



Are used face masks handled as infectious waste? Novel pollution driven by the COVID-19 pandemic

Ebenezer Ebo Yahans Amuah^{a,*}, Edna Pambour Agyemang^b, Paul Dankwa^c, Bernard Fei-Baffoe^a, Raymond Webrah Kazapoe^d, Nang Biyogue Doui^c

^a Department of Environmental Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

^b Department of Geography and Resource Development, University of Ghana, Accra, Ghana

^c Department of Environmental Sciences, C. K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana

^d Department of Geological Engineering, University for Development Studies, Tamale, Ghana

ARTICLE INFO

Keywords:

Face masks
Disposal practices
Ecotoxicity
Microplastics
COVID-19 pandemic

ABSTRACT

The extensive use of face masks has raised concerns about environmental pollution through improper disposal of used face masks after the emergence of COVID-19. The increasing use of PPEs to preventing the spread of COVID-19 has resulted in several environmental hazards, creating a new environmental barrier for solid waste management and worsened plastic pollution. This study aimed at assessing the occurrence and distribution of face masks in a metropolitan (Adum – Kumasi), municipal (Ejisu), community (Abenase) and an institution (KNUST) in Ghana. The study showed that a total of 535 face masks were numerated along a stretch of 1,720 m with a density ranging from 0.04 m to 0.42 m. A no significant relationship ($P = 0.602$) was established between the observation distances and the number of waste face masks numerated. The study also showed that for a 1% increase in the number of face masks on working days, there would be a 0.775% increase in non-working days. A review of literature showed that the disposal of used face masks results in the release of micro- and nano-plastics, Pb, Cu, Sb, Zn, Mn, Ti, Fe and Ca into environmental media. Plastic pollution may be a concern to ecosystems due to its persistence in the environment, lack of environmental awareness, sensitization and education, and poor waste management systems. To ensure a sustainable management of waste face masks, significant efforts are needed. These may include proper disposal, redesigning and producing masks from biodegradable materials, incorporating waste face masks into construction materials, and recycling PPE by pyrolyzing are suggested options for the effective management of face masks.

1. Introduction

On March 11, 2020, the World Health Organization (WHO) pronounced the novel coronavirus (COVID-19) outbreak a worldwide pandemic, affecting everyone directly or indirectly. Many changes have occurred in people's economic and social lives as a result of this unprecedented pandemic (Alonzi et al., 2020; Amuah et al., 2021). Thus, precautionary measures have been put in place to ensure personal and public protection against it. Governments have formulated and passed several legislative and verbal instructions for their citizens to combat this pandemic. Face masks and respirators are one of the most common measures (Kumar, 2020). Also, since the coronavirus outbreak became a pandemic in mid-March, many countries have recommended that their citizens avoid large gatherings and to cover their faces in public using

face masks. As a result, the inappropriate littering of face masks has increased dramatically in many countries and regions (Shutterstock, 2021a). During a beach cleaning in September 2020, more than 100 face masks were found on one of Britain's most popular tourist beaches, according to a story in the Daily Mail (Liu, 2020).

Studies by Mihai (2020) and Sangkham (2020) revealed that in the capital city of Indonesia (Jakarta), the medical waste scale reached 124,740 tons in about 2 months after the first recorded COVID-19 case in the area. In Ghana for instance, as of April 2020, the Government of Ghana had distributed 905,031 face masks, 31,630 clinical scrubs, 31,472 overalls, 46,870 head spreads, and 83,500 N95 face masks. Besides this, other NGOs, corporate, religious, private and government donors have provided similar PPEs to Ghanaians in the fight against COVID-19 (Modern Ghana News, 2020). Besides these donated PPEs, others are

* Corresponding author.

E-mail address: amuahyahans@gmail.com (E.E.Y. Amuah).

<https://doi.org/10.1016/j.rcradv.2021.200062>

Received 23 August 2021; Received in revised form 26 November 2021; Accepted 27 November 2021

Available online 29 November 2021

2667-3789/© 2021 The Authors.

Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

purchased by individuals.

It is recommended that the usage of a face mask spans within a day. Due to this, its disposal has resulted in a tremendous pile of waste face masks. Imagine the quantity of waste generated if practically the entire population of every country wears a face mask every day. While COVID-19 is combated with face masks, disinfectants, sanitizers and respirators, medical waste and their emerging impacts on the environment may outlast the virus (Kumar, 2020). Containers from used hand sanitizers, gloves, waterlogged masks, and other waste generated from precautionary measures against COVID-19 have already been discovered on sea-beds and beaches, adding to the daily debris in our ocean ecosystems. The World Economic Forum (2021) adds that using a single-use face mask per day for a year in the United Kingdom may generate about 66,000,000 kg of contaminated waste and 57,000,000 kg of plastics. To prevent the spread of the COVID-19 pandemic, the WHO anticipated that 89 million additional disposable plastic face masks (DPFs) may be required every month in hospital settings around the world. Jung et al. (2021) stated that after usage, face masks must be discarded as infectious medical waste. However, recent studies including Roberts et al. (2020), Bouchet et al. (2021), Hartanto and Mayasari (2021) Morgana et al. (2021), and Selvaranjan et al. (2021) have shown that the growth in the production, patronage and usage of face masks has led to an increase in waste masks which is becoming a peculiar environmental challenge.

Following the tremendous usage of face masks in the fight against the novel COVID-19 pandemic coupled with its ecotoxic nature, how have used face masks been handled in our environment? This study seeks to (1) synthesize findings of previous studies on the disposal practices of face masks; (2) assess how used face masks are disposed in some parts of Ghana; (3) discuss the deleterious impacts of improperly disposed face masks in environmental media and (4) suggest practical approaches that can be employed to reduce the debilitating impacts of face masks in the environment.

2. Materials and methods

2.1. Literature search

This study focused on two thematic areas: (1) reviewing the disposal of face masks (FM) and (2) assessing the number of face masks disposed of in some areas of Ghana. Information from a range of literature sources including journals, articles, and reports on the usage, disposal and management of used face masks, and the possible environmental implications of indiscriminately disposed of FM were obtained from Microsoft academic, Science.gov, Scopus, BASE, google books, Elsevier BIOBASE, ScienceDirect, Worldwide Science, PubMed central, semantic scholar, Baidu scholar, CORE, google scholar and google book were synthesized and triangulated. In sourcing credible information for this

study, keywords such as COVID-19, SARS-CoV-2, Coronavirus, COVID-19/SARS-CoV-2/Corona virus pandemic, face mask disposal, COVID-19 PPEs disposal and impacts of PPEs disposal on the environment were searched in the aforementioned search engines. A total of 956 papers and online sources were identified from the literature search.

2.2. Screening of literature

After the search, a screening procedure (Fig. 1) was conducted to identify relevant materials based on the study topic. The following variables were taken into account:

- Title and Abstract: papers with titles and/or abstract that lacked relation to the keywords used in the search were omitted.
- Abstract: the abstract of all the selected papers were scrutinized to further select papers that addressed management practices of face masks.
- Credibility of the journal/news (online) source where the paper/information was published: to the maximum, papers published in predatory journals were omitted from this study.
- Content: the contents of all the papers and online sources were read to identify the studies that included disposal of waste face masks, impacts of face masks in the environment, and approaches to handling used face masks.

Therefore, a more specific search was conducted that resulted in 65 papers and credible reportages.

2.3. Disposal of used face masks in some parts of Ghana

To assess the number of waste face masks disposed in some areas in Ghana, two areas each (township/business area and suburb) were considered in a metropolitan (Adum – Kumasi), municipal (Ejisu), community (Abenase) and an institution (Kwame Nkrumah University of Science and Technology (KNUST)). In sampling disposed face masks in each of the sites, two (a non-working (γ) and a working (α) day) transects were established covering a distances between 100 m and 200 m of the areas (Fig. 2). PPEs were visually identified by walking “serpentine” along each transect, counted and photographed. This was done triplicately and the centered values were used for data analysis and drawing inference. The density of face masks disposed was computed using a modified formula suggested by Okuku et al. (2020). This is presented in Eq. (1) as:

$$D = N/d \quad (1)$$

D is the density of disposed face masks, N is the number of face masks counted and d is the distance covered.

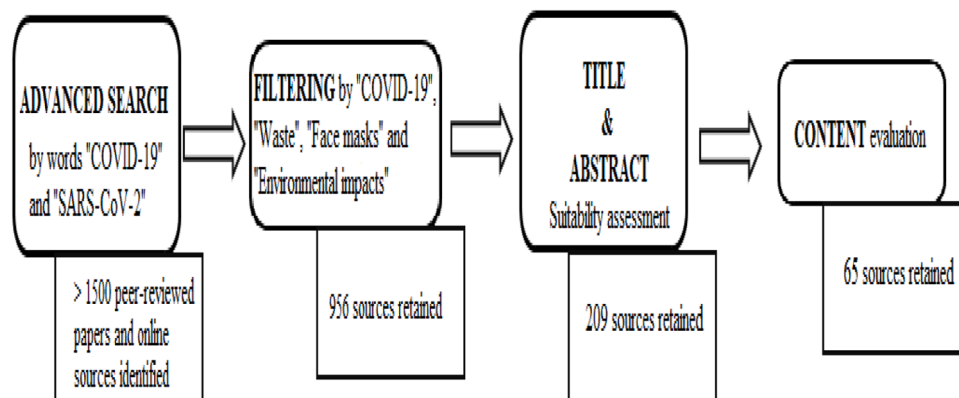


Fig. 1. Diagrammatic description of the method employed in searching for literature.

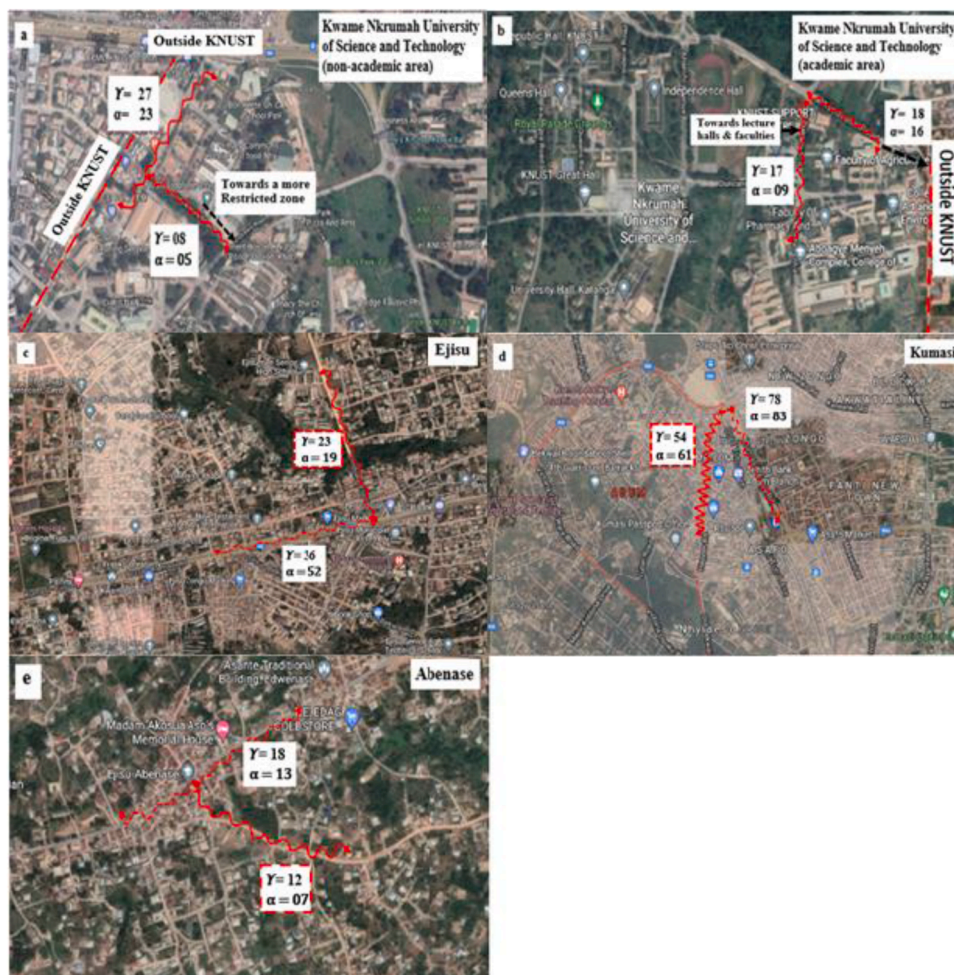


Fig. 2. Enumeration of indiscriminately disposed waste face masks.

2.4. Statistical analysis

The densities of disposed face masks were expressed in PPE $m^{-2} \pm$ standard deviation (SD). Two areas each (township/business area and suburb) were considered in a metropolitan (Adum – Kumasi), municipal (Ejisu), community (Abenase) and an institution (KNUST); non-academic and academic zones to ascertain the density of face masks in these areas with different characteristics. The relationship between distance covered and face mask distribution, and the number of masks counted on non-working and working days were also studied. The statistical assessments were done using the R software (version 3.6.2) and SPSS (version 1.0.0.1406).

3. Results and discussion

3.1. Disposal of waste face masks

Surgical masks have been shown to decrease viral detection in large respiratory droplets and aerosols, implying that virus transmissions can be minimized by wearing surgical masks (Leung et al., 2020). In this pandemic (COVID-19) era, the use of gloves, face masks, hand sanitisers, and syringes, which are primarily made of plastic, has increased dramatically (Harapan et al., 2020; Dharmaraj et al., 2021). Similar to these findings, Grey (2020) indicated that a majority of face masks produced are composed of plastic materials which when discarded can persist in the environment for centuries. Polymers from hazardous medical waste, which includes waste from the management of the COVID-19 pandemic, have recently emerged as a major danger to

ecosystems (Saadat et al., 2020). All healthcare waste generated during patient treatment, including those from people who have been diagnosed with COVID-19 are deemed infectious and should be collected in properly labelled lined containers and sharp safe boxes (WHO, 2020a). It is recommended that COVID-19 related waste materials are disinfected properly before being segregated and discarded into conventional waste disposal systems.

According to Kumar et al. (2020), the manner of usage and disposal healthcare materials may raise the risk of infectious diseases. However, waste generated from the management of the COVID-19 pandemic have not been handled properly in some areas. For instance, the indiscriminate dumping of used face masks in Ghana was reported by the Modern Ghana News (2021). The reportage stated that “sometimes, you are in town and felt the need to change the mask after long use. You have no option other than to drop it in a nearby bush or a street corner. This is the reality. Yes, the best is to bury or drop properly in a bin but there are no bins and it is not safe to carry the mask home to bury”. On April 21, 2021, the Director of the Noguchi Memorial Institute for Medical Research (NMIMR) in Ghana appealed for public awareness on how to properly dispose face masks, which presents a significant risk to humans (GhanaWeb, 2021). Following this, residents of the Tema Metropolitan Area (Ghana) raised to worry about the indiscriminate dumping of used face masks and demanded that health officials begin training/educating people on the appropriate management of used masks. Face masks have been found on the main streets of Tema, Nungua, Sakumono, Lashibi, and Ashiaman (all in Ghana). Thus, residents urged local government officials and other legally obliged institutions such as the Environmental Protection Agency and the Environmental Health and Sanitation

Department to educate the public on how to properly handle face masks since a rise in the generation of used masks is expected (Ghana News Agency, 2021).

The contribution of masks to environmental problems on land and water resources long before they were made mandatory have been reported. However, there has been a geometric increase in the volume of its generation within this COVID-19 era. Used face masks and other PPEs used in the prevention of the spread of the pandemic are indiscriminately disposed without any environmental concerns (Fig. 3). A beach sweep in Hong Kong in February 2021 yielded 70 masks along 100 m of some parts of its coastline, with another 30 emerging a week later. Similarly, in the Mediterranean masks have been found floating as indicated by Keiron et al. (2020) and Reuters (2020). The Environment Journal (2020) revealed that only 10% of the population of the United Kingdom wear face masks, resulting in 53 million masks being discarded every day. This suggests that as the patronage of face masks increases, it is expected that there will be a rise in the indiscriminate disposal of face masks. Mejjad et al. (2021) in a study in Morocco stated that an unknown quantity of face masks is discarded indiscriminately in green areas and surface water resources. According to Tan et al. (2021), though most people (94%) in China properly dispose used masks, 22.5% and 7.6% discarded them into general waste bins with lids and without lids respectively. Though communities and public spaces have been provided with garbage receptacles specially for used masks, abandoned face masks were found in buses, bushes, railway stations, and streets (Wang et al., 2020).

According to a study conducted at the University of Naples (Italy), 34.4% ($n = 881$) of respondents said they keep their masks in a specific plastic bag when not in use, 29.4% ($n = 753$) stated they put their masks on their wrist or arm, 26.2% ($n = 671$) put them into their pockets, and only 8.5% ($n = 218$) indicated that they always threw their used masks away (Scalvenzi et al., 2020). A majority (70.5%, $n = 1806$) of the patients at the Dermatology Clinic of the university indicated that they threw masks and FFP out in general garbage, whereas 13.4% and 11% said they threw their masks away in special wastebaskets ($n = 343$) and any convenient waste container ($n = 282$), respectively. This suggests that used face masks were improperly managed even in an academic (tertiary) institution where it is expected that people will be informed



Fig. 3. Improperly disposed face masks.

about the deleterious impacts of face masks in the environment. However, most of the participants in the study resorted to disposal methods that could pose debilitating impacts on the environment, organism and public health.

The indiscriminate disposal of used face masks is reported by Arduoso et al. (2021) who discovered randomly dumped face masks at Claromec6 beaches, Baha Blanca city, Buenos Aires, the Roble River in Circassia, Imbituba city, Santa Catarina, and the Santa Martha beach in South America. Cordova et al. (2021) also found a cluster of improperly disposed PPEs in two rivers in Indonesian; Cilincing and Marinda. Similarly, Aragaw (2020) identified discarded face masks in Lake Tana (Ethiopia), whereas Ammendolia et al. (2021) and Prata et al. (2020) found comparable circumstances in various Canadian cities. COVID-19 PPE items were recorded on 11 out of 14 monitored streets in Kwale, Kilifi, and Mombasa, as well as certain beaches, according to Okuku et al. (2020).

A study by Fadare and Okoffo (2020) noticed people discarding face masks along highways and in drains in Ile-Ife, Nigeria. Shereen et al., (2020) in Ethiopia also posited that large volumes of face masks have been improperly disposed of. Similar to the finding of Shiferie, (2021), Cozier (2020) mentioned that “if even 1% of the masks are not disposed properly, this would result in as many as 10 million face masks per month dispersed in the environment. Considering that the weight of each mask is about 4 gs, this would result in the dispersion of over 40, 000 kgs of plastic poses a dreadful future”. Archana (2020) also reported a flood of face masks on the streets of California.

The findings of De-la-Torre et al. (2021) in a study of the occurrence of PPEs associated with the COVID-19 pandemic along the coast of Lima (Peru) showed that in coastal zones, a total of 138 COVID-19-related PPE waste materials were enumerated. Masks were the most common sort (88%) of PPE identified. The presence of waste PPEs relates to the findings of Keiron et al. (2020) and Reuters (2020) where face masks were indiscriminately disposed along a beach in Hong Kong. A reportage by Grey (2020) from the Environmental Sustainability Coordinator for the City of Mankato reported that “Like most people, we’ve seen them [face masks] lying in parking lots and different places like that where they don’t belong”. The study presented the views of the Co-Chair of Mankato Zero Waste who stated that “I see them [face masks] too often just being thrown down...littering”. These findings presented generally suggest that the management of used face masks has been poor. The indiscriminate disposal of used face masks has been reported in developing and developed countries, and in a wide spectrum of areas such as along beaches and streets, in institutions, and in water resources. This suggests that the associated debilitating ecological and environmental implications are expected.

3.2. Disposal of face masks in some parts of Ghana

Ghana is beset with managing waste PPEs (face masks) at the community level due to institutional and system constraints, and poor attitudes towards handling used face masks. Fig. 2 presents the number of face masks counted along the various study sites where γ and α represent observations done on working and non-working days respectively. The study showed a decreasing volume of waste face masks from urban to rural localities in order of Kumasi (276 masks), Ejisu (130 masks) and Abenase (50 masks) (Fig. 4). This relates to the findings of Scarlat et al. (2015) who indicated that urban areas generate more waste than rural areas due to high population and economic activities. A similar study by Ammendolia et al. (2021) showed that the lack of signposts to guide people on the proper disposal of PPE into general waste bins was a significant contributor to the poor disposal of used face masks in urban areas. Also, though some studies including Michel et al. (2020) and Benson et al. (2021), and Ammendolia et al. (2021) and Xu and Ren (2021) have respectively recommended the installation of special bins for the collection of used PPEs and discard waste PPEs into separate waste containers or plastic bags to impede the spread of the COVID-19

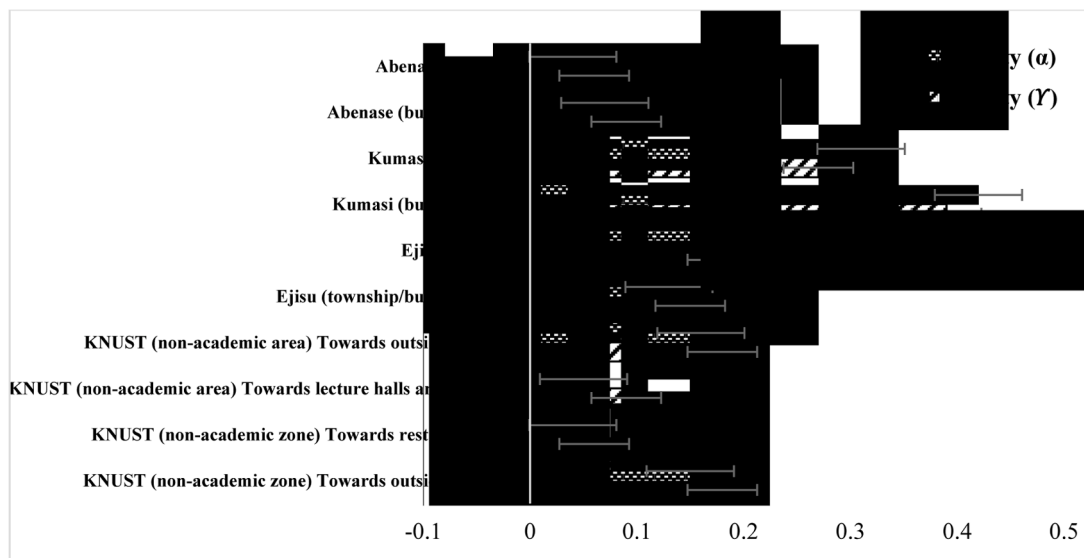


Fig. 4. Face mask density in studied areas.

pandemic, neither of these were observed. This relates to [Douti et al. \(2017\)](#), [Ardusso et al. \(2021\)](#) and [Abanyie et al. \(2021\)](#) who discussed that Ghana and several cities in South American (especially developing countries) continuously lack well-designed infrastructure and systems for proper management of general and healthcare waste. This is a prime problem during the outbreaks of pandemics.

The study ([Figs. 2c-e](#)) further showed that the numerated face masks reduced moving from main townships to suburbs (with red-dashed boxes). Also, more face masks were counted during working days compared to non-working days except for Kumasi where the number of face masks disposed indiscriminately on non-working days exceeded the working days. This could be attributed to the influx of people from rural areas to undertake and partake in economic and social activities.

The exceedance of the number of face masks numerated on working days over non-working days was due to the influx of people from their homes to undertake various activities including work, economic activities, and schooling. In [Figs. 2a-b](#), the number of face masks counted did not vary significantly as a total of 63 and 60 face masks were counted in the KNUST; non-academic and academic zones respectively. Considering the non-academic area ([Fig. 2a](#)), though a higher number of face masks was recorded in this area, there was a swift decline when approaching the restricted zone. This suggests that the intrusion of non-students and no restrictions towards the outskirts of the institution contributed significantly to the indiscriminate disposal of used face masks. It was also observed that this area had a relatively lesser number of waste bins. In [Fig. 2b](#), the main academic area had a lesser number of disposed face masks (26 masks) compared to the area leading to the outskirts of the institution (34 masks). This was largely attributed to the intrusion of non-students in this area as this street is mostly used by pedestrians and people transiting to urban Kumasi. Comparisons made in [Figs. 2a](#) and [b](#), suggest that students were more aware of the need to properly dispose of used face masks. Also, the availability of waste bins influenced the disposal of face masks.

The density of disposed face masks ranged from 0.04 m to 0.42 m ([Table 1](#)). From [Table 1](#), the Kumasi area presented a higher density with a cumulative density of 0.35 m whereas Abenase had the lowest density (0.06 m). The study showed that the density of face masks was not dependent on distance. The findings of this study relate with [De-La-Torre et al. \(2021\)](#) where the PPE density ranged between 0 and 7.44×10^{-4} PPE m^{-2} with an average of 6.42×10^{-5} PPE m^{-2} . The study further showed that recreational beaches recorded the highest average waste PPE density (1.64×10^{-4} PPE m^{-2}). This is attributed to the recreational activities done on beaches ([De-La-Torre et al., 2021](#)).

Table 1

Density of used face masks disposed indiscriminately.

Area	Distance (m)	Number of masks		Density	
		γ	α	γ	α
KNUST (non-academic zone) Towards outside KNUST	150	27 ± 13	23 ± 34	0.18	0.15
		8 ± 24	5 ± 41		
KNUST (non-academic zone) Towards restricted zone	120	17 ± 52	9 ± 28	0.09	0.05
		18 ± 71	16 ± 43		
KNUST (non-academic area) Towards outside KNUST	100	23 ± 19	19 ± 15	0.15	0.13
		36 ± 20	52 ± 18		
Ejisu (township/business area)	200	78 ± 61	83 ± 32	0.39	0.42
		54 ± 03	61 ± 90		
Kumasi (business area)	200	18 ± 27	13 ± 14	0.09	0.07
		12 ± 10	7 ± 13		
Kumasi (less busy)	200	12 ± 10	7 ± 13	0.06	0.04

Similarly, [Daley \(2020\)](#), [Kassam \(2020\)](#), [OceansAsia \(2020\)](#), and [Stokes \(2020\)](#) have also reported a flood of disposed PPE in coastal and urban environments using photographs and videos on social media, news platforms and outlets. The densities of disposed PPEs ranged from 0 to 3.8×10^{-2} items per m^{-2} and 0 and 5.6×10^{-2} items per m^{-2} in beaches in urban and remote areas.

Considering [Fig. 2b](#), it was observed that though the KNUST academic area (towards the lecture halls and faculties) was longer (200 m), it had a lower density than the academic area (towards the outside of KNUST) (100 m). This is further affirmed by the no significant relationship ($P = 0.602$) established between the observation distances and the number of waste face masks numerated. This suggests that other factors such as the number of people visiting the site, awareness of the detrimental impacts of face masks on the environment, and inadequate waste collection receptacles could also influence the indiscriminate disposal of used face masks and the volume disposed.

From [Fig. 3](#), it was observed that used face masks were disposed of indiscriminately in areas including waiting areas, roadsides, vehicles,

bus stops and car parks, grasses, spots or left on office tables. These findings are similar to Mejjad et al. (2021) in Morocco where used face masks on beaches, gardens, roadsides, and hospitals was reported. Also, Rakib et al. (2021), Fadare and Okoffo (2020), De-La-Torre et al. (2021), Thiel et al. (2021), and Okuku et al. (2021) respectively discussed loads of used face masks on beaches in Cox's Bazar; the longest natural beach in the world (Hong Kong), Lima (Peru), the coast of Chile, and Kenya. Though wearing a mask is an effective means of preventing respiratory infectious diseases, and reduce the risk of infection such as COVID-19 as shown by WHO (2006) and Sarkodie and Owusu (2020), its usage also makes it a potential fomite for the spread of the pandemic if it is poorly handled. Besides this, poorly disposed face masks could also pose deleterious environmental and public health implications.

3.3. Relationship between face masks disposal on working (α) and non-working (γ) days

3.3.1. Linear regression analysis

The linear regression model outputs are synthesized in Table 2. It presents the characteristics of the linear regression model; the relationship between the predictor (independent) variable and the dependent variable. The 'R' value represents the correlation between the two variables used in carrying out the analysis. The study (ANOVA) showed a correlation (0.969) which indicates a significantly strong relationship between the two variables (number of face masks counted on working and non-working days). This value commensurate with the paired sample *t*-test in which the correlation from the analysis was 0.969 (Table 3). The R square value reflects the total variation in the dependent variable (non-working day (γ)) that can be explained by the independent variable (working day (α)). The model summary (Table 2) also presents an R square value of 0.940 which is good for further explanation of the analysis.

The ANOVA further defines whether the model fit is substantial enough to decide the outcome of the analysis. The F-ratio (F) obtained (125.073) suggests a higher efficiency for the current model. The significant value (0.000) also shows that the results are statistically significant. Using the coefficients, the strength of the relationship between the two variables and the degree of impact was determined. The significant level of variable α (0.000) which shows a statistically significant relationship forms a foundation to reject the *null hypothesis* that there is no relationship between the two variables (α and γ). Hence, for a 1% increase in working days (α), there would be a 0.775% (B value) increase in the number of face masks on non-working days (γ). There is a statistically significant relation between α and γ in which a change in the predictor variable (α), will correspondent to a correlated change in the dependent variable (γ).

Table 2

Linear regression analysis of face masks disposed on working and non-working days.

Model summary						
Model	R	R Square	Adjusted R Square		Std. Error of the Estimate	
1	.969 ^a	0.940	0.932		0.02684	
Predictors: (Constant), α						
ANOVA						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	0.090	1	0.090	125.073	0.000 ^b
	Residual	0.006	8	0.001		
	Total	0.096	9			
Dependent Variable: γ		Predictors: (Constant), α				
Coefficients						
Model	Unstandardized Coefficients		Standardized Coefficients		t	Sig.
1 (Constant) α	B	Std. Error	Beta		2.738	0.026
	0.039	0.014	0.969		11.184	0.000
	0.775	0.069				
Dependent Variable: γ						

3.3.2. Paired sample *t*-test: working and non-working days

To ascertain if the difference in the means of the two sample populations (α and γ) are equal or not, the paired sample *t*-test hypothesis was used. The paired sample *t*-test statistical technique is used to test the difference of the means of two sample treatments from the sample population. The outputs of the analysis test are presented in Table 3. The analysis was carried out with the *null hypothesis* (H_0) that the difference in the mean of the two variables, α and γ is zero (0) whereas the *alternate hypothesis* (H_1) was that the mean difference between the two sample densities of face mask within the study area is not equal to zero ($\neq 0$). From Table 3, the *t* critical value for the analysis is -0.164 , degree of freedom (df) is 9 and sig. (2-tailed) is 0.873. Since the sig. (2-tailed) is not statistically significant, we fail to reject the null hypothesis and conclude that the means of the two samples are equal to zero implying that there is no statistically significant difference between them. Table 3 and Fig. 5 depict a significantly high correlation (0.969) between the two samples.

3.4. Consequences of poor disposal of used face masks

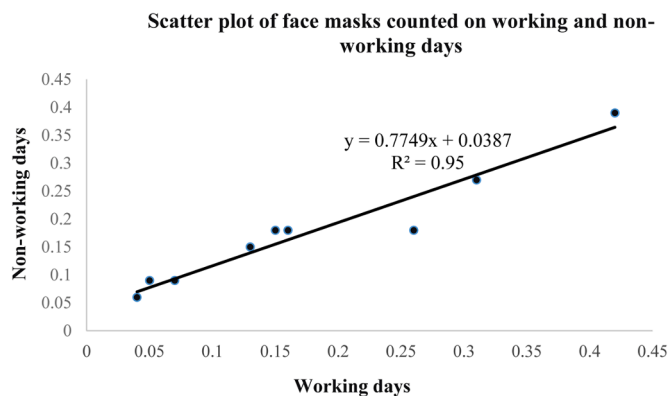
Face mask is ecotoxic since it is composed of non-biodegradable and petroleum-based polymers that are debilitating to the environment and could pose public health problems. This study presents the deleterious impacts of the face masks from 'cradle to grave' (production to disposal) and their possible implications on human health, organisms and the environment. Neglecting the severity of these environmental challenges may result in the discharge of enormous amounts of microplastics into marine systems and landfills, where they mostly end up, severely harming the fauna and flora populations. The production of face masks contributes to the emission of CO₂, which will potentially contribute to global warming (Liebsch, 2020). In manufacturing N95 and surgical masks, the processes of propylene, tiny aluminum strips, and polypropylene (PP) generate a considerable quantity of CO₂ emissions to the environment.

Furthermore, manufacturing fabric, sewing and weaving processes used in the production of cloth masks contribute to CO₂ emissions in the environment (Liebsch, 2020). Abbasi et al. (2020) indicated that N95 and surgical masks respectively contain 9 g and 4.5 g of polypropylene. The ear loops of both face masks are made of natural and synthetic polyisoprene rubber (Selvaranjan et al., 2021). Also, the production of the N95 mask releases 50 g CO₂-eq per mask, excluding the transportation process. The surgical mask is embodied with 59 g CO₂-eq per mask and the highest share is from the transportation process. The production of cloth masks contributes about 60 g CO₂-eq greenhouse gas emission per mask. This can pose debilitating impacts on the atmosphere since millions of face masks are produced globally in the fight against the COVID-19 pandemic (Klemeš et al., 2020; Selvaranjan et al., 2021).

Table 3

T-test of disposal of face masks on working and non-working days.

Paired Samples Statistics		Mean	N	Std. Deviation	Std. Error Mean				
Pair 1	α	0.1630	10	0.12910	0.04083				
	γ	0.1650	10	0.10320	0.03263				
Paired Samples Correlations				Correlation	Sig.				
Pair 1	α & γ			0.969	0.000				
Paired Samples Test									
Paired Differences		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
Pair 1	$\alpha - \gamma$	-0.00200	0.03853	0.01218	Lower	Upper	-0.164	9	0.873
					-0.02956	0.02556			

**Fig. 5.** Relationship between face masks enumerated on non- and working days.

The [World News \(2021\)](#) in a reportage revealed that a study has found elevated levels of elements that pose deleterious environmental and health implications including Pb, Cu and Sb from discarded face masks. The study indicated that “there is a concern amount of evidence that suggests that DPFs waste can potentially have a substantial environmental impact by releasing pollutants simply by exposing them to water”. Reportages by [Mowbray \(2021\)](#) in the MCL News and Media, [Khanna \(2021\)](#) and [Wikins \(2021\)](#) have respectively indicated that recent studies have found compounds including 2-butanone oxime blocked diisocyanates used as crosslinkers for perfluorocarbons (PFCs), aniline and formaldehyde (which are carcinogenic) in face masks. A study by [Jung et al. \(2021\)](#) on the elemental constituents of face masks revealed that aside polyethylene which has been widely discussed, Zn, Mn, Ti, Fe and Ca are also found in face masks. This suggests that DPFs could become one of the main factors impacting the environment negatively even after the COVID-19 pandemic declines.

Face masks in particular is a significant source of microplastics (MPs). Fourier transform infrared (FTIR) analysis has shown that masks are composed of PP and High Density Poly Ethylene (HDPE). [Aragaw \(2020\)](#) and [Fadare and Okoffo \(2020\)](#) have also revealed that electrospinning-made face masks might readily disintegrate and release micro- and nano-fibres (PP and PE) into the environment. Like other forms of litter deposited into marine systems, these PPE may interact with marine biota ([Acharya, 2020](#); [Brochain, 2021](#); [Shutterstock, 2021b](#)). The presence of face masks in surface water resources could choke aquatic animals which can lead to malnutrition since plastic materials from face masks may fill their stomachs but do not provide any nutrients ([Keiron et al., 2020](#)).

The use of elastic cords in the production of face masks puts aquatic animals at risk of becoming entangled. It has been documented that COVID-19 litter, notably face masks interact with aquatic and terrestrial species ([Hiemstra et al., 2021](#)). Littered face masks can impact fauna

through entanglement which can cause death. [Boyle \(2020\)](#) reported in Columbia that a bird was tangled in a discarded face mask on a tree. It died after the mask wrapped its body and beak ([Fig. 6](#)). A single mask may produce millions of particles, of which each can transport harmful elements and germs up the food chain and into people ([Daley, 2020](#); [Fadare and Okoffo, 2020](#)). When animals mistakenly consume face masks as food, the plastic can fill their stomachs, reduce food intake which kills them. For instance, an adult Magellanic penguin (*Spheniscus magellanicus*) was found dead in the Juquehy Beach in Brazil (São Sebastião), as indicated by Neto et al. (2021). This debilitating impact was possibly caused by the consumption of an FFP-2 protective face mask ([Silva et al., 2021](#)).

As described for wastewater treatment facilities (WWTPs), PPE contaminated with SARS-CoV-2 might constitute a conduit for reverse zoonotic transmission in marine animals ([Mathavarajah et al., 2020](#)). Plastics degrade into smaller particles and are environmentally persistent. They disintegrate first into microplastics, then into a smaller size; nanoplastics. These microscopic particles and fibres are environmental persistent polymers that can affect food chains through accumulation. A reportage by [Grey \(2020\)](#) indicated that in southern Minnesota, the accumulation of microplastics in surface water resources has become a major challenge. [Jung et al. \(2021\)](#) advocate for adequate mask sensitization and training, as well as correct mask collection and disposal, treating masks as infectious waste. Several waste disposal and collection techniques, including siting waste collection receptacles at vantage points may be utilized to limit the disposal of used face masks directly into environmental media.

3.5. What can be done to reduce the impacts associated with the indiscriminate disposal of face masks?

Following the deleterious impacts of the indiscriminate disposal of face masks, it is therefore required that face masks are:

- Designed with biodegradable/reusable/recyclable materials: Biodegradable masks are one of the most contemporary and ecological alternatives to masks that produce plastic waste. Other organic and

**Fig. 6.** Threat of improperly disposed face masks to birds ([Boyle, 2020](#)).

biodegradable materials with similar physical, chemical and mechanical properties, including lightweight, ecological safety, high tensile strength, low cost, and high biodegradable potentials such as cotton, hemp and flax can be used in place of polypropylene in the production of face masks. Such natural textile masks can be made anti-microbial by applying various herbal anti-microbial extracts like basil, turmeric, neem, and aloe vera.

- Retrieved and recycled: As recommended by Williams-Wynn and Naidoo (2020) and Selvaranjan et al. (2020) in the management of plastic waste, collected face masks should be shredded and sorted using techniques such as flotation, X-ray fluorescence, density separation, spectroscopy, and magnetic separation. The color is then separated using an optical sorter, and the separated polymers are melted and extruded into pellets for reuse. The recovered plastics are supplied to local plastic manufacturing companies, who can convert them into usable materials such as motor oil, textiles, footwear, and concrete additives. Because this procedure is too costly to be economically viable, an alternative would be to use automated separation of distinct polymers before shredding. This will ensure that they disintegrate and decompose rapidly without posing any persistent environmental challenges.
- Improve waste (used face masks) collection systems: Considering the nature of face masks, they can easily be disposed anywhere. Therefore, it will be essential to increase the coverage of waste bins, encourage waste segregation, ensure timely collection of waste and invest in more productive ways of handling this form of waste.
- Public education/sensitization on the need for proper disposal of used face masks and the associated implications associated with the indiscriminate disposal.

4. Conclusion and future studies

This study sought to ascertain if face masks used in the prevention of the spread of the COVID-19 pandemic which is considered infectious are properly handled. The study presents evidence of poor handling and management of waste face masks though it is described as infectious. Used face masks are indiscriminately disposed into areas including waterbodies, along streets, mixed with general waste, thrown into bushes, left at beaches, left in open spaces, waiting areas, dust/toilet bins, and inside vehicles. Using PPEs to prevent the spread of the COVID-19 pandemic and subsequent improper disposal has exacerbated environmental plastic pollution. In the present study, the number of face masks disposed of indiscriminately were higher in urban > sub-urban > rural areas. Also, areas restricted to elites (institutions) had less littered face masks, whereas institutional areas which were open to the public had a higher litter of waste face masks compared to the restricted areas. This is associated with the high influx of persons compared to the restricted zones. Public sensitization and the formulation of legislation towards proper disposal of used face masks are suggested as an approach to minimizing littering of this potentially infectious waste. In severe cases of deliberate flouting of legislations and systems implemented to curb littering and incorrect disposal of used face masks penalization could be employed to protect the environment. Further studies can focus on:

- Assessing levels of micro- and nano-plastics in environmental media.
- Determining factors that contribute to the indiscriminate disposal of used face masks.
- Estimating the number of waste face masks (PPEs in general) generated from the local to the national level (each country) for proper waste management system development/improvement.
- Understanding the deleterious impacts of plastics and elements from face masks on public health.
- Evaluating the performance of regulations and policies governing the production and disposal of face masks. Stricter measures must be

enforced in the manufacturing and disposal/recycling of DPFs to mitigate their impacts on the environment.

Availability of data and materials

Not applicable

Ethical approval

The study meets all the ethics required for experiments and research. This study does not entail human subjects. It has been submitted with full responsibility following due ethical procedures without any duplicate submission.

Funding

No funds were received for this project.

CRediT authorship contribution statement

Ebenezer Ebo Yahans Amuah: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Edna Pambour Agyemang:** Conceptualization, Methodology, Investigation, Writing – original draft. **Paul Dankwa:** Software, Data curation. **Bernard Fei-Baffoe:** Resources, Supervision. **Raymond Webrah Kazapoe:** Writing – original draft, Writing – review & editing. **Nang Biyogoue Douiti:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

No competing interest is declared. All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version. This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue. The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript

Acknowledgement

Special thanks to all who advised us on how to formulate and draft this paper.

References

- Abanyie, S.K., Amuah, E.E.Y., Douiti, N.B., Amadu, C.C., Bayorbor, M., 2021. Healthcare waste management in the tamale central Hospital, northern Ghana. An assessment before the emergence of the COVID-19 pandemic in Ghana. *Environ. Challenges*, 100320.
- Abbasi, S.A., Khalil, A.B., Arslan, M., 2020. Extensive use of face masks during COVID-19 pandemic: (micro-) plastic pollution and potential health concerns in the Arabian Peninsula. *Saudi J. Biol. Sci.* 27 (12), 3181–3186.
- Acharya, D., 2020. Face masks are invading the ocean at a record level - COVID-19 Consequence. Available at <https://mobygeek.com/features/face-masks-are-invading-the-ocean-at-a-record-level-13897> Accessed June 3, 2021.
- Alonzi, S., La Torre, A., Silverstein, M.W., 2020. The psychological impact of preexisting mental and physical health conditions during the COVID-19 pandemic. *Psychol. Trauma: Theory, Res. Practice, and Policy* 12 (S1), S236.
- Ammendolia, J., Saturno, J., Brooks, A.L., Jacobs, S., Jambeck, J.R., 2021. An emerging source of plastic pollution: environmental presence of plastic personal protective equipment (PPE) debris related to COVID-19 in a metropolitan city. *Environ. Pollut.* 269, 116160.
- Amuah, E.E.Y., Bekoe, E.M.O., Kazapoe, R.W., Dankwa, P., Nandomah, S., Douiti, N.B., Abanyie, S.K., Okyere, I.K., 2021. Sachet water quality and Vendors' practices in Damongo, northern Ghana during the emergence of SARS-CoV-2 using multivariate statistics, water quality and pollution indices, and panel assessment. *Environ. Challenges*, 100164.
- Aragaw, T.A., 2020. Surgical face masks as a potential source for microplastic pollution in the COVID-19 scenario. *Mar. Pollut. Bull.* 159, 111517.
- Archana, K.C., 2020. Face Masks Littered On California Highway Cause Traffic Jam As Drivers Stop To Pick Them Up. California Highway Littered With Face Masks.

- Available at https://im.indiatimes.in/content/2020/May/Face-Masks-Freeway-1_5eae8fcb4aad8.jpg?w=725&h=380 Accessed June 3, 2021.
- Ardusso, M., Forero-López, A.D., Buzzi, N.S., Spetter, C.V., Fernández-Severini, M.D., 2021. COVID-19 pandemic repercussions on plastic and antiviral polymeric textile causing pollution on beaches and coasts of South America. *Sci. Total Environ.* 763, 144365.
- Benson, N.U., Fred-Ahmadu, O.H., Bassey, D.E., Atayero, A.A., 2021. COVID-19 pandemic and emerging plastic-based personal protective equipment waste pollution and management in Africa. *J. Environ. Chem. Eng.*, 105222.
- Bouchet, A., Boucher, J., Schutzbach, K., Senn, N., Genton, B., Vernez, D., 2021. Which strategy for using medical and community masks? A prospective analysis of their environmental impact. *BMJ Open* 11 (9), e049690.
- Boyle, L., 2020. Bird Dies After Getting Tangled in Coronavirus Face Mask Independent New York.
- Brochain, E., 2021. The Ocean Is Now Littered With Disposable Face Masks And Gloves. Available at <https://www.bolde.com/ocean-littered-face-masks-gloves/> Accessed June 3, 2021.
- Cordova, M.R., Nurhati, I.S., Riani, E., Nurhasanah, Iswari, M.Y., 2021. Unprecedented plastic-made personal protective equipment (PPE) debris in river outlets into Jakarta Bay during COVID-19 pandemic. *Chemosphere* 268, 129360.
- Cozier, M., 2020. Disposing of PPE Responsibly is Essential. Available at <https://www.soci.org/news/2020/7/disposing-of-ppe-responsibly-is-essential> Accessed October 6, 2021.
- Daley, B., 2020. Coronavirus face masks: an environmental disaster that might last generations. Available at <https://theconversation.com/coronavirus-face-masks-an-environmental-disaster-that-might-last-generations-1443288> Accessed May 19, 2021.
- De-la-Torre, G.E., Rakib, M.R.J., Pizarro-Ortega, C.I., Dioses-Salinas, D.C., 2021. Occurrence of personal protective equipment (PPE) associated with the COVID-19 pandemic along the coast of Lima. *Peru. Sci. Total Environ.* 774, 145774.
- Dharmaraj, S., Ashokkumar, V., Hariharan, S., Manibharathi, A., Show, P.L., Chong, C.T., Ngamcharussrivichai, C., 2021. The COVID-19 pandemic face mask waste: a blooming threat to the marine environment. *Chemosphere* 272, 129601.
- Douti, N.B., Abanyie, S.K., Ampofo, S., 2017. Solid waste management challenges in urban areas of Ghana: a case study of Bawku Municipality. *Int. J. Geosci.* 8, 494–513.
- Environment Journal, 2020. The environmental impact of abandoned face masks. Available at <https://environmentjournal.online/articles/the-environmental-impact-of-abandoned-face-masks/> Accessed May 19, 2021.
- Fadare, O.O., Okoffo, E.D., 2020. Covid-19 face masks: a potential source of microplastic fibers in the environment. *Sci. Total Environ.* 737, 140279.
- Ghana News Agency, 2021. Health Alert: Disposal of Face Masks Indiscriminately. Available at <https://newsghana.com.gh/health-alert-disposal-of-face-masks-indiscriminately/> Accessed April 20, 2021.
- GhanaWeb, 2021. Coronavirus: noguchi Director calls for proper disposal of face masks. Available at <https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Coronavirus-Noguchi-Director-calls-for-proper-disposal-of-face-masks-1238767> Accessed May 23, 2021.
- Grey, M., 2020. Improper mask disposal has environmental consequences. Available at <https://www.keyc.com/2020/11/29/improper-mask-disposal-has-environmental-consequences/> Accessed October 5, 2021.
- Harapan, H., Itoh, N., Yufika, A., Winardi, W., Keam, S., Te, H., Megawati, D., Hayati, Z., Wagner, A.L., Mudatsir, M., 2020. Coronavirus disease 2019 (COVID-19): a literature review. *J. Infect. Public Health* 13 (5), 667–673.
- Hartanto, B.W., Mayasari, D.S., 2021. Environmentally friendly non-medical mask: an attempt to reduce the environmental impact from used masks during COVID 19 pandemic. *Sci. Total Environ.* 760, 144143.
- Jung, S., Lee, S., Dou, X., Kwon, E.E., 2021. Valorization of disposable COVID-19 mask through the thermo-chemical process. *Chem. Eng. J.* 405, 126658.
- Kassam, A., 2020. "More Masks than Jellyfish": Coronavirus Waste Ends Up in Ocean. Available at <https://www.theguardian.com/environment/2020/jun/08/more-masks-than-jellyfish-coronavirus-waste-ends-up-in-ocean> Accessed May 19, 2021.
- Keiron, P.R., Cressida, B., Simon, K., Steve, F., 2020. Face mask pollution could lead to an environmental disaster. Available at <https://www.mic.com/p/face-mask-pollution-could-lead-to-environmental-disaster-32135830> Accessed May 19, 2021.
- Khanna, M., 2021. Some face masks have toxic chemicals that can harm us, Scientists find. Available at <https://www.google.com/amp/s/www.indiatimes.com/amp/technology/science-and-future/face-masks-coated-toxic-chemicals-study-537528.html> Accessed October 9, 2021.
- Klemeš, J.J., Van Fan, Y., Jiang, P., 2020. The energy and environmental footprints of COVID-19 fighting measures—PPE, disinfection, supply chains. *Energy* 211, 118701.
- Kumar, A., 2020. Environmental impact of disposable masks. Available at <https://www.onlineclothingstudy.com/2020/04/environmental-impact-of-disposable-masks.html> Accessed March 29, 2021.
- Kumar, J., Katto, M.S., Siddiqui, A.A., et al., 2020. Knowledge, attitude, and practices of healthcare workers regarding the use of face mask to limit the spread of the new coronavirus disease (COVID-19). *Cureus* 12 (4), e7737.
- Leung, N.H., Chu, D.K., Shiu, E.Y., Chan, K.H., McDevitt, J.J., Hau, B.J., Cowling, B.J., 2020. Author correction: respiratory virus shedding in exhaled breath and efficacy of face masks. *Nat. Med.* 26 (6), 981.
- Liesch, T., 2020. The rise of the face mask: what's the environmental impact of 17 million N95 masks? *Ecochain* www.ecochain.com.
- Liu, A., 2020. Disposable masks raise environmental concerns. Available at <https://dailytrojan.com/2020/10/08/disposable-masks-raise-environmental-concerns/> Accessed April 10, 2021.
- Mathavarajah, S., Stoddart, A.K., Gagnon, G.A., Dellaire, G., 2020. Pandemic danger to the deep: the risk of marine mammals contracting SARS-CoV-2 from wastewater. *Sci. Total Environ.* 143346.
- Mejjad, N., Cherif, E.K., Rodero, A., Krawczyk, D.A., El Kharraz, J., Moumen, A., Fekri, A., 2021. Disposal behavior of used masks during the COVID-19 pandemic in the Moroccan community: potential environmental impact. *Int. J. Environ. Res. Public Health* 18 (8), 4382.
- Michel, J., Bärnighausen, T., Tediosi, F., Evans, D., Tanner, M., 2020. COVID-19: what else would be helpful to know? *J. Glob. Health Rep.* 4, e2020062.
- Mihai, F.C., 2020. Assessment of COVID-19 waste flows during the emergency state in Romania and related public health and environmental concerns. *Int. J. Environ. Res. Public Health* 17 (15), 5439.
- Modern Ghana News, 2020. "Ghana makes strides in PPE production and supply – Akufo Addo". Available at <https://www.modernghana.com/news/998328/ghana-makes-strides-in-ppe-production-supply.html> Accessed December 2, 2020.
- Morgana, S., Casentini, B., Amalfitano, S., 2021. Uncovering the release of micro/nanoplastics from disposable face masks at times of COVID-19. *J. Hazard. Mater.* 419, 126507.
- Mowbray, J., 2021. Available at <https://www.ecotextile.com/2021040127603/dyes-chemicals-news/exclusive-chemical-cocktail-found-in-face-masks.html> Accessed October 12, 2021.
- OceansAsia, 2020. COVID-19 facemasks & marine plastic pollution. OceansAsia. Available at <https://oceansasia.org/covid-19-facemasks/> Accessed May 24, 2021.
- Okuku, E., Kiteresi, L., Owato, G., Otieno, K., Mwalugha, C., Mbuche, M., Gwada, B., Nelson, A., Chepkemboi, P., Achieng, Q., Wanjeri, V., 2021. The impacts of COVID-19 pandemic on marine litter pollution along the Kenyan Coast: a synthesis after 100 days following the first reported case in Kenya. *Mar. Pollut. Bull.* 162, p111840.
- Prata, J.C., Silva, A.L.P., Walker, T.R., Duarte, A.C., Rocha-Santos, T., 2020. COVID-19 pandemic repercussions on the use and management of plastics. *Environ. Sci. Technol.* 54, 7760–7765.
- Rakib, M.R.J., De-la-Torre, G.E., Pizarro-Ortega, C.I., Dioses-Salinas, D.C., Al-Nahian, S., 2021. Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic in Cox's Bazar, the longest natural beach in the world. *Mar. Pollut. Bull.* 169, 112497.
- Reuters, S., 2020. Discarded coronavirus masks clutter Hong Kong's beaches, trails. Available at <https://www.reuters.com/article/us-health-coronavirus-hongkong-environment/discarded-coronavirus-masks-clutter-hong-kongs-beaches-trails-idUSKBN20ZOPP> Accessed May 2, 2021.
- Roberts, K.P., Bowyer, C., Kolstoe, S., Fletcher, S., 2020. Coronavirus face masks: an environmental disaster that might last generations. *The Conversation*. <https://theconversation.com/coronavirus-face-masks-an-environmental-disaster-that-might-last-generations-144328> (last accessed 17 November 2020).
- Saadat, S., Rawtani, D., Hussain, C.M., 2020. Environmental perspective of COVID-19. *Sci. Total Environ.* 138870.
- Sangkham, S., 2020. Face mask and medical waste disposal during the novel COVID-19 pandemic in Asia. *Case Stud. Chem. Environ. Eng.* 2, 100052.
- Sarkodie, S.A., Owusu, P.A., 2020. Investigating the cases of novel coronavirus disease (COVID-19) in China using dynamic statistical techniques. *Heliyon* 6 (4), e03747.
- Scalvenzi, M., Villani, A., Ruggiero, A., 2020. Community knowledge about the use, reuse, disinfection and disposal of masks and filtering facepiece respirators: results of a study conducted in a dermatology clinic at the university of naples in Italy. *J. Community Health*, 1–8.
- Scarlat, N., Motola, V., Dallemand, J.F., Monforti-Ferrario, F., Mofor, L., 2015. Evaluation of energy potential of municipal solid waste from African urban areas. *Renewable and Sustainable Energy Rev.* 50, 1269–1286.
- Selvaranjan, K., Navaratnam, S., Rajeev, P., Ravintherakumar, N., 2021. Environmental challenges induced by extensive use of face masks during COVID-19: a review and potential solutions. *Environ. Challenges*, 100039.
- Shereen, M.A., Khan, S., Kazmi, A., Bashir, N., Siddique, R., 2020. COVID-19 infection: origin, transmission, and characteristics of human coronaviruses. *J. Adv. Res.* 24, 91–98.
- Siferie, F., 2021. Improper disposal of face masks during COVID-19: unheeded public health threat. *Pan. Afr. Med. J.* 38.
- Shutterstock, 2021a. Used face mask floating sea mediterranean. Available at <https://www.shutterstock.com/image-photo/used-face-mask-floating-sea-mediterranean-1778173526> Accessed May 30, 2021.
- Shutterstock, 2021b. Environmental pollution personal protective equipment. Available at <https://www.shutterstock.com/image-photo/environmental-pollution-personal-protective-equipment-against-1768218473> Accessed June 3, 2021.
- Silva, A.L.P., Prata, J.C., Mouneyrac, C., Barceló, D., Duarte, A.C., Rocha-Santos, T., 2021. Risks of Covid-19 face masks to wildlife: present and future research needs. *Sci. Total Environ.* 148505.
- Stokes, G., 2020. No shortage of masks at the beach - oceans Asia. *OceansAsia* Available at <https://oceansasia.org/beach-mask-coronavirus/> Accessed May 19, 2021.
- Tan, M., Wang, Y., Luo, L., Hu, J., 2021. How the public used face masks in China during the coronavirus disease pandemic: a survey study. *Int. J. Nurs. Stud.* 115, 103853.
- Thiel, M., de Veer, D., Espinoza-Fuenzalida, N.L., Espinoza, C., Gallardo, C., Hinojosa, I. A., Villablanca, R., 2021. COVID lessons from the global south—face masks invading tourist beaches and recommendations for the outdoor seasons. *Sci. Total Environ.* 786, 147486.
- Wang, M.W., Zhou, M.Y., Ji, G.H., Ye, L., Cheng, Y.R., Feng, A.H., et al., 2020. Mask crisis during the COVID-19 outbreak. *Eur. Rev. Med. Pharmacol. Sci.* 24 (6), 3397–3399.
- WHO, 2021. WHO Health Emergency Dashboard. Available at <https://www.worldometers.info/coronavirus/country/ghana/> Accessed August 14, 2021.
- Wilkins, A., 2021. Some Face Masks Contain Dangerous Levels of Toxic Chemicals. Available at <https://www.google.com/amp/s/metro.co.uk/2021/04/01/some-face-masks-contain-dangerous-levels-of-toxic-chemicals-14343781/amp/> Accessed October 12, 2021.

- Williams-Wynn, M.D., Naidoo, P., 2020. A review of the treatment options for marine plastic waste in South Africa. *Mar. Pollut. Bull.* 161, 111785.
- World Economic Forum, 2021. How face masks, gloves and other coronavirus waste is polluting our ocean. Available at <https://www.weforum.org/agenda/2020/06/ppe-masks-gloves-coronavirus-ocean-pollution/> Accessed April 18, 2021.
- World Health Organization (WHO) Writing Group, 2006. Nonpharmaceutical interventions for pandemic influenza, national and community measures. *Emerg. Infect. Dis.* 12, 88–94.
- World News, 2021. Scientists find dangerous chemical pollutants in disposable face masks. Available at <https://www.hindustantimes.com/world-news/scientists-find-dangerous-chemical-pollutants-in-disposable-face-masks-101620189597016.html> Accessed October 18, 2021.
- Xu, E.G., Ren, Z.J., 2021. Preventing masks from becoming the next plastic problem. *Front. Environ. Sci. Eng.* 15, 125.