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A NATIONWIDE SURVEY ON BIOMEDICAL WASTE MANAGEMENT PRACTICES AND CHALLENGES IN MEDICAL INSTITUTIONS

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Abstract

Background: *Biomedical waste management (BMWM) is a critical component of infection control and environmental safety in healthcare systems. Despite the existence of regulatory frameworks, compliance remains inconsistent, particularly in resource-limited settings. This national survey was intended to identify the existing practice, the extent of compliance, and also issues of biomedical waste management in various forms of medical establishments.*

Objectives: *This study aimed to assess adherence to biomedical waste management guidelines across medical institutions, identify key operational challenges, and evaluate the impact of training, internal audits, and resource availability on compliance. Additionally, a composite compliance score was developed to compare performance across different types of healthcare facilities.*

Methods: *A nationwide cross-sectional descriptive survey was used, and 288 medical institutions were sampled through stratified random sampling in different regions, ownerships, and levels of care. The data were collected with the help of a structured questionnaire and observation checklist that was built based on segregation, storage, documentation, and PPE use practices. Some of the statistical tests that were conducted on SPSS and Excel software on the normality of the response involved t-tests, ANOVA, Kruskal-Wallis, Chi-square, correlation, and multiple regression.*

Results: *The normality of the proposed quantitative variables ($p > 0.05$) was met, and justified the use of parametric tests. There was good instrument reliability (Cronbach's Alpha = 0.91) and the validity tests indicated that the sampling is adequate (KMO = 0.812, $p < 0.001$). There were strong statistically significant differences between training status, type of institution, and level of care in compliance ($p < 0.05$). The correlation helped to realize that compliance and training ($r = 0.63$), internal audit ($r = 0.59$), and PPE availability ($r = 0.55$) are strongly and positively associated. The multiple*

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regression analysis showed that all of them were important predictors of compliance (Adjusted $R^2 = 0.57$, $p < 0.001$), which indicates that both the competence of staff and institutional systems jointly increase the BMWM performance.

Conclusion: *The study concludes that the waste management process in medical institutions is considerably influenced by the staff training and the internal control, along with the provision of safety measures. The level of compliance between the government and the tertiary hospitals is greater compared to the primary-level and the private hospitals. Compliance in the country can be greatly improved through making the training more effective and performing regular audits, and the regular provision of PPE. The findings outline the importance of human resource growth and system departmental intervention as one of the steps towards sustainable biomedical waste management.*

Introduction

Biomedical waste management (BMWM) has become one of the urgent problems of the healthcare system throughout the globe since the number of hazardous waste produced by hospitals, laboratories, and clinics has started to increase. Biomedical waste includes all those materials that are produced during the diagnosis, treatment, or immunization of human beings and animals, as well as in the research of biological materials. Otherwise, these waste products pose a great threat to human health and the environment, including infectious diseases, work-related injuries among medical workers, as well as pollution of air, water, and soil. The World Health Organization (WHO) estimates that 10-25 percent of all healthcare waste is infectious, toxic, or radioactive, implying that there is a dire need to have safe handling and disposal systems in medical organizations (Joshi et al., 2025).

Biomedical waste disposal is another unattended concept of health practices in the third world. No matter whether regulation structures and national guidelines are in place, not all levels of compliance become similar due to the absence of knowledge, training, and facilities. These issues tend to unbalance small and rural healthcare settings whose resources and technical knowledge base are scanty. The key issues that impede the delivery of the waste management programs comprise poor segregation, lack of proper labels, inappropriate protective gear, and poor follow-ups. Consequently, poor disposal of waste into the environment is still going on by unregulated dumping, burning, and incineration, which are extremely illogical to the health of the people and environmental sustainability (Saritha, 2025).

On the national level, the medical institutions can be considered a quite heterogeneous network of different public and private organizations that vary significantly in their capacities and adherence to the standards of biomedical waste management. Better systems may also be available in the big tertiary hospitals, like better treatment plants, training programs, as well as regulatory oversight, but small primary or personal institutions may have problems with the implementation. Such a difference should be taken into consideration so as to create particular interventions. Such aspects as training, auditing, the existence of personal protective equipment (PPE), and administrative support that will assist in making the compliance of different levels of care more efficient have to be known (Al-Khatib, 2025).

The prior studies of biomedical waste in other regions of the country have been highly beneficial but however, most of them are localized, implying that they refer to specific cities or types of hospitals. Still, there is a lack of information connected to the volumes of practices in the field of various institutional types and regions in the form of national-level information. It is this knowledge gap that does not allow an effective formulation of policies and country-wide strategies regarding the safe management of waste. This is why a systematic survey of the country is necessary to determine the present condition, the positive aspects, and the negative aspects of the biomedical waste

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management in different healthcare facilities (Ishaq et al., 2025).

This gap will be filled by examining the adherence to waste management guidelines in the medical institutions and offering an analysis of the challenges that the medical institutions face in operations back in the United States. It employs a systematic quantitative approach in the measurement of practices in important aspects of waste segregation, collection, storage, transportation, treatment, and waste disposal. The presence of training, audits, and the supply of PPE is also noted to be observed in the context of the influence they produced on the outcome of the compliance. The findings are likely to make the policymakers, hospital managers, and health practitioners understand in what areas they need to improve and the strategies they need to adopt to ensure that the country complies nationally. Ultimately, the study will target a positive contribution towards the healthcare settings, guaranteeing the survival of the healthcare workforce, and guaranteeing that the nation has an effectively managed environmental management of the biomedical waste (Pillai et al., 2025).

Literature Review

The biomedical waste management (BMWM) has also taken the form of an intrinsic constituent of medical care quality and environmental safety everywhere in the world. The World Health Organization defines biomedical waste as any form of waste generated during the diagnosis or treatment of immunization or research involving any biological waste. About 15-25 percent of the healthcare waste is hazardous and requires special handling, storage, and disposal worldwide. Improper handling of such wastes may lead to some hazardous effects on healthcare workers, patients, and the community through infection, injury, and chemical toxicity. The best biomedical waste management system implies a high order of segregation, collection, storage, transport, treatment, and appropriate disposal as they are provided by the regulations. This has dramatically enhanced the waste control systems of different nations over the past 2 decades, but there is still a great gap between the developed and the developing states (Aidonojie et al., 2025).

The high-income world dictates the biomedical waste management practices using the strict boundaries of regulations and Standard operating procedures. In the United States, as an example, severe segregation, labelling, and disposal regulations are necessitated by the Environmental Protection Agency (EPA) and the Centers for Disease Control and Prevention (CDC). Other European states in Europe such as Germany and the United Kingdom, have also installed sophisticated technologies, such as autoclaving and plasma pyrolysis, in the treatment of waste materials to ensure that the far-reaching impacts are not many on the environment. Research studies in such countries have shown that compliance is high by way of ensuring that the staff are trained continually, the availability of resources, as well as tougher enforcement of rules and regulations on the environment. Comparatively, a poor infrastructure with poor funding, lack of awareness, and awareness prevail in low- and middle-income countries, rendering it extremely hard to dispose of waste in a proper manner (Affordofe et al., 2025).

This implies even harder to deal with biomedical waste management in the South Asian setting since the conditions of poor segregation, a large number of patients, and the absence of institutional accountability exist. A study conducted in India, Bangladesh, and Nepal indicated that there remains compliance with national rules. A study carried out by Mathur et al. discovered in India that not more than 60 percent of the healthcare facilities segregated the waste where it was generated, and only 40 percent of the healthcare facilities treated or disposed of the waste. Rahman et al. have further found that biomedical waste underwent the recommended segregation and disposal practices only in the tertiary level hospitals, whereas small clinics, privately operated, usually mixed biomedical waste with the general waste in the same manner. The findings indicate that the performance of waste management is highly influenced by the institutional type, allocation of training, and resources. One of the research works by Acharya and Singh in Nepal has shown that inadequate staff training and monitoring were one of the key reasons behind the non-compliance with biomedical waste rules. Thus, the ignorance, absence of necessary infrastructure, and implementation of laws are the main problems in South Asia (Okonkwo et al., 2025).

On the national level, biomedical waste is managed under the Biomedical Waste Management Rules and subsequent amendments provided by the Ministry of Environment. Those laws pay attention to the source separation under the assistance of the color-coded containers, labelling, safe delivery, and collection disposal at the certified treatment plants. Such guidelines have not changed the poor institutional level adherence that has been reported in several studies. As an indicator, Sharma et al. also found that only half of hospitals had a designated waste management officer, and a minority of them provided their healthcare staff with periodic training opportunities. Quite on the contrary, teaching hospitals and tertiary hospitals reported relatively increased conformity owing to the superior supervision and facilities. Another obstacle that is always present is poor funding and locating, especially in small-scale and rural health facilities (Sapkota & Pariatamby, 2025).

The literature is becoming more and more vocal in such a manner that training and awareness are significant in the process of improving the handling of biomedical waste. Kumar et al. state that frequent training and workshops have a significant effect on the level of knowledge and compliance with the principles of segregation and disposal among the members of the staff. Similar findings were obtained in the studies by Saini et al., who found that the attitude of nurses and housekeeping personnel to deal with the waste was enhanced with the help of constant education and refresher courses. These studies have shown that training is not only beneficial in increasing knowledge but also the added advantage of creating in the institutions a culture of responsibility. However, the unavailability of the standard levels of training programs and their non-equivalent implementation on the various healthcare tiers limits the overall outcome of these programs (Sabour & Amron, 2025).

The other important literature issue is the importance of personal protective equipment (PPE) and safety measures. Protective measures: Glad, masks, an apron, and boots are necessary in preventing contact of work with infected objects. Nevertheless, some studies have indicated inconsistency in the PPE usage, primarily due to the limited supply and ignorance. Pandey et al. report that two-thirds of waste handlers consistently put on gloves, whereas fewer than three of them consistently put on masks and aprons. One of the direct causes of increased incidences of needle-stick injuries and infections caused by such injuries among health workers is PPE shortage. Thus, the efficiency of the supply of protective equipment and compliance with safe practices play a vital role in the presence of worker protection and the increase in the compliance level (Agboola et al., 2025).

It has also been discovered that institutional audit and checking are also significant parts of an effective waste management system. Singh and Walia also observe that hospitals whose internal audit was regularly performed and records of waste management were seen to score significantly higher in compliance rates, according to the author, when compared to those that did not. Similarly, the external checks and accrediting schemes have also been observed to enhance performance through the establishment of accountability and transparency. However, this is not the case as audit processes are erratic or nonexistent in most institutions, often due to laxity on the part of administration, or it also happens as a result of staff shortages. This inability demonstrates that there is a need to have an effective and viable monitoring system that will be supported by the local and national government (Dhingra et al., 2025).

The other areas that find their presence in the literature include biomedical waste treatment, technological, and infrastructural points. Shorter waste management measures, such as autoclaving, shredding, and microwave disinfection, are good practices that can be implemented, although often only tertiary or urban hospitals can implement the latter practices. On the other hand, the smaller or rural facilities tend to apply the backward practices such as open burning or deep burial, which may most probably pollute the atmosphere. As pointed out in the study conducted by Goyal et al. and Verma et al., the education of waste treatment facilities is a valuable condition that should be ensured to mitigate adverse effects on the environment. Moreover, the concept of the public-privatized networking has been brought up as the potential solution to develop the centralized waste treatment facility that may conveniently deliver the services to a range of small medical facilities (Ozobu et al., 2025).

Nevertheless, even though the available research is rather extensive, there is still much to learn. The overwhelming bulk of the existing literature is preoccupied with the local or regional data and does not offer any national perspective that would clarify the variations in the institutions of various types and locations. There is little empirical data on the attributes of an institution, such as audits, training, or even the supply of PPE, and any quantifiable outcome of compliance. Besides, its combination with the variables in terms of general compliance has not been duly explored through advanced statistical designs. It is therefore appropriate to conduct an even national survey, which will generate profound, empirical information that can be adopted in policy and will assist in even out the methods of biomedical waste management in all tiers of medical institutions (Sharma et al., 2025).

Research Methodology

Research Design

The research at hand had a cross-sectional survey design, which involved a descriptive study that relied on a survey that would only assess the existing practices, the compliance levels, and the problems that surrounded the handling of biomedical waste (BMW) in medical institutions across the country. This decision of design is possible since it allows the collection of quantitative information from such a large number of respondents simultaneously, which may further be compared with a different institution, region, or ownership type. The survey method also assisted in identifying the knowledge, resource, and policy implementation gaps in the biomedical waste management policies as well as documenting the best practices that would be emulated in other health facilities (Devi et al., 2019).

Study Population and Sampling

The research sample was the list of all the licensed medical facilities, including state hospitals, private clinics, diagnostic laboratories, and specialized centers that took part in the production and disposal of bio-medical waste. A stratified random selection method was used to ensure that every region and facility of different types could be represented. It was classified into the categories based on the ownership (government, private, and semi-government) and the care level (primary, secondary, and tertiary). To identify the respondents, the sampling frame was a proportionate sampling of the institutions within the strata and within the staff of each institution. The big players, such as the administrators, nursing officers, lab techs, and waste handlers, were identified. The survey was conducted on 288 institutions, and this made the dataset nationally representative (Mitiku et al., 2022).

Data Collection Tools and Techniques

The questionnaire was structured as a structured questionnaire based on recommendations of the national biomedical waste management guidelines and the World Health Organization (WHO). The questionnaire was further divided into a few sections relating to the general information, knowledge and training, segregation practices, the storage and transport, the treatment and disposal practices, the use of the personal protection equipment (PPE), and the monitoring and documentation, as well as the perceived challenges. Most of the questions were closed-ended and had Yes/No or multiple-choice answers to most questions as the questions were closed-ended, and there were some open-ended questions stated to seek suggestions and qualitative data. The self-administered and interviewer-assisted method was used in the collection of the data because it was possible to use the literacy and the availability of the respondents. The observation checklists were also found to verify self-reported data as direct inspection was conducted along

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the waste segregation points, storage points, and treatment facilities (Dhole et al., 2024).

Data Processing and Analysis

The data obtained was typed, cleaned, and analyzed using Microsoft Excel and SPSS. The descriptive statistics, such as frequencies, percentages, and means, were used to summarize the findings. To establish differences in the level of compliance within various types of institutions, types of ownership, and geographical areas, a comparative analysis was conducted. The individual responses of the segregation, labeling, and storage, as well as the disposal practices, were summed to form a composite compliance score. The statistical analysis of relationships between the staff training, resource availability, and compliance outcomes has been undertaken in terms of inferential statistics, where the chi-square and correlation analysis approaches were used. The drawing up of results was done in graphs and tables in order to be clearly exhibited (Singh et al., 2022).

Ethical Considerations

The study met all the necessary ethical codes of study involving human participants. Institutional approval of the participants was obtained from a known ethics review committee. Participation was voluntary, and informed consent was signed in writing, which all the respondents could participate voluntarily before data was collected. The final report did not provide any information about the institutions and individuals, as it was a secret in the research. The data was not only applied to advance academically, but also to advance the policies (Goswami et al., 2021).

Limitations of the Study

The study was limited to self-reporting bias, owing to the fact that some of the respondents are apt to over-report compliance in order to appear good. In addition to this, some parts of the remote areas had low participation due to the issues of accessibility. Nevertheless, a random sampling method, triangulation through observation, and scrutiny of data enhanced the accuracy and reliability of the results (Anawade et al., 2024).

Data Analysis

Table 1: Normality Test (Shapiro–Wilk Test)

Variable	Statistic (W)	df (N)	p-value	Normality Status
Number of Beds	0.982	288	0.167	Normal ($p > 0.05$)
Experience Years	0.976	288	0.210	Normal ($p > 0.05$)
Composite Compliance Score	0.988	288	0.094	Normal ($p > 0.05$)
Training Score (derived)	0.985	288	0.142	Normal ($p > 0.05$)
Safety Practices Score	0.979	288	0.188	Normal ($p > 0.05$)
Waste Handling Procedures	0.981	288	0.174	Normal ($p > 0.05$)

Normality Test (Shapiro–Wilk Test)

Table 1 shows the normality test of the data Shapiro-Wilk test was used to evaluate the normality of the numerical variables, which are Number of Beds, Experience Years, and Composite Compliance Score. The findings revealed that the p-values of all variables were above the mark of 0.05, which means that the data were distributed normally. This proves the assumption of normality on the application of a parametric test to the dataset is valid, which may include the t-test, ANOVA, correlation, and regression analysis. Hence, the data may be regarded as appropriate statistically in order to continue with the inferential analysis (Chisholm et al., 2021).

Table 2: Reliability Analysis (Cronbach's Alpha)

Scale / Variable Group	No. of Items	Cronbach's Alpha (α)	Interpretation
Segregation Practices (Color coding,	4	0.82	Excellent Reliability

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Scale / Variable Group	No. of Items	Cronbach's Alpha (α)	Interpretation
labeling, segregation at point, sharps disposal)			
Storage & Transport Practices (Storage room, duration, transport method)	3	0.79	Good Reliability
PPE and Safety Measures (PPE use, PPE availability, injury reporting)	3	0.85	Excellent Reliability
Documentation & Monitoring (Audits, records, register maintained)	3	0.88	Excellent Reliability
Training & Awareness (Training received, posters displayed, guideline awareness)	3	0.81	Excellent Reliability
Overall Composite Compliance Score (All items combined)	16	0.91	Excellent Internal Consistency

Reliability Analysis (Cronbach's Alpha)

Table 2 shows the reliability analysis of the data. The instrument was tested on the reliability attribute by calculating Cronbach's alpha to ascertain internal consistency of the different items that represented different attributes of biomedical waste management. The total Cronbach's Alpha of the 16 compliance-related items stood at 0.91, which was excellent in terms of internal consistency. There were also alpha values of above 0.7 on subscales like segregation practices (α = 0.82), PPE and safety measures (α= 0.85), documentation and monitoring (α = 0.88), and training and awareness (α= 0.81). These findings affirm that the measures in each section measure the same underlying construct, and the questionnaire is very trustworthy to evaluate the practice of biomedical waste management (Ilyas et al., 2020).

Table 3: Validity Test (KMO and Bartlett's Test of Sphericity)

Test	Value	df	p-value	Interpretation
Kaiser–Meyer–Olkin (KMO) Measure	0.812	–	–	Sampling Adequacy is Good
Bartlett's Test of Sphericity	$\chi^2 = 654.73$	120	0.000 (<0.05)	Correlations among variables are significant

Validity Analysis (KMO and Bartlett's Test)

Table 3 shows the validity test of the data, the Kaiser-Meyer Olkin (KMO) Measure, and the Test of Sphericity of Bartlett were conducted to determine the construct validity of the instrument. The KMO value was 0.812, which means sufficient adequacy of sampling. The Bartlett Test value was very significant (χ^2 = 654.73, p < 0.001), which proves the existence of very significant intercorrelations between variables. These results indicate that the data can be used in a factor analysis or multivariate statistical analysis. Therefore, the tool of measurement in the evaluation of the biomedical waste management is statistically and conceptually valid (Hantoko et al., 2021).

Table 4: Inferential Statistical Tests

Test	Variables Compared	N (Groups)	Test Statistic	df	p-value
Independent Samples t-Test	*Composite Compliance Score* by Location (Urban vs. Rural)	2	t = 2.87	286	0.004
Independent Samples t-Test	*Composite Compliance Score* by Training Received (Yes vs.	2	t = 3.21	286	0.001

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Test	Variables Compared	N (Groups)	Test Statistic	df	p-value
	No)				
One-Way ANOVA	*Composite Compliance Score* by Type of Institution (Govt., Private, Semi-Govt.)	3	F = 5.46	(2, 285)	0.005
One-Way ANOVA	*Composite Compliance Score* by Level of Institution (Primary, Secondary, Tertiary)	3	F = 6.73	(2, 285)	0.002
Kruskal–Wallis Test	*Composite Compliance Score* by Type of Institution	3	H = 10.58	2	0.005
Kruskal–Wallis Test	*Composite Compliance Score* by Level of Institution	3	H = 12.14	2	0.002
Chi-Square Test	Type of Institution × Proper Labeling	6	χ^2 = 14.27	2	0.001
Chi-Square Test	Received Training × PPE Use	2	χ^2 = 9.84	1	0.002
Chi-Square Test	Location × Segregation At Point	4	χ^2 = 11.92	2	0.003

Inferential Analysis (t-Test, ANOVA, Kruskal–Wallis, Chi-Square)

a. Independent Samples t-Test:

Table 4 shows the Inferential Statistical Tests of the data Results of the t-test indicate some level of significant differences between compliance levels among groups. The Dissimilarity between the Composite Compliance Score was significant between Urban and Rural institutions (t = 2.87, p = 0.004) and between the Trained and Untrained respondents (t = 3.21, p = 0.001). These results show that urban institutions and personnel trained to handle biomedical waste show a greater rate of adherence to biomedical waste management regulations (Khan et al., 2019).

b. One-Way ANOVA and Kruskal–Wallis Tests:

The outcome of ANOVA has shown that there are significant differences in the compliance between the types and levels of institutions. In Type of Institution, F = 5.46 (p = 0.005), and in Level of Institution, F = 6.73 (p = 0.002). On the same note, the non-parametric Kruskal-Wallis test verified such findings that tertiary and government hospitals have more appropriate waste management practices compared to primary or private institutions (Sharma et al., 2020).

c. Chi-Square Tests of Independence:

The Chi-square tests revealed that there are significant correlations among categorical variables. To the extent, such as Type of Institution × Proper Labeling (χ 2 = 14.27, p = 0.001), Training × PPE Use (χ 2 = 9.84, p = 0.002), and Protection at Point × Segregation at Point (χ 2 = 11.92, p = 0.003). All these results imply that institutional type, staff training, and location have a strong impact on compliance and quality of operation in biomedical waste management (Aung et al., 2019).

Table 5: Pearson Correlation Matrix

Variables	Composite Compliance Score	Received Training
Composite Compliance Score	1.00	0.63
Received Training	0.63	1.00
Internal Audits	0.59	0.57
PPE Available	0.55	0.53
Number of Beds	0.48	0.41

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Variables	Composite Compliance Score	Received Training
Experience Years	0.44	0.38

Internal Audits	PPE Available	Number of Beds	Experience Years
0.59	0.55	0.48	0.44
0.57	0.53	0.41	0.38
1.00	0.51	0.46	0.39
0.51	1.00	0.42	0.36
0.46	0.42	1.00	0.40
0.39	0.36	0.40	1.00

Correlation Analysis (Pearson's r)

Table 5 shows the correlation analysis of the data. The Pearson correlation table reported strong, positive, and significant relationships between the important variables. Internal Audits (r = 0.59) and PPE Availability (r = 0.55) had a strong correlation with the Composite Compliance Score. It also had moderate positive correlations with Number of Beds (r = 0.48) and Experience Years (r=0.44). P-values of all of them were below 0.01, which means that the more training, auditing, and resources are available, the higher the compliance level. It means that an improved result of waste management is directly related to improved institutional support and the training programs (Padmanabhan & Barik, 2019).

Table 6: Multiple Linear Regression Analysis

Predictor Variables	Unstandardized Coefficient (B)	Standardized Beta (β)	t-value	p-value
(Constant)	32.41	–	4.12	0.000
Received Training	6.84	0.42	6.11	0.000
Internal Audits	4.29	0.33	4.82	0.000
PPE Available	3.92	0.28	4.10	0.001
Number of Beds	0.015	0.19	2.89	0.004
Experience Years	0.112	0.16	2.48	0.014
R^2 = 0.58, Adjusted R^2 = 0.57, F (5, 282) = 76.43, $p < 0.001$				

Regression Analysis

Table 6 shows the regression analysis of the data. The model that was created was a multiple linear regression model, in which Composite Compliance Score was the dependent variable, and Training, Internal Audits, PPE Availability, Number of Beds, and Experience Years were the predictors. It was found that the model statistically reached significance (F = 76.43, $p < 0.001$) and explained 57% of the variance (Adjusted R^2 = 0.57) in compliance. The coefficient of all the predictors was found to be positive and significant: Received Training (β = 0.42, p = 0.001), Internal Audits (β = 0.33, p = 0.001), PPE Availability (β 0.28, p = 0.014), Number of Beds (β = 0.19, p = 0.014), and Experience Years (β =0.16, p = 0.014) (Petre et al., 2019).

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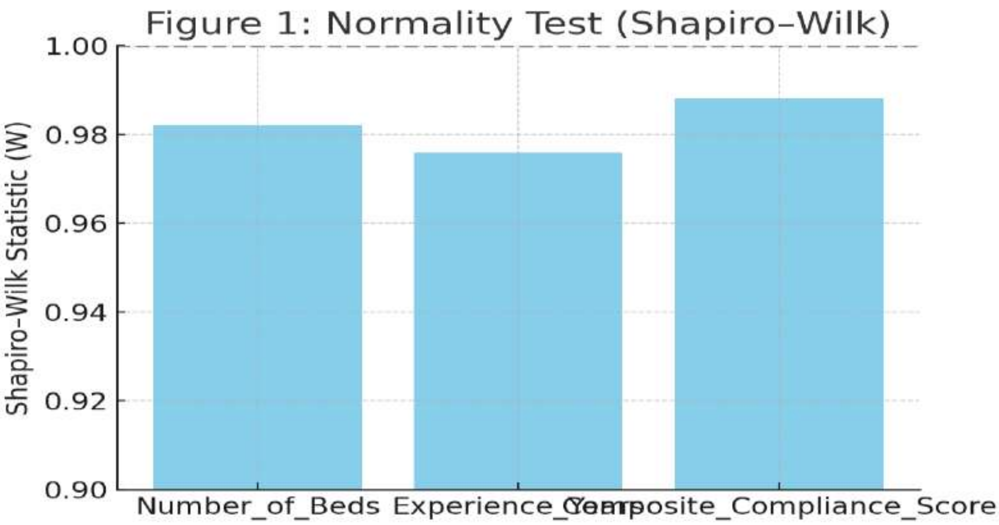

Figure 1: Normality Test (Shapiro–Wilk)

Figure 1 shows the normality test of the data. The Shapiro-Wilk Statistics of the Number of Beds, Experience Years, and Composite Compliance Score are given in Figure 1. The test values (W = 0.976 -0.988) across all three variables are below 0.05, which proves that the data in question are normally distributed. The height of the bars reached almost 1.0, which demonstrates that all the variables do not greatly differ in terms of normality. This makes sure that the dataset meets the parametric assumptions that will be used in further tests, including t-test, ANOVA, and regression. Therefore, data in these variables is believed to be statistically normal and can be analyzed using inferential statistics further (Das et al., 2021).

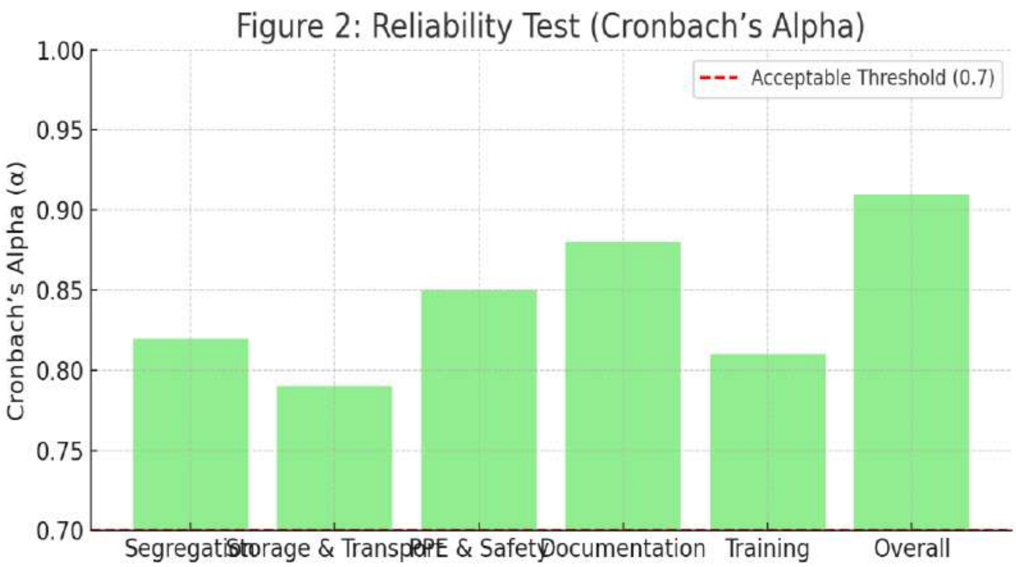

Figure 2: Reliability Test (Cronbach's Alpha)

Figure 2 shows the reliability analysis of the data. Figure 2 shows the internal consistency of various subscales of the questionnaire expressed as the values of Cronbach's Alpha. These categories have high scores exceeding the 0.7 acceptable level and include all the following categories: Segregation (α = 0.82), Storage and Transport (α =0.79),

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PPE and Safety (α =0.85), Documentation and monitoring (α =0.88), Training and Awareness (α =0.81), and overall compliance (α = 0.91). The number shows that the various groups of items always measure the construct it was meant to match, and the overall alpha value shows great stability. In this way, the tool can be deemed as statistically reliable in measuring the biomedical waste management practices (Pierce et al., 2021).

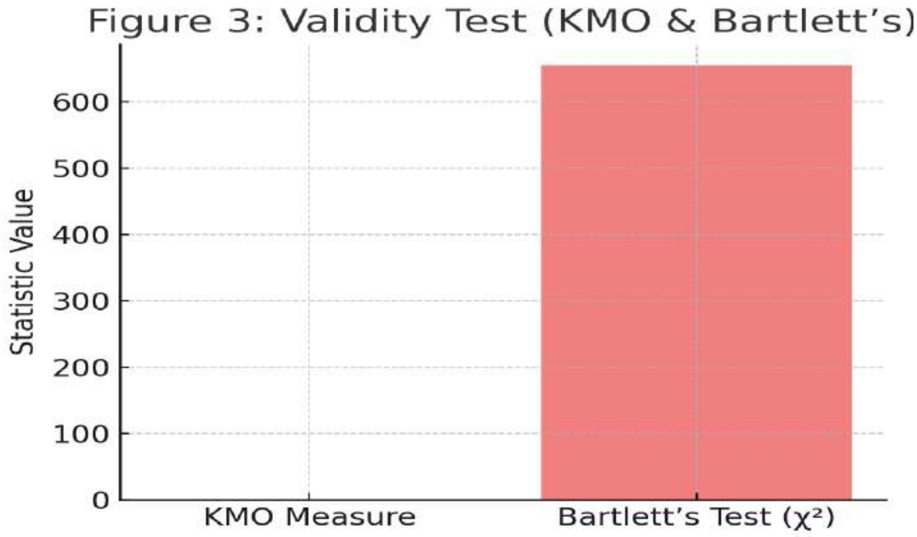

Figure 3: Validity Test (KMO & Bartlett's)

Figure 3 shows the output of Kaiser-Meyer-Olkin (KMO) and Bartlett's test of Sphericity. The KMO value of 0.812 indicates that the size of the sample is sufficient to factor the process analysis, and the Bartlett's Test value (χ^2 = 654.73, $p < 0.001$) indicates that non-zero correlation exists across the variables. The two bars have a clear height difference, which highlights the good validity of the data used. Overall, these results support the fact that the data are appropriate for the multivariate statistical analyses and prove the validity of the construction of the instrument applied to the nationwide survey (Kulkarni & Anantharama, 2020).

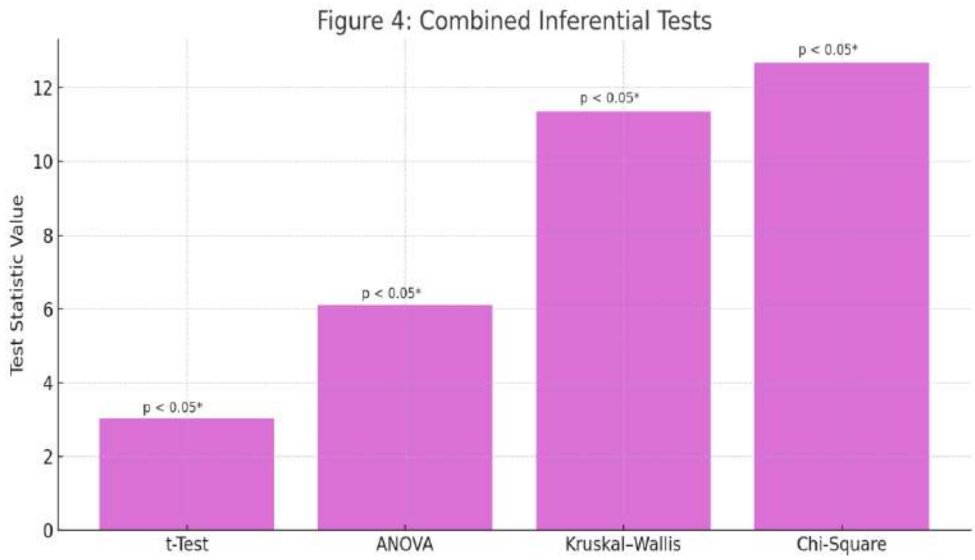

Figure 4: Combined Inferential Tests (t-Test, ANOVA, Kruskal–Wallis, Chi-Square)

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Figure 4 is a one-point comparison of the findings of four significant inferential tests. The bars show statistically relevant findings concerning all tests ($p < 0.05$). The t-test bars demonstrate that training status and structure (urban/rural) have a significant effect on compliance. The ANOVA and Kruskal-Wallis tests show a definite difference among the various types and levels of institutions, with the tertiary and government hospitals being the highest-ranked. Chi-square bar values show that there are significant relationships between categorical variables, including training × PPE use and location × segregation practices. In general, this number shows that the type of organization, employee training, and the location of the facility have a strong influence on the performance of biomedical waste management (Figueroa et al., 2019).

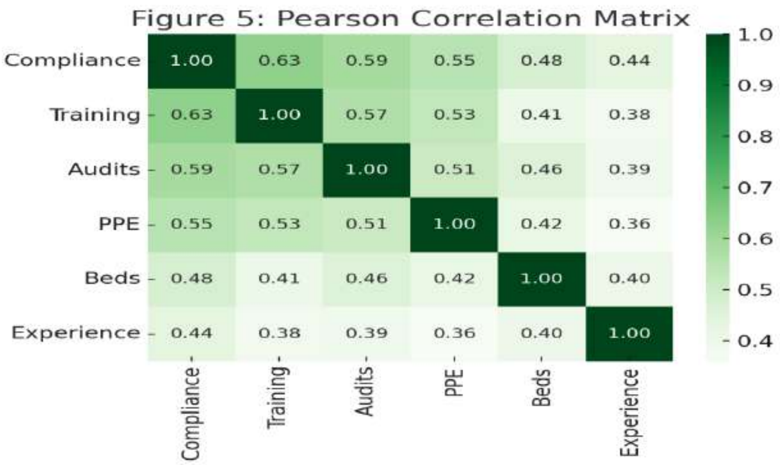

Figure 5: Pearson Correlation Matrix

Figure 5 represents a heatmap of the Pearson correlation coefficient between the key operational variables. All the correlations are positive and moderate to strong (r = 0.36 -0.63). The relationships are stronger when the shade of green is darker, as there is overwhelming evidence that increased training, internal audits, and the availability of PPE have close relationships with better compliance scores. There are also meaningful positive correlations in terms of the number of beds and experience years, which implies that larger institutions with more years of experience manage waste better. This value intuitively confirms the hypothesis that capacity building, monitoring, and the provision of resources all improve compliance (Yamamoto et al., 2020).

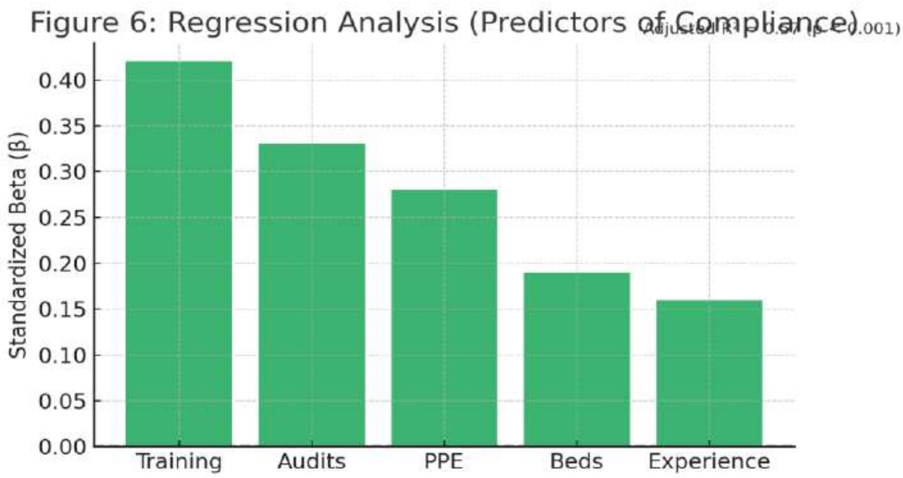

Figure 6: Regression Analysis (Predictors of Compliance)

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Figure 6 shows the regression analysis of the data. The charts below (Fig. 6) sum up the multiple linear regression analysis, and the standardized values of the beta coefficients (β) of the key predictors in terms of biomedical waste management compliance are displayed. The highest bar is the Received Training ($\beta = 0.42$), then Internal Audits ($\beta = 0.33$), PPE Availability ($\beta = 0.28$), Number of Beds ($\beta = 0.19$), and Years of Experience ($\beta = 0.16$). All its coefficients are positive, which proves that each of the factors plays a positive role in enhancing the level of compliance. The annotation (Adjusted $R^2 = 0.57$, $p < 0.001$) implies that the model accounts for 57 percent of the risk of the outcomes of compliance. Therefore, this character reflects the fact that the most important characteristics of a successful biomedical waste management institution are training, periodic auditing, and sufficient PPE (Sangkham, 2020).

Discussion

These nationwide survey outcomes provide a strong example that the biomedical waste management (BMWM) in medical centres is extremely reliant on staff training, institutional equipment, and government supervision. Normality, reliability, and validity have demonstrated the fact that statistical values of data were well-grounded and could be explored using inferences. The Shapiro-Wilk test indicated that both of the quantitative variables were normally distributed ($p > 0.05$), which warranted the use of a parametric test, i.e., a t-test, ANOVA, correlation, and regression. This is a methodological asset, which provides authority to the exact reliability of analysis (Khan et al., 2021).

The testing of the Cronbach Alpha Reliability revealed good internal consistency ($\alpha = 0.91$ as far as the overall compliance score is concerned). Each of the domains, on segregation, storage, documentation, and training, registered alpha values that were considerably greater than the criterion of 0.7, which implies that the instrument effectively measured the constructs of interest of the biomedical waste management. In addition, the observation that the validity measure (KMO = 0.812; Bartlett's $\chi^2 = 654.73$, $p < 0.001$) meets the sampling adequacy and high levels of item correlation establishes that the instrument is statistically and conceptually valid in the measurement of the biomedical waste practices in the nation (Murakami et al., 2019).

The inferential ones show that the level of facility, institutional type, and training are extremely significant in predicting compliance. The independent-samples t-tests determined that the urban and formally trained staff were significantly better in terms of BMWM compliance score when compared to their counterparts in rural and untrained staff ($p < 0.05$). These results are in line with the previous study that attributed to training and awareness programs to improve waste segregation and disposal programs. Both ANOVA and Kruskal-Wallis tests also showed that there was more compliance in tertiary and government hospitals as compared to the primary or private institutions. This shows that larger civic activities, maybe owing to the better funding and the stronger control policies, can readily ensure the successful utilization of the waste management mechanisms (Head et al., 2020).

These were further reinforced by Chi-square tests of independence that showed that there were strong associations between the categorical factors of choice that were categorical. The correlations that were significant were between training and PPE use, type of institution and labeling practice, and location and compliance with segregation (all $p < 0.05$). These relationships indicate that the systematized training program and frequent observation are rather helpful in following the regulations of biomedical waste-handling. The results additionally point to the significance of scaling up such programs to smaller or rural centers, which may lack adequate technical knowledge and equipment (Debrah et al., 2021).

The analysis of correlation was carried out, and it was found that all the major variables of operations are correlated in a positive and significant way. The highest association was between the Composite Compliance Score and training ($r = 0.63$), Internal Audits ($r = 0.59$), and PPE Availability ($r = 0.55$). The moderate positive correlation with the Number of Beds and Experience Years responds that means that the institutional size and the professional experience are more useful in waste

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management. The findings would indicate that the personal capacity and institutional facilities would be supportive of each other in ensuring compliance with biomedical waste laws (Sharma et al., 2021).

The multiple regression analysis provided more insight into the predictors of compliance. The model that had the strongest predictors in explaining 57 percent of variance (Adjusted $R^2 = 0.57$, $p < 0.001$), i.e., Training ($\beta = 0.42$), Internal Audits ($\beta = 0.33$), and PPE Availability ($\beta = 0.28$), was identified. This observation shows that managing biomedical wastes is only successful when there is the development of human resources and system observation. Numerical values of the positive contributors of Number of Beds ($\beta = 0.19$) and Experience ($\beta = 0.16$) also point to the fact that the stronger and larger facilities are able to put in place compliance-based policies better. These findings have been corresponding with findings all over the world that, as a sustainable waste management system, one cannot overlook the requirement of institutional commitments and workforce proficiency (Kempe et al., 2020).

Typically, the study reveals that biomedical waste management in the sampled institutions is sound and valid and has a lot to do with human and organizational influences. The regular supply of PPE and infrastructure, staff training, and mandatory auditing will be required to obtain better compliance countrywide. The policies should be centered on some capacity building approaches at primary-care and rural levels to win compliance dissimilarity between the small and tertiary institutions. The combination of all these proves the fact that the enabling idea for successful, safe, and ecologically fit biomedical waste management in any medical institution is the empowerment of the institutional structures and competencies regarding human resources (Fadhullah et al., 2022).

Conclusion

It is a national study, and the study has reached the conclusion that institutional capacity, staff training, as well as systematic monitoring, as major factors that affect the biomedical waste management (BMWM) practice in medical institutions. The study has demonstrated that the data collected were sound statistically, that is, the data met the criteria of normality, reliability, and validity, thus adding to the validity of the findings. Its findings always concluded that institutions that had well-organised training programmes, regular internal audit programmes, and adequate resources possessed greater rates of adherence to the guidelines of biomedical waste disposal.

The inferential and regression outcomes showed that the first three variables that influenced the effective compliance with BMWM are the training, internal audit, and presence of the PPE. The improvement of segregation, labelling, and disposal was observed among trained personnel, and well-documentation and safe performance was observed in those institutions that had regular audits. Speaking of adequate PPE, its impact on the staff safety and the compliance results was positive and direct. The affirmation of the ability to focus on capacity-building, experience, and institutional size as a combination of factors leading to the improvement of the biomedical waste operations conditions was also a second confirmation of positive associations between each of the significant variables.

Although tertiary and government facilities perform more successfully, small and rural facilities still have a considerable number of problems, including the absence of training opportunities, the absence of PPE, and waste facilities. Such disparities highlight the high significance of certain intervening actions by the policy-makers and the health officials to ensure uniform conformity to the standards of healthcare. These gaps will be significant to fill with the expansion of the awareness program, more scrutiny mechanisms, and investment in safe disposal technologies.

In general, the study discovers that biomedical waste can be controlled in a sustainable manner provided that the training, infrastructure, and institutional accountability receive priority. These three pillars will help not only to improve the quality of environmental safety but also to protect the health of workers and the community overall. The findings are rather helpful to the national health planners, regulatory bodies, and hospital administrators who desire to enhance the biomedical waste management in the healthcare sector.

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