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Estimating marine plastic pollution from COVID-19 face masks in coastal regions

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ABSTRACT

Face masks are playing an essential role in preventing the spread of COVID-19. Face masks such as N95, and surgical masks, contain a considerable portion of non-recyclable plastic material. Marine plastic pollution is likely to increase due to the rapid use and improper dispensing of face masks, but until now, no extensive quantitative estimation exists for coastal regions. Linking behaviour dataset on face mask usage and solid waste management dataset, this study estimates annual face mask utilization and plastic pollution from mismanaged face masks in coastal regions of 46 countries. It is estimated that approximately 0.15 million tons to 0.39 million tons of plastic debris could end up in global oceans within a year. With lower waste management facilities, the number of plastic debris entering the ocean will rise. Significant investments are required from global communities in improving the waste management facilities for better disposal of masks and solid waste.

1. Introduction

Currently, the world is facing a major catastrophe due to the emergence of pandemic COVID-19. Due to its high contagiousness, the global community has adopted preventive measures to control its transmission and spread. One of the effective measures adopted by health workers and the general public throughout the world is the use of face masks. To prevent the transmission of the COVID 19 virus, several countries adopted the use of facemasks early, while others adopted it late. World Health Organization (WHO) also listed the use of facemasks in its guideline to stop the spread of the virus in public places (Worby and Chang, 2020). The global mask production rate has seen tremendous growth and will continue to rise in the upcoming years. As an example, globally, China is the major producer of global face masks. Face mask production in China increased to 116 million per day in February 2020, 12 times higher than usual (Adyel, 2020). The global face mask market's value rose from 0.79 billion USD in 2019 to approximately 166 billion USD in 2020 (Phelps Bondaroff and Cooke, 2020). However, what proved to be an effective approach to slow down the transmission rate has now transformed into a severe environmental threat. Almost every country is prioritizing protecting public health over environmental health, which has badly affected policies regarding decrease usage of single-use plastics (Patrício Silva et al., 2020). Single-use face masks contain a significant portion of a polymer material such as polyurethane, polycarbonate, polypropylene, polystyrene, polyacrylonitrile, polyethylene, or polyester (Fadare and Okoffo, 2020). With the rise in both consumption and production of face masks, the management of these used masks has become a global concern. The waste management system in developed and developing countries is not properly designed to handle solid waste and current pandemic waste (Aragaw, 2020). Although local and international authorities have framed many policies for the safe disposal of COVID wastes, their mass implementation has become challenging and daunting for authorities (Van Fan et al., 2021). As a result, inadequately managed masks thrown into the environment find their way into solid waste and act as a possible medium of transmission (Kampf et al., 2020; Klemeš et al., 2020). Inadequate management of only 1% of face masks may contribute to waste of 30,000–40,000 kg per day (World Wildlife Fund, 2020). Apart from this, these face masks, under environmental conditions, break down into smaller sizes (less than 5 mm) particles and contribute to microplastic pollution (Zambrano-Monserrate et al., 2020). These particles enter both fresh water and coastal environments and poses a severe threat to the aquatic environment and lives (Gall and Thompson, 2015). Being small in size, these particles are easily accessible to marine organisms and enter into the food chain. Microplastic is already found in shellfish and other fish species (Smith et al., 2018). Consumption of microplastics pose severe detrimental effects on human health, such as chromosome

Nomenclature

CP	coastal population
HIC	high income class
IMW	inadequately managed waste
LIC	low income class
MW	mismanaged waste
MSW	municipal solid waste
PPE	personal protective equipment
SM	surgical mask
UMC	upper middle class

Table 1
Data on demography of coastal population and face mask acceptance across the globe.

Countries	Total population 1000 people	Coastal population 1000 people	Coastal Length Km	Coastal population %	Face mask acceptance %
Bangladesh	169,775	93,037	3306	54.8	63
China	1,424,548	341,892	30,017	24	84
Indonesia	272,223	261,062	95,181	96	78
India	1,383,198	363,781	17,181	26.3	80
Vietnam	98,360	81,442	11,409	82.8	91
Sri Lanka	21,084	21,084	2825	100	80
Philippines	109,703	109,703	33,900	100	90
Thailand	69,411	26,862	7066	38.7	86
Myanmar	54,808	26,856	14,708	49	80
Pakistan	208,362	18,961	2599	9.1	68.8
Malaysia	32,869	32,212	9323	98	87
Japan	126,496	121,815	29,020	96.3	83
South Korea	25,841	23,774	4009	92	84
Norway	5450	5199	53,199	95.4	23
Russia	143,787	138,076	110,310	14.9	60
United Kingdom	67,334	66,392	19,717	98.6	71
Spain	46,459	45,861	7268	67.9	95
Sweden	10,122	8877	26,384	87.7	5
France	65,721	26,026	7330	39.6	88
Germany	82,540	12,051	3624	14.6	69
Italy	59,132	46,773	9226	79.1	94
Greece	11,103	11,014	15,147	99.2	80
Ireland	343	343	6437	99.9	83
Finland	5580	4062	31,119	72.8	52
Denmark	5797	5797	5316	100	62
Netherland	17,181	16,047	1914	93.4	75
Belgium	11,620	9645	76	83	85
Portugal	10,218	9472	2830	92.7	87
Romania	19,388	1221	696	6.3	87
Saudi Arabia	34,710	10,482	7572	30.2	83
Iran	83,587	19,977	5890	24	64
UAE	9813	8331	2871	85	88
Nigeria	206,153	52,981	3122	25.7	90
South Africa	58,721	22,843	3751	39	78
Turkey	83,836	48,206	8140	57.5	82
Israel	8714	8417	205	96.6	78
USA	331,432	143,510	133,312	43.3	73
Canada	37,603	8987	265,523	24	78
Argentina	45,510	20,525	8397	45.1	85
Brazil	213,863	103,937	33,379	48.6	50
Chile	18,473	15,055	78,563	81.5	86
Colombia	50,220	15,016	5874	29.9	88
Australia	25,398	22,808	66,530	89.8	32
New Zealand	4834	4834	17,209	100	70
Mexico	133,870	38,421	23,761	28.7	82
Costa Rica	5044	5044	2069	100	87

alteration, obesity, cancer, and infertility, to name a few (Sharma and Chatterjee, 2017). The presence of face masks is already found in many oceans, beaches and freshwater systems (Ardusso et al., 2021; De-la-Torre et al., 2021). Microplastic in the aquatic environment raises concern for public health as ocean and freshwater constitute a significant part of the global food chain. Moreover, plastic materials take longer a time to decay, and these materials will remain in the environment for centuries. Researchers carried out several analyses to estimate plastic debris in the ocean. Jambeck et al. (2015) estimated plastic waste generation for 192 coastal countries in 2010 and found that approximately 4.8 to 12.7 million metric tons (MMT) of debris had entered the global oceans. Law et al. (2020) estimated that in 2016 United States alone contributed five times higher plastic debris into the ocean than in 2010 (0.04–0.11 MMT). Lebreton and Andrady (2019) projected plastic waste generation till 2060 and reported that 91% of mismanaged plastic waste is transported via rivers to oceans. Lebreton and Andrady (2019) also reported an annual input of 5.1 million tons of plastics from land into oceans. The emergence of the COVID pandemic and the increasing usage of PPE and face masks have increased challenges in plastic waste management, especially for developing countries. However, thus far, no quantitative estimates exist on how much plastic will enter into oceans

Table 2
Income status, percentage of Plastic, Inadequately managed and mismanaged waste of selected countries (Law et al., 2020).

| Countries	Income status	%Plastic in MSW	% IMW	% MW
Bangladesh	LMC	4.67	94.75	96.75
China	UMC	9.8	23.25	25.25
Indonesia	LMC	14	58.5	60.5
India	LMC	9.5	77	79
Vietnam	LMC	12.15	62	64
Sri Lanka	LMC	7	85	87
Philippines	LMC	10.55	72	74
Thailand	UMC	17.59	60.25	62.25
Myanmar	LMC	11.5	100	100
Pakistan	LMC	9	70	72
Malaysia	UMC	15	17.88	19.88
Japan	HIC	11	13.3	15.3
South Korea	HIC	24.3	0	2
Norway	HIC	2.25	1.42	3.42
Russia	UMC	14.21	95.5	97.5
United Kingdom	HIC	20.2	2.572	4.572
Spain	HIC	9	0	2
Sweden	HIC	6.58	0	2
Ukraine	LMC	7	47.04	49.04
France	HIC	9	0.02	2.02
Germany	HIC	13	2.02	4.02
Italy	HIC	11.6	11.02	13.02
Greece	HIC	14	1	3
Ireland	HIC	12.4	3	5
Finland	HIC	1.45	0.01	2.01
Denmark	HIC	1.61	0.02	2.02
Netherland	HIC	14	0	2
Belgium	HIC	13.94	2.26	4.26
Portugal	HIC	10.72	0	2
Romania	UMC	12.33	30.53	32.53
Saudi Arabia	HIC	11	0	2
Iran	UMC	8.5	72.3	74.3
UAE	HIC	19	62	64
Nigeria	LMC	4.8	80	82
South Africa	UMC	7.9	0	2
Turkey	UMC	3	45	47
Israel	HIC	18	0	2
USA	HIC	13.1	0.99	2.99
Canada	HIC	3	0	2
Argentina	HIC	14.61	22.6	24.6
Brazil	UMC	13.5	23.21	25.21
Chile	HIC	9.4	13.8	15.8
Colombia	UMC	12.83	4	6
Australia	HIC	7.61	0	2
New Zealand	HIC	8	0	2
Mexico	UMC	10.9	21	23
Costa Rica	UMC	11	9.1	11.1
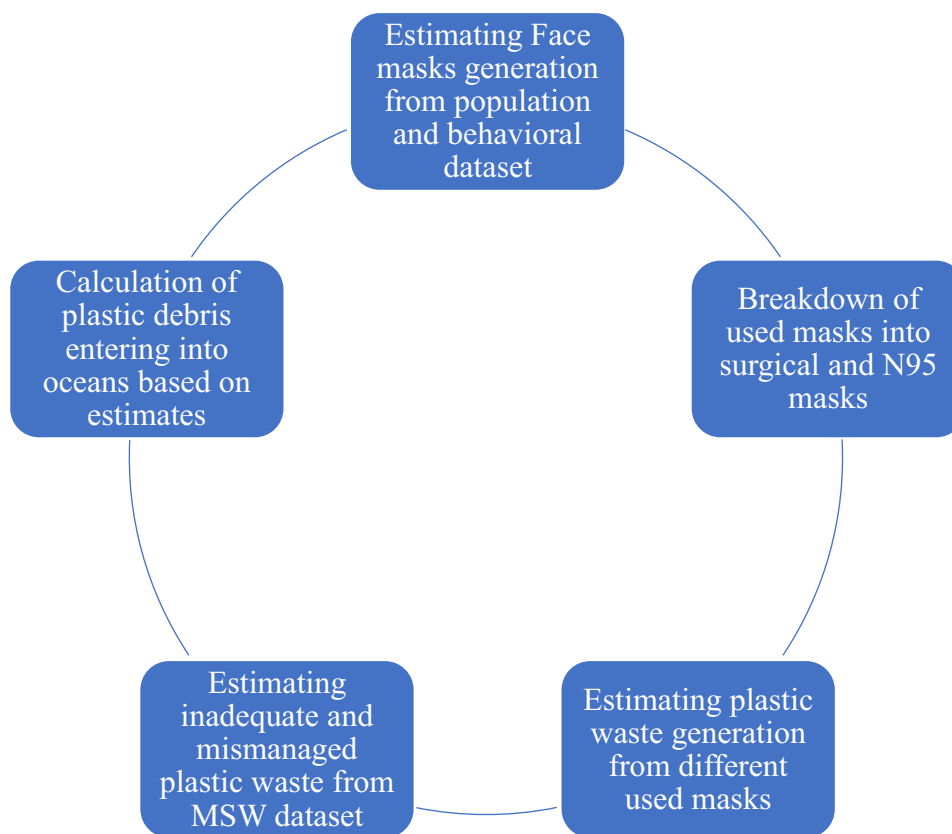
Fig. 1. Methodology adapted in the current study.

from used face masks. This analysis aims to estimate plastic debris entering oceans from disposable face masks used by the coastal population in 46 countries based on the coastal population, their behavioural dataset (usage of face masks), and existing waste management practices. Only two types of masks are considered (N95 masks and surgical masks), as their acceptance rate is higher among health workers and the general public. Daily and annual, face mask generation and mismanaged plastic waste from single-use masks are estimated. We hope that the estimation will shed light on the ongoing plastic waste generation and the detrimental impact of mismanaged face masks on the environment.

2. Material and method

2.1. Estimating face mask usage by coastal population

Daily face mask usage depends on coastal population percentage, mask acceptance rate by the general population, and the number of face masks used by an individual. Eqs. (1) and (2) estimates the daily and annual face mask usage by the coastal population (Sangkham, 2020, Akber Abbasi et al., 2020).

$$DFU = Coastal_{population} \times CP_{percentage} \times Mask_{accaptamce} \times \frac{Daily\ Mask\ Usage}{10000} \tag{1}$$

$$AFU = DFU \times 365 \tag{2}$$

Data regarding coastal population, coastal length and coastal population percentage are taken from the Encyclopedia of Coastal Science and presented in Table 1 (Finkl and Makowski, 2020). Face mask acceptance rate in countries is obtained from international surveys (Statista. Com, Jones, 2020, Badillo-Goicoechea et al., 2020, Daily Tribune) (Table 1). It is assumed that a person uses a single mask daily, and 80% of these masks are surgical masks, and 20% are N95. This

assumption was made, taking into account the cost associated with the masks. As N95 masks are more expensive than surgical masks, general people tend to use them while medical personnel use N95 masks.

2.2. Estimating mismanaged plastic waste and plastic debris

This study uses global solid waste management data compiled by the world bank (Law et al., 2020), which estimated national level waste composition data for approximately 175 countries. The percentage of plastic in MSW inadequately managed waste, and mismanaged waste is reported in Table 2. To estimate mismanaged waste, it is necessary to determine the percentage of inadequately managed waste in the MSW. Inadequate waste is defined as the unaccounted waste that can be openly burnt or that can find its way to an "open dump" and to "waterways." These wastes can find their way into the ocean by tides, wind, wastewater outflows, and inland waterways. Mass of plastic waste transported by the different waterways varies from less than 1 kg per day to 4.2 MT per day (Jambeck et al., 2015). Since the transportation of these wastes is heavily dependent on local waterways characteristics, it is necessary to find a method that can extrapolate these results globally. In this research, the framework developed by Jambeck et al. (2015) has been followed to calculate annual mismanaged plastic waste (from face mask) produced by people dwelling within 50 km of the coast. "Mismanaged waste can be defined as the summation of inadequately managed waste and 2% litter" (Law et al., 2020). The percentage of litter (2%) was adapted from Law et al. (2020) due to lack of standards and incomparable methodologies, among other studies.

Also, data reported in other studies were based on piece count, not based on mass, and the litter's size was variable. This does not signify the proper distribution of litter across the broader landscape. To estimate marine debris conversion from mismanaged waste, two scenarios have been considered. These scenarios are labelled as high (40%), and low (15%) and have been used to determine the number of plastic debris that

Table 3
Daily and annual face mask usage in analyzed countries.

Countries	Daily face mask usage	Daily SM generation in M	Daily N95 generation in M	Annual face masks in M
Bangladesh	32,120,094	25.7	6.4	11,724
China	68,925,427	55.1	13.8	25,158
Indonesia	1,95,483,225	39.1	15.6	71,351
India	76,539,522	61.2	15.3	27,937
Vietnam	6 1,364,918	49.1	12.27	22,398
Sri Lanka	16,867,200	13.5	3.37	6156
Philippines	98,192,700	78.56	19.6	35,840
Thailand	8,940,211	7.15	1.78	32,631
Myanmar	10,527,552	8.42	2.10	3843
Pakistan	1,1 77,478	0.94	0.23	430
Malaysia	27,463,951	21.97	5.42	10,024
Japan	97,062,192	77.64	19.41	35,428
South Korea	18,372,547	14.69	3.67	6706
Norway	1,135,981	0.91	0.23	415
Russia	12,426,840	9.94	2.48	4536
United Kingdom	46,478,383	37.18	9.29	16, 965
Spain	29,626,206	23.7	5.92	10,814
Sweden	389,256	0.31	0.077	142
France	9,069,540	87.7	31	3310
Germany	1,214,017	7.26	1.81	443
Italy	34,777,596	0.97	0.24	12,694
Greece	8,740,710	27.82	6.95	1312
Ireland	284,405	69.2	1.74	104
Finland	1,541,935	0.22	0.056	563
Denmark	3,594,140	1.23	0.31	1312
Netherland	11,240,923	3.61	0.79	4103
Belgium	6,804,547	8.99	2.24	2484
Portugal	7,663,795	5.44	1.36	2797
Romania	63,736	6.13	1.53	23
Saudi Arabia	2,610,018	0.051	0.013	953
Iran	3,068,467	2.10	0.52	1120
UAE	6,231,588	2.45	0.62	2275
Nigeria	12,397,554	4.99	1.25	4525
South Africa	6,948,840	9.92	2.48	2536
Turkey	22,926,773	5.56	1.39	8368
Israel	6,368,302	18.34	4.59	2324
USA	45,362,076	5.94	1.27	16,577
Canada	1,682,366	36.30	9.07	614
Argentina	7,765,326	1.35	0.34	2834
Brazil	25,464,565	20.37	5.1	9295
Chile	10,616,786	8.5	2.12	3875
Colombia	3,964,224	3.17	0.8	1447
Australia	6,554,107	5.24	1.31	2392
New Zealand	3,383,800	2.71	0.67	1235
Mexico	9,136,514	7.31	1.83	3335
Costa Rica	4,388,280	3.51	0.88	1602

can end up in oceans (Jambeck et al., 2015). For estimating the quantity of plastic generation from used face masks, the methodology of Akber Abbasi et al. (2020) is followed. Being multi-layered, both N95 and surgical masks are the most widely use face coverings to prevent COVID-19 virus transmission. Generally, nonwoven fabric is used in the making of these masks, and the material involved in the making of these masks is polypropylene. Polypropylene's density in both layers of surgical masks is around 20–25 g/m^2, while for the N95 mask, it is about 25–50 g/m^2 (Akber Abbasi et al., 2020). Additionally, the filtering portion of N95 also contains 2 g of polypropylene (Liebsch, 2020). Therefore, from a single N95 and surgical mask, approximately 11 g and 4.5 g of polypropylene can be generated, respectively. Fig. 1 highlights the methodology of this study.

2.3. Limitation of the current study

This study aimed to estimate potential marine plastic pollution from the Covid-19 face masks in coastal regions. Behavioural dataset of face masks usage and solid waste management from the World Bank was

used to estimate face masks usage in countries. Face masks acceptance among people is based on the infection rate. We have assumed that face masks acceptance remains consistent within selected countries, which may create inconsistency in results. Also, the distribution of surgical masks and N95 masks may vary among countries. Data regarding litter percentage and marine debris conversion was assumed from Jambeck et al. (2015). A conservative approach was adopted to estimate the conversion of marine debris from mismanaged waste. However, the situation can become worsen due to the lack of waste management facilities in poor and developed countries.

3. Results and discussions

3.1. Estimation of daily and annual face masks usage

The current study estimates daily and annual face mask usages in selected countries (Table 3). Table 3 shows that countries with higher coastal populations and face mask acceptance rates produced higher masks. Daily and annual face mask usage in Indonesia is higher than in other countries. Also, mask usage in Asian countries is higher than in other countries. It is estimated that approximately 289.63 billion face masks were used annually in Asian countries, while European countries contributed 61.02 billion face masks. The United Kingdom contributed the highest, and Romania contributed to lower masks generation among analyzed European countries. Table 3 also estimates that the number of surgical masks is higher than N95 masks. It is also seen that face mask acceptance among the general public varies among countries. Average face mask acceptance in Asian countries (above 65%) is higher than in European countries. Among the analyzed countries, Sweden (5%) and Australia (32%) have lower face mask acceptance. Acceptance of face mask among population depends on various factors such as governmental stricter policies regarding face mask, socioeconomic factors, existing cultural and social norms, infection rate, knowledge of the transmission mode of the disease, health prevention policies, behavioural factors, for example, frequently going out for work, shopping, attending public events and socializing outside home etc. (Badillo-Goicoechea et al., 2020). Despite some exceptions, countries with higher infection rates use more face masks (Fig. 2). Among the analyzed countries, Sweden (5%) and Brazil (50%) have the lowest face mask acceptance with high infection rates. However, it is accepted that face mask usage will continue to increase until a safe and reliable vaccine is available for the general population.

3.2. Estimating mismanaged plastic waste and plastic debris into the ocean

Ongoing pandemic has exacerbated the plastic pollution. Increasing utilization of single-use plastic and heavy dependence on protective items such as face masks, gloves etc., among the general public will aggravate microplastic pollution. Due to delicate composition and risk of transmission, single-use masks are difficult to recycle, and if not properly managed, these masks enter into oceans as litter. These plastic particles can serve as a host of pathogenic microorganisms that could develop biofilms in future (Akber Abbasi et al., 2020). Van Doremalen et al. (2020) found that the SARS-CoV-2 virus can exist on the plastic surface for 72 h and impact living organisms. This situation will worsen for developing and underdeveloped countries where waste management is inadequate or non-existent.

This study estimates mismanaged plastic waste and plastic debris entering into oceans from the used face masks. From Table 4, it can be seen that the estimated annual plastic waste generated from mismanaged masks was 2.37 million tons in the analyzed countries. Indonesia topped the plastic waste generation contributing to 17.46%, while both Japan and the Philippines were responsible for 8% of plastic generation. Plastic waste generation in Asian countries (1.51 million tons) is significantly higher than in Europe (0.48 million tons) due to
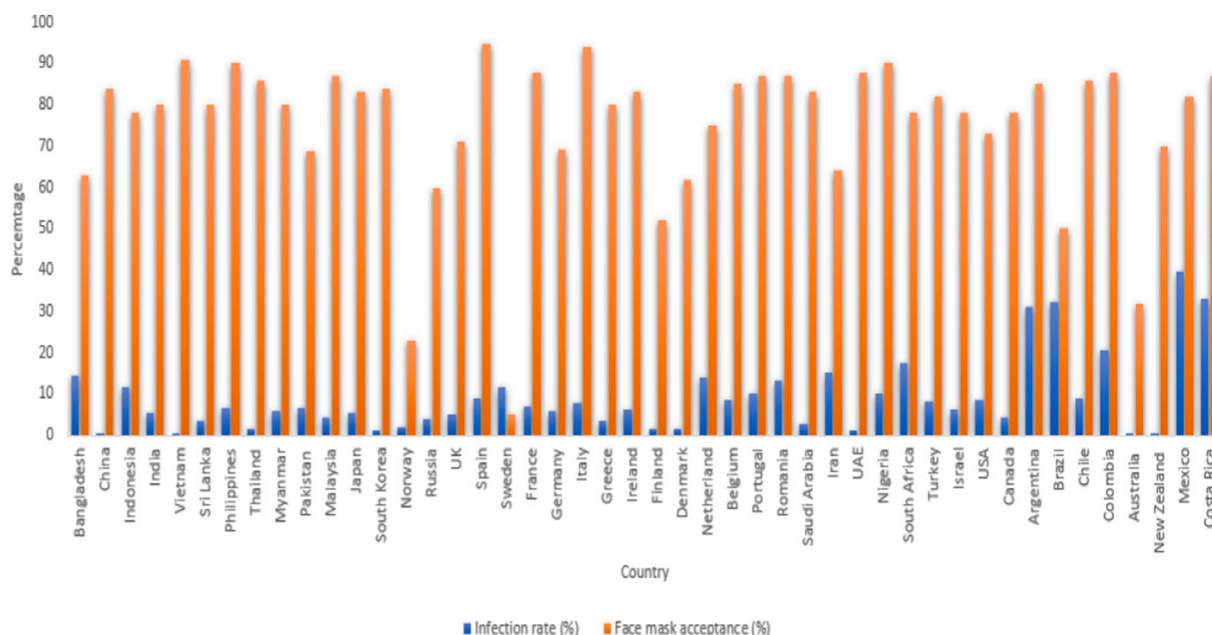
Fig. 2. Face masks acceptance and infection rate in selected countries (Badillo-Goicoechea et al., 2020; www.Worldometer.info, 2020).

higher acceptance of face masks and coastal populations. Similarly, the amount of mismanaged waste is also higher in Asian countries as waste management facilities in Asian countries are not as well developed as in most European countries. Table 2 shows that mismanaged waste percentage in Asian countries is higher than in European countries (highest Myanmar 100% and lowest South Korea 2%). Among the analyzed counties, mismanaged plastic waste is higher in Indonesia (0.25 million tons) and India (0.13 million tons). To estimate plastic debris entering into global oceans from mismanaged face masks, this analysis considered two scenarios (upper level of 40%, lower level of 15%). It can be seen that approximately 0.15 million tons to 0.39 million tons of plastic debris could end up in global oceans within a year. Again, countries with higher mismanaged waste, high per capita waste generation, coastal population and face mask acceptance rate are responsible for higher plastic debris that enters the oceans. The framework used in this analysis can be applied to determine the number of plastic debris and mismanaged plastic waste entering into oceans from COVID-19 face masks. Total mismanaged plastic waste generation is a function of coastal population size and mismanaged plastic waste percentage. Countries with a higher coastal population and higher mismanaged waste percentages produced a higher amount of mismanaged plastic waste. Also, it is seen that lower-income countries have a higher mismanaged waste percentage than upper-middle-class and high-income countries and are responsible for higher mismanaged plastic waste generation. Despite fast economic growth in LMC and UMC countries, waste management infrastructure is not well developed. As a result, a small portion of mismanaged waste will result in a higher number of plastic debris entering into oceans. These plastics, after reaching the marine environment, can sink or have different fates depending upon their characteristics. As stated earlier, various non-degradable synthetic materials are used in the making of PPE. Polymers having high density such as polyvinyl alcohol (PVA), polyvinyl chloride (PVC) and polyester (PEST) may end up at the bottom of the sea, while low density polymers such as polypropylene (PP), expanded polystyrene (EPS), and polyethylene (PE) can float (De-la-Torre and Aragaw, 2020; Fadare and Okoffo, 2020). Under the current scenario, collaborative actions are required from individuals, national and international authorities to protect oceans from plastic pollution. Promoting reusable face masks made from sustainable materials will help to reduce the amount of plastic pollution.

Cloth masks and biodegradable masks having proper filtering qualities (made from fabric, cotton, linen, fabric etc.) will mitigate pressure on single-use masks. Due to the increasing infection rate and widespread use of masks, many innovations in face masks have emerged. The emergence of self-cleaning masks and water-soluble masks are the ideal examples of these innovations. The government should come forward and encourage the usage of these masks through funding grants. Masks should be safely disinfected following proper guidelines for further reuse (Derraik et al., 2020; Barcelo, 2020). This will mitigate pressure in managing these enormous amounts of discarded masks. Due to COVID-19, recycling rates in many countries are still low. Recycling programs should be initiated, and necessary subsidiary incentives must be provided by authorities to enhance the recycling rate.

Proper disposal of used masks should be ensured from individual levels. Depending on the local waste management infrastructure and regulations, local authorities should formulate policies for ensuring the safe disposal of the used masks (Ilyas et al., 2020). Improper disposal should be strictly handled and subjected to punitive measures, such as fines. AI-based technologies, machine learning, and satellite imaging can handle the illegal dumping of solid waste (Abdallah et al., 2020; Dabholkar et al., 2017). In poor and underdeveloped countries, the government can use media to promote public awareness of masks' proper disposal. Apart from these, international laws on controlling marine pollution should be revised and readjusted if necessary. Besides this, plastic generated from PPE due to COVID 19 can be transformed into resources after applying pyrolysis (Aragaw and Mekonnen, 2021). Aragaw and Mekonnen studied the thermoplastic nature of PPE and extracted fuel from them. Jung et al. also used pyrolysis and produced Hydrogen from COVID 19 face masks (Jung et al., 2020). Lee et al. (2021) used a catalytic fast pyrolysis process to synthesize aromatic compounds from COVID 19 face masks. These additional wastes created by this pandemic can be used to produce value-added products which will lead to the circular economy.

4. Conclusion

Increasing use of masks and PPE during this pandemic has contributed to ongoing plastic pollution. A massive number of plastic debris is entering the global oceans and are destroying the marine ecosystem. The need for taking urgent action is getting louder as this problem continues.

Table 4
Annual estimated plastic waste generation, mismanaged plastic waste and debris input into oceans from face masks.

Country	Plastic waste from SM in ton	Plastic waste from N95 in ton	Total plastic waste generation in ton	Mismanaged waste (ton)	Debris (ton) Upper estimate	Debris (ton) Lower estimate
Bangladesh	42,205	25,709.9	67,996	65,786.13	26314.45	9867.91
China	90,567	157,349	145,916	37,573.37	15,029.348	5636
Indonesia	256,865.1	156,972	413,837	250,371.39	100,148.553	7555.71
India	100,572.1	61,462,35	162,034.45	128,007.22	51,202.88	19,201.08
Vietnam	80,632.15	49,275	129,907.15	83,140.58	33,256.23	12,471.08
Sri Lanka	22,162.8	13,545.15	35,707.95	31,065.92	12,426.37	4659.88
Philippines	129,023.85	78,847.3	207,871.15	153,824.65	61,529.86	23,073.69
Thailand	11,745.7	7179.55	18,925.25	11,780.97	4712.38	1767.14
Myanmar	13,833.5	8453.4	22,593.5	22,593.5	9037.4	3389.03
Pakistan	1547.6	945.35	2492.95	1794.92	717.96	269.23
Malaysia	36,087.55	22,053.3	58,140.85	11,558.40	4623.36	1733.76
Japan	127,538.3	77,942.1	205,480.4	31,438.50	12,575.4	4715.77
South Korea	24,141.1	14,753.3	38,894.4	777.90	311.16	116.68
Norway	1492.85	912.5	2405.35	82.26	32.91	12.34
Russia	16,330.1	9979.1	26,309.2	25,651.47	10,260.58	3847.72
United Kingdom	61,071.8	37,321.25	98,393.05	4498.53	1799.41	674.77
Spain	38,927.25	23,790.7	62,717.95	1254.36	501.74	188.15
Sweden	511.0	313.9	824.9	16.50	6.6	2.47
France	11,917.25	7281.75	19,199	387.82	155.12	58.17
Germany	1595.05	974.55	2569.6	103.30	41.32	15.49
Italy	45,698	27,926.15	73,624.15	9585.86	3834.34	1437.87
Greece	114,964.05	7018.95	121,983.0	3659.49	1463.79	548.92
Ireland	372.3	229.95	602.25	30.11	12.04	4.51
Finland	2025.75	1237.35	3263.1	65.60	26.24	9.84
Denmark	5934.9	3175.5	9110.4	184.03	73.61	27.61
Netherland	14,749.65	9026.45	23,776.1	475.52	190.21	71.32
Belgium	8492.5	5464.05	14,406.55	613.72	245.48	92.05
Portugal	10,070.35	6153.9	16,224.25	324.49	129.79	48.67
Romania	83.95	51.1	135.05	43.93	17.57	6.59
Saudi Arabia	3431	2095.1	5526.1	110.52	44.21	16.57
Iran	4033.25	2463.75	6497.0	4827.27	1930.91	724.09
UAE	8186.95	5004.15	13,191.1	8442.30	3377.69	1266.34
Nigeria	16,289.95	9953.55	26,243.5	21,519.67	8607.86	3227.95
South Africa	9132.3	5580.85	14,713.15	294.26	117.71	44.14
Turkey	30,127.1	18,410.6	48,537.7	22,812.72	9125.08	3421.90
Israel	8369.45	5113.65	13,483.1	269.66	107.86	40.45
USA	59,604.5	36,427	96,031.5	2871.34	1148.53	430.70
Canada	2211.9	1350.5	3562.4	71.25	28.5	10.68
Argentina	10,205.4	6234.2	16,439.6	4044.14	1617.66	606.62
Brazil	33,459.55	20,447.3	53,906.85	13,589.92	5435.96	2038.48
Chile	13,950.3	8526.4	22,476.7	3551.32	1420.52	532.69
Colombia	5208.55	3182.8	8391.55	503.49	201.39	75.52
Australia	8610.35	5274.25	13,884.6	277.69	111.07	41.65
New Zealand	4445.7	2715.6	7161.3	143.23	57.29	21.48
Mexico	12,004.85	7336.5	19,341.35	4448.51	1779.41	667.27
Costa Rica	5767	3522.25	9289.25	1031.11	412.44	154.66

This analysis estimates COVID-19 face masks' usage, mismanaged plastic waste, and plastic debris that may enter into oceans from 46 countries. It is estimated that approximately 0.15 million tons to 0.39-million tons of plastic debris could end up in global oceans within a year from the analyzed countries. Plastic waste generation from used masks in Asian countries (1.51 million tons) is significantly higher than in Europe (0.48 million tons). It is also noticeable that mismanaged plastic waste and marine pollution are higher in lower-income countries due to lower waste management facilities. As the pandemic progresses, usage of masks will increase, and also the pollution. As plastic materials remain in the environment for a long duration, and this will continue to destroy marine life. Face masks are now seen on sea beaches worldwide, which exposes the weakness in waste management infrastructures. Under these circumstances, immediate actions are necessary from local and international authorities to frame policies for ensuring safe face masks disposal. The analysis presented can help global and local policymakers to update their waste management policies before it is too late to protect our oceans.

CRediT authorship contribution statement

Hemal Chowdhury: Conceptualization, Writing – original draft, Writing – review & editing. **Tamal Chowdhury:** Investigation, Writing – review & editing. **Sadiq M. Sait:** Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

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