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Review

Challenges and Impacts of COVID-19 Pandemic on Global Waste Management Systems: A Review

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Abstract: Unfortunately, nearly the whole world came to a standstill due to the coronavirus disease 2019, i.e., the COVID-19 pandemic, which negatively and severely impacted almost all facets of society, systems, and lives on the planet during the last few years. During this time, a surge in the generation of a huge volume of diverse wastes at an unprecedented rate occurred due to the extensive use of disposables and personal shielding safety gear such as personal protective equipment (PPE) for both infected and uninfected people as well as frontline staff, etc., as corona protocols, especially in the form of "plastic wastes". Consequently, all these factors induced a novel route for the pollution of air, soil, and water, inviting a great number of health hazards in addition to the pandemic. Beyond a doubt, the susceptibility of the spread of the coronavirus through polluted waste is high, an issue for which the waste management measures are comparatively not up to the mark. The spread of COVID-19 forced the world into lockdown, which had both constructive and unconstructive effects on not only the environment but also systems such as the waste management sector, etc. The unforeseen increase in the quantity of waste created a challenge concerning normal waste disposal facilities, negatively impacting the global waste management industry, and hence, leading to an urgent situation internationally. Still, in developing nations, the sector of waste management is at its nascent stage, and therefore, the sector of waste management during the pandemic period has been influenced severely in many parts of the world. The current comprehensive review provides not only an overview of the impacts and challenges of COVID-19 on the waste management sector but also extends the systematic data of waste generation that has been made accessible so far along with a discussion on the safety of the related workers and staff as well as suggestions for the possible approaches towards better waste management services, which are essential to manage the waste increase resultant of the COVID-19 pandemic in a majority of nations.

Keywords: COVID-19 pandemic; personal protective equipment (PPE); greenhouse gas (GHG); global warming

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1. Introduction

The ongoing COVID-19 pandemic challenged the world with a state of conditions that even First World nations did not witness during the Spanish Flu endemic almost one hundred years ago. This is why, globally, the World Health organisation, i.e., WHO, announced COVID-19 as a pandemic given the shockingly high statistics of reported daily cases and casualties [1–4]. The high-speed progression of this universal pandemic led to decisions for mandatory lockdowns by a number of countries as a measure to avoid gathering and to maintain social distancing, which has in the long run returned both positive as well as negative results on environmental aspects such as reduced air pollution, which has proven to be positive; however, on the other hand, the high generation of novel hazardous waste from the COVID-19 scenario is quite alarming [5]. Not only that, but

COVID-19 became a worldwide health crisis leading to the mandatory closure of businesses and influencing the socioeconomic, tourism, health, environment, education, and other diverse sectors of society in a negative way [6–8].

Conspicuously, the global waste management system was one of the most impacted sectors during the COVID-19 period, wherein the most pronounced and adverse ecological impacts were noticed [9,10]. Moreover, the capacity of health care facilities was overloaded by infected patients; hence, patients were advised to self-isolate and quarantine at their residences, which deepened the issue of household hazardous waste. In regard to testing, treatment, as well as following-up of the protocols, different public health protection directives and measures essential to prevent the spread of this pandemic have altogether resulted in a surge in the exigency for and the enhanced use of essential personal protective gear, such as face masks, rubber boots, hand gloves, white gowns, hand sanitizers, etc.; personal protective equipment (PPE), goggles, protective face shields/face screens; protective clothing; disposable life support equipment; general plastic supplies; medical-use gear such as test kits, syringes, plastic containers, bandages, tissues, etc., thereby leading to a substantial escalation in waste [10,11]. This kind of idiosyncratic and novel hazardous waste use was recorded to amount to 3.40 kg/day for each COVID-19 patient, which was also found to be higher in some developing nations and provinces such as Hubei, China, with a roughly 600% increase [12]. As a result, the addition of such abnormal and unexpected wastes generated from the COVID-19 pandemic added fuel to the dilemma of the pre-existing challenge of environmental contamination, leading to escalating concerns for the global waste management sector and environmentalists, too [13–16].

Globally, medical wastes and household hazardous and plastic wastes during the pandemic require waste management; however, such wastes largely seem to be unaccounted for. This inevitable generation of wastes by anthropogenic activities during the pandemic resulted in a human impact on the environment that includes alterations to not merely bio-physical environments but also ecosystems [17]. In the interest of mitigating the spread of the pandemic, government authorities of different affected countries around the world adopted and enforced a number of unprecedented measures and guidelines such as lockdown, wearing masks, social distancing, limiting people in marriage and funerals, restrictions on local and international journeys, vaccination programs, work from home, and even curfew in containment zones where plenty of cases were reported, etc. However, essential and emergency services were kept free from restrictions, but the education and coaching of students were affected like everything else even though an attempt was made by schools to provide education online. One important indispensable essential service is waste collection and its management so as to keep the environment clean as a regular exercise mostly in the developed world, to decrease the spread of the virus, and increase the efforts by managing the escalating novel waste generation at the household level [3,4,6,18,19].

On the other hand, the inadequate waste management strategies as observed in developing and undeveloped nations place them at a higher risk of community spread of COVID-19 [9,20,21]. For example, poor waste management practices lead to badly managed open landfills, whereby both human and animal scavengers can wander freely with the possibility of coming into contact with contaminated waste and reusing these polluted waste materials in the form of bottles, packages, etc. [9,22]. This is because the severe acute respiratory syndrome (SARS) coronavirus responsible for spreading the disease of COVID-19 possesses a peculiar morphology [23–26] and structure, which help it to retain its lifespan for 3 h in the atmosphere as part of aerosols, 4 h on copper surfaces, 24 h on cardboards, 2–3 days on stainless steel, 3 days on plastics and sewage, and 3–4 days on solid faeces [16,27,28]. This is why the abnormal structure and varied lifespans on different media or object surfaces that might be present in existing wastes have become a topic of concern in relation to the acceleration of this deadly disease [29]. This simply means the methodical waste collection from infected households, quarantine centres, hospitals, and structural systematic waste management is highly essential to controlling the spread of

COVID-19 and the pollution of the environment, water, soil, etc. Looking at statistics of COVID-19′s impacts on the world, it was found that the top ten most affected nations include the U.S.A., India, Brazil, France, Turkey, Russia, the U.K., Italy, Germany, and Spain as per the online reporting on 23 May 2021, which includes a total of 16,70,60,227 confirmed cases of COVID-19 with 34,69,014 deaths in a total of 222 nations of the world [2]. The continental bifurcation of COVID-19 demonstrates the total number of confirmed cases in Europe as 4,61,62,211 (deaths 10,60,272); in North America as 3,94,61,755 total cases (8,84,707 deaths); in Asia as 4,89,29,156 total cases (6,42,543 deaths); in South America as 2,76,47,386 total cases (7,51,694 deaths); in Africa as 47,91,745 total cases (1,28,540 deaths); and Oceania with 67,253 total cases (1243 deaths) [2].

Medical waste is the world's second most hazardous waste. Needles, human body parts, blood, chemical waste, pharmaceutical waste, and medical devices are examples of hazardous and non-hazardous waste. During the COVID-19 pandemic, the generation of medical waste grew significantly in several countries [30,31]. Figure 1 shows the estimation of COVID-19-related medical waste generation around the world. After the pandemic, the amount of medical waste produced every month was 2.5 million tons. Irresponsible treatment of such waste products may facilitate the spread of the disease. It has been noted that the majority of people hired in the waste management process are laborers who are not appropriately qualified to handle such material. They are also not provided with any health precautions or personal protective equipment (PPE) to handle these wastes, which might put them in danger and cause serious sickness. Furthermore, persons in home quarantine frequently dispose of their household rubbish in the same bin as their infected face mask, tissue paper, and other contaminated waste [30,31], which might spread the disease to municipal employees and rag pickers who collect home quarantine garbage. The proper treatment and disposal of such wastes in hospitals, homes, municipalities, and quarantine facilities are critical to preventing the disease from spreading to the general population. The composition of healthcare solid waste during the COVID-19 pandemic is more or less identical to that under normal conditions, with the exception of the production of a large amount of plastics/micro-plastics [32,33]. However, the epidemic resulted in a rise in waste creation. As has been noted under normal conditions, the composition of healthcare solid waste is critical, as it determines its potential to be recycled and managed sustainably, which is critical during the present pandemic.

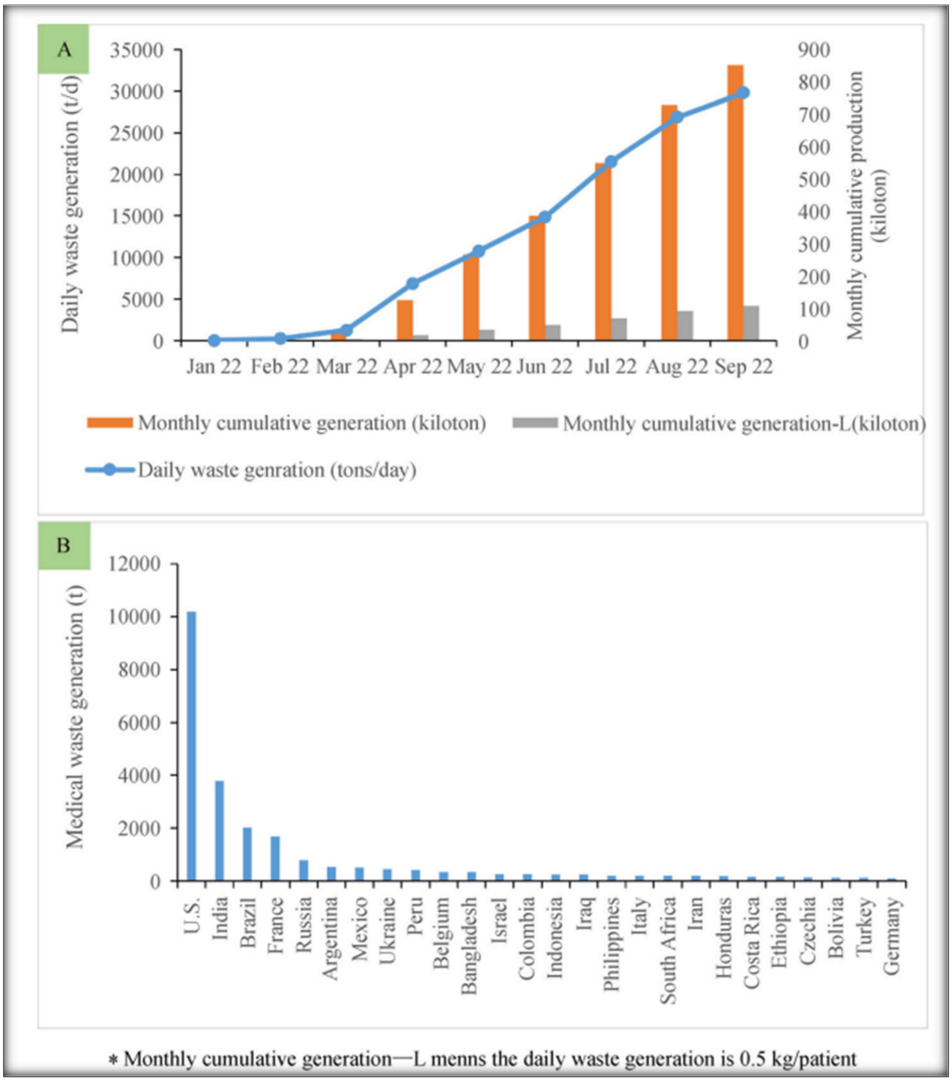

Figure 1. Estimation of COVID-19-related medical waste generation around the world [34].

1.1. Off-Putting Impacts of COVID-19 Scenario on Environments

1.1.1. Escalation in Wastes

Internationally, the generation of a new type of bio-medical waste was escalated subsequent to the onset of the COVID-19 pandemic which represents a prime threat to not merely the general public's health but also to the environment. Despite the guidelines established by concerned authorities and experts with regard to the correct disposal and separation of risky medical wastes and plastic-based PPE as well as organic domestic wastes, the mixing up of all these wastes is knowingly or unknowingly carried out by some people, especially unaware individuals in developing countries with a narrow literacy rate whose actions increase the transmission of COVID-19 and virus exposure for waste management employees [35]. Furthermore, the large quantities of discarded bottles of disinfectants which were utilized to combat the coronavirus in public places, industries and residences have not only accumulated in the form of piles of waste but also carry the possibility of being infectious since they may come from isolation and/or treatment centres as well as hospitals for COVID-19. Currently, in this period of the deadly virulent disease of COVID-19, a large quantity of used disinfectants are found extensively on roads and in markets as well as around residences. This widespread use of disinfectants may be dangerous to the health and lives of some other non-targeted, useful species, thereby creating an ecological imbalance [36]. The extensive application of disinfectants may eliminate other useful organisms that contribute to maintaining ecological balance [37]. What is more, the SARS-CoV-2 virus was found present in the faeces of COVID-19 patients and also in municipal wastewater in many nations such as India, etc. [38]. For this reason, further measures for wastewater treatment are still the need of the hour, which is a challenging job for developing nations such as Bangladesh, etc., where municipal wastewater is directly drained into nearby water bodies and rivers without treatment [39]. Particularly, China reinforced their procedures for wastewater management disinfection by increasingly using chlorine to hinder the spread of the SARS-CoV-2 virus via this route. However, it is also noteworthy that the overuse of chlorine in water may generate destructive by-products at the same time [40].

Likewise, globally, during the present COVID-19 pandemic, governments issued guidelines from time to time stipulating the use of PPE as safety gear including facemasks, gowns, hand gloves and other safety equipment in order to protect the general public from the novel coronavirus infection, which increased the healthcare waste volume at the domestic level. The generation of this new form of plastic-based PPE waste increased internationally, as [37] was the case in China where the daily increase in the production of medical masks was 14.8 million in February 2020 [41]. The lack of awareness when dumping this novel infectious waste has led to the throwing away of used face masks, hand gloves, gowns, and other PPE by most people in open spaces or with other usual household wastes. Thus, the incorrect dumping of these wastes results in the blockage of waterways and further environmental contamination [40]. Facemasks and other plastic-based PPE are considered potential sources of micro-plastic fibres in the atmosphere [41].

Generally, polypropylene is used to manufacture N-95 face masks, protective Tyvek suits, and gloves, as well as face shields, on the surface of which the novel coronavirus can survive for a long period; furthermore, the dioxin and toxic elements can be discharged into the atmosphere. Essentially, the guidelines issued by authorities and health experts suggest that there should be a correct method of disposal and segregation of organic domestic waste as well as plastic-based PPE which constitutes dangerous medical wastes. Moreover, medical waste should not be mixed with household waste since it will increase COVID-19 virus transmission [42].

During the course of testing for suspected COVID-19, patient diagnosis, the treatment of a large number of confirmed patients at centres and/or hospitals, as well as disinfection, and the generation of masses of new kinds of infectious and bio-medical wastes were observed. The escalating quantity of the waste has led to a dilemma for systematic waste management, e.g., in Wuhan, China, over 240 metric tons of waste were recorded in a single day for the duration of the outbreak [10], representing approximately 190 m tonnes more waste than the pre-COVID-19 period. In developing nations, this predicament of methodical waste management is more serious due to limited resources, e.g., in Ahmedabad, India, the quantity of generation of medical waste increased from 550 to 600 kg per day to about 1000 kg per day at the time of the initial phase of COVID-19 lockdown [43]. Therefore, this abrupt and swift increase in infectious wastes of medical and safety equipment has become a key issue for the local waste management authorities of developing nations.

In another capital city of a developing country, Bangladesh, i.e., Dhaka city, these sorts of wastes were found to be generated at a rate of nearly 206 m tonnes per day during the pandemic [37]. In the same fashion, some other cities, namely, Kuala Lumpur, Manila, Bangkok and Hanoi also experienced an increase of 154 to 280 m tonnes more medical waste every day compared to the pre-pandemic period. Such an unprecedented and problematic increase in infectious hazardous medical waste generation alarmed the world, especially in developing nations where limited facilities exist for adequate waste disposal. As described earlier, the COVID-19 restrictions on movements and "stay at home" strategies implemented by governmental authorities in almost the whole world led to a considerable increase in both organic and inorganic kinds of waste.

Conveniently, during the pandemic period, people bought essential commodities and in some cases foods from online platforms with home delivery facilities, which accelerated the amount of waste from packaging mostly in the form of plastics and papers, thereby leading to an extensive rise in the quantity of household wastes. Moreover, a large amount of medical waste of used gloves, face masks, disposable aprons and PPE, syringes, etc., was also generated in treatment centres and hospitals for COVID-19. This unexpected, and pressing issue created by the present circumstances has put the waste management authorities in the world in a confusing state, especially in developing countries where facilities for waste management are limited. In the context of developing nations where people are not fully educated, the unawareness of some sections of society results in random dumping of the said wastes. The haphazard disposal of wastes in landfills, streets or water bodies, etc., may lead to severe impacts on human health since these wastes may be infectious and still can carry traces of viral pollutants. Thus, proper waste management has become a momentous challenge for local waste management authorities, particularly in developing nations. This anxiety has been exacerbated by the recently published literature stating that the novel coronavirus can exist for a prolonged period on the surfaces of objects used daily.

Consequently, the bio-medical wastes generated from hospitals and/or COVID-19 treatment centres in the form of infectious and discarded masks, needles, syringes, bandages, gloves, used tissue, leftover medicines, etc., should be disposed of appropriately with a view to mitigating the further spread of COVID-19 and the contamination of environments. The enhancement in the quantity of both organic and inorganic kinds of municipal waste generation has directly or indirectly impacted the environment by polluting the air, water and soil. In the pandemic period, online shopping with home delivery facilities increased tremendously on account of the quarantine and lockdown policies in many nations; therefore, the volume of waste from shipped packaging materials in the form of household wastes increased [40].

1.1.2. Diminution of Waste Recycling

Due to COVID-19 spreading globally, recycling facilities have been affected severely, especially in developing nations. At the present time, this has proved to be a major crisis since waste recycling can not only prevent contamination but also save energy and preserve limited natural resources. As stated earlier, the rising domestic and medical wastes from COVID-19 facility centres and quarantine facilities may bear traces of virus contaminants, thereby posing a threat of infection to the workers and staff at recycling sites. For this reason, recycling waste management systems have been shut down in many countries. However, efforts to mitigate this issue by most nations for the safe and systematic disposal of infectious COVID-19 wastes are being carried out because the management of these wastes is a pressing issue. Nevertheless, the recycling of waste is an effective route to mitigate contamination, save energy, and preserve restricted natural resources [42].

However, at the moment, a number of nations have stopped waste recycling to mitigate the transmission of the COVID-19 virus, e.g., the U.S.A. narrowed their recycling programs to nearly 46% since the US government expressed concern about the spread of COVID-19 at recycling units [43]. Worldwide, there has been an increase in landfilling and environmental contamination owing to disruptions in routine municipal waste management, recovery as well as recycling. This situation must be brought to an end by reopening recycling plants soon; additionally, recycling must be performed efficiently in order to dispose of hazardous waste while keeping the staff and workers safe.

The primary goal of this research was to identify the challenges associated with the management of COVID-19 medical waste and to recommend safe and sustainable short and long-term solutions for managing COVID-19 medical waste in order to significantly reduce transmission and environmental impacts. As a result, this study examined existing research on COVID-19 medical waste, highlighted difficulties and obstacles that negatively influence COVID-19 medical waste management and, offered an overview of management strategies in different countries. This study draws on prior research findings, evaluates unique circumstances, and proposes future research topics to offer best practices and suggestions for handling and managing pandemic medical waste. The present review aimed to assess the present impacts, challenges and awareness for waste management sectors (See Figure 2) affected during the COVID-19 period by the surge of new kinds of wastes of compulsorily used disposable masks, PPE, syringes, medical wastes, etc., which is an urgent need of the hour for people as well as to assist policymakers when planning for the future in this context. This review is of significance to combat the spread of the COVID-19 pandemic in this vital sector and to mitigate the challenges of COVID-19 with regard to environments and socio-economic conditions.

1.2. Research Methodology

A comprehensive literature review was conducted to identify the available information on record, which returned the pedagogic ideas and referenced examples used in this work. In recent years, one of the rapidly expanding study disciplines that have become a crucial sub-discipline of waste is COVID-19 or Corona. To comprehend in-depth geopolymers as an edifice material, the keywords "COVID wastes", "COVID pandemic", "Corona", "medical waste" and "COVID rules" were methodically searched using the bibliographic databases of "Springer", "Elsevier", "Taylor and Francis", "Wiley" and "Hindawi". Furthermore, a comprehensive data analysis and categorization were carried out based on a thorough understanding of titles, graphical abstracts, highlights, abstracts, keywords, entire texts, conclusions, and impressions. Several synthesis procedures were depicted in figures, graphs, and tables, which were used as references in the current study. The cited literature data represent a comprehensive description of the progress and portrayal of COVID-19-generated wastes.

1.3. Types of Waste Generated in COVID-19

1.3.1. Use of PPE

In order to protect both patients and frontline medical staff from "nosocomial" infection, medical staff and doctors should follow sufficient protective measures.

PPE goods in the contemporary context include, but are not limited to, hand gloves, facemasks, face shields, goggles, and aprons. These are 'intended to protect the wearer's body from infection caused by viral transmission [44]. PPE has been advised for healthcare personnel as well as those involved in the treatment of COVID-19-infected patients [45]. According to a WHO situation report, between June and July 2020, the delivery of PPE increased to 50.40 million (M) pieces (pcs) from 5.50 M the previous month, with over 200 M pcs in stock for emergency delivery to 138 countries [16]. The majority of these items are single-use and must be discarded. PPE is frequently used by the general public as protective clothing against virus infection, and it is also used in medical applications by frontline healthcare personnel. Since the beginning of the pandemic, the use of polyethene bags, gowns, and disposable plastic packaging increased dramatically [46]. Fear of potential contamination, travel limitations, house quarantine, country-wide lockdown measures, cleanliness, and stay-at-home directives all contributed to the tremendous increase in single-use items [47]. Along with PPE, the increase in plastic waste may be ascribed to the purchasing of disinfectants, more food packaging, storing supplies, and extensive internet shopping [48]. In light of the COVID-19 pandemic, numerous nations removed or delayed their restrictions on PPE. The surge was unavoidable, especially since several nations removed or postponed their restrictions on PPE in the aftermath of the COVID-19 pandemic [49]. According to a study from October 2020, recovered patients were reinfected by the same virus in altered forms [50]. With viral immunity being impaired in a short amount of time, the urge to be more careful than before causes individuals to seek PPE protection for longer periods of time than previously believed. Based on pre-pandemic patterns, 12,000 million tonnes (Mt) of plastic waste is expected to accumulate in our landfills by 2050 [51].

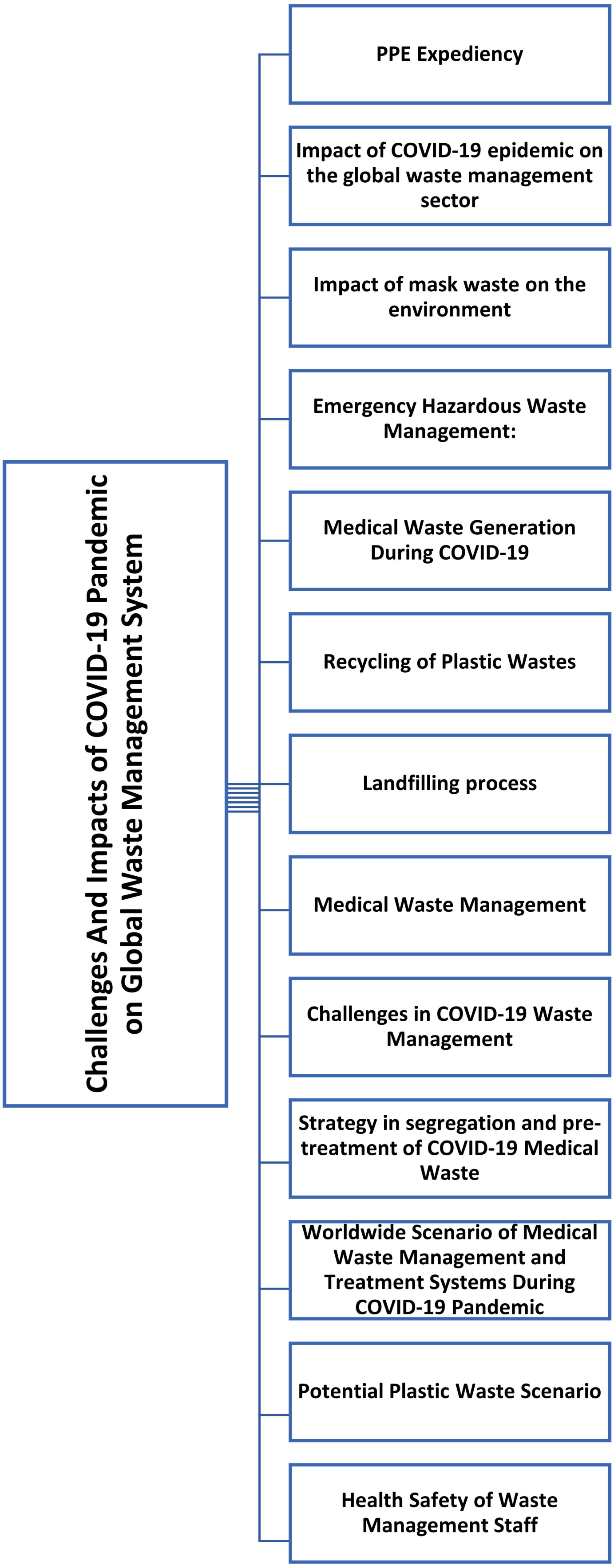

Figure 2. Structure of the Manuscript.

1.3.2. Use of Masks

The use of masks—surgical or protective—has proved to be very significant to prevent the transmissions of the COVID-19 virus from the atmosphere while breathing and also from the human to the human transmission while talking/meeting/going outside of the home to buy essential commodities or in cases of emergency travel. To remain safe, medical-surgical masks should be disposed of after the duration of the effectiveness of protection, i.e., 4 h after wearing them. All masks must be replaced once they are contaminated. The pollution caused by masks is shown in Figure 3. Irrespective of the type of mask, it is essential to wear them correctly on the face. Medical surgical masks can obstruct particles larger than 5 μm, thereby keeping a person safe from the spread of COVID-19 through droplets. In the same way, medical protective masks are also competent enough to stop particles even as small as 0.3 μm. However, if a person wears the mask without adjusting it systematically to serve the purpose, particles of 3, 10, or even 30 μm can enter through the nose and/or mouth opening. This means that wearing a mask without adequate provisions is almost equivalent to wearing no mask at all. The incorrect use of face masks has unfortunately led to the acceleration of the spread of COVID-19. Furthermore, the wearing of a surgical mask inside a medical protective mask is not permitted because it will reduce the efficacy of the protective mask by reducing its tightness of the protective mask. Significantly, hand hygiene is required to keep people safe subsequent to mask removal upon returning to a safer space.

Figure 3. Pollution is caused by face masks [52].

1.3.3. Use of Gloves

The use of gloves is significant and necessary while cleaning and disinfecting or caring and/or treating patients with COVID-19. When medical staff enter high-risk zones, wearing two or three-layered surgical gloves is required in order to keep them safe from infection. Nevertheless, hand hygiene is essential when taking off any protective equipment such as gloves at every step and in between every layer. However, one should avoid touching needless items when wearing latex gloves since it might increase transmission.

1.3.4. Use of Goggles and Protective Face Shields/Face Screens

In medical applications for COVID-19, the use of goggles and protective face shields/screens is essential when using various devices that are helpful in diagnosis and treatment to protect people who may be exposed to blood or other potentially infectious fluids and/or viruses. A CPR mask is used to recover patients' breathing and similarly, PPE is essential to safeguard the face against contact with infectious materials. The efficacy of face shields can protect against aerosols derived from the cough of COVID-19 patients.

1.3.5. Use of Gowns and Protective Clothing

Gowns and protective clothing are used in accordance with the risk of exposure to dissimilar working environments. However, appropriate wearing and undressing are essential. In order to prevent pollution, it is highly necessary to remove PPE in a standardized way according to the guidelines and one should not leave the isolation ward while wearing medical protective clothing. Moreover, shoe covers are useful to extend a barrier against the possibility of being exposed to airborne infectious organisms and/or viruses or coming into contact with polluted environments. Shoe covers should be worn as part of Full Barrier Precautions and used in specified areas only when entering a polluted zone from a semi-contaminated area and when moving to a negative pressure ward from a buffer zone and vice versa.

All of the novel wastes of medical equipment and PPE referred to above and produced during the COVID-19 pandemic period have disturbed the normal global waste management industry severely.

2. Impact of the COVID-19 Pandemic on the Global Waste Management Sector

The transmittable situation has led to lockdown in the interest of preventing the spread of COVID-19 [48–52]. Ultimately, the present scenario has accelerated the use of various face masks, goggles, gloves, protective suits, aprons, boots, face shields, visors, takeaway food containers, water bottles, plastic bags, single-use plastic items and plenty of disposable safety gear items [53,54]. The use of safety gear for human health during this pandemic has seen a momentous increase in quantity which has led to environmentally weakening impacts. Grodzinska-Jurczak et al. [55] reported on this situation in which human health concerns will sooner or later overwhelm environments worldwide. This sudden flow of new wastes has already endangered the pre-existing global waste management infrastructures leading to a number of challenges to cope with it adequately [55]. For example, the researcher Bridges reported that Southeast Asian nations may have extra hazardous waste amounting to 1000 tons/day [56]. The daily hazardous medical wastes of Manila and the Philippines collectively reached 280 tons/day and in Jakarta, it was recorded as 212 tons/day [56]. In Wuhan, China, the highest daily capacity for incineration is 49.0 tons/day; increased pressure has been placed on such infrastructure due to the volume of hazardous medical waste of around 240.0 tons/day from its normal generation amount of 40.0 tons/day [36]. As part of the information for Hubei Province of China, it was reported that a 600% increase in the volume of hazardous waste was experienced during the pandemic period of COVID-19. Furthermore, the assessment by ADB (Asian Development Bank) of the generation of around 3.40 kg/day of hazardous medical waste was made based on data from Chinese COVID-19 patients.

The COVID-19 pandemic forced populations around the world to make a habit of wearing safety gear such as facemasks and hand gloves in public gatherings in accordance with guidelines provided by governments to avoid transmission of the virus. Consequently, these kinds of safety gear have led to a new sort of "PPE pollution" on land and sea. For example, marine divers from a French environmental group estimated the used gloves and face masks floating over the waters off the French coast to account for 80–90% of the waste in the water contributed from the land. That means that the PPE waste of the land is not managed correctly and for that reason, it is found in the seas and oceans [57]. One more example is found on Soko Island of Hong Kong whereby the PPE wastes of used face masks are reported within the 100 m stretch of the beach [58]. In accordance with the projection made based on present trends, copious micro-plastic contamination in the terrestrial environments and ocean water is going to be produced during and after the period of the COVID-19 pandemic. Moreover, plastic wastes from this novel field of diverse medical testing kits, online services and food packaging items as well as hand sanitizer bottles, etc., during the pandemic are significant. This marks a noteworthy movement away from the limitations of single-use plastic packaging and the ban on the use of reusable bags and beverage containers internationally on account of the apparent risk of contamination [59]. A surge in plastics, mostly in the form of single-use plastic items, occurred across the globe due to the assumption that they are safe and do not carry COVID-19. An evaluation made by the Thailand Environment Institute revealed an increase in plastic waste in Thailand from 2120 tons/day in 2019 to approximately 3440 tons/day which is a surge of roughly about 62% between January and April 2019 [60]. The average rate of plastic waste generation for the South East Asian nations was by and large 5500 tons/day prior to the COVID-19 pandemic which is now estimated to be 6300 tons/day in addition to another expected increase of 30% in Thailand's annual plastic waste generation which will keep it at the top of the list of plastic polluter countries in this region. The latest study on the coronavirus unearthed that plastic surfaces facilitate its survival for 4 days, which is the highest among all materials such as paper, cardboard, and fabrics which permit its persistence for only one day during testing [61]. Therefore, there is a higher chance of infection with COVID-19 from plastic items that are not correctly disinfected. Moreover, the industry of plastic recycling is also facing challenges due to inferior valued virgin plastic materials owing to the slimming down of recycling rates and oil prices responsible for bringing a potential financial downturn to this industry [62,63]. In terms of caution, there are more concerns for staff engaged in waste management—especially waste management workers—who provide the backbone of the waste management system and are at potential risk since they are not provided with appropriate safety gear and PPE to shield themselves from virus transmission. The situation is worse in developing areas of the world since waste is managed by hand for the most part in the informal sector. For example, the report of Hughes states that in Indonesia, the informal waste sector functions with approximately 3.7 million waste pickers mostly driven by job security during the pandemic who have no protection measures. Around 1.5–4.0 million people work in the Indian waste management sector and are also at a high risk of potential health hazards because of the pandemic. The details of global waste generation are shown in Table 1.

Table 1. Global waste generation [63].

Region	Projected Waste Generation (Millions of Tons/Year)		
	2016	2030	2050
East Asia and Pacific	468	602	714
Europe and Central Asia	392	440	490
Latin America and Caribbean	231	290	369
Middle East and North Africa	129	177	255
North America	289	342	396
South Asia	334	466	661
Sub-Saharan Africa	174	269	516

2.1. Impact of Mask Waste on the Environment

The rapidly increasing waste of masks across the planet is the result of proper disposal techniques not being adhered to; therefore, a new challenge to ecology has emerged. On the other hand, in developing countries such as China, Pakistan, Sri Lanka, India, etc., there are no suitable precise collecting systems for masks or plastic wastes. Consequently, a large quantity of plastic particles and waste has accumulated in piles and landfills and has contaminated fresh and marine water. The impact of this waste of plastic and plastic particles on human health and environment is highlighted in the literature [64]. Regrettably, face mask waste is associated with the emission of carbon dioxide (CO_2)—a primary greenhouse gas (GHG) that potentially contributes to the dilemma of global warming. The small aluminium strips, polypropylene as well as the chemical processes of propylene in the production of N95 and surgical masks emit a large amount of CO_2 which is harmful to the environment. Additionally, CO_2 emissions also occur during the production of fabric for masks as well as the sewing and weaving processes of cloth masks. The contemporary production process for N95 masks releases 50 g. CO_2 -eq for one single mask without accounting for transportation [10]. On the other hand, one surgical mask contains 59 g CO_2-eq and the largest contribution of CO_2 comes from its transportation. At the same time, the production of a single cloth mask is responsible for 60 g CO_2-eq. Worldwide, millions of face masks are being produced on a daily basis to cope with the global exigency to remain safe from the COVID-19 virus spreading; this has led to a considerable impact on the atmosphere. Face masks used by frontline medical staff in hospitals should be collected very cautiously since they may carry the virus and hence are considered hazardous waste. A statistical study was carried out in the U.K. on the utilization of disposable surgical masks considering the use of one face mask for each individual/day for one year; the study found that this would generate over 124,000 tons of plastic waste which is not recyclable. Furthermore, contaminated waste and waste of plastic packaging would be produced at a rate of 66,000 tons and 57,000 tons per annum, respectively [65]. However, there presently does not exist any specific waste stream to dispose of these hazardous wastes generated by the general public, frontline workers and COVID-19 patients. Hence, such waste is being thrown irresponsibly away in public places, and streets or is collected along with other solid wastes. However, the disposal of urban solid wastes together with dangerous medical wastes represents a noteworthy challenge since the collected hospital face masks and other mixed wastes are sent either for incineration or to landfills for disposal, whereby the presence of plastics in the masks often leads to negative environmental impacts. This is because, for the most part, plastics are chemically stable, resistive to corrosion and are not easily degradable by micro-organisms; thus, they prefer to stay in the soil and lead to environmental threats. A solution that permits the chemical energy content of plastics to be recovered for valuable objectives is the incineration of medical waste together with waste heat recovery. With a view to ensuring the safe destruction of medical waste incineration, the WHO recommended a temperature of between 900 °C and 1200 °C; however, those responsible for incineration are not aware of this temperature range [10]. However, there exist restrictions on the extensive use of incineration for heat recovery due to anxieties about dioxin and furan trace emissions which can be worrying. Furthermore, the transportation of those wastes to a suitable disposal site also requires energy consumption which further emits greenhouse gases into the atmosphere. Recent investigations by Kumar et al. [66] revealed that 10 tons of PPE waste including face masks transported 10 km for disposal resulted in a total GWP (global warming potential) impact of 2.76 kg CO_2 -eq. Unfortunately, masks littered in the soil can influence fauna and cause entanglement and even death. For example, in Columbia, a bird was tangled in a coronavirus facemask on a tree and died subsequent to the wrapping up of the infected mask around its beak and body.

Most commonly, when the mask is mistaken as food by an animal, the plastic can fill their stomach which reduces food intake and results in either starvation of the animal or its death. Additionally, such wastes may reach rivers and seas, causing plastic pollution in aquatic environments.

In marine environments, plastic is adsorbed as toxins and organic pollutants, which causes the contaminant particles to bind as a noxious film on the surface of the plastic. Consequently, oceanic animals that swallow plastic are likely to become poisoned, which either kills them directly or weakens them and renders them increasingly susceptible to other dangers. This ingested plastic can hinder reproduction and the growth of youngsters [10,67,68]. The fragmentation of macro-plastics in masks could occur on account of a variety of "abiotic factors" such as photo-degradation, weathering, corrosion, and aquatic submergence which shapes secondary micro-plastics. As a result, the bio-accumulation of micro-plastic takes place in the food web which is to human existence and results in the accumulation of toxins.

2.2. Emergency Hazardous Waste Management

Owing to the containment purposes of PPE and the potential of coronavirus to remain active for a substantial period on the surfaces of diverse materials, this kind of waste has been regarded as "hazardous", thereby challenging the waste management sector with "meeting effective waste management strategies" [69]. Significantly, incineration or thermal treatment is the most favoured and effective treatment for the large volume of hazardous waste generated during the COVID-19 pandemic [70]. However, besides using the thermal treatment process there are other optional techniques such as pyrolysis, microwave treatment, chemical treatment, dry heat, vaporized hydrogen peroxide, and high-temperature steam which are also useful based on features such as economic budget, the quantity of waste generated, technical advancement and maintenance competence [70].

In line with meeting the public health emergency, a national action plan should be put together with crisis response strategies for the unexpected waste generation rate and its "potential route for the spreading of the Coronavirus" as a result of mismanaging wastes. Here, the strategies adopted in Wuhan, China, can act as potential examples for nations challenged with waste generation during the pandemic. As a result of the lockdown, a considerable volume of risky hazardous waste was generated from diverse sources such as hospitals, households, self-isolation locations, and quarantine centres. The retention of generated waste for extensive periods together with a great growth rate has compelled local authorities to adopt "mobile incinerator" sites to treat discarded PPE and other disposable safety gear. Additionally, strategies such as centralized disposal including thermal treatment or incineration, cement kilns and on-site emergency treatment including domestic incineration, industrial furnaces, and mobile incinerators have been executed very efficiently. Furthermore, other methods were applied as urgent situation response techniques such as autoclave, steam, dry heat, micro-wave and chemical disinfection techniques within the waste management sector in Wuhan for the record quantity of waste during a pandemic. These initiatives can be reviewed and included in the waste management sector for their helpfulness, safety, sound waste treatment and disposal during a pandemic. The construction of an "on-site waste burial pit" to achieve the safe treatment of these hazardous wastes may also lead to issues, especially in developing nations with poor waste management infrastructure; however, it is regarded as an effective solution during the present COVID-19 pandemic. By constructing a hole inside the open and protected space of the hospital periphery isolation ward, a waste dumping zone or other dedicated centres for infected patients, the closed waste burial pit can be prepared. A clay or geo-synthetic liner can be used to line the bed of the pit to avoid pollution of soil or groundwater. A covering of a soil or soil–lime mix on a daily basis should be placed over the discarded waste up to the filling point. It should be plugged with a cemented cover or mortar mix and the top of the pit can be covered further with a 50 cm thick soil cover collectively with an earth mound on both sides, in the interest of preventing water leakage during the rainy season.

This could be a useful option in the context of nations without incineration or thermal treatment options with which to dispose of the dangerous waste volume generated during the COVID-19 pandemic. Additionally, the structure of an on-site waste burial pit for the safe disposal of dangerous wastes during COVID-19 can offer a feasible option for waste transport, mitigate its lethal exposure to the atmosphere and provide a cost-effective and trouble-free solution. This unexpected increase in the volume of dangerous waste generated throughout the pandemic is widespread and has damaged the normal thermal treatment or incineration competence in a number of nations, limiting their ability to cope with such waste. Chinese guidelines permitted cement or other industrial furnaces to be used to treat these hazardous wastes as an emergency measure. Fortunately, China was able to increase its disposal of these dangerous wastes by 6066.80 tons/day from its preceding capability of 4902.80 tons/day using such an approach. Similarly, in Hubei Province and Wuhan city, the emergency disposal level was found to have increased by 667.40 and 265.60 tons/day from its earlier ability of 180 and 50 tons/day [71]. In the same way, other developing nations can use identical strategies as an emergency treatment option for wastes generated throughout the COVID-19 pandemic.

2.3. Medical Waste Generation during COVID-19

The huge quantity of medical wastes in the form of used facemasks, gloves, gowns, syringes, etc., from hospitals, has been chiefly classified as hazardous since they carry with them infectious agents such as viruses [3,4]. Improper handling of the said wastes with common municipal waste may increase the likelihood of virus contamination with a higher chance of its transmission [3,4]. Therefore, its effective management is highly essential through the adoption of certain specific measures, such as its correct identification, collection, segregation, storage, transportation, treatments and ultimate disposal [72]. Globally, caution has been recommended for governmental waste disposal when handling harmful medical waste to ensure a reduction in its secondary impacts on human health and the environment. Hospitals and/or healthcare or COVID-19 centres cannot be considered as the sole source of generation of infectious wastes; asymptomatic people with minor symptoms can generate virus-loaded wastes predominantly in the form of facemasks, gloves, tissues, etc. A research study estimated that the COVID-19 virus is able to survive on surfaces of plastics for 6 to 8 h, stainless steel for 5 to 6 h, and contaminated PPE for as long as 7 days which will infect sanitary workers and staff of waste management centres during or after dumping [22]. Still, the situation is worsening in some parts of the world for handlers and people engaged in waste management as well as for casual waste collectors who are without proper safety gear and PPE. Therefore, the crucial steps that should be followed to manage the pandemic include the establishment of suitable waste management facilities and the safe disposal of these wastes. In line with the precise definition provided by WHO, the waste generated from medical zones such as hospitals, clinics, institutions, research centres, medical laboratories, etc., during various medicinal practices such as diagnosis, prevention, healing, caring treatments of human and animal medicines, etc., are regarded as "Bio-medical wastes". This kind of waste is mostly made up of medicinal, chemical, pathological, infectious, metallic (sharps), radioactive substances, etc. [70]. The improper disposal of these hazardous wastes in open spaces, on the roadsides, in landfills, etc., may lead to the pollution of surface and subsurface waters, and influence their soil enrichment, thereby causing injuries, radioactive leakage, and killing valuable micro-organisms [73]. On account of the higher use of disposables for treatment or in vaccine research and their subsequent production during the pandemic, a large increase occurred in the production of these wastes.

Following recent reports, the primary cause of infections was found to be accidental contact with disposed PPE items of patients, workers, frontline medical staff, etc. A few developed nations crafted certain rules intending to mitigate the unsystematic management of waste, causing hospitals and healthcare centres to adhere to certain correct disposal protocols. The handling of hazardous wastes and their proper management in hospitals, healthcare clinics and COVID-19 centres, etc., decreases the likelihood of spreading the virus or becoming infected. However, an understanding of bio-medical waste management to control and prevent diseases was obtained from earlier experiences of pandemic outbursts [74]. Municipal solid waste is mixed with hazardous waste because of the absence of fundamental amenities such as sealed plastic bags or safety bins to separate it, especially in some developing nations. An unregulated and low-cost treatment or even unlawful throwing away is the result of insufficient waste monitoring systems and a lack of incentives provided by the intermediary company [75].

The reselling and subsequent reuse of used disposables such as gloves, masks, etc., can lead to the spread of COVID-19. One more topic of apprehension is the failure of on-site treatments to address the variance in bio-medical waste generation by existing healthcare centres. According to the norms of the regulatory body, lots of these facilities are provided with steam sterilization, i.e., autoclaving types of infrastructure and treatment of the bio-medical wastes on the basis of methods such as microwave, radio-wave, incineration, chemical disinfection treatments, etc. Nevertheless, the costs and failure to fulfil the rules to mitigate the emission of harmful gases have turned out to be a momentous constraint for the applications of said facilities. Modification in the context of the consolidated waste management system may also result in better fulfilment of emission benchmarks. There should also be a provision to manage waste generation fluxes during the pandemic of COVID-19 in designing these systems. Quite a lot of other issues should also be responded to so as to avoid more infections, namely, emissions of aerosol microbial contaminants from the grinding/shredding of waste, etc. Urban local authorities and the assignment of unique roles can help to ensure the enforcement of well-organized bio-medical waste management by hospital administration and staff. Nowadays, the waste of plastic is significant and the lockdown situation has promoted such waste since the public has to opt for the home delivery of food, groceries and other essential commodities including medicines, etc. This has led to a huge growth in the wastes of plastic packaging, i.e., polypropylene, polyethene, polyethene terephthalate, and polystyrene—the key components of plastic packaging waste.

On the other hand, in some places, recycling operations have temporarily been brought to a standstill on account of the pandemic resulting in a huge quantity of waste plastic packaging. Moreover, pharmaceutical industries have experienced a great demand for medicines because of COVID-19 which is the reason for the extensive generation of plastic packaging waste. Awareness of safety and hygiene led to an unexpected boost in online shopping for safety gear during this pandemic in some nations. The wastes of plastic packaging derived from the home delivery of food and groceries were found in the form of Styrofoam, thin films or thick plastic materials. Presently, environmentalists are chiefly concerned with how to recycle the plastics generated during this pandemic [76]. Owing to the health concerns during the COVID-19 emergency, the public is implementing single-use plastic bags in some parts of the world. Quite often, the utilization of "use and throw" plastic bags is found to be advantageous; however, it generates much waste and leads to further challenges in the already difficult global waste management.

The behavioural patterns of consumers will be modified by the temporary utilization of "use and throw" plastic bags, with consumers opting to employ them as a safety precaution against pollution. If the situation is sustained in the same fashion, then reusable or recyclable plastics will be used less often; on the other hand, single-use plastic bags will be used more often, even after the pandemic [70]. The increase in plastic wastes is represented by 44.8% from packaging and 13.2% from other sources such as medical wastes, etc., which occurred during the pandemic mainly because of online shopping together with the use of consumables such as hand sanitizers, cleaning agents, disinfectants sprays, facemasks, throwaway wipes, gloves, etc. This means that the use of plastic products for packaging and other items has increased, including among government authorities. On the whole, packing materials and bio-medical wastes together with facemasks, gloves, shields, gowns, syringes, etc., are composed of plastic. This kind of plastic waste will increase day by day and the conditions will worsen following the home delivery of food and groceries. The generation of plastic waste during the COVID-19 pandemic will create a momentous threat to the environment and cause major health hazards to lives on Earth.

2.4. Recycling of Plastic Wastes

In nature, there exist different routes to degrade plastics from the environment such as photo-degradation, hydrolytic degradation, thermo-oxidative degradation, and bio-degradation by employing micro-organisms. A few processes such as photo-degradation followed by thermo-oxidation may result in the breaking of plastic materials. Afterwards, the carbon present in the polymer is altered to carbon dioxide (CO_2) through microbial action or consumed for bio-molecular synthesis; however, it may take years for this process to occur. Consequently, the recycling of plastics is the best possible solution. There are four routes to the recycling of plastics including primary, secondary or mechanical routes, chemical routes and energy recovery [77]. The first, i.e., the primary recycling process is the reuse or recycling of the native products. On the other hand, secondary or mechanical recycling is where thermo-plastics are once again melted and processed to their particular end-products. This is a physical method whereby the plastic waste polymers undergo either shredding or are granulated or prepared as pellets and melted to regenerate novel yields. At times, they are amalgamated with virgin plastics to appear as newer ones. The use of these products carries a major setback of their heterogeneity and declining attributes in each recycling. This process is relatively cheap; however, it calls for a substantial initial investment. The third way of recycling is the chemical recycling process whereby waste plastic polymers are converted to monomers or oligomers when subjected to chemical reactions. This process is still in the investigational stage owing to huge investments and the opinions of an expert on their optimization. A number of investigations into gasification and the process of pyrolysis of chemical recycling have been conducted [70]. Pyrolysis includes the degradation of polymeric plastic waste at high-temperature heating with no oxygen. Noticeably, pyrolysis demonstrates the discharge of liquid oil and gas fractions that can be reused as feedstock to develop new plastics. The fourth route of recycling, i.e., quaternary recycling refers to the absolute recovery of energy from waste plastic polymers by means of incineration. Although the method generates significant energy from plastic waste, some airborne toxic substances such as dioxins are discharged into the environment, contributing to the current dilemma of air pollution. The medical waste generated during the pandemic in the form of used masks, gloves, aprons and some other safety gear made up of plastics, is not recyclable at the moment since it may transmit a trace of infectious residues. This is a matter of great concern since such waste may be dangerous to professional workers during handling or collecting and also may pose a risk at waste treatment plants. In order to ensure worker safety, some definite rules are imposed such as regular changing and cleaning of PPE, gloves and professional uniform, along with frequent hand washing since it is highly recommended. The thermal treatment of these wastes is much safer in comparison with other modes. The destruction of pathogenic agents and their meltdown leads to excellent energy recovery from waste plastic polymers. In general, a reusable facemask is mainly made up of polypropylene, which contains numerous layers and is recyclable through thermo-chemical or mechanical recycling processes. It is to be confirmed whether there must be a destruction of residual pathogens present in the wastes from hospitals and healthcare or COVID-19 centres. If the residual pathogens are not correctly disposed of then they may lead to pollution and might become a source of infection [78]. The recycling of wastes generated during the COVID-19 pandemic is a major challenge because most recycling facilities were closed by the orders of government authorities due to the possibility of spreading infection, thereby leading to restrictions in waste management systems. The self-isolation and lockdown situations forced consumers to purchase items online as well as to opt for home deliveries of essential commodities and foods along with medicines which increased plastic waste in the form of packaging. A recent survey revealed that the production of pharmaceutical and medical products, food packages, etc., increased greatly during the pandemic. This represents a great concern to waste management authorities and hence, a high number of regulations during the COVID-19 pandemic were implemented; however, continued recycling of these wastes is one of the significant criteria to adopt otherwise the whole waste management system may collapse on account of the accumulation of these wastes in the form of mounds and landfills, thereby signalling the failure of recycling systems.

2.5. Landfilling Process

In particular, in developing nations, landfilling is regarded as a common mode of dumping in the plastic waste management system. A few developed cities possess modern scientific landfills, dumping yards or unsanitary landfills for the disposal of waste. Landfilling is regarded solely for waste management; incineration is employed for energy recovery from the waste of plastics. It is recognized that lesser CO_2 emissions are found in plastic waste landfills in comparison with the process of incineration [70]. However, in a few underdeveloped or developing countries, waste management is underdeveloped and includes the unhygienic dumping of waste which covers huge spaces, causes the leaching of perilous chemicals, and at times opens fires in the dumping field and discharges dangerous gases and highly toxic chemicals such as dioxins, i.e., the heterocyclic organic compounds (C_4H_4O) which are persistent environmental pollutants as well as furans, i.e., colorless, volatile liquid with a boiling point close to room temperature and consisting of a five-member aromatic ring enclosing four carbons and one oxygen. Recently, recycling capabilities and incineration processes were interrupted on account of the vast increase in waste during the COVID-19 pandemic. For this reason, dumping is performed in open spaces which leads to the creation of huge landfills for wastes to degrade and their pathogenic capacities being neutralized. Furthermore, these practices of waste management during the pandemic period may lead to the incorrect treatment of these novel plastic wastes which may cause environmental concerns in the future. However, the World Health Organization (WHO) recommended that under-developed nations should not develop waste management systems for handling bio-medical wastes and should instead continue burying the accumulated wastes in a closed pit of 2 to 3 m with either clay or geosynthetic coating at the bottom in emergency conditions for the safer disposal of bio-medical wastes. Moreover, once the waste is disposed of in the pit, it should be filled with either a lime mixture or fresh soil on a daily basis. The proximal areas of the pit should be wire-fenced to restrict access for humans and animals [79].

2.6. Medical Waste Management

As has been established, it is highly necessary to deal with the proper collection, treatment, and disposal of diverse kinds of unexpected medical waste generated from healthcare facilities during the COVID-19 period. Characteristically, the composition of medical waste is approximately 85.0% non-infectious, 10.0% hazardous or infectious and 5.0% chemical or radioactive [80]. The handling and treatment of medical waste generated by patients infected by COVID-19 taking the treatment in COVID-centres or hospitals are similar to general infected medical wastes contaminated with other diseases such as TB, Hepatitis, HIV, anthrax, etc. This is because infectious medical waste does play the role of a vector for transmission of the coronavirus. However, the waste generated from infected patients of COVID-19 isolated and quarantined at houses or hotels or in institutions must be treated as hazardous and special care is required when placing such wastes in storage containers, during collection and upon their ultimate disposal.

3. Challenges in COVID-19 Waste Management

The ongoing pandemic of COVID-19 has adversely impacted the world, resulting in a high death rate and COVID-19 patients suffering from post-COVID issues and fears. Bad news is arriving daily from even developed countries regarding new variants of the virus and people facing this unforeseen disaster. Therefore, governments are trying their level best to protect the lives of citizens with more COVID-centred infrastructures, ICUs, oxygen plants, ventilators, testing laboratories and equipment, medicines, vaccination programs, etc. Governments did not expect such a severe situation with the coronavirus; hence, it posed a great challenge due to limited infrastructure facilities and insufficient safety equipment. Consequently, the increased number of testing centres, abrupt modifications and ad-libbing in medical standards, and public policy changes represent responses to the existing public health crisis [81]. In the interest of controlling the spread of the coronavirus, government authorities implemented a complete lockdown and curfew were necessary for affected areas or provinces with social distancing among individuals in public places, self-quarantine of COVID-19 patients and persons who were in contact with them as well as the enforced use of personal protective gear such as masks, socks, goggles, shields, PPE, etc. As a result, the generation of this novel kind of hazardous waste of "used and thrown" safety gears highly influenced waste not only in terms of its generation pattern but also in world waste management models. In pre-COVID-19 times, the generated solid municipal waste was managed by sanitary workers and transported to centres of waste disposal. However, during the COVID-19 situation, the novel kind of unexpected hazardous wastes has proved challenging since it is quite probable that such waste may carry infection; hence, separate facilities for handling, treatment and disposal are needed. Without the systematic disposal of the waste, it may become intermingled with municipal solid wastes and could lead to the transmission of coronavirus among sanitary workers as well as members of the public who come in contact with it. For that reason, a separate waste management system is required to dispose of it in a safer mode. Essentially, definite disinfection technology or treatments are required to remove the infectious agents in these wastes [81]. A correct cyclic system must be followed in the handling of these wastes. Encouragingly, government authorities worldwide warned sanitary workers during the COVID-19 pandemic to transport the said medical and COVID-19 centre, etc., wastes more carefully and safely to the treatment facility centres. This resulted in minimizing the further impacts of the infectious agents present in these wastes on not merely the environment but also on the general health of populations [70]. Unfortunately, the complete lockdown and the total halt in modes of transportation to control the spread of the COVID-19 virus severely impacted farmers and food suppliers. This difficult situation led to a fear of scarcity of essential commodities which resulted in the stocking of foods, groceries, and a few essential medicines and led to disorder in the supply of these items. However, the excess stocking of items with a shorter shelf-life led to them being thrown out or dumped in nearby waste bins, on roadsides or in open spaces against the will of stock-keepers. As a consequence, the COVID-19 pandemic caused an unexpected demand for food chain supplies and other challenges in the route of solid waste management. Additionally, the situation changed the dynamics of medical, plastic, and food waste generation. Accordingly, ground-breaking solutions are needed to efficiently tackle the present pandemic and future pandemic situations more competently which requires definite and effective waste management systems. The sudden appearance of COVID-19 and its spread led to the adoption of mandatory safety gear such as facemasks, gloves, hand sanitizers, and disinfectant sprays to decrease virus transmission [82]. It should be clearly understood that hospitals or health and/or COVID-centres should not be blamed as sources of infectious wastes; asymptomatic people or those with moderate symptoms also cause coronavirus to spread unintentionally by incorrectly disposing of their used masks, gloves, tissues, etc. Furthermore, the virus can survive for an extended period of time on plastics, metals and cardboard which negatively impacts sanitary workers who collect these wastes. Still, the health condition of sanitary workers may be worsened further due either to a lack of proper safety gear such as PPE or not being correctly equipped while handling this waste, especially in underdeveloped or developing parts of the world. This atypical issue of waste generation during the COVID-19 pandemic period presents a challenge to waste treatment facility centres in terms of collection, transportation, treatment and disposal; developing nations are particularly affected owing to limitations of technology as well as scientific knowledge and challenging financial conditions [83]. These issues are taken together and led countries to pay special attention to waste management systems and treatment facilities during the COVID-19 pandemic. On the whole, the proliferation of polluted waste in developing nations is predicted to increase as the pandemic makes communities more prone to the potential spread of the coronavirus through the said waste. This is because of the frequent overlooking of the potential contamination of the waste dumped by individuals diagnosed with COVID-19. Societies readily documented the incompetence of waste management systems; COVID-19 and the waste generated during the pandemic necessitate additional holistic and participatory policies involving stakeholders at all levels. This includes issues such as the likelihood of cross-contamination among locals and landfill scavengers, the noteworthy modifications in waste collection and disposal patterns, the potential knowledge or existing hiatuses for policies and also the social perception of the efficacy of solid waste practices.

4. Methods for Segregation and Pre-Treatment of COVID-19 Medical Waste

The chief sources of COVID-19 medical waste generations are hospitals, clinics, and health care as well as COVID-19 centres since they generate different kinds of COVID-19 medical waste in the form of diagnostics waste, research and laboratory waste, infectious waste, cytotoxic waste, chemical and radioactive wastes, drugs, some other medicinal waste, etc. Mostly, this waste carries harmful materials responsible for the threat to the public and the environment when not disposed of properly. Therefore, the first step (Figure 4) of its management starts with the COVID-19 patient treatment centres and hospitals from where it generates. For that reason, this waste should be categorized appropriately and must be collected in separate bags or bins designated for that objective. The bags of this waste should be disinfected and sealed in double-layered plastic bags prior to transport to the facility centres. The segregated COVID-19 waste bags are for the time being kept in the storage area whereby they are collected on a priority basis or within specified time limits. This provisional storage area and vehicles used for its transportation must be regularly disinfected to mitigate the possibility of infection to workers prior to its transport to common COVID-19 waste treatment and disposal facility centres [84]. Based on the amount, type, cost and maintenance for the treatment of this waste, suitable disinfection technology must be adopted. To provide large-scale treatments for this waste and eliminate the infection surfaces, elevated temperature processes from 540° to 830 °C, such as incineration or pyrolysis techniques, can be employed. The discharged gases or the rest of the residues subsequent to the combustion course can be used for energy conversion yields. In some cases, the hospitals or healthcare or COVID-19 centres possess a small-scale disinfection system for handling this waste whereby it is treated primarily with a chemical disinfectant. Afterwards, it is passed on for micro-wave treatment with steam disinfection technology functioning in the temperature range of 93° to 540 °C.

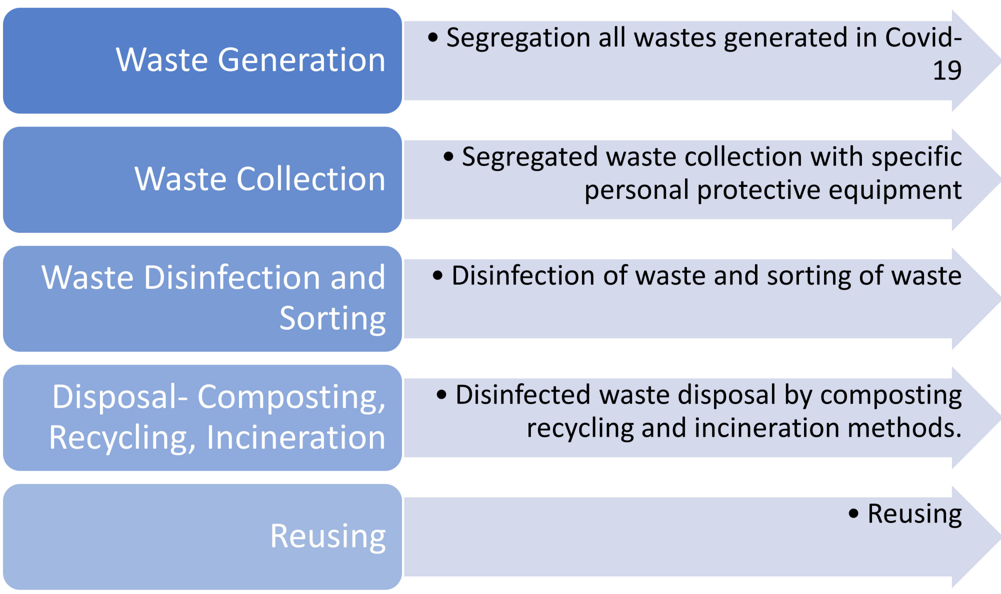

Figure 4. COVID-19 waste management process.

5. Worldwide Scenario of Medical Waste Management and Treatment Systems during COVID-19 Pandemic

The highly affected COVID-19 zones are struggling to deal with the dramatic boost in the medical waste quantity generated during treatment, including personal safety gear and testing procedures [10]. Nevertheless, a number of developing nations inadequately managed medical waste prior to the pandemic. In some parts of the world, medical wastes together with municipal solid wastes are disposed of in open spaces or inadequately managed landfills [9]. Furthermore, burning and incineration with no appropriate contamination control expose the workers and neighbouring communities to poisonous contaminants from the air, emissions, and ash. In the context of India, the net generation of medical waste is 405 tons/day, of which just 292 tons/day is dumped, meaning that 28% of the waste is not treated practically [28]. According to the Asian Development Bank, metropolitan cities such as Manila, Kuala Lumpur, Hanoi, Bangkok, etc., generate 154–280 tons/day of medical waste, and only a few of these cities have the facilities to cope with the referred surplus quantities of wastes [12]. Therefore, it is essential to modernize waste management strategies and scale up the disposal capabilities swiftly to handle the sudden increase in medical waste generation during the COVID-19 pandemic.

5.1. International Guidelines

Internationally, the unexpected waste generation during the current pandemic increased the apprehensions about the prospective role of waste residues in spreading the coronavirus. A few international organizations such as the European Centre for Disease Prevention and Control (ECDC), the WHO, the United Nations Environment Programme (UNEP), and the Basel Convention made public strategies or reports on the systematic management of medical waste along with waste from households.

The Factsheet on Environmentally Sound Management of Medical Wastes, i.e., The Basel Convention's guidance document, offers data on ways to internationally manage the sudden accumulation of medical wastes during the pandemic through the most eco-friendly approach. Primarily, the factsheet is meant for utilization by waste managers at facility centres or for the dumping of this medical waste; however, it provides valuable data for people engaged in its collection and subsequent transport. Importantly, the WHO has extended the data on hygiene practices and the guidelines for the safe management of wastewater and manure, to uphold the quality of the water supply and handle medical care and household waste from quarantined individuals. The waste management research from response to recovery concerns presents management procedures for waste from healthcare or COVID-19 centres, households, and quarantine places [81]. A series of COVID-19 Waste Management Factsheets were made available by UNEP, so as to deliver instructions on its features including a national medical waste capability review and provisions on how to select the best COVID-19 waste management technology [81].

5.2. Policies and Practices for Medical Waste Management

A few governments have adopted active national legislation addressing the predicament of healthcare or medical wastes while some have issued without delay novel policies, guidelines, and plans to tackle the COVID-19 situation. Remarkably, China and South Korea implemented successful steps for medical waste management during the pandemic.

5.2.1. Republic of China

The lessons and successes that China achieved during the COVID-19 period in the context of medical waste management could offer valuable data useful to several developing nations dealing with the unforeseen increase in medical waste. The central government of China published its Guide on Management and Techniques for Emergency Treatment and Disposal of Medical Waste generated through COVID-19 and Notice on Environmental Management of COVID-19 Medical Wastes. In the course of the COVID-19 epidemic, guidance was provided by the authorities with a view to dispose of medical waste in a timely and orderly approach, as well as to regulate management and technical necessities. Additionally, a few provinces issued special rules for COVID-19 waste management. So far, as far as hospital waste management is concerned, the classification of medical waste is regarded as the first step in its handling. Additionally, the medical waste related to COVID-19 includes both medical as well as domestic waste generated from fever clinics, wards of isolation and observation, as well as nucleic acid testing laboratories. Medical and health organizations with sufficient facilities can store infectious medical waste separately. However, the temporary storage time period should not reach beyond 24 h and the storage place should also be disinfected. On the basis of requisites specified by authorities of health departments in order to handle the dumping of medical waste, there should be enough guidance with respect to health and the prevention of the spread of the pandemic.

5.2.2. South Korea

South Korea is one of the nations with the highest number of cases of COVID-19, ranking in the top five during the initial period of its spread. The medical waste from infectious sources should be incinerated on the same day of collection. The time for storage and incineration both are cut down in comparison with earlier rules whereby the highest storage time was 7 days and the waste should be incinerated within two days of delivery. The wastes generated from hospitals and residential treatment centres should also be treated alone and controlled with stringent measures. During the self-isolation period, waste management varies in accordance with the infection condition and the period of illness. The household waste of self-quarantined individuals should also be regarded as COVID-19 waste [85].

5.2.3. India

At present, being a developing nation, India has some facilities for coping with COVID-19 medical waste. For this reason, the response to the unexpected increase in medical waste is a huge challenge for the relevant local Indian departments. On 18 March 2020, the Central Pollution Control Board, New Delhi, published a full strategy to deal with the waste collected from diagnosis, treatment, and COVID-19 isolation centres [28]. In such a case, the isolation ward of the hospital should maintain self-governing light-shielded coded tanks to detach the waste. A specific container labelled as "New Coronary Pneumonia" should be positioned in a different, temporary extra space and the right to its use should be controlled.

5.2.4. Iran

The Iranian COVID-19 pandemic situation entirely put a stop to the usual route of the disposal of infectious wastes from hospitals. In Tehran, medical waste is supposed to be classified into the following four categories: non-hazardous waste, medicine/chemical waste, infectious waste, and sharp waste. However, only 47.3% of hospitals are found to adhere to these principles. At this time, hospital waste is collected using double or triple-layered bags and brought to Aradkouh treatment facilities, whereby it is buried in selected ditches and the denser waste is sprayed using hydrated lime [86].

5.2.5. Romania

The National Institute of Public Health in Romania states that domestic waste from quarantine centres is regarded as infectious, and, for this reason, stringent and methodical waste management processes must be put into practice. Wastes must be accumulated by specific waste operators and moved to incinerators meant for hazardous waste by keeping the temperature at—4 °C [87]. The Center for Disease Control and Prevention (CDC), U.S.A., announced that medical waste from COVID-19 treatment centres is similar to other medical waste and therefore, should be treated scientifically. Both medical and infectious wastes should be subjected to state solid waste regulatory programs [88]. When comparing the management policies and treatment systems in diverse nations, e.g., China and South Korea, some differences are found due to prevailing local conditions including the basic categorized collection, double packing, storage, and dumping. In the context of South Korea, the diverse collection and disposal routes depend on the source of generation of the medical wastes such as hospitals, residential treatment centres and self-quarantined households, COVID-19 centres, etc. In China, there are more stringent requisites on the time of dumping, which should not go beyond 12 h. Additionally, China provides clear-cut guidance for emergency treatment priorities, diversion modes and facilities to treat the patients.

Municipal Solid Wastes Management Modifications

The different survival time of coronaviruses is found to range up to 9 days on the dissimilar surfaces of metal, glass, and plastics; this has caused concern that household waste from COVID19-infected patients may carry with it coronaviruses and might be a source for infection to others for some stipulated time [89,90]. The handling and collection of the said wastes can be dangerous to operators of municipal solid wastes (MSW) provided that they are exposed to the contaminated elements of waste from infected COVID-19 patients.

Management of PPE Wastes

Under the South Korean volume-based waste fee (VBWF) program, discarded masks from households can be collected in a standard waste bag. The used-masks waste must be either incinerated or landfilled, and no recycling is permitted in this case [91]. During self-isolation in the U.K., the wastes of used masks or PPE are required to be collected into a double bag and stored for 72 h prior to being placed in a 'black bag' waste bin; otherwise, used masks and PPE are disposed of in a 'black bag' waste bin with no extra bags or special storage. However, businesses or other organizations are free to collect PPE separately. In Portugal, the Portuguese Environment Agency recommends that all PPE waste from ordinary citizens be treated as mixed waste rather than recyclables; therefore, it should be placed in sealed and leak-proof waste bags and transported to incineration facilities or landfills on a daily basis [92]. China and a few provinces have made public a local technical guide for PPE waste management instead of issuing any national guidelines. In Sichuan province, discarded masks should be accumulated and disinfected previous to incineration. On the other hand, for non-infectious people of Guangdong, the used masks can be thrown into the "other garbage" bin; however, there exist restrictions for their recycling and reuse. The CDC, the Occupational Safety and Health Administration, together with some American agencies provided guidance for waste which carries the possible danger of COVID-19 contamination, stating that it should be managed in the same fashion as any other MSW. With regard to the fact sheet for Oregon, the US Management of COVID-19 Solid Waste reports that states, in general, consider PPE waste, cleaning, and disinfection waste outside the medical and healthcare industry as normal solid waste. Effective collection can help significantly in waste management when compared with the other few PPE waste treatment techniques. The improper dumping of discarded masks such as in open landfills or waters is likely going to lead to them degrading into small plastic pieces and even into micro-plastics. Surprisingly, a survey conducted in the Soko islands found masses of used surgical masks along its seashore, indicating the incorrect disposal of them in the sea.

Collection and Recycling of MSW

The infectious dangers of MSW should not be overlooked even though the ratio of waste that may carry feasible SARSCoV-2 is lower than medical waste. MSW management varies depending upon whether there are confirmed or suspected cases within the household. Romania follows the guidelines of the United Nations Environment Programme (UNEP) and European Centre for Disease Prevention and Control (ECDC) like most other nations in this regard [87]. In accordance with the Italian Health Institute guidelines for Italy, the MSW generated from households of an infected patient should be considered as residual MSW and must be disposed of in a separate bag [93]. However, in the absence of infected cases in the house, household normal wastes can be treated as usual collection. Several nations have agreed that recycling carries very little danger and that recyclable waste is not likely to be contaminated with COVID-19. Accordingly, waste collection and recycling can be conducted according to the original course of action used prior to the pandemic; however, when waste is polluted, it must be collected in sealed bags or containers [94]. This type of condition will not lead to modifications in present household categorization procedures in the case of Finland. In Germany, the authorities classify the transmission danger of waste gathering and dumping as low. Suspected and confirmed

Chinese patients are treated at particular sites, making the likelihood of infectious waste from households transmitting the virus low; however, the best mode of management of PPE waste is challenging. The categorization and recycling of MSW are not fully indispensable in China. Conversely, in a few parts of the world with a high number of COVID-19 patients, in countries facing challenges for adequate medical resources or in places where a policy of keeping patients at their residence is followed, infectious wastes such as bodily fluids and protective gears need to be separately bagged. In some other areas, local authorities have suspended waste recycling processes at a few stages. In the U.K., the non-legislative guidelines provide guidance on the accumulation priorities of such waste during the COVID-19 pandemic.

6. Potential Plastic Waste Scenario

Globally, the present COVID-19 pandemic has led to circumstances whereby hazardous medical wastes are rising at an exceptional rate from both healthcare units as well as infected households. The application of PPE is the only practical alternative in the present scenario to safeguard against the transmission of the COVID-19 virus as protective gear [95]. Due to the high usage of single-use PPE, and the large volume of single-use plastic waste largely in densely populated areas, the waste management sector is encountering lots of challenges such as difficulty in managing hazardous waste disposal [96]. Frontline health workers and other personnel with duties at COVID-19 centres compulsorily wear the disposable PPE kit as safety equipment as guided by the authorities in order to mitigate the possible risk of human to human and airborne transmission of this deadly virus [95]. Nevertheless, such measures impacted the waste sector globally owing to a swift flow in single-use PPE along with epidemic-induced challenges. The throwaway facemasks of different kinds such as N95, KN95, FFP2 orFFP3 type; goggles; hand gloves; face shields; disposable gowns, hand sanitizers; etc., represent the most prevalent plastic PPE waste during COVID-19. This ongoing pandemic incentivized plastic industries to manufacture other single-use plastic items such as disposable grocery bags, food packaging items, etc., which were banned previously. This situation arose with a view to mitigate the transmission of infection through reusable materials which may carry the virus on their surfaces for a prolonged time [97]. Human contact with the polluted surfaces due to immediate touching of the mouth, eyes and nose is the swiftest route of exposure for the virus to be transmitted. Later on, studies suggested that plastic material, on the whole, causes a high threat of virus transmissions since it can survive on polluted plastic surfaces for a longer period. Reusable paper, fabrics, etc., offer short life spans of roughly one day only for coronavirus on their surfaces [98]. The increased need for, use and disposal of single-use PPE and other plastic items in the present circumstances have led to a situation whereby concerns for public health have imbalance the environmental well-being [99]. The used PPE and other single-use plastic items are no doubt deemed to be protective; however, their waste may potentially adversely impact the health of the general public through the further spread of infection as well as micro-and nano-plastic contamination when such kinds of items are littered haphazardly on open land spaces or in water bodies. This leads to contamination with the virus as it can persist for a longer time on plastic surfaces. Furthermore, the COVID-19 pandemic has augmented the demand for plastic yields, in particular for medical products and packaging, contributing to excess plastic wastes. An estimation of increases of approximately 44.80% and 13.20% in plastic waste can be expected from packaging and medical products, respectively [70]. Primarily, this is attributed to the higher consumption and use of online shopping and the delivery of food, hygiene, and other self-protective gear. The care providers or close family members of COVID-19 patients who have been self-quarantined at home are at a higher risk of being infected with the virus through coming in contact with the waste of used masks, gloves, etc., of the infected patient. The majority of nations have agreed to consider discarded plastic-based PPE as 'hazardous'; hence, it should be subjected to incineration in view of the national emergency response plans. The present scenario has led to considerations of the incineration capacity of a particular country due to the unprecedented rise in medical waste. For example, in Hubei Province, China, medical waste reached the figure of 240 t from 40 t per day with an incredible increase of 600% while in Gurugram, India, it was amplified by 40 times during a period of lockdown for only two months [12]. In the statistics for another Indian city, Ahmedabad, the quantity of daily medical waste generation was 1000 kg with projections of reaching 3000 kg because of the widespread usage of PPE. Indonesian medical waste soared to 12,740 t in the 2 month period subsequent to the first confirmed case of COVID-19 infection [100]. Overall, 85% of medical waste is non-hazardous and only 10% is perilous while the rest, 5%, is radioactive and chemical. The World Health Organization (WHO) advised the collection and disposal of the non-hazardous segment of the generated medical waste with municipal solid waste (MSW) owing to the rapid rise and insufficient treatment options. This proposal has resulted in an extra burden on the MSW management system; this is particularly the case in developing nations such as India, Thailand, Myanmar, Indonesia and Malaysia where landfilling and open space dumping are the common disposal modes of MSW. The influences of lockdown on household solid waste generation and its ultimate disposal in the context of the two cities of Khenifra and Tighassaline in central Morocco resulted in an extensive reduction in the organic fraction of household wastes such as container food items, raw meat, etc. In the context of the potential risk of virus transmission, about 87% of the respondents disposed of PPE waste such as hand gloves, facemasks, etc., in a mixed form with household waste in the same bin while 9% of the waste was discarded in public spaces, on roads, drains, lawns, etc. In Italy, the city of Trento generated less MSW because of the normal collection and dumping operation of MSW amid lockdown. It generated 4058 t of MSW amounting to 18.50% less than the preceding record over 10 years of roughly 4978 t during March 2020 [47]. During the same time, in Naples, a potential drop was monitored in the overall generation of MSW, i.e., about −9.50%. Conversely, in Turin, MSW generated from organic, paper and cardboard fractions, and unsorted portions decreased to 5.50%, 1.90% and 10.70%, respectively, and a prospective surge was reported for wastes of glass, i.e., +6.50% and plastic waste, i.e., +4.50% [10]. Despite regulations and progression to reduce plastic waste in recent years, the existing international emergency appears to be a step backwards. The pandemic exhibited an increase in single-use plastic items owing to their ‘cost-effectiveness’ and ‘quick production’ attributes. For example, the WHO projected the demand for disposable PPE for frontline healthcare staff to be 89.0 million “use and throw” facemasks, 76.0 million hand gloves and 1.60 million goggles [3]. Measures to prevent huge piles on roads, in open land spaces, in drainage networks, as well as in water bodies such as rivers, ponds, lakes, seas and oceans should be implemented. With a view to reduce the spread of the COVID-19 virus during the urgent situation, the use of facemasks was made compulsory in all public places by different authorities almost worldwide which resulted in a substantial increase in their unmethodical disposal, which negatively impacted the environment. For illustration, the state-wide lockdown in China and Italy generated the waste of facemasks at a rate 900 million and 40 million pieces per day, respectively [47]. Conversely, in Africa, South Africa, Ghana, and Nigeria are the leaders in such wastes, with roughly 700 million facemasks discarded daily due to their mandatory use in a number of nations [9]. Estimates for the monthly use of facemasks for the approximately 7.9 billion residents of the globe are needed [35]. Incredibly, if only 1% of used masks are discarded inappropriately in the environment, it will result in 10 million disposed facemasks. Considering the average weight of one facemask of almost 3.0–4.0 g, approximately 30,000–40,000 kg of plastic waste will be generated per day with a possibility of carrying the virus of COVID-19 too [92]. Only Italy is estimated to use 20 million facemasks per day owing to the relaxation in the measures for lockdown, equating to 70,000 kg of plastic waste generation. On the other hand, the average annual use of “use and throw” facemasks in the U.K. is around 66,000 t of infectious waste and 57,000 t of packaging wastes [55]. The daily polluted plastic wastes derived from discarded facemasks in other nations can be predicted based on their prevalent use and mandatory regulations. Furthermore, due to the escalating use and disposal of used facemasks, approximately 80% of the land-based sourced plastic waste generation is dumped into the marine environment via river systems or as a result of severe weather conditions such as a flood, storm, winds and wastewater treatment facilities, etc. For example, a large number of facemasks were reported within the 100 m stretch of the beach of Soko Islands, Hong Kong, in a survey conducted by an environmental organization called "Ocean Asia" [68]. Analogously, in the Klang River of Malaysia, the used and disposed of facemasks, hand gloves and disinfectant bottles were met with the Selangor Maritime Gateway (SMG) people associated with the aerial time monitoring system. Referring to the densely populated country of India, more than a billion single-use discarded facemasks will end up in the seas and oceans together with other PPE on account of the inadequate waste management system and under-developed policies during the pandemic [101]. The adverse impacts of the discarded plastic wastes of safety gear will sooner or later influence aquatic lives and the food web since facemasks are largely made up of plastic materials or polyester. This huge unrestrained waste disposal of facemasks can encourage the further outbreak of COVID-19 by spreading infectious pathogens and contaminating the marine ecology with vast particles of plastics. For the reasons mentioned, urgent steps are necessary via a joint endeavor across the globe to bring this unexpected level of marine and terrestrial environmental contamination to an end immediately.

7. Health Safety of Waste Management Staff

A prospective step forward for systematic waste management services should contain assurances and support by authorities to uphold the health and safety of waste management staff. Therefore, authorities of waste management services must provide the following [102]:

- The provision of PPE and disinfectants to workers and associated staff;
- The fulfilment of hygiene protocols for waste management workers such as regular changing and washing of PPE, the provision of clothing during exposure, hand gloves, and the repeated sanitization of vehicle cabins, clothes, storage and collection facilities;
- Shield workers from potential exposure and provide training for adherence to the essential protocols to avoid the transmission of COVID-19 among workers and related staff;
- The required physical distancing among staff members, implement a reduction in the number of workers at a particular work point and special care should be taken of senior staff and workers with chronic illness.

Waste management is a vital public health service, especially in the midst of the current coronavirus outbreak (COVID-19). Those of us who are fortunate enough to have official or informal waste management services right now benefit greatly from avoiding the health dangers associated with accumulating rubbish. While waste management workers throughout the world defend their communities, those in the informal sector face greater threats to their own health and livelihoods as nations close down and economies stagnate. According to the International Labor Organization, just 4 million of the 19–24 million persons working in waste management and recycling are legitimately employed. The dangerous reality of the business is that waste pickers frequently do not wear safety equipment, which is especially important in the present health crisis given the hazards of contaminated materials being mixed in with normal rubbish. Economically, waste pickers are being squeezed even harder by the global dynamics impacting recycling markets. Lower oil demand and prices will further reduce the cost of virgin plastics, reducing the competitiveness of recycled plastic. With restrictions on cross-border migration, nations without sophisticated recycling mechanisms are more inclined to dispose of their waste than recycle it. Global recycling market shocks are expected to influence the prices waste pickers obtain for recyclable material, further limiting their income in these difficult times. Meanwhile, nations are scaling down attempts to encourage domestic waste separation due to health concerns. Some recycling facilities have suspended operations during the pandemic to reduce the amount of workers who come into contact with potentially contaminated items.

Efforts to preserve public health may have substantial unintended consequences for waste management workers across the world if no corrective action is taken.

8. Discussion and Potential Suggestions

Globally, the circumstances of the COVID-19 epidemic across the world have proved debilitating. However, some of the unexpected environmental benefits such as a substantial fall in carbon footprints; air and water contaminants; coal and energy consumption, etc., together with major global infrastructural modifications are noteworthy but the downsides in the form of the environmental harm linked largely to the indiscriminate waste management sector in many parts of the world during the pandemic are alarming in the approaching post-pandemic world [103], which can be summarized as follows:

- A larger quantity of hazardous medical and other waste generation and its systematic management alongside the health and safety crises associated with the handling, collection, transportation, and final methodical disposal of such wastes from society to the individual;
- The possible health hazards associated with frontline workers, health care workers, informal waste collectors, and the general public living in the vicinity of the waste disposal yards alongside the financial issues;
- The unexpected surge in perilous waste and plastic safety gear and packaging will adversely influence the common recycling competence and other waste clearance processes which presents a key long-standing negative impact on the terrestrial and marine environment;
- The new PPE contamination on land and in coastal areas has led to a novel situation for handling and dumping as well as probable issues for the health of the general public living in contact with such haphazardly disposed of items.

The global waste management sector is one of the crucial systems that is no doubt difficult for any nation to implement methodically. Additionally, the COVID-19 pandemic placed excess stress on the waste management sector at its height with the presentation of new challenges [104]. Nevertheless, amidst prevailing challenging global emergency type situations, it is extremely significant to make every endeavor to take corrective action for the waste management sector with equally dynamic steps for public health. The main concern is that the essential societal and environmental factors are mostly ignored because world authorities are chiefly focused on the protection of the public from viral infection. However, the necessary and urgent steps must be managed with regard to the systematic disposal of this new kind of hazardous medical waste in order to avoid the substantial disruption of societal and environmental well-being. It is quite likely that the post-pandemic circumstances may not be able to facilitate the consequences due to the financial downturn which might occur in future. On the basis of existing waste generation and its insufficient disposal management, the projected environmental effects should be explored for the implementation of nationwide waste management practices, technical solutions, response to policies and public awareness in the direction of sustainability. This simply means that we need to urgently rethink the future of our environment on planet earth and respond to the change in climatic conditions as well as degradation of the environment. This is a necessary route to protect the health, livelihoods, food security and nourishment of all human beings. In other words, we should ensure that our "Newer Normal" is a healthier one.

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