about health hazards, insufficient funds and resources and poor control of waste management processes [14]. Financial funds in Indian hospitals get spent in hospital expansion and purchase of advanced equipment and there is lack of funds spent on improvement of biomedical waste management due to the focus of administrators on primary activities on delivering patient care [15]. Many hospitals in India lack proper protocol of collection, segregation, transportation and disposal of biomedical waste [16].

The solving of medical waste disposal is an interdisciplinary issue and affects various aspects of United Nations Sustainable Development Goals (SDG). It directly relates to SDG 3, 12 and 17 and indirectly to SDG 1, 2, 5, 6, 9, 11, 13, 14, 15. SDG 3.9 specifically calls for reduction of deaths and illnesses from hazardous chemicals and air, water and soil pollution. SDG 12.4

calls for ecologically sound management of chemicals and all wastes throughout their lifecycle and SDG 12.5 calls for reduction in waste generation, through prevention, reduction, recycling and reuse. SDG 17 calls for transfer, dissemination and diffusion of ecologically sound technologies to developing countries [17]. For sustainable green healthcare it is important to raise awareness, manage operations, medical waste, conduct proper environmental assessment and train the staff for proper waste management procedures [18]. A connected sensor based monitored health system may be a good way to align with the sustainable development goals [19].

The Indian Government has formulated biomedical waste management rules (1998) which made it mandatory for all hospitals above 1,000 beds to obtain authorization of segregation, sanitising, and disposing of the waste in an ecologically safe manner. Similarly, in 2016, the Government has also issued rules for safe handling of biomedical waste [20].

Most of the studies in biomedical waste management are centred around defining what biomedical waste is and the types of biomedical waste. Very few studies exist to understand the perceptions of medical and paramedical staff and their attitudes towards biomedical waste reduction. What are the main factors (variables) that drive biomedical waste management? What are the main challenges and hindrances in biomedical waste management in India? Do the medical staff understand biomedical waste management from the perspective of United Nations Sustainable Development Goals (SDGs)? The aim of this study is to understand the factors affecting biomedical waste management in a developing Asian country like India in the context of United Nations sustainable development goals (SDGs). The objective is to capture the perceptions regarding knowledge, attitude, practice and compliance-monitoring and its role in biomedical waste management. The motivation for the study is the understand biomedical waste management by examining factors affecting it within the broader goal of sustainability.

LITERATURE REVIEW

BIOMEDICAL WASTE MANAGEMENT (BMWM)

Biomedical waste management is important since it has an overall impact on the society at large and lack of infrastructure and improper behaviour of healthcare workers are major barriers or hindrances to proper biomedical waste management [1]. Proper waste management includes, waste characterization, segregation, generation, collections, storage, transportation, treatment and final disposal. Biomedical waste remains a public health issue and most hospitals do have a policy for waste management and better biomedical waste management depends upon human resource allocation, budget for biomedical waste management, sustainability, attitude amongst many other factors [21–23]. Good objectives of biomedical waste management are to prevent transmission of disease, prevent injury to healthcare workers and prevent exposure to hazardous waste [24]. Biomedical waste management remains a shared framework between all stakeholders and requires constant backing of the government to be successful [25]. While biomedical waste management is important for a hospital from the perspective of infection, it could also have financial implications [26]. Biomedical waste management is a problem in developing countries like India due to lack of resources and low healthcare expenditure spend by the government [2]. Training programs are known to improve the knowledge, attitude and practice of biomedical waste management [27].

KNOWLEDGE

Having proper knowledge about biomedical waste remains the starting point in proper biomedical waste management [28]. Being aware of what needs to be done while handling biomedical waste and managing its disposal. This knowledge is built through multiple trainings [29]. Improvement in knowledge of biomedical waste management is known to improve biomedical waste management [30]. While proper biomedical practices are important, it is equally important to constantly assess and raise awareness and knowledge regarding the same among medical and paramedical staff through proper trainings regarding, risks and protective measures [31]. Understanding the fundamentals of managing biomedical waste is important in terms of colour coding, usage of personal protective equipment and is helpful in improving biomedical waste management practices [32]. Knowledge about infectious waste is important in hospitals and lack of knowledge and training is a barrier to proper biomedical waste management [15]. The developing Asian countries it is important to improve the knowledge to have better biomedical waste management [4]

Hypothesis 1 (H1): Knowledge affects biomedical waste management (BMWM)

Attitude

Attitude consists of how we feel, what we think and what are we inclined to do about something [33]. Attitude includes the inclination to respond in a specific manner to different situations and the ability to perceive and interpret events based on personal pre-dispositions [30]. The personal attitude of healthcare workers, including nurses and house-keeping staff has a direct impact on biomedical waste management [21]. Positive attitude towards the implementation for proper biomedical waste management practices from generation to final disposal is needed or the policy to succeed [29]. Historically biomedical waste management tended to be basic waste management involving cleaning, collection, storage, transport and disposal. As healthcare institutions focus and promote sustainability to focus needs to shift towards waste awareness and waste reduction through careful policy making and requires the positive attitude of the top management [31]. Many hospitals outsource the disposal of biomedical waste and at times commitment is questionable. Having a positive attitude in administrators and management improves biomedical waste management practices [15].

Hypothesis 2 (H2): Attitude affects biomedical waste management (BMWM)

Practice

Having a policy for biomedical is the first step, however its success depends on putting it into practice [29]. Practice is the implementation of the rules and knowledge that results in taking action [30]. Training regarding maintaining health of the community also helps to improve practice of biomedical waste management [34]. Hospital acquired infections is good indicator for proper biomedical waste management and accounts to 10% of the infections. These are known to be due to improper practice of biomedical waste management for example, WHO estimated a 50% reuse of syringes meant for single use [34]. Proper practice of handling biomedical waste includes proper segregation of waste, proper storage, proper transportation and proper handling [16]. In developing Asian countries with resource constraints it is important to improve the implementation of policy to drive better biomedical waste management [4].

Hypothesis 3 (H3): Practice affects biomedical waste management (BMWM)

Compliance-monitoring

Apart from knowledge, attitude and practice, monitoring and surveillance (compliance) are the key to successful biomedical waste management [29]. Compliance and monitoring helps to keep track whether the biomedical practices are implemented properly specially when there are behavioural issues among healthcare workers like resistance to change [1]. Lack of compliance and monitoring is known to increase in negligence while managing biomedical waste apart from lack of knowledge. This problem is more critical in developing countries [31]. Proper biomedical waste management requires sufficient funds for monitoring, training, procurement of resources and treatment. This has also to be backed up by proper supervision [32]. Apart from knowledge and attitude, monitoring and control, regarding management of waste remains a contributing factor in India in biomedical waste management [14]. Monitoring operational processes is important to provide continuous feedback and improve existing systems and is definitely resource and time consuming but a necessary activity in biomedical waste management [15].

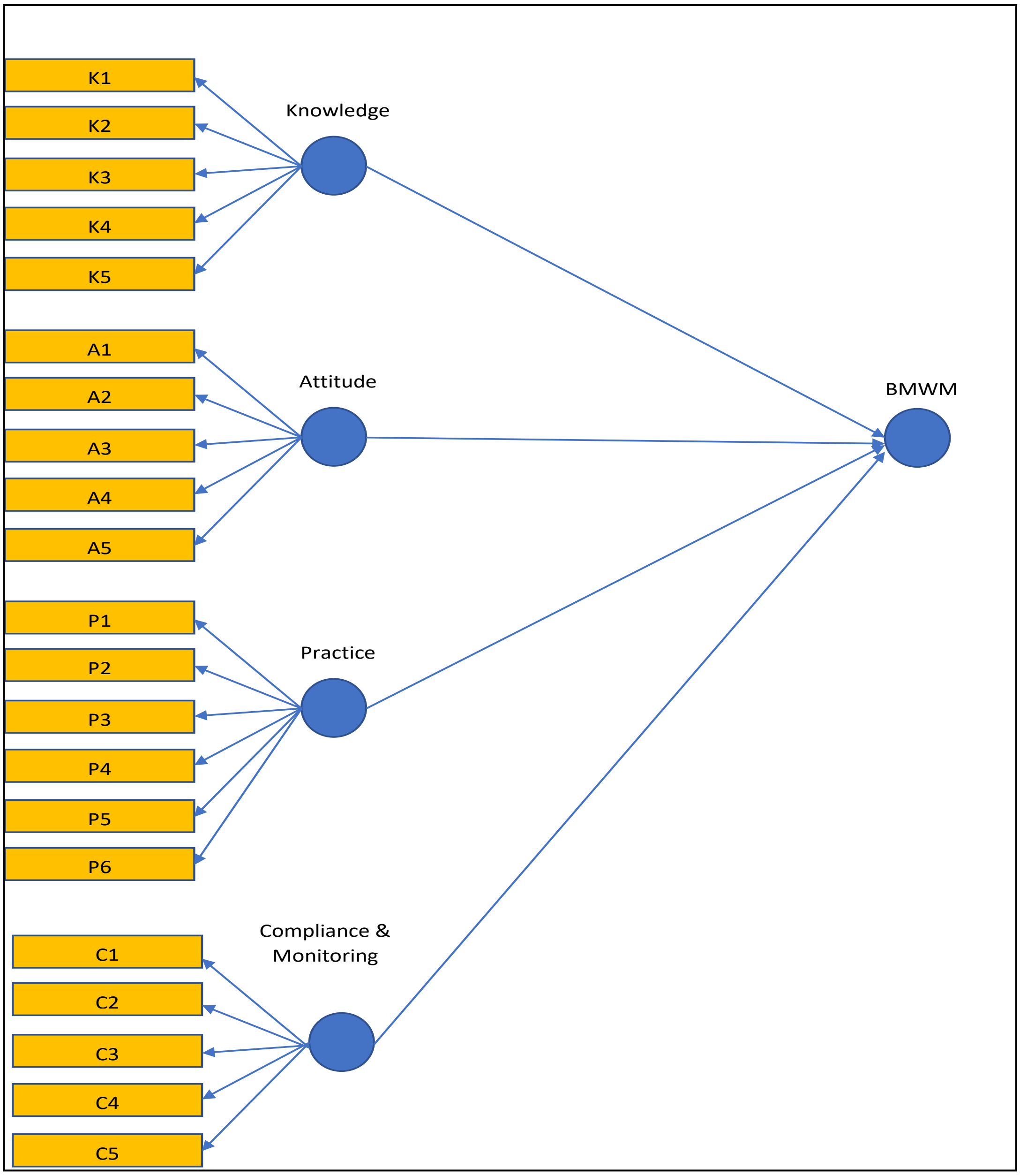
Hypothesis 4 (H4): Compliance affects biomedical waste management (BMWM)

Building on the foregoing review, it is evident that biomedical waste management is not solely a technical or regulatory issue, but a multidimensional health system challenge shaped by behavioural, organisational, and governance-related factors. While prior studies have predominantly examined knowledge, attitude, and practice (KAP) as key determinants, there remains limited integration of these constructs with system-level mechanisms such as compliance-monitoring, which is critical for ensuring sustained adherence to biomedical waste protocols in resource-constrained settings. Furthermore, the alignment of biomedical waste management practices with broader sustainability frameworks, particularly the United Nations Sustainable Development Goals (SDGs), has received insufficient empirical attention in the context of developing healthcare systems. Addressing these gaps, the present study adopts an integrated perspective that combines behavioural (knowledge, attitude, practice) and organisational (compliance-monitoring) dimensions to better understand biomedical waste management within hospital settings. This approach not only extends the traditional KAP framework but also situates it within a health systems and sustainability context. Accordingly, a conceptual model is proposed to examine the relationships between these constructs and their collective influence on biomedical waste management.

MODEL

Based on the synthesis of the literature, this study proposes a conceptual model that integrates behavioural and organisational determinants of biomedical waste management within hospital settings. Specifically, knowledge, attitude, and practice are conceptualised as key behavioural factors, while compliance-monitoring represents an organisational and governance mechanism that supports implementation and accountability. Together, these constructs are hypothesised to influence biomedical waste management as a higher-order outcome. The proposed model reflects a health systems perspective, recognising that effective waste management requires not only individual awareness and behaviour but also structured monitoring and institutional support. Basis the review of literature, the below model is proposed

FIGURE 1: PROPOSED MODEL



Source: Authors own work

METHODOLOGY

Study Approach: The study is designed to be exploratory and cross sectional in nature using a structured questionnaire to capture the perceptions of the healthcare professionals. The study is also a context-specific investigation (biomedical waste management) within a regional healthcare system. A quantitative approach is chosen using PLS-SEM since its ability to give robust results involving complex models with even small data sets [35–37].

PLACE AND DURATION OF STUDY:

For the purpose of the study, data was collected between June 2024 to November 2024, from healthcare professionals (doctors, nurses, pharmacists and other paramedical staff) employing questionnaires. The healthcare professionals represent 10 private hospitals in Goa, India out of the 29 major private hospitals operating in the state.

SAMPLING FRAME, DESIGN AND SAMPLE SIZE:

A list of private hospitals was developed basis the hospitals listed on the Government of Goa website (https://www.goa.gov.in/wp-content/uploads/2021/06/List-of-Private-Hospitals-in-Goa.pdf) Convenience sampling was employed and a final sample consisted of 85 respondents. The sample represents 34% of all the major private hospitals operating in the state. The sample of 85 respondents is consistent with the requirements of Partial Least Squares Structural Equation Modelling (PLS-SEM). PLS-SEM is particularly suitable for exploratory research, complex models, and studies with relatively small sample sizes [35–37]. Using the Inverse Root Square Method proposed by Kock and Hadaya (2018), minimum sample size (n) in PLS SEM is calculated by the formula n = (|pathmin|/threshold) ^-2, where |pathmin| is absolute value of the minimum expected path coefficient and threshold is typically 0.1 for a significance level of 0.05. n in this case works out to be (0.15/0.1) ^-2 = 0.444 X 100 = 44.4 (rounded up to 45) [38,39]. Similarly, from a minimum R^2 value method as proposed by Hair et al (2014), for a R^2 value of .75 and the number of structural paths directed towards the endogenous variable (in this case BWMW) is 4. The minimum sample size requirement from the table is 34 [39]. Similarly, following the "10-times rule," the minimum sample size should be at least ten times the maximum number of structural paths directed at any construct in the model [38,39]. In the present study, the maximum number of paths directed at the endogenous construct (BMWM) is four, indicating a minimum required sample size of 40. The obtained sample size of 85 therefore exceeds these three thresholds and is considered adequate for robust model estimation in PLS-SEM. Given the exploratory nature of this study and its focus on a specific healthcare context, the sample size is appropriate for generating meaningful insights while maintaining analytical rigour.

INSTRUMENT DEVELOPMENT:

The questionnaire was designed keeping in mind the literature review. The questionnaire included five constructs, namely, knowledge, attitude, practice, compliance-monitoring and biomedical waste management. Each of the items associated with each construct was measured using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Items were adapted and refined for clinical relevance (See Appendix A). The questionnaire was discussed and views sought from administrators of the ten hospitals to establish face validity. The administrators were particularly happy on the inclusion of compliance-monitoring of biomedical waste management which according to them was extremely important for private hospitals in India. The questionnaire was pilot tested with non-sampled respondents (10) to establish whether responses are in line with expectations and language in the questionnaire was modified accordingly.

ETHICAL CONSIDERATIONS:

Written informed consent was obtained from all participants, and anonymity and confidentiality were maintained throughout the study. The research did not involve patients, clinical interventions, or sensitive personal data. In accordance with institutional norms applicable during the study period, formal ethics committee approval was not required for non-invasive, perception-based surveys involving healthcare professionals. However, the absence of formal ethical clearance is acknowledged as a limitation, and future studies should seek institutional ethics approval to strengthen methodological rigour.

DATA ANALYSIS:

Collected data was analysed using PLS SEM 4.0 to test the hypothesis. PLS-SEM has been widely applied in health management research where data collection is constrained by access to specialised respondents such as healthcare professionals (small sample sizes). Excel was used for tablature and for descriptive statistics. Keeping in mind the objectives of the study, frequencies and percentages were calculated for describing the sample characteristics. The measurement model and structural model was tested. The model was also tested for model fit and predictive ability.

RESULTS

The sample showed a good representation of both the genders, male (43.5%) and female (56.5%). The sample had both permanent (82%) and contractual (18%) respondents with 43.5% respondents having less than two years' experience, 38.8% of respondents having two to five years of experience and 17.7% of the respondents having more than five years of experience. A more details description of the sample is given below (See Table 1).

TABLE 1: FREQUENCY AND PERCENTAGE DISTRIBUTION OF SAMPLE

Sample Statistic	Number	Percentage
Total Respondents	85	
Gender		
Male	37	43.5
Female	48	56.5
Designation		
Doctors	20	23.5
Nurses	45	52.9
Pharmacist	10	11.8
Other Paramedical	10	11.8
Employment Status		
Permanent	70	82
Contract/Probation	15	18
Years of Experience		
<2 years	37	43.5
2-5 years	33	38.8
>5 years	15	17.7
Main Challenges for implementing BMWM practices (Reported)		
Competing priorities	20	23.5
Resistance to change	10	11.7
Lack of funding	30	35.3
Lack of expertise	15	17.6
Other	5	5.8
Felt Need of training in improving BMWM		
Yes, need more Training	75	88.2
No, don't need more training	10	11.8
Expected frequency of training		
Monthly	20	23.5
Once a quarter	45	52.9
Twice a year	15	17.6

Once a year	5	5.8
Awareness of WHO Sustainability Development Goals (SDG 3, 12, 17)		
Yes	25	29.4
No	65	70.6
Is there a pre-treatment plant for handling liquid biomedical waste (corresponding to SDG 12)		
Yes	45	52.9
No	40	47.1
Is the Environment impact of biomedical waste was advocated at the hospital (corresponding to SDG 12)		
Yes	80	94.1
No	5	5.9
Are you aware of government initiatives promoting sustainability in hospitals (corresponding to SDG 17)		
Yes	48	56.5
No	37	43.5
Does your organization ensure environmentally safe disposal of biomedical waste (corresponding to SDG 12)		
Yes	75	88.2
No	15	11.8

Source: Authors own work

CONCURRENT MODELLING USING PLS SEM

The five factors (variables), namely, knowledge, attitude, practice, compliance-monitoring and biomedical waste management were captured using a Likert scale. The respondents were asked to indicate their agreement or disagreement (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 strongly agree). PLS-SEM 4.0 software was used in the analysis. The measurement model and structural model analysis was conducted, including testing of the four hypotheses.

MEASUREMENT AND STRUCTURAL MODEL ANALYSIS

TABLE 2: MEASUREMENT MODEL

Dimension	Item		Factor Loading	Cronbach's Alpha	Rho_A	CR	AVE
Knowledge	K1		0.812	0.910	0.902	0.918	0.625
	K2		0.787				
	K3		0.823				
	K4		0.761				
	K5		0.790				

Attitude	A1		0.811	0.912	0.916	0.922	0.617
	A2		0.802				
	A3		0.749				
	A4		0.716				
	A5		0.782				
Practice	P1		0.846	0.900	0.926	0.923	0.613
	P2		0.817				
	P3		0.734				
	P4		0.794				
	P5		0.809				
	P6		0.851				
Compliance-Monitoring	M1		0.791	0.905	0.932	0.901	0.602
	M2		0.822				
	M3		0.779				
	M4		0.813				
	M5		0.789				
Biomedical Waste Management	BMWM1		0.762	0.889	0.912	0.907	0.620
	BMWM2		0.778				
	BMWM3		0.812				
	BMWM4		0.841				
	BMWM5		0.752				

Source: Authors own work

The model for this study used five constructs. Knowledge, attitude, practice and compliance-monitoring and biomedical waste management (BMWM) were configured as reflective first-order constructs.

The individual factor loading of each of the items in the construct was found to be greater than 0.8 indicating acceptable item reliability [40]. The composite reliability (CR) values for each of the constructs of knowledge, attitude, practice and compliance-monitoring exceeded the recommended value of 0.7 [41]. Similarly the Average Variance Extracted (AVE), which indicates the amount of variance accounted for by the latent constructs exceeded the recommended value of 0.5 [41]. Similarly the Cronbach's Alpha and rho A were found to be greater than 0.7 [41]. This indicates that the model exhibited good convergent reliability.

TABLE 3: FORNELL-LARCKER CRITERION

	Knowledge	Attitude	Practice	Monitoring	BMWM
Knowledge	**0.823**				
Attitude	0.767	**0.790**			
Practice	0.751	0.712	**0.812**		
Monitoring	0.753	0.716	0.727	**0.779**	
BMWM	0.682	0.663	0.669	0.687	**0.712**

Source: Authors own work

The square root of Average Variance Extracted is provided in the diagonals is found to be greater than the corresponding correlation coefficients indicating good discriminant validity among the constructs [41].

CROSS-LOADING CRITERIA

Each of the indicator items AVE were found to be higher than the AVE of the corresponding items of other variables, showing good discriminant validity [41].

TABLE 4: HETEROTRAIT-MONOTRAIT RATIO

	Knowledge	Attitude	Practice	BMWM
Knowledge				
Attitude	0.814			
Practice	0.781	0.790		
Monitoring	0.765	0.745	0.823	
BMWM	0.693	0.689	0.700	0.688

Source: Authors own work

The Heterotrait-Monotrait (MTMT) ratio for each of the constructs is less than 0.9 showing good discriminant validity [41].

STRUCTURAL MODEL

TABLE 5: PATH COEFFICIENTS

	Original Sample [O]	Rank	SD	T-Statistic	Result
Knowledge -> BMWM	0.273***	2	0.005	32.4	Significant
Attitude -> BMWM	0.235***	3	0.007	32	Significant
Practice -> BMWM	0.282***	1	0.009	23.4	Significant
Monitoring-> BMWM	0.219***	4	0.007	28.4	Significant

Note: *** P Values <0.001

Source: Authors own work

All the probability values are found to be less than 0.001 indicating that all the hypotheses H1-H4 are to be accepted, that is to say that knowledge, attitude, practice and compliance-monitoring all positively affect biomedical waste management.

MODEL STRENGTH

Model fit was assessed using the Standardized Root Mean Square Residual (SRMR), which was found to be 0.05 which is within acceptable thresholds (<0.08), indicating a good model fit. The coefficient of determination (R^2) for biomedical waste management (BMWM) was found to be 74% which demonstrates substantial explanatory power, suggesting that knowledge, attitude, practice, and compliance-monitoring collectively explain a meaningful proportion of variance in the outcome construct. Similarly, Q^2 was found to be greater than 0, confirming predictive relevance.

DISCUSSION

The present study examined biomedical waste management (BMWM) through a health systems lens by integrating behavioural (knowledge, attitude, practice) and organisational (compliance-monitoring) determinants. The findings confirm that all four constructs significantly and positively influence BMWM, with practice emerging as the strongest predictor, followed by knowledge, attitude, and compliance-monitoring. This reinforces the view that while awareness and attitudes are necessary, effective biomedical waste management ultimately depends on consistent implementation and operationalisation within healthcare settings.

From a health management perspective, the results highlight the interdependence between individual-level competencies and institutional mechanisms. Knowledge and training form the foundation for appropriate waste handling, yet without supportive organisational structures, such as monitoring systems, standard operating procedures, and accountability mechanisms, these capabilities may not translate into sustained practice. The inclusion and significance of compliance-monitoring as a determinant extends the traditional KAP framework and underscores the importance of governance and supervision in ensuring adherence to biomedical waste protocols, particularly in resource-constrained environments.

The study also provides important insights into systemic challenges affecting BMWM implementation. The findings indicate that lack of funding (35.3%), competing priorities (23.5%), and lack of expertise (17.6%) are key barriers. These research findings support and extend similar findings from other countries [42,43]. These constraints reflect broader structural issues within healthcare systems in developing economies contexts, where biomedical waste management often competes with core clinical priorities for limited resources. This suggests that BMWM must be repositioned not as a peripheral function but as an integral component of patient safety, infection control, and environmental health within hospital management systems.

A critical contribution of this study lies in its examination of policy awareness and implementation gaps. Despite the existence of regulatory frameworks such as the Biomedical Waste Management Rules (1998; revised 2016), the findings reveal limited awareness (43.6%) of government initiatives among healthcare professionals. This indicates a disconnect between policy formulation and operational execution at the facility level. The effectiveness of regulatory frameworks is therefore contingent not only on their design but also on dissemination, enforcement, and institutional integration. Strengthening compliance mechanisms, conducting periodic audits, and embedding policy awareness within routine training programs are essential to bridge this gap.

The study further highlights a significant deficiency in awareness of the United Nations Sustainable Development Goals (SDGs), with 70.6% of respondents indicating a lack of familiarity. This finding is particularly important in the context of global health and sustainability agendas, as biomedical waste management is closely linked to SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production), and SDG 17 (Partnerships for the Goals). This finding reinforces similar finding in other low resource constrained countries [43]. The low level of awareness suggests that sustainability frameworks have not been adequately translated and internalised into operational practices within healthcare institutions. Addressing this gap requires targeted capacity-building initiatives, including the integration of SDG-linked content into training programs, the use of visual and data-driven communication tools, and alignment of hospital performance metrics with sustainability indicators.

From an operational standpoint, the findings emphasise the need for structured and continuous training interventions. The majority of respondents (76.4%) expressed a preference for quarterly or more frequent training, indicating recognition of the dynamic nature of biomedical waste management practices. Training programs should move beyond compliance-based instruction to include behavioural change strategies, role-specific responsibilities, and real-world simulations to enhance retention and application.

In addition, the study points to the potential role of technological innovations in strengthening BMWM systems. Digital and IoT-enabled waste tracking solutions can enhance monitoring, improve segregation accuracy, and provide real-time data for decision-making. Such technologies can support hospital administrators in ensuring compliance, optimising resource utilisation, and aligning operational practices with environmental sustainability goals. These solutions are particularly relevant in the Asia-Pacific context, where healthcare systems are increasingly adopting digital tools to improve efficiency and accountability and have found success [44,45].

Overall, the findings emphasize that effective biomedical waste management requires a coordinated, multi-level (health system) approach encompassing behavioural change, organisational support, policy enforcement, and technological enablement. By situating BMWM within a broader health systems and sustainability framework, this study provides actionable insights for healthcare administrators, policymakers, and practitioners seeking to improve environmental and public health outcomes.

The uniqueness of the study was that it was able to identify compliance monitoring as an important factor in developing countries like India that affects biomedical waste management apart from knowledge, attitude and practice. This is a premier study to capture perceptions of biomedical waste management in the context of United Nations' Sustainable Development Goals in a developing Asian country like India.

IMPLICATIONS FOR THEORY, HEALTH SYSTEMS, MANAGEMENT AND PRACTICE

The findings of this study offer contributions across four interconnected levels, theoretical, policy, managerial, and practice highlighting the multi-level nature of biomedical waste management within healthcare systems.

Theoretical Implications

This study contributes to the existing literature on biomedical waste management by extending the traditional Knowledge–Attitude–Practice (KAP) framework through the inclusion of compliance-monitoring as an organisational and governance construct. While prior research has predominantly focused on behavioural determinants, the present study demonstrates that effective biomedical waste management is shaped by both, individual-level factors and institutional mechanisms. This integrated perspective advances the conceptualisation of biomedical waste management from a purely behavioural model to a health systems-oriented framework that incorporates elements of governance, accountability, and organisational control. Furthermore, by situating biomedical waste management within the context of the United Nations Sustainable Development Goals (SDGs), the study bridges micro-level healthcare practices with macro-level sustainability agendas. This linkage provides a novel theoretical contribution by connecting operational hospital practices with global public health and environmental sustainability frameworks. The study also contributes methodologically by applying PLS-SEM to validate a higher-order construct of biomedical waste management, thereby offering a structured and empirically tested model that can be extended and validated in other healthcare settings.

Policy Implications

At the policy level, the study highlights the need to strengthen the implementation of existing biomedical waste management regulations, such as the Biomedical Waste Management Rules (1998; revised 2016), through improved enforcement and monitoring mechanisms. The observed gaps in awareness of government initiatives and sustainability frameworks suggest that policy effectiveness is constrained by limited dissemination and engagement at the facility level. Policymakers should prioritise the integration of biomedical waste management into broader health system governance through mandatory training standards, periodic compliance audits, and alignment with accreditation frameworks. Additionally, embedding Sustainable Development Goal (SDG) indicators within national and institutional health policies can facilitate greater accountability and alignment with global sustainability agendas.

Managerial Implications

From a hospital management perspective, the findings highlight the importance of adopting a structured and system-oriented approach to biomedical waste management. Administrators should ensure adequate allocation of financial and human resources, establish clear standard operating procedures, and institutionalise compliance-monitoring mechanisms. The relative importance of practice and knowledge suggests that investments in continuous training and capacity-building initiatives are critical. Hospitals should implement periodic, role-specific training programs, supported by performance monitoring systems and internal audit mechanisms. Furthermore, leadership commitment is essential in fostering a culture of accountability and environmental responsibility within healthcare organisations.

Practice Implications

At the operational level, the study emphasises the need to translate knowledge and attitudes into consistent and compliant practices. Healthcare workers should be supported through regular training, clear guidelines, and access to necessary resources to ensure proper segregation, handling, and disposal of biomedical waste. The low awareness of SDGs indicates the need to embed sustainability concepts into day-to-day practices through practical tools such as visual aids, workflow integration, and feedback systems. Additionally, the adoption of technology-enabled solutions, including digital tracking and IoT-based monitoring systems, can enhance compliance, improve efficiency, and provide real-time data to support decision-making. These interventions can contribute to safer healthcare environments and improved environmental outcomes.

Limitations and Future Research

This study is based on a sample of 85 healthcare professionals from private hospitals in Goa, India. While the sample size represents 34.5% of the private hospitals in the state and is consistent with the requirements of PLS-SEM for exploratory modelling, the use of convenience sampling and a single-state context may limit statistical generalisability. However, the findings offer analytical insights that may be transferable to similar healthcare settings in other parts of India and comparable Asia-Pacific contexts. Future research should expand and adopt multi-site and cross-country designs to validate and extend the proposed model. A future study could also adopt both private and public hospitals for a comparative analysis.

CONCLUSION

This study advances the understanding of biomedical waste management (BMWM) by adopting a health systems perspective that integrates behavioural and organisational determinants. The findings demonstrate that knowledge, attitude, practice, and compliance-monitoring all significantly influence BMWM, with practice emerging as the most critical driver. This highlights that effective waste management in healthcare settings is not solely dependent on awareness, but on the consistent translation of knowledge into practice, supported by institutional mechanisms of monitoring and accountability. The study further reveals important systemic challenges, including resource constraints, competing priorities, and gaps in expertise, which continue to hinder effective implementation of biomedical waste management practices. These findings emphasize the need to reposition BMWM as a core component of healthcare delivery, closely linked to patient safety, infection control, and environmental sustainability, rather than as a peripheral administrative function. A key contribution of this study lies in identifying the disconnect between policy frameworks and on-ground implementation. Despite the presence of regulatory guidelines, limited awareness of government initiatives and sustainability frameworks, particularly the United Nations Sustainable Development Goals (SDGs), suggests that policy translation into practice remains inadequate. Addressing this gap requires stronger governance mechanisms, structured training systems, and alignment of institutional practices with broader sustainability objectives. From a health management perspective, the findings emphasise the importance of coordinated, multi-level interventions encompassing policy enforcement, organisational commitment, and frontline behavioural change. Investments in continuous training, compliance-monitoring systems, and technology-enabled solutions such as digital tracking and IoT-based monitoring can enhance efficiency, transparency, and adherence to biomedical waste protocols.

While the study is context-specific to private hospitals in Goa, it offers a theoretically grounded and practically relevant framework that can inform biomedical waste management strategies in similar healthcare settings across India and the Asia-Pacific region. Future research should extend this model across diverse institutional contexts and explore the role of emerging technologies and policy innovations in strengthening sustainable healthcare waste management systems.

DECLARATION OF CONFLICTS

No conflicts with respect to research, authorship and/or publication of the article

FUNDING

No funding or financial support received for the research, authorship and/or publication of the article

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APPENDIX A: QUESTIONNAIRE

	(1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = strongly agree					
Correct Knowledge of Biomedical Waste Management		1	2	3	4	5
1	All health-care waste is hazardous					
2	Disease spreads due to improper BMWM					
3	Received adequate training for BMWM					
4	I know the rules governing BMWM					
5	I understand how to carry out BMWM					
Favourable Attitude towards Biomedical Waste Management		1	2	3	4	5
1	Important to know the generation, hazards and legislation of BMWM					
2	Safe management of BMW is an issue of concern					
3	Necessary to segregate waste at the point of origin					
4	BMWM is a part of our professional responsibility					
5	Necessary to wear PPE					
Proper Practice of Biomedical Waste Management		1	2	3	4	5
1	Institute has a tie-up with waste disposal agency					
2	Know the place where BMW treated					
3	Maintain BMW records at work place					
4	Follow segregation at work place					
5	Practicing the correct method for collecting BMW					
6	Operational resources are adequate					
Compliance and Monitoring		1	2	3	4	5
1	There is a committee to oversee implementation of BMWM					
2	There is an SOP for BMWM monitoring					
3	Enough financial resources have been allocated for BMWM Monitoring					
4	Monitoring plan exists					
5	Periodic updates are undertaken					
Biomedical Waste Management		1	2	3	4	5
1	Adequate knowledge exists to manage BMW					
2	Right attitude exists towards proper management of BMW					
3	Adequate safe practices exist to manage BMW					
4	Adequate monitoring exists to manage BMW					
5	Management of BMW is important to me					
Other Information						
Gender						
	Male					
	Female					

Designation						
	Doctor					
	Nurse					
	Pharmacist					
	Other Paramedical					
Employment Status						
	Permanent					
	Contract/Probation					
Years of experience						
Main Challenges for implementing BMWM practices						
	Competing Priorities					
	Resistance to change					
	Lack of funding					
	Lack of expertise					
	Other					
Need for training in improving BMMW						
	Yes					
	No					
Expected frequency of training						
	Monthly					
	Quarterly					
	Twice a year					
	Once a Year					
Awareness of WHO Sustainability Development Goals (SDG 3, 12, 17)						
	Yes					
	No					
Is there a pre-treatment plant for handling liquid biomedical waste (corresponding to SDG 12)						
	Yes					
	No					
Is the Environment impact of biomedical waste was advocated at the hospital (corresponding to SDG 12)						
	Yes					
	No					
Are you aware of government initiatives promoting sustainability in hospitals (corresponding to SDG 17)						
	Yes					

	No					
Does your organization ensure environmentally safe disposal of biomedical waste (corresponding to SDG 12)						
	Yes					
	No					