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Quantification and Environmental Burden of Trace Metals in Disposable Facemasks Widely Used in UAE during COVID-19 Pandemic

Lucy Semerjian[1,2], Rand Wardah[1], Kawthar Almatrook[1], Leena Kamali[1], Shahd Almadhani[1], Mohammad H. Semreen[3,4], Khaled Abass[1,2,4,5]
[1]Department of Environmental Health Sciences, College of Health Sciences, University of Sharjah
Sharjah, United Arab Emirates
lsemerjian@sharjah.ac.ae; U19103821@sharjah.ac.ae; U19101439@sharjah.ac.ae; U19101249@sharjah.ac.ae; U16106248@sharjah.ac.ae; kabass@sharjah.ac.ae
[2]Research Institute of Science and Engineering, University of Sharjah
Sharjah, United Arab Emirates
[3]Department of Medicinal Chemistry, College of Pharmacy, University of Sharjah
Sharjah, United Arab Emirates
msemreen@sharjah.ac.ae
[4]Research Institute for Medical and Health Sciences, University of Sharjah
Sharjah, United Arab Emirates
[5]Research Unit of Biomedicine and Internal Medicine, Faculty of Medicine, University of Oulu
Oulu, Finland

Abstract **-** In view of COVID-19 epidemic, the public usage of disposable facemasks as a prophylactic measure to address virus transmission has become widespread and increased exponentially. However, disposable facemasks, when inappropriately discarded, may have major environmental implications as considerable levels of heavy metals, microfibers, and harmful chemicals such as volatile organic compounds may be released into various environmental compartments. The current study seeks to identify and quantify toxic heavy metals in disposable facemasks marketed in United Arab Emirates. Therefore, a total of 68 disposable masks were selected for testing whereby a total of 17 categories of masks were targeted based on their color, brand, and type. Samples were analyzed for eight toxic heavy metals and metalloids (Ni, Cd, As, Sb, Cu, Cr, Tl, and Pb). Recorded results revealed that Pb noticeably had the highest concentration among all metals under study with a maximum concentration of 6.57 µg/g. Antimony concentrations varied in different types of masks, and thallium was noted to be present in the range of 0.36 to 2.60 µg /g. Chromium was present in specific-colored masks distinctly at levels ranging between 2.38 and 4.67 µg/g compared to other samples having ≤1 µg/g Cr. Finally, it was noted that nickel, cadmium, and arsenic showed the lowest concentrations in all investigated samples and a similar pattern was observed for copper, excluding black masks. These findings appear to convey that facemasks can be an environmental burden and a source of heavy metals release into the aquatic and terrestrial environments. Therefore, more stringent facemasks manufacturing methods with reduced metal content, and increased public awareness for appropriate facemask disposal are required to lessen their negative impacts on human and ecological health.

Keywords**:** Disposable facemasks, heavy metals, environmental pollution, United Arab Emirates

1. Introduction

Coronavirus Disease-19 (COVID-19) caused by the virus SARS-CoV-2 was first reported in December 2019 yet had progressed rapidly into a pandemic and had posed a worldwide health threat by March 2020 [1]. A preventive measure was necessary to minimize its high transmissibility and ensure population's health [2]. Numerous governments, including the UAE (United Arab Emirates), have made it mandated to use facemasks in various public settings as a means of protection from the virus after the World Health Organization (WHO) declared that the disease could spread through the air [1, 3]. The WHO predicted that by March 2020, the world would need 90 million masks every month. Subsequently, as of May 2020 and throughout the pandemic, 88 percent of the world's population lived in nations where wearing masks in public areas was mandatory. As a result, 6.7 billion people worldwide have needed to wear masks to go about their daily lives [4].

Facemasks are usually worn to prevent harmful gases, viruses, odors, droplets, and other substances from being inhaled through the mouth and nose. A disposable facemask (DFM) is made up of three nonwoven and melt-blown filter layers, a nose wire metal structure, and an ear brace [5]. The ear straps and filter layers (nonwoven fabrics) are frequently composed of plastics or polymers, and the nose wireframes are frequently made of metallic materials and covered by a plastic layer [6]. Additionally, most DFMs are made of nonrenewable petroleum-based polymers like polyethylene (PE) and polypropylene (PP); thus, they may result in secondary microplastic pollution [7-10].

Besides the discharge of microplastics, heavy metals or metalloids were detected in various DFMs [3, 10, 11, 12] and would eventually end up as environmental contaminants with serious ecological and public health consequences [13-15]. In fact, considering the chemical composition and components of DFMs, excessive use and poor disposal practices may prove detrimental to the environment [10]. Long-term human exposure to heavy metals such as cadmium, copper, lead, nickel, and zinc can have negative consequences on health, especially in higher amounts [16]. The toxicity of heavy metals can lower energy levels and damage the brain, blood composition, and vital organs. Degenerative diseases such as multiple sclerosis, Alzheimer's disease, Parkinson's disease, and muscular dystrophy can be induced by long-term exposure to heavy metals [17]. On the other hand, heavy metals in DFMs, when disposed improperly on terrestrial environments, can degrade soil quality, which subsequently affects the function of chlorophyll, crop yields, and quality and safety of agriculture products [18, 19]. Additionally, heavy metals can seriously impact aquatic ecosystems and pose serious risks to both humans and animals due to their bioaccumulation in food chains. Overall, heavy metals have negative and pervasive consequences on the environment and human health. Therefore, release of heavy metals into the environment through such DFMs should be mitigated as possible by a thorough investigation on DFM metal contents, public awareness on proper DFM disposal, and seeking greener DFM manufacturing methods with reduced metal content.

The current study will investigate the levels of heavy metals and metalloids (Cr, Ni, Cu, As, Cd, Sb, Tl, and Pb) in disposable facemasks of various types and colours widely used in the UAE throughout the COVID-19 pandemic and beyond. The rationale of the study stems from the lack of published data on heavy metal contents of DFM circulating in UAE markets. Findings will assist in optimizing the DFM import and manufacturing practices, promoting greener DFM manufacturing, estimating the environmental burden of facemask disposal, assisting in finding optimal options for DFM disposal or recovery, promoting public awareness in proper DFM disposal, and protecting human and ecological health.

2. Materials and Methods

2.1. Sample Collection

Ten boxes of varying disposable masks were purchased from various locations (supermarkets, a variety of discount stores, and online orders from Amazon) in the UAE. A total of 68 disposable mask samples were selected from the purchased boxes for testing wherein a total of 17 categories of masks were targeted based on their colour, brand, and type (e.g. N95 and others). Moreover, 4 replicates from each category were taken to increase confidence in the analytical precision. Mask colors included white (W), blue (B), black (Z), yellow (Y), purple (P), pink (Pk), green (G), orange (O), N95 white (N95W), and N95 black (N95Z). Each color category included 2 different brands except for orange, N95 white, and N95 black. Further characteristics of the DFMs under study are detailed in Table 1.

Table 1: Characteristics of investigated DFM samples.

Sample ID	Mask colour	Country of Origin	Description of Masks	Mask Type
W1	White	China	3-layer mask	Disposable
W2		China	3-layer mask	Disposable
B1	Blue	UAE	3-layer mask	Disposable
B2		China	3-layer mask	Disposable
Z1	Black	China	3-layer mask	Disposable
Z2		UAE	3-layer mask	Disposable

M1Y	Yellow	China	3-layer mask	Disposable
M1P	Purple			
M1Pk	Pink			
M1G	Green			
M2Y	Yellow	UAE	3-layer mask	Disposable
M2P	Purple			
M2Pk	Pink			
M2G	Green			
M2O	Orange			
N95W	White	UAE	5-layer mask	N95 Disposable
N95Z	Black	UAE	4-layer mask	N95 Disposable

2.2. Sample handling, preparation, and analysis

Samples were handled with utmost care to avoid contamination and were processed as follows. For each DFM sample, the fabric cloth, ear straps, nosepieces, and entire masks were weighed separately. Then the percentage of each component out of the whole mask was calculated. Weight measurement of each component (ear strap, nosepiece, and fabric cloth) was proportionally converted to be part of a total of 0.5 g of the facemask. Subsequently, each sample's components were cut with sterile scissors and mixed to a total of 0.5 g. The prepared 0.5 g sample was further reduced in size by cutting them for better digestibility and more accurate results, and they were introduced into microwave digester vessels (Anton Paar GmBH), 5 ml of nitric acid (70%), 1 ml of 30% hydrogen peroxide, and 5 ml of distilled water were added and vessels were subjected to digestion under an optimal pressure and temperature program. After cooling, samples were diluted to 50 ml with distilled water and filtered into clean 10 ml plastic conical tubes using 15 ml Luer Solo disposable syringes equipped with 0.45µm nylon filters. Filtrates were subsequently analysed using Inductively Coupled Plasma – Optical Emission Spectrometry ICP-OES (ThermoScientific, iCAP 7000 SERIES, USA) for the detection of heavy metals, namely Cr, Ni, Cu, As, Cd, Sb, Tl, and Pb. Potential errors were kept to a minimum by adopting and meeting the quality control measures described below; however, few samples were noted to still have undigested pieces of the sample at the end of the digestion process. This should not pose a significant error contribution to the results as the strong acids as well as the high temperature are adequate as per all read methodology literature to leach heavy metals in the digestate.

2.3. Quality control and quality assurance

All reagents used in the study were of an analytical grade, and ultrapure water was used for the preparations of solutions and standards. Prior to use, all glassware was previously soaked in diluted nitric acid for 24 hours and then rinsed with deionized water. Calibration standard solutions were made by stepwise dilution of the stock solution prepared from a certified 23 multi-element ICP standard (1,000 mg/L in diluted nitric acid, Certipur Merck Chemicals). Working standards used for instrument calibration were prepared in concentrations of 10 ppb, 25 ppb, 100 ppb, 250 ppb, 500 ppb, and 750 ppb of the targeted metals. Calibration was performed using six operational standards and achieved calibration curves exhibited coefficients of determination (R^2) above 0.99. The attained limits of detection (LOD) for analytes under study ranged between 0.55 and 1.10 µg/L. For quality control during ICP-OES analysis of heavy metals, blanks using laboratory grade deionized water were run with each batch of 10 samples to monitor contamination of used reagents, and a standard check was re-run for every 10 samples analyzed. Each prepared sample was run in triplicate, and the recorded metal concentrations were expressed as mean ± SD in µg/L. Relative standard deviations among replicates were always less than 20%. Metal concentrations were converted to µg/g considering weights of DFMs taken to microwave digestion. All experimental procedures were conducted at a controlled room temperature of 24°C, in accordance with well-established laboratory protocols.

3. Results and Discussion

3.1. Concentrations of heavy metals in investigated DFMs

The current study focused on eight highly toxic heavy metals and metalloids (Ni, Cd, As, Sb, Cu, Cr, Tl, and Pb) in DFM samples. Recorded findings showed varying concentrations based on the color of each type of mask; however, Pb exhibited the highest concentration noticeably among all metals under study. While no other heavy metal exceeded 5 µg/g, lead recorded a maximum of 6.5718 µg/g in the M1Pk. Sb concentrations varied in different types of masks with a maximum in the W1 type (2.1247 µg/g) followed by M1P, B1, and N95Z with concentrations of 1.7236, 1.7177, and 1.7059 µg/g, respectively. Green masks had the lowest Sb levels at 0.0631 and 0.3818 µg/g in M1G and M2G. Tl is also noted to be present in higher concentrations within the masks, having most of the samples above 1 µg/g, reaching up to 2.60 µg/g in the W2 mask. Cr is present in the Z1 and B2 masks distinctly with a concentration of 4.67 and 2.38 µg/g, in comparison to the other samples having no more than 1 µg/g of the Cr. Despite the fact that M2P and M2O belong to the same type yet different colors, the results show wide variations. M2P exhibited the lowest Tl levels at 0.3618 µg/g whereas M2O recorded 1.7272 µg/g, the highest levels in Tl. It had been noted that Ni, Cd, and As showed the lowest concentration in all tested samples compared to the rest of the contaminants. A similar pattern was observed with Cu, except for the black masks and B2 (2.0473 µg/g) with the highest concentration. This may be predictable since copper sulfide had been reported to be used in manufacturing the thread of three-layer masks as coating the middle and outer layers [20].

Bussan et al. [11] had conducted a similar study utilizing the ICP-MS method to analyze heavy metals in different mask colors. The study found that copper and antimony had notably higher concentrations compared to other contaminants. Additionally, certain metals such as Cr, Ni, As, and Tl were not detected in any mask color, which supports our results as they were the least observed. Both of research studies concurred that the blue color mask had the highest concentration of Cu. Their reported Pb results also showed a noticeably high concentration, reaching up to 13.33 µg/g, which is similar to our research findings with the highest result of 6.5718 µg/g for lead.

Another study by [12] examined the leachate from facemasks to determine the presence of heavy metals. The investigation found several heavy metals, including Cd, Cr, Cu, Pb, Sb, As, Ni, Hg, Zn, and Tl, in the generated DFM leachate. Sb, Pb, and Cu had the highest amounts of these metals at concentrations of 393 µg/L, 6.79 µg/L, and 4.17 µg/L, respectively. Li et al. [6] conducted a similar study in Malaysia; three metals, namely Pb, Cd, and Cr, were detected in DFM at concentrations of 3.238 µg/g, 0.672 µg/g, and 0.786 µg/g, respectively. These results suggest that Pb had the highest concentration as determined by ICP-OES, a finding that aligns with the results of the current study where lead demonstrated the highest concentration among the other metals.

In a study by [3], the metal levels identified in the DFM leachates using ICP-MS were generally low, particularly for Cd, Cr, Ni, and As. However, the highest levels of metal detected were Cu at 4.68 µg/L, Sb at 2.41 µg/L, and Pb values that went up to 1.70 µg/L. Our research produced similar findings for Cd, Cr, Ni, and As, where they were found to be the least present compared to other metals, as shown in Table 2. Additionally, Table 3 summarizes the overall averages and ranges of heavy metals recorded in DFMs under current study.

Table 2: Average ± standard deviation concentrations of heavy metals in different types of masks under study.

Sample ID	Ni (µg/g)	Cd (µg/g)	As (µg/g)	Sb (µg/g)	Cu (µg/g)	Cr (µg/g)	Tl (µg/g)	Pb (µg/g)
W1	0.0213 ±0.0058	0.0031 ±0.0018	0.0962 ±0.0289	2.1247 ±0.2897	0.0601 ±0.0024	0.1345 ±0.0232	0.8728 ±0.1680	0.3108 ±0.0705
W2	0.0063 ±0.000	0.0056 ±0.0000	0.1798 ±0.0275	0.6852 ±0.0511	0.3502 ±0.0015	0.4297 ±0.0243	2.6008 ±0.0000	3.1908 ±0.1645

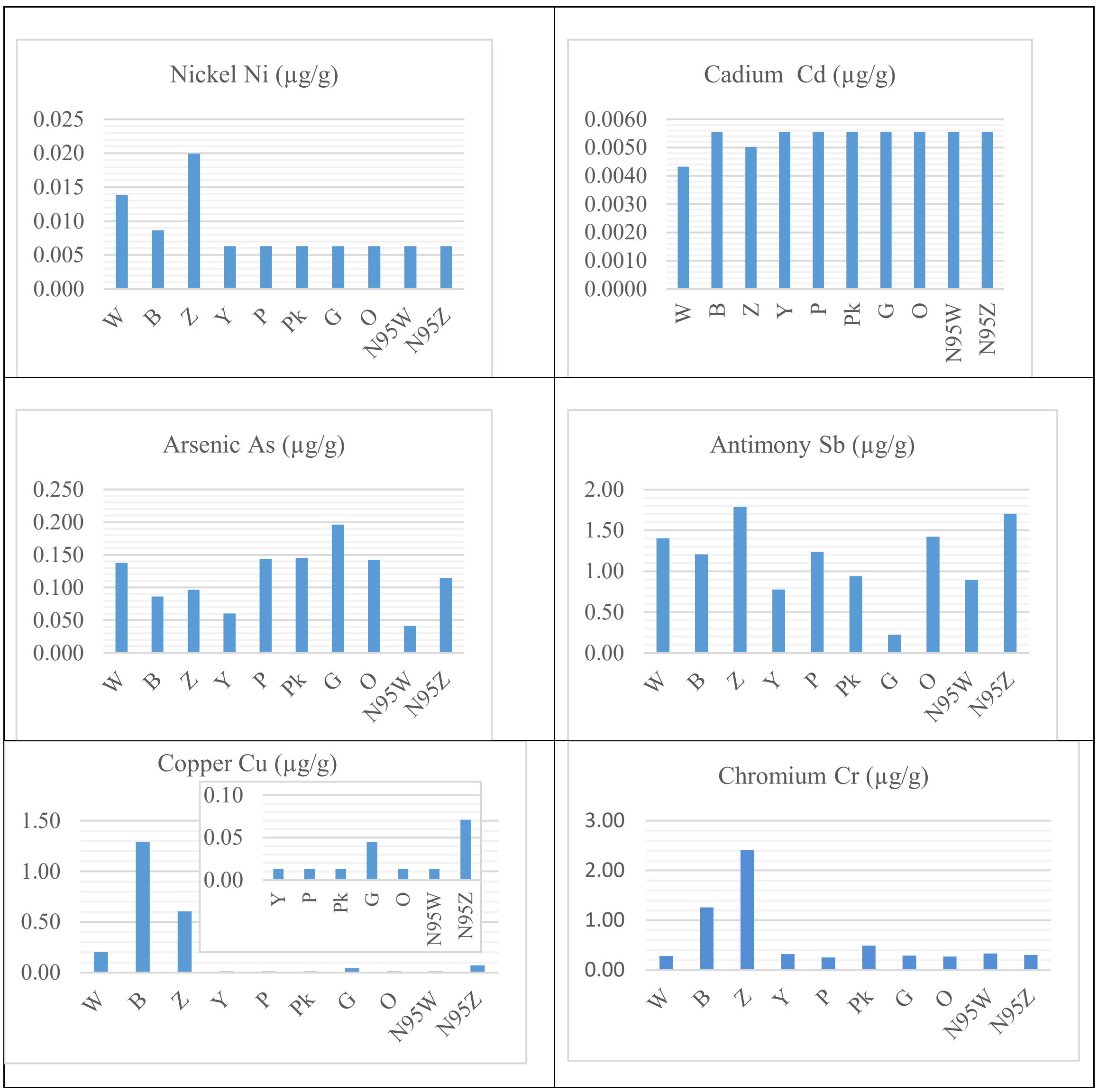
B1	0.0109 ±0.0081	0.0056 ±0.0000	0.0406 ±0.0157	1.7177 ±0.0319	0.5338 ±0.0134	0.1394 ±0.0476	1.3621 ±0.4328	0.2634 ±0.0275
B2	0.0063 ±0.0000	0.0056 ±0.0000	0.1318 ±0.0274	0.6979 ±0.0344	2.0473 ±0.5992	2.3756 ±0.5734	1.9547 ±0.2922	3.4716 ±0.1813
Z1	0.0277 ±0.0059	0.0056 ±0.0000	0.1480 ±0.0234	1.6422 ±0.0992	0.9256 ±0.1160	4.6649 ±0.4525	1.3416 ±0.4541	0.1311 ±0.0695
Z2	0.0122 ±0.0055	0.0045 ±0.0015	0.0451 ±0.0045	1.9307 ±0.0578	0.2861 ±0.0428	0.1606 ±0.0053	2.0459 ±0.1099	0.3149 ±0.0738
M1Y	0.0063 ±0.0000	0.0056 ±0.0000	0.0494 ±0.0046	0.8222 ±0.382	0.0132 ±0.0000	0.2330 ±0.0905	1.0901 ±0.0274	4.5444 ±0.5359
M1P	0.0063 ±0.0000	0.0056 ±0.0000	0.2185 ±0.0367	1.7236 ±0.0523	0.0132 ±0.0000	0.2276 ±0.0831	1.0218 ±0.1437	3.2482 ±0.2735
M1Pk	0.0063 ±0.0000	0.0056 ±0.0000	0.1273 ±0.0051	1.2602 ±0.0337	0.0132 ±0.0000	0.5270 ±0.0277	0.9411 ±0.1200	6.5718 ±0.3863
M1G	0.0063 ±0.0000	0.0056 ±0.0000	0.1549 ±0.0525	0.0631 ±0.0076	0.0132 ±0.0000	0.2194 ±0.0348	1.0213 ±0.0750	2.7469 ±0.4604
M2Y	0.0063 ±0.0000	0.0056 ±0.0000	0.0712 ±0.0077	0.7358 ±0.0522	0.0132 ±0.0000	0.4100 ±0.1710	0.4305 ±0.0728	3.8023 ±0.8538
M2P	0.0063 ±0.0000	0.0056 ±0.0000	0.0696 ±0.0057	0.7550 ±0.0545	0.0132 ±0.0000	0.2784 ±0.0668	0.3618 ±0.0211	3.6960 ±0.1735
M2Pk	0.0063 ±0.0000	0.0056 ±0.0000	0.1635 ±0.0089	0.6212 ±0.0328	0.0132 ±0.0000	0.4521 ±0.1291	1.0013 ±0.0679	4.2162 ±0.7118
M2G	0.0063 ±0.0000	0.0056 ±0.0000	0.2381 ±0.0348	0.3818 ±0.0292	0.0765 ±0.0044	0.3538 ±0.0849	1.4750 ±0.3014	4.1022 ±0.7954
M2O	0.0063 ±0.0000	0.0056 ±0.0000	0.1426 ±0.0059	1.4240 ±0.0875	0.0132 ±0.0000	0.2731 ±0.0302	1.7272 ±0.0638	2.4138 ±0.3031
N95W	0.0063 ±0.0000	0.0056 ±0.0000	0.0411 ±0.0061	0.8929 ±0.0514	0.0132 ±0.0000	0.3288 ±0.0791	1.5342 ±0.2563	3.8477 ±0.1465
N95Z	0.0063 ±0.0000	0.0056 ±0.0000	0.1145 ±0.0064	1.7059 ±0.1679	0.0711 ±0.0158	0.2986 ±0.0832	0.9244 ±0.1838	5.6184 ±0.7061

Table 3: Average, minimum and maximum concentration of heavy metals in overall investigated samples.

Sample ID	Ni (µg/g)	Cd (µg/g)	As (µg/g)	Sb (µg/g)	Cu (µg/g)	Cr (µg/g)	Tl (µg/g)	Pb (µg/g)
Average	0.009	0.005	0.120	1.128	0.263	0.677	1.277	3.088
Min	0.006	0.003	0.041	0.063	0.013	0.135	0.362	0.131
Max	0.028	0.006	0.238	2.125	2.047	4.665	2.601	6.572

3.2. Heavy metal levels relative to colours of investigated DFMs

Average concentration for each heavy metal under study in relation to the color of masks was also comparatively investigated. Lead (Pb) recorded the highest concentration in N95Z and pink (Pk) colors, respectively. This may be attributed to the utilization of lead in the manufacturing of masks, especially nosepiece parts for these DFMs. It is well known that lead is carcinogenic and toxicologically harmful to organisms. Lead also has the capability bioaccumulate, and even low levels of exposure can cause neurological damage to humans and adversely affect fetus development [12]. The concentrations of Ni were notably elevated high in black color masks, possibly as constituents of the black dye [21]. Recorded Cu levels show that blue color masks have the highest concentration, establishing that blue color and Cu are related [22]. Green masks exhibited the highest concentrations of arsenic, evidencing a correlation between the green color and arsenic metalloids. In a study by [23], it was discovered that a greenish-yellow color manifested as a result of the interaction of specific molecules in the magnetic field effects with arsenic. Arsenic exposure from food and drinking water over an extended period of time can result in cancer and skin problems [24]. Tl values were observed to be mostly high especially for white- and orange-colored masks. Finally, the black color mask showed a significant value in Cr as illustrated below in Fig. 1.



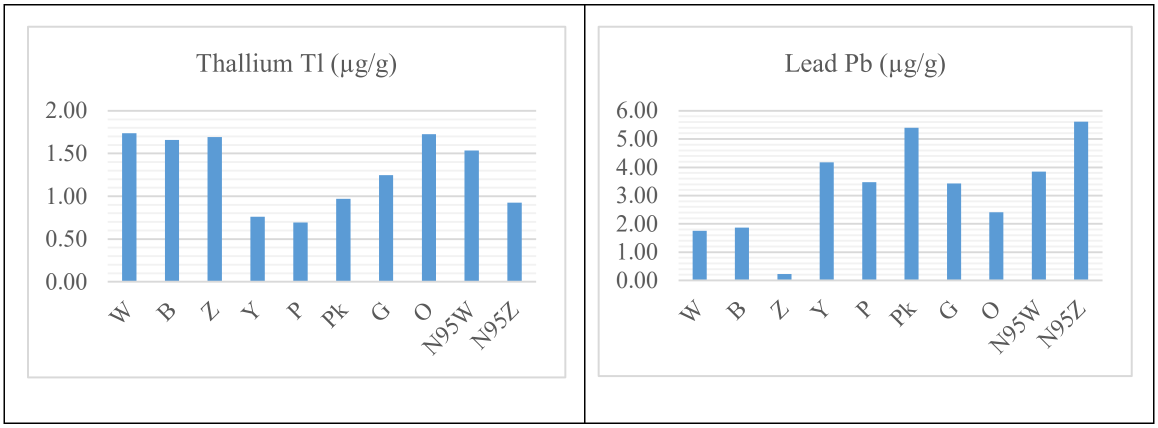


Fig. 1: Average concentrations of heavy metals in varying colors of facemasks.

3.3. Environmental burden of heavy metals in DFMs under study

In 2020, at the peak of Covid-19 pandemic, 52 billion DFMs were produced globally and nearly 1.6 billion ended up in the oceans [25]. Thus, to assess the burden of facemasks contributing to heavy metal pollution into the environment utilizing DFM specifications and metal concentrations recorded in the current study, the following equations were used:

Global heavy metal burden of manufactured facemasks = Average weight of whole mask (3.5485g) × Sum of average concentration of HM (66.5275µg/g) × 52 billion × 10^{-9} kg/µg = 12275.79 Kg

Global heavy metal burden of facemasks in oceans = Average weight of whole mask (3.5485g) × Sum of average concentration of HM (66.5275µg/g) × 1.6 billion × 10^{-9} kg/µg = 37.72 Kg

These computations attest that improper disposal of DFMs will contribute to terrestrial and oceanic pollution with heavy metals. Moreover, environmental pollution caused by heavy metals is persistent, hidden, and long-term and even in low quantities, chronic exposure to such chemicals will cause health concerns and ecological burdens [26].

4. Conclusion

In conclusion, heavy metals can be present at varying concentrations in DFMs. The current study investigated the levels of trace metals and metalloids (Cr, Ni, Cu, As, Cd, Sb, Tl, and Pb) in disposable facemasks of various types and colors widely used in the UAE throughout the COVID-19 pandemic. Findings revealed varying concentrations based on the color of each type of mask, and it was observed that lead (Pb) had the highest concentration (6.5718 µg/g). Thallium (Tl) was noted to be present ranging from 0.3618 µg /g to 2.6008 µg /g. Chromium (Cr) was present in specific-colored masks distinctly with a level of 4.6649 and 2.3756 µg/g. And finally, Nickel (Ni), Cadmium (Cd), Arsenic (As), and Copper (Cu) showed the lowest concentrations. As a result of the aforementioned findings, it is crucial that stricter regulations need to be enforced during manufacturing and disposal/recycling of disposable facemasks to minimize the environmental impacts.

While the purpose of the masks is indisputable, there exists a pressing need that face masks, which are widely available in the marketplace and come from many manufacturers, pass strict quality control and quality assurance tests to couple public health protection with long-term environmental sustainability and pollution control.

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