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Coronavirus disease 2019 (COVID-19) induced waste scenario: A short overview

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ABSTRACT

The COVID-19 pandemic and lockdown situation have shown both positive and negative effects on the environmental aspects. With an unprecedented rate the different types of waste volume have up surged along with the COVID-19 contamination rate. As the situation has mandated people as well as the most infected persons to stay at home, the amount of generated hazardous waste is 3.40 kg that can be expected daily from each infected person. China and other countries have seen a massive increment in the hazardous waste generation (about 600 % increase in Hubei province) amount. While dealing with this sudden increase in waste amount, the conventional incineration facilities have been outstripped and waste management industry is facing an immense pressure over handling hazardous waste generated from COVID-19 infected patients. Alongside with the hazardous waste volume, single-use plastic items and personal protective equipment (PPEs) have induced a new type of "PPE pollution" in the land and aquatic environment. The current review provides a countrywide waste generation amount, estimated using the infected number of cases for some selected countries. In contrast with the poor waste management noticed during this pandemic, some suggested approaches towards a better waste management service and future implications of waste management are discussed with viable consideration for the waste workers.

1. Introduction

The world, although a recent phenomenon but is aware of the devastation associated with the outbreak of new *coronavirus disease 2019* – COVID-19. It is reported that there have been 20,024,263 confirmed cases of COVID-19 across 215 countries of the globe, including 733,995 confirmed death cases as of 10 August 2020 (https://www.worldometers.info/coronavirus/#countries). The detail information about the COVID-19 and its possible treatment and other awareness promoting aspects are detailed by Ali and Alharbi [1]. As a protection measure against this global pandemic many countries have forced to mandate lockdown which eventually resulted in both positive and negative impacts on the environmental aspects (i.e. reduced air pollution, massive production of waste) [2].

The production of waste is an inevitable consequence that is coupled with anthropogenic activities, economic development, and urbanization [3]. The emergence of COVID-19 has led to the increase of medical waste all around the world as well as household hazardous and plastic waste volume where a desperate need for proper waste management has emerged but appears to be a largely ignored affair. Followed by different public health protection directives and measures, a substantial surge in the waste volume has been documented arising from the enhanced use of personal protective equipment (PPEs) including – face masks, hand gloves, rubber boots and white gowns, hand sanitizers and other medically used gears such as – syringes, test kits, plastic containers, bandages, tissues, etc. [4,5].

Waste management in developing countries is still at its primitive stage [6] and the pandemic has affected this sector very harshly in many countries [7]. As a developing nation, Bangladesh has encountered a rise in infection of COVID-19 patients during May 2020 which eventually has amplified the generation of hazardous waste volume, especially in the capital city Dhaka [8]. Moreover, due to the limited capacity of health care facilities of the country, infected persons are largely isolated and quarantined at their residential dwellings which has exacerbated in the rise of household hazardous waste volume. Proper quantification of the waste along with prospective policy response and alternative

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approaches to the waste disposal and treatment facilities are required for building rigid resilience and management of hazardous waste volume generated from different health care and household units in this region. The current study aims at providing a recent overview of COVID-19 waste problem from a global perspective with certain emphasis has been provided for Bangladesh, a developing nation with poor waste management infrastructure which has been further aggravated with the massive surge in COVID-19 induced waste situation. Moreover, this study also discussed an effective waste management response to this contemporary epidemic condition and post pandemic thought over this vital sector irrespective of any nation.

2. Impact of COVID-19 outbreak in the waste sector

Due to highly contagious in nature and lockdown situation, the COVID-19 outbreak has particularly increased the use of face masks (N95 or FFP2 standard or equivalent), gloves, protective suits and aprons, boots, water bottles, visors, take-away food containers, plastic bags, single use plastic (SUP) items and the MSW volume, worlwide [9–12]. A substantial preference over the safety and protection of human health during this pandemic have seen a significant rise in such items that have environmental deteriorating effects about which Grodzinska-Jurczak et al. [13] commented that health concern will eventually overwhelm the environmental carefulness around the world.

Globally, the impending surge in the waste volume has already threatened the existing waste management infrastructures (Fig. 1) and proved to be incapable in dealing with this sudden surge, satisfactorily. In Wuhan city of China, the maximum daily incineration capacity (49.0 t per day) has been astounded by the peak growth rate of hazardous medical waste (about 240.0 t per day) from its usual generation amount of 40.0 t per day [14]. In Hubei Province of China, based on available estimation about 600 % increase in the hazardous waste volume has been recorded during this pandemic period [15]. Bridges [16] claimed that the Southeast Asian countries may experience an additional hazardous waste amount of 1000 t per day. In Manila, Philippines the daily hazardous medical waste has reached 280 t and in Jakarta, this amount was recorded to be of 212 t per day [17]. Based on China's experience of dealing with COVID-19 patients, ADB [15] estimated that approximately 3.40 kg of hazardous medical waste (Table 1) can be expected daily from each infected person as denoted by the Eq. (1). It is

Table 1
Classification of different types of medical waste.

Type	Waste	Description
Type I	Tissue	Human or animal pathological wastes - blood, tissues, organs, pus, and body parts and fluids that are discharged during autopsy or surgery
Type II	Radioactive waste	Radioactive elements - unused liquids from radiotherapy or laboratory research work
Type III	Wastes with high content of heavy metals	Broken thermometers, blood-pressure gauges. batteries
Type IV	Pressurized containers	Gas cylinders, aerosol containers
Type V	Absorbent cotton items	Cotton pads, bandages, disposable diapers or bedding that are stained or soaked with human or animal blood, pus, discharge or secretion
Type VI	Discarded medical plastics	Disposable syringe, blood bags or waste generated from blood dialysis
Type VII	Pathological waste	Culture and stocks of infectious agents from test, culture dishes, discarded blood fluids and containers along with items that were in contact with infectious agents - used slides and cover glass
Type VIII	Waste sharps	Discarded sharps, hypodermic needles, syringes, surgical blades and blood lancets
Type IX	Waste mixed with infectious waste	Wastes that are not classified into the above mentioned categories but mixed with waste types (I) to (V)

Source: Mohiuddin [76],Jang et al. [77].

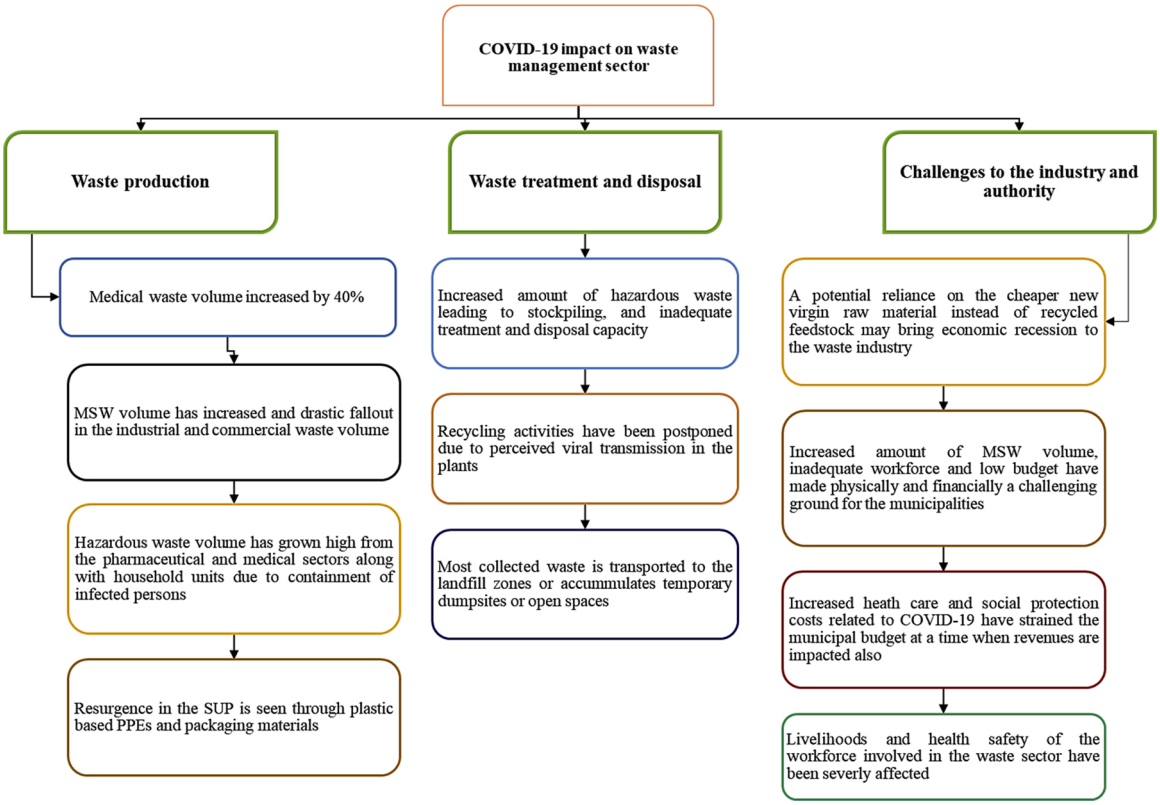


Fig. 1. Impact of COVID-19 outbreak on the waste management sector (drawn based on IFC, 2020).

unavoidable that other countries will confront similar aftereffects in their hazardous waste amount as tendered by the pandemic (see Table 2).

$$W_m = (n_i * 3.40kg) * d_n \quad (1)$$

n_i can be calculated by using the following Eq. (2),

$$n_i = (I_p - D_i - R_i) \quad (2)$$

where,

W_m = total hazardous waste volume for a given number of days;

n_i = total no. of infected persons in a given health care facility or territory or country;

I_p = no. of infected cases;

D_i = no. of deceased cases;

R_i = no. of recovered cases;

d_n = no. of days taken into account.

The pandemic has postulated people to wear hand golves and face masks in the public gathering for the fear of being infected by the airborne transmission [14]. However, this certain conduct has led to a new type of "PPE pollution" in the world's seas and oceans. In Soko Island of Hong Kong, used face masks are reported to be found within the 100 m stretch of the beach [18]. Marine divers from a French environmental group - Opération Mer Propre – have identified the used gloves and face masks floating over the waters off the French coast. 80–90 % of the waste found in the water find its way from the land and as the PPE waste finding its way to the seas and oceans, it is inevitable that the used PPEs in the land are not properly managed [19–21]. Projection based on the current trends, severe microplastic pollution in the terrestrial environment and water of oceans is about to incur during the present and post pandemic period. Moreover, plastic waste from different medical testing kits, hand sanitizers bottles, online services and food packaging items are playing a significant role during the outbreak situation. Due to the perceived risk of being contaminated by the use of reusable items, studies have shown a significant retreat from the restrictions in SUP packagings and banned use in reusable bags and beverage containers around the world [11,22]. In several parts of the world, embracing the assumptions that plastic materials are safe which do not carry the virus have led to a momentous resurgence in the plastic (particularly the SUPs) items [23]. The Thailand Environment Institute has estimated the surgence in plastic waste at Thailand which went up from 2120 t per day in 2019 to about 3440 t per day (about 62 % increase) within January to April [24]. The average generation rate of plastic waste for the Southeast Asian countries was about 5500 t per day before the COVID-19 pandemic which now has reached to 6300 t per day and Thailand, a top plastic polluter country of this region can expect a 30 % increase to its annual plastic waste volume [25,26]. The petrochemical industries have taken a toll in promoting their business interest amidst this outbreak by promoting plastic as "safe and hygenic material". However, the constant pressure from the plastic industries on the unregulated and increased use of plastic items during this pandemic is dismissed by the recent study on survival and persistence of corona virus on the plastic made surface for four days, the longest among all materials (e.g. paper, cardborard and fabrics – 1 day) that have been tested [27,23,28]. Hence, there is a high chance of contamination of the concerned disease from the plastic items if not properly disinfected [10]. Moreover, plastic recycling industries have confronted with a new challenge from the low valued virgin plastic materials due to the reduction in recycling rates and oil prices which can bring a potential economic recession to this industry [29,9]. The vital element of the waste management sector – waste workers - is at potential disruption as the waste workers lack in PPEs and other effective gears to protect themselves from the viral infection [29]. The situation is at worst in the developing nations as waste is managed there largely by the informal sector. In Indonesia, infromal waste sector (about 3.7 million waste pickers) largely driven by the job security and to maintain the daily livelihood was seen to work amidst this outbreak without any protection measures as reported by Hughes [23]. Manuja [30] has claimed that about 1.5–4.0 million people associated with the waste management sector in India is expected to receive potential health crisis due to the pandemic situation.

Table 2
Estimated COVID-19 hazardous waste volume for some selected countries.

Country Name	[a] n_i	Generated daily hazardous waste amount (t/day)	Total production in 100 days (t)
South Africa	137,977	469.12	46912.18
United States of America	2,369,126	8055.03	805502.84
Brazil	815,986	2774.35	277435.24
Mexico	105,515	358.75	35875.10
Iran	23,914	81.31	8130.76
Egypt	37,805	128.54	12853.70
Italy	13,263	45.09	4509.42
India	635,393	2160.34	216033.62
Bangladesh	105,831	359.83	35982.54
Argentina	133,651	454.41	45441.34
Colombia	161,951	550.63	55063.34

Source: [a] data used of 10 August 2020 from https://www.worldometers.info/coronavirus/#countries.

3. Country scenario – Bangladesh

3.1. A brief overview on existing waste management service

As an emerging economy in relation with the increasing population growth and urbanization process, solid and medical waste volume are constantly growing in Bangladesh [31,32]. Based on the available estimation, Bangladesh generates nearly 16,380 t of waste on a daily basis which is projected to reach at 47,000 t per day by 2025 with a generation rate of 0.60 kg per capita per day [31,33]. However, ineffective and poor waste management service when merged with the responsible authorities' maladministration and negligence, about 50 % of the daily produced waste remains uncollected, and seen visible on roadsides, adjacent spaces, drainage networks and waterbodies of the major cities in Bangladesh [31,34,35].

Like most of the developing nations, the solid and medical waste management system are particularly governed by the city authority in the urban areas. The municipal solid waste (MSW) is normally collected by the informal sector, commonly known as "Tokais" (poor people from the slum dwellings of a city), through door to door collection system using cycle vans. The collected waste then transported using vans and trash trailers to the temporary stations or disposal sites (commonly seen at roadsides) where it is piled off in the mixed form (commingled). Finally, the waste is hauled in different sized trucks and transported to the open landfill sites, situated at the suburban areas. A group of Tokais or waste pickers make their living by scavenging through the piled waste volume at the transfer points and landfill sites without any sort of protection measures. The recovered recyclable items are often sold to the informal scrap dealing shops, mostly situated within the city's slum areas [35–37]. Followed by the similar methodology, medical waste from different health care facilities are managed in Bangladesh. Among the 645 public and 288 privately owned hospitals, clinics and diagnostic establishments only a handful of the facilities have on-site waste treatment system including – burning, burial, autoclave machineries and waste segregation options and remainder of the facilities dispose medical waste in own space or municipal waste collection bins along with the other wastes. Subsequently, these waste items are collected and stored with MSW volume at the transfer points and dumped at the landfill zones, largely remain exposed to the ambient environment. However, a single privately regulated non-governmental organization (NGO) – Project on Agriculture, Rural Industry, Science and Medicine

(PRISM) – has been made responsible for collection, storage, treatment, and final disposal of medical waste from selected health care facilities in some urban areas of Bangladesh [38,39]. Although the PRISM's waste management system is satisfactory but the coverage areas under this program cannot cover all of the health care facilities and not operational in all city areas and hence, the usual medical waste management practice is still prevailing in majority of the urban cities. Moreover, Tokais or informal waste pickers cannot allow themselves with any protection gears during their salvaging in the waste piles at transfer points and landfill zones. Apart from the physical injuries like – hand and leg cuts from broken glass pieces and metals, curved fingers from syringe needles, paralysis of legs and hands, these people are also reported to be suffered from various infectious diseases including – viral hepatitis B and C, typhoid, allergy, tuberculosis (TB), malaria and diarrhea [39,40].

3.2. Pandemic induced waste generation situation

From the first tested positive COVID-19 infected cases (on 8 March 2020), Bangladesh has constantly seen rise in the infected cases all over the country which has now reached more than 258,000 confirmed cases (https://coronavirus.jhu.edu/map.html). Government mandated "country lockdown" seems to help no better against the global crisis and situation is getting worsened day by day. Another critical factor interlinked with the rise in infected cases is the generation of hazardous waste volume all over the country (Fig. 2). Although a matter of grave concern, the national response plan HSD [41] has provided no initiative concerning the hazardous waste management during this critical period. A massive surge in the PPEs are depicted throughout the nation and so as its uncontrolled and wishful disposal at roadsides, adjacent open spaces of buildings and hospitals (Fig. 3a), and in drainage networks by the public. Moreover, the hazardous waste from the healthcare units are not effectively managed as the medical waste management system has not upgraded over the years. The only functioning disposal of medical waste is dumping of waste in the landfill zones. Since no incineration facility is installed, some healthcare facilities perform open burning at the backyards of hospital and others even disposed such infectious materials in municipal controlled trash bins [8,42]. Moreover, due to the ineffective and poor waste management service when merged with the responsible authorities' maladministration and negligence, within this outbreak situation some roguish people have collected PPEs from the open trash bins, adjacent to the hospitals (Fig. 3b) and only by washing them such items are reported to be traded in some areas of Dhaka city [43]. This incident is evident enough to demonstrate the level of hazardous waste management facility for this region.

As being a rapid surge, only in a single month of lockdown period (26 Mar – 25 Apr 2020) around 14,500 t of plastic waste has been generated from SUP items and PPEs throughout Bangladesh accounting to a generation rate of about 483 t per day. Polythene (PE) made shopping bags have been up surging with an extraordinary rate which have been regarded as the largest source of plastic pollution, accounting to 5796 t of plastic waste generated within one-month lockdown period with a generation rate of 193.20 t per day (see Table 3). In Dhaka alone, waste induced from SUP items was about 3076 t of which 443 t (14.4 %) was from PE bags. Within the estimated one-month lockdown period potential surge is also seen in the single use face masks (53.07 t per day), PE made hand gloves (101.30 t per day), empty bottles of hand sanitizers (30 t per day) and noninfectious plastic waste from healthcare facilities (8.37 t per day) all over Bangladesh (ESDO, 2020a). In the absence of any restriction in the use of SUP items, 80–85 % of all SUP items are discarded which essentially produces about 250 t of SUP induced plastic waste in a month. Founded on the poor waste collection and recycling facilities, SUP items are found to be omnipresent over roadsides, drains and open spaces (Fig. 3c) in the land areas which ends up by polluting the rivers and eventually the Bay of Bengal. [20]. Moreover, this

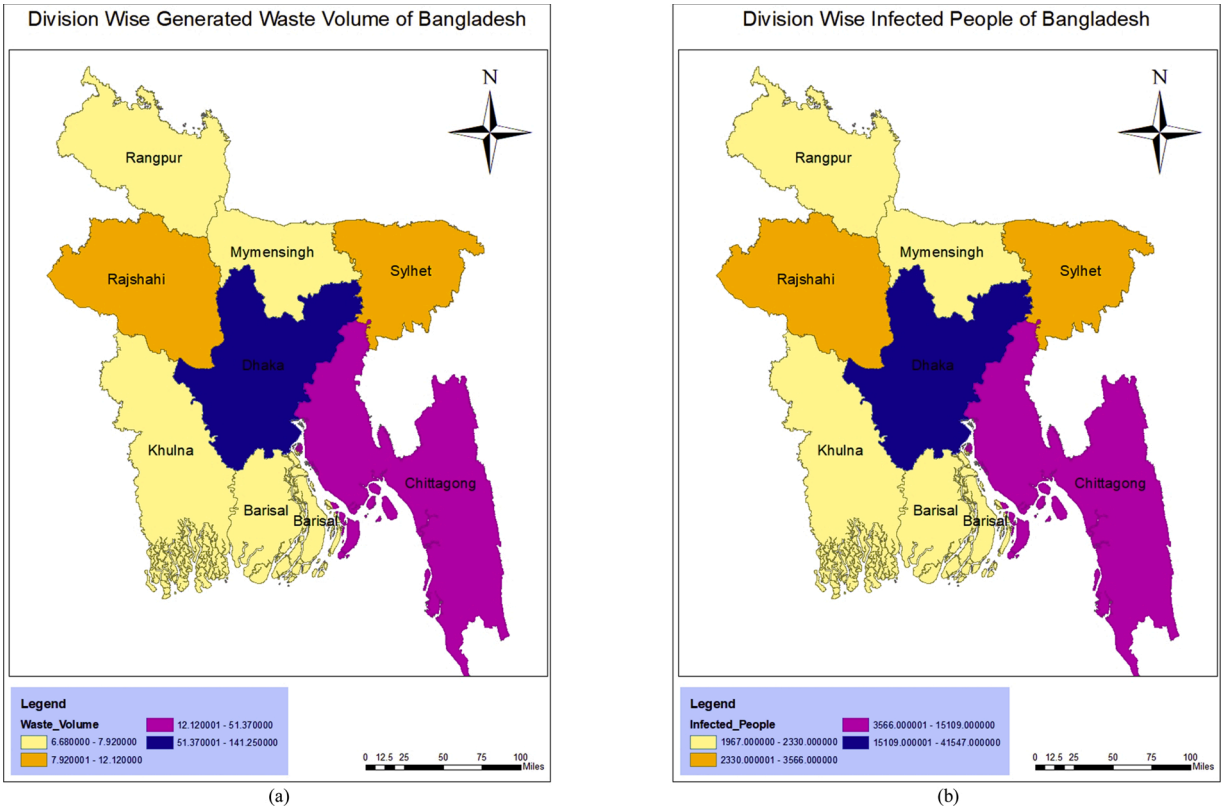


Fig. 2. Map showing the simultaneous increase in (a) hazardous waste volume along with (b) infected number of cases in different divisions of Bangladesh. Dhaka, the capital city has the highest no. of infected cases together with the increased amount of hazardous waste volume. Waste amount estimated using Eq. (1) from infected cases data - ranging from 15 April to 19 June 2020 (http://dashboard.dghs.gov.bd/webportal/pages/covid19.php#).

Fig. 3. (a) Discarded apron after use disposed in front of the public hospital ground of Chittagong; (b) Used surgical hand gloves, PE bags and other SUP items are dumped at the adjacent roadside of a COVID-19 dedicated public healthcare facility of Chittagong; (c) A prospective surge in single use cups (i.e. SUP items) during this pandemic period are seen prevalent at the roadside shops which left dumped in roadsides, unattended by the waste collectors, washed away by rainwater, clogging the drainage, and finally find its way to the waterbodies; (d) Waste workers collected municipal solid waste (MSW) from houses without any sort of PPEs during the outbreak in Bangladesh.

Table 3
Plastic waste generation details of Bangladesh from COVID-19 induced PPEs and SUPs.

Sl. No.	Waste Items	[a] Amount used in one-month lockdown period (nos.)	[a] Total waste generated (t)	Estimated daily generation rate (t/day)	Waste generated in 90 days (t)
1.0	Single-use surgical masks	455 million	1,592	53.07	4,776.30
2.0	Polyethylene (PE) bags	1,449 million	5796	193.20	17,388.0
3.0	PE made hand gloves	1,216 million	3,039	101.30	9,117.0
4.0	Hand sanitizer bottles	49 million	900	30.00	2,700.0
5.0	Non-infectious plastic waste from healthcare units	–	251.10	8.37	753.30

Source: [a]ESDO [44].

pandemic has hit the informal waste sector very harshly with a sudden rise in hazardous waste and MSW volume from healthcare and household facilities, respectively. Waste collectors are at potential risk of being exposed to the contaminated hazardous material while collection, transportation, and segregation of such waste without having any sort of protective gears (Fig. 3d) as reported by ESDO [44].

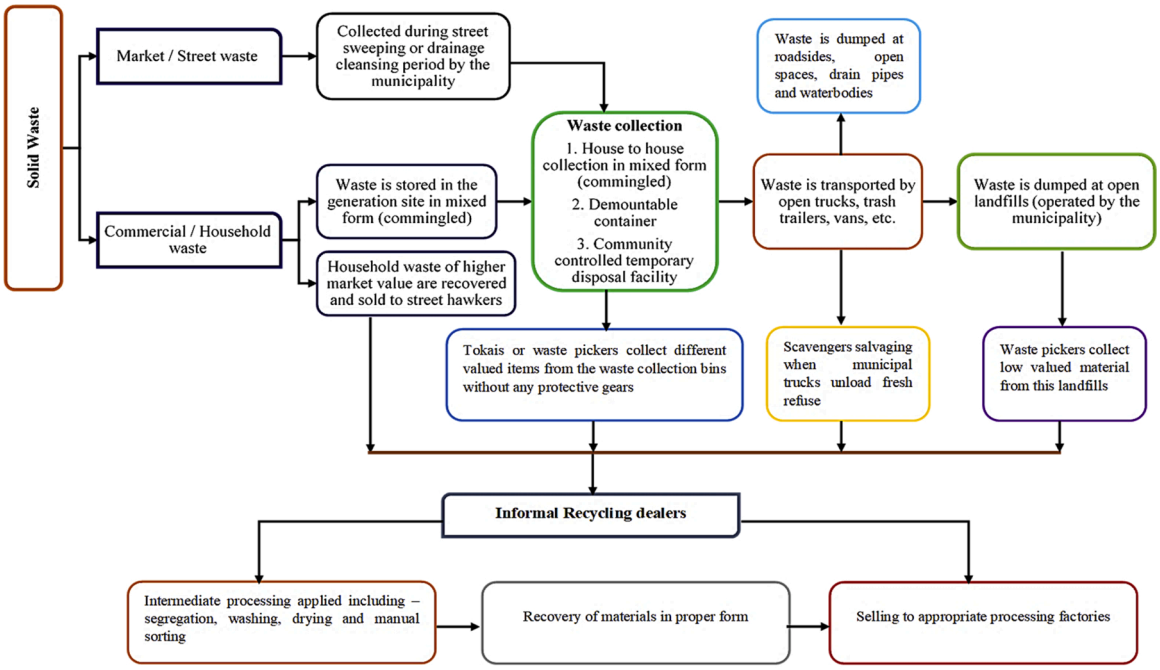
The existing waste management practices for MSW and medical waste in Bangladesh (Fig. 4) have continuously posed serious and aggravated situation to the daily life of residents well before the pandemic by exposing numerous problems including but not limited to - water pollution, drainage clogging, vector borne diseases, bad odor, air pollution, CO_2 emission, etc. [45,46]. Based on the sudden and rapid increase in the hazardous and plastic waste during the pandemic period and the condition of existing waste management services, it is certain that the post-pandemic situation will not be able to cope up with the massive voluminous waste if policy response, and other vital waste disposal and management options are not taken immediately.

4. Discussion and future recommendations

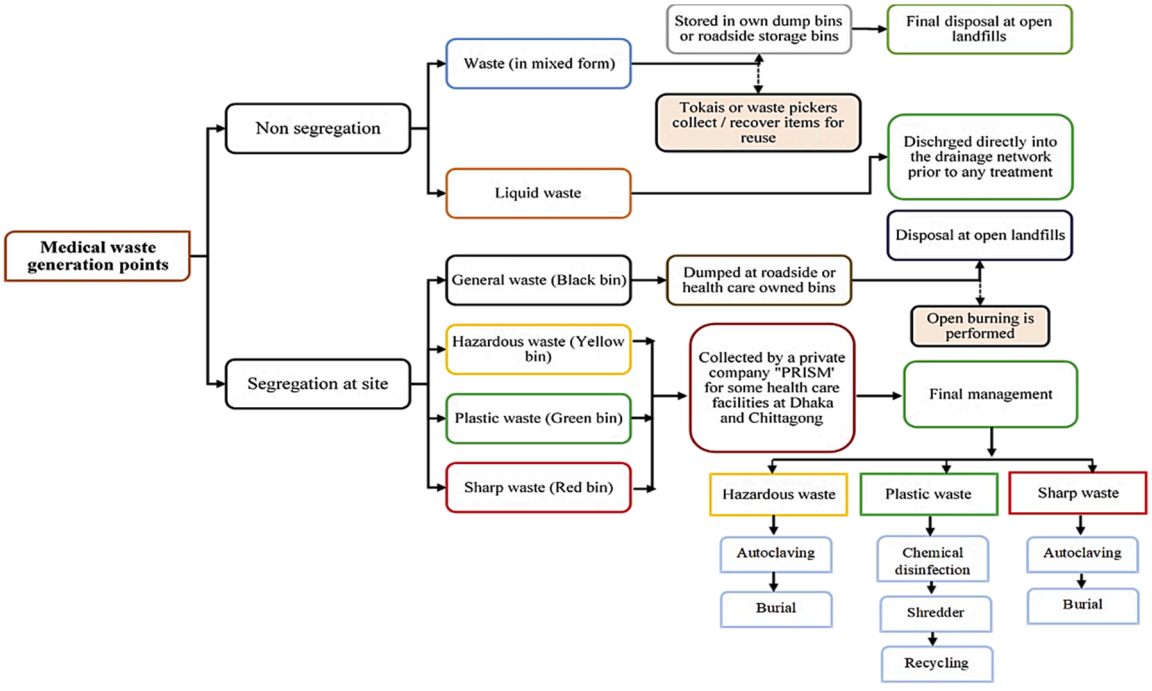
COVID-19 has postulated a massive lockdown situation all over the world. The advantage of such situation has seen long sought environmental advantages including – massive drop in carbon emission and air pollutants in major cities of the world (i.e. New Delhi, New York, Paris, Wuhan), reduction in coal consumption, substantial drop of water pollutants, less energy consumption and so on [2,18]. However, the environmental risks associated with the largely ignored waste management sector during this pandemic are also posturing intense warnings for the upcoming post pandemic world, some of which can be outlined as follows [47] –

- Increased amount of medical and other hazardous waste generation volume and management along with health and safety issues related with the handling, transportation, and disposal of such wastes from community to individual level
- Potential health risks involved with the health care workers, informal waste collectors, and people living near to the waste disposal areas together with the financial crisis
- Sudden surge in hazardous waste and plastic based items will strain the usual capacity of recycling and other waste disposal techniques which will essentially pose a major long-term impact to the terrestrial and aquatic environment
- New emergence of PPE pollution in land and coastal areas will postulate a new challenge of waste collection and disposal along with potential public health crises associated with such unregulated, discarded items

Since the government and authorities around the world has put its main focal point towards the public health protection from the viral infection, other vital elements of societal and environmental aspects are



(a)



(b)

Fig. 4. (a) Prevailing solid waste management system in Bangladesh (drawn based on [78,79]); (b) Existing medical waste management system of Bangladesh (drawn after [38]).

largely taken to be overlooked. But the irony is some under noticed aspects, if not properly managed will eventually postulate a massive disruption in the societal and environmental wellbeing that the post pandemic situation will not be able to cope with such disruption along with the global economic recession that is about to take place. Waste management is one of such sectors which is particularly a tiresome but critical job for any nation. This pandemic situation has overstressed the sector at its peak level with embedding new type of challenges against the conventional practice. However, amidst this global crisis and challenging circumstances it is of paramount importance to make every effort to take proper action for the waste management sector at the same level of public health safety [29].

In this brief pandemic period, major infrastructural alterations have been observed all around the world. Long pursued environmental benefits (i.e. reduction in air pollutants, carbon footprints) have put a new perspective of environmental thoughts in preserving such cleaner environment in the future world. However, as a matter of serious concern, improper waste management perpetuated by this pandemic

can lead to a grave devastation in the post pandemic world. The environmental consequences projected based on the current waste generation trend and its poor management are required to be scrutinized through further studies for possible countrywide waste management techniques, technological solutions, policy response and public attitude development towards the goal of sustainable future. In view of that, the following considerations are needed to be reassessed for maintaining the proper waste management across the nations, worldwide:

4.1. Reopening the postponed waste management services

The waste management has become one of the significant aspects associated with the pandemic and post pandemic period which contribute largely in maintaining the public health safety and environmental protection. A highly priority based approach in the waste management postponed services (i.e. recycling, waste collection and disposal, incineration of hazardous waste) should be restarted without any delay for protection against the further infection and pollution from the mismanaged waste services [48].

4.2. Emergency hazardous waste management

Due to the containment of PPEs and the capability of coronavirus to be active for a considerable amount of period on different materials' surfaces have made the generated waste to be considered as "hazardous" and challenged the waste management sector with "meeting effective waste management strategies" [49]. Thermal treatment or incineration is the most preferred and effective treatment process for the massive load of hazardous waste generated throughout the pandemic [50]. Apart from the thermal treatment process, other techniques – pyrolysis, microwave, chemical, dry heat, vaporized hydrogen peroxide, high temperature steam – can be utilized to treat the produced hazardous waste volume based on the factors such as economic budget, amount of waste generated, technical advancement and maintenance capability [50,51]. Table 4 presents the efficacy of different treatment options for the safe management of COVID-19 induced hazardous waste.

In accordance with meeting the public health emergency, national action plan should integrate the emergency response strategies in response to the unprecedented waste generation rate and its "potential route for the spread of the virus" through the mismanagement of waste items [52]. For instance, the strategies adopted by the City of Wuhan in China can be a prospective example for the countries contested with the extraordinary hazardous waste generation situation during this pandemic. With the strong lockdown and social distancing measures, a significant amount of hazardous waste was generated from the hospitals, households, self-isolation, and quarantine centers. Due to the retainment of generated waste for considerable amount of time together with unparalleled growth rate, local authorities employed "mobile incinerator" treatment facilities to effectively treat the discarded PPEs and other disposable gears. In addition to that, strategies such as centralized disposal (i.e. thermal treatment or incineration, cement kilns) and on-site emergency treatment (i.e. domestic incineration, industrial furnace, mobile incinerator) options performed very effectively in response to the challenges associated with the hazardous waste treatment or disposal. Moreover, autoclave, steam, dry heat, microwave and chemical disinfection techniques were also incorporated as the emergency response techniques for the waste management sector in Wuhan for the record amount of piled up waste in this period [53]. Such initiatives can be assessed for the possible usefulness and incorporated in the waste management sector for the secure waste treatment and disposal during this pandemic situation.

As for the developing nations with poor waste management infrastructure, construction of "on-site waste burial pit" to safely treat the hazardous waste material can bring emergency but an effective solution during the current pandemic situation. By digging a hole (1 m * 2 m or 2 m * 3 m) within the open and secured space of a hospital periphery, isolation ward, existing waste dumping zone or other dedicated places for COVID-19 infected patients, the closed waste burial pit can be constructed. The bottom layer of the pit can be lined with clay or geosynthetic liner to prevent any kind of soil or groundwater contamination from the dumped hazardous waste. A daily cover of soil or soil-lime mix should be placed over the dumped waste up to the filling point. After filling each burial pit, it should be sealed with a cemented cover or mortar mixture and top portion of the pit can be further covered with a 50 cm thick soil cover together with earth mound on both sides, to prevent water leakage during the monsoon. Moreover, to maintain the safe operation of the burial pit from any type of exposure to the human and other animals, security fences should be placed around the burial pit (Fig. 5 [54]). Construction of such on-site waste burial pit to safely dispose the COVID-19 hazardous waste can also provide a viable consideration for the long route hazardous waste transportation and toxic exposure to the ambient environment along with a cost effective and easy solution for the nations that lack in incineration or thermal treatment options for the generated massive hazardous waste volume during this pandemic [51].

Sudden heavy surge in the hazardous waste volume during the pandemic is prevalent in most of the affected countries which has

Table 4
Different treatment techniques for COVID-19 induced hazardous waste.

Sl. No.	Treatment techniques	Efficiency	Challenges
1.0	Thermal treatment	- Total destruction of COVID-19 related hazardous waste - Simple operation technique with ~90.0 % reduction in waste volume	- Generation of secondary pollutants (i.e. dioxin, furans, bottom ash) - Energy intensive process with higher capital cost
2.0	Pyrolysis	- Total destruction of hazardous waste volume along with toxins (i.e. dioxin, furan) - Savings in energy	- Specific requirement needed to be defined for heat value of the loaded wastes - Higher capital cost
3.0	Microwave	- Less energy required due to low action temperature - Can be used as mobile on-site treatment facility - Less environmental impacts due to low gas emissions and less residual waste	- Sometimes autoclaving is required due to low spectrum of disinfection process
4.0	Dry heat	- Compatible with waste items which are polymeric - Ensure the reprocessing capability of the materials used - Reusability of PPEs are possible which can effectively manage the contaminated waste challenges associated with these items	- Decontamination of viruses (enclosed in particles) trapped in all layers is questionable
5.0	Chemical	- Effective control of virus through the destruction of its spores - Quick and steady operation procedure with effective and broad disinfection spectrum - Viable consideration during the manual waste handling (i.e. collection, storage, and transportation) application	- No reduction in the waste volume - Absorbance of atomized particles of chemical disinfectants into skin can cause carcinogenic disease

Source: Ilyas et al. [54],Wang et al. [50].

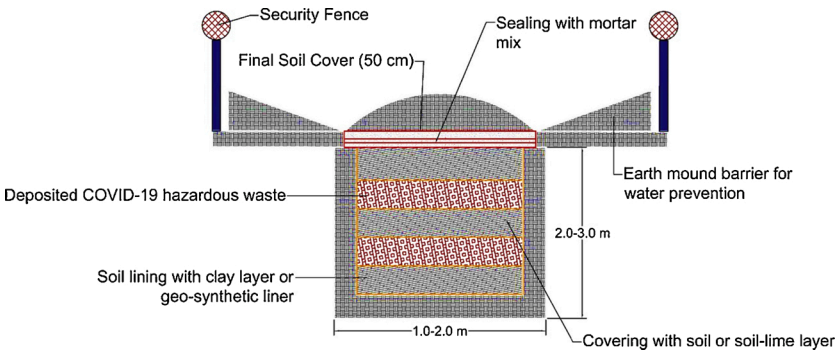


Fig. 5. Graphical representation of emergency on-site waste burial pit for the safe management of COVID-19 related hazardous waste (drawn after [51]).

strained the usual thermal treatment or incineration capacity of dealing with such waste. As an emergency epidemic prevention need, China has issued guidelines where the cement or other industrial furnaces can be used to treat the COVID-19 hazardous waste. Based on such approach the country was able to increase its emergency hazardous waste disposal level by 6,066.80 t per day from its previous capacity of 4,902.80 t per day. The emergency disposal level was increased in Hubei Province and Wuhan city by 667.40 and 265.60 t per day from its previous capacity of 180 and 50 t per day, respectively [55]. In view of that practice countries (particularly developing countries like Bangladesh) can use similar approaches as emergency and post pandemic treatment option for the massive hazardous waste volume generated throughout the pandemic.

4.3. Incorporation of reusable PPEs

Immense usage and poor disposal of PPEs from the residential and healthcare facilities have led to the growing concern over its limited but elongated usage through different disinfection techniques to transform into its reusable form [56]. As part of the efficient techniques that can be applied over the used PPEs, ultraviolet germicidal irradiation (UVGI), thermal or heat treatment and chemical disinfection processes have been applied and considered to be the effective ones as shown by Derraik et al. [57]. Moreover, reusing PPEs through such disinfection techniques are the energy efficient, economically, and environmentally sound processes as they can lessen the waste volume by 93.0 % and consumption in natural resources by 28.0 % [58]. A detailed process flow diagram for each of the disinfection techniques is illustrated in Fig. 6. Instead of producing more new PPEs, integration of reusable PPEs will

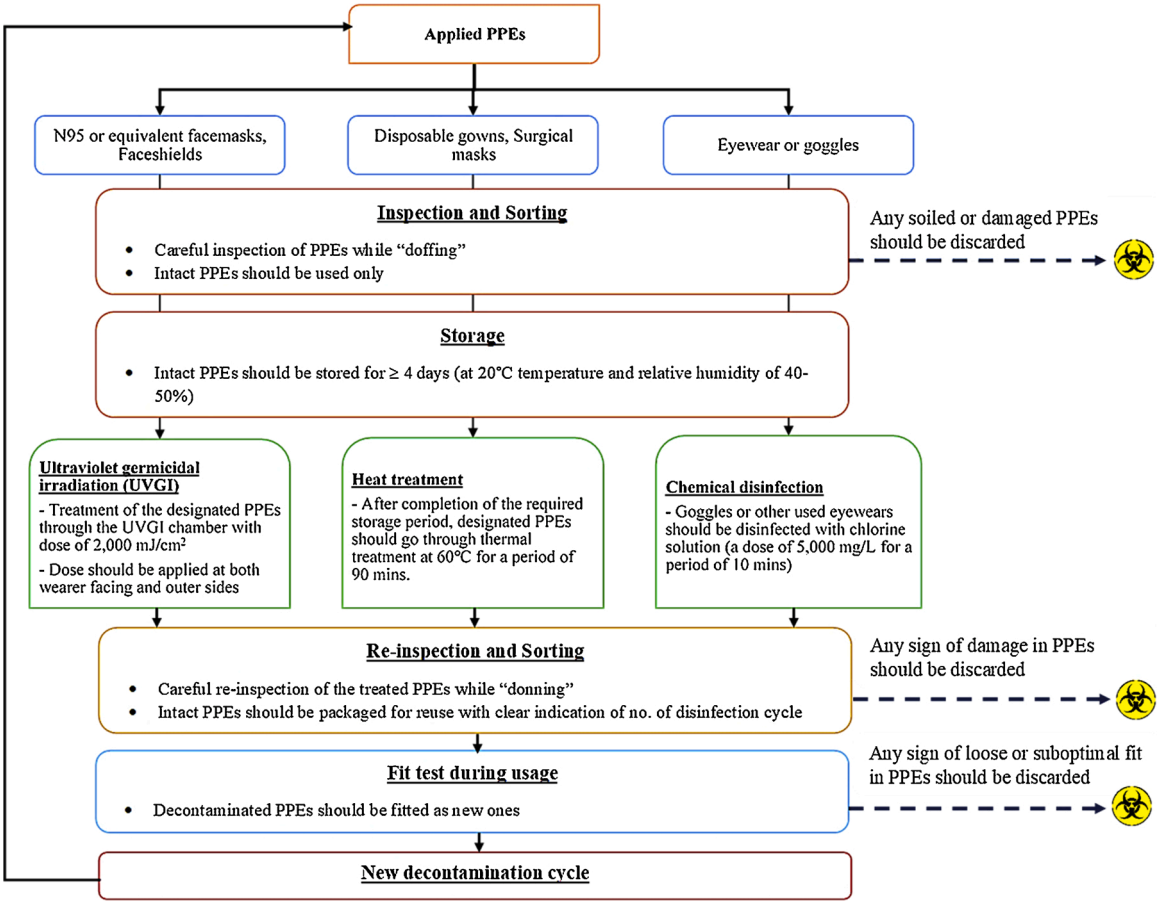


Fig. 6. Effective disinfection techniques to transform the used PPEs into its reusable form (drawn based on [57]).

be the viable consideration in response to the pandemic induced PPE waste pollution.

4.4. Medical waste management

Different types of medical waste generated from healthcare facilities should be dealt with proper collection, treatment, and disposal applications. Typically, the composition of medical waste is about 85.0 % general non-infectious, 10.0 % hazardous or infectious and 5.0 % chemical or radioactive [50]. As the infectious medical waste does not act as the vector for the coronavirus transmission, handling and treatment of medical waste generated from COVID-19 infected patients should be like the general infected medical wastes contaminated with TB, Hepatitis, HIV, anthrax, etc. Waste generated from infected patients isolated and quarantined in the household facilities should be treated as hazardous and require special care while putting in storage containers, and during collection and final disposal [48,59]. Fig. 7 illustrates the prescribed waste management procedures for both household and medical wastes that can be followed during this pandemic situation. Moreover, UNEP [60] presented a detail account of hazardous waste management practice required during the outbreak.

4.5. Municipal solid waste (MSW) management

Due to the massive lockdown, and restricted and limited entry across the cities worldwide when merged with the inadequate waste collection frequency, the increased amount of waste production has overstrained the existing MSW management services. As the application of waste

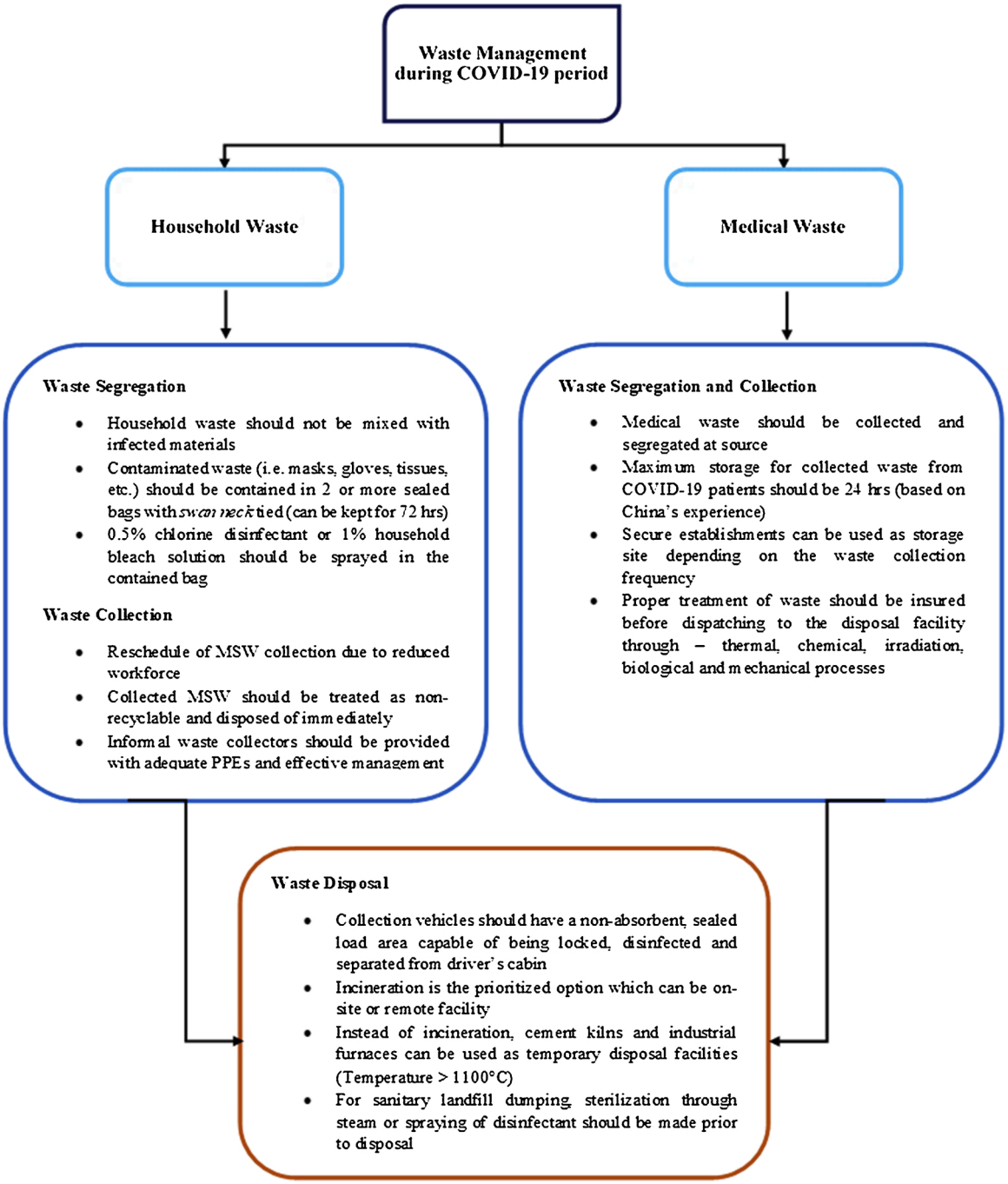


Fig. 7. Hazardous household and medical waste management during COVID-19 period (drawn based on [75,15,80]).

collection, disposal and recycling facilities has been severely disrupted around the world alternative approaches – decentralized waste management service, temporary waste storage and reduction site (TWSRS), waste to energy (WtE) – should be considered to relieve the overburden of MSW management service. Integration of decentralized waste management (Fig. 8) approach can curb the issues of waste collection and transportation services as it integrates waste treatment and recycling at the waste generation source (on-spot) which potentially limits the risk of infection for people involved in the waste management services. TWSRS is an emergency approach for the waste management sector which involves a temporary waste storage facility prior to the final disposal where the stored waste is treated with pretreatment and get reduction in volume by screening and grinding. WtE (Fig. 8) is a viable consideration for the excessive waste generated throughout the pandemic and immediate but an effective response to the post pandemic world against the environmental risks associated with the conventional waste management practice, limited or overburdened land areas for disposal at landfill or open dumping sites and inadequate logistic support for providing waste management services [61].

4.6. Plastic waste management and circular economy

In this pandemic, plastic based items have played as essential protective gears of which there is no dispute. At a same time, it is of paramount importance to not use the same pandemic as a loophole for littering plastic in the land and sea. Since the plastic-based items have already seen a rapid resurgence and find its way to the ocean, necessary plastic reuse and recycling programs need to be started without further delay. Potential surge is seen in the SUP items (i.e. food packaging) against which "Reuse and Refill (R&R)" system can act as the right measure in contrast with this sudden surge. R&R system is an evidence based approach in the circular economy which not only preserves the resources but also reduces waste and mitigates the prospective environmental impacts together with incredible economic productivity through savings in material cost and job creation [10]. Moreover, Klemes et al. [14] advocated on using energy and environmental footprints of plastic based items under the devised "Plastic 4R" programs which basically present a plastic pollution control mechanism by making a synergy between the SUP items and healthcare plastics along with economic viability. However, concerned authorities from the developing nations (i.e. Bangladesh) need to put their attention in modifying the existing plastic waste recycling system, beginning from the informal recycling sector to manufacturer level. As an approach towards the integrated plastic reuse and recycling industry, potential policy reformations should include – upgradation of the informal sector to a recognized and registered entity, pay-as-you-throw (PAYT) programs, economic incentives such as tax waiver, technical assistance, subsidized utilities and space, recycling market, and compliance for possible accidents and environmental hazards [62,63].

4.7. Government action plan, policy response and citizens' responsibilities

The continuousness of the waste management services together with the goals of waste minimization and recycling should be the ultimate policy response alongside with the COVID-19 health safety response as the waste management has a distinct relationship with the public health security and development [48,64]. Governments need to direct viable considerations in maintaining a high level of collection, disposal followed by treatment and recycling of plastic wastes to effectively manage the waste generated during the current and post pandemic period [65]. The following approaches need to be revisited and employed in the action plan and policy response for the safe management of COVID-19 induced waste [51,65,66] –

- Necessary adjustment in postponed waste collection, transportation, disposal and treatment and recycling operations need to be insured with continuation of the postponed waste management services;
- The number of the hazardous waste disposal sites or facilities should be increased. In this regard on-site waste burial pits and mobile incineration facilities can be a cost-effective and safe disposal options for the management of COVID-19 waste with adequateness;
- A quick but rigid coordination among the city authorities, stakeholders, local waste workers alongside with plastic producers, retailers and end-users need to be empowered to reduce the plastic waste issue from the SUPs and disposable PPEs together with the medical waste;
- As the SUPs have a challenging nature in terms of recycling and reuse, life cycle analysis need to be reassessed through different strategies for its proper treatment (waste to energy - WtE) or disposal (in landfills) options;
- Estimation related to the hazardous waste generation amount data from different health care units and residential dwellings, need to be used in local to regional level for developing emergency waste management execution and future treatment or disposal plans;

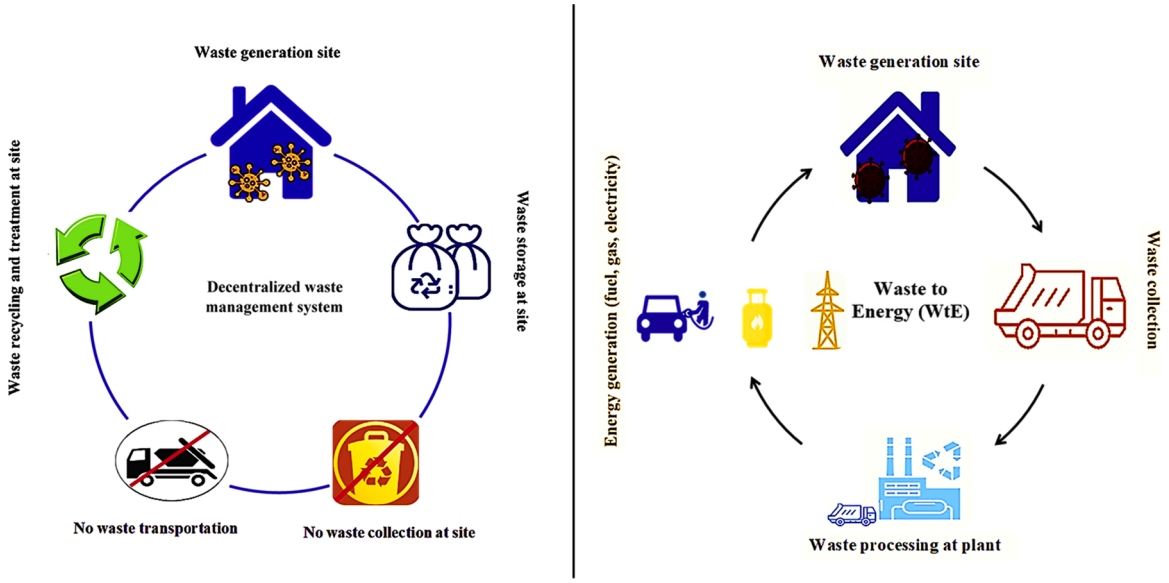


Fig. 8. Alternative approaches in MSW management service during the pandemic and post pandemic period (drawn based on [61]).

- Concerned authorities need to supply adequate protective gears for the waste workers during their service. Apart from the health safety, financial incentives, health insurance and medical support should be prioritized for the people involved in this sector;
- In compliance with the technical and economic support, local NGOs, funding agencies and other national and international donor sources can cooperate with the regional to local level for the establishment of different emergency waste management infrastructures and treatment facilities.

Fan et al. [67] viewed that "the conciousness training and psychological reconstruction of residents" are especially viable considerations "to restore and enhance the engagaement of society in waste management" in this pandemic and post-pandemic period. Governments need to make sure that clear communication is emphasized so that the citizens get aware of the need for waste segregation (i.e. hazardous, non hazardous, plastic) at source and reduction in the generation points. From the point view of "intention to action", increment in the mass media coverage through different public campaigning advertisements and online videos can indirectly induce in the safe management of household waste at source during this pandemic period [51]. Followed by such perspective, goverments can integrate Internet of Things (IoT) through the subscription based social media platforms (i.e. WeChat, Facebook, WhatsApp) that can bring effective and environment friendly solutions for the household waste management [68]. As discussed by Fan et al. [67], IoT technique and technologies related to data mining in the social medial platform – WeChat – showed promising results in terms of household waste management from the residential dwellings of Sanghai City of China during this pandemic period. As people are well connected to the internet as well as different social media apps, using the same initiative can bring safe management of the household waste segregation at source before the collection where the decision makers and city authorities need to provide emphasize through emergency policy interventions [69].

For the developing nations, prospective attention from the authorities and the policy makers should be devoted on the waste workers (particularly, from the informal sector) who have been recognized as the most vulnerable group during this unprecedented period among the working sector. A comprehensive health care and protection support (by providing adequate PPEs) and financial assistance need to be professed and mandated in the policy response and further inclusion of the informal sector in framing the waste management policy need to be reevaluated for the group of people who by compromising their lives protects the community [64].

The distinct features of waste management that need to be reevaluated for the COVID-19 induced waste management are illustrated in Fig. 9.

4.8. Health safety for the waste workers

A potential step forward in providing the continuity of the waste management services should include authority's assurance and support in maintaining health safety and financial take care of waste workers. In lieu of that certain well practices need to be assured by the authority in the waste management sector such as [70] –

- Ensuring the supply and apt use of PPEs and disinfectant items among the waste workers;
- Ensuring heightened and firm compliance of hygiene protocols among the waste workers including – repeated change and cleansing of PPEs and other exposed clothing items and hand gloves, frequent sanitization of vehicle cabins, personal clothes and storage and collection facilities;
- To avoid the accidental contact as well as the contamination, right use of masks and other PPEs need to be trained with strict adherence to such protocols;
- Ensuring physical distancing between the individuals working in the same climate, reducing the number of workers in a certain workplace, and special care for the older people and those with chronic illness.

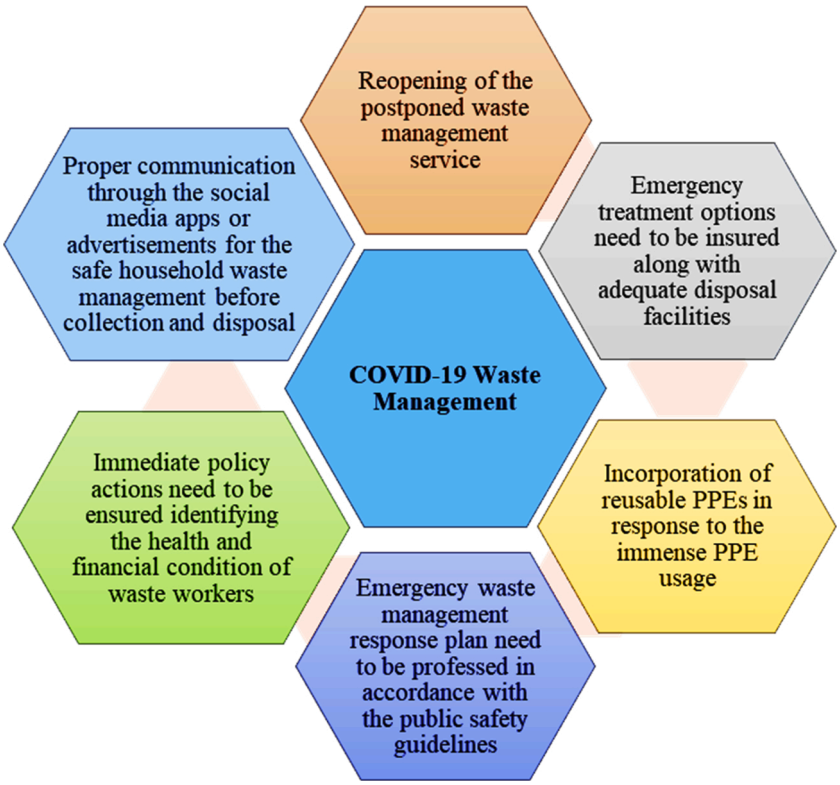


Fig. 9. Distinct features that need to be integrated in the waste management sector for the safe management of COVID-19 induced waste.

5. Conclusion

In this study, a prospective scenario of the current waste generation, possible management options and future implications of various types of produced waste and waste sector throughout the pandemic period have been presented. This study also provided a much-needed hazardous waste amount estimating equation which can assist the engineers, healthcare personnel and city authorities' waste management unit to plan and develop treatment and disposal facilities for the present and post pandemic hazardous waste management.

In the context of current pandemic situation in Bangladesh, the state of the affair should consider the following reflections –

- prospective change in policy response and current practices for the waste management service [28];
- upgradation of the informal waste sector to a recognized entity with potential care for their health safety, financial condition and other living aspects;
- in the given circumstances with numerous challenges of waste management sector, concerned authorities should look unto surrogate options (i.e. industrial furnaces, cement, and brick kilns) that will settle down the challenges associated with the COVID-19 hazardous waste. However, during the incineration process discharge of pollutants in the atmosphere and water needs to be regulated to avoid transmission of disease and pollution of the environment [55];
- a comprehensive recycling and other response strategies (i.e. reusable PPEs) against the SUP and PPE induced plastic as well as microplastic pollution in the land and sea for protection against the "secondary impacts upon health and the environment" [71].

The present waste management infrastructure at global scale is not capable of withstanding with the sudden induced crisis as avowed through the current pandemic. The take home lesson learnt from this pandemic is to transform the existing waste management infrastructure model of "take-make-dispose" to a model of circular economy where waste is transmuted into an efficient resource [72]. Moreover, the current global crisis has ascertained it necessary to look seriously upon the artificial intelligence (AI) modelling approaches for the waste management sector. Since the AI based waste management modelling techniques have the accurate capability to project the possible waste generation amount, thus, the proper and effective waste management system design and operation can be performed by the waste sector of a nation from city to regional level [73,74] for a given situation like the COVID-19 pandemic.

Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jece.2020.104660.

References

[1] I. Ali, O.M. Alharbi, COVID-19: disease, management, treatment, and social impact, Sci. Total Environ. 728 (2020), 138861, https://doi.org/10.1016/j.scitotenv.2020.138861.

[2] S. Muhammad, X. Long, M. Salman, COVID-19 pandemic and environmental pollution: a blessing in disguise? Sci. Total Environ. 728 (2020), 138820 https://doi.org/10.1016/j.scitotenv.2020.138820.

[3] M. Zahur, Solid waste management of Dhaka city: public private community partnership, BRAC Univ. J. 4 (2007) 93–97.

[4] T. Czigány, F. Ronkay, The coronavirus and plastics. eXPRESS, Polymer Lett. 14 (2020) 510–511, https://doi.org/10.3144/expresspolymlett.2020.41.

[5] UNICEF, COVID-19 Emergency Preparedness and Response, United Nations Children's Fund (UNICEF), 2020. Available at: https://www.unicef.org/media/66386/file/WASH-COVID-19-infection-prevention-and-control-in-health-care-facilities-2020.pdf. (Accessed 25 April 2020).

[6] N. Matete, C. Trois, Towards Zero Waste in emerging countries – a South African experience, Waste Manag. 28 (2008) 1480–1492, https://doi.org/10.1016/j.wasman.2007.06.006.

[7] M.A. Zambrano-Monserrate, M.A. Ruano, L. Sanchez-Alcalde, Indirect effects of COVID-19 on the environment, Sci. Total Environ. 728 (2020), 138813, https://doi.org/10.1016/j.scitotenv.2020.138813.

[8] M.A. Razzak, Can Bangladesh Cope with covid-19 Medical Waste? The Daily Star, Dhaka, Available at: https://www.thedailystar.net/opinion/news/can-bangladesh-cope-covid-19-medical-waste-1897327. (Accessed 26 June 2020), 2020.

[9] IFC, COVID-19's Impact on the Waste Sector. International Finance Corporation (IFC), World Bank Group, Available at: https://www.ifc.org/wps/wcm/connect/dfbceda0-847d-4c16-9772-15c6afdc8d85/202006-COVID-19-impact-on-waste-sector.pdf?MOD=AJPERES&CVID=na-eKpI. (Accessed 2 July 2020), 2020.

[10] C. Morawski, L. Copello, Reusable Packaging and COVID-19. Policy Papers. Zero Waste Europe, Reloop Platform, Available at: https://zerowasteeurope.eu/wp-content/uploads/2020/06/2020_06_04_zwe_reloop_joint_position_paper_reusables.pdf. (Accessed 2 July 2020), 2020.

[11] A. Mehta, The War on Plastics Runs Into a Perfect Storm With Covid-19. Ethical Corporation, London, Available at: https://www.ethicalcorp.com/war-plastics-runs-perfect-storm-covid-19. (Accessed 2 July 2020), 2020.

[12] WHO, Rational Use of Personal Protective Equipment (PPE) for Coronavirus Disease (COVID-19), World Health Organization (WHO), Geneva, 2020. Available at: https://apps.who.int/iris/bitstream/handle/10665/331498/WHO-2019-nCoV-IPCPPE_use-2020.2-eng.pdf. (Accessed 26 June 2020).

[13] M. Grodzinska-Jurczak, A. Krawczyk, A. Jurczak, M. Strzelecka, M. Bockowski, M. Rechcinski, Environmental choices vs. COVID-19 pandemic fear - plastic governance re-assessment, Soc. Regist. 4 (2020) 49–66, https://doi.org/10.14746/sr.2020.4.2.04.

[14] J.J. Klemes, Y.V. Fan, R.R. Tan, P. Jiang, Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19, Renewable Sustainable Energy Rev. 127 (2020), 109883, https://doi.org/10.1016/j.rser.2020.109883.

[15] ADB, Managing Infectious Medical Waste during the COVID-19 Pandemic, Asian Development Bank (ADB)., 2020. Available at: https://www.adb.org/sites/default/files/publication/578771/managing-medical-waste-covid19.pdf. (Accessed 25 Apr 2020).

[16] T. Bridges, Innovating for Impact: Dealing with a Mountain of Medical Waste. Eco-business, Available at: https://www.eco-business.com/opinion/innovating-for-impact-dealing-with-a-mountain-of-medical-waste/. (Accessed 4 July 2020), 2020.

[17] S. Ramteke, B.L. Sahu, Novel coronavirus disease 2019 (COVID-19) pandemic: considerations for the biomedical waste sector in India, Case Studies Chem. Environ. Eng. 100029 (2020), https://doi.org/10.1016/j.cscee.2020.100029.

[18] S. Saadat, D. Rawtani, C.M. Hussain, Environmental perspective of COVID-19, Sci. Total Environ. 728 (2020), 138870, https://doi.org/10.1016/j.scitotenv.2020.138870.

[19] S. Ball, 'A New Type of Pollution': Covid-19 Waste Ending up in World's Oceans. France 24, Available at: https://www.france24.com/en/20200610-a-new-type-of-pollution-covid-19-waste-ending-up-in-world-s-oceans. (Accessed 2 July 2020), 2020.

[20] ESDO, Press Synopsis "single Use Plastic (SUP) Pollution and Its Impact on Human Health and Environment in Bangladesh". Environment and Social Development Organization (ESDO), Dhaka, Available at: https://esdo.org/press-synopsis-single-use-plastic-sup-pollution-and-its-impact-on-human-health-and-environment-in-bangladesh/. (Accessed 6 July 2020), 2020.

[21] J. Kitchener, A New Type of Ocean Pollution: PPE. Reuters, Available at: https://www.reuters.com/video/watch/idOVCHNMP9N. (Accessed 1 July 2020), 2020.

[22] R.C. Hale, B. Song, Single-use plastics and COVID-19: scientific evidence and environmental regulations, Environ. Sci. Technol. 54 (2020) 7034–7036, https://doi.org/10.1021/acs.est.0c02269.

[23] K. Hughes, Protector or Polluter? The Impact of COVID-19 on the Movement to End Plastic Waste. World Economic Forum, Geneva, Available at: https://www.weforum.org/agenda/2020/05/plastic-pollution-waste-pandemic-covid19-coronavirus-recycling-sustainability/. (Accessed 3 July 2020), 2020.

[24] T. Godbole, Coronavirus Worsens Thailand's Plastic Waste Crisis, Thailand Environment Institute Foundation, Nonthaburi, 2020. Available at: http://www.tei.or.th/en/highlight_detail.php?event_id=663. (Accessed 3 July 2020).

[25] TEI, Asia Food Delivery Services Add Tonnes of Plastic to Thailand's Landfills During COVID-19 Crisis, Thailand Environment Institute Foundation, Nonthaburi, 2020. Available at: http://www.tei.or.th/en/highlight_detail.php?event_id=651. (Accessed 3 July 2020).

[26] TEI, Plastic Piles up in Thailand Pandemic Efforts Sideline Pollution Fight | Bangkok Waste up 62%, Thailand Environment Institute Foundation, Nonthaburi, 2020. Available at: http://www.tei.or.th/en/highlight_detail.php?event_id=655. (Accessed 3 July 2020).

[27] D.L. Alvares, V. Hernandez, A post COVID-19 world – enabling lasting solutions to the plastic pollution crisis for a more resilient economy. Break Free From Plastic Movement, Brussels, 2020. Available at: https://www.breakfreefromplastic.org/wp-content/uploads/2020/04/BFFP-Open-letter-to-EC-and-EU-MS-covid19-and-plastic-1.pdf. (Accessed 2 July 2020).

[28] L.D. Nghiem, B. Morgan, E. Donner, M.D. Short, The COVID-19 pandemic: considerations for the waste and wastewater services sector, Case Studies Chem. Environ. Eng. 1 (2020), 100006, https://doi.org/10.1016/j.cscee.2020.100006.

[29] Allianz, COVID-19 and Plastic Pollution. Allianz Global Investors GmbH., Available at: https://www.theseacleaners.org/wp-content/uploads/2020/04/2020-04-14-Infographie-COVID-allianz-TSC.pdf. (Accessed 3 July 2020), 2020.
[30] S. Manuja, Can Our Waste Management Systems Handle the covid-19 Pandemic? Livemint, Available at: https://www.livemint.com/opinion/quick-edit/can-our-waste-management-systems-handle-the-covid-19-pandemic-11586418529602.html. (Accessed 26 April 2020), 2020.
[31] S.H. Bhuiyan, A crisis in governance: urban solid waste management in Bangladesh, Habitat Int. 34 (2010) 125–133, https://doi.org/10.1016/j.habitatint.2009.08.002.
[32] M.A. Patwary, W.T. O'Hare, G. Street, K.M. Elahi, S.S. Hossain, M.H. Sarker, Quantitative assessment of medical waste generation in the capital city of Bangladesh, Waste Manag. 29 (2009) 2392–2397, https://doi.org/10.1016/j.wasman.2009.03.021.
[33] M. Sujauddin, S.M. Huda, A.T. Hoque, Household solid waste characteristics and management in Chittagong, Bangladesh, Waste Manag. 28 (2008) 1688–1695, https://doi.org/10.1016/j.wasman.2007.06.013.
[34] M. Mourshed, M.H. Masud, F. Rashid, M.U. Joardder, Towards the effective plastic waste management in Bangladesh: a review, Environ. Sci. Pollut. Res. 24 (2017) 27021–27046, https://doi.org/10.1007/s11356-017-0429-9.
[35] A. Ahsan, M. Alamgir, M.M. El-Sergany, S. Shams, M.K. Rowshon, N.N. Daud, Assessment of municipal solid waste wanagement system in a developing country, Chinese J. Eng. 561935 (2014), https://doi.org/10.1155/2014/561935.
[36] S. Yasmin, M.I. Rahman, A review of solid waste management practice in Dhaka City, Bangladesh, Int. J. Environ. Prot. Policy 5 (2017) 19–25, https://doi.org/10.11648/j.ijepp.20170502.11.
[37] R. Afroz, K. Hanaki, K. Hasegawa-Kurisu, Willingness to pay for waste management improvement in Dhaka City, Bangladesh, J. Environ. Manage. 90 (2009) 492–503, https://doi.org/10.1016/j.jenvman.2007.12.012.
[38] M.M. Hassan, S.A. Ahmed, K.A. Rahman, T.K. Biswas, Pattern of medical waste management: existing scenario in Dhaka City, Bangladesh, BMC Public Health 8 (2008) 36, https://doi.org/10.1186/1471-2458-8-36.
[39] N. Akter, J. Tränkler, An analysis of possible scenarios of medical waste management in Bangladesh, Manag. Environ. Qual. Int. J. 14 (2003) 242–255, https://doi.org/10.1108/14777830310470459.
[40] E.H. Syed, M. Mutahara, M. Rahman, Medical waste management (MWM) in Dhaka, Bangladesh: it's a review, Home Health Care Manag. Pract. 24 (2012) 140–145, https://doi.org/10.1177/1084822311425235.
[41] HSD, National Preparedness and Response Plan for COVID-19, Bangladesh, Health Service Division, Ministry of Health and Family Welfare, Government of Bangladesh, 2020. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/nprp_covid-19_v6_18032020.pdf. (Accessed 24 April 2020).
[42] M. Khan, Where Does All Our Waste End up? The Daily Star, Dhaka, Available at: https://www.thedailystar.net/star-weekend/environment/where-does-all-our-waste-end-1587943. (Accessed 6 July 2020), 2018.
[43] M.I. Hossain, Amid COVID-19 Pandemic, Biomedical Waste Turning More Hazardous, United News of Bangladesh (UNB), Dhaka, 2020. Available at: https://unb.com.bd/category/Special/amid-covid-19-pandemic-biomedical-waste-turning-more-hazardous/49165. (Accessed 27 April 2020).
[44] ESDO, ESDO's Online Press Briefing on COVID-19 Pandemic Outbreak 14,500 Tons of Hazardous Plastic Waste in a Month. Environment and Social Development Organization (ESDO), Dhaka, Available at: https://esdo.org/esdos-online-press-briefing-on-hazardous-plastic-waste-generation-in-a-month-during-covid-19-pandemic/#. (Accessed 6 July 2020), 2020.
[45] M.S. Haque, Sustainable use of plastic brick from waste PET plastic bottle as building block in Rohingya refugee camp: a review, Environ. Sci. Pollut. Res. 26 (2019) 36163–36183, https://doi.org/10.1007/s11356-019-06843-y.
[46] I. Enayetullah, A.H. Sinha, I. Lehtonen, Bangladesh Waste Database 2014. Waste Concern Technical Report Series, Waste Concern, Dhaka, Available at: http://wasteconcern.org/wp-content/uploads/2016/05/Waste-Data-Base_2014_Draft-Final.pdf. (Accessed 7 July 2020), 2015.
[47] E. Masaki, Appraisal Environmental and Social Review Summary (ESRS) - Lao PDR COVID-19 Response Project - P173817, The World Bank Group, Washington D.C, 2020. Available at: http://documents1.worldbank.org/curated/en/921211585917393014/pdf/Appraisal-Environmental-and-Social-Review-Summary-ESRS-Lao-PDR-COVID-19-Response-Project-P173817.pdf. (Accessed 3 July 2020).
[48] A. Scheinberg, A. Woolridge, N. Humez, A. Mavropoulos, C.S. Filho, A. Savino, A. Ramola, Waste Management during the COVID-19 pandemic-ISWA's Recommendations. International Solid Waste Association (ISWA), Rotterdam, Available at: https://www.iswa.org/fileadmin/galleries/0001_COVID/ISWA_Waste_Management_During_COVID-19.pdf. (Accessed 4 July 2020), 2020.
[49] N.J. Rowan, J.G. Laffey, Unlocking the surge in demand for personal and protective equipment (PPE) and improvised face coverings arising from coronavirus disease (COVID-19) pandemic – implications for efficacy, re-use and sustainable waste management, Sci. Total Environ. 752 (2021), 142259, https://doi.org/10.1016/j.scitotenv.2020.142259.
[50] J. Wang, J. Shen, D. Ye, X. Yan, Y. Zhang, W. Yang, et al., Disinfection technology of hospital wastes and wastewater: suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China, Environ. Pollut. 262 (2020), 114665, https://doi.org/10.1016/j.envpol.2020.114665.
[51] H.B. Sharma, K.R. Vanapalli, V.R. Cheelaa, V.P. Ranjan, A.K. Jaglan, B. Dubey, et al., Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic, Resour. Conserv. Recycl. 162 (2020), 105052, https://doi.org/10.1016/j.resconrec.2020.105052.
[52] F.D. Maria, E. Beccaloni, L. Bonadonna, C. Cini, E. Confalonieri, G.L. Rosa, et al., Minimization of spreading of SARS-CoV-2 via household waste produced by subjects affected by COVID-19 or in quarantine, Sci. Total Environ. 743 (2020), 140803, https://doi.org/10.1016/j.scitotenv.2020.140803.
[53] N. Singh, Y. Tang, Z. Zhang, C. Zheng, COVID-19 waste management: effective and successful measures in Wuhan, China, Resour. Conserv. Recycl. 163 (2020), 105071, https://doi.org/10.1016/j.resconrec.2020.105071.
[54] S. Ilyas, R.R. Srivastava, H. Kim, Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management, Sci. Total Environ. 749 (2020), 141652, https://doi.org/10.1016/j.scitotenv.2020.141652.
[55] Y. Ma, X. Lin, A. Wu, Q. Huang, X. Li, J. Yan, Suggested guidelines for emergency treatment of medical waste during COVID19: Chinese experience, Waste Disposal Sustain. Energy (2020), https://doi.org/10.1007/s42768-020-00039-8.
[56] H. Huang, C. Fan, M. Li, H.-L. Nie, F.-B. Wang, H. Wang, et al., COVID-19: a call for physical scientists and engineers, ACS Nano 14 (2020) 3747–3754, https://doi.org/10.1021/acsnano.0c02618.
[57] J.G. Derraik, W.A. Anderson, E.A. Connelly, Y.C. Anderson, Rapid review of SARS-CoV-1 and SARS-CoV-2 viability, susceptibility to treatment, and the disinfection and reuse of PPE, particularly filtering facepiece respirators, Int. J. Environ. Res. Public Health 17 (2020) 6117, https://doi.org/10.3390/ijerph17176117.
[58] Z.M. Jessop, T.D. Dobbs, S.R. Ali, E. Combellack, R. Clancy, N. Ibrahim, et al., Personal protective equipment (PPE) for surgeons during COVID -19 pandemic: a systematic review of availability, usage, and rationing, Br. J. Surg. (BJS). (2020), https://doi.org/10.1002/bjs.11750.
[59] SPREP, Effective Management of Medical Waste Essential during Pandemic. Secretariat of the Pacific Regional Environment Programme (SPREP), Apia, Available at: https://www.sprep.org/news/effective-management-of-medical-waste-essential-during-pandemic. (Accessed 3 July 2020), 2020.
[60] UNEP, Healthcare or Medical Waste-Basel Convention, United Nations Environment Programme (UNEP), 2020. Available at: http://www.basel.int/Portals/4/download.aspx?d=UNEP-CHW-PUB-Factsheets-Healthcare-MedicalWaste-2020.English.pdf. (Accessed 3 July 2020).
[61] B.N. Kulkarni, V. Anantharama, Repercussions of COVID-19 pandemic on municipal solid waste management: challenges and opportunities, Sci. Total Environ. 140693 (2020), https://doi.org/10.1016/j.scitotenv.2020.140693 (in press).
[62] UNESCAP, Closing the loop: unlocking an inclusive circular economy approach. Stakeholder Workshop in Pune, United Nations ESCAP, India, 2018. Available at: https://www.unescap.org/sites/default/files/Pune%20Workshop_Report_FINAL.pdf. (Accessed 5 July 2020).
[63] UNESCAP, Closing the loop: unlocking an inclusive circular economy approach. Stakeholder Workshop in Bangkok, United Nations ESCAP, Thailand, 2018. Available at: https://www.unescap.org/sites/default/files/Closing%20the%20Loop%20Bangkok%20Workshop_Final%20Report.pdf. (Accessed 5 July 2020).
[64] T.C. Nzeadibe, A.U. Ejike-Alieji, Solid waste management during Covid-19 pandemic: policy gaps and prospects for inclusive waste governance in Nigeria, Local Environ. (2020), https://doi.org/10.1080/13549839.2020.1782357.
[65] A.L. Silva, J.C. Prata, T.R. Walker, D. Campos, A.C. Duarte, A.M. Soares, et al., Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment, Sci. Total Environ. 742 (2020), 140565, https://doi.org/10.1016/j.scitotenv.2020.140565.
[66] F.-C. Mihai, Assessment of COVID-19 waste flows during the emergency state in Romania and related public health and environmental concerns, Int. J. Environ. Res. Public Health 17 (2020) 5439, https://doi.org/10.3390/ijerph17155439.
[67] Y.V. Fan, P. Jiang, M. Hemzal, J.J. Klemeš, An update of COVID-19 influence on waste management, Sci. Total Environ. 754 (2021), 142014, https://doi.org/10.1016/j.scitotenv.2020.142014.
[68] P. Jiang, Y.V. Fan, J.J. Klemeš, Data analytics of social media publicity to enhance household waste management, Resour. Conserv. Recycl. 164 (2021), 105146, https://doi.org/10.1016/j.resconrec.2020.105146.
[69] P. Jiang, Y.V. Fan, J. Zhou, M. Zheng, X. Liu, J.J. Klemeš, Data-driven analytical framework for waste-dumping behaviour analysis to facilitate policy regulations, Waste Manag. 103 (2020) 285–295, https://doi.org/10.1016/j.wasman.2019.12.041.
[70] European Commission, Waste Management in the Context of the Coronavirus Crisis, The European Commission, Brussels, 2020. Available at: https://ec.europa.eu/info/sites/info/files/waste_management_guidance_dg-env.pdf. (Accessed 22 June 2020).
[71] UNEP, Waste Management an Essential Public Service in the Fight to Beat COVID-19. United Nations Environment Programme (UNEP), Available at: https://www.unenvironment.org/news-and-stories/press-release/waste-management-essential-public-service-fight-beat-covid-19. (Accessed 29 June 2020), 2020.
[72] K.S. Ng, A. Yang, N. Yakovleva, Sustainable waste management through synergistic utilisation of commercial and domestic organic waste for efficient resource recovery and valorisation in the UK, J. Clean. Prod. 227 (2019) 248–262, https://doi.org/10.1016/j.jclepro.2019.04.136.
[73] U. Soni, A. Roy, A. Verma, V. Jain, Forecasting municipal solid waste generation using artificial intelligence models—a case study in India, SN Appl. Sci. 1 (2019) 162, https://doi.org/10.1007/s42452-018-0157-x.
[74] M. Abbasi, A.E. Hanandeh, Forecasting municipal solid waste generation using artificial intelligence modelling approaches, Waste Manag. (2016), https://doi.org/10.1016/j.wasman.2016.05.018.
[75] ACR+, Municipal Waste Management and COVID-19. Association of Cities and Regions for Sustainable Resource Management, Brussels, 2020. Available at:

https://www.acrplus.org/images/project/Covid-19/ACR_2020_03_Waste_management_covid19_graph.pdf. (Accessed 27 April 2020).
[76] A.K. Mohiuddin, Medical waste: a nobody's responsibility after disposal, Int. J. Environ. Sci. Nat. Resour. 15 (2018), 555908, https://doi.org/10.19080/IJESNR.2018.15.555908.
[77] Y.-C. Jang, C. Lee, O.-S. Yoon, H. Kim, Medical waste management in Korea, J. Environ. Manage. 80 (2006) 107–115, https://doi.org/10.1016/j.jenvman.2005.08.018.
[78] M.R. Kabir, Municipal solid waste management system: a study on Dhaka North and South city corporations, J. Bangladesh Inst. Plan. 8 (2015) 35–48.
[79] M. Shamsuddoha, Solid Waste Management in Bangladesh, SSRN, 2009, https://doi.org/10.2139/ssrn.1434967.
[80] H. Yu, X. Sun, W.D. Solvang, X. Zhao, Reverse logistics network design for effective management of medical waste in epidemic outbreaks: insights from the coronavirus disease 2019 (COVID-19) outbreak in Wuhan (China), Int. J. Environ. Res. Public Health 17 (2020) 1770, https://doi.org/10.3390/ijerph17051770.