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Protective Disposable Face Masks Used During the COVID-19 Pandemic as a Source of Pollutants in the Aquatic Environment – A Study of Short-Term Effects

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ABSTRACT

The paper examines the impact of protective equipment used during the COVID-19 pandemic on the environment. The impact of protective face masks on the aquatic environment was analyzed in more detailed way. The amount of protective face masks penetrated into the environment as a result of the COVID-19 pandemic and their role in the increase of plastic and microplastic things in the environment was noted. The aim of the work was to study the migration of a number of metals from disposable protective masks into the aquatic environment in the short term. Using the method of atomic absorption spectroscopy, the value of Cu, Pb, Mn, Zn, Fe in the investigated model systems containing protective disposable face masks was obtained by varying the pH of the aqueous medium. It was found that for manganese, lead and iron there is a permanent (Mn) or temporary (Pb, Fe) excess of these metals in the aquatic environment according to national and European standards. The probable possibility of sorption effects and the need for further research in this direction were noted.

Keywords: disposable protective face mask, pollution, atomic adsorption spectroscopy, aqueous environment, heavy metal.

INTRODUCTION

The up-to-date world is the result of a complex interaction of natural and anthropogenic factors, where constant changes in the surrounding natural environment cause disturbances in man-made space and vice versa. Thus, it is possible to note significant climatic changes that affect the yield of agro-industrial crops [Rosegrant et. al., 2021] and the population [Sesana, et. al., 2021; Dickerson et. al., 2022]. At the same time, anthropogenic activity is currently the main driving force that changes the natural world as in its individual elements [Popovych V. et. al., 2021; Mali et. al., 2023], and in general [Han et. al., 2023]. Negative anthropogenic actions on the environment can also include the effects of certain types of emergency situations, in particular, hostilities [Weir, 2020], terrorist acts [Divizinyuk et. al., 2019], fires and their consequences [Strelets et. al., 2021; Abramov et. al., 2019]. At the same time, pollution of the environment and of water bodies, in particular, may occur in the point and diffuse sources of pollution [Loboichenko et. al., 2021; Horta Ribeiro Antunes et. al., 2021].

Another challenge to humanity and the planet as a whole was the pandemic which was named COVID-19. Significant human casualties, negative consequences for the health of sick persons, revision of the work of national and international medical, service and transport services are only part of the consequences caused by this disease. The environment has also suffered additional impacts due to the huge amount of medical waste that have started to enter the environment since the beginning of the pandemic, and it primarily concerns personal protective equipment (PPE) [Yang et. al., 2022]. PPE, including protective face masks, have become a problem in many cities [Ammendolia et. al., 2021; Tesfaldet Y et. al., 2022], cluttering city streets and further entering the environment. Thus, the share of medical waste from PPE in urban garbage has grown significantly since the pandemic; the largest, 80-fold increase is noted for disposable protective face masks [Norris, 2021]. Only in the first year of the pandemic the waste was generated containing almost 4 million metric tons of masks [Patrício Silva et. al., 2021a]. So, at the present, the total annual volume of the waste from 36 countries reaches 1.5 million tons of protective face masks [Shukla et. al., 2022].

Among the ways to reduce their number in the environment, in addition to rational waste management [Alieva et. al., 2021], limited reuse of disposable protective masks is also considered [Alcaraz et. al., 2022], their production using biodegradable materials [Babaahmadi et. al., 2021], green technologies [Du et. al., 2022] and stricter approaches to raw materials [Chen et. al., 2022].

The massive use of rubber gloves, disposable suits, and protective face masks additionally caused up to 400,000 tons of waste to enter the marine environment [Patrício Silva et. al., 2022] that cause short-term and long-term, direct and indirect effects on biota.

In many studies the negative effects of plastic and microplastics from PPE on the environment are noted. First of all, the role of disposable protective face masks in polluting the environment with plastic is noted, due to the mass of their use and the fibrous structure of the material [Pizarro-Ortega et. al., 2022]. It is noted that both disposable and reusable protective masks made of polymer and cotton materials are a source of microfibers entering the environment [De Felice et. al., 2022], Moreover, the number of microfibers from used disposable masks is 6-7 times higher than from new ones [Chen et. al., 2021].

It is also noted that in addition to the significant amount of plastic and microplastics entering the aquatic environment from PPE, the leaching of organic compounds that may be a component of the PPE production process [Uddin et. al., 2022] or provide antimicrobial, protective, cleansing properties, for example, of protective face masks [Patrício Silva et. al., 2021b]. Additional polluting components used in the production of protective masks can also be metal nanoparticles, extracts of vegetable oils, etc. [Chen et. al., 2022]

Many studies have noted the negative impact of disposable protective face masks on aquatic ecosystems [Akhbarizadeh et. al., 2021; Wu et. al., 2022]. It is indicated that most of such masks are made of petroleum-based non-renewable polymers that are non-biodegradable and hazardous to the environment [Dharmaraj et. al., 2021]. Considerable attention is paid to the kinetics leaching microplastic and fiber sizes. Thus, [Liang et. al., 2022] it is noted that the rate of the washing out does not depend on the type of the investigated masks, and the size of microplastic fibers is less than 500 μm. It is noted that directly protective masks can act as vehicles for transferring other sorbed pollutants to them in the water environment [Wang et. al., 2022].

The impact of physical factors, in particular, ultraviolet and mechanical impact of shoreline sand on the waste of protective masks and their contribution to the formation of microplastic is noted [Wang et. al., 2021]. The increase in the extraction of microfibers from PPE and protective masks under the influence of the sea water and the current is indicated [Rathinamoorthy et. al., 2022]. This microplastic and compounds washed into the water environment from protective masks can be adsorbed on algae, included in trophic chains [Ma et. al., 2021] and cause toxicogenomic effects on living beings [Sendra et. al., 2022]. Cross-contamination of different types of masks with microplastic of different origins can also occur, which makes it difficult to assess the individual effects of these masks [Torre et. al., 2022].

At the same time, the chemical effects on the environment from protective masks have been studied relatively less. Thus, a significant experiment conducted [Bussan et. al., 2022] for 24 surgical and KN95 face masks showed the direct presence of lead, copper, zinc, and antimony in some of them which can be washed away. The authors [Leonova et. al., 2022] indicate the excess of zinc and lead in the soil in the presence of protective disposable face masks and emphasize the need for further research. In the paper [Sullivan et. al., 2021] a daily study of a number of disposable masks showed the leaching of trace amounts of lead, cadmium, antimony and various organic substances from them. In the paper [Kutralam-Muniasamy et. al., 2022] the authors emphasize the lack of regulation of chemical compounds in protective masks and PPE, although heavy metals and organic pollutants enter the water environment from them. The need for further research into the features of chemical degradation of PPE is noted. The research by the authors [Liu et. al., 2022] showed that leaching of heavy metals from surgical disposable masks is easier than from respirators, and in the filtrates during a 15-day study of a number of samples, Co, Cu, Ni, Sr, Ti, Zn were detected, and in some masks – also Cd, Cr, Mn and Pb. The leaching of microplastics and organic compounds is also shown acetophenone, 2,4-Di-tert-butylphenol, benzothiazole, bisphenol-A, phthalide and environmentally persistent free radicals.

Thus, it can be noted that the specifics of the chemical effects of protective face masks on the aquatic environment are not sufficiently studied today. Considering the above, the aim of the work is to study the migration of a number of metals from disposable protective masks into the aquatic environment in the short term.

MATERIALS AND METHODS

The following reagents, materials and equipment were used in the research process:

- hydrochloric acid, sodium hydroxide, standard samples of the composition of solutions 0.1 g/l Me (Cu, Zn, Mn, Pb, Fe) (Ukraine), distilled water. The qualifications of all reagents were "pure for analysis" and higher;
- laboratory scales AS 220.R2; pH meter PH-150MI (pH error = ±0.02); atomic adsorption spectrophotometer C 115 M1; measuring laboratory equipment (flasks, glasses, pipettes, funnels), laboratory scales TVE-0.21-0.001-a.

The solutions necessary for the work were prepared by diluting from more concentrated solutions or by weighing the required mass of appropriate reagents with their subsequent dissolution. The study used three-layer ("spunbond + meltblown + spunbond" materials) protective disposable masks manufactured by Abifarm (Herbal fresh) - Mask (I) and Meddins - Mask (II). 10 masks from each manufacturer were completely immersed in closed containers with distilled water (250 cm^3), which were stirred 3 times a day. To study the effects of pH, aliquots of 0.1 M NaOH or HCl were added to a number of containers on the 5th, 15th, 25th and 35th day of the study.

The study was conducted by measuring indicators on the 5th, 15th, 25th, and 35th day of the study. A total of 4 measurements were made. Determination of pH of aqueous solutions – place an aliquot of the test solution in a beaker with a capacity of 50 cm^3 and measure its pH according to the instructions for the device.

Preparation of calibration solutions for atomic absorption analysis of the content of heavy metals

Standard solutions are prepared from solutions containing 0.1 g/l of metal (Cu, Zn, Mn, Pb, Fe) by diluting aliquots of HNO_3 ($\omega = 1.5\%$). Solutions with a lower concentration are prepared by diluting the original solution.

Atomic absorption study of the content of heavy metals

The device is prepared for operation according to the instructions. Next, a lamp with a hollow metal (Cu, Zn, Mn, Pb, Fe) cathode is connected to the monochromator of the device, and the analytical line of the corresponding metal is derived. Next, the light absorption of the calibration solutions or the studied aliquot of the solution is measured. Next, they construct calibration dependence for each metal and determine its content in the studied samples. Standard mathematical approaches are used for data processing.

RESULTS AND DISCUSSION

In the work, 4 aliquots of aqueous solutions containing masks were taken, respectively, on the 5th, 15th, 25th and 35th day of the study. First, data of changes in the pH of the water environments in which the investigated masks were located during the experiment were obtained. The dependence of the change in the pH of aqueous solutions in the absence and with the addition of appropriate amounts of hydrochloric acid or sodium hydroxide in the container with the investigated masks is shown in Figure 1. As it can be seen from the obtained values, for both types of masks, similar dependence of the pH change on the time of the study is observed, except point 3 for Mask (II) in hydrochloric acid, which can be considered a fluctuation deviation, which is leveled at point 4.

During the study, the pH of the medium changes by 1 pH both in the direction of increasing acidity (6.2) and in the direction of decreasing acidity (8.2) compared to the original, neutral medium. Fig. 2–6 represent the dependence of the content of heavy metals (Mn, Cu, Zn, Pb, Fe) on the time of the study for Mask (I) and Mask (II) taking into account the pH of the medium. As it can be seen from the obtained data (Fig. 2), the main leaching of manganese occurs on the first days of the mask entering the water for both Mask (I) and Mask (II). For Mask (I) with a slight decrease in the pH of the medium, and for Mask (II) – with an increase in the pH of the medium relative to its neutral state. Under the conditions of a neutral medium, we can tell about a more gradual (within 25 days) leaching of manganese compounds into the solution. A decrease in the manganese content in an acidified or alkaline environment may indicate the possible sorption of

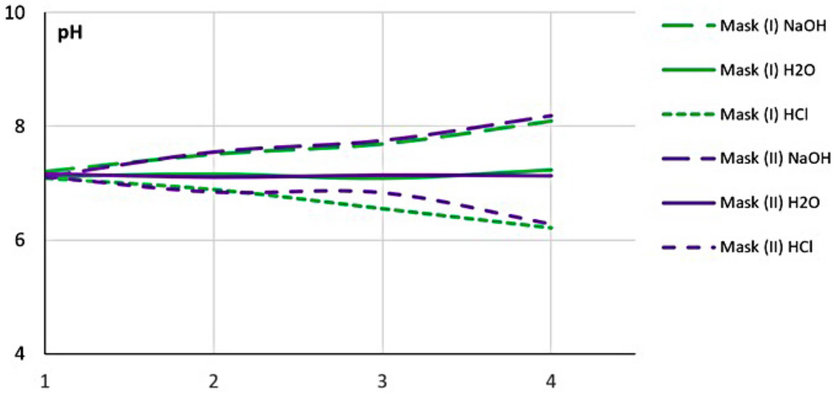

Fig. 1. pH values of aqueous solutions containing Mask (I) and Mask (II) in an acidified (HCl), neutral (H_2O) and alkaline (NaOH) medium on the 5th (1), 15th (2), 25th (3) and 35th (4) day of the research

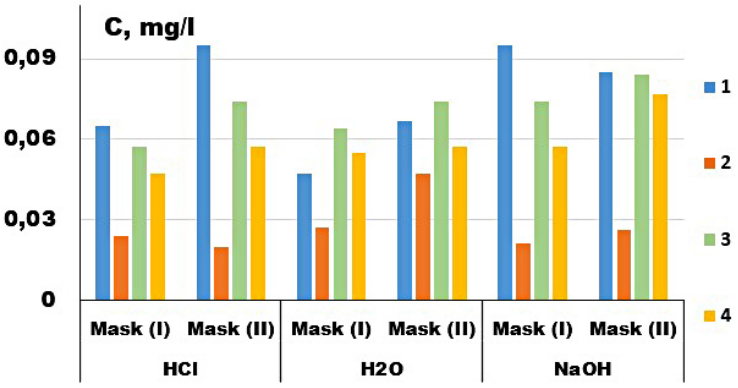

Fig. 2. Manganese content in the solution containing Mask (I) and Mask (II) in an acidified (HCl), neutral (H_2O) and alkaline (NaOH) aqueous environment on the 5th (1), 15th (2), 25th (3) and 35th (4) day of the study

its compounds by the mask material during the study period. For copper (Fig. 3), a similar situation is observed as for manganese, for both types of masks, although for Mask (II) its content is slightly higher in a neutral, acidified and alkaline environment, and leaching occurs more slowly (on the 15th day of the study, the highest values for both types of masks) and in the future, sorption or binding of its compounds into poorly soluble forms also takes place.

For zinc (Fig. 4), it is possible to note the similarity of the values of its content in aqueous neutral and alkaline environments for Mask (I) and Mask (II). The highest values of zinc content in both cases are observed on the 25th day of research. In an acidified environment, zinc is washed out more slowly (higher values are characteristic of the 35th day of the study) and slightly higher values of its content are characteristic of Mask (II). Lead is characterized by more active leaching on the 15th day of the study in all environments for Mask (I) and Mask (II). Possible sorption effects or transfer to a slightly soluble state are also characteristic in this case. Mask (II) is characterized by higher values of lead content in all types of studied aqueous environments compared to Mask (I).

For iron, a more gradual leaching is observed on the 25th–35th day of the studies for Mask (I) and Mask (II), which practically does not depend on the pH of the investigated aqueous environment in both cases. The obtained values of the content of metals in the water environment were also compared with the normative values (Table 1) [DSanPiN 2.2.4–171–10, 2010; Directive (EU) 2020/2184, 2020; WHO, 2022].

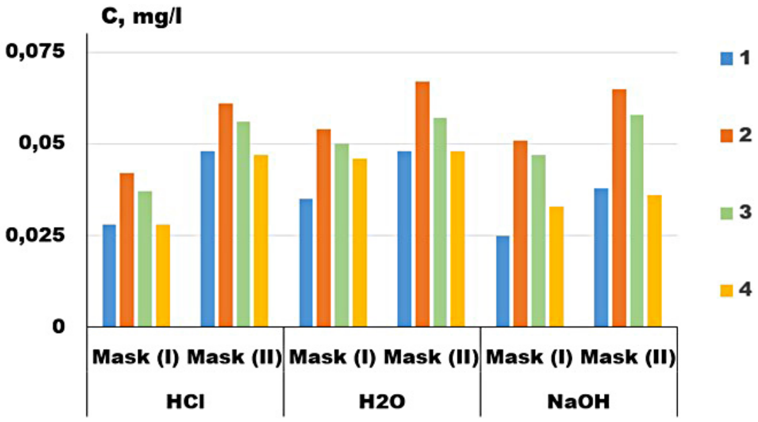

Fig. 3. Copper content in the solution containing Mask (l) and Mask (ll) in an acidified (HCl), neutral (H_2O) and alkaline (NaOH) aqueous environment on the 5th (1), 15th (2), 25th (3) and 35th (4) day of the study

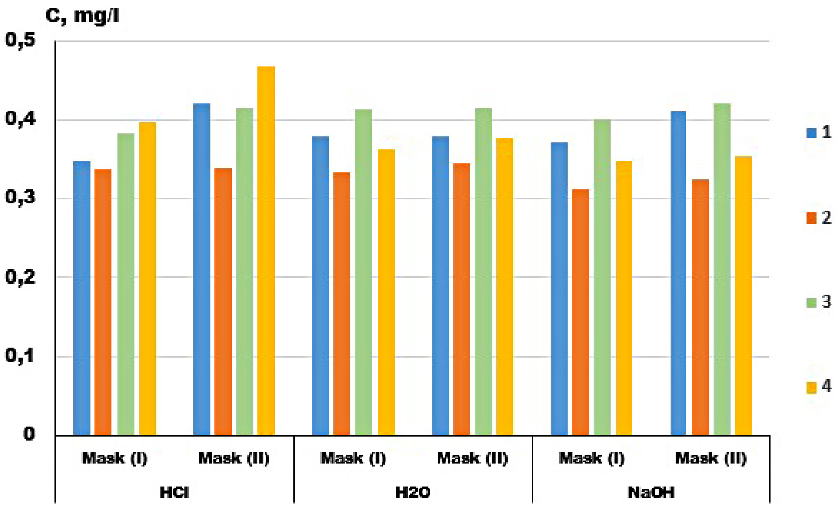

Fig. 4. Zinc content in the solution containing Mask (I) and Mask (II) in an acidified (HCl), neutral (H_2O) and alkaline (NaOH) aqueous environment on the 5th (1), 15th (2), 25th (3) and 35th (4) day of the study

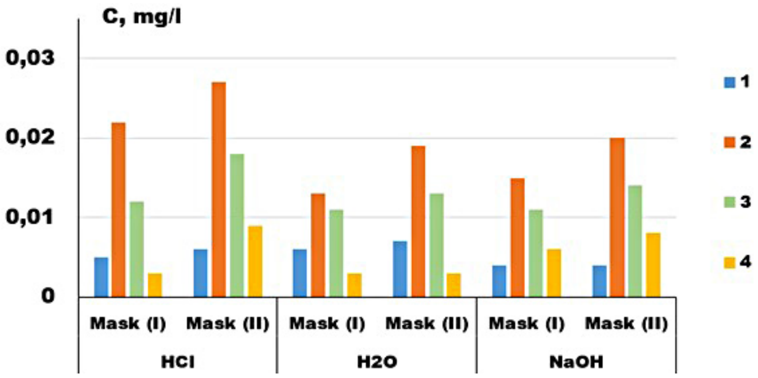

Fig. 5. Lead content in the solution containing Mask (I) and Mask (II) in an acidified (HCl), neutral (H_2O) and alkaline (NaOH) aqueous environment on the 5th (1), 15th (2), 25th (3) and 35th (4) day of the study

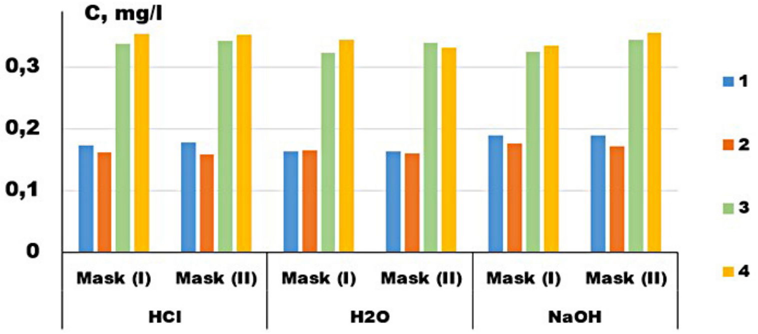

Fig. 6. Iron content in the solution containing Mask (I) and Mask (II) in an acidified (HCl), neutral (H_2O) and alkaline (NaOH) aqueous environment on 5th (1), 15th (2), 25th (3) and 35th (4) day of the study

Table 1. The value of the maximum content of metals being determined in drinking water according to various regulatory documents

Metal	DSanPiN 2.2.4–171–10, mg/l	Directive (EU) 2020/2184, mg/l	WHO, mg/l
Manganese	0.05	0.05	0.08
Copper	1.0	2.0	2.0
Zinc	1.0	-	-
Lead	0.01	0.01	0.01
Iron	0.2	0.2	-

As it can be seen (Figs. 2–6), for manganese there is an excess for both types of masks according to European and Ukrainian standards for drinking water, and an excess according to WHO standards in the first days of the study. For copper and zinc, there is no excess of their content, and for lead and iron there is a temporary excess, respectively, on the 15th and 25th (for lead) and 25th and 35th (for iron) day of the research according to all permissible standards. Accordingly, the obtained results indicate the ambiguity of the short-term impact of disposable protective face masks on the state of the aqueous environment, both neutral and alkaline to 8.2 pH or acidified to 6.2 pH. Thus, during the studied period, multi directional changes in the content of heavy metals Mn, Cu, Zn, Pb in the aqueous environment may be associated with sorption effects or features of the transition to other forms, which requires further study.

CONCLUSIONS

Thus, it is possible to note a significant increase in the interest of scientists all over the world in the issue of finding an additional amount of plastic waste from COVID-19 in the environment. It is noted that essential amount of PPE, in particular, disposable protective face masks enter the aquatic environment. At the same time, both plastic and microplastic, as well as chemical compounds of various nature, enter the environment. The emphasis is on the difficulties of identifying individual sources of pollution, which are represented by masks of various types, and the inadequacy of studying the effects of the chemical component of masks on the aquatic environment.

The short-term effect of two types of protective face masks on the aquatic environment under the conditions of its neutral, acidified and alkalized state was analyzed by the content of Mn, Cu, Zn, Pb and Fe. The multi directionality of the dynamics of fluctuations in the content of various heavy metals in the aqueous environment for both types of masks was noted, depending on the period of the study, which is probably related to sorption effects or the binding of metals into poorly soluble compounds. At the same time, there is a similarity in the dynamics of heavy metal content fluctuations for Mask (I) and Mask (II) under the same research conditions. For manganese, lead and iron, there is a permanent (Mn) or temporary (Pb, Fe) excess of these metals in the aqueous environment according to national and European standards. It is possible to note the insufficiency of data to unambiguously determine the short-term effects of disposable protective face masks on the state of the aquatic environment, which indicates the need for further research in this direction.

REFERENCES

1. Abramov Y., Basmanov O., Salamov J., Mikhayluk A., Yashchenko O. 2019. Developing a model of tank cooling by water jets from hydraulic monitors under conditions of fire. Eastern-Euroean Journal of Enterprise Technologies, 1(10–97), 14–20. https://doi.org/10.15587/1729-4061.2019.154669
2. Akhbarizadeh R., Dobaradaran S., Nabipour I., Tangestani M., Abedi D., Javanfekr F., Jeddi F., Zendehboodi A. 2021.Abandoned Covid-19 personal protective equipment along the Bushehr shores, the Persian Gulf: An emerging source of secondary microplastics in coastlines. Marine Pollution Bulletin, 168, 112386. https://doi.org/10.1016/j.marpolbul.2021.112386
3. Alieva T., Ayvazi N., Patonia A. 2021. Waste and Water Management in the Time of COVID-19: A Tale of Six Countries. EaP CSF COVID-19 POLICY PAPER. PrepareEaP4Health. Eastern Partnership Civil Society Forum. https://eap-csf.eu/wp-content/uploads/Waste-and-Water-Management-in-the-Time-of-the-COVID-19.pdf
4. Alcaraz J.P., Le Coq L., Pourchez J., Thomas D., Chazelet S., Boudry I., Barbado M., Silvent S., Dessale C., Antoine F., Guimier-Pingault C., Cortella L., Rouif S., Bardin-Monnier N., Charvet A., Dufaud O., Leclerc L., Montigaud Y., Laurent C., Verhoeven P., Joubert A., Bouhanguel A., Andres Y., Gaffé J., Martin D.K., Huet C., Boisset S., Maurin M., Rumeau P., Charlot F., Richaud E., Moreau-Gaudry A., Bonneterre V., Cinquin P., Landelle C. 2022. Reuse of medical face masks in domestic and community settings without sacrificing safety: Ecological and economical lessons from the Covid-19 pandemic. Chemosphere, 288(Pt 1), 132364. https://doi.org/10.1016/j.chemosphere.2021.132364
5. 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., 69, 116160. DOI: 10.1016/j.envpol.2020.116160
6. Babaahmadi V., Amid H., Naeimirad M., Ramakrishna, S. 2021. Biodegradable and multifunctional surgical face masks: A brief review on demands during COVID-19 pandemic, recent developments, and future perspectives. The Science of the total environment, 798, 149233. https://doi.org/10.1016/j.scitotenv.2021.149233
7. Bussan D.D., Snaychuk L., Bartzas G., Douvris C. 2022. Quantification of trace elements in surgical and KN95 face masks widely used during the SARS-COVID-19 pandemic. The Science of the total environment, 814, 151924. https://doi.org/10.1016/j.scitotenv.2021.151924
8. Chen X., Chen X., Liu Q., Zhao Q., Xiong X., Wu C. 2021. Used disposable face masks are significant sources of microplastics to environment. Environmental pollution (Barking, Essex: 1987), 285, 117485. https://doi.org/10.1016/j.envpol.2021.117485
9. Chen Z., Zhang W., Yang H., Min K., Jiang J., Lu D., Huang X., Qu G., Liu Q., Jiang G. 2022. A pandemic-induced environmental dilemma of disposable masks: solutions from the perspective of the life cycle. Environ Sci Process Impacts*,* 24, 649-674. https://doi.org/10.1039/d1em00509j
10. De Felice B., Antenucci S., Ortenzi M. A., Parolini M. 2022. Laundering of face masks represents an additional source of synthetic and natural microfibers to aquatic ecosystems. The Science of the total environment, 806(1), 150495. https://doi.org/10.1016/j.scitotenv.2021.150495
11. 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. https://doi.org/10.1016/j.chemosphere.2021.129601.

12. Dickerson S., Cannon M., O'Neill B. 2022. Climate change risks to human development in sub-Saharan Africa: a review of the literature, Climate and Development, 14(6), 571-589. https://doi.org/10.1080/17565529.2021.1951644
13. Divizinyuk M., Kasatkina N., Melnyk B. 2019. The Use of Electrical Monitoring and Surveillance Systems to Prevent Emergencies of a Terrorist Nature (on the Example of Motor Vehicles), 2019 IEEE 20th International Conference on Computational Problems of Electrical Engineering (CPEE), 1-4. https://doi.org/10.1109/CPEE47179.2019.8949101
14. Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast) (Text with EEA relevance). 2020. https://eur-lex.europa.eu/eli/dir/2020/2184/oj.
15. DSanPiN 2.2.4–171–10. 2010. Hygienic requirements for drinking water intended for human consumption. Order of the Ministry of Health Protection of Ukraine dated 12.05.2010 No. 400. URL: https://zakon.rada.gov.ua/laws/show/z0452–10#Text (in Ukrainian).
16. Du H., Huang S., Wang J. 2022. Environmental risks of polymer materials from disposable face masks linked to the COVID-19 pandemic. The Science of the total environment, 815, 152980. https://doi.org/10.1016/j.scitotenv.2022.152980
17. Han J., Yin J., Wu X., Wang D., Li C. 2023. Environment and COVID-19 incidence: A critical review. Journal of Environmental Sciences (China), 124, 933–951. https://doi.org/10.1016/j.jes.2022.02.016
18. Horta Ribeiro Antunes I.M., Brás A.F., Reis A.P.M. 2021. Surface Water and Contamination Sources in Urban River Watersheds (Northern Portugal). Ecological Engineering & Environmental Technology, 22(2), 67-74. https://doi.org/10.12912/27197050/133327
19. Kutralam-Muniasamy G., Pérez-Guevara F., Shruti V.C. 2022. A critical synthesis of current peer-reviewed literature on the environmental and human health impacts of COVID-19 PPE litter: New findings and next steps. J Hazard Mater., 422, 126945. https://doi.org/10.1016/j.jhazmat.2021.126945
20. Liang H., Ji Y., Ge W., Wu J., Song N., Yin Z., Chai C. 2022. Release kinetics of microplastics from disposable face masks into the aqueous environment. The Science of the total environment, 816, 151650. https://doi.org/10.1016/j.scitotenv.2021.151650
21. Leonova, N., Loboichenko, V., Divizinyuk, M., Shevchenko, R. 2022. Study of Short-Term Effects on the Soil of Disposable Protective Face Masks Used in the COVID-19 Pandemic. KEM, 925, 197–210. https://doi.org/10.4028/p-zjo35h
22. Loboichenko V., Leonova N., Shevchenko R., Strelets V., Morozov A., Pruskyi A., Avramenko O., Bondarenko S. 2021. Spatio-Temporal Study of the Ecological State of Water Bodies Located within the Detached Objects of the Urbanized Territory of Ukraine. Ecological Engineering & Environmental Technology, 22(6), 36-44. https://doi.org/10.12912/27197050/141610
23. Liu Z., Wang J., Yang X., Huang Q., Zhu K., Sun Y., Van Hulle S., Jia H. 2022. Generation of environmental persistent free radicals (EPFRs) enhances ecotoxicological effects of the disposable face mask waste with the COVID-19 pandemic. Environmental pollution (Barking, Essex: 1987), 301, 119019. https://doi.org/10.1016/j.envpol.2022.119019
24. Ma J., Chen F., Xu H., Jiang H., Liu J., Li P., Chen C. C., Pan K. 2021. Face masks as a source of nanoplastics and microplastics in the environment: Quantification, characterization, and potential for bioaccumulation. Environmental pollution (Barking, Essex: 1987), 288, 117748. https://doi.org/10.1016/j.envpol.2021.117748
25. Mali H., Shah C., Raghunandan B.H., Prajapati A.S., Patel D.H., Trivedi U., Subramanian R.B. 2023. Organophosphate pesticides an emerging environmental contaminant: Pollution, toxicity, bioremediation progress, and remaining challenges. Journal of Environmental Sciences, 127, 234-250. https://doi.org/10.1016/j.jes.2022.04.023
26. Norris J. 2021. COVID-19: Research unmasks the environmental impact of PPE. Medical news today. https://www.medicalnewstoday.com/articles/covid-19-research-unmasks-the-environmental-impact-of-ppe.
27. Patrício Silva A.L., Prata J.C., Duarte A.C., Barcelò D., Rocha-Santos T. 2021a..An urgent call to think globally and act locally on landfill disposable plastics under and after covid-19 pandemic: Pollution prevention and technological (Bio) remediation solutions. Chemical Engineering Journal, 426,131201. https://doi.org/10.1016/j.cej.2021.131201
28. Patrício Silva A.L., Prata J.C., Mouneyrac C., Barcelò D., Duarte A.C., Rocha-SantosT. 2021b. Risks of Covid-19 face masks to wildlife: Present and future research needs. The Science of the total environment, 792, 148505. https://doi.org/10.1016/j.scitotenv.2021.148505
29. Patrício Silva A.L., Tubić A., Vujić M., Soares A. M.V.M., Duarte A.C., Barcelò D., Rocha-Santos T.2022. Implications of COVID-19 pandemic on environmental compartments: Is plastic pollution a major issue?, Journal of Hazardous Materials Advances, 5, 100041. https://doi.org/10.1016/j.

hazadv.2021.100041

30. Pizarro-Ortega C.I., Dioses-Salinas D.C., Fernández Severini M.D., Forero López A.D., Rimondino G.N., Benson N.U., Dobaradaran S., De-la-Torre G.E. 2022. Degradation of plastics associated with the COVID-19 pandemic. Marine pollution bulletin, 176, 113474. https://doi.org/10.1016/j.marpolbul.2022.113474
31. Popovych V., Bosak P., Petlovanyi M., Telak O., Karabyn V., Pinder V. 2021. Environmental safety of phytogenic fields formation on coal mines tailings. News of the National Academy of Sciences of the Republic of Kazakhstan Series of geology and technical science, 2(446), 129–136.
32. Rathinamoorthy R., Raja Balasaraswathi S. 2022. Impact of coronavirus pandemic litters on microfiber pollution—effect of personal protective equipment and disposable face masks. Int. J. Environ. Sci. Technol. https://doi.org/10.1007/s13762-022-04462-8
33. Rosegrant M.W., Wiebe K.D., Sulser T.B., Mason-D'Croz D., Willenbockel D. 2021. Climate change and agricultural development. In Agricultural development: New perspectives in a changing world, eds. Keijiro Otsuka and Shenggen Fan. Part Four: Emerging Challenges and Opportunities in Agricultural Development, Chapter 19, 629-660. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896293830_19
34. Sendra M., Pereiro P., Yeste M.P., Novoa B., Figueras A. 2022. Surgical face masks as a source of emergent pollutants in aquatic systems: Analysis of their degradation product effects in Danio rerio through RNA-Seq. Journal of hazardous materials, 428, 128186. https://doi.org/10.1016/j.jhazmat.2021.128186
35. Sesana E., Gagnon A.S., Ciantelli C., Cassar J.A., Hughes J.J. 2021. Climate change impacts on cultural heritage: A literature review. WIREs Clim. Change, 12, e710. https://doi.org/10.1002/wcc.710
36. Shukla S., Khan R., Saxena A., Sekar S. 2022. Microplastics from face masks: A potential hazard post Covid-19 pandemic. Chemosphere, 302, 134805. https://doi.org/10.1016/j.chemosphere.2022.134805
37. Strelets V.V., Loboichenko V.M., Leonova N.A., Shevchenko R.I., Strelets V.M., Pruskyi A.V., Avramenko O.V. 2021. Comparative assessment of environmental parameters of foaming agents based on synthetic hydrocarbon used for extinguishing the fires of oil and petroleum products. SOCAR Proceedings Special Issue, 2(2021), 001-010.
38. Sullivan G.L., Delgado-Gallardo J., Watson T.M., Sarp S. 2021. An investigation into the leaching of micro and nano particles and chemical pollutants from disposable face masks - linked to the COVID-19 pandemic. Water research, 196, 117033. https://doi.org/10.1016/j.watres.2021.117033
39. Tesfaldet Y.T., Ndeh N.T., Budnard J., Treeson P. 2022. Assessing face mask littering in urban environments and policy implications: The case of Bangkok. The Science of the total environment, 806(4), 150952. https://doi.org/10.1016/j.scitotenv.2021.150952
40. Torre M., Kafritsa M.E., Anastasopoulou A. 2022. Cross-contamination by COVID-19 mask microfibers during microlitter analysis of marine biota. Marine Pollution Bulletin, 181, 113883. https://doi.org/10.1016/j.marpolbul.2022.113883
41. Uddin M.A., Afroj S., Hasan T., Carr C., Novoselov K.S., Karim N. 2022. Environmental Impacts of Personal Protective Clothing Used to Combat COVID- 19. Adv. Sustainable Syst., 6, 2100176. https://doi.org/10.1002/adsu.202100176
42. Wang Z., An C., Chen X., Lee K., Zhang B., Feng Q. 2021. Disposable masks release microplastics to the aqueous environment with exacerbation by natural weathering. Journal of hazardous materials, 417, 126036. https://doi.org/10.1016/j.jhazmat.2021.126036
43. Wang F., Wu H., Li J., Liu J., Xu Q., An L. 2022. Microfiber releasing into urban rivers from face masks during COVID-19. Journal of environmental management, 319, 115741. https://doi.org/10.1016/j.jenvman.2022.115741
44. Weir D. 2020. How does war damage the environment? Conflict and Environment Observatory. https://ceobs.org/how-does-war-damage-the-environment/
45. WHO. 2022. Guidelines for drinkingwater quality Fourth edition incorporating the first and second addenda. World Health Organization, 2022.
46. Wu P., Li J., Lu X., Tang Y., Cai Z. 2022. Release of tens of thousands of microfibers from discarded face masks under simulated environmental conditions. Science of The Total Environment. 806(2), 150458. https://doi.org/10.1016/j.scitotenv.2021.150458
47. Yang S., Cheng Y., Liu T. Huang S., Yin L., Pu Y., Liang G. 2022. Impact of waste of COVID-19 protective equipment on the environment, animals and human health: a review. Environ Chem Lett. https://doi.org/10.1007/s10311-022-01462-5