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Mask consumption and biomedical waste generation rate during Covid-19 pandemic: A case study of central India

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ABSTRACT

The rapid generation of biomedical waste (BMW) due to covid-19 pandemic has created burden on the existing municipal solid waste management (MSWM) system in both developed and developing countries. The substantial influx of covid patients in Maharashtra, India has influenced the pattern of BMW generation, especially for the yellow category of BMW and incineration facilities. The objective of the study was to estimate the daily face mask consumption (D_FM) and BMW generation from May 2020 to August 2021 in Maharashtra, India. The study was carried out based on the confirmed covid-19 cases, population forecast, urban population (%), BMW generation rate (kg/bed/day), and so on. The data set for the each parameters were collected from web-portals, published reports based on previous studies. These data sets were further regrouped, processed and analysed using mathematical equations. The study also revealed that Mumbai, Pune, and Thane districts, India has contributed > 60% of the D_FM and BMW generation. It was found that the D_FM by non-covid patients was higher compared to the covid patients (D_CFm). Further, it was revealed that BMW generated in the months of July 2020 (152 tons/day), August 2020 (192 tons/day), September 2020 (304 tons/day), October 2020 (177 tons/day), March 2021 (405 tons/day), April 2021 (1,102 tons/day), May 2021 (705 tons/day), June 2021 (194 tons/day), and July 2021 (149 tons/day), exceeded the existing BMW treatment capacity of 132 tons/day. The sudden spike in covid-19 cases has influenced the pattern of D_FM and BMW generation, especially for the yellow category of BMW (BMW_Y) and has increased the burden on BMW incineration facilities. The daily emission rates from BMW-incineration was in the order PM_{10}> NO_{2}> CO>SO_{2}, with maximum emission of PM_{10} (85.61 kg of pollutant/day). The F-test was performed using one-way ANOVA to understand the influence of covid cases on daily face mask consumption. It was found that F-statistic of D_CFm and BMW_Y is more than the F-critical i.e., increase in covid cases had a significant effect on mass consumption rate and BMW generation.

1. Introduction

The sudden outbreak of the covid-19 pandemic on March 11, 2020 led to chaos, resulting in the closure of necessary amenities across the globe (Saadat et al., 2020) Globally, the international borders were closed to avoid the spread of covid-19 virus (Saadat et al., 2020) As...
precautionary measures, the World Health Organization (WHO, 2020) published its health care guidelines, including home quarantine rules and compulsory usage of personal protective equipment (PPE) (surgical masks, cloth masks, face shields, gloves, etc.) (WHO, 2014). The pandemic spread across more than 219 countries, which led to 6.82 million death and 491 million confirmed covid-19 cases (as of April 6, 2022) (Worldometer, 2021). The continents, such as Europe and Asia have contributed more than 300 million confirmed covid-19 cases. The countries, such USA (81 million), India (43 million), Brazil (30 million), France (26 million) and UK (21 million) have reported maximum cases across the globe (as of April 6, 2022). Developing countries, such as India has reported 0.52 million death and 42 million recovered cases (as of April 6, 2022) (Worldometer, 2021). Among all the 28 states in India, Maharashtra is the most affected region, with more than 7.8 million confirmed covid-19 cases (as of April 6, 2022) (Worldometer, 2021). The burden to manage the increased cases of covid-19 was faced by the health care facilities and other governing bodies (Sangkhram, 2020; Adams and Walls, 2020). In India, many states have also failed to address this situation due to lack of resources, such as quarantine camps, isolation buildings, research facilities, personal protective equipment (PPE) kits, chemicals, reagents, medicines, etc. (Singh et al., 2021; Nzediegwu and Chang, 2020).

The rapid increase in biomedical waste (BMW) generation and utilization of PPE has created burden on the existing treatment facilities. While in other developing countries, the unorganized management and collection scheme from hospitals, dispensaries, and other sources have caused dumping and landfilling of BMW along with the commingled municipal solid waste (MSW) (Singh et al., 2021). This can lead to the direct exposure of contigues and hazardous waste into the environment. The BMW comprises non-hazardous waste (80%) and hazardous waste (20%), consisting of 15% infectious waste and 5% chemical or radioactive waste (WHO, 2014). During the first few months of the pandemic, China and Indonesia had reported 470 tons/day and 212 tons/day of BMW generation (Mihai, 2020; Peng et al., 2020). The quantity of BMW generated in the pandemic phase was found to be 2.5 kg/bed/day as compared to the usual time of 0.68 kg/bed/day, which was 5 times more during the pandemic phase (Anwer and Faizan, 2020; Shammis et al., 2021).

The studies have revealed that an increase in covid-19 cases is directly proportion to the rate of BMW generation (Sangkhram, 2020). Moreover, the domestic usage of masks was made compulsory among the residents to maintain hygiene and safety which led to excess disposal of masks and other than PPE kits (Alcaraz et al., 2022; Sangkhram, 2020). The unorganized BMW management from domestic and medical sectors are the potential source of infection. Presently, no such study was reported to estimate the BMW generation and mask consumption rate for highly covid affected state in the country. The present study is an attempt to motivate scientific community in developing better treatment technology and handling methods for BMW management. It is conclusive that the pandemic has caused severity and challenges in BMW treatment facilities in India. At present, the state of Maharashtra in India lacks the desired treatment facilities compared to the increase in mask consumption and BMW rate, and safe disposal of BMW is a serious challenge. Therefore, it is essential to develop alternative preventive measures and treatment facilities to meet the future demand at such pandemic, resulting in low risk to the environment, public health, and safety. The present study provides a comprehensive research, projecting BMW generation and masks consumption rates in Maharashtra, India.

2. Materials and methods

2.1. Study area

The Maharashtra state in India, located at 19.7515° N latitude and 75.7139° E longitude, was selected as the study area, as shown in Fig. 1. In terms of the geographical stretch, it is the second-largest state in India, spread over 0.308 million square km. It occupies India’s central and western parts with a coastline stretch of 720 km along the Arabian Sea. The state comprises 36 districts divided into six revenue divisions for administrative purposes viz. Konkan, Pune, Nashik, Aurangabad, Amravati, and Nagpur. The districts are Ahmednagar (Ah), Akola (Ak), Amravati (Am), Aurangabad (Au), Beed (Be), Bhandara (Bh), Buldhana
Table 1  
Population forecast and mask consumption in all districts of Maharashtra state during March 2020 to August 2021.

| District | Growth rate (r) | Population Forecast (10^5) | Covid Cases (10^5) | Mask Usage Phase 1 | Mask Usage Phase 2 | Mask Usage Phase 3 |
|----------|----------------|----------------------------|-------------------|--------------------|--------------------|--------------------|
|          |                |                            |                   | DCM (10^5) Rate | DCN (10^5) Rate | DCM (10^5) Rate |
|          |                |                            |                   | (masks/day)       | (masks/day)       | (masks/day)       |
| Ah       | 1.11           | 96                         | 3.08              | 1.37               | 0.011             | 259.07            |
| Ak       | 1.13           | 38.69                      | 0.59              | 0.26               | 0.002             | 104.37            |
| Am       | 1.08           | 60.18                      | 0.96              | 0.35               | 0.003             | 162.45            |
| Au       | 2.67           | 135.95                     | 1.55              | 1.55               | 0.013             | 366.92            |
| Be       | 1.97           | 76.74                      | 1.01              | 0.32               | 0.003             | 207.17            |
| Bh       | 0.57           | 18.81                      | 0.60              | 0.07               | 0.00              | 50.80             |
| Bu       | 1.62           | 67.67                      | 0.85              | 0.22               | 0.002             | 182.69            |
| Ch       | 0.61           | 35.45                      | 0.88              | 0.16               | 0.001             | 95.70             |
| D         | 2.00           | 61.53                      | 0.43              | 0.53               | 0.004             | 166.08            |
| Ga       | 1.06           | 22.12                      | 0.30              | 0.10               | 0.00              | 37.20             |
| Go       | 1.02           | 26.70                      | 0.40              | 0.10               | 0.00              | 72.10             |
| Hi       | 1.93           | 34.51                      | 0.18              | 0.10               | 0.00              | 93.19             |
| Jal      | 1.49           | 105.51                     | 1.40              | 1.85               | 0.015             | 284.71            |
| Ko       | 1.03           | 78.51                      | 2.04              | 1.51               | 0.012             | 211.84            |
| La       | 1.81           | 68.93                      | 0.91              | 0.54               | 0.004             | 186.08            |
| Mu       | 0.87           | 236.67                     | 7.43              | 9.84               | 0.080             | 638.03            |
| Nag      | 1.49           | 115.69                     | 4.93              | 1.89               | 0.015             | 312.19            |
| Na       | 1.72           | 91.40                      | 0.91              | 0.48               | 0.004             | 246.74            |
| Nan      | 2.59           | 59.18                      | 0.40              | 0.18               | 0.002             | 159.78            |
| Nas      | 2.24           | 198.11                     | 0.40              | 1.18               | 0.002             | 354.63            |
| Os       | 1.26           | 37.44                      | 0.66              | 0.40               | 0.003             | 101.04            |
| Par      | 2.31           | 60.83                      | 1.34              | 1.72               | 0.014             | 164.09            |
| Pal      | 2.10           | 17.06                      | 0.52              | 0.17               | 0.001             | 46.04             |
| Pu       | 3.05           | 382.12                     | 11.17             | 11.81               | 0.095             | 1030.55            |
| Rai      | 1.94           | 77.47                      | 1.88              | 2.04               | 0.016             | 208.98            |
| Rat      | 0.50           | 25.42                      | 0.75              | 0.28               | 0.002             | 68.60             |
| San      | 0.93           | 54.48                      | 2.01              | 0.89               | 0.007             | 147.03            |
| Sat      | 0.74           | 52.25                      | 2.38              | 0.94               | 0.008             | 140.98            |
| Si       | 0.14           | 9.83                       | 0.50              | 0.08               | 0.00              | 26.53             |
| So       | 1.20           | 94.96                      | 2.04              | 1.32               | 0.011             | 256.26            |
| Th       | 3.61           | 509.43                     | 5.96              | 8.95               | 0.073             | 1374.58           |
| Wa       | 0.57           | 20.42                      | 0.58              | 0.06               | 0.001             | 55.13             |
| Was      | 1.74           | 32.80                      | 0.42              | 0.11               | 0.00              | 88.55             |
| Ya       | 1.27           | 62.86                      | 0.76              | 0.21               | 0.002             | 169.70            |

Ah: Ahmednagar, Ak: Akola, Am: Amravati, Au: Aurangabad, Be: Beed, Bh: Bhandara, Bu: Buldhana, Ch: Chandrapur, Dh: Dhule, Ga: Gadchiroli, Go: Gondia, Hi: Hingoli, Ja: Jalgaon, Jh: Jalna, Ko: Kolhapur, La: Latur, Nm: Navi Mumbai, Mu: Mumbai, Nag: Nagpur, Na: Nanded, Nan: Nandurbar, Nas: Nashik, Oc: Osmanabad, Par: Parbhani, Pal: Palghar, Pu: Pune, Rai: Raigad, Rat: Ratnagiri, San: Sangli, Sat: Satara, Si: Sindhudurg, So: Solapur, Th: Thane, Wa: Wardha, Was: Washim, and Ya: Yavatmal.


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2.2. Population forecast and confirmed Covid-19 cases

The population data for 2001 and 2011 were retrieved from Census (2011). The data on confirmed covid-19 cases data over 16 months from May 2020 to August 2021 were retrieved from covid-19 updates (2020). Depending upon the reported number of covid cases, the data set was categorized as low, medium and high group i.e., phase 1 (May 2020 to August 2020), phase 2 (September 2020 to January 2021), and phase 3 (February 2021 to August 2021). The projected populations for 2020 and 2021 were estimated using Eqs. (1) and (2) (Talaiekhozani et al., 2018). The method of variations in covid-19 cases in each district of Maharashtra state was used. The projected population data was further used to estimate the quantity of BMW.

\[
P_p = P_1 (1 + r)^n
\]

\[
r = \left( \frac{(P_1 - P_2) \times 100}{P_2} \right) / N
\]

Where, \( P_p \) is the projection population, \( P_1 \) is population as per Census, 2011, \( P_2 \) is population as per census 2001, \( r \) is the rate of increase in population, \( n \) is the number of decades, \( N \) is a number of the year from 2001 to 2011.

2.3. Estimation of monthly face mask consumption

The monthly face mask usage for covid and the non-covid patient was estimated using Eqs. (3) and (4). The survey was performed with 50 participants, including both covid affected and not affected residents in National Environmental Engineering Research Institute (NEERI) colony at Nagpur, India. The survey was conducted in July 2020 (Phase 1), November 2020 (Phase 2), and May 2021 (Phase 3) to estimate the maximum usage of masks during the peak duration of the pandemic.

\[
D_{CFM} = P_C \times P_U \times R_{CFM} \times A_{CFM}
\]

\[
D_{NCFM} = P_C \times P_U \times R_{NFM} \times A_{CFM}
\]

Where, \( D_{CFM} \) and \( D_{NCFM} \) is the estimation of facemask consumption by covid-19 and non-covid-19 patients, \( P_u \) is the population not affected with covid-19, \( P_C \) is the population affected with covid, \( P_U \) is the percentage of the urban population, \( R_{CFM} \) is the mask acceptance rate by covid-19 patients, \( R_{NFM} \) is the mask acceptance rate by non-covid-19 patients, \( A_{CFM} \) is the average number of masks used per month for covid-19 patients, \( A_{NFM} \) is the average number of masks per month for non-covid-19 patients.

2.4. Estimation of biomedical waste generation (BMWG) for Covid-19 patients

BMW generated is proportional to the number of patients utilizing beds in each hospital and other services (private clinics). As it was difficult to estimate the number of covid-19 patients using medical facilities in Maharashtra, the present study has assumed 80% population affected by covid-19 have utilized medical facilities. The percentage of the patient admitted to the hospital facility was considered to be 50%. The rate of BMW generated from medical facilities in each district was collected from the MPCB Report (2020). The quantity of BMW from each district was estimated using Eq. (5).

\[
BMWC = \left( \frac{P_C \times T_p \times R_{BMWG} \times H_p}{1000} \right)
\]

Where \( P_C \) is the population with confirmed Covid-19 cases, \( T_p \) is the percentage of the patient using medical facility = 0.80, \( R_{BMWG} \) is the rate of BMW = 3.5 kg/day (Singh et al., 2021), \( H_p \) is the percentage of the patient admitted to hospital = 0.50, \( BMWC \) is the estimated BMW generated from covid patients utilizing medical facilities (tons/days).

2.5. Estimation of yellow biomedical waste from covid patients (BMWCY)

The CPCB and MPCB Reports (2020) were accessed and analyzed to estimate the percentage of BMW in BMWC for Maharashtra. The average proportion of BMWC was 44%, and it was considered to estimate the quantity of BMWCY. The finding was used to estimate the daily and monthly generation of BMWCY for covid patients in each district from May 2020 to August 2021. Further, to determine the load on the treatment facilities in Maharashtra, the BMWCY were compared to

Fig. 2. Mask consumption by covid and non-covid-19 patients in phase 1, 2, and 3.
net incineration capacity in Maharashtra. The pollutants released due to the incineration process were calculated using the net weight of BMW and the emission factor reported for each pollutant.

2.6. Statistical analysis

The statistical analysis was performed using one-way ANOVA in Microsoft Excel (2019). The study examined the significance of variance...
in $D_{\text{CFM}}$ and $BMW_{\text{CY}}$ for covid affected population in all the three phases of study area. The problem was defined using null hypothesis i.e., the increase in covid cases will cause increase in $D_{\text{CFM}}$ and $BMW_{\text{CY}}$. The Pearson correlation coefficient was analysed to understand the dependence of $D_{\text{CFM}}$ and $BMW_{\text{CY}}$ with respect to reported covid-19 cases.

2.7. Limitation of the Study

The study was aimed to provide an estimation for the daily face mask consumption and BMW generation in Maharashtra, India. The study depends upon the reliability of the reported covid-19 cases, population forecast, urban population (%), BMW generation rate (kg/bed/day), and so on. The data set for these parameters were taken into consideration and support by previous studies (Sangkham, 2020; Singh et al., 2021).

3. Results and discussion

3.1. Population and covid cases

The State of Maharashtra in India is among the highest contributor to India’s economy and population growth rate. The state contributes 9.29% to the overall population of India with 45% residing in cities and towns. This change in population growth rate and industrialization have boosted the financial model of the state (Census, 2011). However, during the covid-19 pandemic, the state has faced a drastic economic drop-down, lack of resources, and load on treatment facilities. The hike in BMW was also predominant due to the higher population and covid infection rate. Therefore, it is essential to estimate the population forecast and BMW generation. In the present study, the growth rate model was used to forecast the population for the year 2020–2021. The percentage change in growth rate ($r$) for the pandemic year was similar to the Census (2011). The detailed population forecast for each district has been estimated using Eq (1) and discussed in Table 1. The study estimated that Mumbai and Sindhudurg districts comprises the highest (23.66) and lowest (0.98) million population. At the same time, the estimated population for the state was 316.39 million. Further, the predicted population count was compared with covid reported data to determine the non-affected population with the covid pandemic in each district. The state has reported 6.46 million covid-19 cases from May 2020 to August 2021. The registered number of covid cases reported in 35 districts has been discussed in Table 1. The highest and lowest cases reported within the states were 1.78 and 0.067 million in April 2021 and May 2020, respectively. The study revealed that Mumbai and Pune districts had contributed the highest number of cases of $0.74 \times 10^6$ and $1.11 \times 10^6$ from May 2020 to August 2021. In comparison, the Hingoli and Gadchiroli districts reported a minimum of $18.44 \times 10^3$ and $30.35 \times 10^3$. However, the population of Mumbai and Pune was found to be 11 times higher than Hingoli and Gadchiroli. Phase 1, 2, and 3 of the pandemic have reported $0.79 \times 10^6$, $1.23 \times 10^6$, and $4.43 \times 10^6$ covid cases, respectively. It was conclusive that the lockdown during the pandemic was effective enough to reduce the number of cases by 40%–60%. During phases 1, 2, and 3, the highest and lowest covid cases were reported in August 2020 ($0.06 \times 10^6$), September 2020 ($0.59 \times 10^6$), April 2021 ($1.78 \times 10^6$), and May 2020 ($0.37 \times 10^6$), January 2021 ($0.10 \times 10^6$), February 2021 ($0.13 \times 10^6$), respectively.

The study concluded that the Pune district has reported maximum cases in all the phases, i.e., $175 \times 10^3$, $213 \times 10^3$, and $729 \times 10^3$. At the same time, Gadchiroli and Hingoli have reported minimum cases in phase 1 ($0.79 \times 10^3$) and phase 2 ($2.92 \times 10^3$), $3 (14 \times 10^3)$, respectively. Compared to Mumbai and Thane, Pune has reported 40%–50% higher covid cases. Generally, the districts with higher population and urbanization growth rates have reported maximum covid–19 cases. The majorly populated districts, such as Mumbai, Thane, Pune, Nagpur, Nashik, Aurangabad, Kolhapur, and Jalgaon have altogether reported
Fig. 4. $BMW_{CV}$ generation in phase (a) 1, (b) 2 and (c) 3.
3.85 × 10^6, which is 60% of overall covid cases reported in Maharashtra.

3.2. Daily face mask consumption

Since April 2020, the subsequent increase in covid cases has enforced compulsory usage of masks among the residence. However, the masks consumption depends upon residences acceptability, literacy, active covid cases, and many others. In the present study, the questionnaire survey was conducted in NEERI colony (Nagpur, India) to estimate the approximate quantity of masks used by covid patients and non-covid residents during the pandemic. During pandemic phases 1, 2, and 3, the non-covid residence had a mask usage rate of 3, 6, and 10 masks/person/month, respectively. At the same time, covid patients had a higher mask consumption rate of 15 masks/person/month during all the phases. It was concluded that during phase 1 of the pandemic, the mask usage was ≤3 masks/person/month due to the lockdown imposed by the Maharashtra state government and strict restrictions in the mobilization of residence. However, the mask consumption was increased to 6 masks/person/month after implementing the first unlock in August 2020. The study also relieved a decline in masks consumption (≤3 to 2 masks/person/month) from October to December 2020, which was predominantly due to the decrease in covid cases within the states. The study reported maximum consumption of masks during phase 3 due to the sudden increase in covid cases within the states.

During phases 1, 2, and 3, the estimated mask consumption for non-covid residents during the pandemic. During pandemic phases 1, 2, and 3, the non-covid residence had a mask usage rate of 3, 6, and 10 masks/person/month, respectively.

was higher than cured cases. The second covid wave that occurred from April 2021 to June 2021 may have influenced the change in the pattern of mask consumption in phase 3. The estimated quantity of masks produced in phases 1, 2, and 3 for non-covid residents and covid patients is represented in Table 1. The study also calculated the rate of mask consumption in each district, as represented in Table 1. During phases 1, 2, and 3, covid patients in Mumbai, Pune, and Thane had a mask consumption rate of 8 × 10^3, 12 × 10^3, and 15 × 10^3 masks/day, respectively. At the same time, non-covid patients in Mumbai, Pune, and Thane had a mask consumption rate of 0.52 × 10^6, 1.71 × 10^6, and 2.77 × 10^6 masks/day, respectively. It was found that the rate of masks consumption has increased twice the speed. The study revealed that Mumbai, Pune, and Thane had contributed 55%–60% of total mask usage compared with other districts. These districts had higher pollution levels of 2.66 × 10^6, 38.21 × 10^6, and 50.94 × 10^6, proving that the population growth and urbanization have influenced maximum mask consumption. Therefore, it was essential to have a sophisticated and planned BMW collection scheme for metropolitan cities, such as Mumbai, Navi Mumbai, Pune, and Thane to dispose of the high quantity of masks consumed per day.

3.3. BMW_C and BMW_Y

The average BMW generation (BMW_G) considered for the present study in India is 3.5 kg/day (Singh et al., 2021). The proportion of BMW_Y is the most hazardous component of BMW. It comprises infectious matters, such as anatomical (body parts, blood bags, and human organs) and clinical waste (gloves, bandages, wipes, aprons, etc.). The studies have reported that BMW in Maharashtra comprises 44% of BMW_C (CPCB, 2020). The BMW_C and BMW_Y generated from phases 1, 2, and 3 were 1,109, 1,728, 6,208 tons/day, 488, 760, and 2,732 tons/day. The BMW_C and BMW_Y generated was higher in phase 3 compared to phases 1 and 2. Fig. 3(a) and (b), (c) and 4(a), (b), (c)
represent the monthly BMW_C and BMW_CY generation for phases 1, 2, and 3. Based on the monthly data, the calculated BMW_C was maximum in April 2021 (2505 tons/day) and May 2021 (1603 tons/day). At the same time, the calculated BMW_CY was maximum in April 2021 (1102 tons/day) and May 2021 (704 tons/day). The sudden spike in BMW_C and BMW_CY in April 2021 was due to the second wave of covid with 1,789,492 active covid cases. In comparison, the calculated BMW_C was minimum in May 2020 (95 tons/day) and June 2020 (150 tons/day). At the same time, the calculated BMW_CY was minimum in May 2020 (42 tons/day) and December 2020 (65 tons/day). In phase 1, the percentage

| District Code | Average Rate of BMWG (tons/day) | Treatment Technology | Disposal |
|---------------|---------------------------------|----------------------|----------|
|               | Incinerator (units) | Incineration (tons/day) | Autoclave (tons/day) | Other Facilities (tons/day) | Landfilling (units) | Deep Burial (tons/day) |
| Ah            | 2.15 | 1 | 3.2 | 0.8 | – | – | – |
| Ak            | 0.73 | – | – | – | – | – | – |
| Am            | 0.85 | 1 | 4 | 0.75 | – | – | – |
| Au            | 2.71 | 1 | 5 | 0.8 | – | – | – |
| Be            | 0.57 | 1 | 3 | 2 | – | – | 0.11 |
| Bh            | 0.37 | – | – | – | – | – | – |
| Bu            | 0.32 | – | – | – | – | – | – |
| Ch            | 0.98 | 1 | 2.4 | 1 | 0.05 | – | – |
| Dh            | 0.56 | 1 | 1.6 | 1.6 | 0.3 | – | – |
| Ga            | 0.33 | – | – | – | – | – | – |
| Go            | 0.3 | 1 | – | – | – | – | 0.05 |
| Hi            | 0.16 | – | – | – | – | – | – |
| Ja            | 1.42 | 1 | 1.68 | 0.41 | – | – | – |
| Jal           | 0.25 | 1 | 3 | 2 | – | – | – |
| Ko            | 1.84 | 2 | 3.2 | 0.7 | 0.22 | – | – |
| La            | 1.15 | 1 | 3 | 0.5 | – | – | 0.06 |
| Mu            | 21.16 | 3 | 2.4 | 8 | 0.06 | – | – |
| Nag           | 3.35 | 1 | 4.8 | 1 | 0.2 | – | 0.03 |
| Na            | 0.927 | 1 | 2.4 | 1 | – | – | – |
| Nan           | 0.39 | – | 0.8 | 0.96 | – | – | 0.35 |
| Nas           | 4.35 | 1 | 4 | 0.9 | – | – | – |
| Os            | 0.56 | – | – | – | – | – | – |
| Par           | 0.22 | – | – | – | – | – | – |
| Pal           | 1.15 | – | 0.07 | 0.05 | – | – | 1 |
| Pu            | 1.11 | 3 | 7.4 | 3.1 | 0.13 | 1 | – |
| Rai           | 3.37 | – | 6 | 2.4 | – | – | 1 |
| Rat           | 0.47 | 1 | 0.8 | 0.3 | – | – | – |
| San           | 1.14 | 1 | 0.9 | 1.6 | 0.12 | – | – |
| Sat           | 1.82 | 3 | 2.88 | 1.2 | 0.12 | – | – |
| Si            | 0.4 | – | – | 0.36 | 0.12 | 1 | 0.54 |
| So            | 2.14 | 1 | 6 | 2.4 | 0.20 | – | – |
| Th            | 13.46 | 1 | 3.6 | 1.65 | – | – | – |
| Wa            | 0.48 | – | – | – | – | – | 0.07 |
| Was           | 0.27 | – | – | – | – | – | – |
| Va            | 0.68 | – | – | – | – | – | – |
| Total         | 82.11 | 28 | 93.73 | 35.48 | 1.53 | 5 | 1.21 |

**Fig. 5.** BMW_CY generation in phase 1, 2 and 3.


### Table 3

Emission factor and categorization of different pollutants emitted during the incineration (Singh et al., 2021; EPA, 1995).

| Category     | Pollutants                  | Emission Factor | Environmental Impact and Human Health Hazards |
|--------------|-----------------------------|-----------------|---------------------------------------------|
| PE1          | Carbon Monoxide (CO)        | 1.48            | Global warming                              |
| PE2          | Nitrogen dioxide (NO₂)      | 1.78            | Smog formation and respiratory disorders    |
| PE3          | Sulfur dioxide (SO₂)        | 1.09            | Smog formation and respiratory disorders    |
| PE4          | Particulate matter (PM₁₀)  | 2.33            | Respiratory disorders, hormonal imbalance   |
| PE5          | Total Volatile Organic Compounds (TVO) | 0.15   | Acidification and damage to building infrastructure |
|              | Hydrochloric Acid (HCl)     | 0.07            | It may cause congenital abnormalities and different types of cancer, such as skin, lungs, brain, breast, kidney etc. |
|              | Fluoride (F)                | 0.073           | May cause congenital abnormalities          |
|              | Mercury (Hg)                | 0.0537          | Abnormality and different                   |
|              | Polycyclic Aromatic Hydrocarbons (PAHs) | 0.05 | Types of cancer, such as skin, lungs, brain, breast, kidney etc. |
|              | Lead (Pb)                   | 0.0364          | May cause congenital abnormalities          |
|              | Cadmium (Cd)                | 0.00274         | May cause congenital abnormalities          |
|              | Nickel (Ni)                 | 0.000295        | May cause congenital abnormalities          |
|              | Arsenic (As)                | 0.000121        | May cause congenital abnormalities          |
|              | Beryllium Compounds (Be)    | 3.12E-06        | May cause congenital abnormalities          |
|              | Copper (Cu)                 | 0.00624         | Water and soil pollution                   |
|              | Polychlorinated dioxins and furans | 0.05 | Decline in the birth rate                   |

### Table 4

Emission of pollutants from incineration facilities.

| Months | Emission of Pollutants (kg of pollutant/day) |
|--------|---------------------------------------------|
|        | PE1₄BMW-CY | PE₂₄BMW-CY | PE₃₄BMW-CY | PE₄₄BMW-CY | PE₅₄BMW-CY |
| May 2020 | 2.06 | 2.47 | 1.51 | 3.23 | 0.21 |
| Jun 2020 | 3.27 | 3.91 | 2.40 | 5.12 | 0.33 |
| Jul 2020 | 7.26 | 8.74 | 5.35 | 11.44 | 0.74 |
| Aug 2020 | 10.87 | 13.09 | 8.02 | 17.13 | 1.10 |
| Sep 2020 | 17.97 | 21.60 | 13.23 | 28.28 | 1.82 |
| Oct 2020 | 8.73 | 10.52 | 6.44 | 13.77 | 0.89 |
| Nov 2020 | 4.60 | 5.52 | 3.38 | 7.23 | 0.47 |
| Dec 2020 | 3.23 | 3.87 | 2.37 | 5.07 | 0.33 |
| Jan 2021 | 3.00 | 3.60 | 2.20 | 4.71 | 0.30 |
| Feb 2021 | 3.90 | 4.70 | 2.88 | 6.16 | 0.40 |
| Mar 2021 | 20.00 | 24.05 | 14.72 | 31.48 | 2.03 |
| Apr 2021 | 54.37 | 65.40 | 40.05 | 85.61 | 5.51 |
| May 2021 | 34.77 | 41.83 | 25.61 | 54.75 | 3.52 |
| Jun 2021 | 9.57 | 11.50 | 7.04 | 15.05 | 0.97 |
| Jul 2021 | 7.37 | 8.86 | 5.42 | 11.59 | 0.75 |
| Aug 2021 | 4.77 | 5.74 | 3.51 | 7.51 | 0.48 |

The excess BMW in BMW₉ and BMW₅ was 57.8%, 130%, 49.71%, and 59.65%. It was observed that in July 2020, the percentage increase (130%) in BMW₉ and BMW₅ was maximum. In phase 2, there was a subsequent decline in BMW₉ and BMW₅. The percentage decline was 105%, 90%, 43%, and 7.25%. It was observed that in August 2020, the percentage decline (105%) in BMW₉ and BMW₅ was maximum. In phase 3, there was an increase and a decline in BMW₉ and BMW₅. From February 2021 to April 2021, the percentage increase was 30% and 412%. It was observed that in April 2021, the percentage increase (412%) in BMW₉ and BMW₅ was maximum compared to any months of phases 1, 2, and 3. From May 2021 to August 2021, the percentage decline was 36%, 72%, 0%, and 50%. It was observed that in June 2021, the percentage decline (72%) in BMW₉ and BMW₅ was maximum. However, there was no decline in BMW₉ and BMW₅ from June 2021 to July 2021. The present study observed that the percentage change in BMW₅ and BMW₉ was directly proportional to active covid cases reported each month. Therefore, this increase in BMW might affect treatment and disposal facilities, leading to unethical handling and disposal of waste. It is essential to understand the maximum load on the treatment facility based on its composition to maximize required facilities.

### 3.4. Load on incineration facilities

The data for BMW treatment and disposal facilities in Maharashtra was collected from MPCB Report (2020). As per the report, Maharashtra state has a BMW rate of 82 tons/day as represented in Table 2. The rate of BMWG was maximum and minimum for Mumbai (21.16 tons/day) and Hingoli (0.15 tons/day) districts. The treatment facilities include incineration, autoclave, and other facilities (pyrolysis, plasma, and chemical disinfection techniques). Technologies such as plasma and pyrolysis are less preferred due to high energy consumption demand compared to incineration and autoclave (PCPB, 2020). Besides this, it may also cause extra maintenance and fuel charge expenses. In the present study, the quantity of BMW₅ is only considered for treatment facilities, as 40%–50% of BMW comprising recyclable materials.

The state has 28 incinicators with a processing capacity of 93.73 tons/day. In comparison, autoclave and other facilities have a processing capacity of 35.48 tons/day and 1.53 tons/day, respectively. The state has a treatment facility of 130 tons/day. However, the maximum quantity of BMWG calculated in April 2021 was 1100 tons/day, approximately 8 times higher than the present treatment capacity. Fig. 5 presents existing BMWG capacity and predicted BMWG generation from Covid-19 patients. It can be concluded that July 2020, August 2020, September 2020, October 2020, march 2021, April 2021, May 2021, June 2021, and July 2021 have exceeded their respective BMWG treatment capacity during the pandemic phases.

The excess BMWG might have been landfilled or dumped at the cities’ outskirts, similar to the municipal solid waste (MSW) dump sites. However, the state has only 5 engineered landfills and open dumping sites with an overall capacity of 1.2 tons/day. This practice of open dumping can be a major source for direct transmission of the covid virus. Therefore, it is essential to install more treatment facilities to avoid direct transfusion of the covid virus into the residents residing near the dumpsites. From 2020 to 2021, the varying rate of covid cases in each district has made it essential to facilitate more treatment facilities apart from incineration. As the BMW is contagious and hazardous in nature, it is essential to use the upgraded treatment technologies, such incineration, autoclaving, irradiation, chemical disinfection etc. Incineration is the most commonly preferred treatment technology across the globe. It comprises of rotary kiln, pyrolytic and fluidized bed chamber (Dehal et al., 2022). The optimum design for incinerator is based upon the BMW characteristics, such as moisture content, composition, calorific value, etc. Apart from this, it is essential to estimate the initial investment and maintenance cost to achieve optimum cost-benefit ratio (UNEP, 2012). Generally, in India, modular dual chamber incinerators are preferred which can be operated under controlled air principle. The dual chamber
incinerators are economical as compared to the other types of the incinerators (Chen et al., 2013; Kho et al., 2021). Autoclave is other such technology which is preferred as a substitute to the incineration. The process of disinfection and sterilization is carried out under high temperature (~121°C) and pressure for not more than 20 to 30 minutes. This technique is found to be highly efficient and risk free (WHO, 2003).

There are other techniques, such as irradiation, which uses X-rays, UV-rays, gamma rays etc. to disinfect and kill harmful pathogens. It is operated under a closed condition and is also an expensive method. Indirect and direct exposure of human being to these rays can lead to cancer (Oweis et al., 2005). Apart from these techniques, there are pretreatment method of chemical disinfection which can be preferred prior to the mechanical shredding. The disinfection is performed in a closed chamber where the crushed BMW is mixed with the optimum dosage of the chemical disinfectants (chlorine). The harmful pathogens and microbes are killed and organic matters are decomposed (Wang et al., 2020).

3.5. Emissions from incineration facilities

The incineration of BMW-CY during the pandemic phase (March 2020 to August 2021) led to emission of several pollutants into the atmosphere in Maharashtra, India. The reported data for emission factors from the EPA (1995) was used to estimate the emission rate as indicated in mentioned in Table 3. The study conducted by Singh et al. (2021) suggested that carbon monoxide (CO), sulphur dioxide (SO2) and particulate matter (PM10) have contributed 80% to the overall emission of pollutants from incineration facilities. However, the traces of other compounds were less compared to CO, SO2 and PM10. Therefore, the pollutants were categorized as PE1, PE2, PE3, PE4, and PE5 i.e., CO, Nitrogen dioxide (NO2), SO2, PM10, and other compounds. The pollutants were categorized as PE1, PE2, PE3, PE4, and PE5. Table 4 represents the estimated data for pollutant emission due to BMW-CY incineration. From Table 4, PE4BMW-CY and PESBMW-CY have reported maximum (85.61 kg of pollutant/day) and minimum (0.21 kg of pollutant/day) concentrations in April 2021 and May 2020, respectively. The maximum concentration of PE1BMW-CY (54.37 kg of pollutant/day), PE2BMW-CY (65.40 kg of pollutant/day), and PE3BMW-CY (40.05 kg of pollutant/day) was also reported in April 2021. The concentration of pollutants emitted from BMW-incineration facilities is in the order PE4 > PE2 > PE1 > PE3 > PE5. In the present study, the concentration of PM10 was maximum compared to heavy metal concentration, which might cause respiratory disorders and hormonal imbalance in the human body. However, the concentration of CO, NO2, and SO2 was also found to be in a significant proportion, which may cause an increase in ambient temperature (Sharma et al., 2013) and respiratory disorders due to smog formation. It was also observed that a small proportion of heavy metal concentration, which may cause congenital abnormality (Singh et al., 2021) and cancer (skin, lungs, brain, breast, kidney, etc.) (Elliot et al., 2000; Singh et al., 2021) cases among the residents. Studies have also suggested that direct emission of these gases into the atmosphere may cause covid-induced respiratory disorder; no such cases have been reported till date (Elliot et al., 2000; Singh et al., 2021). Therefore, to avoid any such future consequences, it is essential to develop better handling and treatment facilities in Maharashtra, India.

3.6. Statistical analysis

Pearson correlation coefficient was found to be 1 for DCYM and BMW-CY with respect to increase in covid cases. In the present study, p-value less than 0.05 was set to be significant to prove the hypothesis. The existing relation between DCYM and covid cases had a p-value of 0.00053, suggests that there is a strong relation and dependency of both the variables. Similarly, BMW-CY and covid cases had a strong relation with the p-value of 4.60 × 10–6. The F-statistic of the hypothesis test is compared with F-critical to conclude the results of one-way ANOVA, as shown in Table 5. The F-statistic of DCYM is more than the F-critical, i.e., 8.11 > 3.08, which revealed that the increase in covid cases had a significant effect on mass consumption rate. The F-statistic of BMW-CY is more than the F-critical, i.e., 13.89 > 3.08, indicating that the increase in covid cases had a significant effect on BMWG.

4. Conclusion and Recommendations

The present study provides comprehensive information about projecting monthly mask consumption and BMW generation in Maharashtra, India during the pandemic. From the results, it has been observed that Mumbai, Pune, and Thane districts contributed up to 60% of the total mask consumption and BMW generation in Maharashtra. It was also found that the daily mask consumption by non-covid residents was higher compared to covid patients. Further, it was revealed that the BMW generated in the months of July 2020 (152 tons/day), August 2020 (228 tons/day), September 2020 (364 tons/day), October 2020 (177 tons/day), March 2021 (405 tons/day), April 2021 (1102 tons/day), May 2021 (705 tons/day), June 2021 (194 tons/day), and July-201 (149 tons/day) exceeded existing BMW treatment capacity of 132 tons/day. It was evident that BMW-incineration caused maximum emission of PM10 (85.61 kg of pollutant/day). The daily emission rate of different pollutant from BMW-incineration was PM10 > NO2 > CO > SO2. In the present study, it was found that the lack of awareness among the residents led to the cheaper cost availability of PPE (face masks, gloves, etc.) led to the maximum usage and disposal. It is highly recommended that the social awareness and understanding among the residents have to be cultivate through social media and other influencing platforms. It is also essential to conduct a comprehensive annual audit by an expert team to track the performance of BMW treatment facilities. It is expected that the present study might encourage the researcher and also policy makers across the globe to develop and adopt the alternative precautionary measures to manage increased loads of BMW wastes generated due to covid-19.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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