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ORIGINAL STUDY

Sustainable Management of Facemask Waste Generated From COVID-19 Pandemic in Bhutan

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Abstract

Background: **The rise in facemask waste with the uncertainty of deposition data and all its concomitant pressure on management has resulted in new risks and challenges for achieving sustainable development goals (SDGs). The purpose of this mixed methods study was to estimate facemask waste generation and examine management in Bhutan since the COVID-19 pandemic.**

Method: **One thousand five hundred and twenty-seventh (1,527) consenting members of the public from Class A Thromdes (self-governing municipalities) were surveyed online from February to April 2022, to estimate mask waste using descriptive statistics. This was supported by the waste characterization conducted in Memelhakha, the biggest open landfill in Thimphu Thromde. In-depth interviews were conducted with environmental officers, later summarized on emerging themes.**

Results: **The participants discarded on average 3–4 surgical facemasks in a week. Thimphu Thromde generated 144.5 and 186 surgical and N95 waste (tons/year), while those respective figures were (30.7, 54.2), (47.3,65.7), and (65.8, 91.8) for Samdrup Jongkhar, Gelephu, and Phuentsholing. The pandemic has exposed the fragility of the waste system, with an increase in plastic waste that is largely landfilled. This issue can persist and result in big problems, given Thromde negligence and the country's inefficiencies and inadequacies in social and technical aspects.**

Conclusion: **The findings can be used as a tool to re-examine Bhutan's overwhelmed management system to incorporate disaster preparedness and resilience to resist the change and; impact beyond the pandemic.**

Keywords: COVID-19, Facemask waste, Sustainable management, Municipal waste management, Bhutan

1. Introduction

Coronavirus disease (COVID-19) is one of humanity's worst ongoing respiratory illnesses of the century. In the aftermath of the COVID-19 emergency, face masks are one of the most used preventative measures by the public as it is a cost-effective way of limiting the airborne spread of Coronavirus (SARS-CoV-2) [1]. Roughly, 129–210 billion single-use-face masks are discarded in a month which equates to approximately 50,000 per second across the globe [2].

The haphazard dumping of face masks coupled with conflicting views regarding facemask waste has become an imperative issue, and affected the UN's Sustainable Development Goals (SDGs) including *SDG 12 Responsible consumption and production: risks associated with single use, plastic PPE*. The issue has grown in importance in creating a circular economy and sustainable development for all by substantially reducing waste generation and its release into the environment. It also disturbed the other areas of sustainability that has been amplified over the years.

Regarding the need for proper collection and disposal of face masks, several studies proposed recommendations, however, these fail to consider the environmental impact of the open dumping system of disposal, mainly visible in low-income countries [3,4,5,6,7,8]. Waste management systems have remained an unsolved problem faced globally,

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and this has further escalated as facemasks have changed the dynamic of waste generation in line with the provision of the virus protocol [6,7,9].

Bhutan is no exception and has reported an 85% increase in daily cases since the peak of the third COVID-19 wave [10,11]. Unlike other countries, Bhutan did not have any experience of dealing with the 2003 SARS pandemic, where valuable lessons were learned in waste management protocol [7,9,12].

Despite the strong COVID-19 surveillance of cases in Bhutan, there is no published detailed study on facemask waste generation and management in the country since the pandemic. Arguably, many of the mathematical equations to estimate facemask waste currently in use are very questionable because it doesn't accurately represent facemask consumption in the long run. Unlike previous studies, in this study, our estimation incorporated the "reuse of facemask" variable to provide a more precise waste estimation. This study aims to estimate facemask waste and examine management during a pandemic. The findings of this study will highlight the effect of the COVID-19 pandemic on the waste management system, which is still not fully understood, and to manage facemask waste sustainably during and beyond the COVID-19 pandemic.

2. Methods

2.1. Study site

A mixed-method approach was used to collect data in Class A Thromde (self-governing municipalities) of Bhutan: Thimphu, Gelephu, Phuentsholing, and Samdrup Jongkhar. Class A Thromde was selected as sampling area because in accordance with the Waste Prevention and Management Act of Bhutan, Thromde is responsible for overall waste management and is predominantly urbanized with a resident population of more than 10,000 [13].

2.2. Data collection and analysis

Since it is the first of its kind to conduct research in Bhutan, all questionnaires were adapted after rigorous revision from other countries that have conducted similar studies. The questionnaire was prepared in both English and Dzongkha to ensure consistency. All the research instruments were pilot tested and the questionnaires had high content validity ($IOC = 0.95$), determined by a panel of environmental health experts [14]. Data screening and descriptive statistics was performed in SPSS Statistics version 20.0.

2.2.1. Phase 1. Data collection through exploratory survey

Exploratory surveys were targeted at the general population aged between 18 and 64 years of age who reside in Class A Thromde. Participants who did not consent to participate, or public who were exempted from wearing a facemask were exempted from the study.

The target population was selected by using a consecutive sampling method. A target population of 1,527was estimated by using the formula for the infinite population of the four Thromdes by considering 95% CI and a 5% margin of error. Taking into account a 10% dropout rate, the final sample size was 1679 and data was collected from February to March 2022 (during the peak time of COVID-19 in Bhutan).

2.2.2. Phase 2. Qualitative data collection through face-to-face interview

In-depth interviews were conducted with the environment officer of Class A Thromdes, later summarized to get insight from the environmental officers on their new approach to the provision of proper facemask management during the pandemic. Each Class A Thromde has only one assigned environmental officer; therefore, informants were directly selected based on their specification for the role.

2.2.3. Phase 3. Waste characterization at the landfill

Waste characterization was conducted at Memelhakha, the biggest open landfill in Bhutan located in Thimphu Thromde to provide information on subsequent changes in dry waste statistics and to see the real waste behavior of respondents in relation to discarding facemasks. The experiment was conducted only in Thimphu Thromde due to the pandemic circumstances and lockdown.

The researchers wore quality assured personal protective equipment (PPE) such as gloves, gowns, and face shields to prevent cross-contamination of infectious diseases, including COVID-19 during the entire experiment.

2.2.4. The technique for evaluating the characteristics of waste followed the below steps

We selected a total of 200 kg of waste from a waste truck and placed it on a large plastic, then manually mixed the waste and divided it into 4 stacks. This was done through standard waste quartering methods for precision and efficiency in the analysis of municipal solid waste (MSW), it can be done accurately if the weight of MSW is less

Table 1. The estimation of the surgical and N95 mask wastes generated by the total population who reside in Class A Thromde.

Quantity of facemask discarded in a week	Thimphu n = 383	Samdrup Jongkhar n = 381	Phuentsholing n = 382	Gelephu n = 381
	n (%)	n (%)	n (%)	n (%)
Surgical mask discarded in a week (Pieces)				
1–3	169 *(44.1)*	193 *(50.7)*	174 *(45.6)*	168 *(44.1)*
4–6	113 *(29.5)*	77 *(20.2)*	96 *(25.1)*	102 *(26.8)*
7–8	57 *(14.9)*	61 *(16.0)*	79 *(20.7)*	78 *(20.5)*
N/A *(Do not wear surgical mask)*	44 *(11.5)*	50 *(13.1)*	33 *(8.6)*	33 *(8.7)*
Mean ± SD	3.90 ± 2.03	3.77 ± 2.14	4.03 ± 2.16	4.09 ± 2.1
Median	4.00	3.00	4.00	4.00
Min, Max	1, 8	1, 8	1, 8	1, 8
N95 mask discarded in a week (Pieces)				
1–3	105 *(27.4)*	122 *(32.0)*	119 *(31.2)*	121 *(31.8)*
4–6	12 *(3.1)*	26 *(6.7)*	30 *(7.8)*	28 *(7.4)*
7–8	12 *(3.1)*	35 *(9.2)*	15 *(3.8)*	17 *(4.4)*
N/A *(Do not wear N95)*	254 *(66.4)*	198 *(52.1)*	218 *(57.1)*	215 *(56.4)*
Mean ± SD	2.51 ± 1.96	3.32 ± 2.48	2.81 ± 1.96	2.81 ± 1.98
Median	2.00	2.00	2.00	2.00
Min, Max	1, 8	1, 8	1, 8	1, 8

Notes: *N/A = number of people who do not wear either surgical or N95 among respondents.

than about 50 kg. We then retained two piles of waste (two quarters) that were opposite, and the remaining two piles were rejected. After that, the selected quarters were quartered again where we retained two piles of waste, each weighing approximately 25 kg. The waste was then poured back into the pile and we carefully declassified the waste, and assessed and recorded the proportion of waste in a spreadsheet.

2.2.5. Ethical issue

All the research activities were carried out in accordance with ethical guidelines. The research became active only after the approval of the Research Ethics Board of Health (REBH) of the Ministry of Health, Bhutan (*Protocol number: PO/2022/002*).

3. Results

3.1. Phase I-Estimation of facemask waste

A total of 1572 respondents completed the questionnaire. The age of the study participants ranged from 18 to 65 years with a mean age of 27 (SD = 6.953) years. More than 30% of the respondents of all Class A Thromde belonged to the age group of 18–34 years and made up the largest pool of respondents. The highest reported percentage of the respondent's educational level was an undergraduate/diploma qualification and more than 50% of total respondents were office workers followed by students.

3.2. Estimation of facemask waste in Class A Thromde

The majority of respondents in Class A Thromde commonly used surgical masks followed by cloth masks, while the use of N95 was occasional and as low as 20%. In response to objective 1, most of those surveyed discarded on average 3–4 surgical facemasks in a week. We ranged the quantity of facemask discarded in a week as shown in Table 1 below after rigorous revision/literatures from other countries that have conducted similar studies.

The values of the amount of polypropylene in surgical and N95 are 4.5 and 9 g, and were abstracted from the study done by Akbar [15].

Based on the study results, Thimphu Thromde generated 144.5 and 186 surgical and N95 waste (tons/year), while those respective figures were (30.7, 54.2), (47.3, 65.7), and (65.8, 91.8) for Samdrup Jongkhar, Gelephu, and Phuentsholing as shown in Tables 2 and 3.

3.3. Management of facemask at the individual level

In terms of a common method of facemask disposal in Class A Thromde, more than 50% of respondents did not have separate bins for the disposal of facemask waste in their home, workplace, and school. Therefore, more than 50% of respondents discarded their masks with household waste. Further analysis showed that only 5.34% of Thimphu Thromde residents threw their facemasks

Table 2. Estimation of the surgical face mask wastes generated by the total population who reside in Class A Thromde.

Study Area	Total Population	Mean of face mask disposal per week per person	Generated face mask wastes per person/year		Total face mask wastes generated per year	The total amount of polypropylene wastes generated from surgical masks (ton/year)
Thimphu	158,386	Min	1	52	8,236,072	37.1
		Mean	3.9	202	32,120,680	144.5
		Median	4	208	32,944,288	148.2
		Max	8	416	65,888,576	296.4
Samdrup Jongkhar	34,908	Min	1	52	1,815,216	8.1
		Mean	3.77	196	6,843,364	30.7
		Median	3	156	5,445,648	24.5
		Max	8	416	14,521,728	65.3
Phuentsholing	69,820	Min	1	52	3,630,640	16.3
		Mean	4.03	209	14,631,479	65.8
		Median	4	208	14,522,560	65.3
		Max	8	416	29,045,120	130.7
Gelephu	49,472	Min	1	52	2,572,544	11.5
		Mean	4.09	212	10,521,705	47.3
		Median	4	208	10,290,176	46.3
		Max	8	416	20,580,352	92.6

outside carelessly. It was found that more than 50% of total respondents had not attended an awareness program on the proper disposal of facemasks, and 29.5% of total respondents were not aware of the proper disposal practice for used masks. This pattern was relatively consistent throughout Class A Thromde.

3.4. Facemask management at the Thromde level

Overall view on facemask waste: To date, one of our major findings was that face masks used by the general public are categorized as 'general waste'. Therefore, they don't have data on the accumulated and average quantities of face masks discarded since the pandemic. Based on these interviews, Thromde had Standard Operating Procedure (SOP) as a guideline to manage waste management. However, they didn't have published accessible documents of management strategies as a contingency plan for all the waste generated by COVID-19.

Major challenges faced in terms of waste management during the pandemic: In response to the question about the challenges, officers said Thromde provided safe and timely collection, transportation, and disposal of waste services during the pandemic

Table 3. Estimation of the N95 wastes generated by the total population who reside in Class A Thromde.

Study Area	Total Population	Mean of face mask disposal per week per person	Generated face mask wastes per person/year	Total face mask wastes generated per year	The total amount of polypropylene wastes generated from surgical masks (ton/year)	The total amount of polypropylene wastes generated from surgical masks (ton/year)
Thimphu	158,386	Min	1	52	8,236,072	74.1
		Mean	2.51	130	20,672,540	186.0
		Median	2	104	16,472,144	148.2
		Max	8	416	65,888,576	592.9
Samdrup Jongkhar	34,908	Min	1	52	1,815,216	16.3
		Mean	3.32	172	6,026,517	54.2
		Median	2	104	3,630,432	32.6
		Max	8	416	14,521,728	130.6
Phuentsholing	69,820	Min	1	52	3,630,640	32.6
		Mean	2.81	146.1	10,202,098	91.8
		Median	2	104	7,261,280	65.3
		Max	8	416	29,045,120	261.4
Gelephu	49,472	Min	1	52	3,630,640	23.1
		Mean	2.84	147.6	7,306,024	65.7
		Median	2	104	5,145,088	46.3
		Max	8	416	20,580,352	185.2

Table 4. The change in dynamic of waste generation with an influx of used facemasks.

Material	Quantity (Kg)	Percentage of waste composition: Thimphu Thromde, 2022 (%)	Waste composition of dry waste: Thimphu Thromde, 2018 (%)	National Waste Inventory Survey of Bhutan Report, 2019 (%)
Paper	3.5	7	10.0	9.3
Plastic	18	36	17.4	15.1
Fabric	10	20	15.4	1.8
Metal	0.2	0.4	0.3	1.4
Glass	3	6	5.3	4.5
Rubber	0.8	1.6	8.0	0.9
Food waste	7	14	6.2	59.2
Others	7.5	15	37.4	7.7
Total	50.6	100	100	100

despite the circumstances being challenging. Solid waste including facemasks is directly dumped at the open landfill without intermediate treatment.

Also, one of the participants mentioned that no segregation was put in place, thus real-time data on waste generation and composition were not maintained.

3.5. Change in the composition of waste influences mask management

The study found the major waste composition was plastic accounting for around 36% of which 1.1% (500 g) of a face mask was found followed by fabric at around 20%. Based on these results, we can make the following observations by comparing with published work done prior to pandemic as shown in Table 4 [24]:

First, the components of MSW have changed during the pandemic.

Second, facemasks are new types of waste that have been added as a quantity of MSW generated during the pandemic. Safe disposal of facemasks are still questionable in the context of developing countries, despite stringent recommendation adopted during the pandemic [16,17].

4. Discussion

In line with the first objective on the estimation of facemask waste, the study found that on average, 3−4 surgical masks are discarded per week. The estimated total face mask waste generated (tons/years) by Class A Thromde indicates the effect of mask mandates on mask adherence. These results agree with the findings of other studies and help us to understand the potential environmental challenges that could result from the mismanagement of this waste [18,19,20,21]. However, the estimated waste data calculated from the 1572 sample may not be sufficiently accurate to represent the general public.

The second objective of this research was to examine mask waste management at individual levels. More than 50% of Class A Thromde respondents don't have separate mask bins to dispose of facemask waste. By comparison, 87% of Moroccans, and 10% of Nigerians and Guyanese discarded their used facemask with their domestic waste, putting waste workers at risk of secondary transmission if not properly managed [18,22,23].

The result demonstrates the prevalence of the inadequacy of proper facemask waste collection at the source. Also, more than 50% of the total Class A Thromde respondents reported a lack of awareness of proper disposal as unregulated disposal of waste can be amplified [24,25,26,27].

However, it is quite surprising to find that less than 5% of respondents disposed of their facemasks carelessly. The overwhelming evidence of improper disposal has been studied, for instance, Selvaranjan et al. conducted an international online survey (in Australia, U.S., U.K., Singapore, Sri Lanka, and India) and reported that 19% of people carelessly discarded their facemasks [20,28,29]. The conclusions are difficult to draw in this case as we are not able to estimate or investigate the indiscriminate disposal of facemask waste given its extensive area and limited resources and time further challenged by lockdown restriction. Future research is needed to assess the indiscriminate disposal of facemasks in Bhutan.

Since the pandemic, little attention has been paid to facemask waste by Thromde, given that facemask waste poses a major environmental and health threat. This finding was unexpected and suggests this concern can result in quite significant problems, given Thromde is responsible for overall waste management. It is more concerning because Thromde did not have any experience dealing with the 2003 SARS pandemic, where valuable lessons in waste management protocol could have been gained. Whereas in Wuhan, China, COVID-19

waste was successfully managed and was greatly influenced by the local government's anticipated waste crisis and explored the best strategies during the pandemic [7,30].

The increased amount of solid mixed waste including facemasks is directly dumped in the Memelhakha landfill, Thimphu without real-time data on new waste composition. The lack of data on facemask waste since the pandemic suggests that no action is taken regarding mask waste management throughout Class A Thromde. In response to safe disposal and management at the Thromde level, there are no new strategies to tackle arising issues as it is still hampered by the country's technological, economic, and social complexity.

With these limited facilities, the increased volume of waste generation exacerbated pressure on strategic and operational levels for both local and Thromde levels. To respond to this emergency adequately is a very challenging and complex decision as it depends on a series of factors, including social, economic, and environmental sustainability [31,32].

The implication of unpredictable change in MSW with improper handling of waste, leads to a similar conclusion in circumstances when the diseased or suspected individual is being treated or cared for at home, possible means of transmission include coming into contact with contaminated surfaces and items during household cleaning [33,34]. This scenario is highly likely to occur at any moment due to the following reasons:

1) *There is a greater increase in home isolation cases in Bhutan than ever before.*
2) *Lack of dissemination on the proper use and disposal of face masks for home*

Also, most importantly, this possibly raises further concerns about waste collectors' safety as they are among the most at-risk groups for SARS-Cov-2 exposure. In several Italian cities for example, the contamination risks and transmission of COVID-19 infection through household garbage have been emphasized [35,36,37].

4.1. Facemask waste reduction

The study identified that the main problem of mismanagement of facemask disposal was primarily lack of waste data. Additionally, strategies to understand challenges and environmental pressure were exacerbated by the crisis thereby necessitating the urgent prevention and reduction of the waste. As reported in the study, more than 39% of all Class A Thromde used cloth face masks, suggesting respondents have a positive outlook on cloth masks. Among these, the most preferred option is using biodegradable masks made from plant fiber, thus conforming to sustainable initiatives, followed by recycling facemask waste. Importantly, the use of a right facemask should be precisely defined not only to have better safety precautionary measures but also reduce waste issues. Improving the social awareness on choice of facemask, for instance, "Conserve" means choosing reusable masks in less crowded spaces as explained in Prof. Dr. Pisut's studies via accessible social media platforms are highly recommended [38].

Also, upgrading reusable cloth masks to be more protective by incorporating filters into them are a sustainable approach and could be adopted as a long-term action to reduce waste. Also, an interesting sustainable initiative was introduced by the VIDA-3 Ply face mask where we can send our used disposal masks to be fully recycled by the company. Thromde and the government should support such innovative initiatives, and also enhance local production lines to be strengthened and continue to minimize the environmental and health crisis.

4.2. Facemask waste management

At the individual level: The use of labelled waste bags or bins at home and in public spaces such as schools, offices and so on to facilitate proper mask waste collection from communities to incineration facilities, and more to stop mass littering should be a priority. In addition, robust policy intervention is needed to strictly prohibit mass littering by constantly updating public health guidelines and policies through information, education, and campaigns (IEC). Furthermore, we need to assume that all used masks are potentially infectious waste as we can't tell if it has a virus on it.

At the Thromde level: Thromde and relevant stakeholders should develop management plans inclusive of all types of waste generated by COVID-19 by the general public and formulate an adequate contingency plan on the safe collection, sorting, proper disposal, and treatment of waste. Facemasks generated by the general public must be stored for 72 h before safely discarding it in a separate waste bin.

Facemasks shouldn't be mixed with other domestic solid waste, must be disinfected and collected on a different schedule to treat best available technologies such as polymerization using a

microwave technique, steam treatment over incinerators that have ignited controversy over implementation. Also, it would be advisable to address the need for a transformative solution by incorporating AI based technologies either to readjust or enhance recycling activities to ensure continuity of services. Informal and formal waste workers should receive additional training on safe practices, therefore, their activities should be supported and most importantly their safety must be prioritized. Existing facilities or services can be utilized to ramp up the treatment capacity if the medical waste incinerators or plants are overloaded as it is very challenging to increase or build treatment capacity in a short time during the pandemic. For instance, COVID-19 waste can be co-disposed in existing thermal treatment facilities such as autoclaves, cement kilns, or deep burial can be used as an emergency treatment method in existing dumpsites with existing medical facilities. Finally, the safe disposal of facemasks waste needs to be redefined in the context of COVID- 19 due to the lack of proper waste disposal premises, especially in developing countries.

5. Conclusion

In general, this is the first of its kind study conducted in Bhutan on facemask waste and management as an important indicator of environmental pressure. Face mask-wearing is both personal and collective social awareness to build more effective prevention and control guidelines to combat environmental and health effects beyond COVID-19.

The unprecedented surge in facemask waste requires more attention from Thromde given that facemasks pose a major environmental and health threat even though it is challenging to manage complexities as it involves both social and technical aspects. Due to the lack of proper mask waste disposal premises, there was a 51.6% increase in plastic waste landfilled during the pandemic and a failure to take environmental concerns about the open dumping system of disposal, mainly visible in low-income countries into account. This highlighted the sustainable approaches to manage facemask waste based on the subsequent changes in waste statistics induced by COVID-19 in the context of Bhutan's overwhelmed management system.

6. Recommendation

The conclusions of improper disposal are difficult to draw in this case as we have not been able to estimate rough facemask waste that was seen or dumped. This study could form the basis for information for improper disposal methods, but a further detailed survey on indiscriminate disposal of facemasks is needed. Most studies fail to take the environmental concerns about the open dumping system of disposal facemask waste into account. Further research should be done to investigate the impacts of such a situation on the environment and ecology through experimental validation by chemical and physical structure analyses.

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Conflict of interest

The authors declare that they have no personal relationships that could have influenced the work reported in this paper.

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