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Estimation of the healthcare waste generation during COVID-19 pandemic in Bangladesh

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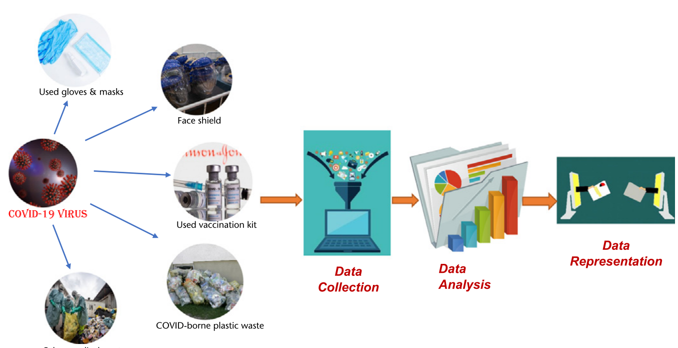
HIGHLIGHTS

- COVID-19 healthcare waste generation in Bangladesh is estimated.
- Daily Face masks and hand gloves usage in Bangladesh is determined.
- Medical waste increased from 658.08 tons in March 2020 to 16,164.74 tons in April 2021.
- Infected and isolated patients are responsible for major waste generation.
- Special attention is needed both in MSW and medical waste management.

GRAPHICAL ABSTRACT



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ABSTRACT

COVID-19 pandemic-borne wastes imposed a severe threat to human lives as well as the total environment. Improper handling of these wastes increases the possibility of future transmission. Therefore, immediate actions are required from both local and international authorities to mitigate the amount of waste generation and ensure proper disposal of these wastes, especially for low-income and developing countries where solid waste management is challenging. In this study, an attempt is made to estimate healthcare waste generated during the COVID-19 pandemic in Bangladesh. This study includes infected, ICU, deceased, isolated and quarantined patients as the primary sources of medical waste. Results showed that COVID-19 medical waste from these patients was 658.08 tons in March 2020 and increased to 16,164.74 tons in April 2021. A top portion of these wastes was generated from infected and quarantined patients. Based on survey data, approximate daily usage of face masks and hand gloves is also determined. Probable waste generation from COVID-19 confirmatory tests and vaccination has been simulated. Finally, several guidelines are provided to ensure the country's proper disposal and management of COVID-related wastes.

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Nomenclature

DGHS	Directorate General of Health Services
ESDO	Environment and Social Development Organization
ICU	Intensive Care Unit
MWGR	Medical Waste Generation Rate
PPE	Personal Protective Equipment
SDG	Sustainable Development Goal
UN	United Nations
UP	Percentage of Urban Population
WHO	World Health Organization

1. Introduction

Currently, the world is facing a serious concern due to the emergence of the pandemic COVID-19. Every country globally has undertaken different preventive measures such as social distancing, imposing lockdown, border closure, face masks, gloves, aprons, and face shields to prevent the virus from spreading. However, local and international authorities' attempts remain unsuccessful in most countries as the number of infected patients and death rates increase day by day. Approximately 240 million people have been infected, and 4.90 million have suffered tragic death till October 15, 2021 (Worldometers, 2020). General people and medical personnel use PPE, such as face masks, hand gloves, and face shields to prevent transmission, ultimately increasing medical and healthcare waste at an alarming rate. Biomedical waste poses a severe threat to lower-income countries like Bangladesh. Owing to diseases caused by unmanaged medical waste, at least 5·2 million people, including 4 million children, die each year around the world (WHO, 2020). Several studies have shown the severity of healthcare waste generation due to this pandemic. According to Peng et al. (2020), daily medical waste generation in China was around 469 tons. After the first case was detected in Indonesia, 12,740 tons of medical waste were generated in 60 days (Mihai, 2020). The disposal of these infectious wastes requires special attention as these can serve as a medium of transmission. Waste produced due to this pandemic has caused many environmental and health concerns in many countries (Yu et al., 2020). Plastic pollution from the used PPE has gained global attention and will contribute to ongoing microplastic pollution. In many developing and emerging countries, there are no proper guidelines for the disposal of these wastes, resulting in the future spread of this virus transmission (Klemeš et al., 2020). Kampf et al. (2020) have shown that this virus can remain active on hard surfaces for up to 9 days, raising concern in many countries where lack of solid waste management plans will contaminate general waste. Besides, in many countries, recycling workers collect material without using proper PPE, and these collected materials are reused; hence there is a greater chance of transmission (Nzediegwu and Chang, 2020). Improper management of this solid waste will exacerbate the disease transmission even in the ongoing and after the pandemic period. Therefore, the need for biomedical waste management, especially for low and developing countries, is a must for preventing the widespread of this pandemic.

Bangladesh has the second most COVID-infected patients in South Asia. Bangladesh first identified COVID infected patient on March 8, 2020. To prevent the widespread of this virus, the Government of Bangladesh first imposed a nationwide lockdown from March 26 to May 30 (Shammi et al., 2021). Since then, many partial and complete lockdowns have been imposed to control the widespread virus. However, the infection rate slowly increased, and currently, more than 1.46 million are infected, while more than 25,000 (as of August 23, 2021) people lost their lives due to COVID (Worldometers, 2020). The country's health sector experienced massive pressure due to an alarming rise in infected patients. In Bangladesh, the number of Government and private hospitals is 654 and 5055 (Rahman et al., 2020). Approximately 9061 diagnostics centers are also located nationwide (Shammi and Tareq, 2020). All of these hospitals and centers produce a vast amount of medical waste. Due to COVID, many makeshift isolations and quarantine centers are also set up, contributing to biomedical waste generation. The history of medical waste management in Bangladesh is not satisfactory, and this country has been facing overwhelming challenges in ensuring the safe disposal of COVID waste. According to Rahman et al. (2020), in April, more than 14,500 tons of biomedical waste were produced throughout the country due to COVID. In its capital city (Dhaka), the daily waste was 206 tons (Rahman et al., 2020). This situation is alarming throughout the country, as many hospitals do not follow proper disposal methods (Shammi and Tareq, 2020). Incineration is the best way to dispose of medical waste, and many hospitals in Bangladesh do not possess such a facility. Many burn wastes in the backyard, which further increases the possibility of air pollution (Shammi and Tareq, 2020). Due to the large volume of COVID waste and regular waste, solid waste management, and plastic waste management have faced enormous challenges throughout the country.

According to a survey, more than 49% of people use the same container to dispose of household waste and COVID waste, which may increase infection (Shammi et al., 2021). Besides, for ensuring the safety of medical personnel, the Government supplies PPE throughout the country, and improper handling of these used PPE also contributes to plastic pollution. Table 1 shows the number of supplied PPE.

The primary objective of this study is to estimate COVID-19 related medical waste and urban generation in Bangladesh from March 2020 to May 2021 to highlight the importance of solid waste and medical waste management to meet international standards. Besides, a detailed literature review has found that limited studies have addressed waste generation due to the vaccination process and conducted tests. So, probable waste generation due to the vaccination process and COVID confirmatory tests have been outlined in this study. Estimating the COVID-19 related wastes will help policymakers to manage them properly, ultimately preventing disease transmission. Moreover, this analysis can serve as a helpful guideline for many developing and low-income country decision-makers to estimate the waste generated due to this pandemic. It is believed that this analysis will draw the attention of scientific communities to frame appropriate policies for the safe handling of COVID-19 waste.

2. Materials and methods

2.1. Data collection

Data regarding infected and deceased patients is collected from Worldometer (Worldometers, 2020). The number of isolated and quarantined persons is collected from the daily COVID-19 press release of the Directorate General of Health Services of Bangladesh (DGHS, 2020). Data regarding vaccination programs and conducted tests are collected from the COVID-19 vaccination dashboard of DGHS (https://dghs.gov.bd.).

2.2. Medical waste generation

Total COVID medical waste generation in a hospital is the product of infected persons and the waste generated per patient. (Minoglou et al., 2017)

Table 1
Distributed COVID-19 PPE from Government throughout Bangladesh in Millions (http://dashboard.dghs.gov.bd, COVID-19 Dashboard, 2020).

PPE products	Supplied till August 23, 2021
Apron and Gowns	0.086
Gloves for examination	0.823
Gloves surgical	0.841
Hand /face/ eye shields	0.823
Masks	7.50
PPE kits	0.794
Sanitizer	0.274
Shoe protector	0.044
Others	6.19

determined that the amount of medical waste production in Jordan was 2.69 kg/bed/day. Korkut (2018) determined the increase in daily medical waste generation from 0.43 kg/bed/day in 2000 to 1.68 kg/bed/day in 2017 in Istanbul, Turkey. Table 2 shows the daily waste generation in different countries (Minoglou et al., 2017). Waste reported in Table 2 includes both infectious and non-infectious waste. According to WHO, "High-income countries generate hazardous waste 0.5 kg per hospital bed daily, whereas, for low-income countries, it is 0.2 kg per bed" (WHO, 2020). WHO also reported that 80% of health care waste is non-hazardous. Due to the increase in COVID-infected patients, the amount of waste generation has also increased. For example, in the study of (Abu-Qdais et al., 2020), the average waste generated from a COVID infected patient was 3.95 kg/bed/day. So, the amount of waste generated by an infected person can be calculated via Eq. (1) (Mihai, 2020; Sangkham, 2020).

$$W_M = N_{Patient} \times W_{MGR} \quad (1)$$

Where, W_M is the total waste generated per day in kg, is the number of the patient, and is the waste produced by an individual patient per bed in kg.

In an earlier study, the Asian Development Bank (ADB) estimated that daily waste generation from a COVID infected patient is 3.40 kg (ADB, 2020; Haque et al., 2021). This study assumes daily waste generation from a COVID infected, deceased, and ICU patient is 3.40 kg. According to WHO, quarantined patients do not exhibit any symptoms but have been in contact with infected patients or have traveled to areas affected by the pandemic, and isolated patients are those who are generally infected. The general quarantined period is 14 days, and the waste produced by these patients requires special attention (Mihai, 2020). To estimate waste generated from quarantined patients, this study has considered the municipal waste generated by quarantined households (Mihai, 2020). In Bangladesh, the daily municipal waste generation rate is 0.49 kg per person in urban areas and 0.33 kg per person in rural areas. The latter was considered a conservative option to determine waste flow in quarantined households (Huda et al., 2014). Eq. (2) (waste generation rate 3.40) is used to estimate waste generation from isolated patients. Eq. (2) can further be modified to estimate waste generation from quarantined patients.

$$W_{Quarantined\ waste} = N_{No\ of\ quarantined\ person} \times 0.33\ kg \quad (2)$$

2.3. Estimation of daily used face mask and hand gloves

Daily usage of face masks can be determined by the Eq. (3) (Mihai, 2020; Nzediegwu and Chang, 2020):

$$P_{Face\ mask} = N_{population} \times UP \times FM_{acceptance} \times \left(\frac{FM_{usage}}{10000}\right) \quad (3)$$

Where, $P_{Face\ mask}$ = Daily Face mask generation, $N_{population}$ = Population, UP = Percentage of the urban population, $FM_{acceptance}$ = Acceptance of face masks in the population (63%) (Chowdhury et al., 2021), FM_{usage} = general assumption that a person in the total population utilizes one mask every day.

Similarly, daily usage of face masks and hand gloves can be determined by Eq. (4).

$$P_{Hand\ gloves} = N_{population} \times UP \times HG_{acceptance} \times \left(\frac{HG_{usage}}{10000}\right) \quad (4)$$

Where, $HG_{acceptance}$ = Hand gloves acceptance rate among the general population (30%) (Islam et al., 2020). HG_{usage} = general assumption that a person in the total population utilizes one pair every day.

2.4. Estimation of medical waste generated from COVID vaccination and conducted tests

The onset of 2021 has seen a global vaccination drive against COVID-19. Global authorities have taken initiatives to vaccinate a significant portion of the population to protect human health and prevent the widespread of this virus. To achieve the desired level of immunization among people, the production of vaccines has risen significantly. With this increasing demand for vaccines, a massive rise in materials such as rubber, plastic, and glass is also expected (Phadke et al., 2021). These wastes will negatively impact the environment, especially in developing countries where insufficient waste management infrastructure is developed (Omran et al., 2021). Vaccination and test kits contain chemical bottles, swabs, and syringes which can act as a potential source of infectious medical waste. Thus, proper disposal of these potential infectious wastes is necessary to avoid future transmission. To estimate the waste from vaccination kits and COVID-19 test kits, the total weight of these kits is determined, shown in Table 3. Data regarding conducted tests and vaccination are collected from the Directorate General of Health Services (https://dghs.gov.bd.). Eqs.5 and 6 can be used to estimate waste from Vaccination programs and COVID-19 tests:

$$Waste_{Vaccination} = W_{vaccination\ set} \times N_{no\ of\ vaccinated\ people} \quad (5)$$

$$Waste_{COVID-19\ test} = W_{Test\ kit} \times N_{no\ of\ test\ conducted} \quad (6)$$

2.5. Limitations of this analysis

This analysis aims to introduce a method for the rapid estimation of COVID-19 related medical waste in Bangladesh. However, this study is subjected to several uncertainties. The accuracy of the results largely depends on the transparency of COVID-19 related data (number of infected, quarantined, ICU, and isolated patients) taken from several local and international databases. Medical and municipal waste generated due to COVID was not available for Bangladesh. So, estimation was made based on data from supportive literature. Researches should be undertaken in health care facilities and affected areas to determine the waste generation rate. Also, careful consideration is needed to determine waste generated in ICU and general units. These analyses are essential to improve hospitals and households' baseline scenarios and upgrade the current model.

3. Result and discussion

3.1. Medical waste generation

Table 4 shows that the number of infected, isolated, and quarantined patients has increased significantly from March 2020 to May 2021. All of these patients generated a massive amount of biomedical waste within the analyzed months. Table 5 shows the monthly estimated COVID-19 medical waste generated in the country.

Table 5 shows that waste generation was low in March 2020 compared to other months as fewer persons were infected. It can also be noticed that the amount of waste generation increased rapidly from June 2020. The

Table 2
Medical waste generation statistics of selected countries (Collected from Minoglou et al., 2017).

Country	MWGR (kg/bed/day)	Reference
Bangladesh	1.24	(Patwary et al., 2009)
India	1.55	(Rabeie et al., 2012)
China	4.03	(Yong et al., 2009)
Egypt	1.03	(Shouman et al., 2013)

Table 3
Weight of kits related to a single dose of COVID-19 vaccination and test (Omran et al., 2021).

Vaccination Kits	Weight (g)	Test Kits	Weight (g)
Glass vial	1.59	Chemical preservative bottle	11.30
Syringe	5.82	Nasopharyngeal swab	1.23
Alcohol Swab	0.83		
Total	8.24	Total	12.53

Table 4
COVID-related patients from March 2020 to May 2021.

Year	Month	Infection	ICU	Deceased	Isolation	Quarantine
2020	March	51	NA	5	359	60,052
	April	7618	NA	163	1420	71,482
	May	39,486	NA	482	5794	60,181
	June	98,330	NA	1133	7862	64,667
	July	96,048	331	1300	18,310	56,824
	August	75,933	301	1165	19,942	52,217
	September	51,221	293	971	15,057	43,177
	October	44,205	87	672	4676	20,852
	November	56,548	117	721	5122	25,241
	December	48,578	130	915	5084	24,606
2021	January	21,629	160	568	2920	14,500
	February	11,077	66	281	1686	9720
	March	65,079	253	638	4347	21,853
	April	147,837	464	2404	18,005	62,079
	May	41,408	122	1169	12,140	35,607

NA = Not Available

Government of Bangladesh imposed a nationwide lockdown from March 26 to May 30, 2020. Due to lockdown, people's movements were restricted, and hence the number of fatality and infection rates was lower. Lockdown was lifted in June, and people traveled across the country to celebrate the holy festival EID-Al -Fitr. Due to people's carelessness in traveling and not following proper safety protocols, the infection rate and death rate doubled. The amount of waste generation also increased tremendously in June and July 2020.

In April 2021, the second wave of transmission peaked, and the number of infected patients also increased rapidly, contributing to the highest waste generation. Infected patients generated about 81% of waste, whereas the quarantined patients generated 16% of waste. Isolated waste can also be regarded as potentially infectious waste, and the treatment of this waste needs special attention. The number of infected, quarantined, and isolated patients declined from September, and waste generation also shows a decreasing trend. Mihai (2020) also found that quarantined and isolated wastes were significantly higher for Romania from February to June. The number of quarantine and isolated wastes was 553.75 tons and 3305.1 tons, respectively, significantly higher than 453.95 tons during the analyzed period. Sangkham (2020) determined COVID-19 waste generation for several countries. This study determined that daily COVID waste generation in India was 6491.49 tons and for Pakistan was 1100 tons. These countries have a higher number of infected patients, and the waste generation rate per patient is higher than in Bangladesh. So, the amount of waste generation is also higher.

3.2. Estimation of daily usages face mask and hand gloves

This section discusses the estimated number of daily face masks and hand gloves used in Bangladesh. The estimation depends on several variables, such as the percentage of the urban population, acceptance rate, the number of the general population, and the number of affected patients. Table 6 shows the number of variables used in determining daily face mask and hand gloves generation.

Table 6
Variables used in determining face masks and hand gloves (Chowdhury et al., 2021; Islam et al., 2020).

Country	Population	UP %	$FM_{acceptance}$ %	$HG_{acceptance}$ %	FM_{usage}	HG_{usage}
Bangladesh	164,820,045	40	63	30	1 piece	1 pair

From Table 6, it can be calculated that daily face mask generation is 41.5 million pieces, and daily hand gloves generation is 19.8 million pairs. The number of face masks and hand gloves will increase along with the infected patients in the future. Hence, careful attention is necessary to control this waste.

3.3. Estimation of vaccination and test kits waste

Like other countries in the world, the vaccination program is currently in full swing in Bangladesh. The country administered the first dose of vaccine on January 27, 2021, and since then, 16.4 million first doses and 6.32 million second doses of vaccines have been administered (as of August 2021) (https://dghs.gov.bd.). With the Government's continuous efforts, only 4.44% of the total population have been vaccinated as of August. The Government plans to vaccinate 80% of the total population and provide 117.9 million vaccination doses throughout the country. However, with this growth in vaccination demand, waste generated from these kits has created significant concerns among environmentalists. It is estimated that about 135.90 tons and 52.10 tons have been generated throughout the country from the first and second doses of vaccination. It will rise to 973.13 tons if the target population is vaccinated. Another source of waste that is creating primary concern is COVID-19 test kits. According to Celis et al. (2021), 37.27 g of plastic waste is generated from a single real-time PCR (polymeric chain reaction) test, and these plastics are fully disposable (Tang et al., 2020). A sample is collected from the nose, mouth, or lungs via a swab and preserved in chemical preservatives during this test. In Bangladesh, PCR test is conducted, and as of August 23, 2021, about 8.65 million tests have been conducted, which will create 108.40 tons of waste. This amount will surely increase as the pandemic progresses. This waste management is challenging for a developing country like Bangladesh as waste management facilities are not fully developed. Most of these wastes need to be incinerated, and Bangladesh does not possess adequate incineration facilities. About 97% of wastes are mismanaged in Bangladesh, and the countries waste management infrastructures are already struggling against COVID wastes.

Table 5
Estimated monthly COVID-19 related waste generated in Bangladesh.

Year	Month	Infectious waste ton	ICU waste ton	Deceased patient waste ton	Isolation waste ton	Quarantine waste ton	Total medical waste ton
2020	March	5.38	NA	0.53	37.84	614.33	658.08
	April	777.04	NA	16.63	144.84	707.68	1646.19
	May	4161.82	NA	50.80	610.7	615.65	5438.97
	June	10,029.66	NA	115.57	801.92	640.20	11,587.35
	July	10,123.46	34.90	137.02	1929.87	581.31	12,806.56
	August	8009.66	31.73	122.80	2101.90	534.18	10,800.27
	September	5224.54	29.90	99.04	1535.81	427.45	7316.74
	October	4509	8.87	68.54	476.95	206.43	5269.79
	November	5767.90	11.93	73.54	522.44	249.9	6625.71
	December	5120.12	13.71	96.44	535.85	251.72	6017.84
2021	January	2279.70	16.86	59.87	29.87	148.34	2534.64
	February	1054.53	6.28	26.75	15.58	89.81	1192.95
	March	6859.33	26.67	67.25	44.47	223.56	7221.28
	April	15,079.37	47.33	245.21	178.25	614.58	16,164.74
	May	4364.40	12.86	123.21	124.19	364.26	4988.92

4. Environmental concern and public health

Worldwide lockdowns were imposed in various countries to prevent the widespread of this virus. During lockdowns, a significant increment in both municipal and medical waste has been observed. Besides, during this period, online food services and online shopping have also increased. As a result, organic and inorganic waste generated from the residential sector has also increased. These organic and inorganic wastes are indirectly responsible for air, water pollution, and soil erosion (Zambrano-Monserrate et al., 2020). Besides, the waste recycling rate is also reduced in some countries, such as in some USA cities. Due to the fear of spreading the virus, these cities or states stopped recycling during lockdown (Liu et al., 2020). In Bangladesh, approximately 40,000 waste collectors work without proper PPE, and these wastes can cause future transmission of this virus (Shammi and Tareq, 2020). The number of workers was declined by half due to the fear of transmission, thus posing a severe challenge to dispose of these enormous amounts of wastes. Only one landfill facility in Matuail is available for disposing of hospital waste in Dhaka city. Still, collecting and transporting such a massive amount of waste poses a severe threat to public health and the environment.

Among various types of waste, plastic wastes severely increased due to the increment use of personal protective equipment. During eight weeks of lockdown in Singapore, an additional 1400 tons of plastic is generated. This lockdown has put extra pressure on waste management facilities. ESDO surveyed Bangladesh from March 26 to April 25 and found that about 5887 tons of waste were generated from hand gloves. About 3039 tons were plastic gloves, and the rest were surgical gloves. The amount of plastic waste also increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and 900 tons of waste, respectively (Shammi et al., 2021; Haque et al., 2021). Table 7 shows the astounding rise in single-use plastic during the lockdown period. Besides, these plastic wastes are a source of microplastic pollution. Ocean plastic pollution is projected to be increased due to COVID 19. About 30,000 tons of plastic products are dumped into four significant rivers around Dhaka city, and this situation will worsen due to pandemic (Chowdhury et al., 2021).

5. Formulation of waste management policies for disposing of COVID-19 related waste

Along with controlling the propagation of the COVID-19, managing vast amounts of solid, plastic, and medical waste is more than challenging, especially in developing countries like Bangladesh, where the number of populations living in the area is not small. Besides, solid waste management in Bangladesh is not fully dynamic and potential, and along with the existing solid waste, additional COVID waste creates an extra burden to handle. Ineffective disposal of solid waste may increase the health risk of the municipal worker, health worker, rag-pickers, and others directly or indirectly involved with the COVID-19 war. In this situation, implementing a fair and efficient COVID waste management policy is the only way to handle and manage this enormous amount of waste. Here we proposed some potential approaches that can make it possible to manage COVID waste more efficiently (Fan et al., 2021; Shammi et al., 2021; Singh et al., 2020; Barua and Hossain, 2021).

- All the solid, plastic, and medical waste products during the COVID-19 patient care home quarantine must be collected safely in a secure sharp box. Distinguished color containers should be installed in localities or supplied to residents to differentiate among MSW, medical waste. All the collected waste must be disinfected first and placed in the standard waste disposal bags.
- Biowaste management policy needs to be followed stringently, i.e., red label bag should be used for the collection of the PPE; non-chlorinated red bag needs to be used for the collection of the oxygen mask, urine bags, tubing, bottles, catheters; non-chlorinated yellow bags must be used for the collection of meters contaminated with human body blood or fluid. Leakproof and puncture-proof bags need to be used to collect scissors, syringes, needles, blades, and other sharp objects. The contaminated and broken glass needs to be collected in a puncture-proof blue-colored container. Before the collection and final disposal, all this waste material should be disinfected with 1% sodium hypochlorite (NaOCl). For disinfection of reusable non-medical components, 70% alcoholic solution should be used (Nzediegwu and Chang, 2020).
- After collecting the COVID waste as discussed in 1 and 2, separating the waste from the non-infectious waste like cardboard, paper, and food scraps is necessary. After the separation, all the waste should be in their respective bags. All the bags must not be stored for more than 24 h, and after the waste delivery, it is necessary to disinfect the place with 1% chlorine solution.
- After the storage, it is necessary to transport the COVID waste bags to the Common Biomedical waste treatment plant. It is required to use suitable routes (strongly recommend avoiding the busy area and rush hour), dedicated and trained driver, and the particular vehicle to transport the waste. The vehicle and trolley used in waste carrying need to be disinfected with 1% sodium hypochlorite.
- It is strongly suggested to use autoclaving, chemical processes, and incineration to treat the COVID waste. It is not recommended to store the waste for more than 12 h in the transportation area. Particular caution needs to avoid contamination with any river, drinking water sources, park, residential, school, and other public places.
- Better waste management practices to treat or dispose of these medical wastes should be shorted out. Disinfection technologies such as ultraviolet germicidal irradiation, chemical heat, and thermal treatment processes should be applied to reuse the PPE (Derraik et al., 2020). In case of large waste volumes, installation of mobile incineration facilities and utilization of existing industrial furnaces and kilns ban be approved to dispose of these wastes. The infected wastes can be burned using the plasma method with very high temperatures, not presenting any environmental air pollution problem. Kumar et al. studied the best disposal options of plastic bags via a life-cycle assessment approach, and for this, this study compared to landfill, decentralized and centralized incineration (Kumar et al., 2020). This study found that the most environmentally friendly approach is decentralized incineration while the least is landfill.
- Introducing a recycling program will help handle the COVID waste and make medium- and long-term benefits in converting the wastes to green energy and resource recovery.
- It is necessary to keep a record of waste collected for effective management. Surveys should be conducted across the country to determine the amount of waste. Also, it will be helpful in future research and development.

Table 7
Single-use plastic and PPE waste during the lockdown period in Bangladesh (Haque et al., 2021).

Items	Number of amounts used during 30 days lockdown (nos)	Total waste produced (ton)	Estimated daily waste production rate (ton/day)	Waste produced in 3 months (ton)
Hand Sanitizer bottles	49 million	900.0	30.0	2700.0
Single use surgical face masks	455 million	1592	53.07	4776.30
Polyethylene (PE) bags	1449 million	5796	193.20	17,388.0
Non-infectious plastic waste from healthcare units	–	251.10	8.37	753.30
Polyethylene made hand gloves	1216 million	3039	101.30	9117.0

- Reusable bags made from clothes, paper, and cardboard boxes can be used to prevent the widespread usage of plastic bags during shopping. Unnecessary packaging during online product delivery should be avoided. Plastic leakage can be tackled by feedstock recycling, sterilization, and applying bioplastics (Patrício Silva et al., 2021). Recovering value-added products and energy from waste plastic products can be another option. Clothes masks can be a suitable alternative to face masks in reducing plastic pollution. Recycled plastic products should be encouraged through benefits and imposing taxes on virgin plastics. Clean-up programs and technologies should be undertaken to retrieve floating plastics from water bodies. Social, institutional and behavioral changes need to be developed to reduce and manage plastic waste properly. This dream can only become a reality through suitable infrastructure, marketing, investments in research by public and private, and circular and sustainable practices.

6. Conclusion

In this study, a rapid assessment has been made to estimate medical waste generation due to COVID 19 in Bangladesh. Data on total confirmed cases, people in isolation, quarantine, and ICU from March 2020 to May 2021 were used. Our model estimated that there had been an 80% rise in medical waste generation within one year. Wastes from COVID-19 tests and vaccinations have also been estimated. Our model will generate an additional 973.13 tons of COVID vaccination waste and 108.40 tons of test kit waste throughout the country. The quarantined and medical waste often get mixed up and pose a severe threat to public health and the environment. Recommendations are provided, which will help authorities to frame policies for ensuring the proper disposal of waste. The current analysis sheds light on healthcare waste management during the COVID-19 pandemic in Bangladesh. Hence, the current model can help policymakers estimate COVID-related waste and frame policies to ensure sustainable waste management facilities.

CRediT authorship contribution statement

TC: Conceptualization, Data collection, Methodology, Writing- Original and revised Draft; **HC**: Conceptualization, Data collection and analysis, Formal Analysis, Writing- Original Draft; **MSR**: Writing: Revised version, data collection, **NH**: Software, Analysis, Original Draft- Review and Editing; Revision, **AA**: Editing, Review, Data analysis, **SMS**: Original and revised Draft- Review and Editing.

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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