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Review

Uncontrolled Disposal of Used Masks Resulting in Release of Microplastics and Co-Pollutants into Environment

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Abstract: The global panic caused by COVID-19 has continued to increase people's demand for masks. However, due to inadequate management and disposal practice, these masks have, unfortunately, entered the environment and release a large amount of microplastics (MPs), posing a serious threat to the environment and human health. Understanding the occurrence of mask waste in various environments, release of mask-origin MPs, and related environmental risk is essential to mask-waste management in current and future epidemic prevention and control. This paper focuses on the global distribution of mask waste, the potential release of waste-origin MPs, and the impact on the environment. Specifically, the physical and chemical properties of polypropylene (the most common plastic material in a mask), which show a high adsorption capacity for heavy metals and organic pollutants and play a role as a support for microbial growth, were extensively reported. In addition, several important issues that need to be resolved are raised, which offers a direction for future research. This review focuses on the essentiality of handling masks to avoid potential environmental issues.

Keywords: microplastics; microfibers; masks; COVID-19; polypropylene

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1. Introduction

With the global COVID-19 pandemic, masks have become essential personal protective equipment (PPE) for people to avoid infection by the virus. It has been proved that wearing masks can greatly prevent the rapid spread of respiratory droplets containing SARS-CoV-2 [1]. Many countries around the world, such as Germany [2], Austria [3], Israel [4], etc., enforced or still enforce mask wearing in public places. According to the prediction of a model made by the World Health Organization, it is estimated that at least 89 million medical masks and 129 billion ordinary masks are needed each month [5]. During the worst period of the epidemic, the amount of medical waste, including masks, reached 240 ton·d^{-1} in Wuhan, China. The generation of a similar amount of medical waste has been observed in Thailand, the Philippines, Malaysia, India and other places, too [6].

The use of these masks will inevitably pose a great threat to the natural environment. According to the World Wild Fund for Nature, 10 million masks per month end up in the environment, even when only 1% of masks are improperly disposed of [7]. Recent studies have also shown that 1.56 billion masks leaked into the ocean in 2020 alone, which will have unpredictable and serious effects on marine life [8]. In fact, masks have been unintentionally or accidentally disposed of in cities [9], rivers [10], coasts and beaches [11].

Masks in markets are made mainly of polypropylene, polyurethane, polyacrylonitrile, polyethylene or polyester and other polymers [12]. Among them, the most common N95 mask (which can filter 95% of air particles smaller than 0.3 μm) consists, essentially, of polystyrene [13]. These plastic-made masks can, if dumped into the environment, release microplastics (MPs) under conditions of wind, waterpower, light, etc. [14]. Due to their difficulty in degrading under environmental conditions, this released debris in the environment will likely continue to accumulate in the biosphere. It is noteworthy that mask-origin MPs are mostly fibrous and have a greater toxicity and adsorption capacity, which differs from common granular MPs [15]. Given the situation of the current serious epidemic, the released MPs will absorb nutrients in the environment and create a relatively stable microenvironment for bacteria or viruses, thereby improving the survival time and range of the latter [16]. Recent studies have shown that the longest survival time of SARS-CoV-2 on a plastic surface is 3 days. However, the virus could survive only 3 h in the air [17]. Even after 7 days, used masks could still contain infectious SARS-CoV-2 RNA [18]. Therefore, whether wasted masks and released microplastics can act as carriers of bacteria or viruses, extending their spread under wind and water flow conditions requires further research. It has been established that masks discarded by people can release heavy metals and organics into the environment [12,19], as well as adsorbing some pollutants in the environment and acting as a carrier of toxic substances [20].

So far, there have been a few reports on disposable masks exposed to the environment. They only discuss the direct negative effects of these masks on wildlife, but not the mask-origin MPs and their combined environmental toxicity over time in the environment. In this paper, therefore, we review recently reported studies about the fate of disposable masks and the potential environmental threat caused by MPs released from the wasted masks.

2. Disposable MASKS Exposed to the Environment

As one of the greatest environmental challenges affecting human survival, plastic pollution has received global attention in recent years. Since the outbreak of the new COVID-19 epidemic in 2019, however, people's demand for mask production has increased significantly. Since masks are mainly made of plastics (the main component is polypropylene), if they are inappropriately disposed of, they can cause serious environmental problems. Assuming each person uses one mask per day, at least 5.052 billion masks need to be supplied every day in the world [21].

In the past two years alone, people could find a variety of PPE, including masks, in every corner of the world [22,23]. Up to now, the phenomenon of disposing of masks on the beach has been reported the most. In Bangladesh, 29,254 pieces of medical waste were found on one beach alone, of which 97.9% were masks [24]. In the Bushehr region of Iran, 1578 gloves were found at nine coastal sites [25]. Among them, the densely populated beaches were the most polluted. At Kwalai Beach in Kenya, one discarded mask could be found every ten square meters [26]. In addition, a large number of mask waste has been found on the beaches of Chile [27] and Morocco [28]. Incredibly, waste masks were also found on the beaches of some uninhabited islands in Hong Kong, China [29]. Chowdhury et al. [22] investigated mask-waste pollution in the coastal areas of 46 countries and found that about 150,000 to 390,000 tons of masks leaked into the ocean in 2020. Not only the marine environment is affected; plastics could be found in 76.5% of ponds in Bangladesh, most of which was floating mask waste [30]. According to an on-site study of river debris in the port of Garda, Indonesia, an unprecedented amount of PPE, including face masks, was discovered in 2020, reaching around 117 pieces per day [10]. A similar amount of mask waste was also found in Turkish cities, with an average of 182 masks per square kilometer [9]. By comparing pollution by masks in different parts of the city, it was found that the random disposal of masks in parking lots of hospitals with large population flows would be more serious [31]. What is worrying is that the demand for masks is still high, especially in developing countries, as shown in Figure S1a. However, due to economic and managemental reasons, these areas have an insufficient capacity to deal with their mask waste. For example, Africa has become a major source of mask waste in the world; due to the lack of necessary waste management capacity, 15 out of 57 African countries have been major emitters of mask-origin plastic waste. It is estimated that masks, as much as 105,000 tons month^{-1}, are not properly handled and disposed of directly into the environment [32]. A survey performed in Poland's Silesia region shows that 42% of people disposed of mask waste mixed with household garbage [33]. It is worth noting that in many coastal countries, due to the massive use and uncontrolled disposal of masks, a large amount of mask waste will flow into the marine environment (Figure S1b). It is found that lower-income countries and developing countries will be the major source of mask-waste emissions [22].

Like most plastic products, mask waste can float, settle or be suspended in the water body [25]. It is, therefore, expected that a large part of the mask waste is transported around the world by ocean currents, while the other part remains in the sediments on the sea floor [8]. In addition, microbial degradation and photochemical weathering can cause fragmentation and decomposition, resulting in the production of MPs. Therefore, PPE is considered a new source of secondary MP pollution in the environment that can endanger wildlife and human health [8]. Since plastic waste also promotes the spread of microorganisms and pathogens, this discarded mask waste can also be a vector of disease outbreaks [23,34].

3. Release of MPs from Masks

Plastic products can naturally decompose into tiny plastic particles. If the diameter of these particles is less than 5 mm, they are defined as MPs [35]. Compared to the pollution caused by larger plastics, MPs can more easily penetrate into the oceans [36], rivers [35], land [37] and even the atmosphere [38] because of their size and lower density. They have potential to harm ecological and human health. So far, MPs of various sizes have been found in animals and a large amount of MPs have been found in commercial products for adults [39] and even for babies [40]. Owing to their relatively stable and porous structure, these released MPs accumulate in the human body, not only through respiration but also through the food chain. Microplastics released into the environment quickly combine with some toxic substances [41] and viruses (respiratory viruses and human enteroviruses) to form a new micro-environment, which is called the plastisphere [42]. However, the release and spread of mask-origin MPs, as a secondary route of transmission of human-disease-causing viruses, e.g., COVID-19 corona viruses, do not seem to receive public attention.

As shown in Figure 1, the medical mask is a combination of three layers of PP-made non-woven fabric and PA-made ear ribbon, and it is easy to disperse some fiber fragments in the environment. Coupled with the effects of hydraulic scouring, mechanical wear and UV aging, the release of MPs will be faster [43–47]. Plastic waste generated in sanitary/medical facilities, laboratories and other contaminated sanitary/social facilities must be properly treated and disposed of in accordance with the relevant international/national regulations. In general, they must go through incineration/disinfection and then sanitary bottling or waste conversion. For example, during the lockdowns in cities, China set up mobile waste treatment stations and converted industrial waste treatment facilities into biomedical waste treatment facilities [48]. In Catalonia, medical waste has been given priority by existing incinerators [49]. However, not all countries can follow strict treatment procedures and infectious waste is often inappropriately disposed of; some developing countries (such as Thailand, the Philippines and India) dispose of PPE waste, including masks, in open landfills [50]. Studies have shown that in 2020 alone, 3.5 million tons of mask waste was landfilled worldwide. Surprisingly, these deposited masks have the potential to release 2.3×10^{21} MPs into the environment [48].

The release capacity, size and existing detection methods of mask MPs are highlighted in Table 1. Basically, there are different types of masks, such as N95 surgical masks, disposable surgical masks, medical masks, surgical face masks, ecopark disposable masks, etc. Together they are all made of PP or PE with three layers. The released capacity of MPs was mentioned in Table 1. Detection of MPs was confirmed using SEM, stereomicroscope and bench-top flow cytometry techniques. It was found that a minimum 1000 particles per mask/day to 1,566,560 particles per mask were released, depending on different conditions. In the water environment, a new mask may release 24,300 MPs, even in a closed glass container without the influence of wind. After three washings, 116,600 microplastics were released. When the mask is naturally aged for 2 months, it can release billions of microfibers into the aquatic environment [43]. In the marine environment, a single surgical mask can release 17,300 units of microplastic fibers in just 180 h, while a mask discarded in the ocean can completely disintegrate into microfiber fragments and aggregates within two years [46]. Masks left on the beach are washed away by sand and waves, further exacerbating the release of microplastic particles. A single mask can release more than 16 million MPs, which is more than ten-times higher than the release in a purely aqueous environment [47]. In addition, there are a large number of mask products that have not undergone uniform treatment, but are directly thrown away and scattered into the environment. For example, during the rainy season in Africa, masks are washed into rivers and streams through floods and ditches. In water, they are broken down into fibrous MPs, which eventually accumulate in freshwater and seawater environments [51]. Further, 42.1 MPs per liter were also found in the fish pond of the Pearl River estuary in Guangzhou, China, most of which were fibrous [52].

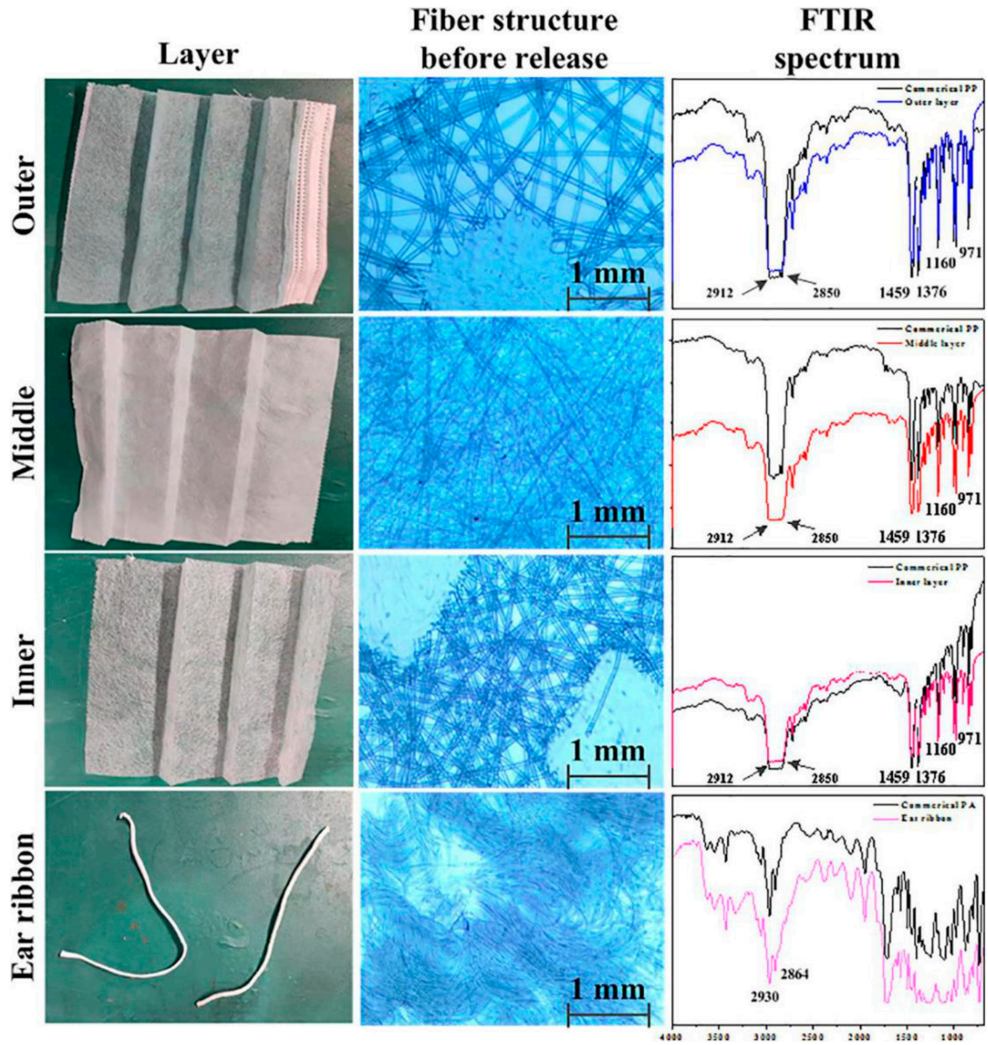

Figure 1. Structure and chemical composition of disposable surgical mask before release. Electron microscopy resolution of 3.66 μm [43].

Table 1. The release capacity, size and existing detection methods of mask MPs.

Mask Type	Description	Microplastic Release Capacity	Fragment Size	Detection Method	Ref.
N95, surgical mask	3-layers, polypropylene	3.1–3.3 × 10^9 nanoparticles per N95, 1.6–3.8 × 10^9	79 ± 14.1 nm	Counting of particles taken by scanning electron microscope (SEM).	[53]
Disposable surgical mask	3-layers, pleated cellulose polypropylene, polyester	116,600 MPs released from a mask after washed three times.	50% of MPs: <0.5 mm 80% of MPs: <1 mm	Counting of MPs in SEM images.	[43]
Medical surgical face masks, disposal medical face masks, normal disposal face masks and N95 face masks	PP/PET, Blue/White	1146 ± 308 to 1478 ± 266 particles per piece in 24 h.	MPs of 100–500 µm predominanting	Counting of MPs in an image taken by stereomicroscope after filtering.	[15]
N95, surgical masks, cotton mask, fashion mask, nonwoven mask, and activated carbon mask.	Nonwoven and activated carbon masks are made from nonwoven fiber. Cotton masks are made of cotton. Fashion masks are made of organic polymer. N95 are made of five PP layers	After 72 h, the fiber-like MPs of 1521, 1913, 2824, 2576, 2134, 3180, 3984, and 1835 (per mask in air) detected for N95, surgical-A, cotton, fashion	20–500 µm	MPs counted under a microscope	[44]
Surgical face masks	3 layers, PP spunbond nonwoven fabric	Average of MPs: 2.1 ± 1.4 × 10^{11} pieces m^{-2} per mask	0.1–0.5 µm (78.9 ± 6.5%) and < 0.1 µm (20.5 ± 7.5%)	Bench-top flow cytometry used to detect MPs.	[45]
Surgical masks	3 layers, Polypropylene	17,300 particles per mask/day	25–500 µm	Counting of MPs in an image taken by stereomicroscope	[46]
Ecoparksg disposable masks	3-layers, polypropylene	1,566,560 particles per weathered mask	10–500 µm	Laser-equipped in-situ scattering and transmission-metry analyzer for calculating particles	[47]

Laboratory experiments simulating the release of MPs from masks under wet and dry weather conditions have shown that the increase in fuzz formation in the dry environment leads to a higher release of MPs from masks. Further, the high salinity and density of seawater compared to freshwater was also found to result in the release of more MPs from masks [54]. Meanwhile, the presence of UV rays in sunlight will also affect the release of MPs in masks. As shown in Figure 2, UV radiation causes obvious deformation and fracture of the smooth fiber surface. If the UV radiation time is further increased, small particles attached to fibers will be produced. The increased surface roughness and fractures of the fiber surface undoubtedly enhance the ability of the mask surface to bind contaminants and the potential for release of MPs. Akhbarizadeh et al. [25] recovered discarded PPEs from the Bushehr coast in the Persian Gulf and found that more than 10% of this waste PPEs might enter the marine environment as secondary microfibers and MP sources. With the global disease situation still serious, this will result in countless MPs entering the marine environment in the coming years, with unprecedented negative effects on fisheries and marine ecology.

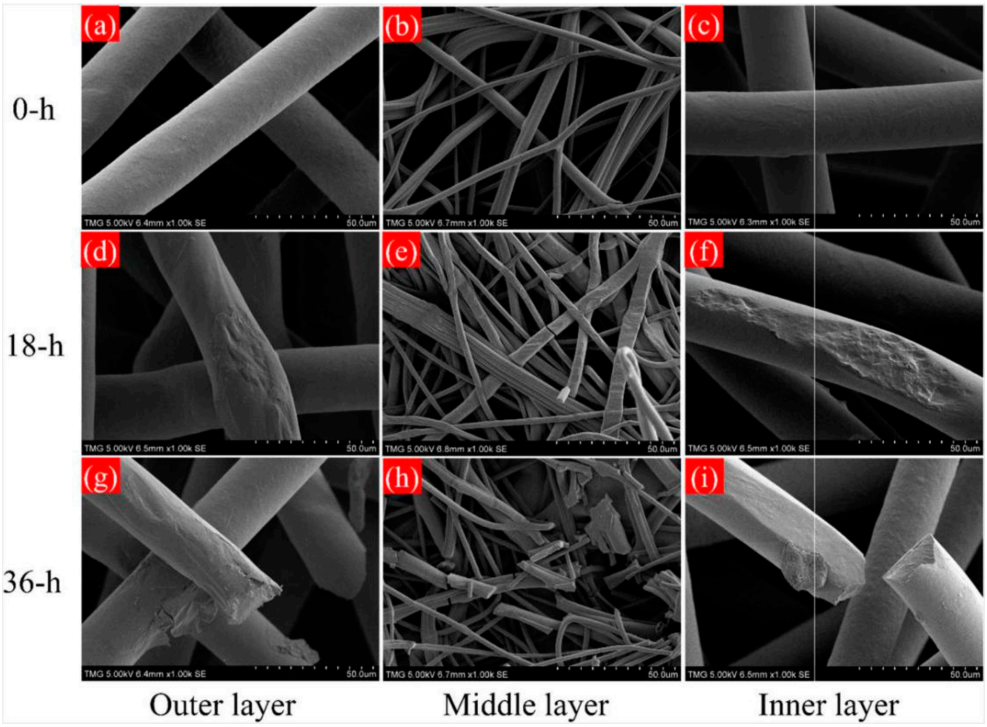

Figure 2. SEM images for the three layers of masks with different UV weathering durations: (**a**,**d**,**g**) Images at 1000 magnification of the outer layer of mask with UV irradiation for 0, 18 and 36 h (**b**,**e**,**h**). Images at 1000 magnification of the middle layer of mask with UV irradiation for 0, 18 and 36 h (**c**,**f**,**i**). Images at 1000 magnification of the inner layer of mask with UV irradiation for 0, 18 and 36 h [47].

Liang et al. [55] investigated the release kinetics of several commonly used masks under laboratory conditions and found that the rate of MPs releasing from masks gradually slowed down with time, which was well described by the Elovich release kinetic model. They also found that fibrous MPs of less than 500 μm in length were dominant in the MPs releasing from the masks. Due to the inevitable exposure to radiation and material wear for the used masks, the production and release of MPs is further promoted. Studies have shown that the amount of MPs released from a used mask is 6.0–8.1-times higher than those from a new mask [51]. During the wearing process, people inevitably breathe in fibrous MPs. Li et al. [44] conducted an investigation into the inhalation risk of MPs using seven popular masks on the market. The results show that both N95 masks and medical surgical masks release fibrous MPs into the air, bringing about a higher risk of MPs inhalation for humans. Even reusable masks can release 124 to 308 mg of microfiber per kilogram during the washing process, which corresponds to 640,000 to 1,500,000 microfibers [56]. Therefore, it can be said that, regardless of mask type, a large amount of fibrous MPs is released. The size of these MPs is known to be between 5 nm and 600 µm; most of the MPs are <1 µm [53]. Using flow cytometry, Mogana et al. (2021) analyzed the size of MPs released from submicron masks and found it was 0.1–0.5 µm [45]. Microplastics of this size are easily ingested by aquatic organisms to enter the food chain. Therefore, there is an urgent need for action to prevent mask waste from entering the environment.

4. Environmental Effects

4.1. Eco-Toxicity of Masks and Released MPs

Masks can affect organisms through ingestion and entanglement [57]. Both ingestion and entanglement affect the biological functions of organisms, such as reproduction, or even lead to death. Over the past 20 years, the number of marine species known to be affected by solid waste, including plastic-made masks, has increased from about 200 to 680 [58]. With the increase in mask waste, more and more biological species are affected. Possibly, MPs released from wasted masks will negatively affect the growth of various organisms, as some researchers have shown in their laboratory studies, where the potential threat of MPs to rats, fishes, microalgae, etc., was evidenced (Table 2). An evaluation of the biological toxicity of MPs from mask fragments is shown in Table 2, with PP particles or PP fibers being the main cause. Microparticles ranging from 1.6 µm to 1–5 mm were tested for a few hours to a few weeks to find a biological toxicity assessment; all the tested particles were considered to be a threat to wildlife. In some cases, this results in death.

Neto et al. [59] found a Magellanic penguin that had died from the ingestion of N95 masks on the Juksi Beach in San Sebastian, Brazil (Table 2). This is not an isolated incident. About 36% of the Magellanic penguins in Brazil are negatively affected by the ingestion of solid (plastic) waste, which leads to acute death or reproduction failure and delayed ovulation [60]. Media around the world are frantically reporting that various animals, including seagulls, peregrine falcons, swans, mallards, robins, hedgehogs, bats, etc., have their paws, wings or beaks caught in mask waste [29]. More seriously, the ingestion of mask waste has been found in seagulls, long-tailed macaques, cats and dogs [29]. In addition, as a new type of pollutant that is present in a large quantity, mask waste can affect in-land animals. In the Netherlands, for example, people found mask waste in a bird's nest [29]. This mask waste can be swallowed by young birds, impairing nutritional needs and development [61]. Lavers et al. [62] used chemical blood parameters to measure bird health and found that the presence of plastics in digestive organs would have a significant negative impact on bird morphology and blood calcium levels, increasing uric acid, cholesterol, and amylase. The additives released from plastics, such as bisphenol A, also negatively influence the development of the brain in primates [63].

In a city, countless non-recycled PPE will pour out into urban streets and clog sewers [51]. In addition, large-scale mask manufacturers and waste-mask-treating facilities will emit greenhouse gas and, thus, affect global climate change [64].

Table 2. Toxicity of mask fragments or MPs.

Contaminant Type	Size	Test Species	Exposure Conditions			Biological Toxicity Evaluation	Ref.
			Concentration	Medium	Duration		
Polypropylene(PP) particles	70 μm	zebrafish Danio rerio, nematode Caenorhabditis elegans	0.001, 0.01, 0.1, 1 and 10 mg L^{-1}	Water with suspended PP	10 d	Causes damage to the intestines, including villi bursting and intestinal cell division.	[65]
PP particles	25–200 μm	Human derived cells	0, 10, 50, 100, 500, and 1000 μg mL^{-1}	Microbial culture medium	48 h	Stimulate the immune system	[66]
PP particles	0.5–1 mm^2	Spirulina sp. microalgae	500 mg 500 mL^{-1}	Artificial microalgae culture medium	30 d	Significant reduction of Spirulina growth rate; Damage to the surface	[67]
PP particles	40–165 μm	Sprague Dawley (SD) rats	1234.8 ± 213.8 particles per 100 μg	Oral administration	14 d	No adverse effects by secondary MPs (PP and PS)	[68]
PP particles	8–125, 71–383, 761–1660 μm	Eisenia fetida	0.25% (*w*/*w*)	Soil with PP particles	28 d	Causing neurotoxicity, oxidative stress and inflammation	[69]
PP particles	13 μm	Earthworm Metaphire guillelmi gut microbiota	0.25% (*w*/*w*)	Soil with PP particles	28 d	Significantly reduces the bacterial diversity and changes the community structure in the soil	[70]
PP particles and triclosan (TCS)	1–15 μm	Zebrafish	200 μg mL^{-1}	Culture water	28 d	PP changes the distribution of TCS in tissues and increases the accumulation of TCS in the liver and intestines	[71]
Non-woven fabric	<300 μm	Springtails and earthworm	1000 mg kg^{-1} $_{\text{dry soil}}$	Soil with fibers and masks fragments	28 d	Suppresses Springtails growth and sperm production by male earthworms.	[14]
PFF-2 protective mask	A whole mask	Magellanic penguin		Juquehy Beach, Sebastian, Brazil		Death	[59]
Face mask	A whole mask	Gull		A mask tangled around the leg	14 d	Death	[29]
PP debris from the beach	1–5 mm	Zebrafish, sea urchin and jellyfish	333, 1000 and 3333 mg L^{-1}	Artificial seawater	24–48 h	Sublethal effect on sea urchins and jellyfish; Not affecting the development of Zebrafish embryos	[72]
Powdered plastics	100–250 μm	Acutodesmus obliquus	0, 5, 10, 15, 25, 100, 150, 200, and 250 mg L^{-1}	BG11 medium with MPs	21 d	Significantly reduced protein content	[73]
PP fibers	50–60 μm	Medaka	10,000 particles L^{-1}	AHAB recirculate-ing system	21 d	Production of more eggs by females	
PP fibers			0.4% *w*/*w*	sandy soil	31 d	Decreased soil enzyme activity	[74]
PP fibers	20–100 μm	Green mussel Perna viridis		Natural environment collection		Various negative physiological and structural changes in P. viridis	[75]
PP fibers	1.6 μm in diameter and 30.3 μm in length	Male Fischer 344 rats	15, 30, or 60 mg m^{-3} of PP	negative control	90 d	Induce pulmonary fibrosis	[76]

As a large amount of mask waste leaks into the environment, the release of countless PP MPs will be a matter of course. These PP MPs released into the environment are having an impact on living organisms, which should not be neglected. As shown in Table 3, ingestion of PP substances lowers the reproductive ability of organisms, affects the survival rate of embryos and even results in the death of the organisms. Importantly, studies have shown that the fibrous MPs released by masks have a greater impact on the ecosystem than other forms [77]. To date, we have observed the uptake of fibrous PP MPs by various living species (e.g., B. crabs, crustaceans, carnivorous plants) and indirect effects of the particles on the organisms in the aquatic environment [78]. Through their kinetic studies and analysis of relevant data, Sun et al. [79] showed that the release of microplastics from masks would affect the reproduction of copepods and have a long-term domino effect on coastal ecosystems. Terrestrial ecosystems are also threatened by PP microfibres. Microfibers have been taken up by saprophytes, earthworms and snails [78]. The presence of these microfibers causes microbes and cells to generate oxidative stress and to show lower activity [80]. When these fibrous MPs are exposed to ultraviolet radiation, a number of oxygen-containing functional groups are formed on the MP surface, which often increases the toxicity of the MPs [81]. At the same time, disposable masks also contain additives, such as plasticizers and flame retardants [82]. Among them, organophosphates are widely used insecticides that have important effects on endocrine and reproductive systems, as well as on the development of the nervous system [83]. In addition to releasing MPs, masks can become an important source of organophosphate pollution in the environment. In particular, an N95 mask has organophosphate as much as 11.6 g, while a surgical mask has a lower amount (i.e., 0.24 g per mask) [12]. Sullivan et al. [19] reported that, in addition to micro- and nano-scale microplastics, a mask could spontaneously release heavy metals, including the highly biotoxic Cd (1.92 $\mu g\ L^{-1}$) and Cu (4.17 $\mu g\ L^{-1}$). In the leachate from mask-origin MPs, nylon-66, surfactant molecules, dye-like molecules, PP glycol and other toxic substances could be found [19].

Table 3. Pollutant adsorption capacity of PP fiber.

Chemical Group	Sorbate	Adsorbent	Conditions	Adsorption Capacity	Ref.
Heavy metal	Cd	Carboxylated PP fibers-ball	Agitated at room temperature for 15 min.	90% of Cd was adsorbed by PP fiber balls	[84]
	Cd	Anion-exchanger chelating fibers (PP)	50 mL cadmium solution, agitated at 150 rpm for 2 h	125.34 mg g^{-1}	[85]
	Au, Hg	Modified PP fabrics	Agitated at 5, 20 and 50 °C from 2 to 120 h	500 mg g^{-1} (Au)	[86]
	Cu, Pb	Dopamine-modified PP fibers	25 °C, pH = 6.8, 180 min	1.28 mg g^{-1} (Cu), 1.73 mg g^{-1} (Pb)	[87]
Organic Pollutants	RhB	PP fibers	25 °C, pH = 7.0, 12 h	17.4 mg g^{-1}	[88]
	Oil	PP nanofibers	Soaked in oil long enough	It can absorb oil more than 60 times its own weight.	[89]
	Toluene	PP melt-blown nonwovens	20 g PP loaded into adsorption column at 25 °C and 5 m s^{-1}.	13.12 g g^{-1}	[90]
	Parabens	Amphiphilic functionalized PP fiber	Added to parabens (35 mL, pH = 7) and stirred for 24 h.	138.4 mg g^{-1}	[91]
Bacteria	Bacillus licheniformis, Bacillus subtilis	Modified PP (MPP) fibers	Incubated for 24 h on a shaker at 30 °C at 170 rpm	Bacteria can be adsorbed	[92]
Virus	Adenovirus	Ionic surface active PP fibers	Place 5, 10, 20, 40 min at room temperature, add 200 µL culture solution	Viruses can be adsorbed	[93]

4.2. Adsorption and Accumulation of Pollutants in PP Fiber

During COVID-19, the disposal of masks contaminated with a deadly infectious virus has become a huge and widespread problem. In addition to the direct harmful effects by the viruses, the MPs released from the masks can also serve as a carrier for harmful microorganisms and pollutants and may result in more serious indirect effects [94]. It has been found that hydrophobic organics, dyes and antibiotics could be well absorbed by MPs in water [95]. As shown in Table 3, there have been many studies on the adsorption of heavy metals by PP fibers and their modified materials in the environment. Zou et al. [84] showed that PP fibers had a strong adsorptive capacity for heavy metals and could absorb the metals in the soil into their own structure. After the anion exchange modification treatment, the adsorption capacity of the PP fiber for Cd became greater to adsorb more heavy metals in the soil. In addition, the adsorption capacity of the fibers was found proportional to the temperature [85]; higher absolute values of ΔG (the Gibb's free energy) were obtained at higher temperatures. Ehrhardt et al. [86] used PP fibers to adsorb gold or mercury ions at three temperatures of 5, 20 and 50 °C, and found that the highest adsorption capacity could be obtained at 50 °C for both gold and mercury ions. In addition, only little adsorption competition could be observed between the two ions. According to the experimental results, the adsorption of heavy metals by PP fibers corresponds more closely to the Freundlich isotherm, which suggests that the adsorption of heavy metals by PP fibers would be a multilayer adsorption [85]. In fact, a change in the hydrophilicity and hydrophobicity in the PP surface can also improve the ability to adsorb heavy metals in water [85].

These contaminants adsorbed by mask-origin microplastics will be transferred to the environment and organisms. For example, the contaminants, such as those attached to the surface of the microplastics, will undergo widespread transport along with the microplastics under wind and hydrodynamic conditions [96], and eventually, spread through the food chain [97].

Not only heavy metals but also organic substances are easily adsorbed by PP fibers. A variety of hydrocarbons released via oil spill, which often happens in the ocean, can also be easily adsorbed by MPs, including PP. Existing studies have shown that nano-PP fibers can absorb motor oil 60-times higher than their own weight through the combination of hydrophilicity, capillary action and surface tension [89]. Polypropylene nonwovens, on the other hand, can remove 90.4% of the toluene from wastewater within ten minutes. The main adsorption mechanism is based on a strong capillary action [91]. In addition, Xu et al. [88] found that PP fibers had a high adsorption capacity for dye molecules and that the adsorption followed the Langmuir isotherm, suggesting that the adsorption would correspond to mono-layer adsorption. If the surface of PP is modified with hydrophilic polyamines and hydrophobic linear alkyl groups, the adsorption of organics by PP microfibers would follow the Freundlich isotherm. In the aqueous environment, disposable medical masks can act as a carrier of dyes (methylene blue, crystalline violet and malachite green) and the heat treatment of the masks will result in a carbonaceous material with a higher adsorption capacity for dye molecules [95]. Therefore, reusing masks and their microplastics after some treatment as efficient adsorbents for organic pollutants in the environment would serve as a safe and environment-friendly way to dispose of mask waste.

As aforementioned, the MPs released into the environment can adsorb surrounding pollutants and transport them to other places. There is also the potential for adsorption to viruses and microorganisms to provide a stable living environment. Existing studies have shown that PP fibers can absorb part of the adenovirus due to their large specific surface and pore structure [93]. At the same time, due to the larger specific surface and the easily modified fiber structure, the ability of PP fibers to adsorb bacteria, if coated with chitosan, can be increased ten-fold [92].

It is reported that about 92% of MPs in the air are fibrous MPs. These MPs can remain unaffected by weather and meteorological conditions and can travel 95 km in mild wind [39]. According to a study performed in China, the annual mass of MPs suspended in the air in Shanghai, China, was estimated around 121 kg [98]. In fact, it is easily expectable that more fibrous MPs are present in indoor air. Another study reported that a man could inhale up to 272 MP particles per day [99]. Given that masks are commonly used in our daily life under this COVID-19 pandemic, the control of MPs is crucial. If MPs are not well controlled, the viruses that adhere to the surface of the MPs can potentially migrate over a long distance due to the relatively stable microenvironment formed on the MPs. In addition, due to the large adsorption site provided by an MP, a higher biodiversity could be observed in the surface of MPs than that in the natural environment [16]. These microorganisms will secrete extracellular polymers containing lipopolysaccharides, proteins and nucleic acids to form a biofilm on the surface of MPs [100]. On the one hand, the formation of biofilm can facilitate microorganisms to survive under dry or nutrient-poor conditions. On the other hand, biofilm can offer a new platform for virus attachment and improve the viral survival rate and survival time [42].

5. Concluding Remarks and Future Prospects

Many efforts have been made in recent years to reduce pollution from plastic refractory products. At the same time, however, people have ignored the ubiquitous pollution by used masks. Due to the impact of the COVID-19 epidemic, our demand for masks far exceeds any other time in history. Most people, however, only know the fact that masks can protect them from infection but ignore the potential risk caused by used mask waste. If handled improperly, it leads to an unimaginable environmental problem. Tens of thousands of used masks are disposed of around the world to release microfibers and potentially toxic environmental pollutants. Compared to masks that are visible to the naked eye, these released mask-origin MPs are suspended in the air and water and ingested by animals or humans, potentially resulting in a serious impact on the ecosystem.

Microplastics have a large specific surface area and porosity, whereby the various pollutants, bacteria and viruses in the environment can be easily adsorbed on the surface of the former, which further increases the environmental toxicity of MPs. At the same time, it should be kept in mind that MPs can extend the survival time of viruses and increase the range of virus migration. Inappropriate disposal of mask waste will pose a challenge to the epidemic prevention in severely affected areas, which cannot be neglected. In order to design a safer and more appropriate disposal method for mask waste, two tasks should be carried out. First of all, we need to fully understand the current amount and source of mask debris. However, so far, only limited information is available, even on a small scale. Understanding the amount and source of mask waste worldwide is the starting point for all subsequent works. Second, we need to understand the ability of mask waste to release MPs and their migration into the environment. So far, some researchers have studied the ability of a mask to release MPs. However, still, a limited number of studies have been reported due to a lack of standard methods for measuring MPs in the environment and high testing costs for the measurement. In addition, there is currently no research showing how these released fibrous MPs affect living organisms and how they migrate though the environment. In order to overcome the increasingly serious pollution by mask-origin MPs, understanding their environmental toxicity and migration is currently the most important task.

Given the ecological toxicity caused by mask waste, we propose several tasks for the future. In order to study and account for the effects of mask pollution on the environment, future research must consider the following issues. So far, only a limited number of studies have been carried out on MP pollution caused by mask waste, so we do not yet understand the post-release effects of PP microfibers on organisms. We need to understand what kinds of stresses can be caused to organisms if these uptake MPs or microfibers. In addition, we need to understand whether aging affects the physical and chemical properties of the MP fibers from the mask, thereby increasing their toxicity.

Future research should consider the compounding toxic effects of released microfibers in different environments, too. In real life, there can be heavy metals and other organic pollutants in the places where used masks are disposed of. The released MPs will adsorb the surrounding pollutants due to their hydrophobicity and large specific surface area, which may lead to more serious pollution. When masks release MPs into the environment, they inevitably get combined with other pollutants to enhance their toxicity.

The release of additives from manufactured masks needs to be explored. Recently reported research has confirmed that the MPs from masks contain a number of surfactant molecules, dye-like molecules and other substances. To study the environmental toxicity of mask-origin MPs, it is necessary to understand the process of releasing these toxic additives over time.

If the masks used by some SARS-CoV-2-infected patients are not handled properly, the viruses attached to the mask MPs can spread into the air and water, posing a major public health hazard. At the same time, it must also be checked whether the MPs from masks can also absorb viruses originally present in the air and facilitate the migration and enhanced survival rate of the virus. The increasing amount of mask waste in the environment poses a threat to the ecosystem and human health that cannot be ignored. Therefore, we need to treat mask waste and mask-origin MPs as a serious environmental problem and urgently undertake more research on mask waste and its MPs and their fate in the environment.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14152403/s1, Figure S1: (a) Demand for masks in countries around the world; (b) emissions of masks in various coastal countries.

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