European Journal of Sustainable Development Research
2022, 6(4), em0196
e-ISSN: 2542-4742
https://www.ejosdr.com

Review Article

A Review of the Effects of COVID-19 Pandemic on Solid Waste Management

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Citation: Kathambi, B. E. and Obiero, L. M. (2022). A Review of the Effects of COVID-19 Pandemic on Solid Waste Management. *European Journal of Sustainable Development Research, 6*(4), em0196. https://doi.org/10.21601/ejosdr/12221

ARTICLE INFO

Received: 29 Oct. 2021

Accepted: 21 Jun. 2022

ABSTRACT

Pandemics affect the very existence of human life and their effects going beyond human life to the environment. Natural resources within evolving city milieus require sustainable environmental management. In the COVID-19 pandemic, disposal of face masks in rivers have been witnessed illustrating the implications of COVID-19 on solid waste management and ultimately on the environment. The risks associated and enhanced from improper waste management continues to have adverse impact on water bodies like rivers further aggravating the previous conditions of pollution, which contribute to the effects of climate change. Interestingly, COVID-19 pandemic has had positive environmental effects especially during the lockdowns evidenced by reduced travelling hence reduced global carbon dioxide emissions thereby resulting in improved air quality. However, the pandemic has imposed a further strain on the municipal waste system of many developing economies whose waste management structures and frameworks are still straining from doubled waste generation. As part of the COVID-19 protocol, advisory of wearing face masks was made mandatory for prevention purposes. Unfortunately, a constraint exists in developing protocols towards the management of the used face masks, gloves and PPEs. Increased generation of used face masks and gloves further accelerates indiscriminate dumping of these wastes not only in water bodies but also in dumpsites. Burning of these wastes will lead to increased production of greenhouse gases that have been cited as contributing to climate change. Beyond the COVID-19 pandemic, it is advisable for governments in developing countries to treat waste management as an essential service to avoid future foreseeable and unforeseeable adverse impacts on the environment.

Keywords: COVID-19, waste management, climate change, natural resource management, environment

INTRODUCTION

The COVID-19 pandemic has caused an unparalleled effect in most countries globally. This virus has affected close to all countries in the world, with over 157.8 million people having contracted the corona virus and resulted in about four million deaths (WHO, 2021). In the wake of the COVID-19 pandemic, little about this was known and neither researched. Of interest, COVID-19 virus have been noted to cause severe respiratory illness affecting the human breathing systems, contagions in a widespread array of animal hosts as well as mankind taking an enteric and systemic nature resulting in rapid fatalities if not promptly attended to (Ankit et al., 2021).

With unprecedented increase in loss of human life, scientific attention has grown since the occurrence of COVID-19 evidenced in Wuhan, China and which was declared a "Public Health Emergency of International Concern" by World Health Organization (WHO) (WHO, 2021). The strategy employed in this pandemic is characterized by a preventive outlook through frequent hand washing, use of gloves, wearing face masks as well as other personal protective equipment coupled with social distancing. Globally, governments have focused on performing tests to identify people infected with COVID-19 and subsequently to quarantine them to avoid the uncontainable spread among its citizenry (Islam and Kibria, 2020). WHO (2021) has estimated that the needs of PPE for the health care workers per month is approximately 76 million medical gloves, 1.6 million face goggles and 89 million medical masks.

Conversely, routine activities of people of all ages globally was disrupted which resulted to a change in the trends of waste generation by households, streets and especially medical facilities as well as quarantine centers (Tripathi et al., 2020). Mandatory face masks use, sanitization, medical gloves including personal protective equipment (PPEs) by frontline workers such as the medical personnel, bank employees, supermarkets, pharmacies among others has skewed the trend of waste generation to a dissimilar course. The population globally had accepted the replacement of single use plastics

but the COVID-19 pandemic has reverted to the previous situation of use of single use plastics and it is projected to worsen in the long term (Tripathi et al., 2020). The pandemic has had an overwhelming effect on management of solid waste and influenced the characteristics of solid waste as well as quantities generated especially in cities and urban centers (Nzediegwu and Chang, 2020).

In addition, COVID-19 might cause divergent indirect and direct effects on the environment and more specifically on natural resources (Zambrano-Monserrate et al., 2020). Handling of wastes in ways which are not sustainable in many developing countries makes them susceptible to the possibilities of increased spread of COVID-19 due to their improper waste management practices (Zand and Heir, 2020). Current and future strategies against COVID-19 ensue an outlook for enormous amount of plastic products (personal protective equipment (PPE) kits for example hair nets, face shields, aprons among others), masks, and chemicals (for instance chloroxylenol, chlorine, and hydrogen peroxide), which further increase the waste generated in the near future and further complicate the water resources which will increase per person consumption (Benson et al., 2021; Fadare and Okoffo, 2020). These negative outcomes might have unanticipated effects on the environment and more so on water bodies if proper waste disposal and management is not effected (Ankit et al., 2021; Arimiyaw et al., 2021; Islam and Kibria, 2020).

Kenya as a developing country followed the global trends and through its Ministry of Health (MoH) outlined a number of preventive as well as mitigative policies and measures to curtail further advancement of corona virus disease. Policies and interventions instituted include hand washing, dusk to dawn curfew, social distancing, compulsory wearing of face masks in public spaces, cessation of movement in and out of areas classified as COVID-19 hot spots, isolation of infected and exposed individuals global travel ban together with vaccination rollout effected in phase forms (Abdullahi et al., 2020; Arimiyaw et al., 2021). The repercussions of the ensuing lockdowns have had a notable effect on reduced air pollution levels; for example, there has been a notable reduction in greenhouse gas emissions, black carbon, water pollution and nitrogen dioxide have reduced intensely (Zambrano-Monserrate et al., 2020). The COVID-19 has triggered unparalleled effects countrywide in the economic, medical, environmental and social levels in addition to the realities of the implications settling in with waste generation increasing significantly (Ankit et al., 2021; Aura et al., 2020).

Worth noting, the shutdowns of power plants, manufacturing plants, reduced conveyance and shipment lead to declining amount of pollutants such as sulfur oxide (SO_2), methane (CH_4), nitrogen oxide (NO_2) and carbon monoxide (CO) (Ankit et al., 2021; Rume and Islam, 2020). Owing to a decrease in public transport as well as business activities; noise and air pollution declined notably following international flights ban (Arimiyaw et al., 2021; Benson et al., 2021). However, these positive effects were as a result of the imposed lockdowns and international bans in a number of countries all through the early stages of COVID-19 pandemic and the positive environmental impacts turned out to be short term (Arimiyaw et al., 2021; Rume and Islam, 2020). With the resumption of the numerous activities to usual levels, noted positive environmental effects have begun to diminish rapidly with businesses increasing their productions to recover from the lockdowns (Benson et al., 2021; Rume and Islam, 2020).

As health measures against COVID-19, the use of facemasks, sanitizers, wet wipes, and gloves were essential for the protection of the frontline workers and was deemed a necessity (Abdullahi et al., 2020; Benson et al., 2021; Selvaranjan et al., 2021). However, the safe discarding of plastics after use has turned out to be a matter of serious concern especially when this is emptied off in rivers and lakes (Al-Khatib et al., 2015; Aura et al., 2020; Bello et al., 2016). This has dealt a huge blow to the fight against plastic pollution with an increase of facemasks being found in rivers, lakes and unfortunately ending up in places where they must not be such as green and national game parks (Benson et al., 2021; Ferronato and Torretta, 2019; UNEP, 2020).

Remarkable change in the composition of the generated waste during this COVID-19 pandemic included hand sanitizer bottle, PPEs including face masks, which are part and parcel of our day to day lives, consequently the wastes generated has further increased the load on waste management systems in developing countries. Further waste generation has been impacted by the lock downs and working from home by vast majority of the population so as to reduce incidences of disease transmission.

The hazardous waste generated has also surpassed the capacity of the waste treatment facilities in existence adding strain to already overwhelmed waste management systems (Klemeš et al., 2020). Usage of singe use plastics as well as PPEs has added immense burden to the waste treatment facilities given that the availability of working staff is low in order to maintain the safety norms. On account of this, it's apparent that the waste management practices will be disrupted from its regular operations of waste collection and recycling at a global level (Mol and Caldas, 2020).

Additionally, the disposal of the face masks, gloves can easily be found on streets, parks, bus stops and open markets and more visibly on the riparian of rivers, lakeshores in developing countries (UNEP, 2020). The disposal of PPEs safely is also a matter of serious concern more so due to its negative impacts on natural resources when not effectively disposed (Benson et al., 2021; Selvaranjan et al., 2021). In general, human activities on land such as uncontrolled dumping of biomedical wastes are deemed as potential sources of radioactive pollutants and toxic infectious when drained off in natural resources like rivers, lakes among others (Fadare and Okoffo, 2020; WHO, 2018). Typically, the COVID-19 pandemic has caused increased biomedical wastes in the form of plastics waste which if not disposed correctly ends up in wrong places such as rivers which a number of households depend on (UNEP, 2020; WHO, 2018).

This paper seeks to elucidate the implications of COVID-19 pandemic on the environment. It seeks to shed light on continued pollution of natural resources if unabated and the need for robust waste management policies that address pandemics after effects. The research that has been done on COVID-19 has majorly focused on human health while research on environmental impacts of COVID-19 is limited.

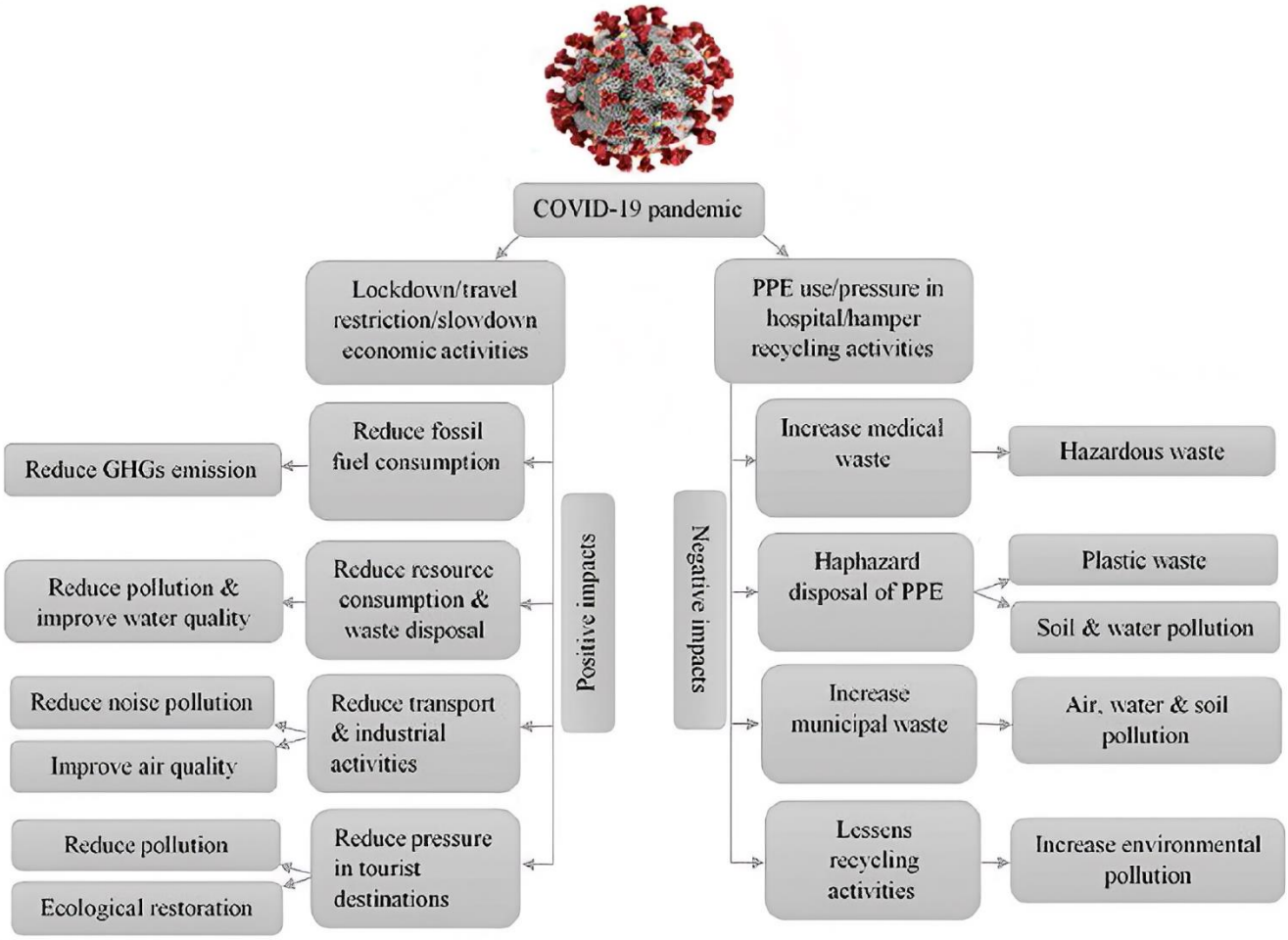

Figure 1. Positive and negative effects of COVID-19 Pandemic on the environment (Rume and Islam, 2020)

METHODOLOGY

The study was conducted by review of published literature though not systematically, perspectives, case studies, organizational information from both governmental and non-governmental information from official websites and reports. Scientific literature was collected electronically from databases such as dimension ai, springer, Science Direct, Google scholar, Web of Science, and Research Gate. This study compiled and presented data relevant to effects of COVID-19 pandemic on the environment.

RESULTS AND DISCUSSION

Ramifications of COVID-19 on the Environment

Global warming is caused by increased concentration of greenhouse gases. Human beings have been degrading the environment in the course of meeting their needs. Consequently, environmental pollution has become a huge concern presently. However, due to the COVID-19 pandemic countries globally had restricted the movement of its citizens through either a partial or total lockdown over a period of time as well as restricted economic activities. This had a remarkable positive effect on the environment; vehicles were barely found on the road resulting into almost zero emissions of greenhouse gases as well as toxic tiny suspended particles to the environment. Industries have downscaled their operations thus resulting into reduced consumption of fossil fuels or conventional energy sources (Chakraborty and Maity, 2020).

Even though the COVID-19 pandemic had an unparalleled effect on the economy and society, on the other hand it aided in repairing some environmental damage; to some extent the ozone layer was found to have revived (Chakraborty and Maity, 2020). Nitrogen dioxide, greenhouse gas productions, pollution in beaches, water pollution as well as noise pollution had lessened notably because of partial or full lockdowns as well as stringent cessation of movement orders enforced by numerous régimes globally (Chakraborty and Maity, 2020; Zambrano-Monserrate et al., 2020). These restrictions have aided in reducing pollution on the environment thus improving on air quality albeit temporarily given that with resumption of normal economic activities it will result in increased energy consumption as well as pollution (Rume and Islam, 2020); Wang and Su, 2020). **Figure 1** summarizes both the good and bad ramifications on the environment as a result of the COVID-19 pandemic.

It has been projected that about half of the decrease in emissions occurred because of the closure of manufacturing plants in China whose impacts on reduction of global warming is significant (Caine, 2020). Nitrous oxide is normally emitted when fossil fuel is burned and with 80% of these emissions originating from the exhaust of motor vehicles. Nitrogen dioxide (NO_2) present in the atmosphere causes acid rain when

water and oxygen react thus causing various respiratory ailments to man (USEPA, 2016). The European environmental agency (EEA) projected that due to the restricted movements necessitated by the pandemic, nitrogen dioxide emissions reduced from thirty to sixty percent in various European cities such as Rome, Milan, Barcelona, Paris as well as Madrid (EEA, 2020).

There is no doubt that the COVID-19 has caused untold havoc on human life; however, the effect of the COVID-19 hasn't been researched in depth to document side effects arising after recovery. Few of the studies conducted that have analyzed the effect of the COVID-19 epidemic on the environment have gauged a desirable unintended environmental impact (Zambrano-Monserrate et al., 2020). Climate experts on the other hand have predicted that emissions in greenhouse gases (GHG) might decline to levels that have never been witnessed before since World War II (Global Carbon Budget, 2020). One of the ways to stop the spread of the COVID-19 disease at the moment is restricted movement as well as working from home and this has been adopted globally. This has resulted to reduced travelling hence declined carbon emissions in the air globally thereby positively impacting the environment and aiding climate change mitigation measures (Zambrano-Monserrate et al., 2020).

The implementation of the strong social distancing measures by various governments globally has slowed down countries' main economic activities. Consequently, industrial facilities as well as power plants have been forced to stop their production activities. In addition, the use of motor vehicles declined notably thus resulting into a huge decrease in the concentrations of particulate matter that have a thickness that is less than 2.5 um (PM 2.5) in the focal metropolises (ESA, 2020). In other areas of the globe, like Europe there has been a notable reduction in air pollution following the government's directive to its citizens to stay at home as a containment measure to the COVID-19 disease.

Unseen Effects of COVID-19 on Solid Waste Management

One of the effect of outbreaks of diseases is the fast change in the constitution and amount of solid waste in urban centers and cities (Klemeš et al., 2020). This alteration in solid waste generation has been brought about by two important points: in a pandemic the lifestyle of population is bound to change in response to the prevailing condition and secondly the health needs of the community will raise the rate of production and consumption which have an essential role in altering the amount and configuration of solid waste in urban and city settings (Yousefi et al., 2021). These changes have been seen through the increased generation of used single use face masks and other PPEs following the advice of WHO that people should wear masks in public spaces to protect themselves from COVID-19.

It is estimated that about 1.6 million tons globally of plastic wastes are generated on a daily basis since the COVID-19 outbreak. Approximately 3.4 billion one use face shields and face masks were disposed daily (Benson et al., 2021). A notable increase in fiber and plastic based solid waste in urban centers and cities is evident because of the widespread use of disposable gloves and face masks as well as other PPEs during this COVID-19 pandemic (Klemeš et al., 2020). The pandemic has caused a lifestyle change characterized by increased online shopping and home deliveries which has resulted in increased plastic and paper waste from the packaging materials (Klemeš et al., 2020; Zambrano-Monserrate et al., 2020). These conditions might not be uniform everywhere due to degree of the pandemic's impacts on day to day activities, lifestyle, and geographical location.

In other instances, it might even lessen the rate at which urban solid waste is generated. For instance, in China generation of waste in medium and large cities has reduced by 30%; however, the rate of medical waste generation has gone up in the same cities; for instance in Wuhan, this rate has been described as being 6 times more which is replicated in other global cities as well (Klemeš et al., 2020). Conversely, in countries like Italy, following the recommendation of the epidemiology and health policy, there is increased usage of single use throwaway plates in cafes and restaurants thus giving rise to an increased solid waste generation within the urban centers (Zambrano-Monserrate et al., 2020). This means increased plastic waste generation; plastic take several years to break down thus these micro plastics will remain in the environment for decades thereby exacerbating environmental degradation.

Zambrano-Monserrate et al. (2020) noted that the containment measures have negative effect on the environment because of the increased generation of medical as well as domestic waste that may be harmful and has the potential to transmit diseases if not well managed. It is estimated that used 65 billion gloves and 129 billion face masks are generated every month; improper management of theses discarded PPEs has led to far reaching contamination of the environment further affecting natural resources indiscriminately (Prata et al., 2020). There is a turnaround in the form of the wastes generated due to the COVID-19 pandemic for instance an unexpected increase in not only the number but also the amount of plastic wastes utilized in packaging of food or single use PPEs such as, gloves, syringes, respirators, masks. This means increased generation of wastes dumped not only in the dumpsites but openly in the environment as well which finds its way to natural resources like rivers (Zambrano-Monserrate et al., 2020).

Waste recycling has been severely affected by the COVID-19 pandemic. In Europe and USA for instance the municipal recycling centers have either been banned or restricted due to alarm about the rapid spread of the COVID-19 virus (Zambrano-Monserrate et al., 2020). This means that there will be increased dumping of wastes in landfills or dumpsites resulting into environmental pollution in developing countries as evidenced in Dandora dumpsite in Nairobi City. In emerging economies, the recycling sector is dependent on the separation done by waste pickers at either the disposal stage or landfills. Changing the situation in this informal sector is quite impossible and complex. Thus the risk of spread of diseases as a result of improper management of waste is anticipated to be heightened in emerging economies compared to high income developed countries (Nzediegwu and Chang, 2020).

Taking in to account the current situation, the COVID-19 pandemic is projected to prevail even after the year 2025 therefore it is imperative that countries globally have in place

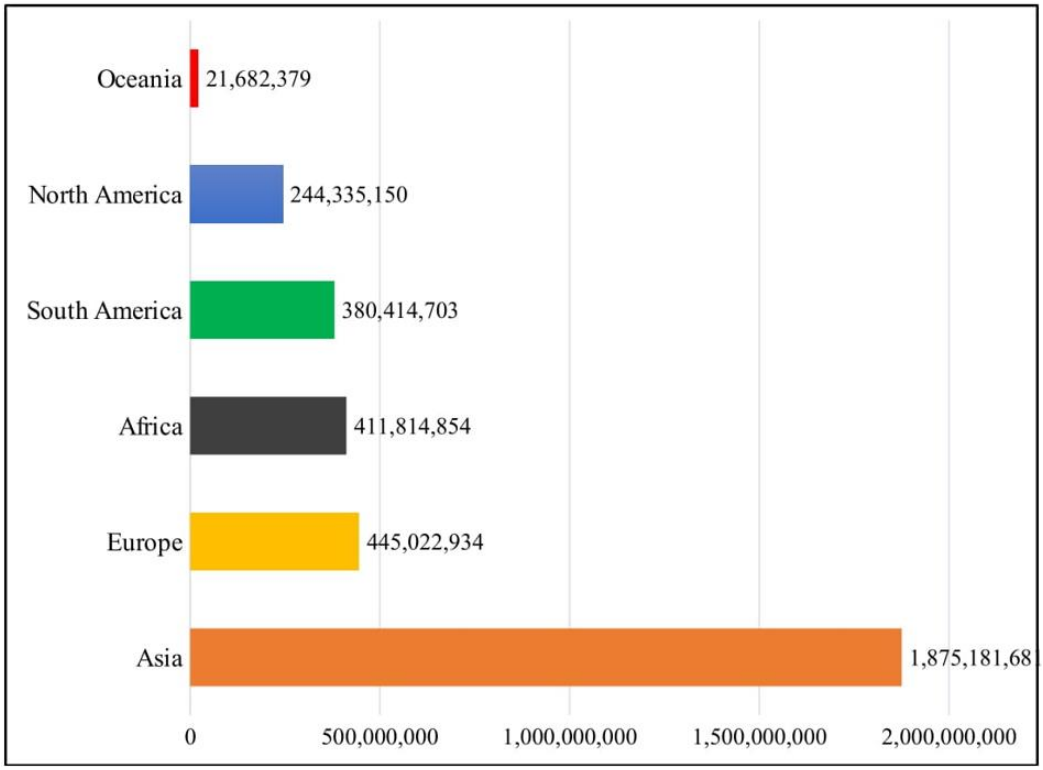

Figure 2. Estimated quantity of daily single-use facemasks (face shields) used per population per day for each region of the world (Benson et al., 2021)

a long term strategy for management of solid waste (Scudellari, 2020). Tripathi et al. (2020) notes that rather than using single use masks, reusable masks can be sterilized and used. They further state that there is also need to ensure that the disposed PPEs are sufficiently managed at the source to avoid riparian pollution.

Further, energy recovery from the plastic waste can minimize plastic waste footprint and subsequently mitigate climate change effects (Tripathi et al., 2020). **Figure 2** summarizes the estimated use of daily single use plastics per day globally with Asia having the highest number. If the trend continues, then the waste management facilities globally will be overwhelmed in the long run. Subsequently if these wastes are not managed well, the globe will soon be dealing with another crisis on environmental degradation from plastic pollution as well as climate change effects brought about by burning of these plastics in a bid to manage the high volume of plastic waste generated.

This global health crisis has exerted increased pressure on the regular management of waste practices thus causing unsuitable waste management practices such as mobile incineration, local burnings as well as direct landfills which impact heavily on the environment (Patrício Silva et al., 2020). PPEs such as face masks and gloves have played a very important role in increasing litter being found in natural resources like rivers (Zambrano-Monserrate et al., 2020). COVID-19 related plastics which are water logged have not only been sighted at the beaches but also in water bodies explicating the implications on the natural resources (Stokes, 2020). It is evident that there is transfer of used facemasks to water bodies as well as an upsurge in the quantities of single use facemasks and gloves haphazardly disposed off in the rivers and beaches (Fadare and Okoffo, 2020; Saadat et al., 2020).

Further research disclosed that single use face masks are accumulating on the beaches and has increased over time during the pandemic (Akhbarizadeh et al., 2021). The number of disposed one use face masks in African countries are estimated at 12 billion per month (about 105,000 tons of infected waste per month) which impacts gravely on the solid waste management structures (Benson et al., 2021). These described situations are not only unique to beaches, but also riverine debris have ballooned in rivers and lakes amidst the epidemic. Masks were the top most type of plastics, accounting for about 16% of the total riverine debris impacting negatively on the rivers (Cordova et al., 2021). Results of a research in Toronto, Canada, found that facial masks and disposable gloves attributed approximately 31% and 44%, respectively of garbage related to PPEs, identified as a new source of plastic pollution because of the micro plastics contained in them (Ammendolia et al., 2021). Another research conducted in Kenya exemplified that up to 16.5% of the entire amount of garbage present in the streets is linked to the personal protective items used as a result of the COVID-19 pandemic, while litter related to the COVID-19 wasn't restricted to recreational beaches but included national game reserves and green recreational parks (Okuku et al., 2021).

WHO estimated the needs of PPEs for healthcare workers on a monthly basis as 1.6 million goggles, 76 million gloves, and 89 million medical masks (WHO, 2021). Italy has a population of 60.4 million people and it has been approximated that the monthly needs for the population during the period of restricted movement is about 0.5 billion gloves and 1 billion face masks per month. A similar

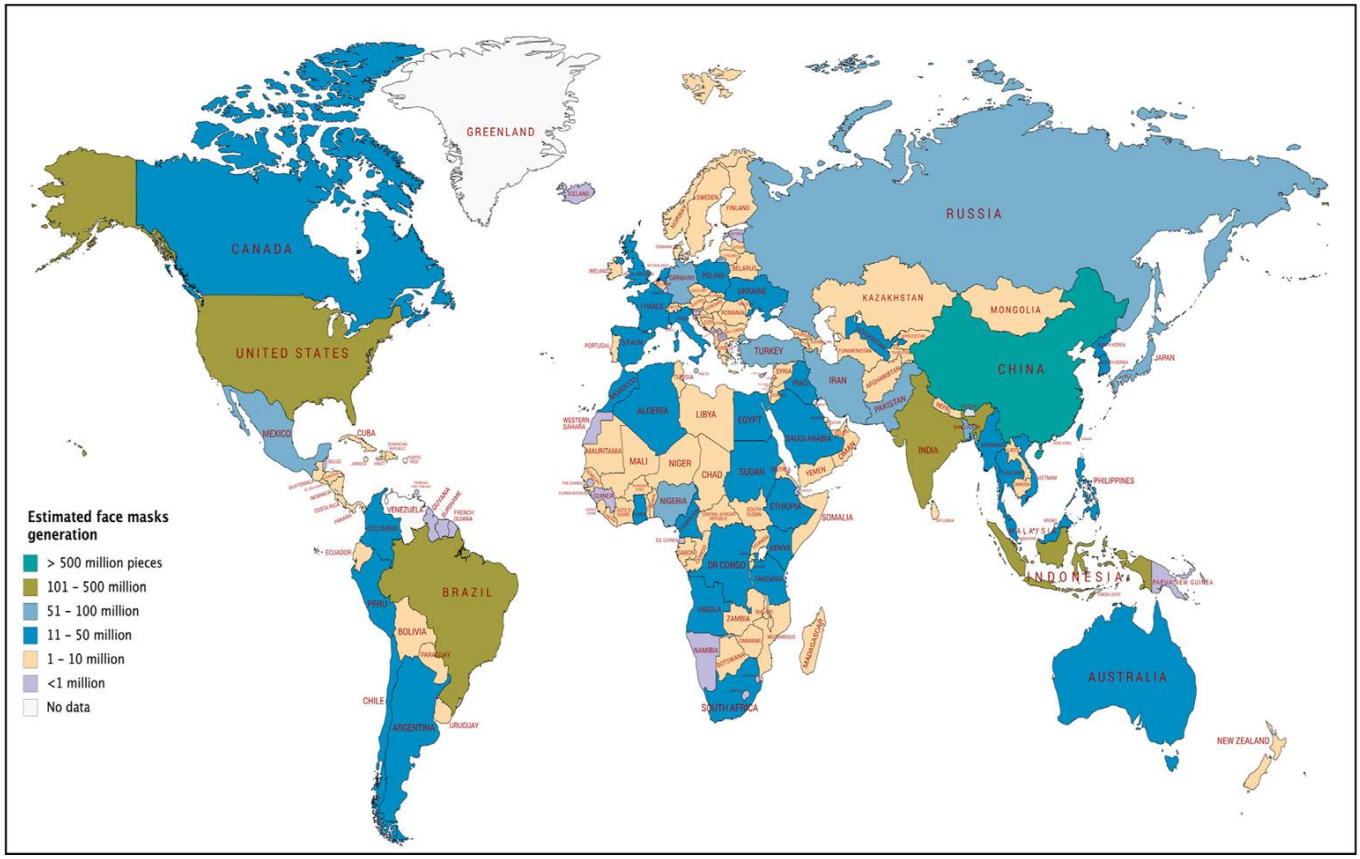

Figure 3. Estimated global share of face masks discarded as COVID-waste generated from a given country (Benson et al., 2021)

consumption globally with 7.8 billion populaces would result in a monthly consumption of 65 billion gloves and 129 billion face masks (Prata et al., 2020). **Figure 3** indicates the worldwide portion of face masks disposed of as COVID-19 waste from a certain country. The number of discarded masks globally paints a grave picture of what the environment may endure with improper waste management systems. There is therefore need for governments globally to come up with policies and strategies for the safe disposal and management of the discarded PPEs which are already being disposed haphazardly in the environment (Tripathi et al., 2020).

Concerns about improper disposal of PPEs by the public was not baseless, since used masks and gloves can be found littering public spaces and riparian. This litter has the capacity to cause infections and will be present in the environment for decades prospectively disintegrating into micro plastics unless appropriately cumulated and discarded since it is majorly made up of plastic (Tripathi et al., 2020). Single use masks are manufactured from plastics such as polyurethane, polyacrylonitrile or polypropylene. The endorsed N95 masks, with the ability of filtering air particulates <0.3 µm by 95%, are manufactured from plastics such as polyethylene terephthalate and polypropylene. Equally, other one-use PPEs such as masks and surgical gowns are manufactured out of non-woven materials such as spun bond meltdown spun bond often incorporating polyethylene, polypropylene and polyethylene terephthalate. Thus, usage and mishandling of medical wastes by the community is contributing to increased plastic contamination of natural resources like rivers in urban centers and cities (Okuku et al., 2021). Carried by rivers, streams and currents, these plastics have the capability to transverse globally and as a result of environmental conditions disintegrate into micro plastics (Prata et al., 2020).

Prata et al. (2020) further state that owing to survival of plastics in the environment for decades, PPE remains from the COVID-19 pandemic will probably be a prevalent waste item present in the environment for over 10 years visibly devastating all living things underscoring the environmental degradation foreseen. This will therefore impact on the health of the environment and management of natural resources affecting future of humanity. Human health has been placed ahead of environmental health; plastic waste management strategies and plastic reduction policies have either been recently reversed or temporarily postponed whose negative implications on the environment remain adverse and contribute highly in the climate change discourse (Prata et al., 2020).

CONCLUSION

COVID-19 pandemic has had quite a remarkable effect on the environment as well as on solid waste generation and management. The reduced greenhouse gas emissions that have been noted globally as a result from reduced transportation owing to the lock downs and more people working from home are only a short-term measure that will have a short-term positive effect on the environment. With containment of COVID-19 pandemic, the world will go back to its business as usual approach thus increased generation of the greenhouse gases and consequently climate change effects doubled.

Inevitably, human health has been prioritized by the governments globally at the expense of environmental health however it is more prudent that a balance be struck between the two; given that this pandemic has far reaching effects on the environment which can't be envisioned currently. As much as governments have taken a myriad of measures to curb the spread of this deadly pandemic, long term measures aimed at sustainable management of solid waste including the PPEs which have been used during and after the pandemic scores poorly. The gains that had started being seen from the ban of single use plastic will be lost given that the containment measures of the COVID-19 pandemic involves the use of one use plastics in the form of PPEs. It's imperative that the Kenyan government view municipal waste management as an essential service so as to find a lasting solution to the management of solid waste management including the used PPEs to avoid adverse effects on the environment. There is need for further research on the state of the environment post containment of the COVID-19 pandemic and the policies put in place to manage COVID-19 related waste.

Author contributions: All co-authors have involved in all stages of this study while preparing the final version. They all agree with the results and conclusions.

Funding: No external funding was received for this article.

Declaration of interest: The authors declare that they have no competing interests.

Ethics approval and consent to participate: Not applicable.

Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

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