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Face masks: protecting the wearer but neglecting the aquatic environment? - A perspective from Bangladesh

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ABSTRACT

In Bangladesh, as with many countries, the spread of COVID-19 made the wearing of single-use face masks, a non-pharmaceutical intervention to reduce viral transmission, surge in popularity amongst the general population. Consequently, irresponsible discarding of used masks into the environment, and mismanagement of the waste they produce, is potentially placing a large pollution burden on aquatic ecosystems in the country. Slow degradation of mask-derived polypropylene and polyethylene fibres creates large reservoirs of microplastic pollutants and these have acute and chronic effects on aquatic organism physiology. Using literature reviews, extrapolation of published data, and field observations, we present an emerging issue of pollution from COVID-19 personal protective equipment such as face masks in Bangladesh. We have estimated the volume of waste generated and document the potential consequences of its improper disposal, and subsequent degradation, in aquaculture ponds within country. In a field survey of 30 ponds in the Muktagacha upazilla, 76.7% were found to have plastics in contact with the water, or within 1m of the pond, and there was an average of 63 pieces of macro-plastic pollution per $5m^2$. This included floating discarded face masks. Bangladesh has a rich freshwater and marine resource which it depends upon for export trade, nutrition of the population, and jobs. To mitigate potential acute and chronic impacts on aquaculture and the environment, recommendations are made that, if adopted, would reduce entry of microplastics into the aquatic environments via face mask waste mismanagement.

Outline of the paper

In this paper we introduce and compile information surrounding a potential unintended consequence of COVID-19, namely the long-term accumulation of microplastics within the aquaculture environment of Bangladesh, and potentially the final consumed product. Relevant information was gathered by literature review, extrapolation of data from previous studies, and from preliminary field studies performed around aquaculture systems in country. The reader is directed to the supplementary materials for specific details on the methods employed.

COVID-19, the increase in plastic waste, and the threat to the aquatic environment

Almost all countries of the world were hit hard at the end of 2019 by the emergence of a novel flu-like coronavirus (SARS-CoV-2; the causative agent of COVID-19), which has interrupted normal activities of public life ever since (Hasan and Haque, 2020a; Zhou et al., 2020). With the most prevalent symptoms of breathlessness, agitation, drowsiness, pain, and delirium (Lovell et al., 2020), at the time of writing there were no efficacious pharmaceutical measures for prevention or treatment[1] and every country is following non-pharmaceutical interventions (NPIs) to control spread (Ferguson et al., 2020; Hasan and Siddik, 2020). Hand washing, wearing face masks and maintaining social distance have been identified as the most effective NPIs measures against COVID-19 and are recommended as the "new normal" (Kobayashi et al., 2020; Ngonghala et al., 2020; Vieten, 2020).

As in all other countries across the world, the government of Bangladesh mandated a shutdown with social distancing on the 26th March 2020 as a precautionary measure for safeguarding its population (Bodrud-Doza et al., 2020; Sakamoto et al., 2020). Unfortunately, in many places of Bangladesh, for example the Dhaka megacity, it was practically impossible to maintain interpersonal distancing and difficult to enforce people to stay at home, (Ahmed and Yunus, 2020; Anwar et al., 2020; Shammi et al., 2020). Promoting awareness for about 1.1 million slum dwellers, located near the megacity, was an additional major challenge that was almost impossible to realize (Ahmed et al., 2020; Anwar et al., 2020; BBS, 2015). The major socioeconomic bur-

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[1] Since submission treatments such as dexamethasone have been identified and vaccination programmes have started.

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Table 1
Face mask use and the estimated waste they generate due to the Covid pandemic in selected countries[a].

Country	Population (million)	Total mask use (Million Units)		Estimated waste production from face masks (Millions MT)[b]	
		Per Day	Per Person	Per 30 Days	Per 30 Days Per Person
South Africa	5.9	31.8	5.39	3510	595.0
France	65.3	42.8	0.66	4728	72.4
Iran	84	51.1	0.61	5638	67.1
Ukraine	43.7	24.1	0.55	2665	61.0
Kazakhstan	18.8	8.7	0.46	962	51.2
Indonesia	273.5	122.5	0.45	13,528	49.6
Nigeria	206.1	85.8	0.42	9468	46.0
Philippines	109.6	41.2	0.38	4549	41.5
Bangladesh	**164.7**	**51.4**	**0.31**	**5672**	**34.5**
India	1380	386.4	0.28	42,659	30.9
Pakistan	220.9	61.8	0.28	6828	30.9

[a] Information adapted from Nzediegwu and Chang (2020).
[b] Assumed 3.68 g waste from a single-use face mask with packaging material (from Allison et al. (2020).

dens posed by the pandemic, and drop of GDP growth rate from 7.9% (2019) to 2.0% (2020) (IMF, 2020) forced the government to rethink the strategy of 'dying at work or dying from no work'. In late May 2020, lockdown was eased and masking the face in public places became mandatory, except in educational establishments, and was adopted as a preemptory non-pharmaceutical solution to limit the spread of the virus (Ahmed and Yunus, 2020).

A recent report published by The Economist (2020) revealed that, since the emergence of the pandemic, the use of NPIs has become widely accepted by both health-care professionals and the general public, with the latter inexperienced users more likely to dispose NPIs incorrectly. No other pandemic has impacted countries in differing ways concerning the use, and disposal, of face masks. As shown in Table 1, varying levels of mask usage, and therefore potential waste, has been recorded, the result of different mandatory and voluntary regulations and levels of social acceptance. In countries like Japan, the use of face masks is a more culturally adopted practice and the people are considerably more adept at their use and disposal (Li, 2017; Miyazawa and Kaneko, 2020). By contrast, masking the face for the general population in south Asia, including Bangladesh, is relatively novel. Disposal of these NPIs usually ends up in municipal landfill, but NPIs may enter watercourses either directly via inconsiderate disposal, or indirectly through municipal runoff from waste sites. As a consequence, in Bangladesh single-use NPIs represent a potential additional 11 million MT of plastic waste entering the waste stream, exacerbating the problem of plastic pollution in marine and freshwater environments.

Among the different NPIs disposed, single-use face masks, gloves and bottles of hand sanitizer, termed "Covid waste" have been listed as potential sources of microplastics (Aragaw, 2020; Fadare and Okoffo, 2020). Since these single-use NPIs are typically disposed without any formal recycling procedure, and with microplastics (MPs) being released during their degradation, they are likely to be an increasing threat to human and aquatic health (Sana et al., 2020).

A recent survey carried out by Hiemstra et al. (2021), presented an overview of cases of entanglement, entrapment or ingestion of *Covid waste* (termed Covid 19 litter in the paper) by animal life. Using a web-scraping approach they identified 28 cases, reported in English or Dutch, relating to issues with gloves and face masks. Of these 24 (86%) were from discarded face masks and their inconsiderate disposal affected a wide range of animals such as dogs, gulls, swans, coots, penguins, shore crabs, bats, hedgehogs, macaques, fish, and the common octopus. Furthermore, between May and June 2000, 86 gloves and 17 masks found littering the Netherlands were collected (Groot, 2020) and the annual beach clean in the UK reported 30% of beaches littered with discarded PPE (Riglen, 2020). More worryingly, even on beaches on uninhabited islands such as the Soko Islands, Hong Kong, discarded face masks have already been found (Kassam, 2020). Such studies reveal the presence and upward trend of the problem for terrestrial and aquatic environments.

Between 1950 and 2015, the world plastic production has increased about 200 times from 2 million metric tonnes (MT) to 381 million MT (Ritchie and Roser, 2018). In Bangladesh alone, about 0.82 million MT of plastic waste is produced annually by all the cities, with one fourth (0.21 million MT) discarded into the marine environment. The trend appears to be showing a rapid increase and by 2019 the amount of discarded plastic in the marine space had increased to 17.52 times that recorded just five years previously (Waste Concern, 2019). In order to reduce this burden, the honorable High Court of Bangladesh recently issued an order commanding concerned authorities to ban single-use plastic products in coastal areas, hotels, motels and restaurants (Holy, 2020). However, the sudden rise of this "new normal" situation has placed this order into doubt with increasing demand of these single-use NPIs for healthcare purposes.

Types of face masks used by Bangladeshis to tackle COVID-19

Field observations by the authors have revealed a wide variety of masks are in use in Bangladesh, ranging from high quality certified masks (e.g. N95) to low quality cloth made masks (Table 2). Choice and use of masks are highly influenced by factors such as the propensity to use face-coverings, affordability, quality, price and mask availability (Personal observation). Certified masks, used by professional health workers, tend also to be used by wealthier individuals in Bangladesh, although KN95 masks produced in China are also affordable to the middle classes. However, most middle-class and working-class individuals use locally produced, single-use surgical masks or cloth-made non-surgical masks, whereas those in extreme poverty use face-coverings made from available free materials such as tissue paper or strips of fabric from clothes such as old t-shirts.

Prior to the government's enforcement of face mask use in Bangladesh, many in the population started to wear them in public, even though the lack of availability drove up their price. This was driven largely from fear perpetuated by the growing mortality rate due to COVID-19 in China and the western world (Islam et al., 2020). The slowing down of the worldwide mortality rate between May to October of 2020 including Bangladesh (JHU, 2020), publication of stories questioning the efficacy of the ability of face masks to protect against droplets (Feng et al., 2020) and therefore their nationwide use (Mantzari et al., 2020), along with the financial impact of furloughing of the middle and working-classes, resulted in increasing numbers of people reducing face mask use (Bodrud-Doza et al., 2020; Mantzari et al., 2020). This trend

Table 2
Categories of available face masks in Bangladesh with their product features, market price and main user groups .

Types of Masks	Mask features	Price per unit*	Main users
Certified respirators			
N95	➢ NIOSH approved; close facial fit. ➢ Efficient filtration of airborne particulates protecting the face from liquid contamination. ➢ 4 ply - outer and inner layer composed of spun-bound PP while third layer composed of melt-blown PP following by polyester for the 2nd layer. ➢ Thermoplastic straps with aluminum nose clip and polyurethane nose foam.	5.66 USD[1] (480 BDT)	Health workers, Upper class[2]
KN95	➢ GB 2626 standard; close facial fit. ➢ Prevention of transmission of small particulates such as bacteria, smoke, or dirt. ➢ 3 ply - composed of electrostatic melt blown cloth layer, spun bound PP layer and electrostatic cotton filter with aluminum nose pin and elastic strap.	0.18 USD (15 BDT)	Upper class, middle class[3]
FFP2	➢ EN 149 standard (CEN approved); good facial fit. ➢ Efficient as N95 for particulate transmission prevention. ➢ 4 ply - composed of non-woven PP outer two layers, melt blown PP 3rd layer and a soft inner cotton layer with plastic valve and thermoplastic strap.	11.8 USD (1000 BDT)	Health workers, Upper class
Carbon face mask	➢ Indonesian National Standard; close facial fit. ➢ Prevents transmission of airborne contaminants and smoke. ➢ 3 ply - spun bound PP outer layer, melt blown PP inner layer and activated carbon layer in between.	12.99 USD (1101 BDT)	Upper class
Surgical masks			
Certified surgical mask	➢ NIOSH and CE approved; loosely fitting/tie on mask. ➢ Does not provide full protection from pathogen transmission. ➢ 3 ply - hydrophobic rayon outer web, non-woven microfibre middle layer and PP inner layer with ethylene strip and aluminum nose bridge.	0.29 USD (24.5 BDT)	Health workers
Locally produced surgical mask	➢ Loosely fitting mask; no study on efficiency. ➢ 1–3 ply - made of polypropylene, polystyrene, polyester, polyethylene, and polyacrylonitrile etc.	0.05 USD (3.92 BDT)	Middle class, lower class[4]
Other masks locally produced			
Cloth masks	➢ Not efficient for protection from pathogen transmission. ➢ Made from a wide variety of materials, mainly cotton.	0 – 0.59 USD (0 – 50 BDT)	Lower class

* Average market price for these masks was sourced by the authors from online for delivery in Bangladesh (prices correct at April 2021).
[1] 1 USD = 84.78 BDT.
[2] Daily income more than 20 USD/capita.
[3] Daily income ranges from 2 to 20 USD/capita.
[4] Daily income less than 2 USD/capita.

was only reversed by the second wave of infection hitting many parts of the world and countries entering second lockdowns[2].

Prata et al. (2020) estimates 2.65 billion masks are needed monthly by a population of 160 million habitants in Bangladesh, whereas the Environment and Social Development Organization provided a more conservative estimate of 455 million surgical masks per month (ESDO, 2020). Moreover, ESDO, (2020) estimated that 472.3 MT of daily *Covid waste* production from PPEs will give a rise to 172,402 MT of *Covid waste* in Bangladesh, with 36,987 MT (21.45%) derived just from surgical masks (Fig. 1). Prior to sale in the retail outlet (market, shop, or supermarket), bulk consignments of product are often packaged into small units using another layer of plastic packaging. This additional layer of retail plastic packaging further risks being discarded into the environment without any formal recycling. Researchers have previously shown that globally 18% of plastics wastes are recycled, 24% are incinerated and 58% are either landfilled or find their way into the environment (Geyer et al., 2017). Although these values are for non-fiber plastics, similar values are likely to be true for the *Covid waste* associated with face masks in Bangladesh and this presents a new challenge for waste management. Therefore, where no structured policy and/or legislative framework exists for the management of waste from single-use surgical masks, associated plastic packaging, gloves, bottle of sanitizers and other personal protective equipment from the non-healthcare sector, there is a significant possibility of resultant damage to the environment.

[2] Bangladesh went into a second lockdown on 14th April 2021

Degradation of single-use face masks in the aquatic environment

Single-use, disposable surgical face masks are highly effective at preventing the transmission of airborne aerosols (and pathogens; Ueki et al., 2020) making their use essential during a pandemic. An early indication by the World Health Organization (WHO, 2020) made an estimation of a monthly demand of 89 million face masks just for worldwide health professionals, and as a whole it is expected to be 129 billion (Prata et al., 2020). However, some of the materials they are made from, such as polypropylene (PP) and polyethylene (PE), may pose a threat to terrestrial and aquatic ecosystems. Their composition and routes of degradation in the environment are considered in this section.

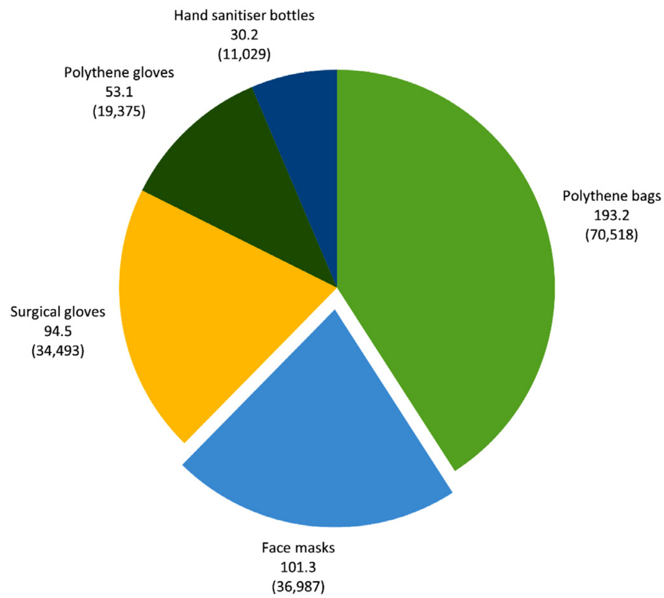

Fig. 1. Estimated non-degradable waste production in Bangladesh, broken down by the most common types of PPEs used. Values shown are metric tonnes per day (MT per year). (Adapted from ESDO, 2020).

Single-use masks are mainly manufactured from different thermoplastic polymers including polyethylene terephthalate; high, low, and linear-low density polyethylene (PE); polyvinyl chloride; polypropylene (PP); polystyrene; nylons; polylactic acid and polyamide. Among these polymers, PP and PE are most popularly used in face masks (Fadare and Okoffo, 2020) and out of the three layers comprising the face mask, PP is generally used in the nonwoven, water resistant and colored outer layer, and in the middle section as the melt gusted component that allows rapid movement of filtered air. The inner layer is typically fabricated from highly dense fibrous PE (Aragaw, 2020). Good material characteristics, ease of processing, low costs and potential recyclability make these two polymers popular to the manufacturers (Pelegrini et al., 2019). As an alternative to PP, manufacturers in Bangladesh also use polystyrene, PE and polyester to reduce their production costs, especially when PP stock becomes limited due to demand.

Mismanaged single-use plastic waste, deposited on land, or in landfill, can find its way to aquatic ecosystems by many routes including weathering, aging, and microbial degradation. Eventually the plastic reaches the oceans via rivers, and other water courses, and under specific ocean currents can produce marine “garbage patches” (Castro-Jiménez et al., 2019). During this journey, the face mask or other plastic wastes, will undergo fragmentation and degradation, changing in size from the macro scale debris (≥ 5 mm) through to micro (< 5 mm) and finally to nano (1–100 nm) size debris (Vered et al., 2019; Xu et al., 2020). By existing in a wide range of particle sizes they are therefore accessible to a wide range of organisms and ecosystems, with the potential to exert damaging effects (Ríos et al., 2020).

The fate of the plastic components of a disposed face mask depends on the composite materials and the nature of environment they are exposed to. Improperly disposed face masks are likely to pose a bigger problem for the aquatic environment when compared to the terrestrial environment. A study conducted by Chamas et al. (2020), pointed out that plastics in the soil will degrade more readily compared to those exposed directly to the aquatic environment. This was mainly due to the temperature variation between these two thermal divergent ecosystems. Furthermore, the water absorption capacity, and subsequent partial submergence of face masks in an aquatic environment, will further slow their degradation compared to other pieces of floating plastic. Partial or complete water coverage decreases the incident light on the material and therefore photooxidation is more limited (Leonas and Gorden, 1993).

The vertical range within the water column that plastic polymer fibres occupy is dictated by their density, surface area and particle size (Chubarenko et al., 2016; Kowalski et al., 2016). Both PP and PE are categorized as low-density polymers [PP: 0.90 – 0.91 g/cm^3, PE: 0.91 – 0.97 g/cm^3 (Schwarz et al., 2019)] and are typically buoyant in freshwater and seawater (Cole et al., 2011). However, the increasing demand for face masks has driven producers to switch toward talc-filled PP, instead of pure PP, which increases the particle size distribution, and thereby reduces the cost, with only a marginal impact on filter efficacy. By converting the PP to a high-density (HD) polymer [0.97 – 1.25 g/cm^3] this results in HD polymers occupying a larger vertical range within the water column, due to enclosed air pockets, following disposal. In addition, different local environmental factors, such as storm and water turbulence, cause the polymers to sediment and propagates a cycle of submerging and re-suspension behavior (Andrady, 2011; Cole et al., 2011; Lattin et al., 2004). Biofouling can also cause vertical transmission from pelagic to benthic zones by increasing the density and weight of PP and PE following the adsorption of clay minerals (Besseling et al., 2017; Corcoran et al., 2015).

As a result of the processes outline above, microplastics from PP and PE fibres from degrading face masks can occupy a wide range of niches within the aquatic environment. Previous studies have already documented the presence of the MPs in the gut of different aquatic organisms (de Sá et al., 2018; Jovanović, 2017; Teuten et al., 2007) with evidence of MP presence in the stomach of some commercial fishes (Adeogun et al., 2020). This suggests a transmission route of MPs back into terrestrial ecosystems via predatory birds (Eerkes-Medrano et al., 2015) and even to humans through seafood consumption (Akoueson et al., 2020). In terrestrial and aquatic environments these MP polymers persist for between 100 and 1000 years (half-lives ranging from 50 to 500 years) following their fragmentation and slow degradation from ultraviolet radiation (Yousif and Haddad, 2013), ultrasonic wave action (Kim and Lee, 2002), and other physical, chemical and biological processes (da Luz et al., 2014). Measured MP abundances in freshwater habitats have a very large range from 12,932 per m^3 in the Los Angeles River in the USA (Moore et al., 2011) to less than 1 particle per m^3 in Lake Victoria, Uganda (Egessa et al., 2020). Typically, values are in the order of thousands of MPs per m^3 (see Table 2 from Pan et al., 2020 for comparisons). Discarded face masks could become a major source of MPs in the aquatic environment.

Effect of macro and microplastics in freshwater and marine environments

In general, the problem of plastic pollution in the freshwater environment has received less attention compared to the marine environment, largely because the waste is dominated by macro-sized pieces which pose less threat to the freshwater biota. Nevertheless, as freshwater ecosystems are often adjacent to large sources of discarded plastic, and with less water volume present, the presence of smaller quantities of macro and micro-plastic waste shouldn’t be ignored (Pan et al., 2020). The damaging effects of plastic wastes in aquatic ecosystems and the potential harm to human health is summarized in Fig. 2.

Macro-plastics can be damaging to aquatic biota physically, with examples of fish, invertebrates, birds, mammals, and reptiles, including turtles, becoming entangled by, or ingesting, discarded face masks or other plastics (Caron et al., 2018; Castro-Jiménez et al., 2019; Gall and Thompson, 2015). For large animals they can interfere with breathing and gill structures and hinder swimming (Kögel et al., 2020). This can reduce animal foraging, movement, and therefore food intake and utilization rate in animals, whilst increasing their energy expenditure (Cole and Galloway, 2015). Microplastics can accumulate dissolved organic matter to form microgels (Shiu et al., 2020) which can settle on the benthic regions of the river and ocean, interrupting the food web of

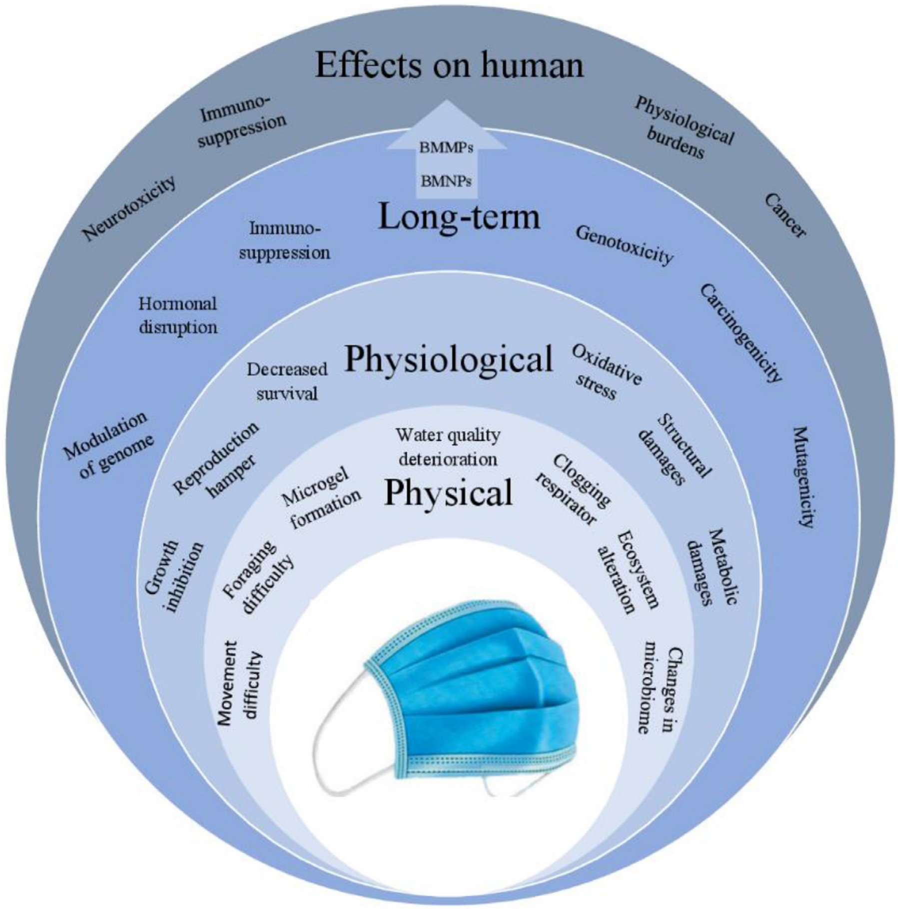

Fig. 2. Potential long-term effects of microplastic pollution on aquatic ecosystems and human health in Bangladesh. The inner three layers present reported effects on the aquatic environment and the outer layer reflected potential effects on humans from ingestion of contaminated animals with biomagnified microplastics (BMMPs) and biomagnified nano plastics (BMNPs) as seafood.

aquatic ecosystems (Cole et al., 2013; Shiu et al., 2020). Microgel formation in aquatic ecosystems are more acute in the marine environment as salinity promotes their formation; and may disturb filter feeding fishes and invertebrates; and over time become threats for humans through the food chain (Shiu et al., 2020). Biofilm formation can also deteriorate water quality, changing the microbiome (Kirstein et al., 2019) and reducing dissolved oxygen concentrations by increased organic material decomposition as the microbial community interacts with it as it would any other substrate (Ogonowski et al., 2018). Furthermore, some polymers such as polystyrene degrade under sunlight to release carbon dioxide and dissolved inorganic carbon further destabilizing the carbon cycle (Ward et al., 2019).

Micro and nano plastics can affect the physiology of aquatic organisms, though in general, there is no definitive evidence to show they are lethal (Franzellitti et al., 2019; Wright and Kelly, 2017). When fish ingest MPs with food or directly with water, gut mucosa become damaged with structural and metabolic disorders as MPs act as heavy metal carriers. In zebrafish (*Danio rerio*) exposed to 40 mg/L MPs in the presence of natural organic matter, MPs were shown to induce copper-toxicity in the liver and gut of the fish (Qiao et al., 2019). Furthermore, nanoparticles (NPs), can be ingested by filter feeder plankton thereby representing another point of entry to the food chain. In freshwater ecosystems several studies have indicated the presence of microplastics in their inhabitants. For example, McNeish et al. (2018) observed an average of 19 microplastic particles for each *Neogobius melanostomus* present in a riverine ecosystem in the USA; Zheng et al. (2019) found 27.4 microplastic particles per redbelly tilapia in riverine ecosystem in China; Li et al. (2020) noted 6.1 microplastic particles in each *Hemiculter leucisculus* in freshwater ecosystems surrounding plastic productions sites in China.

Micro and nano-sized plastics are able to pass through biological barriers (Ganesh Kumar et al., 2020) and persist in organisms. As a result, this pervasiveness allows them to bioaccumulate in food chains through trophic transfer (Browne et al., 2007) and when accumulated into higher animals including fish and mammals, can get translocated to organs, particularly to digestive systems (Hu et al., 2016). MPs have been reported from the stomachs of 56% of aquatic birds (Holland et al., 2016) with a prediction of 99% birds being affected by 2050 (Wilcox et al., 2015). Ingestions of MPs by sea birds can cause gastro-intestinal blockage, internal inflammation, pseudo-satiation, and reproductive difficulties (Carbery et al., 2018; Chen et al., 2019). Bivalves mediated by ciliary movements are extremely sensitive as benthic habitats are the ultimate sinks for micro and nano plastic particles. Researchers found that microplastic accumulated through the gills of bivalves and zooplankton, transferred to digestive systems within 12 h and then to hemolymph and hemocytes within 72 h (Browne et al., 2007), and finally to lysosomal systems (Ribeiro et al., 2017; von Moos et al., 2012). In the case of arthropods, formation of skeleton and arm length are adversely affected by the presence of MPs in water (Della Torre et al., 2014). In an experimental setting, MPs were also found to alter gene expression of fish (Zebrafish larvae exposed to 400 mg/L uPVC over 4 days; Sleight et al., 2017), crustaceans (*Daphnia pulex* exposed to 10 mg/L polystyrene over 1 day; Liu et al., 2019), and bivalves (Mediterranean mussel exposed to 50 mg/L polystyrene over 5 days; Brandts et al., 2018), and at the molecular level, Tang et al. (2018) revealed that MPs, acting as environmental hormones can modulate the physiology of corals. In the long run, toxicity arising from accumulated MPs through ingestion affects the growth, reproduction, and survival of animals (Tang et al., 2018; Yu et al., 2018). Neurotoxicity from nano plastics, in conjugation with genotoxicity and oxidative stress are also reported from many types of aquatic biota, even in coral by Xu et al. (2020), Ding et al. (2018) and Tang et al. (2018). MPs, serving as vector for other potential pollutants like PCBs, PAHs, heavy metals etc. can be carcinogenic and mutagenic to aquatic organisms and can cause hormonal disruption and immune suppression (Xu et al., 2020).

In addition, MPs generally accumulate in muscle, gonad, and the foot of bivalves and other aquatic food organisms (Kolandhasamy et al., 2018) from where biomagnification to human and birds occurs upon consumption. The ultimate effects of biomagnified microplastics in humans is largely unknown. However, MPs may cross the cell membrane and their retention in blood, brain and placenta may pose physiological burdens and immunosuppression to human beings (Häder et al., 2020; Lusher, 2015).

Potential consequences for Bangladesh's aquaculture industry

Aquaculture and fisheries are major protein sources in Bangladesh and represent very important national sectors to feed future generations (Ahamed et al., 2020; Aziz et al., 2021). Recently there has been a boom in aquaculture farming (Rashid et al., 2019), with strong sectors in shrimp and freshwater fish farming. In fact, shrimp farming is the second largest foreign currency sector, with a yearly export production of 40,000MT worth around USD 500 million (DoF, 2017). Overall, in 2018 Bangladesh was the fifth largest producer of aquaculture in the world yielding 2.2 million MT of mainly shrimp, pangasius and tilapia in 2018 (FAO, 2018). The sector is important both financially and for food security.

The fisheries and aquaculture sector of Bangladesh will not be spared from the afore mentioned problems arising from MPs – with the uncontrollable subsistent emerging issue of disease (Chaput et al., 2020; Haque et al., 2021) and this may pose a threat for crustaceans (notably shrimps and crabs), migratory fishes including hilsa, and freshwater fish cultured in ponds and cages. This will put the shrimp industry, the most flourishing sector of Bangladesh, under pressure as breeders and extensive farmers depend open waters for brood stock and post-larvae respectively (Hasan et al., 2020; Hasan and Haque, 2020b). It could also impact the important finfish aquaculture sector which supplies a significant amount of protein for national nutrition.

In order to understand the potential of macro and micro plastics to enter the watercourses used in aquaculture premises in Bangladesh, a field survey of production ponds was carried out in Muktagacha, Mymensingh. In total, 30 ponds were surveyed for the presence of plastic material in or around the grow-out ponds; this could be material used in pond construction, farm management, or discarded litter that had entered the water. In total, 76.7% of the ponds had plastic material that was in contact with the water or within 1 m of the water surface. Examples of discarded plastic waste floating in the ponds was recorded, including the presence of discarded plastic bottles, containers of personal care products, plastic bags from packaged food, leftover packages or containers of used chemicals and discarded face masks, see Fig. 3. The collected data reveals that on average 63 potential sources of microplastics (range was 51 to 106) were found settled on every 5m^2 of the aquaculture ponds within Muktagacha.

Aquaculture products represent a significant proportion of the nutritional supply in Bangladesh, contributing around 56% of national consumption (DoF, 2018). A recent study into the effect of COVID-19 on finfish aquaculture revealed that some farmers were maintaining their stock in ponds for longer periods of time (Hasan et al., 2021), potentially further increasing exposure to MPs. Biomagnification of MPs in aquaculture systems may lead to supply of proteins and lipids contaminated with high levels of MPs threatening a food safety issue, reducing production, and increasing consumer's negative attitudes towards aquaculture. At present, the presence of microplastics in aquaculture products, either shrimp or fish, is not monitored routinely. A reduction in consumer confidence in the product may put the sustainability of the industry at stake.

Recommendations

In light of the set of unique potential problems of microplastics in aquatic ecosystems in Bangladesh, we present here some practical recommendations to mitigate their effects. The recommendations are summarised in Table 3, along with the stakeholders required for implementation, and the potential of their realization.

- At present very little is known about the level of macro and micro plastic pollution within the aquaculture setting in Bangladesh. To generate success criteria for waste reduction schemes in operation, the primary recommendation is to commission field surveys to measure the extent of the problem. To understand the general problem, citizen science approaches using mobile phone apps to gather location and photos of waste could be used to monitor and map the presence of plastic litter in all settings. For aquaculture, a survey via mobile app with the shrimp and finfish farmers is recommended to register macro-plastic levels in their aquaculture units. This would simply build on existing surveys being employed. Furthermore, this citizen science approach could be extended by provision simple equipment to specific farmers enable them to determine microplastic levels; this could be done whilst they are performing water quality checks.
- The use of plastic polymers in face masks should consider the degradation of the polymers in the environment, including potential routes of biodegradation. Ideally, "eco-friendly" 3D filament or wood fibres, or green polymers (e.g. hemp fibres), should be considered as sustainable alternatives for manufacture instead of plastic polymers. However, the efficacy of these fibres in pathogen filtration and sequestration needs to be established before expanding use into the healthcare section.
- For the general public, lower cost, reusable options, such as cloth masks with a high cotton content, should be encouraged as an effective option to stop the spread of COVID-19 (excluding the health professionals). A recent study simulating viral transmission between mannequin "heads" revealed a 20–40% reduction in viral uptake and a greater than 50% decrease in viral transmission for cotton masks (Ueki et al., 2020). This compares to the N95 mask which had a 80–90% reduction of viral uptake and almost completely prevented viral transmission. Thus, the cloth (cotton) mask represents a good balance of being effective at reducing COVID-19 spread whilst causing the least amount of damage to the environment (multiple use and natural fibres). Before reuse, washing masks at 60 °C should be promoted to remove and disable any virus particles. Although washing of materials containing polymers such as viscose can release MPs, reducing the number of single-use, high polymer content face masks would reduce the overall MP burden with little effect on COVID transmission.
- Consumers should be made aware about household disposal of the masks and warning markings should be mandated on the packaging and on the face-mask. This could potentially reduce the number of masks that are incorrectly disposed of.
- The Bangladeshi government should seek to improve their waste management policies, with particular focus on single-use plastics. Disposal in sealed or leak-proof containers, followed by incineration, would reduce contamination routes into water courses. This would need to be balanced against resultant air pollution.
- Technology should be developed to monitor and reduce the level of plastic waste entering water courses. For example, governments can develop new technologies and take the initiative for responsible disposal to optimize the problem of plastic pollution from *Covid waste*. To reduce entry into water courses, different waste captur-

Fig. 3. Examples of plastic litter in aquaculture ponds in the Muktagacha upazilla of Mymensingh district, Bangladesh. Pictures were taken in April 2021.

Table 3
Summary of recommendations and potential implementation.

	Recommendation	Implementation	Stakeholders	Potential
R1	Plastic pollution survey in Bangladesh aquaculture systems	• Use existing structures to deliver survey to farmers	• Government (DoF) • Farmers	High[a]
R2	Production of more biodegradable masks	• R&D on potential materials and their effectiveness • Government policy to regulate material use	• Manufacturers • Government	Low[c]
R3	Promotion of mask reuse by the general-public	• Education campaign	• Government	High
R4	Consumer packaging warnings	• Government policy to ensure disposal of items is considered	• Government • Manufacturers	Medium[b]
R5	Upgrade of government waste policies	• Government policy to consider and manage increase waste stream	• Government	Medium
R6	Technological monitoring of waste-water for MPs	• Government policy from R5 to require monitoring. • Technology embedded into waste infrastructure	• Government • Technology providers	Low

c

[a] High – could be implemented quickly.
[b] Medium – requires policy changes but once these are in place implementation could be quick.
[c] Low – requires significant policy and implementation time.

ing technologies like Storm Drain Inlet Trash Capture Technologies, In-Line and End of Pipe Trash Capture Technologies or Open Water Trash Capture Technologies should be installed in the municipal drains and entry points to rivers to minimize plastic entry to aquatic environment (EPA, 2016).

Hopefully by adopting some, or ideally all, of these recommendations Bangladesh can ensure that the impact of COVID-19 does not result in a legacy of microplastic pollution of the aquatic environment on which much of the population relies on for their nutrition and livelihood.

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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Note that the opinions expressed in this article are those of the contributing authors and are not necessarily those of the institutions within which they work.

Supplementary materials

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