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Assessment of bio-medical waste before and during the emergency of novel Coronavirus disease pandemic in India: A gap analysis

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Abstract

Considering the widespread transmission of Coronavirus disease (COVID-19) globally, India is also facing the same crisis. As India already has inadequate waste treatment facilities, and the sudden outbreak of the COVID-19 virus has led to significant growth of Bio-medical waste (BMW), consequently safe disposal of a large quantity of waste has become a more serious concern. This study provides a comprehensive assessment of BMW of India before and during the COVID-19 pandemic. Additionally, this article highlights the gaps in the implementation of BMW rules in India. This study uses various government and non-government organizations, reports and data specifically from the Central Pollution Control Board (CPCB). The finding of the study demonstrated that most of the States/Union Territories (UTs) of India are lacking in terms of COVID-19 waste management. India has generated over 32,996 mt of COVID-19 waste between June and December 2020. During this period, Maharashtra (789.99 mt/month) is highest average generator of COVID-19 waste, followed by Kerala (459.86 mt/month), Gujarat (434.87 mt/month), Tamil Nadu (427.23 mt/month), Uttar Pradesh (371.39 mt/month), Delhi (358.83 mt/month) and West Bengal (303.15 mt/month), and others respectively. We draw attention to the fact that many gaps were identified with compliance of BMW management rules. For example, out of all 35 States/UTs, health care facilitates (HCFs), only eight states received authorization as per BMW management rules. Moreover, the government strictly restricted the practice of deep burials; however, 23 States/UTs are still using the deep burial methods for BMW disposal. The present research suggests that those States/UTs generated on an average of 100 mt/month COVID-19 waste in the last 7 months (June–December 2020) should be considered as a high priority state. These states need special attention to implement BMW rules and should upgrade their BMW treatment capacity.

Keywords

Bio Medical Waste, COVID-19 Waste, Waste Generation, State-Distribution, Management, Policy Gaps

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Introduction

Bio-medical waste (BMW) is one of the emerging pollutants generated by healthcare facilities, such as medical diagnosis, treatment, or immunization of human beings, animals, and biological research activities (Datta et al., 2018; Ilyas et al., 2020; Shaida and Singla, 2019). BMW is infectious and hazardous waste. It includes wastes of sharps, non-sharps, pathological/anatomical, synthetic substances, personal protective equipment (PPE), pharmaceuticals, and other infectious wastes (Ilyas et al., 2020; Ramteke and Sahu, 2020). According to Bio medical waste (Management and Handling) Rules, 1998 of India, "Bio medical waste is defined as any waste, which is generated during the diagnosis, treatment, or immunization of human beings or animals, or in research activities pertaining thereto, or in the production or testing of biologicals" (Mathur et al., 2012). Although, BMW is composed of non-hazardous waste (85%) and hazardous waste (15%), consisting of infectious waste is 10% and chemical or radioactive waste is 5% (World Health Organization (WHO), 2014). It is estimated, globally more than 5.2 million people, including 4 million children died each year because of diseases related to medical waste (Rahman et al., 2020). The sudden surge in the healthcare waste generation was due to severe acute respiratory syndrome Coronavirus-2 (SARS-CoV-2) also known as Coronavirus disease (COVID-19) and this excessive BMW has become a threat to public health and the environment. India is

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Table 1. Status of management of BMW in India.

Parameter	Number/quantity
Number of healthcare facilities	270,416
Number of bedded healthcare facilities	97,382
Number of beds	2,206,362
Number of non-bedded healthcare facilities	173,831
Healthcare facilities that have applied for authorization	111,122 (41%)
Healthcare facilities granted authorization	110,356 (40%)
Number of Common Bio Medical Waste Treatment and Disposal Facility (CBMWTFs)	200* + 28**
Number of authorized captive bio-medical waste treatment facilities and incinerators operated by healthcare facilities	12,326
Number of captive incinerators operated by healthcare facilities	120
Total generation of bio medical waste	614 mt/day
Bio medical waste treated by CBMWTFs	534 mt/day (87%)
Bio medical waste treated by captive treatment facilities or disposed of at deep burial sites	80 mt/day
Number of healthcare facilities violating the 2016 rules	27,301
Number of show-cause notices or directions issued	16,956
Number of CBMWTFs that have installed continuous emissions monitoring systems (CEMS)	172

Source: CPCB (2018).
*CBMWTFs in operation.
**CBMWTFs under installation.

already struggling with poor BMW practices due to technical, practical, and financial constraints, also COVID-19 pandemic has hit us hard by this sudden increase in the volume of medical waste.

The outbreak of COVID-19 first emerged in the end of December 2019, in Wuhan City, China, and it was declared an international public health emergency by the World Health Organization (WHO) (Rume and Islam, 2020; WHO, 2020a). As of March 12th 2021, the virus spread over 219 countries, with the death of approximately 2.62 million humans out of 110.82 million confirmed cases globally (WHO, 2020b). India is also facing the same crisis; until now there are approximately 11.30 million confirmed positive cases and 0.15 million deaths have been reported (as of March 12th, 2021) (MoHFW, 2020). It has been estimated that after the spread of COVID-19 disease, the amount of BMW has increased over 15 times more compared to the waste generated from the general patients (Anwer and Faizan, 2020). It is also reported in many studies that increase in the number of COVID-19 cases can be positively associated with the increase in the number of BMW (Agamuthu and Barasarathi, 2020; Tsai, 2021).

In India, the annual growth rate of BMW is 7% with a projected estimate up to 775.5 metric tons/day by 2022 (Das et al., 2020). As per the annual bio-medical waste management (BMWM) report (2018), in India, only 40% HCFs are granted authorization under the BMW Rules. However, 27,301 HCFs are violating the provisions of the BMW rules (Table 1). Thus, effective management, including advanced disinfection and disposal techniques, is necessary to control the generation of COVID-19 waste.

India is on the precipice of a COVID-19 induced waste crisis (Ramteke and Sahu, 2020), as per the consolidated status report of Central Pollution Control Board (CPCB) [as on 31st May, 2020]. In India, there are 2907 hospitals, 20,707 quarantine camps, 1539 sample collection centers, and 264 testing laboratories are involved in generation of COVID-19 waste (CPCB, 2020a). It is also indicating that total generation of COVID-19 BMW is about 101 mt/day. As per the latest statistics, Maharashtra, Kerala, Gujarat, Andhra Pradesh, and Delhi are the top five BMW generator states in December 2020 (Figure 1). Also, a sudden rise in generation of BMW may create a critical situation for those states which have 70% or more capacity incinerators for waste treatment (CPCB, 2020a). Therefore, the government should utilize alternative treatment technologies (autoclaving, mechanical, and chemical disinfection) to reduce the burden of waste treatment. In response to the COVID-19 pandemic in India, the CPCB functionary under the Ministry of Environment, Forest & Climate Change (MoEFCC) published the guidelines for handling, treatment, and discharge of COVID-19 BMW, which segregated the BMW waste into four categories such as yellow, red, white, and blue. In addition, individual state pollution control boards (SPCB) provided more detailed guidelines for concerned stakeholders in their respective states.

In the above context, it is clear that the ongoing pandemic has aggravated the severity of challenges of the BMW sector in India. As India had an already inadequate infrastructural treatment capacity and with COVID-19 cases having crossed the 11 million mark, BMW safe disposal has become a more serious challenge. Therefore, there is an urgent need to take precautionary measures to reduce BMW growth and avoid the risks associated with public health and the environment. The current study provides a comprehensive assessment of BMW generation, collection, and management across the 28 States and eight Union Territories (UTs) of India before and during the COVID-19 pandemic.

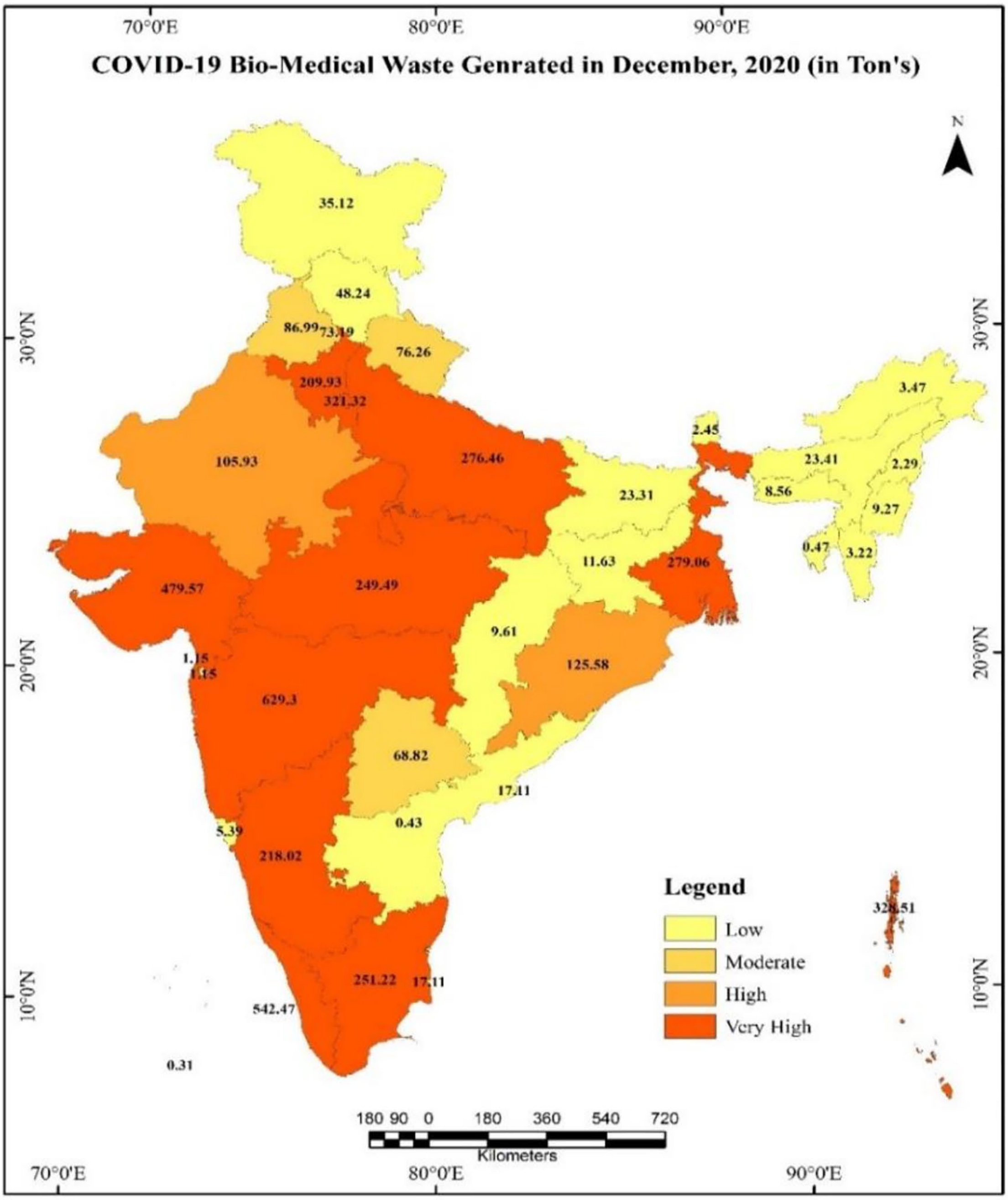

Figure 1. State-wise distribution of COVID-19 BMW in December 2020 (in metric tons).
Source: CPCB (2020d). Map prepared by the authors.

Additionally, this article highlights the gaps in the implementation of BMW rules in India.

Materials and methods

This study was performed by reviewing the available published literature, news articles, and different government and non-government organization's information from reports and official websites. We also used data from various sources such as WHO, CPCB, Ministry of Health and Family Welfare (MoHFW), MoEFCC, etc. Scientific literature was collected through electronic means from the database of Springer, Science Direct, PubMed, Taylor and Francis, Research Gate, Google Scholar, and Z-library but not in a systematic manner. To highlight the gaps in the implementation of BMW rules, we extracted the data from the government report (Gap analysis compliance report, CPCB, 2019). This report specifically observed the gap in implementation of BMW rules by considering selected indicators of all the States and UTs of India. However, we selected only those indicators; their information was available for every States and UTs. For example, indicators like "Availability of District Level Monitoring Committee (DLMC)" is reported only in a few states; hence this indicator is excluded. In this process, we identified the eight major indicators which are highly responsible for

Table 2. Top ten states/UTs of BMW generator in India (metric tons/day), 2014–2018.

Sr. no.	Name of state/ UTs	2014	2015	2016	2017	2018	Average BMW generation
1	Karnataka	82.12	51.56	66.46	67.33	65.62	66.62
2	Maharashtra	53.38	62.47	71.51	61.91	62.41	62.34
3	Kerala	52.79	53.16	37.77	40.99	71.97	51.34
4	Tamil Nadu	43.28	43.88	43.78	46.81	47.19	44.99
5	Uttar Pradesh	29.13	37.49	37.65	43.55	46.4	38.84
6	West Bengal	42.23	32.82	26.85	29.77	34.12	33.16
7	Gujarat	29.9	32.7	30.29	29.07	33.7	31.13
8	Delhi	14.94	14.64	24.99	24.66	26.75	21.2
9	Rajasthan	16.74	19.48	21.72	22.5	22.26	20.54
10	Bihar	1.28	1.39	8.8	33.8	34.81	16.02

Source: CPCB (2020c).

appropriate BMWM to analyze State/UTs performance. After the selection of indicators, authors had reviewed the report and extracted data manually. The process of extraction of data is the "Yes" and "No" category. For example, indicators like "All HCFs are authorized under BMWM Rules, 2016," under this indicator, those states that have this facility, considered as "Yes" and otherwise consider as "No." We continued this process for all the eight indicators and every State/UTs of India. After this whole process, we made dichotomous data for every State/UTs.

The selected eight indicators are:

1. All HCFs are authorized under BMWM Rules, 2016
2. Inventory on number of HCFs generating BMW is completed
3. Common Biomedical Waste Treatment Facility (CBMWTFs) facilities are available
4. CBMWTFs are upgraded in compliance with new emission rules
5. Use of deep burial
6. Barcode systems are implemented
7. Annual report submitted within the deadline
8. Regular monitoring of HCFs and CBMWTFs.

Authors further used data to construct a map by the choropleth technique in ArcGIS (version 10.3.1) to represent the existing gaps in BMW management rules and its implementation.

Results and discussion

Generation, distribution, and Management of BMW in India before and during the COVID-19 pandemic

As per CPCB, approximately 587 mt of BMW was generated daily in 2018 and it is likely that India will generate nearly 775.5 mt of medical waste per day by the year 2022 (Sogi and Sudan, 2019). The CPCB data indicated that over the 4-year period (2014-2018), Karnataka state topped the list in average highest BMW generation with about 66.62 mt/day followed by Maharashtra (62.34 mt/day), Kerala (51.34 mt/day), Tamil Nadu (44.99 mt/day), Uttar Pradesh (38.84 mt/day), West Bengal (33.16 mt/day), Gujarat (31.13 mt/day) and others respectively. This indicates that the average BMW generated in these states is between 30–70 mt/day (Table 2). These seven states are the worst offenders as a sizable portion of BMW does not get disposed scientifically and probably gets mixed with other municipal waste. At the national level, the BMW generation is growth was upward from 476.18 mt/day in 2014 to 587.99 mt/day in 2018 (Figure 2). However, the authors found that few north-east states and UTs, like Lakshadweep (0.23 mt/day), Andaman & Nicobar Island (0.27 mt/day), Sikkim (0.37 mt/day), Arunachal Pradesh (0.44 mt/day), Manipur (0.55 mt/day), Nagaland (0.65 mt/day), Dadra and Nagar Haveli & Daman and Diu (0.27 mt/day) are the lowest waste generated states as compared to other States/UTs of India (Table 3).

Present status of COVID 19-related BMW in India

During the pandemic, it was found that there was a massive increase in the quantum of COVID-19-related BMW from the hospitals, quarantine centers, and testing laboratories. As per the latest statistics of CPCB, India has generated over 32,996 mt of COVID-19 waste between June to December 2020. This huge amount of COVID-19 waste of medical and non-medical equipment such as PPE kits, masks, gloves, cotton swabs, and shoe covers, needles, syringes, etc. Figure 3 indicated that in the early months of the COVID-19 period (June–October 2020), the generation of waste rose from 3025 mt/month in June to 5597 mt/month in October 2020. However, we found a decreasing trend in the next 2 months, that is, 4864 mt/month in November and 4527 mt/month in December 2020. The quantity of COVID-19 waste was extremely high in July and August months probably due to BMW from households and quarantine centers that may not have been segregated and general waste was mixed with BMW. This increase put pressure on the facilitators of BMW disposal. Therefore, now there is an emphasis on the need to segregate the BMW from general waste, including households where there are COVID-19 patients (EPCA, 2020). Apart from this,

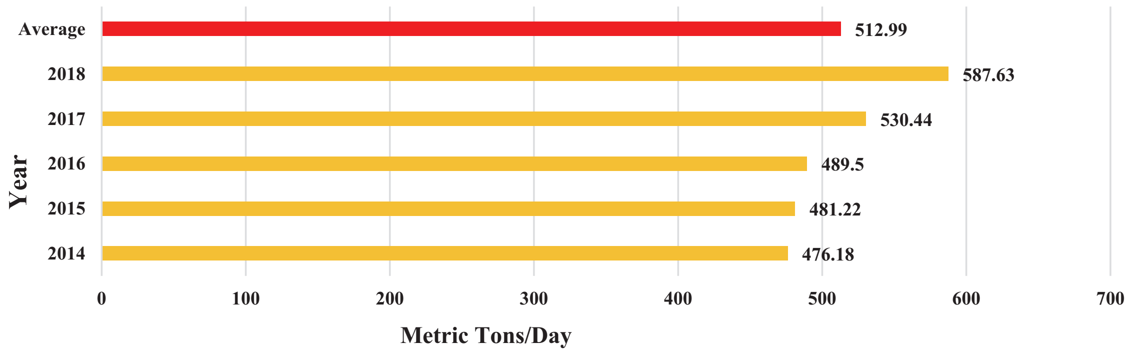

Figure 2. Bio-medical waste generation in India, between 2014 and 2018 (metric tons/day).
Source: CPCB (2020c).

Table 3. Bottom ten states/UTs of BMW generator in India (metric tons/day), 2014–2018.

Sr. no.	Name of state/UTs	2014	2015	2016	2017	2018	Average BMW generation
1	Mizoram	2.97	5.37	0.44	0.74	0.83	2.07
2	Tripura	1.33	1.37	1.6	1.6	1.4	1.46
3	Meghalaya	1.06	1.15	0.97	1.06	1.43	1.13
4	Nagaland	0.67	0.59	0.75	0.62	0.63	0.65
5	Manipur	0.37	0.37	0.36	0.52	1.14	0.55
6	Arunachal Pradesh	0.05	0.06	0.57	0.64	0.88	0.44
7	Sikkim	0.45	0.42	0.38	0.23	0.39	0.37
8	Andaman and Nicobar Island	0.31	0.28	0.38	0.18	0.19	0.27
9	DD and DNH	0.19	0.25	0.25	0.32	0.33	0.27
10	Lakshadweep	0.07	0.07	0.08	0.42	0.52	0.23

Source: CPCB (2020c).
DD and DNH, Daman Diu and Dadra Nagar Haveli.

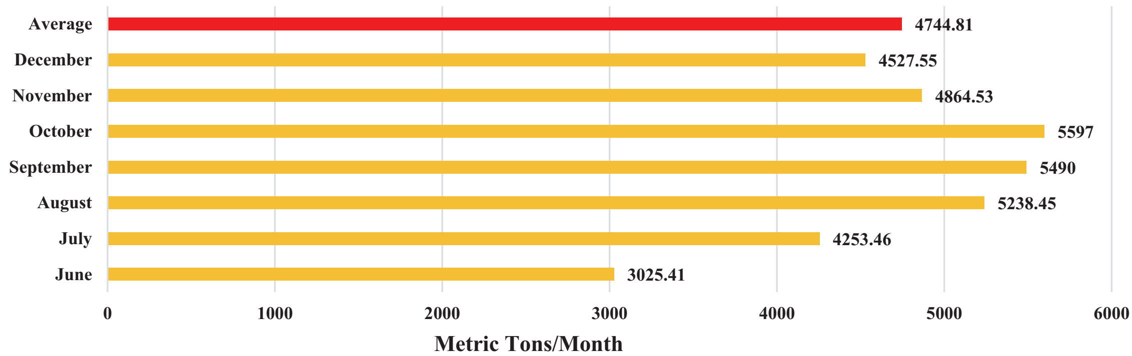

Figure 3. Total generation of COVID-19 waste in India, between June and December, 2020 (in metric tons/month).
Source: CPCB (2020d).

50% of the States/UTs have inadequate disposal facilities (Singh and Saha, 2020). In state-wide distribution, Maharashtra is highest average generator of COVID-19 waste, that is, 789.99 mt/month, followed by Kerala (459.86 mt/month), Gujarat (434.87 mt/month), Tamil Nadu (427.23 mt/month), Uttar Pradesh (371.39 mt/month), Delhi (358.83 mt/month), West Bengal (303.15 mt/month), Karnataka (301.55 mt/month), etc., respectively (Table 4). This quantity is added to the regular BMW generation of approximately 609 mt/month/day (as of June 2020) (Ahuja, 2020). The result of the study shows that Maharashtra is the highest BMW generating state not only in the current COVID-19 period but also before the pandemic situation. Nevertheless, Maharashtra has 31 CBMWTFs, treating 95.93% of BMW regularly, and 3.63% is treated by captive treatment facilities (Maharashtra Pollution Control Board, 2018). But then again, the situation is worse in terms of COVID-19 waste generation and its treatment. It has also been noted that the majority of populated states of India have a rapid increase of COVID-19 positive cases; simultaneously, the quantum of BMW is also increasing. However, few States/UTs that are less populated and less exposed

Table 4. Top ten COVID-19 waste generator states/UTs in India, between June and December, 2020 (in metric tons/month).

Sr. no.	State/UTs	June	July	August	September	October	November	December	Average COVID-19 waste generation
1	Maharashtra	524.82	1180	1359	524.82	542.314	609.00	629.3	789.99
2	Kerala	141.3	293.32	588.05	494.1	641.98	600.39	542.47	459.86
3	Gujarat	350.79	306.14	360.04	622.89	545.879	423.51	479.57	434.87
4	Tamil Nadu	312.3	401.29	481.1	543.78	524.179	300.75	251.22	427.23
5	Uttar Pradesh	210	307.54	408.86	507.15	478.082	316.71	276.46	371.39
6	Delhi	333.42	389.58	296.14	382.5	365.89	385.47	321.32	358.83
7	West Bengal	195	136.37	235.12	434.76	486.79	330.84	279.06	303.15
8	Karnataka	84	540.28	588.03	168	218.02	210.99	218.02	301.55
9	Madhya Pradesh	224.58	56.4	106.59	339	308.42	208.65	249.49	207.27
10	Haryana	75.33	184.18	210.69	112.35	238.45	239.4	209.93	176.73

Source: CPCB (2020d).

Table 5. Bottom ten COVID-19 waste generator states/UTs in India, between June and December, 2020 (in metric tons/month).

Sr. no	State/UTs	June	July	August	September	October	November	December	Average COVID-19 waste generation
1	Manipur	5.13	0.2	2.09	5.13	5.3	5.13	9.27	4.61
2	Jharkhand	INP	INP	2.59	4.8	4.96	4.8	11.63	4.29
3	Mizoram	4.2	INP	INP	4.2	3.22	3.12	3.22	3.69
4	Arunachal Pradesh	3.36	3.36	3.8	3.36	3.47	3.36	3.47	3.45
5	Sikkim	6	0.2	0.3	6	4.22	3.69	2.45	3.27
6	Nagaland	3.6	3.4	3.1	2.85	3.32	1.86	2.29	2.92
7	DD and DNH	0.00	INP	0.00	0.48	2.39	1.08	1.15	0.79
8	Tripura	0.45	INP	INP	0.45	0.47	0.45	0.47	0.46
9	Andaman and Nicobar Island	0.42	INP	INP	0.42	0.43	0.42	0.43	0.42
10	Lakshadweep	0.3	INP	INP	0.3	0.31	0.3	0.31	0.3

Source: CPCB (2020d).
DD and DNH*, Daman Diu and Dadra Nagar Haveli; INP, information not provided.

to the COVID-19 virus (Nagaland, Tripura, Lakshadweep, Andaman & Nicobar Island, Arunachal Pradesh, Daman and Diu, Dadra, and Nagar Haveli) the generation of COVID-19 waste is also not as much as other populated states (Table 5).

The CPCB and SPCB are jointly combating efforts to minimize the COVID-19 waste by framing the rules and guidelines for BMWM. Also, all the stakeholders such as CBMWTFs and urban local bodies of different States/UTs are likely to implement BMWM rules.

All COVID-waste comes under the hazardous BMW (Ilyas et al., 2020). Hence, the CPCB proposed a guideline, specifically for the COVID-19 waste management. The whole process of COVID-19 waste management is graphically presented in Figure 4.

Challenges and gaps in BMW management in India

Successive BMW rules (1998, 2016, and 2018) were implemented in India since the late 2000's. However, separate guidelines had to be given by the CPCB for ensuring the COVID-19 waste disposal in a scientific manner. Implementation of these guidelines during the pandemic becomes a major concern, as there are many gaps identified with compliance of BMWM Rules. According to a recent study, 70% of BMW generated in India gets treated in incinerators and 30% is either illegally dumped or found as common garbage on the roads (Singh and Saha, 2020). In addition, small towns and villages do not have the proper facilities to treat the COVID-19 waste; they are either depending on neighboring cities for BMW treatment or using a deep burial system.

As per the map representation (Figure 6), out of all 35 States/UTs, HCFs, only eight states got authorization as per BMWM rules, 2016. Even, the national capital territory of Delhi is not listed in all HCFs authorization under BMWM rules, 2016. It was seen that after the 4 years of implementation of BMW rules 2016, not all States/UTs have been able to establish CBMWTFs treatment facilities. States/UTs like Arunachal Pradesh, Goa, Mizoram, Nagaland, Sikkim, Tripura, Andaman and Nicobar Island, and Lakshadweep have no CBMWTFs facilities but these states have generated approximately 18.03 mt tons of

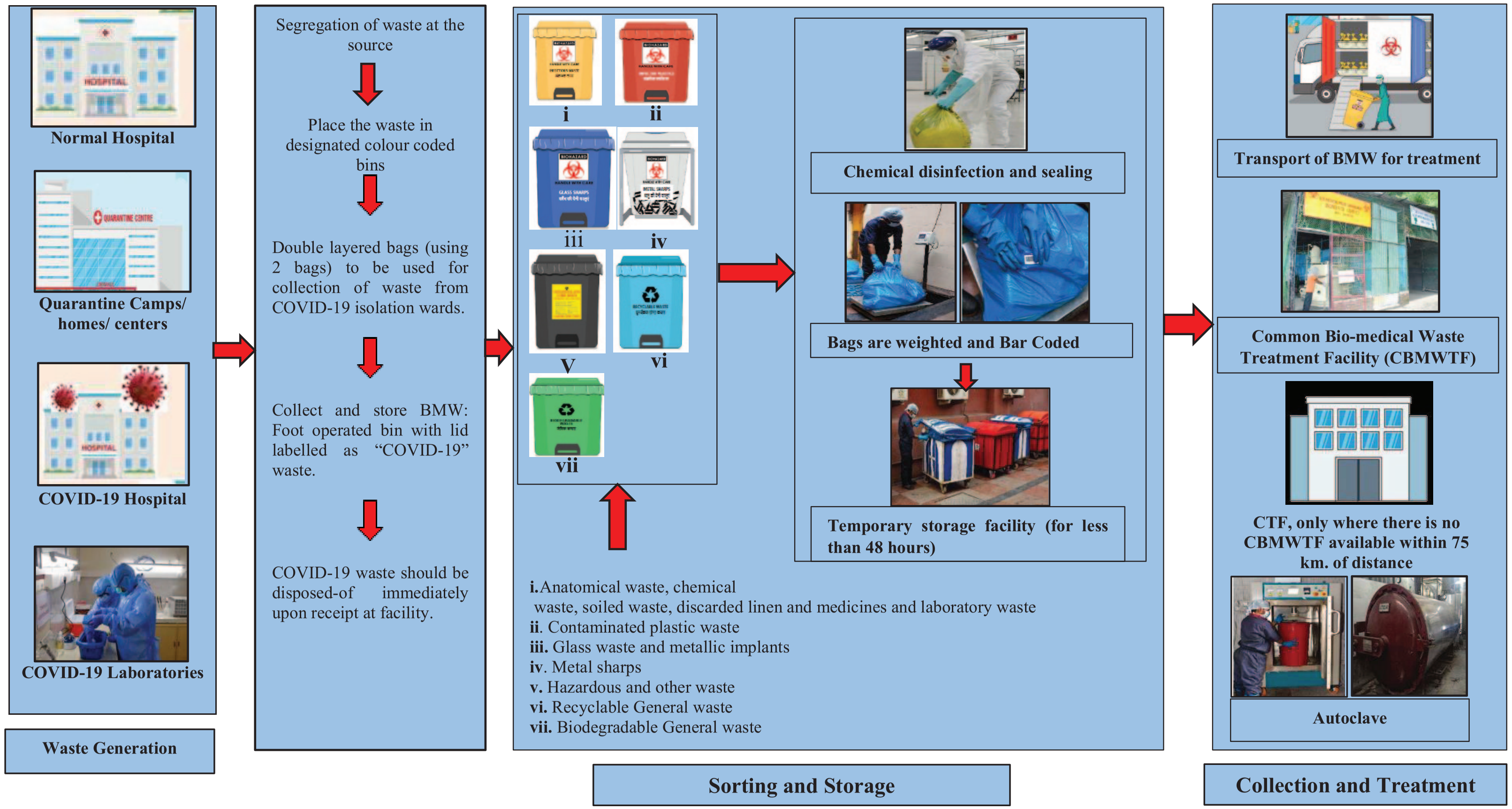

Figure 4. Bio-medical waste management practices during COVID-19 period.
Source: Images were collected from the open data sources.

- CPCB (2020e) Available from: https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/Pictorial_guide_covid.pdf (accessed 14 December 2020).
- Mongabay Series: Environment And Health. (2020) (24th March 2020) (Accessed 10 December 2020). Available at: https://india.mongabay.com/2020/03/pollution-watchdog-releases-guidelines-to-handle-covid-19-biomedical-waste/ (accessed 20 November 2020).
- Ramteke and Sahu (2020).
- Ilyas et al. (2020).

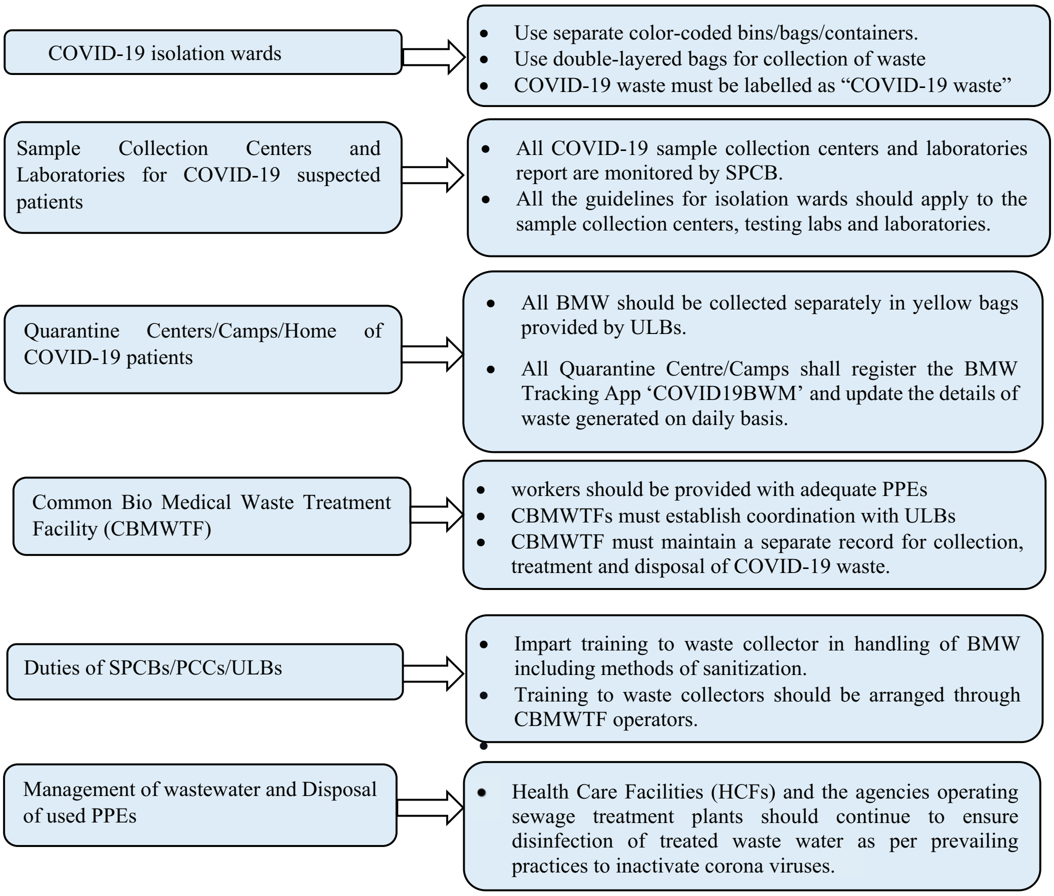

Figure 5. Guidelines and directions by CPCB for COVID-19 BMW management.
Source: Adopted and modified from CPCB (2020b) (Available at: https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/BMW-GUIDELINES-COVID_1.pdf).
SPCB, state pollution control board; PCC: pollution control committee; ULBs, urban local bodies; PPE, personal protective equipment's.

COVID-19 waste, December 2020. When CBMWTFs are upgraded to comply with new emissions, only 12 States/UTs are in line with the rules. Similarly, the barcode system, one of the most important reforms in BMW rules, 2016, was also not implemented well. Moreover, the government strictly restricted the practice of deep burials, however, 23 States/UTs are still using deep burial methods for the disposal of BMW generated from HCFs. Therefore, SPCBs and CPCB are making an effort to reduce the use of deep burial methods and upgrade the alternative treatment facilities to fill this gap. Another important aspect was the monitoring of HCFs and CBMWTFs, study indicated that out of all States/UTs, 70% have not well-established systems of regular monitoring. As per the new rules of CPCB (2020b), the district level monitoring committee should plan out a strategy to monitor these facilities (Figure 5). Moreover, until now, India has only 200 CBMWTFs for waste treatment; these facilities are inadequate and running at 60% limit, which is a 15% increase since March 2020 (Ramteke and Sahu, 2020). States/UT's namely Goa, Andaman & Nicobar Island, Arunachal Pradesh, Lakshadweep, Mizoram, Nagaland and Sikkim have been using deep burial for the disposal of BMW which is not recommended as per BMW Rules 2016 as well as CPCB guidelines (Figure 6). Therefore, previous research studies have recommended that India should focus on installation of more CBMWTFs and should work on increasing connectivity up to the Primary Health Center level (Bhushan, 2018).

State/UTs performance and response during COVID-19

Considering the Indian scenario, most of the States/UTs have exceeded the capability of existing treatment/disposal facilities. A total of 200 CBMWTFs is available across India, but these facilities are insufficient to treat the large quantum of waste, especially in the COVID-19 period. Most of the States/UTs (Maharashtra, Kerala, Gujarat, Tamil Nadu, Delhi, Uttar Pradesh, Karnataka, and West Bengal) have almost reached their threshold capacity to manage the BMW waste. At the same time, these states contributed 72% of total COVID-19 waste between June and December 2020. In contrast, States/UTs (Meghalaya, Goa, Manipur, Jharkhand, Mizoram, Arunachal Pradesh, Sikkim, Nagaland, Tripura, Andaman & Nicobar Island, Lakshadweep, Daman and Diu, and Dadra & Nagar Haveli,) contributed a very negligible amount of total COVID-19 waste during the same period (Table A1). In brief, the majority of the States/UTs have faced similar problems associated with the BMWM.

This study also shows that a massive amount of BMW has piled up in the different health institutions; however, due to lack

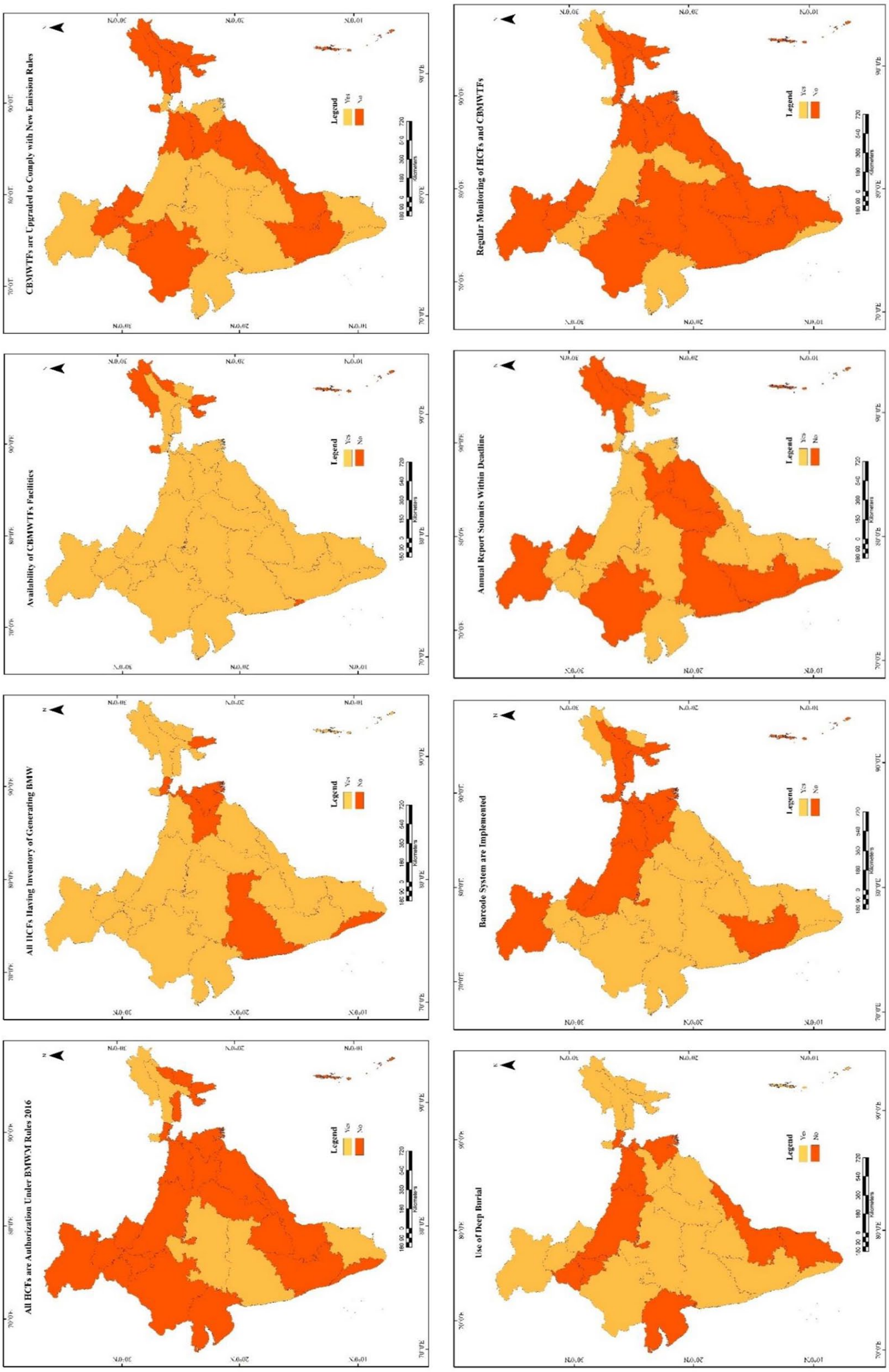

Figure 6. Geographical representation of BMW facilities and gaps in India.
Source: Gap analysis of the compliance reports, CPCB (2019). Maps prepared by the authors.

of proper management of waste segregation and recycling, the situation has worsened. Maharashtra is the highest COVID-19 waste generator state, but it has an inadequate existing treatment facility; therefore, it made a stand-by treatment arrangement, called "TSDFs" (Treatment, Storage, and Disposal Facilities) in Mumbai, Pune, and Nagpur cities. National capital of Delhi accounts for 11% of India's daily COVID-19 BMW generation. However, at present, Delhi has only two incinerators, and 70% of their capacity is already utilized (Ahuja, 2020). Apart from these two states, many other states are also facing problems. There is a need for the rapid development of more CBMWTFs to fulfill the need for treatment and management of BMW generated in India (Vishwanath and Mehrotra, 2020). In context of captive treatment facilities installed in different States/UT's HCFs in India, about 15,181 HCFs have captive BMW treatment and disposal facilities, which are involved in the treatment and disposal of BMW. However, in five States/UTs, namely Daman and Diu, Dadra and Nagar Haveli, Gujarat, Mizoram, and Punjab have no single HCFs that have installed the captive treatment facilities for treatment of BMW. Six states/UT's, namely, Andhra Pradesh, Puducherry, Haryana, West Bengal, Bihar, and Chandigarh, and have only three or less than three HCFs that have installed captive treatment facilities (MoHFW, 2018). Therefore, India is still struggling to manage BMW effectively. The government of India reported that nearly 87% of BMW is treated as per BMWM Rules (CPCB, 2018). However, the finding of this study shows a huge gap between total BMW generation and total BMW treated in a timely manner. Additionally, nine States/UTs, including Meghalaya, Goa, Mizoram, Arunachal Pradesh, Sikkim, Nagaland, Tripura, Andaman & Nicobar Island, and Lakshadweep, have no facilities of CBMWTFs. These nine States/UTs may depend either on captive treatment facilities or disposed of in deep burial, which is not a widely accepted treatment method. Lastly, Northeastern states of India (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, and Sikkim) and other hilly states of India, needs special attention with respect to treatment and disposal of BMW. As per government records, only five CBMWTFs are available in these eight states (CPCB, 2020d). These states are still using deep burial methods for the treatment of BMW. Therefore, the government should develop additional capacities of the CBMWTFs in these hilly states.

Conclusion

This study provides a comprehensive assessment of COVID-19 waste generation and highlights the challenges and gaps on the current waste management system in India. The findings demonstrate that most of the States/UTs of India have poor performance in terms of COVID-19 waste management. Therefore, the quantity of average daily waste generation is still growing rapidly. The major limitation is the unavailability of recent years' data of BMW, that is, 2019 and 2020. Therefore, this study represents only 5 years (2014–2018) scenario of BMW generation in India. Hence, it is very difficult to assess the current scenario of BMW in India through statistical analysis. The present research suggests that those States/UTs generated on an average of 100 mt/month COVID-19 waste in the last 7 months (June–December 2020) should be considered as a high priority state. Secondly, all States/UTs should have categorized their districts as low, medium, and high priority regions based on BMW generation status and treatment capacities. Based on their categories concerned authority should provide the facilities and upgrade their BMW treatment capacity to achieve a safe and sound waste management system. Finally, this study can help policymakers, regulatory bodies, and academicians design efficient BMW management with robust implementation strategies. However, further research on the global perspective of COVID-19 waste will provide more constructive understanding toward better management during a similar crisis.

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Appendix 1

Table A1. State wise distribution of COVID-19 related BMW during June–December, 2020 (in metric tons/month).

State/UTs	June	July	August	September	October	November	December	Average COVID-19 waste generation
COVID 19 related BMW waste generation during June–December, 2020 (in metric tons/month)								
Very high waste generating states/Uts								
Maharashtra	524.82	1180	1359	524.82	542.314	609.00	629.30	789.99
Kerala	141.3	293.32	588.05	494.1	641.98	600.39	542.47	459.86
Gujarat	350.79	306.14	360.04	622.89	545.879	423.51	479.57	434.87
Tamil Nadu	312.3	401.29	481.1	543.78	524.179	300.75	251.22	427.23
Uttar Pradesh	210	307.54	408.86	507.15	478.082	316.71	276.46	371.39
Delhi	333.42	389.58	296.14	382.5	365.89	385.47	321.32	358.83
West Bengal	195	136.37	235.12	434.76	486.79	330.84	279.06	303.15
Karnataka	84	540.28	588.03	168	218.02	210.99	218.02	301.55
High waste generating states/Uts								
Madhya Pradesh	224.58	56.4	106.59	339	308.42	208.65	249.49	207.27
Haryana	75.33	184.18	210.69	112.35	238.45	239.4	209.93	176.73
Andhra Pradesh	165.48	182.81	118.82	0.42	116.1	317.91	328.51	150.26
Odisha	31.86	106.63	109.19	134.01	183.46	222.66	125.58	131.30
Rajasthan	177.00	7.15	50.43	145.08	171.55	141.93	105.93	115.52
Punjab	48.0	35.59	21.19	234.42	149.61	96.51	86.99	97.55
Telangana	12.3	10.5	24.04	188.82	144.8	103.89	68.82	80.73
Medium waste generating states/Uts								
Chandigarh	29.85	5.65	55.34	43.02	73.19	70.83	73.19	46.31
Puducherry	18.63	35.82	41.54	63.00	58.65	28.74	17.11	41.06
Jammu and Kashmir	10.71	9.77	51.77	57.39	59.3	44.82	35.12	38.96
Uttarakhand	0.45	0.82	41.85	21.72	109	56.76	76.26	38.43
Assam	28.38	20.68	12.57	62.61	51.74	50.07	23.41	37.68
Bihar	6.84	20.76	41.54	45.36	44.64	28.08	23.31	31.20
Himachal Pradesh	3.81	12.5	4.94	25.20	28.12	30.03	48.24	17.43
Chhattisgarh	11.19	INP	13.39	9.30	9.61	9.30	9.61	10.56
Low waste generating states/Uts								
Meghalaya	5.1	1.74	6.34	9.90	12.03	7.65	8.56	7.33
Goa	0.81	0.81	INP	15.00	7.75	5.43	5.39	5.87
Manipur	5.13	0.2	2.09	5.13	5.3	5.13	9.27	4.61
Jharkhand	INP	INP	2.59	4.80	4.96	4.80	11.63	4.29
Mizoram	4.2	INP	INP	4.20	3.22	3.12	3.22	3.69
Arunachal Pradesh	3.36	3.36	3.8	3.36	3.47	3.36	3.47	3.45
Sikkim	6.0	0.2	0.3	6.00	4.22	3.69	2.45	3.27
Nagaland	3.6	3.4	3.1	2.85	3.32	1.86	2.29	2.92
DD and DNH	0.00	INP	0	0.48	2.39	1.08	1.15	0.79
Tripura	0.45	INP	INP	0.45	0.47	0.45	0.47	0.46
Andaman and Nicobar Island	0.42	INP	INP	0.42	0.43	0.42	0.43	0.42
Lakshadweep	0.3	INP	INP	0.3	0.31	0.30	0.31	0.30
India	**3025.41**	**4253.46**	**5238.45**	**5490.00**	**5597.00**	**4864.53**	**4527.55**	**4744.81**

Source: CPCB (2020d).
Very High: 800.00–300.00 mt; High: 300.01–80.00 mt; Medium: 80.01–10.00 mt; Low: 10.01–0.01 mt
DD and DNH, Daman Diu and Dadra Nagar Haveli; INP, information not provided.