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Status of Biomedical waste Management in Madhya Pradesh

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Abstract

Proper and scientific management of bio-medical waste (BMW) is essential for healthy life. It includes critical dimension of public health administration systems that is rapidly expanding. Present study assesses the status of spatial-temporal characteristics of bio-medical waste management in Madhya Pradesh. For this study the secondary data has been used reported by Madhya Pradesh Pollution Control Board over the period 2010–2024. The study provides a comprehensive assessment of the state's bio-medical waste management framework particularly healthcare infrastructure development, waste generation dynamics, treatment capacity, regulatory performance, and district-level variation. The findings of this study highlights that Madhya Pradesh has measured a substantial expansion in healthcare infrastructure between 2019 and 2024, with the total number of healthcare facilities increased nearly 60 percent, having significant increase in non-bedded institutions and hospital bed capacity. Further, in the same period, bio-medical waste generation increased by nearly 17.6 percent. This shows the expansion of healthcare services and improvements in reporting coverage. Although generation and disposal capacity of biomedical waste increased simultaneously due to strengthening of Common Bio-Medical Waste Treatment Facilities (CBWTFs), persistent treatment shortfalls remain visible, indicating lack of operational and logistic efficiencies. Furthermore, the increasing dominance of CBWTFs, alongside a marked decrease in captive treatment facilities, highlights a structural shift toward centralized waste management systems. Long-term trend assessment of the data for the period of 2010 to 2024 reveals continuous increase in bio-medical waste generation, punctuated by short-term fluctuations due to public health related issues. District-level analysis of data highlights significant spatial disparities in biomedical waste generation and management. This shows that large urban centres like Indore, Bhopal, Gwalior, and Jabalpur are generating disproportionately large quantity of the total biomedical waste generated whereas several districts indicate irregular or decreasing reporting patterns. This study concludes that although, there has been commendable progress in treatment infrastructure and institutional coverage for biomedical waste management, the overall issues of spatial imbalance, compliance deficiencies, and increasing waste intensity remain unresolved. For addressing these issues, there is urgent need to strengthened regulatory enforcement mechanism, rationalize CBWTF service areas, and adopt region-specific biomedical waste management strategies to maintain environment sustainable and healthy.

Keywords: Bio-medical waste management; Healthcare facilities; Common Bio-Medical Waste Treatment Facilities (CBWTFs); Spatial disparity; Regulatory compliance.

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1. Introduction

Biomedical waste management in India has started receiving systematic policy and regulatory attention with the notification of the Biomedical Wastes (Management and Handling) Rules in 1998 (Patil & Shekdar, 2001). This established the first comprehensive guidelines for segregation, treatment, and disposal of bio-medical waste in India. Considering the emerging gaps in compliance of guidelines, their monitoring framework and accountability of concerned

authority, the Government of India subsequently replaced these frameworks by Bio-Medical Waste Management Rules, 2016. These revised guidelines introduced more tight regulatory mechanisms and clearly defined responsibilities for biomedical waste generators, healthcare institutions, and biomedical waste treatment operators.

Biomedical waste includes all types of hazardous waste generated during course of medical diagnosis, treatment, immunization, research activities, and related healthcare

services (Central Pollution Control Board, 2016). Improper handling and disposal of biomedical waste resulting into serious problems for environmental quality and human health owing to the presence of infectious agents and toxic materials. These risks not only effect healthcare providers but also waste handlers, informal recyclers, and finally over all community. Therefore, effective, and scientific management of biomedical waste has become as a critical component of public health governance, especially in developing countries where healthcare institutions are increasing rapidly. The scientific and environmentally safe treatment and disposal of biomedical waste is legal obligation and collective responsibility of all stakeholders involved in healthcare delivery facilities. Therefore, ensuring effective biomedical waste management is necessary for safeguarding human health and protecting environmental quality (Datta, Mohi, & Chander, 2018).

Over the last few years, healthcare sector of India has undergone rapid expansion, reflected in the increasing number of healthcare institutions, diagnostic centres, and hospital beds. Because of this rapid growth in healthcare facilities causing corresponding rise in the volume of bio-medical waste, thereby intensifying the urgency for tight regulatory oversight and proper waste treatment and disposal infrastructure. The World Health Organization has highlighted that strengthening institutional capacity and regulatory compliance is essential for addressing biomedical waste-related problems in rapidly developing healthcare systems (WHO, 2014). In Madhya Pradesh, enforcement and supervision of biomedical waste management rules are executed by the Madhya Pradesh Pollution Control Board (MPPCB), basically through annual reporting and authorization mechanism, and periodic compliance inspections (MPPCB, 2019; MPPCB, 2024).

Due to one of the largest states in India regarding geographical area, Madhya Pradesh is showing a complex and heterogeneous picture for bio-medical waste management. This includes large metropolitan regions, newly developing urban centre, tribal belts, and remote rural districts. Each of them has distinct healthcare access patterns and infrastructural limitations. In recent years, Madhya Pradesh has measured rapid increase in healthcare facilities causing pressure on already burdened existing bio-medical waste treatment infrastructure. To address this challenge by centralize treatment and disposal system, establishment and expansion of new Common Bio-Medical Waste Treatment Facilities (CBWTFs) have been crucial. However, concerns remain regarding the adequacy of spatial coverage by Common Bio-Medical Waste Treatment Facilities, their operational efficiency, treatment and disposal capacity and regulatory compliance.

Although the Madhya Pradesh Pollution Control Board publishes annual data of healthcare facilities, biomedical waste generation, their treatment and disposal capacity, an extensive academic assessment that integrate long-term temporal pattern, spatial variations at district-level and availability of healthcare infrastructure remain limited. Given these shortcomings into consideration, this study tries to highlight a systematic assessment of bio-medical waste management in Madhya Pradesh for the period from 2010 to 2024, with special focus paid on the years 2019–2024. By analysing state-level indicators of biomedical waste management, district-wise patterns of waste generation, and the operational characteristics of CBWTFs, this study searches to assess development made over time, detect spatial

disparity, and uncover recurring discrepancies as well as governance-related challenges in bio-medical waste management.

2. Objectives of the Study

The main objectives of this study are to critically examine the current state, evolving pattern, and spatial characteristics of bio-medical waste management in Madhya Pradesh based on officially reported secondary datasets. The specific objectives of present study are as follows:

1. To assess the growth of healthcare infrastructure in Madhya Pradesh from 2019 to 2024.
2. To evaluate the temporal trends of generation and disposal of bio-medical waste across the state from the year 2010 to 2024.
3. To examine the status of operational performance of Common Bio-Medical Waste Treatment Facilities (CBWTFs) in Madhya Pradesh.
4. To assess the district-level spatial variations and disparities in bio-medical waste generation between 2022 and 2024.
5. To evaluate the trends of regulatory compliance and institutional monitoring framework regarding bio-medical waste management in Madhya Pradesh.
6. To formulate policy-relevant recommendations for strengthening bio-medical waste management through effective infrastructure planning, advanced regulatory oversight, and region-specific biomedical waste management strategies in Madhya Pradesh.

3. Study Area

Madhya Pradesh has central location in India, extending approximately between 21°06' N and 26°30' N latitudes and 74°09' E and 82°48' E longitudes. The Tropic of Cancer passes through the central part of the state, underline its locational importance within the tropical belt of India. Madhya Pradesh spreading nearly 605 km from north to south and about 870 km from east to west characterized by noticeable physiographic diversity, including plateaus, hill ranges, and intermontane plains resulting into heterogeneous physical environment, population distribution, and socio-economic conditions. Administratively, the state is divided into 52 districts including large metropolitan centres, fast developing industrial towns, extensive rural landscapes, and various predominantly tribal districts. This pronounced spatial diversity give a suitable reason for assessing regional disparity in healthcare infrastructure development and the related patterns of bio-medical waste generation and disposal. Noticeable geographical factors play a significant role in shaping the efficiency of bio-medical waste management system in Madhya Pradesh. Significant inter-district distances, uneven distribution of settlements, and transportation constraints affect the operational performance of Common Bio-Medical Waste Treatment Facilities (CBWTFs), especially in peripheral and remote districts situated far from centralized treatment sites. Due to rapid healthcare infrastructure expansion, increasing dependency on centralized biomedical waste treatment facilities, and marked geographical heterogeneity, Madhya Pradesh provide a suitable case for assessing the adequacy, resilience, and long-term sustainability of bio-medical waste management systems.

4. Data Sources

This study depends exclusively on secondary data taken from

officially published sources. The dataset is taken mainly from the *Annual Reports on Bio-Medical Waste Management* published by the Madhya Pradesh Pollution Control Board (MPPCB). These reports were compiled in accordance with the systematized reporting formats and guidelines stipulated by the Central Pollution Control Board under the provisions of the Bio-Medical Waste Management Rules, 2016. The datasets used in the present study includes officially reported and publicly available information, thereby securing a high degree of data reliability and internal uniformity. Any minor inconsistencies found in the data arising due to administrative boundary changes, intermittent reporting gaps, or incomplete district-level submissions were corrected through cautious evaluation and cross-verification, without any data alteration. Because this study does not include primary data collection, field surveys, or human involvement, it does not require any ethical clarification.

5. Methodology

This study incorporated a descriptive-analytical research design based completely on secondary datasets to evaluate the status, evolution, and functional performance of bio-medical waste management in Madhya Pradesh. The methodological approach consists temporal trend analysis, comparative evaluation, and spatial interpretation to systematically assess officially reported datasets and provide contextually grounded inferences.

5.1 Analytical Framework

The analytical framework focused on four interconnected components have distinctive dataset and analytical objective. These components are:

- i) Evaluation of expansion of healthcare infrastructure and regulatory status for the period 2019–2024;
- ii) Assessment of long-term trends in bio-medical waste generation and disposal from 2010 to 2024;
- iii) Assess the district-level spatial patterns of bio-medical waste generation for the period 2022–2024; and
- iv) Analysis of the treatment capacity, spatial coverage, and operational status of Common Bio-Medical Waste Treatment Facilities (CBWTFs) in 2024. Together, all these four components give an integrated outlooks on institutional achievements, spatial disparities, and system-level sufficiency.

5.2 Data Processing and Interpretation

All quantitative data were carefully compiled and cross-checked from official sources before their analysis. To perform analytical procedures basic statistical measures such as absolute values, percentage shares, growth differentials, and ratio were calculated for assessment of inter-temporal and inter-district comparisons. Data interpretation in the present study was performed within the comprehensive regulatory, infrastructural, and administrative context ruling bio-medical waste management of Madhya Pradesh.

5.3 Limitations

The study is not out of limitations due to use of secondary, officially reported data by CPCB and MPPCB. Discrepancy in reporting practices, delays in data submission, under-reporting, and administrative inconsistencies across districts may influence data perfection and comparability. Considering the importance of transparency and avoid artificial data adjustments, missing data of a particular district for particular year were considered as non-reporting units rather than being excluded from the analysis. Regardless of these limitations, the datasets used give a sufficiently reliable base for assessment of trends, spatial disparity, and structural characteristics of bio-medical waste management in Madhya Pradesh.

6. Results and Analysis

6.1 Status of Biomedical Waste Management in Madhya Pradesh

Table 6.1 highlights the comparative status of bio-medical waste management between the period 2019 to 2024. It shows noticeable structural expansion of healthcare infrastructure resulting into increasing pressure on bio medical waste management systems in Madhya Pradesh.

The total number of healthcare infrastructure increased from 7,677 in 2019 to 12,261 in 2024, showing growth of about 60 percent. This growth is mainly driven by rapid increase in non-bedded healthcare infrastructure. This growth was more than doubled (104.6 percent) during the study period. On the other hand, the number of bedded healthcare infrastructure increased nearly 14 percent, showing a shift toward outpatient and diagnostic service delivery models. Furthermore, the total hospital bed capacity increased about 48.5 percent, indicating both healthcare infrastructure development and growing service utilization.

As far as issues related to authorization present a mixed picture. Table 6.1 shows that the number of healthcare facilities applying for and receiving authorization increased by over 30 percent, a considerable number of facilities remain operational without authorization in 2024. Even though, unauthorized facilities declined by 20 percent, their actual number is still relevant, showing gaps in regulatory outreach and enforcement.

Operational footprint of shared healthcare waste processing centres (CBWTFs) increased markedly throughout the timeframe. Table 6.1 demonstrate that the number of healthcare facilities being served by Common Biomedical Waste Treatment Facilities increased by about 88 percent, showing the growing dependency on centralized treatment infrastructure. The number of active CBWTFs expanded from 12 to 20, accompanied by growing number of upcoming units. On the other hand, the use of captive treatment facilities reduced, shown by the drop in both captive incinerators and the quantity of biomedical waste treated through these systems.

Table 6.1: Status of Biomedical waste management in Madhya Pradesh

Status of Biomedical Waste Management	2019	2024	Change (%)
Total No. of HCFs	7677	12261	+59.7%
Total No. of bedded HCFs	3817	4363	+14.3%
Total No. of non-bedded HCFs	3860	7898	+104.6%
Total No. of beds	100401	149114	+48.5%
Total No. HCFs applied for authorization	5629	7403	+31.5%
Total No. of HCFs granted authorization	5616	7317	+30.3%
Total No. of HCFs operating without authorization	2048	1640	-19.9%
Total No. of HCFs utilizing CBWTFs	5701	10705	+87.8%

Total No. of HCFs having Captive Treatment Facilities	2	4	+100.0%
Total No. of Captive Incinerators operated by HCFs	2	1	-50.0%
Total No. of CBWTFs operational	12	20	+66.7%
Total No. of CBWTFs under construction	1	4	+300.0%
Quantity of bio-medical waste generated (kg/day)	17846.68	20993.039	+17.6%
Quantity of bio-medical waste treated and disposed (kg/day)	17289.00	20268.605	+17.2%
Quantity of BMW treated by captive treatment facility (kg/day)	281.92	142.303	-49.5%
Quantity of BMW treated by CBWTFs (kg/day)	17007.08	20126.302	+18.3%
Total No. of HCFs and CBWTFs violated BMW Rules	907	2419	+166.7%
Total No. of Show-cause notices/Directions issued to defaulter HCFs and CBWTFs	907	695	-23.4%
Total No. of CBWTFs that have installed OCEMS	12	20	+66.7%

Sources: Annual Report on Bio-Medical Waste Management, Madhya Pradesh Pollution Control Board, 2019 & 2024

Table 6.1 demonstrate that bio-medical waste generation increased from 17,846.68 kg/day in 2019 to 20,993.04 kg/day in 2024, showing about 17.6 percent increase in waste production. While treatment and disposal capabilities grew simultaneously, continued shortfall in treatment capacity indicates that operational efficiency has failed to keep pace with rising waste production. Remarkably, biomedical waste treated by CBWTFs grown by over 18 percent, strengthening their crucial role in the state’s waste management mechanism. More so, compliance measures expose a disturbing trend. The number of medical institutions and CBWTFs flouting bio-medical waste management rules witnessed nearly 166 percent spike between 2019 and 2024. On the other hand, the number of notices to show-cause issued decreased during the same time, which suggest potential enforcement constraints or shifts in regulatory strategy. The widespread adoption of Online Continuous Emission Monitoring Systems (OCEMS)

in all working CBWTFs demonstrate progress in air quality tracking, yet increasing non-compliance underscore the requirement for more robust compliance framework. Overall, foregoing analysis leads to conclude that while Madhya Pradesh has gained commendable progress in developing bio-medical waste treatment infrastructure but coverage, regulatory compliance and operational efficiency require much more to be done.

6.2 Trends in Bio-medical Waste Generation and Treatment in Madhya Pradesh

Table 6.2 shows the long-term assessment of bio-medical waste generation and treatment in Madhya Pradesh from 2010 to 2024. This analysis reveals continuous progress in healthcare activity and resultant waste generation, alongside gradual improvements in biomedical waste treatment infrastructure.

Table 6.2: Status of Biomedical waste generated and treated in Madhya Pradesh

Year	Total No. of HCFs	Total No. of Beds in HCFs	Total quantity of BMW generated (kg/day)	Total quantity of BMW treated and disposed (kg/day)	Gap in (kg/day)	Total BMW treated by CBWTFs (kg/day)	BMW treated through non-CBWTF routes (kg/day)
2010	2373	53390	4973.49	4713.36	260.13	3058.73	1,654.63
2011	2579	60159	8250.24	7910.72	339.52	5645.59	2,265.13
2012	2663	63260	9405.15	9014.73	390.42	6597.50	2,417.23
2013	2850	65428	8960.00	8691.00	269.00	7864.00	827.00
2014	2853	71417	9409.00	9140.00	269.00	8716.00	424.00
2015	3002	77310	10714.00	10654.00	60.00	10130.00	524.00
2016	5080	82449	12810.00	12810.00	00.00	12406.00	404.00
2017	6362	87165	14824.00	13773.00	1,051.00	13569.00	204.00
2018	6436	95421	15846.74	14547.37	1,299.37	14308.91	238.46
2019	7677	100401	17846.68	17289.00	557.68	17007.08	281.92
2020	8901	115505	20008.91	19003.55	1,005.36	18761.45	242.10
2021	9811	130000	19754.33	19124.73	629.60	18921.91	202.82
2022	10371	135695	15631.80	15450.70	181.10	15387.70	63.00
2023	11985	147165	16681.70	16092.92	588.78	16000.50	92.42
2024	12261	149114	20993.04	20268.61	724.43	20126.30	142.31

Sources: Annual Report on Biomedical Waste Management, MPPCB and CPCB, 2010-2024

This table shows that the total number of healthcare facilities grew more than fivefold, side by side about threefold increase in hospital bed capacity. Bio-medical waste generation increased from 4,973.49 kg/day in 2010 to 20,993.04 kg/day in 2024, demonstrating the collective result of expansion of healthcare facility, improved reporting, and increased service utilization. While treatment and disposal capacity increased, the speed of waste production often surpassed the disposal efficiency.

The treatment gap which is defined as the difference between waste produced and waste treated shows noticeable inter-annual variability. Although near-complete treatment efficiency was measured in the year 2016, succeeding years observed recurring gaps, with pronounced decline during

2017–2020 and again in 2024. These gaps demonstrate operational limitations, logistical obstacles, and possible reporting irregularity.

Furthermore, a structural shift in treatment and disposal is noticed from the data analysis. The volume of bio-medical waste treated through Common Bio-Medical Waste Treatment Facilities (CBWTFs) increased consistently throughout the period, while waste treated through non-CBWTF routes drop off sharply. By 2024, CBWTFs constitute a dominant share of treated waste, highlighting their central role in the state’s bio-medical waste management mechanism. The shortfall in non-CBWTF treatment routes also denotes the reduced dependency on captive treatment infrastructure and on-site biomedical waste disposal framework.

More so a noticeable fluctuation measured during 2020 and 2021 align with periods of remarkable healthcare demand and systemic stress that influenced both biomedical waste production and its treatment and disposal dynamics. The partial recovery noticed in following years shows resilience within the system, though the perpetual treatment gaps indicate that infrastructure development has not fully associated with increasing biomedical waste quantity.

By and large, the aforementioned analysis highlights sequential institutionalization of centralized biomedical waste treatment in Madhya Pradesh, aligned with improved coverage efficiency. Nevertheless, the recurring mismatch observed between biomedical waste production and treatment demarcate the necessity of strengthening operational capacity of present biomedical waste management infrastructure.

6.3 District-wise Spatial Pattern of Bio-medical Waste Generation in Madhya Pradesh

Table 6.3 shows the district-wise assessment of bio-medical waste generation. This highlights remarkable spatial disparities across Madhya Pradesh, demonstrating unequal healthcare facilities development, urban concentration, and service accessibility. The total reported bio-medical waste production increased from 15,631.86 kg/day to 20,993.04 kg/day between 2022 and 2024, showing considerable increase in healthcare activity at the state level. A small number of districts generate disproportionately large volume of biomedical waste. Large urban centres namely Indore, Bhopal, Gwalior, Jabalpur, and Ujjain measured significantly large amount of biomedical waste in 2024, with Indore alone showing a rise exceeding 5,400 kg/day during the study period. Such concentration demonstrates the clustering of tertiary healthcare facilities in large urban centres.

Table 6.3: District-wise Bio-medical Waste Generation, Madhya Pradesh (2022 & 2024)

S. No.	District	BMW Generation (kg/day), 2022	BMW Generation (kg/day), 2024	Change BMW Generation (kg/day)
1.	Sheopur	81.83	136.81	+54.98
2.	Morena	84.23	475.00	+390.77
3.	Bhind	85.90	290.31	+204.41
4.	Gwalior	91.44	1026.90	+935.46
5.	Datia	168.00	379.33	+211.33
6.	Shivpuri	167.46	169.20	+1.74
7.	Guna	192.33	136.60	-55.73
8.	Ashok Nagar	82.66	91.70	+9.04
9.	Dewas	2391.48	298.87	-2092.61
10.	Shajapur	252.49	233.92	-18.57
11.	Ratlam	127.50	456.07	+328.57
12.	Ujjain	239.17	732.30	+493.13
13.	Agar-Malwa	157.78	150.15	-7.63
14.	Mandsaur	37.48	235.66	+198.18
15.	Neemuch	273.99	145.41	-128.58
16.	Indore	311.84	5735.89	+5424.05
17.	Burhanpur	52.00	206.81	+154.81
18.	Khargone	119.80	349.22	+229.42
19.	Barwani	581.85	234.34	-347.51
20.	Khandwa	86.46	303.5	+217.04
21.	Dhar	285.92	673.67	+387.75
22.	Alirajpur	3515.83	-	NA
23.	Jhabua	1178.00	-	NA
24.	Bhopal	207.30	4289.78	+4082.48
25.	Sehore	332.11	217.63	-114.48
26.	Rajgarh	340.77	124.68	-216.09
27.	Vidisha	345.16	280.75	-64.41
28.	Hoshangabad	107.00	300.01	+193.01
29.	Raisen	79.43	110.85	+31.42
30.	Harda	80.40	90.41	+10.01
31.	Sagar	133.00	409.48	+276.48
32.	Damoh	89.04	122.93	+33.89
33.	Panna	61.38	68.48	+7.10
34.	Chhatarpur	95.16	118.78	+23.62
35.	Tikamgarh	104.25	78.08	-26.17
36.	Niwari	155.21	-	NA
37.	Jabalpur	422.65	1220.00	+797.35
38.	Narsinghpur	236.00	134.00	-102.00
39.	Seoni	170.24	196.00	+25.76
40.	Mandla	185.33	165.00	-20.33
41.	Balaghat	128.00	215.00	+87.00
42.	Chhindwara	286.30	465.05	+178.75
43.	Betul	178.06	270.96	+92.90
44.	Katni	17.86	294.33	+276.47
45.	Rewa	116.44	512.40	+395.96
46.	Sidhi	119.52	127.55	+8.03
47.	Singraulli	111.28	99.22	-12.06

48.	Satna	79.25	212.87	+133.62
49.	Umaria	-	106.31	NA
50.	Shahdol	520.03	158.16	-361.87
51.	Dindori	109.80	68.50	-41.30
52.	Anuppur	255.44	83.99	-171.45
Total BMW Generation		15631.86	20993.039	5361.18

Source: Annual Report on Bio-Medical Waste Management, 2024, Madhya Pradesh Pollution Control Board (MPPCB)

Furthermore, various districts such as Morena, Dhar, Ujjain, Rewa, Katni, and Sagar, also measured significant increases in biomedical waste production, indicating expanding healthcare coverage and improvement of reporting framework. Conversely, some districts such as Dewas, Barwani, Neemuch, Shahdol, Rajgarh, Dindori, Anuppur etc. reported decline in biomedical waste generation. These declines could have been possible due to official reclassification, shifting of facility linkage to CBWTFs, under-reporting, or redistribution of healthcare services rather than an actual decline in healthcare activity.

More so, this Table also shows the presence of non-reporting or partially reported districts in 2024. These districts are Alirajpur, Jhabua, Niwari, and Umaria. The non-availability of updated data for these districts causes limitation in comprehensive spatial analysis. Cases of non-reporting indicate persistent gaps in data reporting within the regulatory mechanism.

The forgoing analysis leads to conclude that spatial pattern of bio-medical waste production in Madhya Pradesh is not equal. Uneven spatial pattern of biomedical waste generation, strong urban dominance and inconsistent district-level reporting are some outcomes of this table analysis. These findings highlight the urgency for region-specific planning of biomedical waste treatment facilities, improved reporting compliance in peripheral districts, and targeted capacity enhancement in high-burden urban centres.

6.4 Assessment of Common Bio-Medical Waste Treatment Facilities (CBWTFs) in Madhya Pradesh (2024)

Table 6.4 demonstrate the status of Common Bio-Medical Waste Treatment Facilities (CBWTFs) in Madhya Pradesh for the year 2024. It highlights the operational capability, spatial coverage efficiency, and infrastructure of the state’s bio-medical waste management system. A total of 19 CBWTFs were reported to be functional during the study period and collectively provide services of healthcare facilities across the state. The spatial coverage of CBWTFs varies significantly, with service radii ranging from 50 km to 250 km. Facilities situated in central and urban regions like those serving Indore and Bhopal, cater to a high density of healthcare facilities and hospital beds, causing large quantity of biomedical waste collection and treatment. On the other hand, CBWTFs operating in peripheral and sparsely populated regions provide services to fewer facilities but cover larger geographical regions resulting into high operational costs that may affect transportation efficiency. Regarding service capacity, CBWTFs collectively covered thousands of healthcare facilities and hospital beds, showing widespread institutional dependency on centralized treatment facilities. This table shows that the quantity of bio-medical waste collected are nearly equal to quantity treated across most facilities, indicating effective operational efficiency and least storage backlog. This alignment shows improved logistics, systematized treatment processes, and effective monitoring framework.

Table 6.4: Status of CBWTF (All 19 CBWTF Facilities) – Madhya Pradesh, 2024

S. No.	Name and Place of CBWTF	Districts/Areas Covered	Coverage Area (km)	HCFs Covered	Beds Covered	BMW Collected (kg/day)	BMW Treated (kg/day)	Major Treatment Facilities	Disposal Method
1	M/s. Elite Engineers, Kthonda, Jabalpur	Jabalpur, Katni	75–154	749	9351	1515.169	1515.156	Incinerator, Autoclave, Shredder	Ash to TSDF, Recyclers
2	M/s. Krupa Wastages, Pindraikhurd, Seoni	Seoni, Mandla, Balaghat, Dindori, Chindwara, Pandurna	150	472	7501	1110.40	1104.28	Incinerator, Autoclave	Landfill, Recycler
3	M/s.Hoswin Incinerator Pvt. Ltd., Indore	Indore, Barwani	150	1593	18264	3496	3496.02	Incinerator, Autoclave	TSDF
4	M/s.Indo Water Management & Pollution Control Corp. Satna	Satna, Rewa, Sidhi Singraulli, Panna, Chhattarpur, Damoh	150	732	8952	787.04	787.04	Incinerator, Autoclave	TSDF
5	M/s.MP Bio-Medical Waste Disposal System, Umaria	Shahdol, Anuppur, Umaria	150	142	2402	356.20	356.20	Incinerator, Autoclave	TSDF
6	M/s.Biomedical Waste Mgmt System, Ratlam	Ratlam, Mandsaur & Neemuch	150	354	5916	837.15	837.00	Incinerator, Autoclave	TSDF
7	M/s.India Waste Management (P) Ltd. Raisen	Bhopal, Raisen	75	854	16432	3556.94	3550.55	Incinerator, Autoclave	TSDF
8	M/s. J.K. Medical Waste Management System, Ashok Nagar	Ashok Nagar Guna, Shivpuri, Rajgarh, Tikamgarh, Niwari	150	372	6295	595.99	595.99	Incinerator, Autoclave	TSDF
9	M/s. J. R. R. Waste Management Pvt. Ltd., Bhind	Morena & Bhind	105	204	3011	654	654	Incinerator, Autoclave	TSDF
10	M/s. Devis Surgico, Sagar	Sagar, Damoh	150	393	4630	487.07	487.06	Incinerator, Autoclave	TSDF
11	M/s. Davis Surgico, Sagar	Gwalior	75	679	18693	1018.36	1018.36	Incinerator, Autoclave	TSDF
12	Environmental Protection Corp. Sehore	Sehore, Bhopal, Vidisha, Hosangabad, Hard, Betul	150	868	8782	1482.50	1482.50	Incinerator, Autoclave	TSDF

13	M/s. BMW Solutions, Bhopal	Bhopal	75	441	6289	273.81	273.81	Incinerator, Autoclave	TSDF
14	M/s. Medisure Incinerators, Khandwa	Khandwa, Khargone & Burhanpur	75	297	4229	829	829	Incinerator, Autoclave	TSDF
15	M/s. Hostech Eco Management, Ujjain	Ujjain, Dewas, Shajapur, Agar-Malwa	75	750	9769	1405	1405	Incinerator, Autoclave	TSDF
16	M/s. Agni Mitra Indore	Indore, Dhar, Alirajpur & Jhabua	50	1126	7369	1131	1131	Incinerator, Autoclave	TSDF
17	M/s. VNS Solution, Bhind	Datia, Sheopur	250	79	1926	422.48	422.48	Incinerator, Autoclave	TSDF
18	M/s. CBWTF Narsinghpur	Narsinghpur	75	84	1604	135.548	135.55	Incinerator, Autoclave	TSDF
19	M/s. Chitra Kiran Waste Management, Rewa	Rewa, Sidhi Singraulli	150	277	5768	538.57	538.57	Incinerator, Autoclave	TSDF

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Regarding technology, all CBWTFs have facilities of incinerators and autoclaves, with shredders integrated where required. While, final disposal of incineration ash is mainly routed to Treatment, Storage, and Disposal Facilities (TSDFs), whereas recyclable constituents are rerouted to authorized recyclers. The homogeneity in treatment technology shows regulatory standardization across CBWTFs. Regardless of these strengths, imbalances in coverage area, service load, and biomedical waste generation demonstrate differential stress on CBWTFs. CBWTFs serving high-burden districts operate near peak capacity, causing the risk of operational pressure during rush hours. On the other hand, CBWTFs in low-density area may face economic ineffectiveness owing to their underutilization.

By and large, the CBWTF network has considerably improved bio-medical waste treatment capacity in Madhya Pradesh. Though, optimizing service radii, balancing facility load, and tactically locating future CBWTFs are critical for securing long-term system resilience.

7. Results and Discussion

The foregoing study indicates that bio-medical waste management in Madhya Pradesh has measured considerable structural reconfiguration over the past decade, with especially significant changes during the period of 2019–2024. Rapid advancement of healthcare services, as shown by increasing number of healthcare infrastructure and hospital beds, has caused escalation in the quantity of bio-medical waste produced across the state. Though, treatment capacity has grown in parallel, the continued presence of untreated or partially treated waste demonstrate that infrastructural advancement alone has not been satisfactory to meet the operational efficiency.

Furthermore, the increasing importance of Common Bio-Medical Waste Treatment Facilities (CBWTFs) indicates a deliberate policy change toward centralized treatment concept. This shift has provided enhancement in overall coverage and higher homogeneity in biomedical waste treatment and disposal practices. Meanwhile, increasing reliance on CBWTFs has caused structural susceptibilities, including increasing transportation routes, disproportionate distribution of treatment loads. Moreover, the gradual decreases of captive treatment infrastructure have increased more reliance on CBWTF causing concerns about network redundancy and resilience under stress situations.

Spatial analysis of bio-medical waste production indicates a significant concentration in urban and metropolitan regions, which constituent the bulk of total waste generated. This pattern occurred due to clustering of tertiary-level healthcare

services, advanced diagnostic centres, and specialized healthcare facilities in urban areas. On the other hand, fluctuating or decreasing waste generation figures reported from some districts suggest reporting irregularity and monitoring shortcoming than of genuine curtailment in healthcare activity. Such spatial discrepancy entangles inclusive planning efforts and hidden the true scale of bio-medical waste generation in rural and peripheral regions.

Regulatory compliance trends emerge as a crucial focal point. The sharp increase in recorded violations of bio-medical waste management rules indicate either escalating defiance of regulations or intensified oversight and disclosure by governing bodies. Conversely, the simultaneous decrease in the issuance of show-cause notices indicate toward possible enforcement limitations, administrative overburdens, or a tactical shift toward advisory and remedial measures. This discrepancies between detection and enforcement may diminish regulatory deterrence and ultimately erode the long-term effectiveness of compliance mechanisms.

Taken together, the findings reveal that while Madhya Pradesh has measured impressive improvement in expanding treatment facilities and institutional coverage for bio-medical waste management, strengthening governing mechanism, enforcement consistency, and spatially responsive planning have not kept pace. Tackling these intertwined structural and regulatory gaps is critical to enhancing the sustainability, resilience, and public health safety of the state's bio-medical waste management system.

8. Policy Implications and Recommendations

The foregoing analysis provides critical insights for enhancing bio-medical waste management framework in Madhya Pradesh. As healthcare facilities expands and bio-medical waste increases, policies must move beyond simply increasing treatment capacity to adopting integrated, adaptive, system-wide solutions. Considering these findings, adopting adaptive capacity planning is not just beneficial but, essential for future operations. Despite the expansion of Common Bio-Medical Waste Treatment Facilities (CBWTFs), persistent treatment gaps underscore the necessity of aligning treatment capacity with shifting, district-level waste generation patterns. Developing area-specific capacity standards leveraging predictive analysis models would enable more adaptive and future-oriented infrastructure planning. Furthermore, it is equally crucial to refine the geographical layout of CBWTFs network. Large service catchments in several districts result in extended logistics, elevated operational costs, and higher environmental hazard exposure. Optimizing service areas and strategically placing new treatment centres in high demand or isolated regions will boost logistical efficiency, ease system pressure, and enhance overall resilience.

The study also points to the vital need to tighten regulatory compliance and enforcement processes. Rising violation reports indicate a requirement for rigorous audits, structured, fair, and transparent punishments, and continuous compliance monitoring. Combining digital monitoring platforms with field-level regulatory oversight could strengthen accountability, boost traceability, and reduce administrative burdens. Moreover, enhancing data accuracy and openness are another essential requirement. Fragmented district-level data inhibits effective management and masks the spatial distribution of biomedical waste generation. The use of standardized reporting formats, mandatory online data submission of bio-medical waste, and focused skill development efforts for district regulatory offices would essentially increase data reliability and utility.

In additionally, institutional skill development within healthcare facilities ensures rapt attention, especially among non-bedded institutions and small private hospitals that have grown rapidly in recent years. Capacity building training programmes highlighting waste segregation, interim storage, and compliant handover practices would help to decrease source-level non-compliance and enhance the overall operational capability of the management system.

Finally, environmental protection must remain focal to bio-medical waste management policy. Even though the installation of Online Continuous Emission Monitoring Systems at CBWTFs represents a considerable regulatory improvement, their performance depends on periodic third-party audits and open and honest reporting of emission performance. Consolidating, environmental monitoring and transmission of information would improve regulatory credibility and promote greater public trust in the system.

Conclusion

The foregoing analysis offers a systematic assessment of bio-medical waste management in Madhya Pradesh based on secondary data including the period from 2010 to 2024. This study paid emphasis particularly on institutional arrangements, waste generation pattern, spatial differentiation, and treatment facilities. The analysis demonstrate that the fast increase of healthcare infrastructure and hospital bed capacity has caused considerable increase in bio-medical waste production across the state. Even though biomedical waste generation and treatment capacity have increased simultaneously mainly due to consolidation and expansion of the Common Bio-Medical Waste Treatment Facility (CBWTF) network-a persistent disparity between waste generation and treatment capacity continues to increase operational and environmental stress.

Furthermore, the increasing dependence on centralized treatment systems has resulted into improvement in procedural standardization and broader service coverage. On the other hand, this structural shift has exposed underlying system susceptibility related with unequal spatial distribution, increased transportation demand, and concentration of treatment loads at select facilities. District-level assessment further indicates a robust urban concentration of bio-medical waste production, whereas inconsistent and incomplete reporting from several peripheral and mainly tribal districts hamper in-depth analysis of state wide system performance.

Regulatory supervision and compliance appear as paramount governance obstacles. The observed surge in reported violations, associated with decrease in enforcement actions, indicates the urgency for more logical, transparent, and regular applied regulatory mechanism.

Finally, Madhya Pradesh has gained considerable progress in advancing its bio-medical waste management mechanism; however, upholding and expanding this progress will call for holistic and responsive policy interventions. Comprehensive focus on infrastructure planning in accordance with spatial realities, strengthening regulatory compliance and enhancement in data quality and transparency are necessary for sustainable biomedical waste management. The study highlights the requirement of region-specific planning and responsive governance structures for coping with the increasing complexity of bio-medical waste management systems. Subsequent studies might expand on this result by incorporating empirical data gathered from the field, site specific productivity analyses, and environmental impact assessment to further improve evidence-based policy development.

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