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An Investigation of Microplastic Occurrence and Heavy Metals Concentrations in Street Dust on the Left Side of Mosul City, Iraq

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ABSTRACT

The issue of street dust pollution is primarily related to levels of microplastic particles (MPs) and heavy metals, raising concerns about their potential risk to the environment. In this work, twenty street dust samples with three replicates were collected from different areas (residential, commercial, and industrial) on the left side of Mosul city/Iraq, to investigate the presence of MPs and study their characteristics. Additionally, to assess the potential ecological risk impact of twelve heavy metals. Among the 60 dust samples taken from the streets, an average of MPs ranging between 244 and 2760 per 15 grams of dust was detected. Most of these plastic particles were transparent fragments with sizes varying from less than 10 to 200 µm as observed through a stereomicroscope and a scanning electron microscope (SEM). Furthermore, results from FTIR analysis indicated that polyvinyl chloride (PVC) was the dominant polymer type found in MPs, accounting for around 63%. The levels of metal in road dust were assessed using X-ray fluorescence (XRF) showing that quantification of Cr, Ni, Cu, Zn, As, Sb, Hg, and Pb surpassed the background values of world soils among the twelve elements studied. Variation coefficients (VCs) coupled with enrichment and contamination factors revealed that Cr, Cu, Zn, As, Se, Cd, Sb, Hg, and Pb are associated with both sources (anthropogenic and natural). On the other hand, Mn, Fe, and Ni originate from natural sources. Calculated potential ecological risk (Er) indicated high ecological risk by Hg. Approximately half of the samples exhibited moderate ecological risk indices (RI).

Keywords: microplastic, heavy metals, FTIR, street dust, ecological risk, enrichment factor, ecological risk index.

INTRODUCTION

The rapid urbanization of developing countries and the continuous change of land use for infrastructure development are devastating the local environment (Suryawanshi et al., 2016a). Especially, production of plastic has grown steadily for over 60 years, gradually replacing materials like glass and metal with durable, petroleum-based materials. Today, plastics are used widely in a variety of fields, including packaging (Dehghani et al. 2017a). As a result, urban environments are becoming undesirable (Ordóñez et al. 2003). The activities of humans lead to increased pollution of the environment with MPs, and heavy metals. The term MPs refers to plastic particles, which are smaller than 5 mm. The source of these pollutants can be primary sources such as synthetic textiles, cosmetics, road surface etc. or secondary sources such as fragmentation and abrasion of large plastic debris The source of these pollutants can be originating sources like fabrics, beauty products, road surfaces, etc., or secondary sources such as fragmentation and abrasion of large plastic debris (Huang et al. 2020).

Throughout the last years the pollution of MPs in the water systems has received a great deal of attention worldwide. Conversely, urban environments including street dust have received little attention in terrestrial ecosystems (Wang et al. 2022). As stated by (Pandey et al. 2022), there is a limited number of documentations about the existence of MPs in the street dust. Moreover, some countries have investigated that street dust contains highly toxic organic and inorganic pollutants. In particular, heavy metals and MPs. Therefore, Street dust is a great local environmental measurement of quality, reflecting pollutants from the air, water, and soil (Abbasi et al., 2017). Various ecosystems are adversely affected by MPs and heavy metals accumulation in street dust, soil, and surface water samples (Al-Radady et al. 1994, Tüzen 2003). Due to that this study mainly aimed to quantify the accumulation MPs and heavy metals in street dust.

The main sources of MPs pollution and heavy metals in street dust as shown in (Figure 1), MPs road dust mainly derives from the tear of vehicle tires, road paint, bitumen, and fragmented plastics scattered across the road surface (Rødland, 2022), (Monira et al., 2021). Heavy metals found in road dust can originate from anthropogenic, like burning petroleum, diesel and industrial processes. Natural factors, like the weathering of buildings and pavement, can also contribute to the presence of these metals. (Rajaram et al., 2014; Rawat et al., 2009). In urban areas, toxic metals are a major concern because they are non-biodegradable and last for a long time. As illustrated in Figure 2, long-term exposure to contaminants found in city settings, especially dust, from roads (heavy metals and MPs), and their close proximity to humans increases the risk of inhalation, ingestion, and dermal contact by urban residents. Furthermore, A metal accumulates in the fatty tissues of the body, which can affect organ function and disrupt the nervous or endocrine systems, and some metals may be mutagenic, teratogenic, or carcinogenic (Suryawanshi et al. 2016b).

MPs found on dust streets are often used in ecotoxicology studies at concentrations several times higher than in the environment. In light of this, more monitoring studies should be conducted in different matrixes using reliable and comparable analytical techniques. The precautionary principle should be applied until then, which means that MPs emissions should be regarded as an environmental risk until they are properly

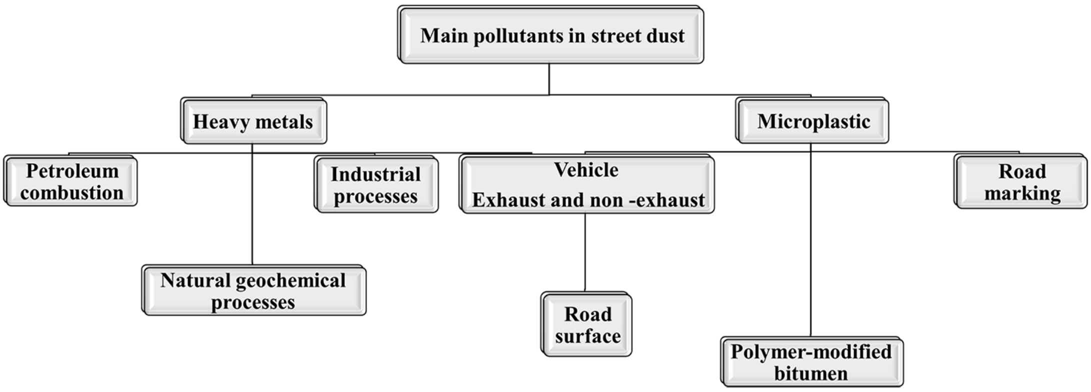

Figure 1. A summary of the sources of microplastics and heavy metals pollution in street dust

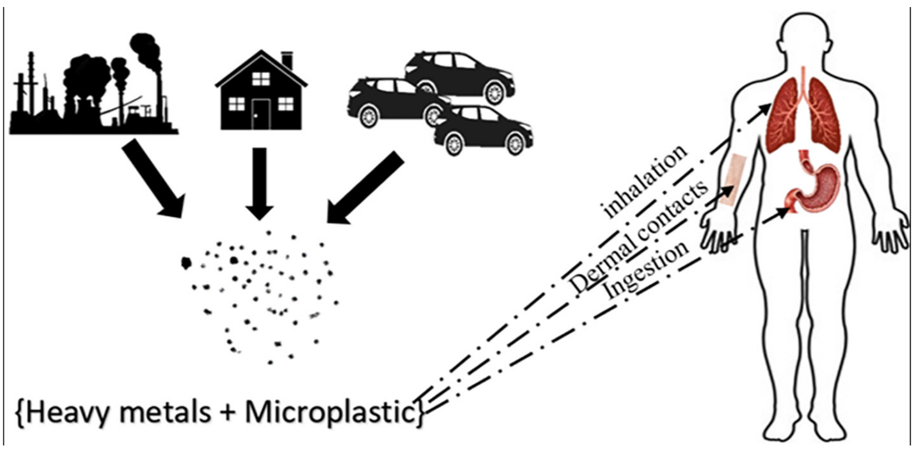

Figure 2. Impact of microplastics and heavy metals on the nervous, cardiovascular, kidney, and reproductive systems

evaluated (Järlskog 2022). As a result of unmonitored industrial activities and traffic loads, street dust in developing countries such as Iraq has become polluted with toxic metals and MPs. Thus, the streets in Mosul city were chosen as a case study to evaluate road dust pollution in Iraq.

Mosul is the city at the center of the Nineveh Governorate of Iraq. It is situated in northern Iraq on the banks of the Tigris River. In terms of population, it is the second largest city in the country after Baghdad. This city has a population of about (five million seven hundred and fifty thousand) with primary contributors to its pollution including automobiles, industrial areas, and the long-distance dispersal of dust from neighboring areas, like Iran, Syria, and Turkey. It is an excellent natural laboratory for examination of the pollution of street dust due to the combination of human activity pollution and high dust loads. As a result, our work aimed to (1) quantify the amount of MPs and heavy metals on the street surfaces in different regions (residential, commercial, and industrial) on the left side of Mosul city, (2) assess the physicochemical and morphology properties of MPs in the study area, (3) assessment of ecological risk for elements and, (4) statistical analysis to identify the relationships among different lands (residential, industrial and commercial) depending on heavy metals concentrations in street dust.

MATERIALS AND METHODS

Collection of samples

Plastic items and containers were avoided, and cotton coats and gloves were worn during the experiments to protect against contamination. During stable weather circumstances, twenty samples of road dust were collected in triplicate in this study. on the left side of Mosul city, throughout the dry season from June to October 2023. Figure 3 and Table 1 illustrate sites and their features that were selected for sampling of street dust to detect MPs abundance and measure the levels of heavy metals. Approximately 30 m^2 of debris was collected by sweeping the area adjacent to the road curbs. Metal bowls with wooden brushes were used to collect dust, which was then transferred to glass containers for laboratory analysis. After being collected from the streets, bulk dust specimens were allowed to dry at room temperature for one day. To remove large particles like stones and vegetation from the dust samples, a 2 mm sieve is used (Wang et al. 2022). To minimize errors owing to suspended particles on roads and disruption of particles in the air during cleaning, the measurement of MPs is expressed as the amount of debris per 15 grams of dust rather than MPs number per square meter of dust.

Moreover, similar to the experimental samples, a blank sample was prepared. Furthermore, an empty petri dish was set on the laboratory bench to detect contamination from airborne MPs in the laboratory. Blank samples and control petri dishes showed no contamination.

Extracting of MPs from street dust

MPs extractions from 60 samples of street dust for twenty sites were performed. The sampling sites were from several land uses as follows; residential (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10), commercial (S11, S12, S13, S14, S15, S16, S17, S18), and industrial (S19, S20) in the Mosul

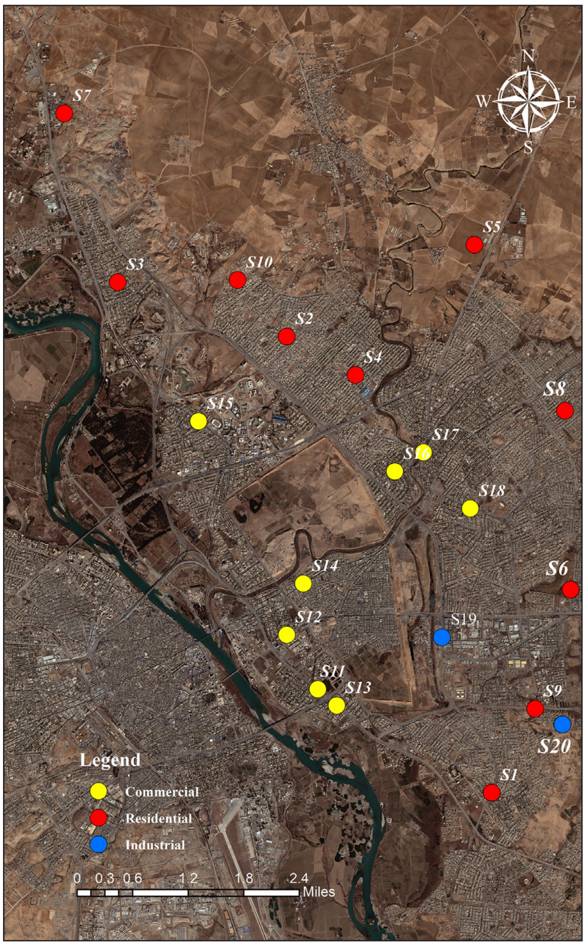

Figure 3. Sampling locations in the left side of Mosul city

Table 1. Details of sampling sites for MPs and heavy metals study

Site no.		Sampling sites	Traffic volume*	Latitude	Longitude
S1	Residential	Alwahda	50-60	337892.1	4021236.3
S2		Alhadba		334329.1	4029169.4
S3		Alarabi		331392.1	4030114.2
S4		Alsukar		335525.4	4028500.0
S5		Alfalah		337591.6	4030764.7
S6		Aden		339577.6	4025064.9
S7		Albina aljahiz		330461.9	4033049.3
S8		Alzahraa		339165.4	4027877.3
S9		Almithaq		338649.0	4022694.3
S10		Alkendei		333475.1	4030151.7
S11	Commercial	Almalia	75-90	334870.6	4023036.3
S12		Alfaysalia		334332.1	4023982.3
S13		Alfurqan		335198.3	4022753.8
S14		Aldarikazlia		334618.7	4024873.8
S15		Almajmuea althaqafia		332797.2	4027694.3
S16		Almuthanaa		336210.1	4026822.8
S17		Alzuhur		336709.0	4027155.0
S18		Alnuwr		337519.4	4026178.6
S19	Industrial	Sinaeat almaearid	70-90	337027.3	4023938.7
S20		Sinaeat alkarama		339640.2	4022605.1

Note: * The data was taken from the Traffic Directorate of Nineveh Governorate.

city. The presence of organic substances hinders the counting of MPs. Initially, to eliminate these organic materials from the street dust samples, 15 grams of street dust were combined with 35 milliliters of 30% hydrogen peroxide for 8 days (until the bubbles stopped forming). The dust particles were vacuum filtered through filter papers (F2042 Grade, Quantitative Ashless, 2 µm pore size) before being washed with distilled water and dried in a sand bath at 60°C to remove any hydrogen peroxide residue. A zinc chloride solution with a density of 1.78 ± 0.2 kilograms per liter was utilized as the separating fluid in this experiment. To prepare the $ZnCl_2$ solution, 1120 grams of anhydrous $ZnCl_2$ (zinc chloride dry, 98% AR/ACS) were dissolved in 700 ± 0.5 ml deionized water, which resulted in an increase of volume of approximately 1050 milliliters as a result of its exothermic reaction. 100 ml of this $ZnCl_2$ solution was mixed with each sample and then shaken for at least five minutes to separate any aggregated particles. Subsequently, the samples were left undisturbed overnight to settle. Then filtered using a vacuum filtration unit, onto 0.45 micrometers filter paper (pore size of 0.45 µm, size of 47 mm Ø). After that, the filter papers were left to dry in the air for 24 hours and finally, plastic particles were then transferred to a glass petri dish using tweezers.

Microplastics identification and quantification

Visual sorting is challenging, MPs are widely detected by this method, as discussed in (Duis and Coors 2016). The MPs are sorted based on their characteristics, like shape and colour utilizing a stereomicroscope (Motic2300S-V37-45X Zoom, Italy). The MPs were sorted into groups according to their shapes; fiber, fragment, foam and others. Additionally, they were classified by colour; blue, black, red, green, white, and yellow (Sultan et al., 2023).

It was used scanning electron microscope (SEM) (ZEISS EVO 10, Germany) for the analysis of MPs. As plastics are non-conductive, therefore the particles were covered with a layer conductive of gold, before examination and observed using an acceleration voltage of, up to 8.7 kV to allow the SEM to show the particles without interference (Ramaremisa et al., 2024).

Additionally, it's crucial to check the makeup of the polymer ideally using Fourier transform infrared spectroscopy (IRAffinity 1S, SHIMADUZ

Japan) to understand its origins. The analysis covered a range, from 600 cm 1 to 4000 cm 1. Each sample was scanned for 3 seconds with fifteen scans, per measurement. The spectroscopic resolution was set at 4 cm^{-1}.

Measurements of heavy metals

Various heavy metals and metalloids, such as (chromium, manganese, iron, nickel, copper, zinc, arsenic, selenium, cadmium, antimony, mercury, and lead) were measured using an X-ray fluorescence device (XRF, Genius 9000 XRF Handheld Heavy Metals). The samples underwent collection, purification, drying, grinding, and sieving to ensure testing outcomes. The device projects bursts of high energy waves onto the soil samples, which excites the electrons of the soil, leading them to move into outer orbits. This process disrupts the electron distribution within the soil. Subsequently, the electrons transition back from the orbit, causing the emission of X-ray radiation. Each element has its own unique wavelength. In this study, 12 mineralogical analyses were conducted in duplicate at the accredited Acme Analytical Laboratory in Arbil.

Assessment of heavy metals contamination

To assess the extent of street dust pollution from metals five criteria are employed: enrichment factor (EF), contamination factor (CF), pollution load index (PLI), ecological risks (Er) and, risk index (RI).

Enrichment factor

To find out whether the components in street dust are natural or anthropogenic sources, the enrichment factor (EF) is used. The following equation (1) is applied to calculate EF (Abdullah et al. 2020).

$$EF = \frac{\left(\frac{Cn}{Fe}\right)samples}{\left(\frac{Bn}{Fe}\right)background} \quad (1)$$

In the data of elements concentration collected from the research site the proportion of heavy metals concentration to iron concentration, in street dust is denoted as (Cn/Fe). The proportion of metal to iron content, in the background values is denoted by (Bn/Fe). In terms of value, iron is accepted as a standard element (Al Shurafi et al., 2023). Because it is one of the geochemical elements frequently, in the natural environment (Chandrasekaran et al. 2015). If the value of EF is less than 1, then the heavy elements come from the source rocks or natural weathering processes, and if it is greater than 1, the heavy metals were derived from human or industrial activity (Jiang et al., 2019). There are five classes of fortification plants proposed by Barbieri (2016), as shown in Table 2.

Contamination factor (CF)

Contamination factor (CF) is an effective way to illustrate the impact of human activities on street dust (Abed et al., 2015). The following equation are used to calculate CF:

$$CF = \frac{Cn}{Bn} \quad (2)$$

In this formula, *CF* stands for contamination factor of heavy metal, while a street dust sample's concentration of an element is called *Cn* and *Bn* refers to the background concentration of the heavy element in the world soil (Kabata-Pendias, 2011). The contamination factor was classified into four groups by Fiori et al. (2013) as shown in (Table 3).

Pollution load index

The pollution load index is commonly employed to evaluate the presence of metals in a specific location. The PLI value, for a location, is determined using Equation (3) (Abed et al., 2015).

$$PLI = \sqrt[n]{\prod_{i=1}^{n} CF_i} \quad (3)$$

The PLI > 1 means the region is contaminated, while PLI <1 refers to an unpolluted area (Shen et al., 2019b).

Table 2. Enrichment factor category

Value	EF category
EF < 2	Deficiency to minimal enrichment
2< EF < 5	Moderate enrichment
5< EF < 20	Significant enrichment
20 < EF < 40	Very high enrichment
EF > 40	Extremely high enrichment

Table 3. Contamination factor category

Value	CF category
CF < 1	Low contamination
1 ≤ CF < 3	Moderate contamination
3 ≤ CF < 6	Considerable contamination
CF ≥ 6	Very high contamination

Potential ecological risk index

Hakanson introduced the ecological risk index as a technique to monitor metal pollution and assess ecological risks. This method involves analyzing the impact of metals on the environment considering their toxic effects. The RI allows for an evaluation of the risk levels associated with heavy metal contamination (Liu et al. 2022). The potential ecological risk index is present the sum of the individual ecological risks for assessing the level of elements pollution in street dust as the following:

$$RI = \sum_{i=1}^{n} E_r \quad (4)$$

Ecological risk is one of the indicators used to estimate the environmental hazards of each element, whose pollution must be studied based on the toxicity of heavy metals in various environments. This calculation method was developed by the scientist Hakanson. Can be determined using the equation provided (Hakanson, 1980).

$$Er = Tr \times Cf \quad (5)$$

Hakanson defined *Tr* as a "toxic-response factor" for a given substance and proposed values of 2, 1, 1, 5, 5, 1, 10, 30, 7, 40, 5 for Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, Sb, Hg and Pb, respectively (Zhang and Liu 2014, Aguilera et al. 2022). Cf is defied previously. Table 4 represent ecological risk levels.

STATISTICAL ANALYSIS

To identify the relationship among different areas (residential, industrial and commercial) based on the average levels of heavy metals in street dust was examined using ANOVA (Duncan test) with the statistical software SPSS version 22, for Windows in 2023.

RESULTS AND DISCUSSION

Abundance of MPs in street dust

MPs were discovered in the street dust samples at all locations as illustrated in Figure 4 and Table 5. The average of MPs concentration displayed the following decreasing trend according to the sampling site S19 >S20 >S17 >S16 >S18 >S13 >S12 >S11 >S15 >S14 >S3 >S2 >S9 >S4 >S1 >S6 >S5 >S8 >S7 >S10. Samples 19 and 20 contained the highest concentration of the MPs with 2760 and 2313 items/15g dust, respectively, due to it being an industrial area, followed by samples from S17 to S11 of commercial areas, while sample 10 contained the lowest concentration of MPs with 244 items/15g dust because it was, in a residential zone. According to the results, traffic load, industrial activity, population and shop numbers strongly correlated amount of MPs.

Table 4. Classification of ecological risk levels into five categories (Nwineewii et al., 2018; Shen et al., 2019b)

E_r	RI	Level of ecological risk
$E_r < 40$	RI < 94	Low ecological risk
$40 \le E_r < 80$	94 ≤ RI < 188	Moderate ecological risk
$80 \le E_r < 160$	188 ≤ RI < 376	Considerable ecological risk
$E_r \ge 160$	RI ≥ 376	Very high ecological risk

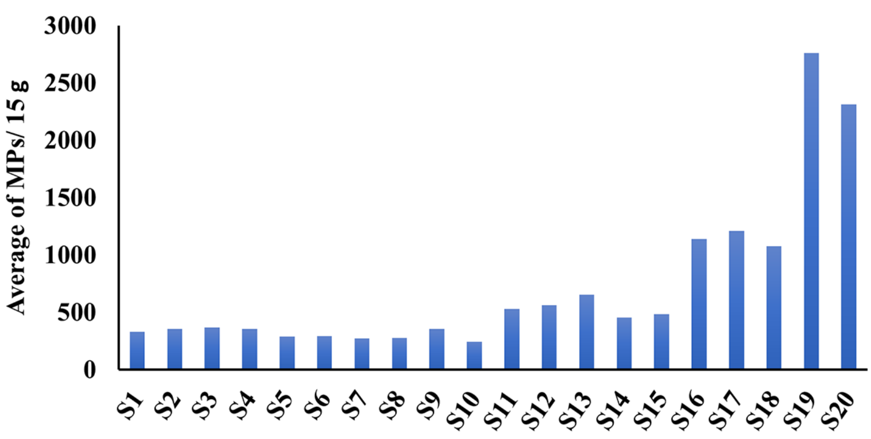

Figure 4. Average abundance of MPs in different sites

Table 5. Abundance of MPs in different sites

Residential					
Site.no	Duplicate 1	Duplicate 2	Duplicate 3	Total	Average
S1	329	328	333	990	330.00
S2	356	355	357	1068	356.00
S3	368	371	370	1109	369.67
S4	351	360	352	1063	354.33
S5	288	284	290	862	287.33
S6	298	290	294	882	294.00
S7	273	278	270	821	273.67
S8	275	279	281	835	278.33
S9	356	353	359	1068	356.00
S10	247	238	248	733	244.33
S11	526	532	527	1585	528.33
S12	562	560	563	1685	561.67
S13	650	656	656	1962	654.00
S14	453	459	454	1366	455.33
S15	481	484	484	1449	483.00
S16	1141	1132	1144	3417	1139.00
S17	1209	1216	1206	3631	1210.33
S18	1078	1083	1076	3237	1079.00
S19	2762	2760	2758	8280	2760.00
S20	2305	2316	2318	6939	2313.00

MORPHOLOGY CHARACTERISTICS OF MPs

Shape of microplastic

The road dust samples studied showed all possible shapes, including fragments, fibers, and foam. Figure 5 displays the images of these shapes. As depicted in Figure 6, fragments were the dominant shape of MPs accounting for 70%, followed by fibers at 28%, and foam at 2%. The large number of identified MPs was fragmented because of the mechanical abrasion of the tire that contributes to increases in the likelihood of producing MPs by breaking down plastic pieces (Andrady 2011). Fibers were probably plenty due to deposited dust samples which could include natural organic fibers like cotton and wool along with inorganic fibers

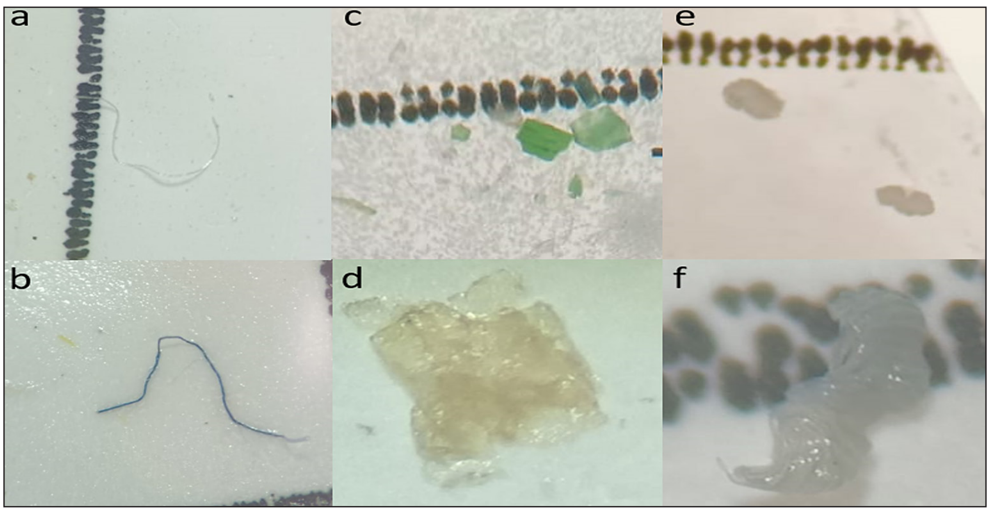

Figure 5. Images of microplastics, where (a) and (b) are fibers, (c) and (d) are fragments while (e) and (f) is foam

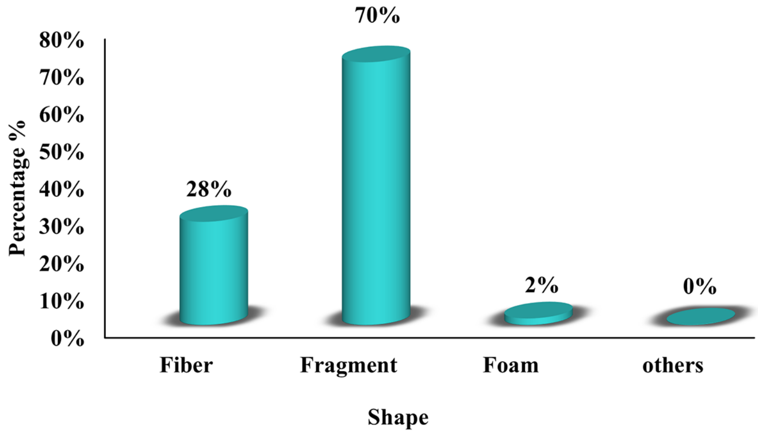

Figure 6. Percentage of MPs shapes

such as asbestos and other fibrous minerals. The visual features of these fibers can pose a challenge, in differentiating them from plastic fibers. Street dust also contains a significant amount of tire dust in fiber shapes (Adachi and Tainosho 2004).

Colour of microplastics

Data analysis shows for samples the predominant colour of microplastics found near roads is transparent accounting for 42% of the total. Following white makes up 19% and yellow 14%. Conversely, the colour of black, red, blue, green and orange have levels of abundance at 9%, 5%, 4%, 4% and 3%, respectively, as displayed in Figure 7.

Microplastic size

The scanning electron microscope images (Figure 8). revealed that the particles in street dust varied in size from less than 10 µm to 200 µm. Among plastic particles, those sized between 200 and 100 µm made up 20% of the plastics counted, followed by MPs with sizes from 100 µm to 50 µm, which accounted for an average of 13.3% of all MPs found in dust samples. The fraction ranging from 50 to 10 µm had an occurrence of around 26.6%. Interestingly, the number of MPs in the category below 10 µm exceeded that of size classes by around 40.1%. This difference could be attributed to challenges in distinguishing MPs (less than <5 µm) under a microscope. Furthermore, the majority of micro-particles are 10 µm or smaller which is similar to the results obtained by Abbasi et al. (2017b). Microscopic plastic particles smaller than 50 µm are highly susceptible to being swallowed or carried back into the air, where they can be breathed in Dehghani et al. (2017c). Therefore, most of the particles present in street dust have the potential to get absorbed and accumulate in the

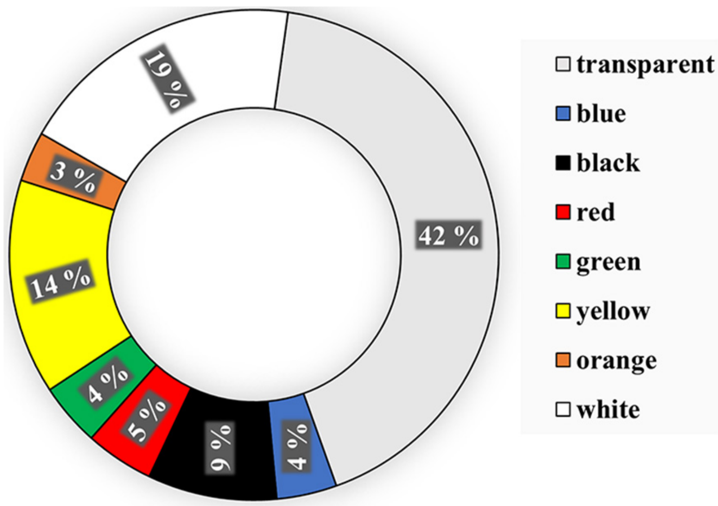

Figure 7. Percentage of MPs colours

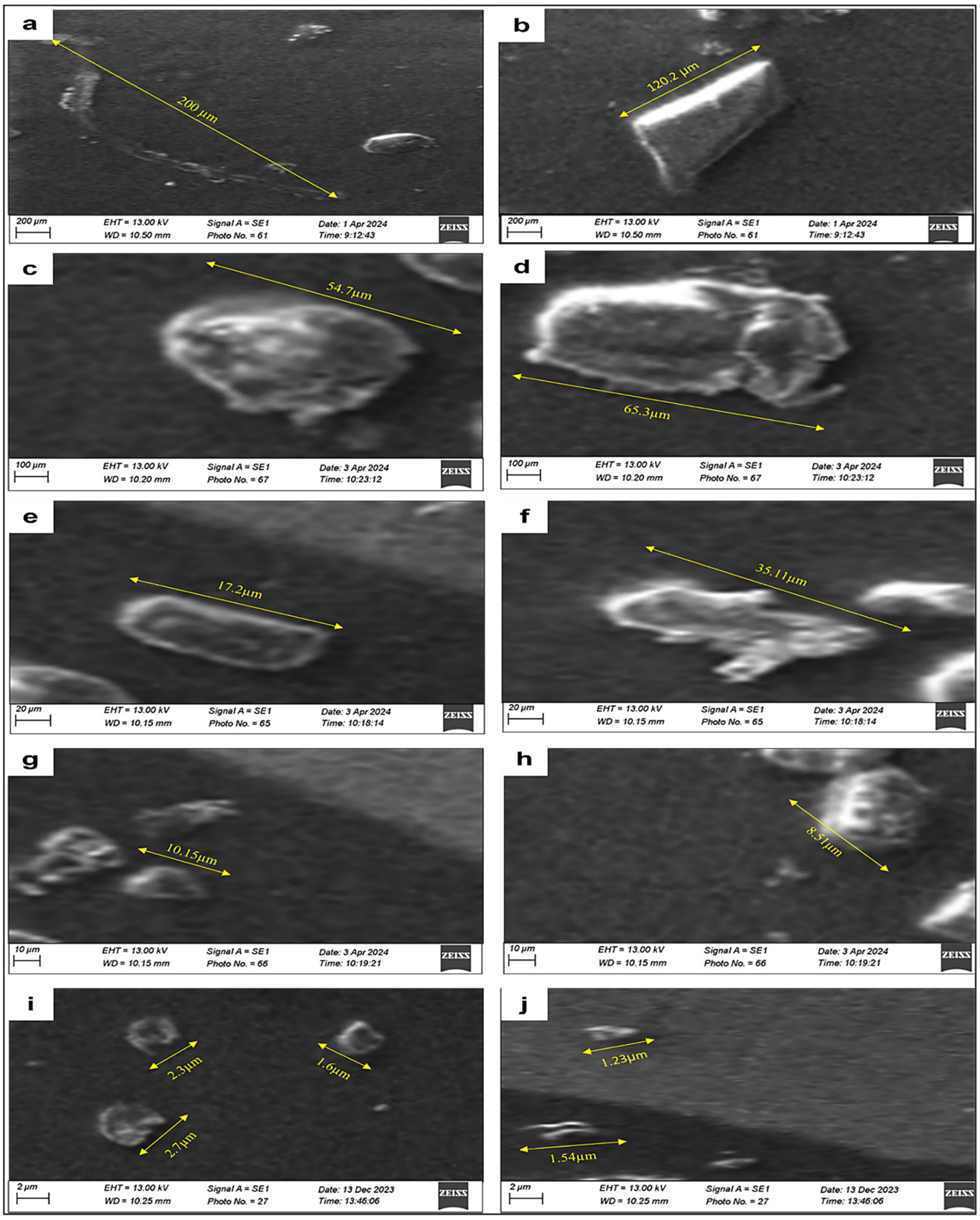

Figure 8. Scanning electron microscopy image of microplastics, where (a), (b) are 100 < size ≤ 200 µm, (c) and (d) are 50 < size ≤ 100 µm, (e), (f) and (g) are from 10 to 50 µm, (h) (i) and (j) are from are ≤ 10 µm

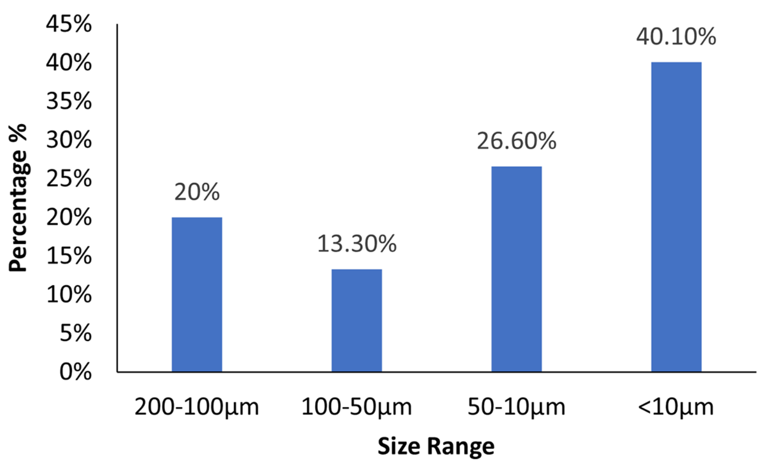

Figure 9. Percentage of microplastic size in street dust in Mosul city

human body. The sizes of MPs can be observed in the images depicted in Figure 9.

Microplastic composition

FTIR testing was conducted on the plastic materials identified during the inspection. Figure 10 showcases the polymer categories found in road dust samples gathered from different areas. The analysis of the data showed that there are several types of microplastics (MPs) present, in the dust on the road; polyvinyl chloride (PVC), polyethylene terephthalate (PET), Polyamide (PA), polypropylene (PP), polyethylene (PE), and polystyrene (PS). The most dominant polymers of MPs particles were (PVC, 63%), (PET, 16%), (PA, 8%), (PP, 6%), (PE, 4%) and (PS, 2%) may be due to use PVC as tensile reinforcement to asphalt pavement (Saiyari et al., 2015).

In Taiwan, researchers discovered a range of polymers, in microplastics collected from road dust. Where the PVC was the polymer constituting 32% of the microplastics followed by PE (9.8%) PP (8.6%) and PS (7.9%). PVC, widely used in industries was notably prevalent, among the polymer types found in Taiwan (Mon et al., 2022). Another study found that MPs in road dust were mainly made up of PE, PP, and PVC, suggesting that consumer products and road paint are potential sources (Yang et al. 2023).

HEAVY METALS CONCENTRATIONS

Table 5 shows the mean concentrations of metals in street dust along with background values of world soils. The average of elements Cr, Ni, Cu, Zn, As, Sb, Hg and Pb surpassed background values of world soils (Kabata-Pendias, 2011). The mean concentrations of the elements are 78.13, 78.21, 122.25, 348.84, 9.24, 9.28, 0.48 and 170.32 ppm, respectively. In Table 7, the high concentrate of Cr, Ni, Cu, Zn, As, Sb, Hg and Pb elements dominated by both anthropogenic and natural sources likely heavy traffic road vehicular, erosion of surrounding soil, atmosphere deposition, pavement, gases emitted from the exhaust of cars, lubricant, abrasion of tires and brake surfaces, also anthropogenic activity (Adimalla, 2020; Wuana & Okieimen, 2011). Statistical analysis results of Duncan ANOVA illustrated that the values of Mn, Fe and Ni have not significant variation among the three locations (Table 6), furthermore, Cr, Cu and As showed significant variation of residential with commercial and residential with industrial**.** In three sites showed significant variations in case of Zn, Sb, Hg and Pb. Residential regions were found to be significantly varying from

Table 6. The mean of heavy metals in street dust collected from left side of Mosul city

Element mean	Mean	Background of soil
Cr	78.13	59.50
Mn	307.70	488.00
Fe	17077.40	35000.00
Ni	78.21	29.00
Cu	122.25	38.90
Zn	348.84	70.00
As	9.24	6.83
Se	0.14	0.44
Cd	0.35	0.41
Sb	9.28	0.67
Hg	0.48	0.07
Pb	170.32	27.00

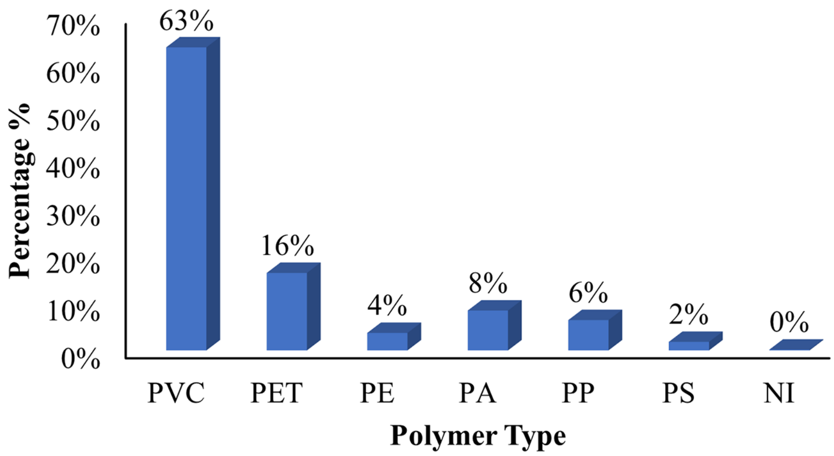

Figure 10. Polymer types percentage of microplastics

Table 7. Mean concentration of heavy metals (ppm) in different sites

Site no.	Region	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Sb	Hg	Pb
S1	Residential	64.361	354.015	81.239	90.977	170.854	1.732	0.040	0.113	1.192	0.288	106.375	16828.000
S2		55.210	270.180	78.102	89.144	169.885	2.033	0.052	0.129	0.822	0.275	105.540	19422.000
S3		48.544	349.387	124.175	90.729	178.531	1.855	0.032	0.107	1.514	0.261	101.379	17171.000
S4		47.618	202.755	23.281	64.961	176.310	3.295	0.012	0.135	1.160	0.290	99.565	18629.000
S5		39.776	333.856	71.488	71.926	171.368	2.364	0.021	0.141	1.287	0.284	97.529	17996.000
S6		54.501	262.502	69.880	43.349	173.785	2.256	0.041	0.142	1.520	0.295	89.597	18380.000
S7		47.946	288.376	82.298	49.547	168.453	2.243	0.051	0.135	1.341	0.370	86.357	15637.000
S8		68.926	241.237	99.465	34.598	169.263	3.744	0.031	0.142	1.469	0.352	100.455	16630.000
S9		64.817	259.640	87.229	45.412	171.274	2.970	0.041	0.132	1.339	0.329	96.712	15387.000
S10		57.923	297.994	87.858	58.929	170.114	3.934	0.061	0.187	0.761	0.392	85.716	14874.000
S11	Commercial	85.910	291.966	92.231	196.970	430.586	6.459	0.160	0.772	9.490	0.525	264.737	14646.000
S12		94.885	319.329	80.524	178.844	494.064	16.840	0.190	0.937	10.532	0.657	255.011	17948.000
S13		82.669	351.187	75.066	210.452	458.768	9.561	0.604	0.698	11.638	0.626	175.618	19557.000
S14		91.579	317.253	82.564	189.956	523.979	9.987	0.246	1.500	12.196	0.612	174.744	18856.000
S15		107.960	354.982	70.630	152.352	436.696	23.322	0.257	0.162	7.097	0.639	196.925	19384.000
S16		98.263	346.673	73.814	160.561	493.175	12.566	0.477	0.384	9.750	0.544	174.458	9611.000
S17		154.546	321.144	67.121	147.977	536.569	21.166	0.134	0.553	14.528	0.415	273.129	17563.000
S18		101.941	317.544	72.330	192.450	481.353	32.983	0.122	0.124	20.246	0.615	274.322	18740.000
S19	Industrial	99.000	331.500	75.240	186.518	712.210	12.300	0.110	0.255	35.753	0.950	338.915	15755.000
S20		96.277	342.574	69.610	189.336	689.500	13.100	0.178	0.250	41.885	0.850	309.362	18534.000

commercial in case Se and Cd, whereas the residential and commercial regions have not significant variation with industrial. Statistical analysis reveals that most trace elements have significant variation between sites, which can be related to features of the region, in relation, to traffic density, human activities and the materials used for road surfaces.

EVALUATION OF HEAVY METALS CONTAMINATION

Heavy metal contamination and source identification in street dust

Enrichment factors and contamination factors for metals were computed for every street

Table 8. Analysis of variance (Duncan ANOVA) of heavy metals comparing three regions of the left side Mosul

Parameters	Residential	Commercial	Industrial	P value (Comparing regions)
	Mean± SD			
Cr	54.962±9.2^{a}	102.2190±22.6^{b}	97.6381±1.9^{b}	0.0000 (S)
Mn	285.99420 ±48.8^{a}	327.50960±21.5^{a}	337.03720±7.8^{a}	0.063 (NS)
Fe	17095.4000±1509.2^{a}	17038.1250±3381.3^{a}	17144.5000±1965^{a}	0.998 (NS)
Ni	80.5014±25.4^{a}	76.7850±8.0^{a}	72.4250±3.9 ^{a}	0.835 (NS)
Cu	63.9571±21.1^{a}	178.6953±22.7^{b}	187.9268±1.99^{b}	0.0000 (S)
Zn	171.9836±3.2^{a}	481.8987±38.2^{b}	700.8550±16.0^{c}	0.0000 (S)
As	2.6425±0.79^{a}	16.6106±8.8^{b}	12.7000±0.56^{b}	0.0000 (S)
Se	.0383±0.014^{a}	.2738±0.17^{b}	.1439±0.04^{ab}	0.0020 (S)
Cd	.1362±0.02^{a}	.6413±0.44^{b}	.2526±0.003^{ab}	0.0060 (S)
Sb	1.2405±0.2^{a}	11.9345±4.0^{b}	38.8189±4.3^{c}	0.0000 (S)
Hg	0.3136±0.04^{a}	0.5791±0.08^{b}	0.9000±0.07^{c}	0.0000 (S)
Pb	96.9220±7.4^{a}	223.6175±47.0^{b}	324.1400±20.9^{c}	0.0000 (S)

Note: NS – not significant, S – significant, SD – standard deviation, P< 0.05 significant, P> 0.05, not significant.

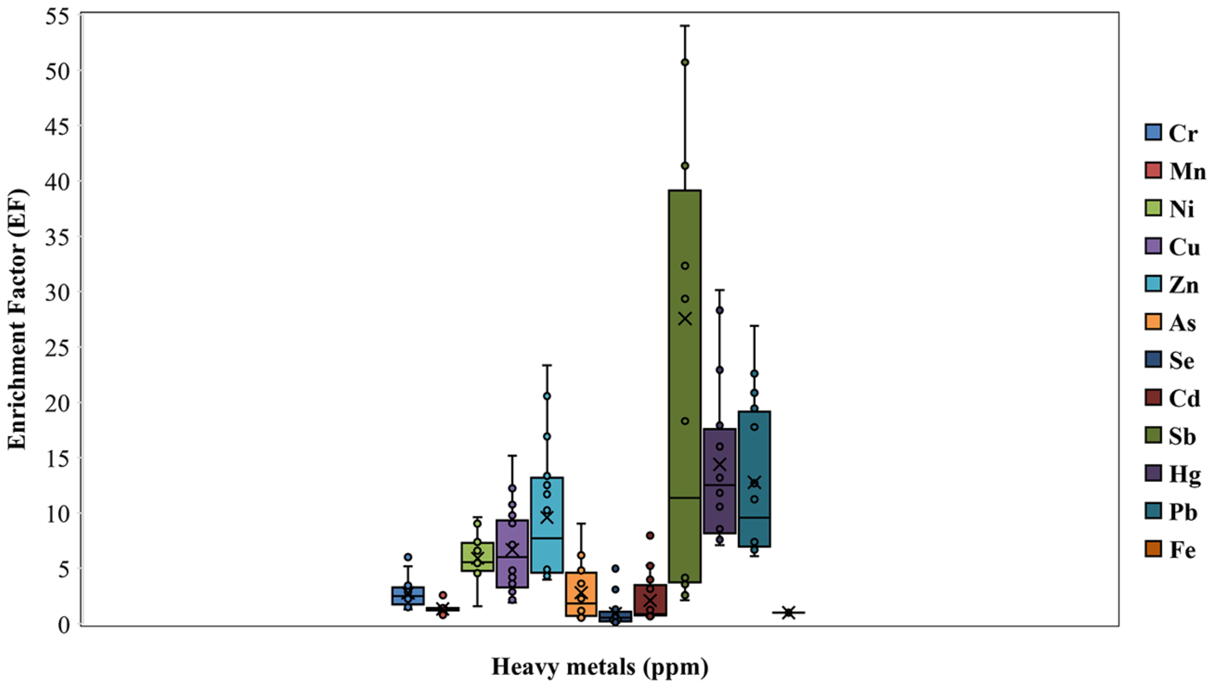

Figure 11. Box-plot of EF for heavy metals of Mosul's left side streets dust

Table 9. EF values of heavy metals in street dust on a left side of Mosul city

Site no.	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Sb	Hg	Pb
S1	2.250	1.503	1.000	6.035	4.915	4.615	0.528	0.239	0.671	3.541	8.557	7.902
S2	1.672	0.994	1.000	5.027	4.173	3.976	0.537	0.268	0.666	2.117	7.080	6.793
S3	1.663	1.453	1.000	9.040	4.803	4.726	0.554	0.186	0.621	4.407	7.600	7.380
S4	1.504	0.777	1.000	1.562	3.170	4.302	0.907	0.064	0.723	3.113	7.784	6.681
S5	1.300	1.325	1.000	4.966	3.633	4.328	0.674	0.118	0.785	3.576	7.891	6.774
S6	1.744	1.020	1.000	4.752	2.144	4.298	0.629	0.224	0.770	4.134	8.025	6.093
S7	1.804	1.317	1.000	6.579	2.881	4.897	0.736	0.327	0.864	4.288	11.831	6.903
S8	2.438	1.036	1.000	7.476	1.891	4.626	1.155	0.188	0.851	4.417	10.583	7.551
S9	2.478	1.205	1.000	7.086	2.683	5.060	0.990	0.268	0.859	4.352	10.691	7.857
S10	2.291	1.431	1.000	7.383	3.602	5.199	1.356	0.411	1.255	2.558	13.177	7.204
S11	3.450	1.424	1.000	7.872	12.226	13.363	2.262	1.092	5.271	32.398	17.923	22.595
S12	3.110	1.271	1.000	5.608	9.059	12.513	4.812	1.059	5.221	29.340	18.303	17.760
S13	2.487	1.283	1.000	4.798	9.783	10.663	2.507	3.089	3.571	29.754	16.004	11.225
S14	2.857	1.202	1.000	5.473	9.158	12.631	2.716	1.306	7.955	32.341	16.226	11.584
S15	3.276	1.308	1.000	4.555	7.145	10.240	6.170	1.324	0.837	18.305	16.483	12.699
S16	6.014	2.576	1.000	9.600	15.187	23.324	6.705	4.967	3.990	50.721	28.301	22.690
S17	5.176	1.306	1.000	4.777	7.660	13.887	6.180	0.764	3.149	41.359	11.815	19.439
S18	3.200	1.210	1.000	4.825	9.336	11.675	9.026	0.651	0.662	54.018	16.409	18.298
S19	3.696	1.503	1.000	5.970	10.762	20.548	4.004	0.698	1.620	113.466	30.149	26.889
S20	3.056	1.320	1.000	4.695	9.287	16.910	3.625	0.959	1.348	112.994	22.931	20.864
average	2.773	1.323	1.000	5.904	6.675	9.589	2.804	0.910	2.084	27.560	14.388	12.759
median	2.482	1.307	1.000	5.541	6.030	7.719	1.809	0.531	0.861	11.361	12.504	9.563
max	6.014	2.576	1.000	9.600	15.187	23.324	9.026	4.967	7.955	113.466	30.149	26.889
min	1.300	0.777	1.000	1.562	1.891	3.976	0.528	0.064	0.621	2.117	7.080	6.093
STD	1.197	0.348	0.000	1.820	3.799	5.933	2.553	1.180	2.082	34.003	6.727	6.830
C.V %	0.432	0.263	0.000	0.308	0.569	0.619	0.911	1.296	0.999	1.234	0.468	0.535

dust sample in comparison, to the values of world soil in Figure 11, the mean EFs decrease in the order of (Sb >Hg >Pb >Zn >Cu >Ni >As > Cr >Cd >Mn >Fe >Se). The sequence of their pollution levels, in street dust samples can also be interpreted as decreasing an order. It should be noted, that Sb, Hg, Pb, Zn, Cu, Ni, As, Cr and Cd have wide range and Mn, Fe and Se have low range box plots. Also, based on variation coefficients (VCs) (Table 9), the examined elements can be classified into two groups: Mn, Fe, and Ni with VC < 0.4; and those with VC > 0.4. Elements sourced from natural sources are expected to have low VCs, while those affected by both sources (anthropogenic and natural) should display higher VCs (Yuan et al. 2014). The CV value (1.29) of Se was the highest of the all heavy metals, suggesting that Se has the greatest variation among the studied metals and thus would have the highest possibility of being influenced by the extrinsic factor such as human activities, automobile exhaust, and deposition of aerosol (Fujiwara et al. 2011). Sb have mean EFs higher than 27.56, which mean very high enrichment; while Hg, Pb, Zn, Cu and Ni with their mean EFs values 14.83, 12.75, 9.58, 6.67 and 5.9, respectively, were classified as significant enrichment. For the As, Cr and Cd, the rate of EF around 2.55, which place it within the field of moderate enrichment. The average of EF for Mn, Fe and Se are found with range between (0.91–1.32), this implies that these components fall into the category of deficiency to minimal enrichment. The highest EFs might indicate how much local pollution impacts each metal.

After calculating the contamination factor for the samples of the study area given in Table 10 and Figure 12, it is found that the CF of the Sb is between (1.14–62.51) with mean of 13.84, indicating moderate contamination. CF for both Hg and Pb were between (3.17–13.57) with average of 6.57, reflecting the very high contamination.

Table 10. CF values of heavy metals in street dust on a left side of Mosul city

Site no.	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Sb	Hg	Pb
S1	1.082	0.725	0.481	2.801	2.339	2.441	0.254	0.091	0.276	1.779	4.114	3.940
S2	0.928	0.554	0.555	2.693	2.292	2.427	0.298	0.118	0.315	1.227	3.929	3.909
S3	0.816	0.716	0.491	4.282	2.332	2.550	0.272	0.073	0.260	2.259	3.729	3.755
S4	0.800	0.415	0.532	0.803	1.670	2.519	0.482	0.027	0.328	1.731	4.143	3.688
S5	0.668	0.684	0.514	2.465	1.849	2.448	0.346	0.048	0.344	1.921	4.057	3.612
S6	0.916	0.538	0.525	2.410	1.114	2.483	0.330	0.094	0.345	2.268	4.214	3.318
S7	0.806	0.591	0.447	2.838	1.274	2.406	0.328	0.116	0.330	2.002	5.286	3.198
S8	1.158	0.494	0.475	3.430	0.889	2.418	0.548	0.071	0.345	2.193	5.029	3.721
S9	1.089	0.532	0.440	3.008	1.167	2.447	0.435	0.094	0.322	1.999	4.700	3.582
S10	0.973	0.611	0.425	3.030	1.515	2.430	0.576	0.139	0.455	1.136	5.600	3.175
S11	1.444	0.598	0.418	3.180	5.064	6.151	0.946	0.363	1.883	14.164	7.500	9.805
S12	1.595	0.654	0.513	2.777	4.598	7.058	2.466	0.432	2.285	15.719	9.386	9.445
S13	1.389	0.720	0.559	2.588	5.410	6.554	1.400	1.373	1.703	17.370	8.943	6.504
S14	1.539	0.650	0.539	2.847	4.883	7.485	1.462	0.560	3.659	18.204	8.741	6.472
S15	1.814	0.727	0.554	2.436	3.917	6.239	3.415	0.583	0.396	10.592	9.129	7.294
S16	1.651	0.710	0.275	2.545	4.128	7.045	1.840	1.085	0.935	14.552	7.771	6.461
S17	2.597	0.658	0.502	2.315	3.804	7.665	3.099	0.305	1.349	21.683	5.929	10.116
S18	1.713	0.651	0.535	2.494	4.947	6.876	4.829	0.277	0.303	30.218	8.786	10.160
S19	1.664	0.679	0.450	2.594	4.795	10.174	1.801	0.250	0.622	53.363	13.571	12.552
S20	1.618	0.702	0.530	2.400	4.867	9.850	1.918	0.404	0.610	62.514	12.143	11.458
Average	1.313	0.631	0.488	2.697	3.143	4.983	1.352	0.325	0.853	13.845	6.835	6.308
Median	1.274	0.653	0.507	2.644	3.071	4.351	0.761	0.195	0.370	6.430	5.764	5.201
Max	2.597	0.727	0.559	4.282	5.410	10.174	4.829	1.373	3.659	62.514	13.571	12.552
Min	0.668	0.415	0.275	0.803	0.889	2.406	0.254	0.027	0.260	1.136	3.729	3.175
STD	0.474	0.087	0.067	0.635	1.623	2.767	1.278	0.355	0.898	17.390	2.888	3.183
C.V %	0.361	0.138	0.137	0.235	0.516	0.555	0.945	1.093	1.052	1.256	0.422	0.505

Table 11. Ecological risk index

	Er											RI
Tr	2	1	1	5	5	1	10	30	7	40	5	
Site no.	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Sb	Hg	Pb	
S1	2.163	0.725	0.481	14.007	11.694	2.441	2.535	8.268	12.453	164.571	19.699	239.037
S2	1.856	0.554	0.555	13.466	11.458	2.427	2.976	9.461	8.591	157.143	19.544	228.031
S3	1.632	0.716	0.491	21.410	11.662	2.550	2.715	7.800	15.814	149.143	18.774	232.706
S4	1.601	0.415	0.532	4.014	8.350	2.519	4.824	9.849	12.119	165.714	18.438	228.375
S5	1.337	0.684	0.514	12.325	9.245	2.448	3.462	10.332	13.447	162.286	18.061	234.141
S6	1.832	0.538	0.525	12.048	5.572	2.483	3.303	10.354	15.876	168.571	16.592	237.694
S7	1.612	0.591	0.447	14.189	6.369	2.406	3.284	9.885	14.011	211.429	15.992	280.215
S8	2.317	0.494	0.475	17.149	4.447	2.418	5.482	10.354	15.348	201.143	18.603	278.230
S9	2.179	0.532	0.440	15.040	5.837	2.447	4.349	9.666	13.994	188.000	17.910	260.392
S10	1.947	0.611	0.425	15.148	7.574	2.430	5.760	13.661	7.951	224.000	15.873	295.381
S11	2.888	0.598	0.418	15.902	25.318	6.151	9.457	56.488	99.148	300.000	49.025	565.394
S12	3.189	0.654	0.513	13.884	22.988	7.058	24.656	68.561	110.036	375.429	47.224	674.192
S13	2.779	0.720	0.559	12.942	27.050	6.554	13.999	51.095	121.590	357.714	32.522	627.524
S14	3.078	0.650	0.539	14.235	24.416	7.485	14.622	109.756	127.425	349.657	32.360	684.224
S15	3.629	0.727	0.554	12.178	19.583	6.239	34.147	11.868	74.143	365.143	36.468	564.676
S16	3.303	0.710	0.275	12.727	20.638	7.045	18.399	28.061	101.861	310.857	32.307	536.183
S17	5.195	0.658	0.502	11.573	19.020	7.665	30.989	40.471	151.784	237.143	50.579	555.579
S18	3.427	0.651	0.535	12.471	24.736	6.876	48.291	9.080	211.526	351.429	50.800	719.824
S19	3.328	0.679	0.450	12.972	23.974	10.174	18.009	18.673	373.539	542.857	62.762	1067.418
S20	3.236	0.702	0.530	12.002	24.336	9.850	19.180	18.285	437.601	485.714	57.289	1068.726
Average	2.626	0.631	0.488	13.484	15.713	4.983	13.522	25.598	96.913	273.397	31.541	478.897

The CF of Zn was ranged from 2.41 to 10.17 with mean of 4.98, pointing to classified as considerable contamination, also the same classified for Cu which its CF was between (0.89–5.41) with mean of 3.14. The rates of Ni, As and Cr were as following; 1.35, 2.7 and 1.31, which mean moderate contamination classification. CF of Cd is between (0.26–3.66) with mean of 0.85.

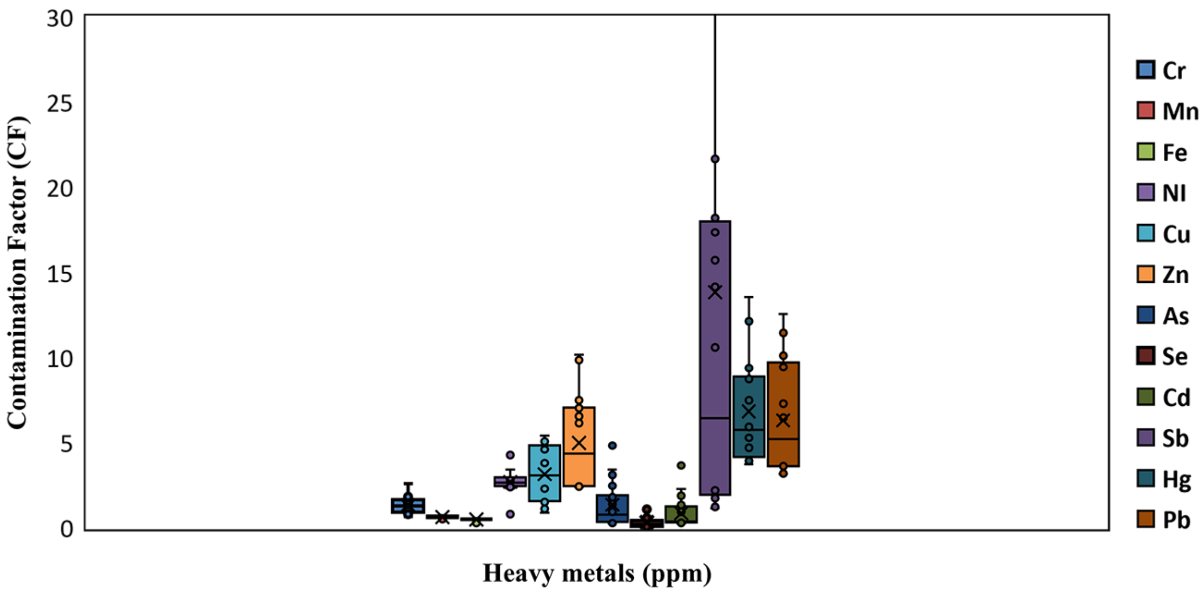

Figure 12. Box-plot of CF for heavy metals in left side Mosul in street dust

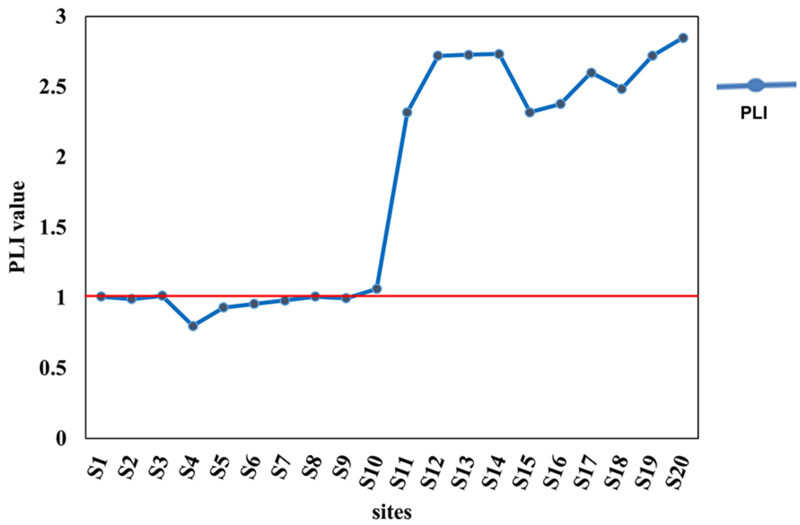

Figure 13. PLI value of the street dust of study area

CF for Mn is between (0.42–0.73) with mean of 0.63. CF of Fe is between (0.27–0.56) with mean of 0.49. CF of Se is between (0.03–1.37) with mean of 0.33. The mean CF of Cd, Mn, Fe and Se was very low, reflecting the lack of contamination with these elements. The CF of the twelve elements (Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Sb, Hg, Pb) in the study area indicate that they are classified between low contamination – very high contamination according to Table 3.

Pollution load index

The Figure 13 is displayed, PLI values of 10 sites of street dust were > 1, indicating that the street dust is highly polluted with toxic heavy metals due to industrial and commercial activities in these sites. As for, S1, S2, S3, S4, S5, S6, S7, S8, S9, and S10, the PLI values were ≤ 1, which are considered unpolluting regions.

Ecological risk levels

To determine the extent of metal pollution, in street dust, the ecological risk index (RI) was measured as detailed in (Table 11). The majority of metals assessed, including Cr, Mn, Fe, Ni, Cu, Zn As, Cd, and Pb exhibit average Er values, below 40 suggesting low ecological risk. The ecological risk posed by Sb is considerable. On the other hand, Hg indicates a very high ecological risk. Around 30% of the samples show RI values above 600 indicating very high ecological risks. Another 20% fall, between the range of 300 and 600 suggesting a high risk of contamination. Furthermore, 10 samples, which represent half of the total have RI values ranging from 150 to 300 implying a moderate of potential ecological risk.

CONCLUSIONS

The research delved into examining the presence and quantity of MPs and heavy metal pollution in the street dust of Mosul city. Out of the 60 dust samples collected from the streets, an average of 244 to 2760 MPs per 15 grams of dust was detected. It was observed that the plastic particles were mostly transparent fragments ranging in size between ≤10 and 200 mm when viewed under a stereomicroscope and a scanning electron microscope. According to Fourier transform infrared spectroscopy, 63% of the MPs identified were polyvinyl chloride. X-ray fluorescence measurements revealed metal concentrations higher than the background values of world soils for Cr, Ni, Cu, Zn, As, Sb, Hg, and Pb. Variation coefficients along with enrichment and contamination factors analysis suggested that certain metals, like Cr, Cu, Zn As, Se, Cd, Sb, Hg and Pb have both natural and synthetic sources contributing to their presence. Based on the calculated enrichment factors, street dust contains very high levels of antimony Sb contamination. An analysis of the statistics indicates variations, in trace elements among sites likely influenced by factors such as traffic density, human activities and the materials used for road surfaces in the region. Low ecological risk was discovered due to contamination by Cr, Mn, Fe, Ni, Cu, Zn, As, Cd and Pb, in the urban dust of the studied cities. In contrast, the higher metal contribution to the ecological risk in all the locations was from Hg. About half of the samples showed ecological risk indices. This underscores that street dust could be a source of contamination, in urban areas necessitating the implementation of control measures. This is the first study to determine the pollution from MPs and heavy metals in road dust in Mosul city.

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REFERENCE

1. Abbasi, S., Keshavarzi, B., Moore, F., Delshab, H., Soltani, N., and Sorooshian, A. 2017a. Investigation of microrubbers, microplastics and heavy metals in street dust: a study in Bushehr city, Iran. Environmental Earth Sciences, 76(23).
2. Abbasi, S., Keshavarzi, B., Moore, F., Delshab, H., Soltani, N., and Sorooshian, A. 2017b. Investigation of microrubbers, microplastics and heavy metals in street dust: a study in Bushehr city, Iran. Environmental Earth Sciences, 76(23).
3. Abdullah, M.I.C., Md Sah, A.S.R., and Haris, H. 2020. Geoaccumulation index and enrichment factor of arsenic in surface sediment of bukit merah reservoir, Malaysia. Tropical Life Sciences Research, 31(3), 109–125.
4. Abed, M.F., Altawash, B.S., and Ali, S.M. 2015. Zn (39.5-374.7), Ag (0.064-0.14), Ni (90.7-210), Co (12.8-26.6). Iraqi Journal of Science.
5. Adachi, K., Tainosho, Y. 2004. Characterization of heavy metal particles embedded in tire dust. Environment International, 30(8), 1009–1017.
6. Adimalla, N. 2020. Heavy metals contamination in urban surface soils of Medak province, India, and its risk assessment and spatial distribution. Environmental Geochemistry and Health, 42(1), 59–75.
7. Aguilera, A., Cortés, J.L., Delgado, C., Aguilar, Y., Aguilar, D., Cejudo, R., Quintana, P., Goguitchaichvili, A., Bautista, F. 2022. Heavy Metal Contamination (Cu, Pb, Zn, Fe, and Mn) in Urban Dust and its Possible Ecological and Human Health Risk in Mexican Cities. Frontiers in Environmental Science, 10.
8. Al-Radady, A.S., Davies, B.E., French, M.J. 1994. Distribution of lead inside the home: case studies in the North of England. The Science of the Total Environment.
9. Andrady, A.L. 2011. Microplastics in the marine environment. Marine Pollution Bulletin.
10. Barbieri, M., 2016. The Importance of Enrichment Factor (EF) and Geoaccumulation Index (Igeo) to Evaluate the Soil Contamination. Journal of Geology & Geophysics, 5(1).
11. Chandrasekaran, A., Ravisankar, R., Harikrishnan, N., Satapathy, K.K., Prasad, M.V.R., Kanagasabapathy, K.V. 2015. Multivariate statistical analysis of heavy metal concentration in soils of Yelagiri Hills, Tamilnadu, India - Spectroscopical approach. Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy, 137, 589–600.
12. Dehghani, S., Moore, F., Akhbarizadeh, R. 2017a. Microplastic pollution in deposited urban dust, Tehran metropolis, Iran. Environmental Science and Pollution Research, 24(25), 20360–20371.
13. Dehghani, S., Moore, F., Akhbarizadeh, R. 2017b. Microplastic pollution in deposited urban dust, Tehran metropolis, Iran. Environmental Science and Pollution Research, 24(25), 20360–20371.
14. Duis, K., Coors, A. 2016. Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. Environmental Sciences Europe.
15. Fiori, C. da S., Rodrigues, A.P. de C., Santelli, R.E., Cordeiro, R.C., Carvalheira, R.G., Araújo, P.C., Castilhos, Z.C., Bidone, E.D. 2013. Ecological risk index for aquatic pollution control: a case study of coastal water bodies from the Rio de Janeiro State, southeastern Brazil. Geochimica Brasiliensis, 27(1), 24–36.
16. Fujiwara, F., Rebagliati, R.J., Marrero, J., Gómez, D., Smichowski, P. 2011. Antimony as a traffic-related element in size-fractionated road dust samples collected in Buenos Aires. Microchemical Journal, 97(1), 62–67.
17. Hakanson, 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Research. Sweden.
18. Huang, Y., Qing, X., Wang, W., Han, G., Wang, J. 2020. Mini-review on current studies of airborne microplastics: Analytical methods, occurrence, sources, fate and potential risk to human beings. TrAC - Trends in Analytical Chemistry.
19. Järlskog, I. 2022. Occurrence of traffic derived microplastics in different matrices in the road environment.
20. Jiang, F., Ren, B., Hursthouse, A., Deng, R., Wang, Z. 2019. Distribution, source identification, and ecological-health risks of potentially toxic elements (PTEs) in soil of thallium mine area (southwestern Guizhou, China). Environmental Science and Pollution Research, 26(16), 16556–16567.
21. Kabata-Pendias, A. 2011. Trace Elements in Soils

and Plants, Fourth Edition.
22. Liu, S., Peng, B., Li, J. 2022. Ecological Risk Evaluation and Source Identification of Heavy Metal Pollution in Urban Village Soil Based on XRF Technique. Sustainability (Switzerland), 14(9).
23. Mon, E.E., Tun, T.Z., Agusa, T., Yeh, H.-M., Huang, C.-H., Nakata, H. 2022. Monitoring of microplastics in road dust samples from Myanmar and Taiwan. Environmental Monitoring and Contaminants Research, 2, 112–119.
24. Monira, S., Bhuiyan, M.A., Haque, N., Shah, K., Roychand, R., Hai, F.I., Pramanik, B.K. 2021. Understanding the fate and control of road dust-associated microplastics in stormwater. Process Safety and Environmental Protection.
25. Nwineewii, J.D., Edori, O.S., Onuchukwu, P.U.G. 2018. Concentration, ecological risk and enrichment factor assessment of selected heavy metals in sediments from New Calabar River, Nigeria. Journal of Applied Sciences and Environmental Management, 22(10), 1643.
26. Ordóñez, A., Loredo, J., De Miguel, E., Charlesworth, S. 2003. Distribution of heavy metals in the street dusts and soils of an industrial city in Northern Spain. Archives of Environmental Contamination and Toxicology, 44(2), 160–170.
27. Pandey, D., Badola, N., Banerjee, T., Chauhan, J.S. 2022. Evidences of Microplastics in Air and Street Dust: A Case Study of Varanasi City, India.
28. Rajaram, B.S., Suryawanshi, P.V., Bhanarkar, A.D., Rao, C.V.C. 2014. Heavy metals contamination in road dust in Delhi city, India. Environmental Earth Sciences, 72(10), 3929–3938.
29. Ramaremisa, G., Tutu, H., Saad, D. 2024. Detection and characterisation of microplastics in tap water from Gauteng, South Africa. Chemosphere, 356.
30. Rawat, M., Ramanathan, A., Subramanian, V. 2009. Quantification and distribution of heavy metals from small-scale industrial areas of Kanpur city, India. Journal of Hazardous Materials, 172 (2–3), 1145–1149.
31. Saiyari, D., Anuran Griño, A., Marie Anselmo, A.C., Rafael Loyola, E.G., Lyn Medina, I.M., Niones Jr, E.P., Saiyari, D.M., n.d. Waste Polyvinyl Chloride (PVC) as Tensile Reinforcement to Asphalt Pavement Utilization of Waste Plastic Food Packaging with Impregnated Halloysite Nanotubes (HNTs) as Potential Building Material.
32. Shen, F., Mao, L., Sun, R., Du, J., Tan, Z., Ding, M. 2019a. Contamination evaluation and source identification of heavy metals in the sediments from the lishui river watershed, southern China. International Journal of Environmental Research and Public Health, 16(3).
33. Shen, F., Mao, L., Sun, R., Du, J., Tan, Z., Ding, M. 2019b. Contamination evaluation and source identification of heavy metals in the sediments from the lishui river watershed, southern China. International Journal of Environmental Research and Public Health, 16(3).
34. Al Shurafi, R.M., Hussien, A.K., Al-Mallah, A.Y. 2023. Spatial distribution of heavy metals in the soil of different areas at a left bank in Mosul City, Iraq: Part 2. Iraqi National Journal of Earth Science, 23(1), 132–153.
35. Sultan, M.H., Al-Ahmady, K.K., Mhemid, R.K.S. 2023. Microplastics Evaluation in Tap Water in Left Side Districts of Mosul City, Iraq. Journal of Ecological Engineering, 24(8), 353–362.
36. Suryawanshi, P.V., Rajaram, B.S., Bhanarkar, A.D., Chalapati Rao, C.V. 2016a. Determining heavy metal contamination of road dust in Delhi, India. Atmosfera, 29(3), 221–234.
37. Suryawanshi, P.V., Rajaram, B.S., Bhanarkar, A.D., Chalapati Rao, C.V. 2016b. Determining heavy metal contamination of road dust in Delhi, India. Atmosfera, 29(3), 221–234.
38. Tüzen, M. 2003. Investigation of heavy metal levels in street dust samples in Tokat, Turkey. Journal of Trace and Microprobe Techniques, 21(3), 513–521.
39. Wang, Q., Enyoh, C.E., Chowdhury, T., Chowdhury, A.H. 2022. Analytical techniques, occurrence and health effects of micro and nano plastics deposited in street dust. International Journal of Environmental Analytical Chemistry.
40. Wuana, R.A., Okieimen, F.E. 2011. Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. ISRN Ecology, 2011, 1–20.
41. Yang, C., Niu, S., Xia, Y., Wu, J. 2023. Microplastics in urban road dust: Sampling, analysis, characterization, pollution level, and influencing factors. TrAC Trends in Analytical Chemistry, 168, 117348.
42. Yuan, G.-L., Sun, T.-H., Han, P., Li, J., Lang, X.-X. 2014. Source identification and ecological risk assessment of heavy metals in topsoil using environmental geochemical mapping: Typical urban renewal area in Beijing, China. Journal of Geochemical Exploration, 136, 40–47.
43. Zhang, L., Liu, J. 2014. In situ relationships between spatial-temporal variations in potential ecological risk indexes for metals and the short-term effects on periphyton in a macrophyte-dominated lake: A comparison of structural and functional metrics. Ecotoxicology, 23(4), 553–566.