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## Environmental risks of polymer materials from disposable face masks linked to the COVID-19 pandemic



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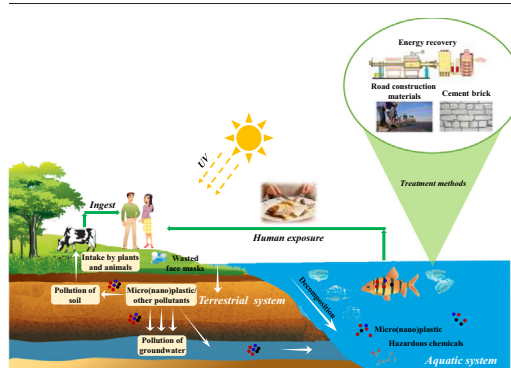
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### HIGHLIGHTS

- Randomly discarded face masks became a popular environmental waste.
- Disposable face masks released MPs and other pollutants with the potential for combined impacts.
- Both wasted face masks and MPs showed severe environmental risks.
- The conversion of face masks to valuable products is desirable.

### GRAPHICAL ABSTRACT



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### ABSTRACT

The indispensable role of plastic products in our daily life is highlighted by the COVID-19 pandemic again. Disposable face masks, made of polymer materials, as effective and cheap personal protective equipment (PPE), have been extensively used by the public to slow down the viral transmission. The repercussions of this have generated million tons of plastic waste being littered into the environment because of the improper disposal and mismanagement amid. And plastic waste can release microplastics (MPs) with the help of physical, chemical and biological processes, which is placing a huge MPs contamination burden on the ecosystem. In this work, the knowledge regarding to the combined effects of MPs and pollutants from the release of face masks and the impacts of wasted face masks and MPs on the environment (terrestrial and aquatic ecosystem) was systematically discussed. In view of these, some green technologies were put forward to reduce the amounts of discarded face masks in the environment, therefore minimizing MPs pollution at its source. Moreover, some recommendations for future research directions were proposed based on the remaining knowledge gaps. In a word, MPs pollution linked to face masks should be a focus worldwide.

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## 1. Introduction

Due to the outbreak of COVID-19 originating from a novel coronavirus (SARS-CoV-2) and its declaration as a pandemic by the World Health Organization (WHO), the world is facing a great crisis (Silva et al., 2021b). More than 146 million people have been infected and 3 million people died worldwide (Ju et al., 2021). It has posed a considerable threat to people's economic and social lives (Amuah et al., 2022). The severity of the COVID-19, as well as its high infectiousness (e.g., contact with contaminated waste/surfaces or direct human contact, oral-faecal transmission and respiratory/atmospheric droplets) and the lack of safe and effective vaccines have aroused the concerns and fears of the general public, and the scientific community, medical staff towards the prevention and control of its transmission (Heller et al., 2020; Kitajima et al., 2020). To curb the spread of this deadly coronavirus disease, most countries around the world have implemented several precautionary measures (Fadare and Okoffo, 2020), such as partial or total lockdown of municipalities/regions/cities, travel restriction, social distancing, and isolation (Tobias, 2020).

The pandemic situation has put most people out of work, and most companies are also struggling. Among all possible routes, a growing body of evidence demonstrated that the rapid spread of COVID-19 relied heavily on airborne transmission of SARS-CoV-2 (Buonanno et al., 2020). This ongoing epidemic created that plastic-based PPE for frontline health workers, as well as face masks for common citizens have been utilized to fight the spread of COVID-19 (Kahlert and Bening, 2020). Face masks mainly include three layers: an outer layer being made up of non-woven fibers to ensure waterproof performance; a middle layer composed of a melt-blown filter; and an inner layer consisting of soft fibers (Fadare and Okoffo, 2020). The melt-blown filter is the key filtering layer consisting of nano- and microfibers, in which melted polymer is extruded via tiny nozzles with the help of high speed blowing gas (Xu et al., 2021). Wearing a face mask has been regarded as the most effective measure against COVID-19 and is proposed as the "new normal" (Kobayashi et al., 2020; Vieten, 2020). The efficacy of wearing masks was confirmed by a test that was performed in a hair salon in Missouri (Ju et al., 2021). Both stylists infected by novel coronavirus and all 139 clients wore face masks when in the salon. Although they were close to the infected stylists, these results showed that none of the 139 clients was infected by novel coronavirus during the two-week quarantine. As one of the effective measures to slow down the human-to-human transmission of COVID-19 (Wu et al., 2020), the usage of masks has caused a shortage of masks worldwide, stimulating the mass production of masks in turn. Hence the global face masks production has witnessed an amazing growth and may continue to grow in the following years. Improper disposal of masks has caused the ubiquitous distribution of plastic waste in the environment, such as urban areas (parks, gardens, and streets), beaches, natural reserves, and even mountain areas (Neto et al., 2021; Prata et al., 2020), which exacerbates the plastic contamination. Some studies reported that the existence of plastics in the environment contributed remarkably to climate change because of carbon emission (Shen et al., 2020). Table B.1

summarized the occurrence and number of masks linked to COVID-19 pandemic in the environment. This is not surprising because an international online survey (Sri Lanka and India, Singapore, U.K., and Australia, U.S.) reported that 9% of people considered that they threw away disposable masks recklessly (Fadare and Okoffo, 2020). According to a recent study reported by the World Wide Fund for Nature (WWF), the incorrect disposal of masks—even if only 1% of the total masks utilized—would lead to around 10 million mask per month, which was equivalent to 30–40 tons of plastic waste discarded in the ecological environment (Kwak and An, 2021).

Hence the growth in both production and consumption of face masks increased the plastic waste. It was estimated that 79% of plastic waste ended up in landfills or other environmental medias, 12% was incinerated, and 9% was recycled (Fig. A.1) (Geyer et al., 2017), which has aroused the global concern. Most face masks are composed of polypropylene (PP), polyacrylonitrile (PAN), polycarbonate (PC), polystyrene (PS), polyurethane, polyethylene (PE) (Abbasi et al., 2020). Such wasted face masks broke down or decomposed into substantial levels of nanofibers and/or plastics <5 mm defined as MPs under environmental conditions through physicochemical (e.g., currents, wind, and UV radiation) and biochemical (enzymatic activity) processes. It is not feasible for the complete mineralization/(bio) degradation of plastics because of its exceptionally resistant nature (Du et al., 2021b). Therefore, most plastics will stay in environment for a long time (Khoo et al., 2021). This implies that the present ongoing epidemic aggravates the environmental contamination and thus poses a serious threat to human health and organisms. However, till now, the combined contamination of the co-exposure to MPs and pollutants from the release of wasted face masks as well as the environmental risks of face masks and MPs are rarely reported.

In this work, the objective of this paper is to (1) review the combined contamination of MPs and other pollutants from the release of wasted face masks; (2) discuss the environmental risks of face masks and MPs; (3) propose some methods to reduce the amounts of face mask littered in the environment and thereby minimize MPs pollution at its source; (4) introduce some techniques to converse wasted face masks to valuable products.

## 2. Combined effects of the coexistence of MPs and other pollutants

Currently, more attentions have been paid to the environmental fate of face masks. And whether they release contaminants, such as microcrystalline silica, microscopic polymeric fibers, and other secondary contaminants (e.g., glues, dyes, and surfactants), on which there is little information. Therefore, we will discuss the combined effects of MPs and these pollutants.

### 2.1. Organic pollutants

Most face masks consist of plastic fibers, however, some novelty face masks usually are colored with dyes to attract customers. These dye compounds pose a severe risk to human health and the environment (Lellis

et al., 2019). Many of them are water-soluble organic molecules that can be leached, resulting in their presence in aquatic environment or food web. Most dyes are also chromophores, competing with aquatic plants for light, reducing the photosynthesis, and thereby destroying the ecosystem. (Sullivan et al., 2021). It is very difficult to remove them from aquatic system with traditional wastewater treatment approaches because of high polarity of these compound molecules. Besides, due to their high aromaticity, most of these compounds exhibit mutagenic and carcinogenic properties. In addition, these molecules are capable of intercalating with the duplex RNA (Khan and Kumar, 2016) and helical structure of DNA (Haq et al., 2018), thereby destroying the transcription processes of the cell. The majority of dye compounds are considered to be persistent organic pollutants (POPs) and may bio-accumulate in numerous species. As stated above, face masks contain many chemical compounds, such as flame retardants and plasticizers, some of them are hazard to human health. Sometimes commercial face masks are made up of a certificate of chemical analysis including some plasticizers such as phthalates, chlorinated phenols, and polycyclic aromatic hydrocarbons (PAHs). Therefore, along with the release of MPs, these disposable face masks would slowly release toxic chemicals (Prata et al., 2020).

Organophosphate esters (OPEs), as emerging pollutants, are high-production-volume chemicals widely utilized as flame retardants and plasticizers, and they are physically added, rather than chemically bonded to plastic, and prone to leach out into the environment in the production of plastics (Deng et al., 2018), which has attracted increasing attention because of their reported hazard impacts. It was reported that tri-n-butyl phosphate (TNBP) could disrupt nervous system development, reproductive functions, and endocrine and was suspected carcinogen (He et al., 2020). Relevant epidemiological studies had stated that exposure to tris (1,3-dichloro-2-propyl) phosphate (TDCPP) could lead to a decrease in semen quality. Further, some OPEs were also associated with allergies and asthma (Meeker and Stapleton, 2010; Van der Veen and de Boer, 2012). Fernandez-Arribas et al. (2021) demonstrated that OPEs were detected for the first time in face masks at levels up to 28  $\mu\text{g mask}^{-1}$ , and KN95 masks presented the highest OPE values and concluded that a 10% of OPE content in masks was inhaled during their use. MPs are usually regarded as carriers for the enrichment and migration of these organic pollutants (Sun et al., 2020; Han et al., 2021; Sun et al., 2021; Zhou et al., 2021), which amplifies the concentrations of organic pollutants on/in MPs (Xiang et al., 2022). And there is no doubt that the biological toxicity and combined environmental effects and of MPs and organic pollutants are more complex (Liu et al., 2021). After entering the organisms, MPs with these pollutants primarily accumulated in gastrointestinal tract and even lead to diseases (Lu et al., 2019). Some studies have demonstrated that the combined contamination of MPs and organic pollutants (Liu et al., 2021). For example, the health risks of the co-exposure to MPs and organophosphorus flame retardants (OPFRs) were evaluated and the results showed the coexistence of MPs and OPFRs induced greater oxidative stress and neurotoxicity, and enhanced disruption of amino acid metabolism and energy metabolism in mice (Deng et al., 2018). While related modeling experiments confirmed that the adsorption of pollutants on MPs could not remarkably enhance their bioaccumulation (Koelmans et al., 2016; Zhou et al., 2020a). Even so, the toxic effects of MPs and organic pollutants on organisms should not be neglected.

## 2.2. Heavy metals

Disposable face masks also release heavy metals in natural environment. For example, Sullivan et al. (2021) performed the hazardous pollutants leachates analysis, and found that the leachable inorganic substances such as Cu, Sb, Cd, and Pb reached up to 4.17, 393, 1.92, and 6.79  $\mu\text{g L}^{-1}$ , respectively. It was reported that many dye compounds were related to heavy metals which were known to pose a negative effect to public health and ecosystem (Sungur and Gulmez, 2015). Metals such as Cr, Cu, and Sb were utilized as catalysts in the processing of dyes and these trace amounts of metals were found in plastic additives at times

(Hahladakis et al., 2018). Some heavy metals, such as Cr, Cu, Ni may form complexes with reactive dyes. The formed complexes had been found in moisture droplets of saliva and sweat, which may be deemed as a medium for transport into the human body. Furthermore, these complexes associated with MPs resulting from the release of face masks can transfer and enter the respiratory track through inhalation or skin contact. Liao and Yang (2020) assessed the hazard quotients (HQs) and bioaccessibilities of Cr(III) and Cr(VI) onto MPs and the results showed the Cr(VI) bioaccessibilities for polylactic (PLA) reached the highest values of 3.9%, 15.6% and 19.9% in large intestinal, small intestinal and gastric phases, respectively, and the maximum daily total Cr intake for various human groups via MPs consumption was estimated in the range of 0.50–1.18  $\mu\text{g day}^{-1}$ . The hazards associated with these chemicals, particularly heavy metals, ranged from mild allergic reactions to more serious health problems caused by repeated exposure, such as cancer, emphysema, and kidney disease, which may be harmful to the fetus (Luch, 2009). The combined effects of Cu (a leachable metal from masks) and MPs improved physiological, neurotoxicity, and genotoxicity impacts on the *neotropical teleost Prochilodus lineatus*, with greater impacts than each pollutant alone (Roda et al., 2020). The combination of Cd and MPs exhibited synergistic effects on the common carp *Cyprinus carpio*, which was greater impacts on immunological and biochemical parameters than individual stressors (Banaee et al., 2019). Moreover, when exposed to MPs and Cd mixtures, antagonistic effects can also occur (Zhang et al., 2020), whereas they did not pose a threat to organisms performance. Even so, heavy metals in disposable face masks also should arouse the attention of researchers.

## 2.3. Micro/nano-silica particles

Apart from these, micro/nano-silica particles were usually utilized in the processing of plastics (Masuki et al., 2020). There had some studies reporting that nano-silica particles could result in silicosis (fibrosis of the lung) and lung irritation and even developed into lung cancer and emphysema if inhaled (Masuki et al., 2020; Murugadoss et al., 2017). These two silica lead to cell damage through oxidative stress, causing DNA damage, genotoxicity and even cell death (Murugadoss et al., 2017). The toxicity of micro/nano-silica particles is also obvious in other tissues, resulting in neurotoxicity in brain tissues and cancers in bone tissue and blood (Masuki et al., 2020; Murugadoss et al., 2017). Nonetheless, they have lower environmental effects, if ingested, they may result in slight negative impacts on terrestrial animals and aquatic organisms (Fruijtjier-Polloth, 2012). However, the existence of these two particles in face masks water leachate indicates that their discharge is easy. This may raise further concerns about possible release when wearing face masks; are they easily inhaled? As discussed above, regardless of their mild impact, further direction should also focus on the release of micro/nano-silica particles from face masks and their health impacts. In addition, the combined effects of these micro/nano-silica particles and pollutants remains unclear and also should be concerned.

## 3. Environmental risks of disposable face masks and MPs

Excessive utilization of face masks has generated a remarkable amount of plastic waste in natural environment, and both plastic waste and MPs from their release also readily result in serious environmental contamination and damage (Fig. A.2) (Aragaw, 2020; Fadare and Okoffo, 2020). Next, we will discuss the adverse effects of disposable face masks and MPs on the environment systematically.

### 3.1. Terrestrial ecosystem

In most cases, disposable face masks are littered randomly or collected as plastic waste mixtures. These collected waste mixtures are transported to the landfill or incinerated. Whereas, there is a strong possibility that such methodologies lead to adverse environmental effects because of the presence of plastics in face masks. Once discarded in the terrestrial system,

these mixed plastic waste may block the sewage system in cities or towns (especially in developing countries) and will also negatively influence normal agricultural soils aeration and water percolation, thereby affecting the productivity of land (Prata et al., 2020). Moreover, these plastic pieces from the decomposition of face masks pose a severe risk to biodiversity because they can result in physical impacts such as internal blockages and abrasions if ingested (Wright et al., 2013). Due to their environmental inertia, most plastic waste including face masks tend to stay in the soil, thus polluting the soil environment (Webb et al., 2013). These collected plastic waste is sent to relevant disposal sites, which not only consumes energy but also releases greenhouse gases to the environment. For example, a study reported by Kumar et al. (2021) confirmed that the total global warming potential (GWP) impact caused by 10 tons of PPE wastes after being transported 10 km to the disposal site was 2.76 kg CO<sub>2</sub>-eq. These face masks discarded in the soil can affect the fauna, where they caused entanglement and even death. According to a report (Selvaranjan et al., 2021), a bird was tangled in littered face masks in a tree in Columbia. Then died after the face mask was wrapped around its beak and body. In addition, when face masks are mistaken for food by animals (unfortunately, this happens often), these plastics can fill animals' stomach, reduce food intake, and lead to their starvation and even death.

Environmental conditions induce the breakdown of wasted face masks to MPs which are regarded as a new type of environmental pollutant. Once their arrival in soil, soil ploughing, bio-disturbance, or wet-dry cycles readily drive MPs particles into the soil medium (Zhou et al., 2020b), which may lead to the changes in soil bulk density, water holding capacity, and soil structure. Moreover, MPs with other pollutants are transferred from topsoil to deeper topsoil with the help of tillage activities and leaching can drive MPs to groundwater. Related studies also reported that MPs in soil not only reduced the activity of soil microbial and functional diversity, but affected the cycle of plant nutrients, thereby indirectly affecting the germination of plant seeds and seedling growth (Du et al., 2021a). Again, Li et al. (2020) demonstrated plant roots could adsorb MPs and subsequently these MPs entered the plants through a crack-entry mode at root tips with porous structure due to the active cell division, and then were transferred from the roots to other tissues in the plant, mainly through a transpirational pull force. Su et al. (2019) reported that nano-sized microbeads could enter the tobacco cells through endocytosis, suggesting that small size plastics could enter the plant via the absorption in rhizosphere. As a result, all these MPs will end up in human body through food web, as observed in Fig. A.3. In a word, the migration and aggregation of MPs with other pollutants in plants posed a severe threat to human health and ecosystem via food chain (Zarus et al., 2021).

### 3.2. Aquatic system

Face masks waste, deposited in landfill or on land is transported into the aquatic environment and finally ocean ecosystem via rivers, or other water courses. The fate of disposed face masks is determined by the nature of the environment they are exposed to and the composite materials. Compared with the terrestrial environment, inappropriate disposal of masks may cause greater problems to the aquatic environment. For example, Chamas et al. (2020) stated that plastics in soil decomposed more readily in comparison of those exposed directly to the aquatic environment, which was mainly ascribed to temperature change between these two different thermal ecosystems. Moreover, their water absorption capacity and subsequent partial submergence hindered the decomposition of face masks in aquatic environment.

Once enter the aquatic environment, the accumulation of disposable masks may pose a severe risk to aquatic species. These face masks littered in the environment may become a vector for disease outbreak, since plastics are well known to propagate microorganisms, such as invasive pathogens (Reid et al., 2019). Furthermore, these face masks adsorb organic pollutants and toxins, thereby ensuring that pollutant particles are attached to the plastic surface in the form of a toxic film (Williams-Wynn and Naidoo, 2020). Hence it is possible to weaken them, or destroy them directly, or

make them more susceptible to other risks. Marine apex predators and megafauna including seabirds, mammals, turtles, sharks, and whales could ingest PPE items such as face masks entirely (Fernandez and Anastasopoulou, 2019; Kuhn and van Franeker, 2020), and marine faunas could be entangled by the elastic cords of face masks and some other face shields. In aquatic environment, the fragmentation and decomposition of face masks and other plastic wastes can occur with the help of aquatic immersion, corrosion, and weathering generating MPs. Therefore, the bioaccumulation of these formed MPs occur in the main food chain to human presence and result in the accumulation of toxic pollutants, which causes not only detrimental environmental impacts but social and economic impacts (Yang et al., 2020). Table B.2 listed the occurrence and density of MPs from the release of disposable face masks and negative effects on aquatic species. For example, the degrading face masks were analyzed by FTIR technique with PerkinElmer, UATR Two, USA (Fadare and Okoffo, 2020). The obtained spectra exhibited the characteristic peaks of PE with high density for the inner layer and PP for the outer layer. These spectra offered evidence that masks readily released MPs from these polymers to the environment in short periods of time. In addition, Saliu et al. (2021) carried a study that simulated the release of fibers from surgical masks to the marine ecosystem with the help of UV radiation. The achieved results showed that one tested mask exposed to 180 h of UV irradiation and violent stirring in artificial seawater could release more than 173,000 microfibrils per day. Recently, Ma et al. (2021) demonstrated mask MPs were detected in the nasal mucus of mask wearers, suggesting that they could be inhaled while wearing a mask (Fig. A. 4), and mask NPs/MPs also adsorbed onto diatom surfaces and were ingested by marine organisms of different trophic levels. This data is beneficial to assess the environmental and health risks of face masks. MPs ingested by corals and bivalves stay inside of the organisms and transfer between tissues (Hall et al., 2015; Van Cauwenberghe and Janssen, 2014). Additionally, the inflammation, hepatotoxicity (Lu et al., 2016), and neurotoxicity (Tang et al., 2020b) caused by MPs had been demonstrated. Other negative impacts including alterations in olfactory-mediated behaviors (Shi et al., 2021), changes and infertility of metabolism, and clogging of the digestive tract (Sharma and Chatterjee, 2017) as well as immunotoxicity (Shi et al., 2020; Tang et al., 2020a) had also been reported. However, apart from the pollution caused by nanofibers and/or MPs from the release of disposable masks, the potential harm to aquatic organisms is also one of the greatest concerns about the combined pollution of MPs and other pollutants in the surrounding environmental, which have been extensively investigated in previous studies.

In short, both the disposable face masks themselves and MPs resulting from their release pose a serious threat to the aquatic ecosystem. Hence, it is essential to explore effective treatment measures to minimize MPs pollution at its source.

### 4. Some potential green technologies to reduce MPs at its source

There are many technologies such as gasification, KDV (Katalytische Drucklose Verölung) process, hydrogen technologies, fluid catalytic cracking, pyrolysis, and chemo-lysis for the conversion of plastic waste to valuable products. Pyrolysis is one of the common technologies involved in the conversion of plastic waste (Fig. A. 5). Till now, only a few papers related to pyrolysis of disposable face masks have been reported. A study reported by Park et al. (2021a) found that pyrolysis of disposable face masks produced fuel-range hydrocarbons, such as CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>3</sub>H<sub>6</sub>, and C<sub>3</sub>H<sub>8</sub>, and no solid char was generated through the pyrolysis of the discarded masks. Pyrolysis based on catalysts had been explored to produce high value-added aromatic compounds such as xylene, toluene, ethylbenzene, and benzene (Lee et al., 2021) from carbonaceous substances (e.g., organic waste and biomass). The use of the catalysts reduces molecular weight, and changes the chemical structure similar to that of petrochemicals, thereby further increasing the value of pyrolytic (Park et al., 2021b). Additionally, the employment of catalysts not only increases more cracking but promotes the aromatic yield of pyrolytic oil through deoxygenation, decarboxylation, and dehydration. Jung et al. (2021) performed a study that



provided a versatile thermo-chemical process to valorize the wasted COVID-19 masks, and syngas and  $C_{1-2}$  hydrocarbons (HCs) were produced. Furthermore, they also found syngas production from pyrolysis of disposable face masks got promoted with the help of Ni catalyst. Further research should pay much more attention to the yield of valuable chemicals and the conversion efficiency of disposable face masks. This method can reduce the amounts of wasted face masks and simultaneously produce valuable products.

In addition to the conversion of plastic waste to valuable products, recent studies also reported the utilization of plastic waste as construction materials, such as concrete, cement, and roads (Fig. A.5). For example, [Saberian et al. \(2021\)](#) put forward an innovative method to reduce the plastic waste linked to the pandemic by recycling the discarded masks with other littered materials in civil constructions and performed the experiment on the blends of the shredded face mask (SFM) added to the recycled concrete aggregate (RCA) for subbase and road base applications. They found the inclusion of shredded face masks can improve strength, flexibility and ductility of RCA/SFM blends and the disposed masks can be applied for pavement base/subbase applications, which may lower the cost of municipal constructions. Nonetheless, the cement, concrete or roads are exposed to sunlight all day long. Evaluating whether face masks blended in the concrete will undergo thermal decomposition which may generate harmful MPs is significant ([Khoo et al., 2021](#)). Furthermore, human living in the house comprised masks-based concrete may be exposed to toxic MPs for a long time ([Khoo et al., 2021](#)). Therefore, these issues need to be fully considered. In general, these above measures not only reduce the amounts of face masks discharged in the environment but mineralize MPs pollution at its source.

## 5. Conclusions and recommendations for further research

Face masks can effectively prevent the spread of COVID-19. It is acknowledged that if the circular economy methods are suitably integrated, face masks could play a protective role, not pollution. Otherwise, this protective measure puts enormous burden on the disposal and management of plastic waste. The excess usage of face masks, which may carry a trace of infectious agents along with them, has generated a massive number of

plastic wastes in the environment. This work presents an obvious overview of the combined effects of MPs and pollutants from the release of wasted face masks under environmental conditions considering all the remarkably influenced components of terrestrial and aquatic ecosystem. In addition, some green technologies to reduce the amounts of littered face masks and minimize MPs pollution at its source are also provided. Given the current environmental pollution and energy shortage, it is urgently essential to develop highly efficient approaches to convert wasted face masks to valuable products with high production rate. Wearing a face mask is regarded as the “new normal”, hence future research should evaluate health risks associated with the inhalation of MPs. And much more attention should also be paid to the additives in face masks.

## CRediT authorship contribution statement

**Hao Du:** Data curation, Writing-Original draft preparation, Conceptualization, Methodology, Software; **Shushi Huang:** Visualization, Investigation; **Jun Wang:** Writing- Reviewing and Editing, Supervision, Funding, Project management.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A

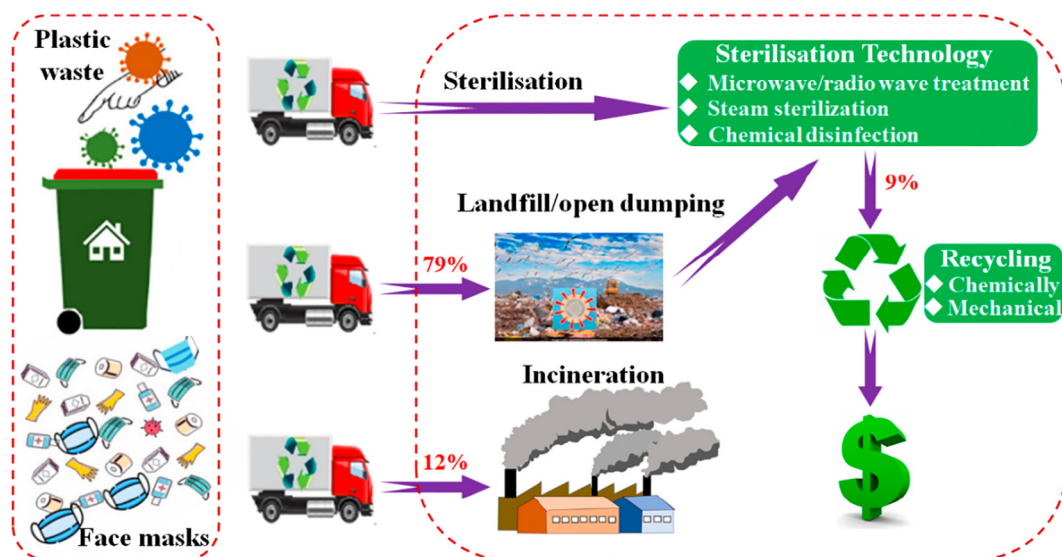


Fig. A.1. The overall flow of disposable face masks treatment ([Khoo et al., 2021](#)).

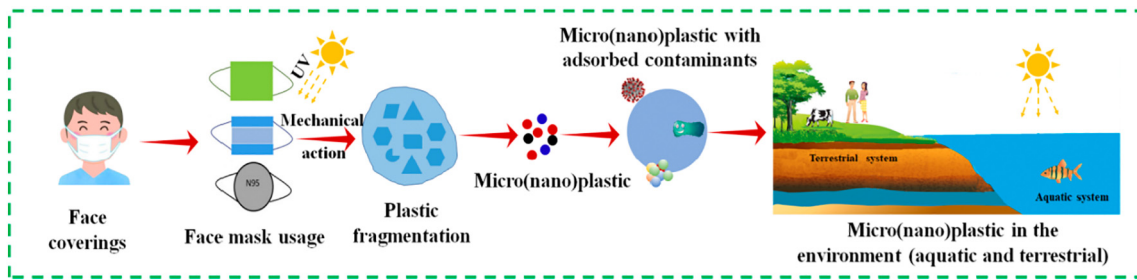


Fig. A.2. A general description on the fate of MPs from disposable face masks in the environment (Abbasi et al., 2020).

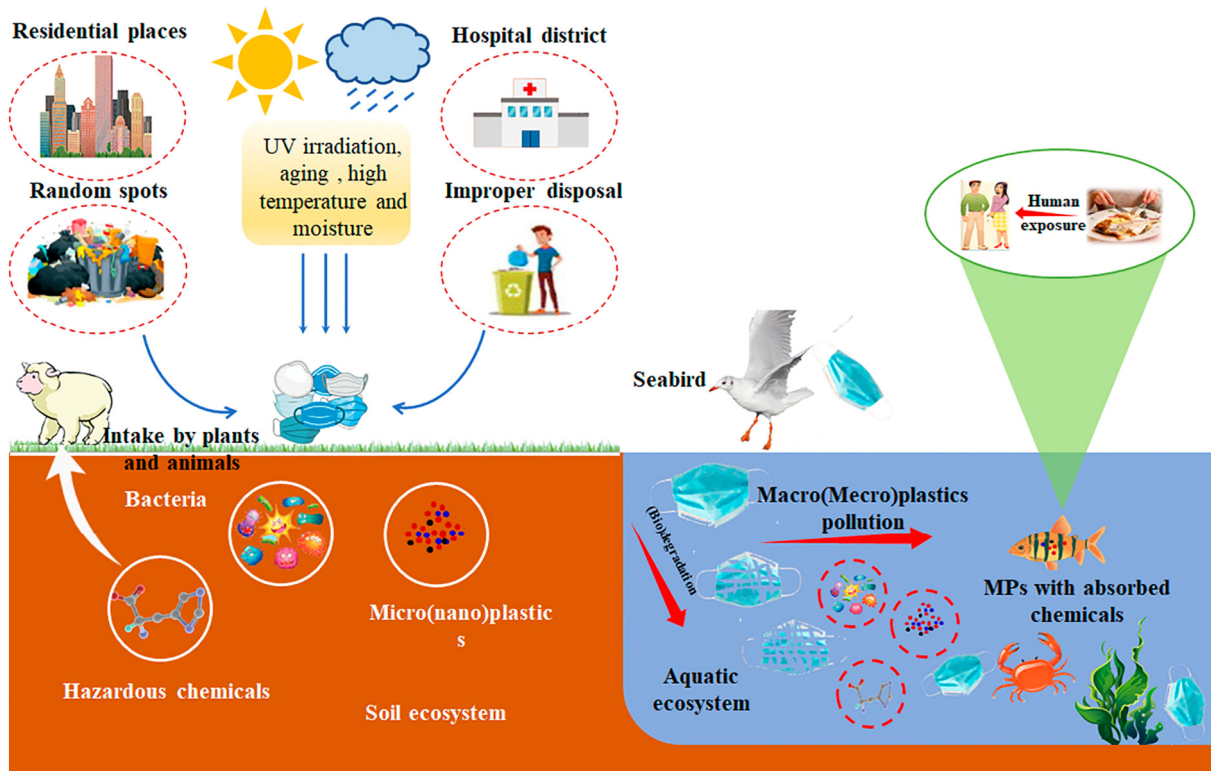


Fig. A.3. The potential health impacts of disposable face masks and MPs in aquatic and terrestrial system (Jedruchniewicz et al., 2021; Silva et al., 2021a).

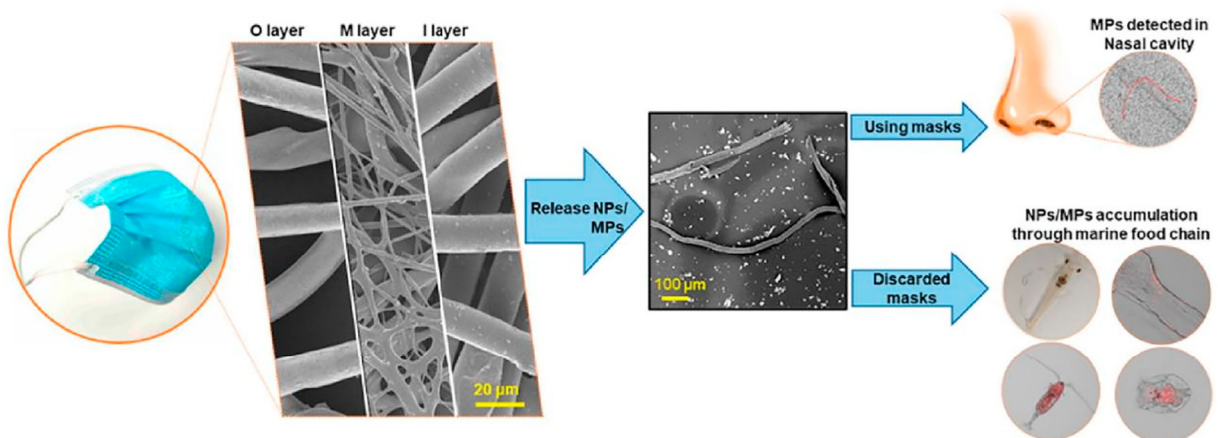


Fig. A.4. The potential bioaccumulation of MPs/NPs from the release of face masks (Ma et al., 2021).

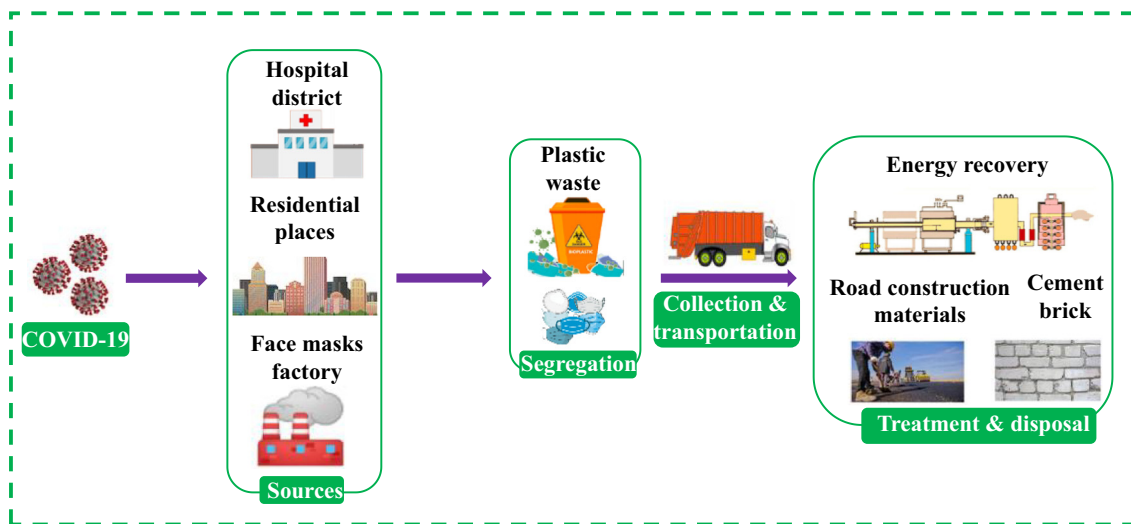


Fig. A.5. The fate of disposable face masks during COVID-19 pandemic (Parashar and Hait, 2021).

Appendix B

Table B.1

Occurrence and density of wasted face masks related to COVID-19 pandemic in the environments.

Number	Location	Sampling sites	Average densities	Research findings	Ref.
1	Toronto; Canada	Residential areas, hospitals, Parking lots,	1306 items, 31% representing face masks. Residential areas ( $2.9\text{--}2.7 \times 10^{-4}/\text{m}^2$ ). Hospitals and parking lots and ( $1.60\text{--}1.33 \times 10^{-3}/\text{m}^2$ )	Parking lots and hospitals had higher numbers of face masks	(Ammendolia et al., 2021)
2	Jakarta bay; Indonesia	Cilincing and Marunda river mouths	4500–5000 items (~254.7–246 items/day), 5.36–4.92% representing face masks	COVID-19 waste increased 5% the debris found in riverine sediments.	(Cordova et al., 2021)
3	Lima; Peru	11 beaches	138 items ( $7.44 \times 10^{-4}$ items/ $\text{m}^2$ ), 66.4% representing disposable masks (surgical, KN95)	Recreational beaches exhibited the highest number of items (73%), followed by surfing (24.6%), fishing and inaccessible beaches (< 1%).	(De-la-Torre et al., 2021)
4	Cox's Bazar; Bangladesh	One beach (13 sampling sites; 12 weeks)	$6.29 \times 10^{-4}/\text{m}^2$ , 97.9% representing face masks	–	(Rakib et al., 2021)
5	Kwale, Kilifi, Mombasa; Kenya	Beaches (sediments and water), and streets	Streets: 0.01 item/m Beaches: 0.1 items/ $\text{m}^2$	Kwale beaches had more items than Kilifi; Mombasa had a higher number of masks in the streets.	(Okuku et al., 2021)

Table B.2

An overview of MPs from the release of disposable face masks related to COVID-19 pandemic in the environment.

Number	Environmental media	Exposure conditions	Microplastics size	Number of items	Ref.
1	Water	A mask was shaken on a rotary shaker at 120 rpm for 24 h	100–500 $\mu\text{m}$	$183.00 \pm 78.42\text{--}1246.62 \pm 403.50$ particles/piece	(Chen et al., 2021)
2	Aquatic environment	1 s = 1.6 kJ/L, 15 s = 24 kJ/L, 30 s = 48 kJ/L, 60 s = 96 kJ/L, 120 s = 192 kJ/L)	0.1–0.5 $\mu\text{m}$ and < 0.1 $\mu\text{m}$	$2.1 \pm 1.4 \times 10^{10}$ items/mask	(Morgana et al., 2021)
3	Marine environment	180 h UV-light irradiation	–	173,000 fibers da	(Saliu et al., 2021)
4	Water	Burned at 500 °C for 4 h. and shaken rigorously for 3 min	<1 $\mu\text{m}$	–	(Ma et al., 2021)
5	Aquatic environment	Stirred for 24 h with a speed of 120 rpm,	50% were less than 0.5 mm and 80% were less than 1 mm	116,600, 168,800 and 147,000 items by one mask in water, deter-gent solution and alcohol solution, respectively.	(Shen et al., 2021)
6	<i>Eisenia Andrei (Opisthopora)</i>	1000 mg/kg dry soil; 21 days	PP achieved from PPE microfibres (< 300 $\mu\text{m}$ )	Biochemical alterations (esterase activity dropped 62%; spermatogenesis declined to 0.8). No effects on survival and absence of pathological symptoms	(Kwak and An, 2021)
7	<i>Folsomia candida (Collembola)</i>	1000 mg/kg dry soil; 28 days	PP achieved from PPE microfibres (< 300 $\mu\text{m}$ )	Ingestion/egestion observed, reproduction and growth decreased by 48% and 92%, respectively, no biochemical and behavioural alterations	(Kwak and An, 2021)



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