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Microplastics from face masks: A potential hazard post Covid-19 pandemic

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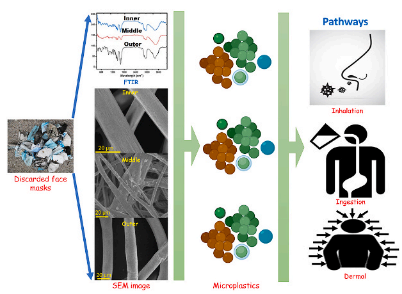
HIGHLIGHTS

- Management of Microplastic waste is the most critical issue around the globe.
- More than 1.5 million face masks are generated annually in the thirty-six nations considered in the current study.
- 9774 thousand ton of microplastic is generated per year from these discarded face masks.

GRAPHICAL ABSTRACT



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ABSTRACT

The tremendous use of plastic products to averse the infection rate during Covid-19 pandemic has developed great pressure on the management and disposal systems of plastic waste. The compulsory use of face masks to curb the infection and prevent transmission of the virus has led to addition of millions of face masks into the terrestrial and marine environment. The current study attempts to assess and quantify the rate of infection in coherence with the annual usage of face masks in various nations across the globe. The ecological footprint of the plastic waste generated from used and discarded face masks along with their potential impacts have also been discussed. The current study has quantified the total annual face masks across thirty-six nations to be more than 1.5 million ton. The total estimated figure for annual plastic waste and microplastics in all these nations was ~4.2 million tonnes and 9774 thousand tonnes, which emerges as a great threat to the global efforts towards reduction of plastic usage. The emergence of Covid-19 pandemic has modified the living habits with new enterprises being set up for Covid essential products, but the associated hazard of these products has been significantly ignored. Hence this study attempts to present a quantitative baseline database towards interpretation and understanding of the hazards associated with microplastics and increased dependence on plastic products.

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1. Introduction

The surge of Covid-19 pandemic paved the way for various unprecedented measures to prevent the further spread of the virus (Khan et al., 2021). One of these measures included introduction of face masks to prevent the transmission of Covid-19. The use of plastic products in safeguarding the human population from the infectious coronavirus has been very prominent. The multilateral expansion in the employment of single-use plastics (SUPs) including personal protective equipment (PPE), sanitizer bottles, medical test kits, polyethylene packaging material, gloves, and face masks has consequently distorted the supply and disposal cycle. The excessive burden on the waste management systems consequent to the colossal rise in the medical and domestic waste has raised concerns across the globe. The single use plastics are a very prominent contributor to plastic pollution in the environment (Schnurr et al., 2018). The lockdown directives during the pandemic were issued across the globe to safeguard the lives of billions of people. The use of sanitizers, masks, gloves, PPE kits was promoted, and people were motivated to adapt to the 'new normal' scenario of COVID-19. The nature of microplastics as vehicles for microbes including bacteria, fungi, and bacteria is also a potential growing hazard (Abbasi et al., 2020). The street vendors, and supermarkets started using single use plastics to cover fruits and vegetables for safety purposes. The use of face masks was also made compulsory across the globe to prevent human-to -human transmission of the virus, which led to the rise of a new problem associated with their disposal and management (Benson et al., 2021). The presence of plastics in the terrestrial and aquatic systems is a threat to the survival of the fauna population as illustrated in Fig. 1. The stray animals mistakenly eat plastics which can huge damage to their physiological functioning. Birds are often seen to get trapped in the strings of face masks making their survival very difficult.

Use of face masks prevented the transmission of coronavirus; however, these face masks became a potentially rising source of microplastics considering their degradation into smaller pieces (<5 mm). The consequent path of microplastic/fibers to the environment through disposal of face masks in public spaces, dump yards, gutters, rivers, beaches, oceans are some major issues (Fadare and Okoffo, 2020). The leaching down of microplastics in the groundwater sources, accumulation in oceans, rivers lakes, and ponds has been previously reported (Aragaw, 2020). The primary source microplastics include Polypropylene and its derivative (e.g., polyethylene, polyurethane, polystyrene, polycarbonate, polyacrylonitrile) (Shen et al., 2021). While the secondary microplastics include plastics originating from the fragmentation of plastic waste due to various processes (physical, biological and chemical) (Selvam et al., 2020a). The ultraviolet (UV) rays cause rapid fragmentation of plastic waste through photooxidation. Cold and anoxic conditions of marine environment can lead to very slow pace of decomposition of plastics. The various sources of microplastics and different processes they undergo while fragmentation emerges as the reason of their varying shapes including fibers, fragments, pellets etc. (Akdogan and Guven, 2019).

The various pathways for entrance of microplastics into the ecosystem include surface water, sub surface water, soil, air etc. (Chen et al., 2020; Kwak and An, 2021; Saliu et al., 2021; Torres-Agullo et al., 2021). The existence of microplastics in the aquatic ecosystem creates a huge hazard for the fish farming units. The prevalence of microplastics in the marine environment also highlights their potential nature as pollutant vehicles and transmitters to the biotic aquatic population (Wang et al., 2021). The ingestion of microplastics by aquatic population causes harmful impacts on their biological functioning which further through biomagnification can potentially encroach the food chain/food web (Ma et al., 2021; Kavya et al., 2020). The possible biomagnification can cause severe impacts on the health of humans (developmental disorders, decreased appetite, etc.) (Issac and Kandasubramanian, 2021). The presence of MPs in sea salts including nylon, polyethylene, polypropylene has also been previously reported in a study by (Selvam et al., 2020b). Thus, the hazard of MP ingestion through the direct/indirect modes cannot be ignored. Thus, the quantification and detailed understanding of the plastic waste being generated due to face masks is very critical to safeguard the ecosystem and human health.

In the current scenario of Covid-19 pandemic, disposable masks and N95 masks were one of the most used and advertised face covering which helps in safeguarding against the risk of Sars-Cov-2. In the present study, the approximate quantity of plastic waste generated annually, and the annual face mask usage is calculated. Moreover, the approximate estimate of microplastic waste generated from these face masks (disposable and N95 masks only) is also done. Thirty-five countries around the globe with more than 10 million Covid-19 cases were chosen for the study and additionally China was also included for the present

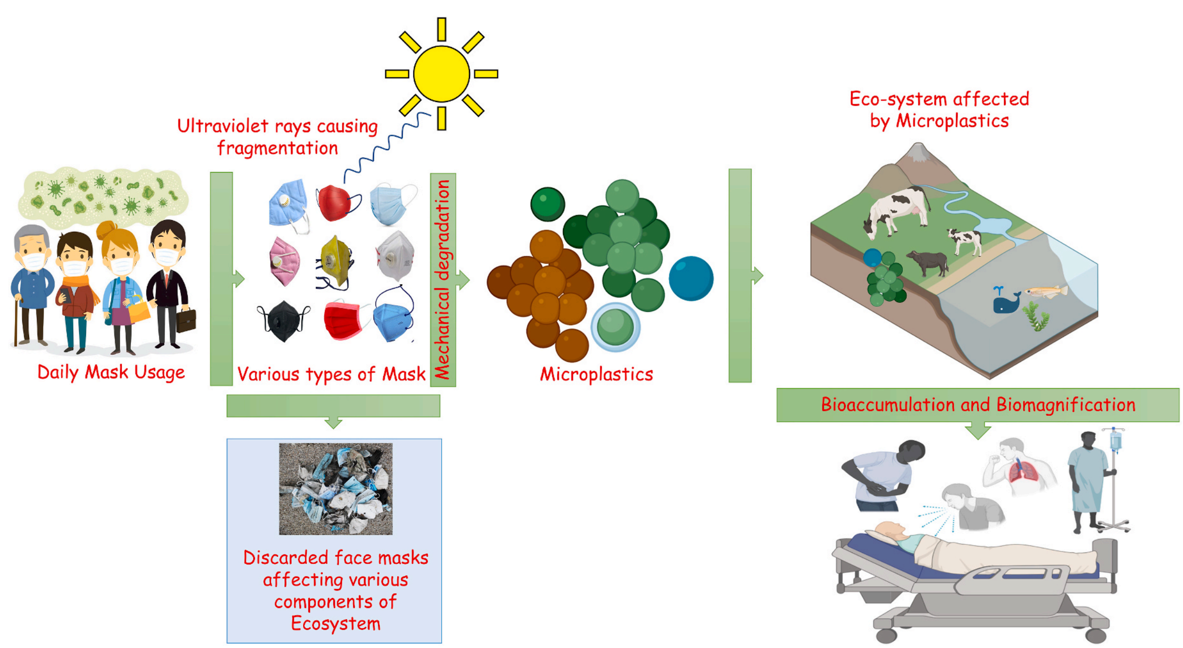

Fig. 1. Fate of Microplastics in the Environment and their impacts on environment and human health.

study. These 35 countries were chosen as the usage and acceptance of mask would be higher in these countries in comparison to other countries where cases were low. China was selected because it was the epicenter of outbreak of Sars-Cov-2. It is evident that the use of face masks is going to increase as the fight against Covid-19 pandemic. Hence, more microplastic will be released into ambient atmosphere which in turn will reach human body through bioaccumulation and biomagnification. Moreover, the current situation may worsen over time and it may contribute towards longer persistence of pathogens including severe acute respiration syndrome coronavirus 2 (SARS-CoV-2) which consequently affect the human and environmental health. The current study aims at identifying and evaluate this risk by calculating the possible quantity of microplastics released in the environment by face masks. Further, there is a clear lack of awareness and knowledge regarding the usage of face masks and its suitable disposal. This study will help in identifying the risks associated with unsuitable disposal of face masks in the ambient environment.

2. Methods

The multi layered masks are made up of non-woven fabric and the chief constituent is polypropylene and its derivative. In general, the two layers of N95 masks consists of 25–50 g/m^2 of polypropylene, and the filter consists of 2 g of polypropylene, making a total of 11 g of polypropylene (Shruti et al., 2020). Whereas, the polypropylene content in a single disposable mask is around 4.5 g (Shruti et al., 2020). The N95 masks are mostly used by health care professionals (medical staff, doctors etc.) and Covid-19 patients. These N95 masks provide better protection against the virus, yet the general public relies mostly on disposable mask in many countries (Abbasi et al., 2020; Benson et al., 2021).

In the present study, the data regarding total population, urban population, and Covid-19 related information like, total number of cases, total deaths, total recovered, cases/million, and tests/million (Table 1) were collected from the online portal (www.worldometer.com) as on September 10, 2021. The annual plastic waste estimate is done on the basis that 0.075 ton of plastic waste is generated per capita in a year (Benson et al., 2021). The total number of masks used in these countries on annual basis, i.e., annual mask usage (AMU) is estimated based upon the urban population (P_u), remaining population (P_r), acceptance rate of urban and remaining population (A_u and A_r, respectively), and the average number of masks used per person per day (N_u and N_r, respectively) using equation (1).

$$AMU = \{(P_u \times A_u \times N_u) + (P_r \times A_r \times N_r)\} \times 365 \times 10^{-6} \quad (1)$$

where, AMU is number of masks used (millions), country wise P_u and P_r are mentioned in Table 2, N_u and N_r are taken as 1.5 and 0.75, respectively. We have considered the acceptance of face masks to be 80% by the urban population and 10% by the remaining population, hence, A_u and A_r are taken as 80% and 10%, respectively. The values of A_r and N_r were taken based on the field visits in the nearby rural areas. The infection rate was calculated using equation (2).

$$\text{Infection Rate } (\%) = \frac{\text{Cases/million}}{\text{Tests/million}} \times 100 \quad (2)$$

The annual estimated wight of masks is calculated using equation (3).

$$\text{Estimated wight of masks (EWM)} = AMU\{(U_{95} \times W_{95}) + (U_{DM} \times W_{DM})\} \quad (3)$$

where, EWM is expressed in thousand tonnes generated annually. New

Table 1
Demographics and Covid-19 details of Countries considered for this study.

S. No.	Country	Total number of Cases	Total number of Deaths	Total recovered	Cases/million	Tests/million	Infection Rate (%)
1	USA	4,17,44,465	6,77,018	3,18,21,036	1,25,238	18,12,303	6.91
2	India	3,32,00,877	4,42,350	3,23,58,246	23,779	3,85,765	6.16
3	Brazil	2,09,74,850	5,85,923	2,00,16,161	97,847	2,66,348	36.74
4	UK	71,68,115	1,33,988	57,46,286	1,04,932	41,30,198	2.54
5	Russia	71,02,625	1,91,165	63,57,272	48,645	12,51,291	3.89
6	France	68,87,791	1,15,442	64,86,949	1,05,244	20,00,764	5.26
7	Turkey	66,13,976	59,384	60,90,902	77,427	9,30,210	8.32
8	Iran	52,58,913	1,13,380	45,09,905	61,670	3,52,005	17.52
9	Argentina	52,21,809	1,13,282	50,67,105	1,14,286	5,30,803	21.53
10	Colombia	49,26,772	1,25,529	47,63,695	95,610	4,78,390	19.99
11	Spain	49,07,461	85,290	45,42,552	1,04,913	13,31,626	7.88
12	Italy	45,96,556	1,29,828	43,38,241	76,158	14,39,018	5.29
13	Indonesia	41,58,731	1,38,431	39,01,766	15,015	1,23,983	12.11
14	Germany	40,71,607	93,095	38,10,100	48,412	8,36,812	5.79
15	Mexico	34,79,999	2,66,150	28,19,991	26,657	77,399	34.44
16	Poland	28,92,643	75,417	26,57,981	76,531	5,32,041	14.38
17	South Africa	28,48,925	84,608	26,56,534	47,324	2,82,180	16.77
18	Ukraine	23,10,554	54,251	22,18,873	53,215	2,81,372	18.91
19	Philippines	21,79,718	34,899	19,69,324	19,581	1,75,628	11.15
20	Peru	21,59,306	1,98,673	N/A	64,419	5,11,547	12.59
21	Netherlands	19,66,634	18,062	18,74,046	1,14,471	9,73,108	11.76
22	Iraq	19,44,125	21,394	18,08,692	47,076	3,56,260	13.21
23	Malaysia	19,40,950	19,827	16,78,959	59,066	7,26,215	8.13
24	Czech Republic	16,82,479	30,413	16,48,905	1,56,762	34,22,843	4.58
25	Chile	16,43,156	37,178	16,00,353	85,084	10,76,741	7.90
26	Japan	16,14,124	16,603	14,42,637	12,809	1,82,769	7.01
27	Canada	15,38,093	27,170	14,71,725	40,331	10,83,580	3.72
28	Bangladesh	15,27,215	26,832	14,72,067	9164	55,223	16.59
29	Thailand	13,52,953	13,920	11,97,391	19,325	1,31,434	14.70
30	Belgium	12,03,326	25,447	11,05,366	1,03,291	16,36,253	6.31
31	Pakistan	11,97,887	26,580	10,79,867	5300	81,183	6.53
32	Israel	11,54,286	7321	10,63,507	1,23,771	21,27,775	5.82
33	Sweden	11,38,017	14,662	10,94,421	1,11,850	11,73,057	9.53
34	Romania	11,15,901	34,914	10,63,360	58,473	6,22,808	9.39
35	Portugal	10,53,450	17,843	9,96,987	1,03,674	17,14,268	6.05
36	China	95,199	4636	89,823	66	1,11,163	0.06

Table 2
Number of masks and Annual generation of microplastics/polypropylene for all the countries considered for this study.

S. No.	Country	Total Population	Urban Population (P_u)	Remaining Population (P_r)	AMU (millions)	Microplastics/ Polypropylene (thousand tonnes)	Annual Plastic Waste (tonnes)	Estimated weight of masks (thousand tonnes)
1	China	1,43,93,23,776	87,79,87,503	56,13,36,273	3,99,925	2580	1,07,949	4079
2	India	1,39,61,98,159	48,86,69,356	90,75,28,803	2,38,881	1541	1,04,715	2437
3	United States	33,33,20,757	27,66,56,228	5,66,64,529	1,22,727	792	24,999	1252
4	Indonesia	27,69,75,366	15,78,75,959	11,90,99,407	72,410	467	20,773	739
5	Pakistan	22,60,02,908	8,36,21,076	14,23,81,832	40,524	261	16,950	413
6	Brazil	21,43,63,613	18,64,96,343	2,78,67,270	82,448	532	16,077	841
7	Bangladesh	16,66,47,683	6,33,26,120	10,33,21,563	30,565	197	12,499	312
8	Russia	14,60,09,250	10,95,06,938	3,65,02,313	48,963	316	10,951	499
9	Mexico	13,05,49,393	10,57,45,008	2,48,04,385	46,995	303	9791	479
10	Japan	12,60,13,523	11,59,32,441	1,00,81,082	51,054	329	9451	521
11	Philippines	11,13,20,853	5,23,20,801	5,90,00,052	24,532	158	8349	250
12	Turkey	8,54,22,091	6,49,20,789	2,05,01,302	28,997	187	6407	296
13	Iran	8,52,75,465	6,48,09,353	2,04,66,112	28,947	187	6396	295
14	Germany	8,41,04,015	6,47,60,092	1,93,43,923	28,894	186	6308	295
15	Thailand	7,00,09,252	3,57,04,719	3,43,04,533	16,578	107	5251	169
16	United Kingdom	6,83,11,940	5,73,82,030	1,09,29,910	25,433	164	5123	259
17	France	6,54,46,096	5,30,11,338	1,24,34,758	23,559	152	4908	240
18	Italy	6,03,55,544	4,28,52,436	1,75,03,108	19,249	124	4527	196
19	South Africa	6,02,00,777	4,03,34,521	1,98,66,256	18,210	117	4515	186
20	Colombia	5,15,30,120	4,17,39,397	97,90,723	18,550	120	3865	189
21	Spain	4,67,76,422	3,78,88,902	88,87,520	16,839	109	3508	172
22	Argentina	4,56,90,827	4,20,35,561	36,55,266	18,512	119	3427	189
23	Ukraine	4,34,19,506	3,03,93,654	1,30,25,852	13,669	88	3256	139
24	Iraq	4,12,97,323	2,93,21,099	1,19,76,224	13,170	85	3097	134
25	Canada	3,81,37,190	3,12,72,496	68,64,694	13,885	90	2860	142
26	Poland	3,77,97,061	2,26,78,237	1,51,18,824	10,347	67	2835	106
27	Peru	3,35,19,674	2,61,45,346	73,74,328	11,654	75	2514	119
28	Malaysia	3,28,60,701	2,53,02,740	75,57,961	11,289	73	2465	115
29	Chile	1,93,12,093	1,69,94,642	23,17,451	7507	48	1448	77
30	Romania	1,90,84,187	1,03,05,461	87,78,726	4754	31	1431	48
31	Netherlands	1,71,80,174	1,58,05,760	13,74,414	6961	45	1289	71
32	Belgium	1,16,49,875	1,14,16,878	2,32,998	5007	32	874	51
33	Czech Republic	1,07,32,721	79,42,214	27,90,507	3555	23	805	36
34	Sweden	1,01,74,470	89,53,534	12,20,936	3955	26	763	40
35	Portugal	1,01,61,161	67,06,366	34,54,795	3032	20	762	31
36	Israel	93,26,000	86,73,180	6,52,820	3817	25	699	39
Total		5,62,44,99,966	3,31,54,88,515	2,30,90,11,451	15,15,393	9774	4,21,837	15,457

N95 masks and disposable masks were bought to estimate the weight of these masks. The weight of N95 masks (W_{95}) was found to be 20 g, whereas the weight of disposable mask (W_{DM}) was found to be 6 g. For analytical purpose of this study, the average use of N95 masks (U_{95}) is considered as 30% and the use of disposable masks (U_{DM}) is considered as 70%.

3. Results

In the current study, thirty-six countries across the globe were considered with respect to the Covid-19 cases and infection rate. As stated in Table 1, the highest number of Covid-19 cases were witnessed in USA with more than 4 million cases and an infection rate of 6.91%. The least number of Covid-19 cases were seen in Romania (~11,000), and infection rate of 9.39%. The highest infection rate was witnessed in Brazil (36.74%) with more than 2 million cases of Covid-19. The lowest infection rate (3.72%) was seen in Canada with more than 15 lac cases of Covid-19.

The different acceptance rate in urban and rural population has been used to estimate the number of masks i.e., AMU (millions) and the content of polypropylene along with annual plastic waste (tonnes) in all the countries. The highest number of face masks has been estimated for China (3,99,925 million) which is the most populated nation in the world (>1.4 billion). The total annual plastic waste generation in China is estimated to be more than 0.1 million. India is the second most populated nation across the globe with a population of more than 1.39 billion and an estimated usage of more than 2 lac masks. The total annual plastic waste to be generated in India is estimated to be ~0.1 million with microplastic/polypropylene content of 1541 thousand tonnes. The USA is the third highest consumer of masks (1,22,727 million) with an annual plastic waste of ~25,000 tonnes and microplastic content of 792 thousand tonnes.

4. Discussion

China, despite being the most populated nation and the origin of Covid-19 pandemic showed the least infection rate. The highest usage of mask was estimated in China which can be a possible reason of the low infection rate, consequent to the maintenance of Covid-19 guideline of wearing the masks. The highest production of plastic waste was estimated in China with a microplastic content of 2580 thousand tonnes. The plastic waste production by India was estimated to be the second highest (>1 lac tonnes) consequent to the increased use of face masks. The Covid-19 tests per million were found to be approximately 3.9 lacs in India. While the lowest tests per million were found in Bangladesh i.e., 55,223 with an infection rate of 16.59.

The unprecedented increase in the use of face masks during the Covid-19 pandemic has created a great threat for the terrestrial and marine ecosystem. The various issues associated with the microplastic pollution have been illustrated in Fig. 2.

The improper accumulation of discarded face masks in heaps and waste piles around the city corners specially in developing nations raises

Fig. 2. Occurrence and impacts of discarded face masks on various components of eco-system (Reproduced with permission from Selvaranjan et al., 2021).

the alarm against the spread of the virus at a wider scale. The contamination of soil due to the fragmentation of discarded face masks and the potential risk of leaching of microplastics into the groundwater have also been reported in various studies in the recent past (Chia et al., 2021; Choi et al., 2020; Dioses-Salinas et al., 2020). The presence of microplastic in the sea salts in Southern India have been reported in a study by Selvam et al. (2020b). The intake of sea salt contaminated with microplastics is a serious threat to the lives of millions of people considering the export to various countries (Jang et al., 2020; Kelly et al., 2020). Fadare and Okoffo (2020) found peaks of polypropylene and polyethylene in outer and inner layers of face masks respectively. They have also suggested that the microplastic particles may accumulate in the ambient environment within a very short span of time. Moreover, it is reported that the plastic particles can also act as a potential carrier of pathogenic organisms such as bacteria, viruses, fungi etc. (Baptista Neto et al., 2019), which may develop a biofilm over these microplastic surface (Jang et al., 2020). Zettler et al. (2013) has coined a term 'plastisphere' after observing a diverse microbial growth on the surface of microplastics. The Sars-Cov-2 virus has been found to be highly stable on plastic surfaces up to 72 h (Jang et al., 2020; Jiang, 2018; Kelly et al., 2020). Hence, it can be said that the discarded face masks have potential to cause a disease outbreak similar to Covid-19 and it may also impact the living organisms directly exposed to the pathogens (Orive et al., 2020).

The ratio between infection rate of Covid-19 and annual mask usage (AMU) across the thirty-six nations in the present study has been illustrated in Fig. 3. It can be observed that the trend of infection rate and AMU is similar, except for countries like USA, India, Brazil, and China. For rest of the countries the incline and decline in AMU is consistent with the respective trend of Infection rate. However, in USA, number of tests conducted per million of population is highest and it has low infection rate value. Similarly, India had lower number of Covid-19 cases per million of population and hence a low infection rate. However, large population has created a higher value of AMU. Brazil had the highest infection rate owing to third-highest number of Covid-19 active cases and subsequently high number of cases per million of population. In China, infection rate was lowest due to the least number of Covid-19 cases reported. However, the AMU value was highest owing to the highest population in the world. It can be concluded that the countries having high infection rates in general, had high AMU, and are at higher risk of microplastic contamination from discarded face masks.

Increasing plastic pollution and challenges associated with combating these issues has been a critical consequence of ongoing Covid-19 pandemic and the corresponding strategic measures taken by the officials to reduce the Covid-19 transmission. This could possibly have a negative impact on a global scale against the reduction in single-use plastic. Hence, immediate interventions are required to manage the global plastic and microplastic contamination especially during the pandemic. Some possible solutions may include:

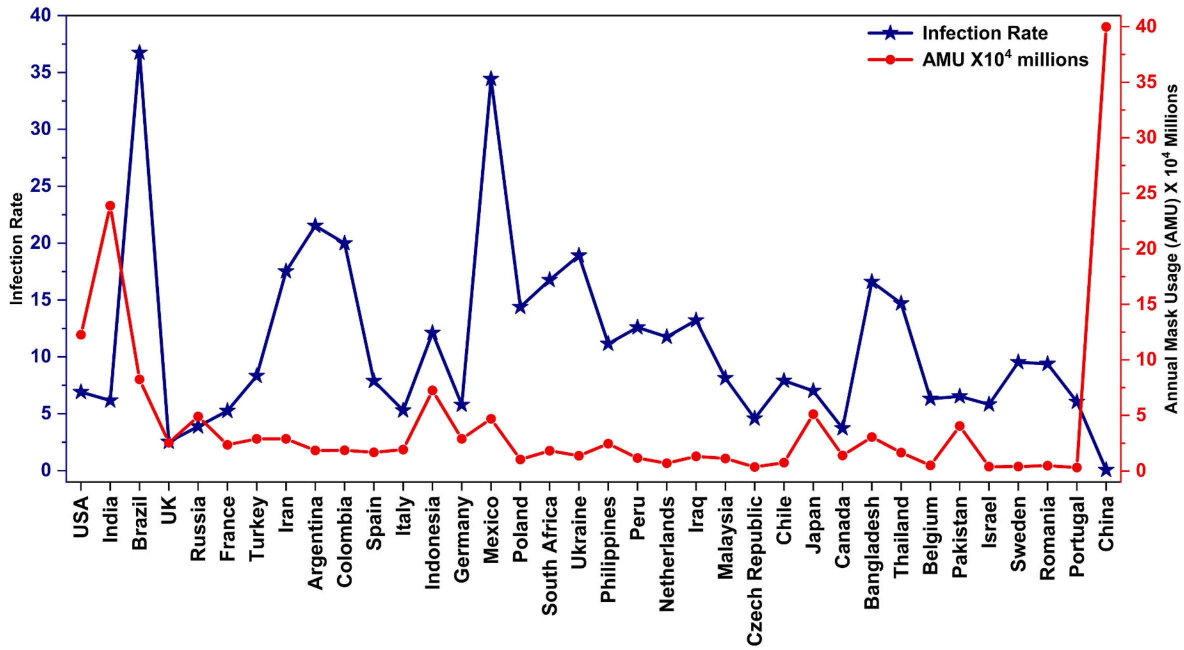

Fig. 3. Correlation between Infection Rate and Annual Mask Usage generated from discarded face masks. (USA: United States of America; UK: United Kingdom).

- Guidelines for suitable disposal and strict adherence for rules of hazardous medical waste management, especially for single-use gloves, face masks, suits, face shields, aprons etc.
- Proper sterilization and disinfection must be carried out before disposal of surgical products.
- Implementing the use of reusable surgical products, especially the PPE kits as also recommended by United States Food and Drug Administration (USFDA, 2020).
- The PPE kits must be disposed of in labelled bins especially suited for clinical products, followed by their suitable disposal/recycling at designated waste management facility.
- Promote and provide incentives to reuse the plastic products in construction materials, pavement materials etc.
- Most importantly, the common public must understand their responsibility to prevent discarding the masks, and other plastic products by being individually responsible.The respective governments must also ensure strict compliance for the same.

5. Conclusion

The Covid-19 lockdown potentially provided a 'window of reinstatement' for the air and water quality, but the tremendous need and use of face masks has created a new issue of single use plastics disposal. An immense increase in the rate of plastic production has been witnessed across the globe. According to the current study the total number of masks being used annually is the highest in China (~0.4 million) followed by India (~0.2 million) and United States (~0.1 million). These estimates highlight the rising peril of single use plastics consequent to the need and consumption of face masks due to the Covid-19 pandemic. The potential impact of microplastics on the marine life is an emerging issue endangering the marine fauna (sea turtles, fishes, whales etc.). These marine faunas often ingest microplastics mistakenly and get entangled many times leading to injuries and fatality. The consumption of marine fauna by humans also elevates the risk of biomagnification and disruption of the food cycle as well. Hence, when the whole world is attempting to discover solutions in combating the Covid-19 outbreak, the present study attempts to bring the attention towards challenges associated with increasing plastic and microplastic contamination. The stakeholders, government officials, and healthcare professionals are urged to adopt suitable management practices so as to reduce the coronavirus-generated microplastic load on environment. This would also reduce the risk of virus and disease transmission during the pandemic and in post-pandemic times as well.

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Data availability

Data will be made available on reasonable request.

Authors' contributions

Saurabh Shukla: Conceptualization, Methodology, Software, Data curation, Visualization, Writing- Reviewing and Editing. **Ramsha Khan:** Conceptualization, Visualization, Writing – original draft preparation, Writing- Reviewing and Editing. **Abhishek Saxena:** Reviewing and Editing. **Selvam Sekar:** Reviewing and Editing.

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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