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Assessment of Biomedical Waste Management, Segregation Compliance and Disposal Practices in Public Hospitals of Charsadda District, Khyber Pakhtunkhwa, Pakistan

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Abstract

The management of biomedical waste is a crucial public health concern; however, few studies have assessed the situation at the district level in Pakistan. This study assessed and compared biomedical waste management (BWM) practices across three public hospitals in Charsadda District, Khyber Pakhtunkhwa, Pakistan. A cross-sectional descriptive assessment was conducted during the fourth week of February 2025 at the District Headquarters Hospital (DHQ) Charsadda, the Women and Children Hospital (WCH) Charsadda, and the Tehsil Headquarters Hospital (THQ) Tangi. The assessment employed structured questionnaires administered to healthcare workers (HCWs n = 90 across three facilities: DHQ = 35; WCH = 30; THQ = 25), observational checklists, key-informant interviews with waste management officers, and retrospective hospital waste records. Descriptive statistics and cross-facility comparisons were used for analysis. Monthly waste generation was highest at DHQ Charsadda (900 kg; 580 beds), followed by WCH (600 kg; 450 beds) and THQ Tangi (500 kg; 350 beds). The waste composition at DHQ comprised general waste (38%), infectious waste (36%), pharmaceutical waste (10%), pathological waste (8%), and sharps waste (8%). At WCH, 40% was general waste, 25% infectious, 15% pathological, 10% pharmaceutical, and 10% sharps. THQ Tangi lacked detailed composition data. Segregation compliance varied considerably: WCH achieved greater than 90% compliance across departments, DHQ ranged from 50% to 90% depending on the department, and THQ Tangi had no functional segregation system. At WCH, 60% of waste was disposed of through licensed incineration, whereas open dumping without pre-treatment was the primary method at THQ Tangi. Approximately 90% of staff at WCH had received formal BWM training compared with 30% at DHQ and 40% at THQ Tangi. The main barriers reported at THQ Tangi were lack of resources (50%), weak regulations (30%), and lack of awareness (20%). Considerable variation was observed among the three hospitals in BWM practices, with THQ Tangi demonstrating the weakest performance in segregation and treatment, and WCH displaying comparatively stronger practices in training and compliance.

Targeted investments in infrastructure, systematic training programmes, and enhanced regulatory enforcement at the facility and district level are recommended.

Keywords: Biomedical waste management; Healthcare waste; Waste segregation; Hospital waste disposal; Environmental health; Occupational safety

Introduction

Biomedical waste refers to any waste generated during medical care, testing, diagnosis, vaccination, surgical procedures, or medical experiments conducted on humans or animals. This waste arises from hospitals, clinics, research laboratories, and other healthcare institutions, and may include hazardous chemicals, infectious agents, or radioactive substances (WHO, 2014). According to the World Health Organization (WHO), healthcare waste is broadly classified into six categories: infectious waste, pathological waste, sharps waste, pharmaceutical waste, chemical waste, and general non-hazardous waste. Approximately 85% of healthcare waste is general non-hazardous waste that can be managed similarly to domestic waste, whereas the remaining 15% requires special handling and disposal procedures.

Hospitals worldwide generate waste in the range of 0.5–2.0 kg per bed per day, with 10–25% of this waste being hazardous (Patil and Shekdar, 2001; Shalini et al., 2012). The risk of infection transmission is considerable because blood-borne pathogens, such as Hepatitis B virus (HBV), Hepatitis C virus (HCV), and Human Immunodeficiency Virus (HIV), may be transmitted through needlestick injuries and contact with contaminated materials during waste handling (Ananth et al., 2010). Occupational health risks are particularly elevated for healthcare workers, sanitation personnel, waste handlers, and communities residing near healthcare facilities. In addition, improper disposal practices contribute to environmental pollution of water, air, and soil, and the release of pharmaceutical residues may promote the development of antimicrobial resistance (Misra and Pandey, 2005; Lakshmikantha, 2006).

Despite growing recognition of biomedical waste management (BWM) as a public health priority, adoption of effective BWM systems remains poor in many low- and middle-income countries. The WHO (2014) estimated that only 31% of healthcare facilities in the least developed countries had basic waste management systems in place. Pakistan faces considerable challenges in this regard. Ali et al. (2016) reported poor segregation practices and unsafe storage and transport procedures in hospitals in Gujranwala. Ahmed and Ahmed (2008) documented shortages of trained personnel and inappropriate waste disposal in hospitals in Karachi. Ali et al. (2015) observed weaknesses in labelling, transportation, and segregation practices in hospitals in Rawalpindi and Islamabad despite generally satisfactory hygiene standards. In Peshawar, Khalid et al. (2021) found no meaningful differences in waste management between public and private facilities and recommended the adoption of standardised protocols.

Although these studies from major Pakistani cities provide valuable insights, district-level assessments remain limited. Charsadda District in Khyber Pakhtunkhwa houses several healthcare facilities; however, BWM practices in this district have received little scholarly attention. The absence of empirical data hinders understanding of local waste management challenges and the development of context-specific solutions. This study aimed to: 1) Describe and compare biomedical waste generation, segregation, treatment, and disposal practices across three public hospitals in Charsadda District. 2) Evaluate the training status and self-reported awareness of healthcare workers regarding BWM practices at each facility. 3) Identify operational barriers to safe BWM through questionnaire-based surveys and direct observation. 4) Formulate evidence-based recommendations for facility-level and district-level stakeholders.

Materials and methods

Study Design

A cross-sectional descriptive assessment was conducted to evaluate BWM practices in three public healthcare facilities in Charsadda District, Khyber Pakhtunkhwa Province, Pakistan. The study employed a multi-source assessment methodology comprising structured questionnaires, observational checklists, key-informant interviews, and retrospective hospital waste records.

Study Setting and Duration

The study was conducted in Charsadda District, situated in the Khyber Pakhtunkhwa Province of Pakistan. Charsadda and Tangi tehsils were purposively selected from among the three tehsils (sub-districts) in the district based on comparable health indicators and logistical accessibility. Field data collection, including questionnaires, observations, and interviews, was conducted during the fourth week of February 2025.

Facility Selection

Three public hospitals were purposively selected to represent different levels of the public healthcare system in the district. The selection was guided by the following criteria: (a) the facility operates as a government-funded public hospital; (b) the facility represents a distinct tier of healthcare delivery (district, specialised secondary, or sub-district); and (c) the facility is located within one of the two selected tehsils. Facilities were included if they had an

operational bed capacity exceeding 100 beds, generated biomedical waste on a daily basis, and had at least one designated waste management officer. Private healthcare facilities, primary-level health centres, and dispensaries were excluded from the study. The selected facilities were:

- District Headquarters Hospital (DHQ) Charsadda (coded G2): the highest-level public hospital in the district with 13 wards and 580 beds, providing tertiary-level care.
- Women and Children Hospital (WCH) Charsadda (coded G3): a specialised secondary-level hospital with 8 wards and 450 beds.
- Tehsil Headquarters Hospital (THQ) Tangi (coded G1): a sub-district-level secondary hospital with 5 wards and 350 beds.

As purposive sampling was employed, the findings are not generalisable to all healthcare facilities in the district or province.

Study Participants and Sampling

A total of 90 healthcare workers (HCWs) were surveyed across the three facilities. The distribution of participants was: DHQ Charsadda (n = 35), WCH Charsadda (n = 30), and THQ Tangi (n = 25). Participants were selected through convenience sampling to include representation from multiple professional categories, namely doctors, nurses, laboratory technicians, pharmacists, and sanitation/waste handling staff. Within each facility, respondents were drawn from all functional departments to ensure coverage of diverse waste generation contexts. The response rate across all three facilities was approximately 95%, with refusals attributed to time constraints during clinical duties.

Data Collection Instruments

Structured questionnaire: A structured questionnaire was developed based on the WHO guidelines for safe management of wastes from healthcare activities (WHO, 2014) and Pakistan's Hospital Waste Management Rules (2005). The instrument comprised both open-ended and closed-ended items and was organised into sections covering socio-demographic characteristics (age, sex, education, work experience, professional category), awareness of BWM practices, attitudes toward waste management, and self-reported practices. The questionnaire was reviewed by two faculty members from the Department of Environmental Sciences, Abdul Wali Khan University Mardan, for face and content validity. Prior to fieldwork, the questionnaire was pilot-tested with 10 HCWs at a non-sampled healthcare centre. Minor modifications in question phrasing and sequencing were made based on pilot feedback. Formal reliability testing (e.g., Cronbach's alpha) was not performed owing to resource constraints; this is acknowledged as a limitation.

Observational checklists: Structured observational checklists were used to document the existing BWM systems at each facility. The checklists covered segregation practices, colour-coding implementation, treatment methods, storage facilities, and final disposal practices. Observations were conducted by trained data collectors.

Key-informant interviews: Semi-structured interviews were conducted with the district healthcare waste management consultant (a district-level officer responsible for BWM oversight) and with facility-level medical officers or staff nurses responsible for waste management at each hospital. Interviews explored current practices, human resource provisions, training activities, material supplies, and disposal mechanisms.

Waste Generation Measurement

Data on monthly waste generation volumes were obtained from hospital administrative records and through interviews with facility management officers. The reported values represent estimated total monthly waste generation as documented in each facility's internal records. It should be noted that waste quantities were not directly measured using standardised weighing instruments during the study period; rather, the values were derived from existing hospital records and management estimates. Daily waste production at the departmental level was further estimated through direct observation and staff reports at DHQ Charsadda and WCH. Because the data were record-based estimates rather than direct measurements, some degree of under- or over-reporting is possible, and the reported waste generation rates should be interpreted with this limitation in mind.

Data Analysis

Data were analysed quantitatively using descriptive statistics, with results presented in tables using frequencies and percentages. Cross-tabulation was used for comparison across the three facilities. No inferential statistical tests (e.g., chi-square test, ANOVA, or Kruskal–Wallis test) were applied; therefore, all observed differences between facilities are reported as descriptive variations and should not be interpreted as statistically significant. The absence of inferential testing is acknowledged as a limitation of the study design.

Ethical Considerations

This study was conducted under the academic guidance of the Department of Environmental Sciences, Abdul Wali Khan University Mardan. Ethical approval was obtained from the Departmental Research Ethics Committee of Abdul Wali Khan University Mardan (Reference No. AWKUM/ENV/2025-02). The study was conducted in compliance with institutional academic research standards. All participants were informed about the purpose and

procedures of the study and provided voluntary informed consent prior to participation. Participants were assured that their involvement was voluntary and that they could withdraw at any time without providing any reason. The identities of respondents were kept confidential throughout the study, and all data were anonymised and stored securely.

Results

Waste Generation

Monthly waste generation varied across the three facilities (Table 1). DHQ Charsadda, the largest facility with 13 wards and 580 beds, reported the highest waste volume at 900 kg per month. WCH reported 600 kg per month (8 wards, 450 beds), while THQ Tangi reported 500 kg per month (5 wards, 350 beds). These differences were associated with facility size, bed capacity, patient volume, and the range of clinical services offered.

Table 1. Characteristics and Monthly Waste Generation of Selected Healthcare Facilities

Facility	Level	Beds	Wards	HCWs Surveyed (n)	Waste (kg/month)
DHQ Charsadda (G2)	District (Tertiary)	580	13	35	900
WCH Charsadda (G3)	Specialised Secondary	450	8	30	600
THQ Tangi (G1)	Sub-district (Secondary)	350	5	25	500

Note: Waste quantities are based on hospital administrative records and management estimates, not direct weighing.

Waste Composition

Biomedical waste composition varied across the facilities (Table 2). At DHQ Charsadda, general waste constituted 38% and infectious waste 36% of total waste output, followed by pharmaceutical waste (10%), pathological waste (8%), and sharps waste (8%). The relatively high proportion of infectious waste compared to the WHO guideline benchmark—which recommends that 75–90% of properly segregated healthcare waste should be general non-hazardous waste (WHO, 2014)—may indicate inadequate segregation and potential cross-contamination at this facility.

At WCH, the composition was: general waste (40%), infectious waste (25%), pathological waste (15%), pharmaceutical waste (10%), and sharps waste (10%). This distribution suggests comparatively better waste classification at the point of generation.

THQ Tangi was reported to generate general, infectious, and sharps waste; however, detailed percentage-based composition data were not available from hospital records, which limits direct comparability across all three facilities. This data gap is acknowledged as a limitation.

Table 2. Waste Composition by Facility (%)

Waste Category	DHQ Charsadda	WCH	THQ Tangi
General waste	38	40	N/A
Infectious waste	36	25	N/A
Pathological waste	8	15	N/A
Pharmaceutical waste	10	10	N/A
Sharps waste	8	10	N/A
Total	**100**	**100**	N/A

THQ Tangi reported generating general, infectious, and sharps waste, but detailed percentage-based composition data were unavailable from hospital records.

Waste Segregation Practices

The three-colour-coded container system was reported to be nominally in place at all three facilities; however, the extent of functional implementation varied considerably (Table 3). At DHQ Charsadda, segregation compliance was highest in the Out-Patient Department (OPD; approximately 90%) and lowest in Paediatrics (approximately 50%), with intermediate levels in the Emergency Department (approximately 75%) and Surgery (approximately 65%). This departmental variation suggests inconsistent implementation and monitoring of segregation protocols.

WCH demonstrated consistently high segregation compliance (greater than 90%) across all departments including OPD, Paediatrics, Emergency, and Maternity. Colour-coded bins were clearly labelled and regularly audited.

At THQ Tangi, although colour-coded bins were nominally present, the facility lacked a functional segregation system in practice. Different waste types were frequently collected together without sorting, rendering the system non-operational.

Table 3. Waste Segregation Compliance by Department and Facility

Department	DHQ Charsadda	WCH	THQ Tangi
OPD	≈90%	>90%	Non-functional
Emergency	≈75%	>90%	Non-functional
Surgery	≈65%	N/A	N/A
Paediatrics	≈50%	>90%	N/A
Maternity	N/A	>90%	N/A

Note: N/A = department not present or not assessed at that facility. Compliance percentages are based on observational assessment and staff reports.

Waste Disposal Methods

Waste disposal methods varied considerably among the facilities (Table 4). At DHQ Charsadda, the primary disposal methods were landfilling (50%), incineration (20%), open burning (15%), and outsourced disposal (15%). The heavy reliance on landfill and open burning for infectious waste presents environmental and public health concerns. Biohazard waste containers were available only at DHQ Charsadda among the three facilities.

WCH employed a more structured disposal system, with 60% of waste disposed of through licensed incineration, 20% through authorised landfills, and 20% through certified outsourcing partners. Systematic documentation of waste collection and disposal was maintained.

THQ Tangi had no on-site incineration facility and relied primarily on open dumping. The Tehsil Municipal Administration (TMA) collected infectious waste without pre-treatment and disposed of it alongside general municipal waste. No biohazard containers were in use at this facility.

Table 4. Waste Disposal Methods by Facility (%)

Disposal Method	DHQ Charsadda	WCH	THQ Tangi
Incineration	20	60	None
Landfilling	50	20	None
Open burning/dumping	15	None	Primary method
Outsourced disposal	15	20	TMA (as general waste)

Waste Treatment Infrastructure

Treatment infrastructure differed markedly among the facilities. Both DHQ Charsadda and WCH had operational incinerators for the disposal of infectious and sharps waste. Photographic evidence from DHQ Charsadda indicated the presence of modern incinerator equipment with digital control panels alongside older, non-functional units, suggesting gaps in equipment maintenance and replacement. WCH operated a licensed incineration facility conforming to health and safety standards. THQ Tangi had no on-site treatment facility, and untreated infectious waste was disposed of alongside regular municipal waste, posing substantial public health risks.

Staff Training and Awareness

Staff training in BWM varied considerably among the three facilities (Table 5). At DHQ Charsadda, 70% of surveyed staff reported having received no formal BWM training, and no training had been provided to cleaning personnel regarding hygiene and disinfection procedures. At THQ Tangi, 60% of respondents reported no formal training. In contrast, 90% of staff at WCH had received formal training through monthly workshops, standard operating procedure (SOP) refresher sessions, and accountability reviews. Regarding personal protective equipment (PPE), WCH provided adequate PPE and associated training, whereas both DHQ Charsadda and THQ Tangi had inadequate PPE provision and training. DHQ Charsadda was the only facility offering safe lifting technique training for waste handlers. WCH was also the only facility reporting a vaccination programme for HCWs against common infectious diseases; no such programmes were reported at DHQ Charsadda or THQ Tangi.

Self-Reported Awareness

At THQ Tangi, 65% of respondents self-reported high awareness of BWM practices, 25% reported moderate awareness, and 10% reported no awareness. The majority (90%) stated that proper BWM is important; however, actual compliance with guidelines was observed to be poor, indicating a gap between perceived importance and practice. Awareness of infection control procedures among cleaning staff was lacking at both DHQ Charsadda and THQ Tangi, while cleaning staff at WCH showed moderate levels of awareness. Respondents at all three facilities agreed that hospital waste cannot be considered as regular solid waste.

Perceived Barriers to Effective BWM (THQ Tangi)

Respondents at THQ Tangi identified the following main barriers to effective BWM: lack of resources (50%), weak regulations (30%), and lack of awareness (20%). Regarding the adequacy of existing regulations, 15% considered them adequate, 50% considered them inadequate, and 35% perceived them as partly adequate.

Table 5. Staff Training, PPE, and Vaccination Status by Facility (n = 90)

Indicator	DHQ (n=35)	WCH (n=30)	THQ Tangi (n=25)
Staff trained (%)	30	90	40
PPE provision	Inadequate	Adequate	Inadequate
Safe lifting training	Yes	No	No
Staff vaccination programme	Not reported	Yes	Not reported
Biohazard containers	Yes	No data	No

Facility Satisfaction

Staff at WCH expressed satisfaction with the waste management systems in place. In contrast, staff at both DHQ Charsadda and THQ Tangi expressed dissatisfaction. THQ Tangi respondents specifically cited insufficient tools, resources, and external support for waste management.

Summary Comparison

Table 6. Comprehensive Comparison of BWM Indicators Across Facilities

Indicator	DHQ (n=35)	WCH (n=30)	THQ Tangi (n=25)
Monthly waste (kg)	900	600	500
Documented waste management plan	Yes	Yes	Yes
Colour-coded bins	Yes	Yes	Yes (nominal)
Functional segregation	Partial (50–90%)	Yes (>90%)	Non-functional
On-site incinerator	Yes	Yes (licensed)	No
Staff trained (%)	30	90	40
Primary disposal method	Landfilling (50%)	Incineration (60%)	Open dumping
PPE provision	Inadequate	Adequate	Inadequate
Vaccination programme	Not reported	Yes	Not reported
Staff satisfaction	Dissatisfied	Satisfied	Dissatisfied

Note: The following figures are recommended for inclusion in the final manuscript: (1) a study area map showing the location of Charsadda District and the three selected hospitals; (2) a methodology workflow diagram; (3) a bar chart comparing monthly waste generation; and (4) bar charts comparing waste composition, segregation compliance, disposal methods, and staff training status.

Discussion

Summary of Findings

This study revealed considerable variation in BWM practices across the three public hospitals assessed in Charsadda District. Although all facilities had documented waste management plans and all staff reported familiarity with colour-coding systems, the extent of practical implementation differed markedly. WCH demonstrated comparatively robust practices, including high segregation compliance (greater than 90%), licensed incineration, systematic staff training, and a staff vaccination programme. THQ Tangi, by contrast, exhibited substantial deficiencies including the absence of on-site treatment facilities, non-functional waste segregation, reliance on open dumping, and inadequate tools and resources for waste management.

Waste Generation and Composition

The monthly waste volumes across the three facilities (500–900 kg) are broadly comparable to values reported at similar district-level public hospitals in Pakistan. The calculated waste generation rate at DHQ Charsadda is approximately 0.05 kg per bed per day, which falls below the internationally reported range of 0.5–2.0 kg per bed per day (Patil and Shekdar, 2001). This discrepancy may reflect incomplete reporting, selective recording of only certain waste categories, or genuinely low waste volumes; verification through standardised direct weighing is recommended. Similar underreporting has been documented in lower-tier facilities in India (Gupta and Sharma, 2020) and Nigeria (Adefisoye and Odukoya, 2020), where record-keeping infrastructure is often inadequate. The composition of waste at DHQ Charsadda, with 38% general waste and 36% infectious waste, deviates substantially from WHO guidelines, which recommend that 75–90% of properly segregated healthcare waste should be classified as general non-hazardous waste (WHO, 2014). Such an imbalance suggests inadequate segregation resulting in cross-contamination, a pattern also reported by Chandran et al. (2017) and Singh and Rathi (2020) in healthcare facilities with insufficient staff training. The more balanced distribution at WCH (40% general, 25% infectious) indicates better classification at the point of generation, consistent with the higher training coverage at that facility.

Segregation and Disposal

The departmental variation in segregation compliance at DHQ Charsadda—from 90% in OPD to 50% in Paediatrics—reflects uneven enforcement and monitoring, a pattern also reported by Shakya and Singh (2019) in

Indian hospitals. The particularly poor compliance in Paediatrics is concerning given the vulnerability of this patient population. In contrast, the uniformly high compliance at WCH (greater than 90% across all departments) may be attributed to the systematic training, regular auditing, and accountability mechanisms in place at that facility. The non-functional segregation system at THQ Tangi mirrors conditions documented in lower-tier facilities in Karachi (Ahmed and Ahmed, 2008) and Gujranwala (Ali et al., 2016).

The high reliance on landfilling (50%) and open burning (15%) at DHQ Charsadda does not conform to WHO guidelines or the Hospital Waste Management Rules (2005), which mandate incineration, autoclaving, or chemical disinfection as the primary treatment for infectious waste. Open burning releases dioxins, volatile organic compounds, and heavy metals, posing environmental and health hazards (Basu et al., 2019). The disposal situation at THQ Tangi is more concerning, as untreated infectious waste is transported by the TMA and disposed of as general municipal waste. Similar findings have been reported at lower-tier healthcare facilities in Pakistan (Ali et al., 2016) and in other developing-country contexts (Gupta and Sharma, 2020; Reddy et al., 2017).

Training and Awareness

The finding that 60–70% of staff at DHQ Charsadda and THQ Tangi had received no formal BWM training represents a critical gap. The literature consistently identifies training as one of the most effective interventions for improving waste management outcomes. Singh et al. (2017) demonstrated that comprehensive training programmes improved segregation and disposal practices, while McGowan and Smith (2019) reported that structured training combined with regular audits reduced hazardous waste mismanagement. The WCH model of monthly workshops and SOP refresher sessions appears to be effective, as reflected in its high training coverage (90%) and consistently high segregation compliance (greater than 90%); however, a causal relationship cannot be established from this cross-sectional assessment.

The absence of training for cleaning staff at DHQ Charsadda and THQ Tangi is particularly concerning, as this group faces the highest occupational exposure to biomedical waste in the hospital setting. The lack of vaccination programmes at two of the three facilities further compounds occupational health risks, consistent with findings reported by Kumar and Agarwal (2020) and Ofori and Mensah (2020). The gap between self-reported awareness (65% of THQ Tangi respondents reporting high awareness) and actual compliance underscores the well-documented knowledge–practice gap in waste management (Ghosh and Rahman, 2018).

Infrastructure and Resource Constraints

The identification of lack of resources as the most frequently cited barrier (50% of THQ Tangi respondents) is consistent with findings from developing-country contexts, where resource constraints are repeatedly identified as a primary impediment to effective BWM (Gupta and Sharma, 2020; Reddy et al., 2017). The absence of biohazard containers, on-site incineration, and adequate PPE at THQ Tangi reflects chronic underinvestment in waste management infrastructure at lower-tier facilities. The contrast between DHQ Charsadda, which possesses modern incinerator equipment, and THQ Tangi, which lacks any treatment infrastructure, highlights the inequitable distribution of resources across healthcare tiers—a pattern noted by Reddy et al. (2017) who observed that lower-tier facilities, despite serving as the primary point of contact for communities, are frequently neglected in resource allocation.

Regulatory Compliance Assessment

Assessing compliance against the Hospital Waste Management Rules (2005), the three facilities demonstrated varying levels of adherence across key domains. In terms of waste segregation, WCH demonstrated high compliance, DHQ showed partial compliance, and THQ Tangi was non-compliant. Regarding storage and containment, only DHQ and WCH used designated biohazard containers. For treatment methods, only WCH employed licensed incineration conforming to regulatory standards; DHQ used a combination of approaches with substantial reliance on non-compliant methods, and THQ Tangi had no treatment capability. Staff training requirements were met only at WCH. PPE provision was adequate only at WCH. These findings suggest that the gap between regulatory provisions and actual implementation remains substantial, consistent with the assessment by Khalid et al. (2021), who attributed implementation gaps to limited regulatory capacity and the absence of systematic monitoring and enforcement mechanisms in Khyber Pakhtunkhwa.

Limitations

Several limitations of this study should be noted. First, the three hospitals were purposively selected from two of the three tehsils in the district; therefore, the findings are not generalisable to the district, province, or country. Second, private healthcare facilities, which constitute a substantial portion of healthcare provision, were not assessed. Third, the cross-sectional design precludes causal inference and measurement of temporal changes. Fourth, self-reported data are subject to social desirability and recall biases. Fifth, detailed waste composition data were unavailable for THQ Tangi, limiting comparability. Sixth, observational assessments may have been influenced by the observer effect, as facility staff were aware of the assessment. Seventh, exact sample sizes per facility category and response rates were not systematically documented in sufficient detail to permit precise

interpretation of all percentage-based findings. Eighth, the study did not assess seasonal variation in waste generation, which may influence volumes and composition. Ninth, no direct environmental contamination analysis (e.g., soil or water sampling near disposal sites) was conducted. Tenth, economic evaluation of waste management systems, including cost–benefit analysis of potential improvements, was beyond the scope of this study. Finally, formal reliability testing of the questionnaire was not performed.

Conclusion

This study documented considerable variation in BWM practices across three public hospitals in Charsadda District. WCH demonstrated comparatively strong practices characterised by high segregation compliance (>90% across all departments), licensed incineration (60% of waste treated through licensed incineration at WCH), systematic staff training (90% training coverage), a vaccination programme, and staff satisfaction with waste management systems. DHQ Charsadda showed moderate performance: functional infrastructure (incinerators and biohazard containers) was present, but departmental segregation was inconsistent (50%–90% depending on department), reliance on landfilling was high (50% of waste disposed via landfill), and staff training coverage was low (only 30% of staff formally trained). THQ Tangi exhibited the weakest performance, with no on-site treatment facility, non-functional segregation, reliance on open dumping, absence of biohazard containers, and insufficient staff training (only 40% trained, vs. 90% at WCH). The findings highlight interconnected challenges of resource limitations, weak regulatory implementation, and knowledge deficits that require coordinated, multi-level interventions. The absence of treatment and segregation capacity at THQ Tangi represents an immediate public health and environmental concern. These results contribute to filling the gap in empirical evidence on BWM at the district level in Khyber Pakhtunkhwa Province.

Recommendations

Targeted investments are required across five priority areas to improve BWM in Charsadda District. First, mandatory and regular training programmes should be implemented for all categories of healthcare workers, including doctors, nurses, sanitation workers, and waste handlers, using the WCH monthly workshop and SOP refresher model as a replicable framework, with priority given to cleaning staff who face the highest occupational exposure. Second, adequate infrastructure investment must be directed to under-resourced facilities, particularly THQ-level hospitals, to ensure access to basic segregation equipment, colour-coded biohazard containers, adequate PPE, and either on-site or certified outsourced licensed waste treatment. Third, the Hospital Waste Management Rules (2005) must be actively enforced through systematic external monitoring, regular inspections and audits, and meaningful penalties for non-compliance, addressing the gap between existing regulations and their implementation. Fourth, standardised waste weighing and recording systems should be established at all facilities to enable systematic monitoring against defined performance indicators and support continuous, evidence-based improvement. Fifth, future research should include longitudinal studies, economic cost–benefit analyses, assessments of private facilities and seasonal variation, and environmental contamination analysis near disposal sites to guide targeted district- and provincial-level policy.

References

Adefisoye M and Odukoya O (2020) Waste management practices in Nigerian hospitals: a review. Journal of Environmental Management 261:110221.

Ahmed S and Ahmed R (2008) Healthcare waste management in Karachi hospitals. Pakistan Journal of Medical Sciences 24(4):578–583.

Ali M, Wang W and Chaudhry N (2016) Management of wastes from hospitals: a case study from Gujranwala, Pakistan. Waste Management & Research 34(1):87–94.

Ali S, et al. (2015) Assessment of hospital waste management in Rawalpindi and Islamabad. Journal of Material Cycles and Waste Management 17(2):320–328.

Ananth PA, Prashanthini V and Visvanathan C (2010) Healthcare waste management in Asia. Waste Management 30(1):154–161.

Basu R, et al. (2019) Environmental and health impacts of healthcare waste incineration. Environmental Science and Pollution Research 26(15):15326–15340.

Chandran A, et al. (2017) Waste segregation challenges in healthcare facilities. International Journal of Environmental Health Research 27(5):385–398.

Ghosh S and Rahman M (2018) Training needs assessment for hospital waste management: a case study. International Journal of Health Services 48(3):579–590.

Government of Pakistan (2005) Hospital Waste Management Rules, 2005. Ministry of Environment, Islamabad.

Gupta S and Khan M (2014) Regulatory frameworks for healthcare waste management in developing countries. Health Policy 117(3):378–387.

Gupta S and Sharma A (2020) Challenges in biomedical waste management in Indian hospitals. Environmental Science and Pollution Research 27(14):16789–16800.

Khalid S, et al. (2021) Comparison of waste management practices in public and private hospitals of Peshawar. Pakistan Journal of Public Health 11(2):89–96.

Kumar R and Agarwal A (2020) Workplace education and biomedical waste handling practices. Journal of Environmental Management 267:110583.

Lakshmikantha H (2006) Report on waste dump sites near Bangalore. Waste Management 26(6):640–650.

McGowan R and Smith D (2019) Navigating the complexities of healthcare waste management regulations in the United States. Journal of Healthcare Management 64(5):315–323.

Misra V and Pandey SD (2005) Hazardous waste, impact on health and environment for development of better waste management strategies in future in India. Environment International 31(3):417–431.

Ofori C and Mensah A (2020) Enhancing waste management practices in hospitals: the role of training. International Journal of Environmental Research and Public Health 17(4):1456.

Patil AD and Shekdar AV (2001) Health-care waste management in India. Journal of Environmental Management 63(2):211–220.

Reddy MV, et al. (2017) Financial barriers to biomedical waste management in smaller healthcare facilities. Waste Management 68:512–520.

Shakya S and Singh R (2019) Challenges and strategies for effective healthcare waste management in India. Waste Management 83:34–43.

Shalini S, et al. (2012) Biomedical waste management: a review. Journal of Environmental Science and Health, Part C 30(1):1–15.

Singh A and Rathi S (2020) Improper waste segregation in healthcare facilities: causes and consequences. Journal of Cleaner Production 261:121183.

Singh R, et al. (2017) Impact of training programs on biomedical waste segregation and disposal. International Journal of Infection Control 13(2):1–8.

World Health Organization (2014) Safe management of wastes from health-care activities. WHO, Geneva. (ISBN: 9789241548564).

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MJK, NUSK, KU, IK, SA, FUH, UM and MSI conceived the concept, wrote and approved the manuscript.

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