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Study of presence of microplastic particles and heavy metals in street dust in right bank of Mosul city / Iraq

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Abstract

Issue of street dust pollution is primarily related to levels of microplastic particles (MPs) and heavy metals, raising concerns about their potential risk on environment. In this research twenty street dust samples with three replicates were collected from different areas (residential, commercial, and industrial) from right bank of Mosul city / Iraq, to investigate the presence of MPs and study their characteristics. Additionally, to assess potential ecological risk impact of twelve heavy metals. Among the 60 dust samples taken from streets, an average of MPs ranging between 274 and 2914 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 dominant polymer type found in MPs, forming around 63%. levels of metal in road dust were assessed using X-ray fluorescence (XRF) showing that quantification of Cr, Ni, Cu, Zn, As, Cd, Sb, Hg, and Pb surpassed basic values of world soils regarding 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 samples exhibited moderate ecological risk indices (RI).

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دراسة تواجد الجسيمات البلاستيكية الدقيقة والمعادن الثقيلة في غبار شوارع الجانب الأيمن من مدينة الموصل / العراق

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مستخلص البحث

ترتبط قضية تلوث غبار الشوارع في المقام الأول بمستويات جزيئات البلاستيك الدقيقة (MPs) والمعادن الثقيلة، مما يثير المخاوف بشأن مخاطرها المحتملة على البيئة. في هذا العمل تم جمع عشرين عينة من غبار الشوارع وبثلاث مكررات من مناطق مختلفة (سكنية، تجارية، صناعية) في الجانب الأيمن من مدينة الموصل / العراق، للتحقق من وجود الجسيمات البلاستيكية الدقيقة ودراسة خصائصهم. بالإضافة إلى ذلك، لتقييم تأثير المخاطر البيئية المحتملة لاثني عشر من المعادن الثقيلة. ومن بين ٦٠ عينة غبار تم أخذها من الشوارع، تم الكشف عن متوسط الجسيمات البلاستيكية الدقيقة وكان يتراوح بين ٢٧٤ و٢٩١٤ لكل ١٥ جرام من الغبار. كانت معظم هذه الجزيئات البلاستيكية عبارة عن شظايا شفافة بأحجام تتراوح من أقل من ١٠ إلى ٢٠٠ ميكرومتر كما لوحظ من خلال المجهر المجسم والمجهر الإلكتروني الماسح (SEM). علاوة على ذلك، أشارت نتائج تحليل FTIR إلى أن كلوريد البولي فينيل (PVC) هو نوع البوليمر السائد الموجود في الجزيئات البلاستيكية النموذجية، وهو ما يمثل حوالي ٦٣٪. تم تقييم مستويات المعدن في غبار الطريق باستخدام مضان الأشعة السينية (XRF) مما يوضح أن القياس الكمي لـ Cr, Ni, Cu, Zn, As, Cd, Sb, Hg وPb تجاوز القيم الأساسية للتربة العالمية بين العناصر الاثني عشر درس. كشفت معاملات التباين (VCs) إلى جانب عوامل التخصيب والتلوث أن الكروم والنحاس والزنك والأسمدة والسيليكون والكادميوم والسيليكون والزئبق والرصاص ترتبط بكلا المصدرين (البشري والطبيعي). من ناحية أخرى، المنغنيز والحديد والني تنشأ من مصادر طبيعية. أشارت المخاطر البيئية المحتملة المحسوبة (Er) إلى وجود مخاطر بيئية عالية بواسطة الزئبق. أظهر ما يقرب من نصف العينات مؤشرات مخاطر بيئية معتدلة (RI).

الكلمات المفتاحية: مؤشر المخاطر البيئية؛ تحويل فورييه الطيفي بالأشعة تحت الحمراء؛ البلاستيك الدقيق؛ غبار الشارع.

1. Introduction:

The rapid urbanization of developing countries and the continuous change of land use for infrastructure development are devastating the local environment hi [1] 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 [2]. As a result, urban environments are becoming undesirable[3]. 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 [4].

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 [5]. As stated by [6], 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[7] Various ecosystems are adversely affected by MPs and heavy metals accumulation in street dust, soil, and surface water samples [8],[9]. 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 [10]. 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. [11],[12]

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[13].

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 evaluated [14]. 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.

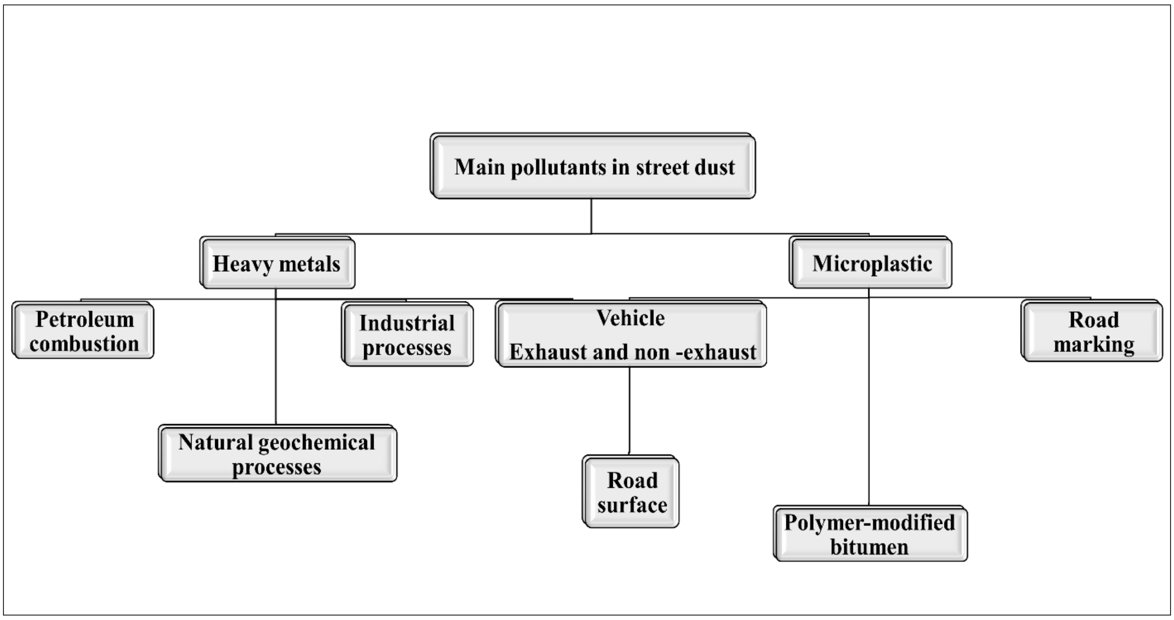

Figure 1. A summary of the sources of microplastics and heavy metals pollution in street dust.

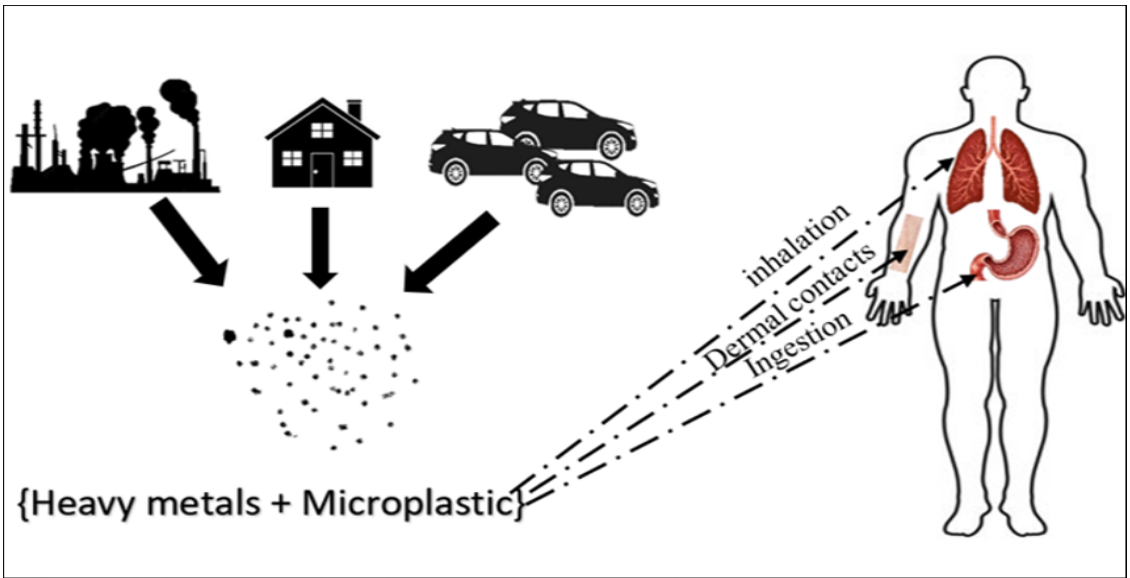

Figure 2. Impact of microplastics and heavy metals on the nervous, cardiovascular, kidney, and reproductive systems

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.

2. Materials and methods:

2.1. 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 right side of Mosul city-Iraq, 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 [(5)]. 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.

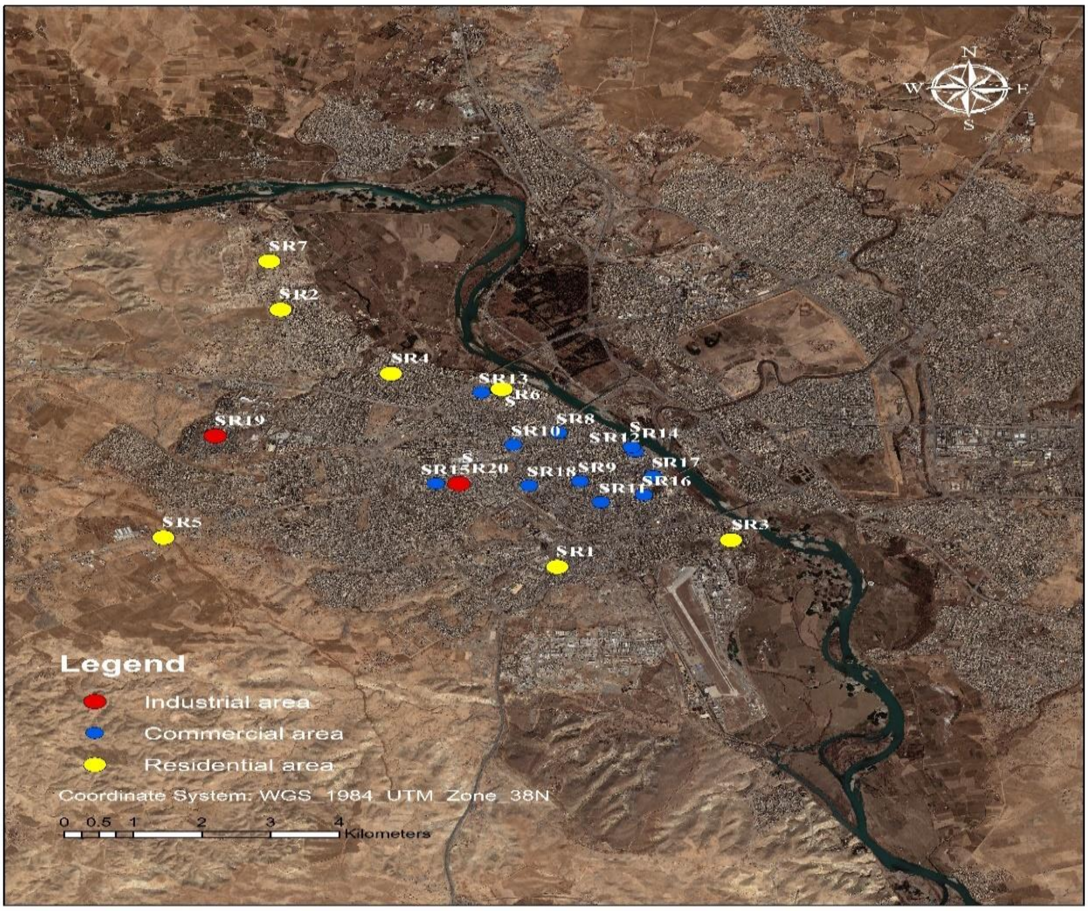

Figure3. Sampling locations in the right side of Mosul city.

Table 1. Details of sampling sites for MPs study.

site no.		sampling sites	Traffic volume*	Latitude	Longitude
S R1	Residential	**Wadi Hajar**	**(50-60) %**	**331543.4**	**4021129.88**
S R2		**Tamuwz**		**327523**	**4026955.35**
S R3		**Aljawsaq**		**334070.9**	**4021738.2**
S R4		**Al-rifai**		**329125.1**	**4025504.35**
S R5		**Aleubur**		**325819**	**4021793.9**
S R6		**Alshifa**		**330737.6**	**4025155.86**
S R7		**Mushairfa**		**327355.6**	**4028051.33**
S R8		**Alyarmuk**		**328467**	**4023205**
S R9		**Almamun**		**329342**	**4020873**
S R10		**Almahata**		**332089**	**4022216**
S R11	Commercial	**Al Farouk**	**(75-90) %**	**331567.8**	**4024168.61**
S R12		**Bab Al-tuwb**		**331881.3**	**4023067.26**
S R13		**Bab jadid**		**332182.9**	**4022592.31**
S R14		**Almaydan**		**332629.6**	**4023840.08**
S R15		**Mosul Al-jadida**		**329779.5**	**4023018.8**
S R16		**Aldawaasa**		**332808.8**	**4022758.57**
S R17		**Sharie halab**		**332938.1**	**4023180.24**
S R18		**Ras Aljada**		**331136.5**	**4022974.52**
S R19	**Industrial**	**Sunaaeuh wadi eugab**	**(70-90) %**	**326572.6**	**4024094.94**
S R20		**Sunaaeuh Alqadima**		**330113.9**	**4023010.58**

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

2.2 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 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) [(15)].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[(16)]. 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.

2..3 Microplastics identification and quantification

Visual sorting is challenging. (MPs) are widely detected by this method, as discussed in [(17)]. 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 [(18)]

It was used scanning electron microscope (SEM) (ZEISS EVO 10, 3 nm resolution with magnification (less than 7 to 1,000,000 X), 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 [(19)]

Additionally, it's crucial to check the makeup of the polymer ideally using Fourier transform infrared spectroscopy, FTIR (IRAffinity 1S, SHIMADUZ Japan) to understand its origins by compare 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}. The plastic particle was placed under the piston, the piston was pressed on it, and then data was obtained in the form of wavelengths of the polymer spectrum and comparison of the obtained spectra with previous reference data to identify the type of polymer as referred to [(20)]

2.4 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 dust samples, which excites the electrons of the dust, leading them to move into outer orbits. This process disrupts the electron distribution within the dust. 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 Erbil.

2.5 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).

2.5.1 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[21]

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

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 [22] is denoted by (Bn/Fe). In terms of value, iron is accepted as a standard element [23] Because it is one of the geochemical elements frequently, in the natural environment. [24]. 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 [25] There are five classes of fortification plants proposed by [26]As shown in Table (2).

Table 2. Enrichment Factor (EF) 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**

2.5.2 Contamination Factor (CF)

Contamination factor (CF) is an effective way to illustrate the impact of human activities on street dust [27]The following equation are used to calculate CF:

$$CF = \frac{Cn}{Bn} \text{………} (2)$$

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 rocks of the earth's crust (Kabata-Pendias, 2011). The Contamination Factor (*CF*) was classified into four groups by [28] as shown in Table (3).

Table 3. Contamination Factor (CF) Category.

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

2.5.3 Pollution Load Index

The pollution load index (PLI) is commonly employed to evaluate the presence of metals in a specific location. To determine the PLI value for the entire sampling location, PLI was calculated as the nth root of the product of the n CF using equation (3) [27]

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

The PLI > 1 means the region is contaminated, while PLI ≤ 1 refers to an unpolluted area [29]

2.5.4 Potential ecological risk index (RI)

Hakanson introduced the ecological risk index (RI) 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. [30].

The potential ecological risk index (*RI*) is present the sum of the individual ecological risks *(Er)* for assessing the level of elements pollution in street dust as the following:

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

Ecological risk (Er) 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. [31]

$$Er = Tr * Cf \text{ ………} (5)$$

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 [32],[33]. Cf is defied previously. Table (4) represent ecological risk levels.

Table 4. Classification of ecological risk levels into five categories [(34),(35)]

E_r	RI	Level of ecological risk
Er <40	**RI <150**	**Low ecological risk**
40 ≤ Er < 80	**150 ≤ RI< 300**	**Moderate ecological risk**
80 ≤ Er <160	**300≤ RI < 600**	**Considerable ecological risk**
160 ≤ Er < 320	**-**	**High ecological risk**
Er ≥320	**RI ≥600**	**Very high ecological risk**

2.6 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 one-way analysis of variance (ANOVA-Duncan test) with the statistical software SPSS version 22, for Windows in 2023.

3. Results and Discussion

3.1 Abundance of MPs in street dust

MPs were discovered in the street dust samples at all locations, in Mosul. (Figure 4 and Table A-1). The average of MPs concentration displayed the following decreasing trend according to the sampling site S20 >S19 >S13 >S15 >S14 >S11 >S16 >S18 >S12 >S17 >S2 >S8 >S4 >S7 >S9 >S7 >S3 >S5 >S10 >S1. Samples 20 and 19 contained the highest concentration of the MPs with 2914 and 2765 items/15g dust, respectively, due to it being an industrial area, followed by samples from S18 to S11 of commercial areas, while sample 1 contained the lowest concentration of MPs with 274 items/15g dust because it was, in a residential zone. According to the results, traffic load, industrial activity, shop numbers strongly correlated amount of MPs.

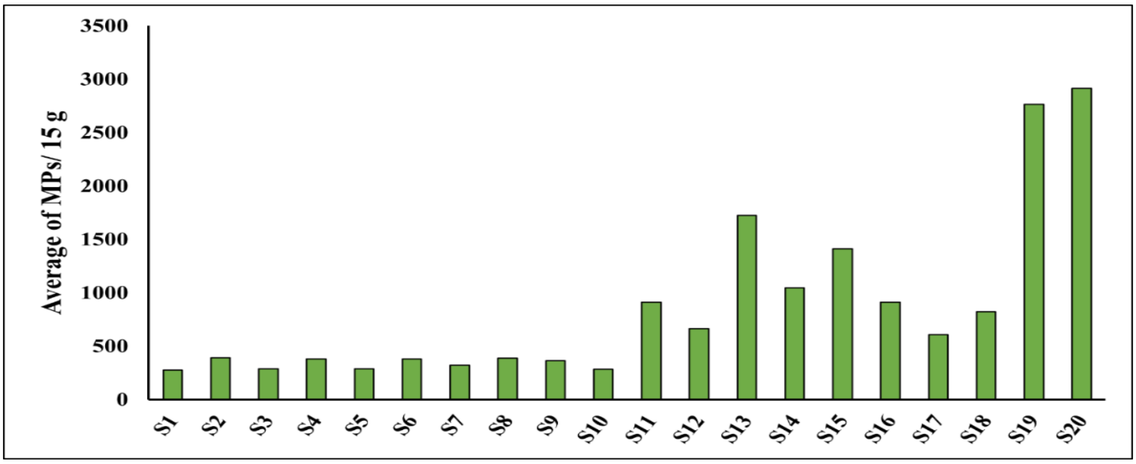

Figure 4. Average abundance of MPs in different sites

3.2 Morphology characteristics of MPs

3.2.1 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 69%, followed by fibers at 29%, and foam at 1%.

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 [36]. Fibers were probably plenty due to deposited dust samples which could include natural organic fibers like cotton and wool along with inorganic fibers 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 [37].

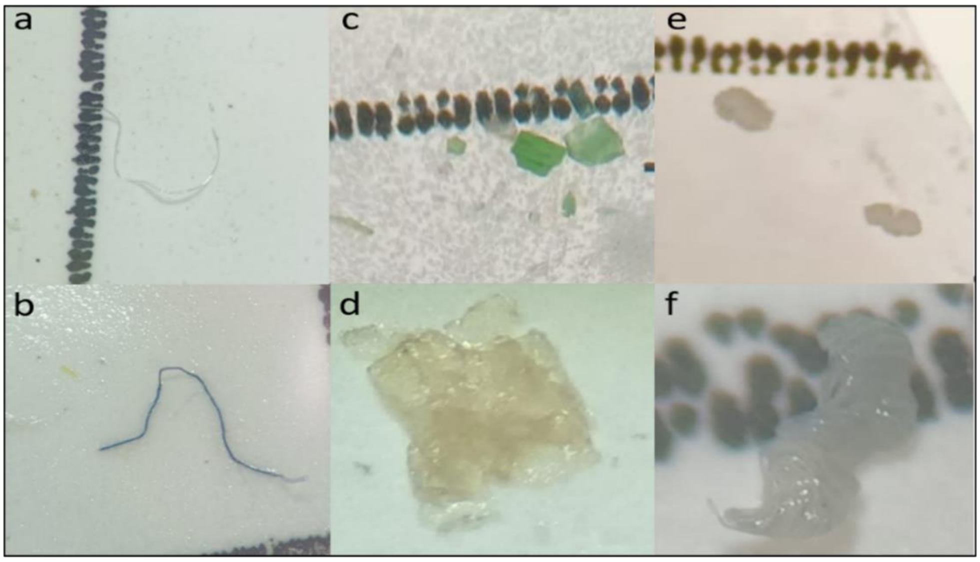

Figure 5. Images of microplastics, where (a) and (b) are fibers, (c) and (d) are fragments while (e) and (f) is foam.

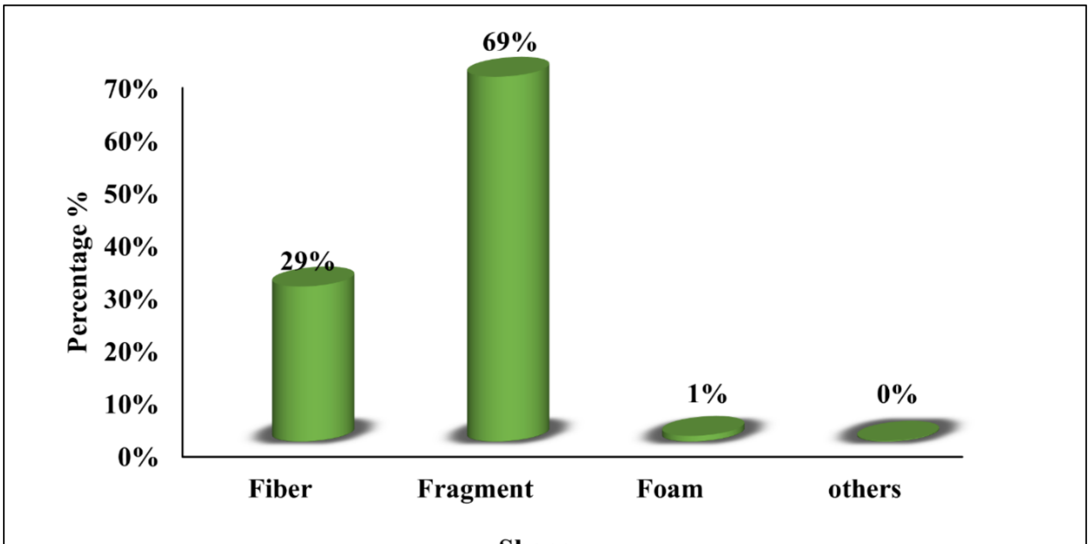

Figure 6. Percentage of MPs shapes.

3.2.2 Colour of microplastics

Data analysis shows that, across sampling stations, the predominant colour of microplastics found near roads is transparent accounting for 42% of the total. Following white makes up 19%. Yellow 14%. Conversely orange represents the color at just 3%. Colors, such as black, red, blue, and green have levels of abundance at 9%, 5%, 4%, and 4% respectively (Figure 7).

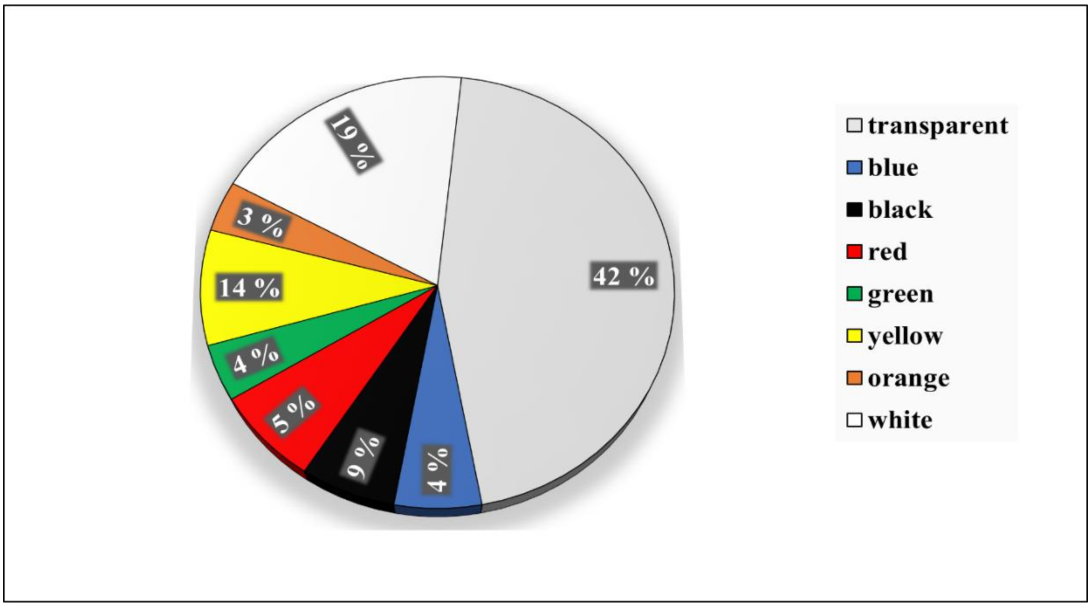

Figure 7. Percentage of MPs colors.

3.2.3 Microplastic Size

The scanning electron microscope (SEM) 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 [15] 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 [16].Therefore, most of the particles present in street dust have the potential to get absorbed and accumulate in the human body. The sizes of MPs can be observed in the images depicted in (Figure 9).

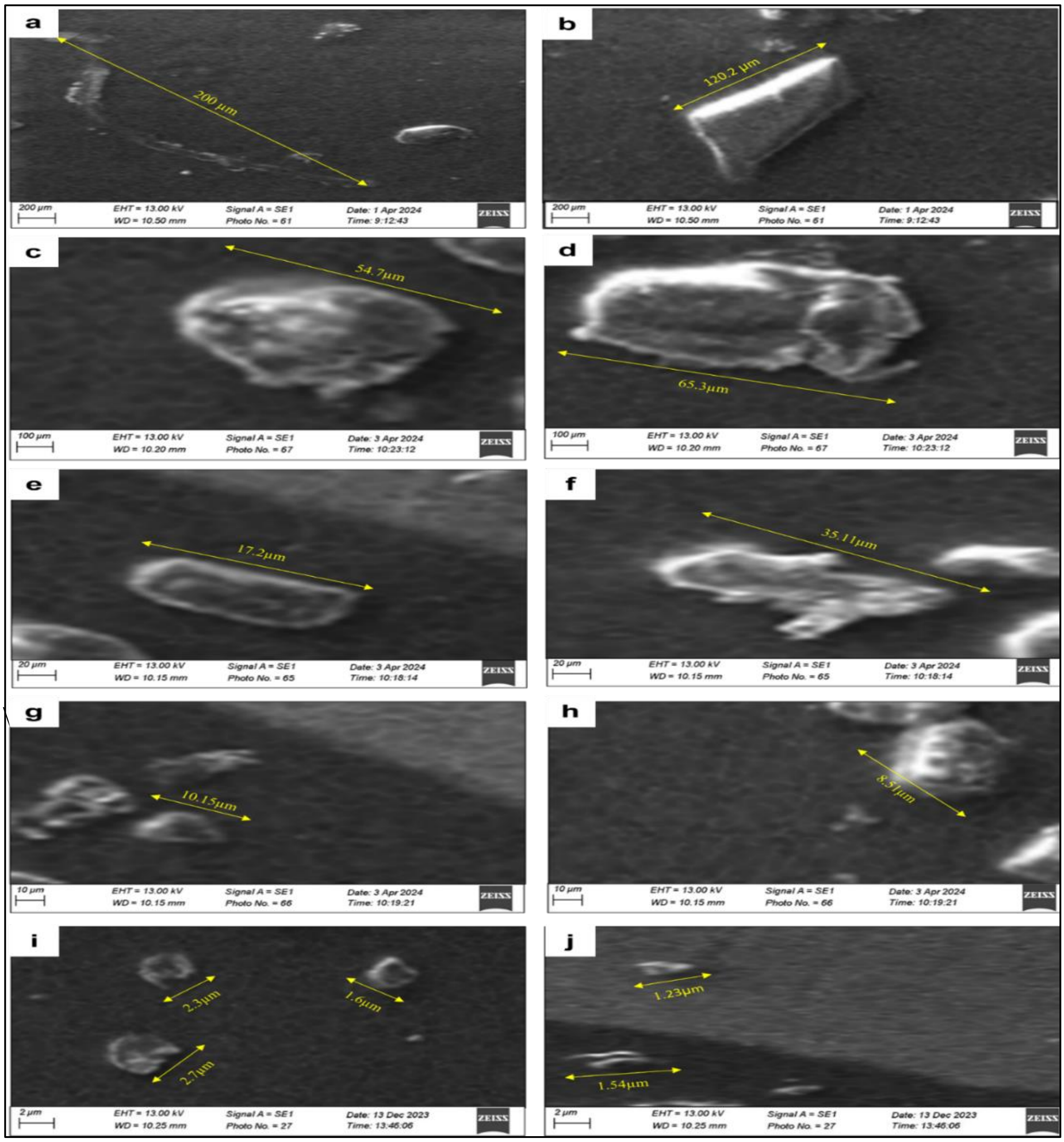

Figure 8. Scanning electron microscopy (SEM) image of microplastics, where (a), (b) are 100 < size ≤ 200 µm, (c) and (d) are 50 < size ≤ 100 µm, (e), (f) and (g) are from 10 to 50 µm, (h) (i) and (j) are from are ≤ 10 µm.

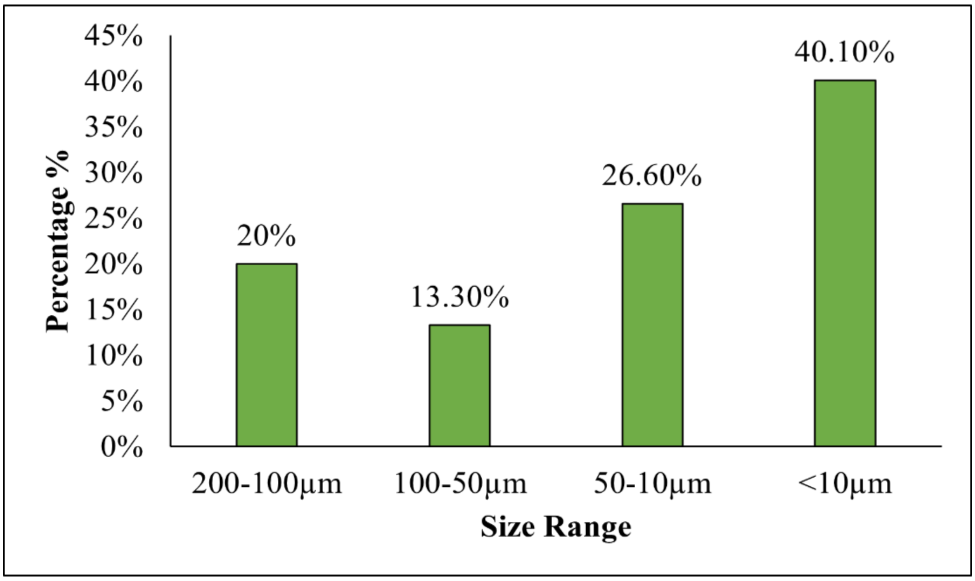

Figure 9. Percentage of microplastic size in street dust in Mosul city.

3.2.4 Microplastic composition

FTIR testing was conducted on the plastic materials identified during the inspection. (Figure 10) show cases the polymer categories found in road dust samples gathered from different areas.

The analysis of the data showed that there are 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, 67%), (PET, 13%), (PE, 5%), (PA, 6%), (PP, 8%), and (PS, 1%) may be due to use PVC as tensile reinforcement to asphalt pavement [(38)]. The researchers[(39)]) found that the proportions of the most common types of polymers in plastic particles were PE (27-39%) and PP (12%), which are used in a wide range of low-cost products such as plastic bags, containers, tubes, packaging, and others.

In Taiwan, researchers discovered a range of polymers, in microplastics collected from road dust. 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. [(40)]Another study [(41)] 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.

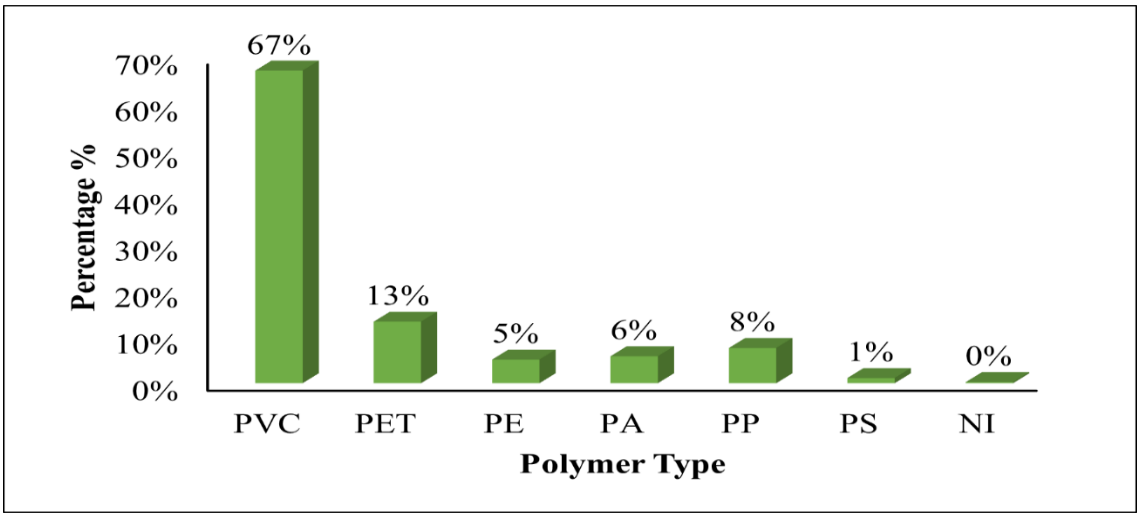

Figure 10. Polymer types percentage of microplastics.

3.3. 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, Cd, Sb, Hg and Pb surpassed background values of world soils [22] The mean concentrations of the elements are 77.412, 59.811, 80.12, 201.55, 27.747, 0.556, 6.5452, 0.4579, and 98.327 ppm, respectively. In Table (A-2), the high concentrate of Cr, Ni, Cu, Zn, As, Cd, 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 [42],[43]

Table 5. The mean of heavy metals in street dust collected from left side of Mosul city.

Element mean	Mean	Background of soil
Cr	77.412	59.5
Mn	276.14	488
Fe	15628	35000
Ni	59.811	29
Cu	80.12	38.9
Zn	201.55	70
As	27.747	6.83
Se	0.1583	0.44
Cd	0.556	0.41
Sb	6.5452	0.67
Hg	0.4579	0.07
Pb	98.327	27

Statistical analysis results of Duncan ANOVA illustrated that the values of Fe and Ni have no significant variation among the three locations in Table (6), furthermore, Mn, Cu, As, and Se showed significant variation of residential with commercial and residential with industrial. Three sites showed significant variations in the case of Cr, Zn, Cd, Sb, Hg, and Pb. 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 materials used for road surfaces.

Table 6. 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	47.162±12.13289[a]	101.8393±25.79282[b]	130.9535±12.03991[c]	0.0000 (S)
Mn	230.1545±21.07119[a]	317.1488±24.97819[b]	341.9900±8.01859[b]	0.0000(S)
Fe	15136.3±1117.76046[a]	15959.375±1286.11996[a]	16759.5±600.33366[a]	0.147(NS)
Ni	52.2456±16.59901[a]	66.0725±9.31615[a]	72.5900±2.92742[a]	0.06(NS)
Cu	31.7100±19.92784[a]	121.6875±31.95892[b]	155.9000±1.83848[b]	0.0000(S)
Zn	84.0825±8.24984[a]	294.6813±72.70631[b]	416.3750±32.70369[c]	0.0000(S)
As	6.8430±1.26629[a]	46.8638±23.17729[b]	55.8000±4.66690[b]	0.0000(S)
Se	0.0316±0.01728[a]	0.2651±0.13213[b]	0.3645±0.03465[b]	0.0000(S)
Cd	0.1431±0.01303[a]	0.6998±0.16099[b]	2.0450±1.03945[c]	0.0060(S)
Sb	0.6748±0.29405[a]	9.5824±2.12268[b]	23.7485±3.69746[c]	0.0000(S)
Hg	0.2763±0.05027[a]	0.5805±0.09024[b]	0.8750±0.03111[c]	0.0000(S)
Pb	46.6470±8.75170[a]	130.1450±24.35871[b]	229.4650±15.93112[c]	0.0000(S)

NS= Not significant, S= significant, SD= Standard Deviation, P< 0.05 significant, P> 0.05, Not significant

3.4. Evaluation of heavy metals contamination

3.4.1 Heavy metal contamination and source identification in street dust

Enrichment factors (EF) and contamination factors (CF), for metals, were computed for every street dust sample in comparison, to the values of world soil In (Figure 11), the mean EFs decrease in the order of (Sb >Hg >As >Pb >Zn >Ni >Cu >Cd >Cr >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, As, Pb, Zn, Cu, Cd, and Cr have wide range and Mn, Fe, Ni and Se have low range box plots. Also, based on variation coefficients (VCs) (Tables A-3), 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 [(44)]. The CV value (1.105) of Sb was the highest of the heavy metals, suggesting that Sb has the greatest variation among the studied metals and thus would have the highest possibility of being influenced by extrinsic factors such as human activities, automobile exhaust, and deposition of aerosol [(45)].

Sb have mean EFs higher than 20.19, which means very high enrichment; while Hg, As, Pb, and Zn with their mean EFs values of 14.52, 8.81, 7.73, and 5.77, respectively, were classified as significant enrichment. For the Cr, Ni, Cu, and Cd, the rate of EF is around 3.9, which places it within the field of moderate enrichment. The average of EF for Mn, Fe, and Se are found with a range between (0.98-1.26), 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.

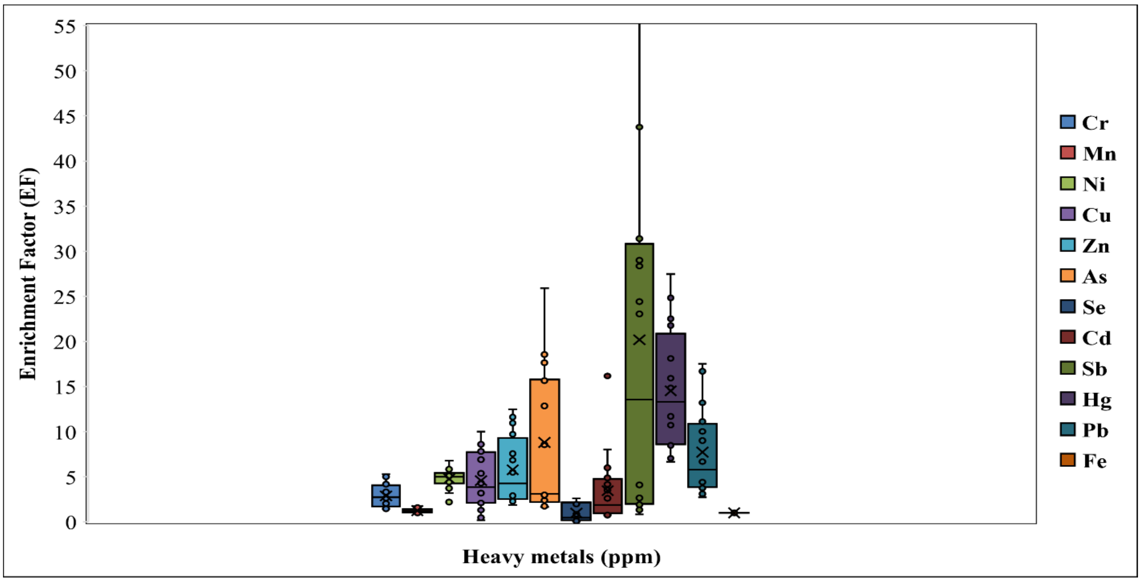

Figure 11. Box-plot of EF for heavy metals of Mosul's right side streets dust.

After calculating the contamination factor (CF) for the samples of the study area given in Table (A-4) and (Figure 12), it is found that the CF of the Sb is between (0.33-39.3) with a mean of 9.76, indicating very high contamination. Cf for both Hg and Pb were between (1.2 – 12.8) with an average of 5.09. The CF of As was ranged from 0.79 to 13.08 with a mean of 4.06, also the same classified for Pb which its CF was between (1.28 - 8.9) with a mean of 3.64. The rates of Cr, Ni, Cu, Zn, and Cd were as follows; 1.30, 2.06, 2.05, 2.87, and 1.35, which mean moderate contamination classification.

CF of Mn is between (0.41-0.71) with a mean of 0.56. CF of Fe is between (0.39-0.50) with a mean of 0.44. CF of Se is between (0.025-0.94) with a mean of 0.35. The mean CF of 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 indicates that they are classified between "low contamination-very high contamination according to Table (3).

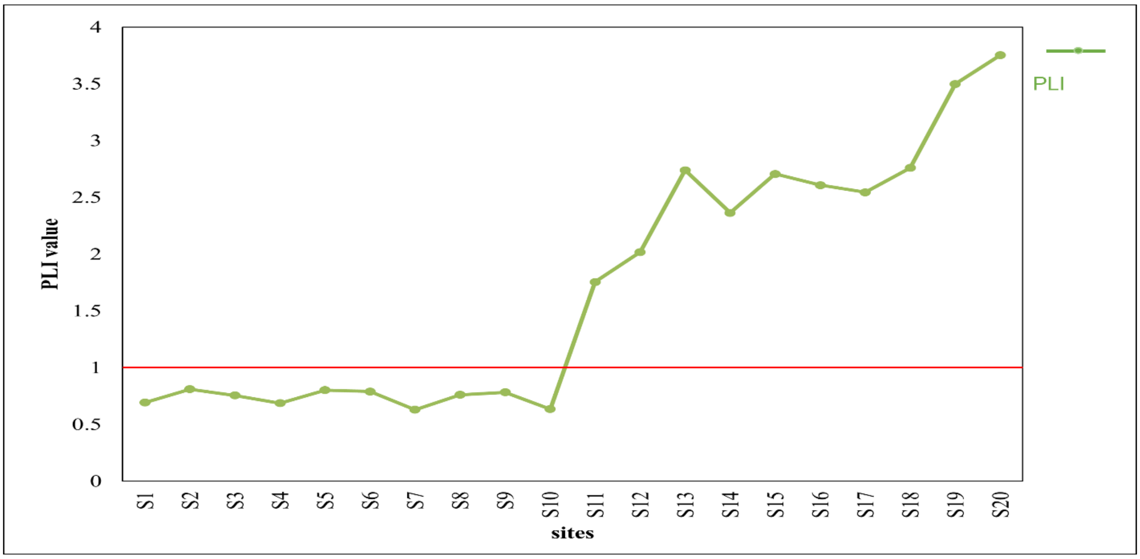

Figure 12. Box-plot of CF for heavy metals in right side Mosul in street dust.

3.4.2 Pollution load index (PLI)

The (Figure 13) is displayed, PLI values of 10 sites (S11-S20) 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.

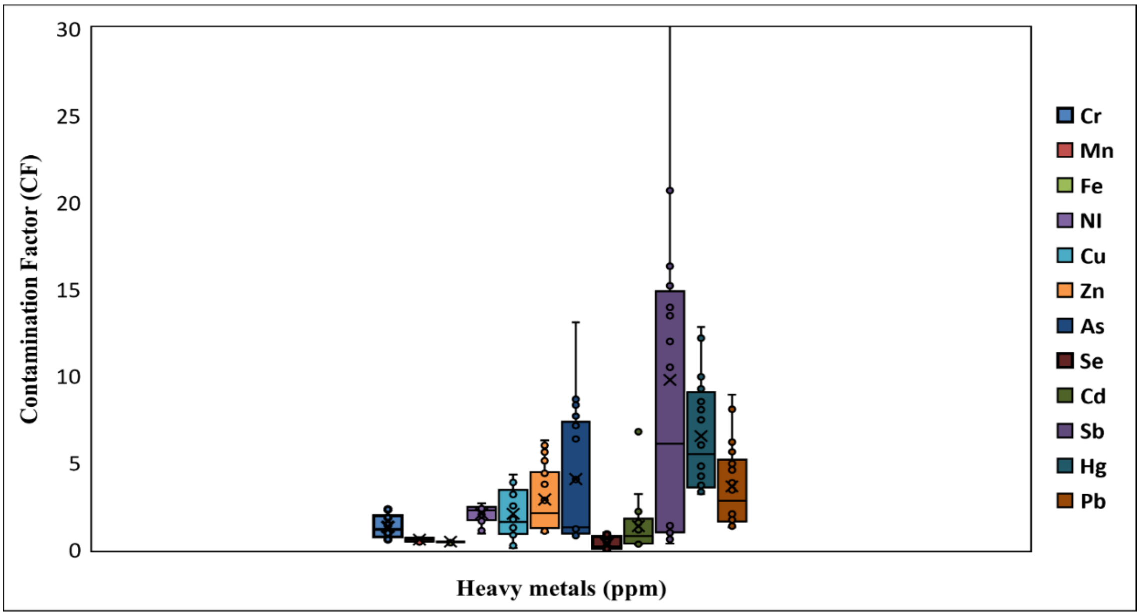

Figure 13. PLI value of the street dust of study area.

3.4.3 Ecological risk levels

To determine the extent of metal pollution, in street dust, the ecological risk index (RI) was measured as detailed in Table (A-5). The majority of metals assessed, including Cr, Mn, Fe, Ni, Cu, Zn and Pb exhibit average Er values, below 40 suggesting low ecological risk. The ecological risk posed by As, Cd, and 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.

4. Conclusion

The research delved into examining the presence and quantity of MPs and heavy metal pollution in the street dust of Mosul city/ Iraq. Out of the 60 dust samples collected from the streets, an average of 274 and 2914 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 (SEM). According to Fourier transform infrared spectroscopy (FTIR), 67% of the MPs identified were polyvinyl chloride (PVC). X-ray fluorescence (XRF) measurements revealed metal concentrations higher than the background values of world soils for Cr, Ni, Cu, Zn, As, Cd, Sb, Hg, and Pb. Variation coefficients (VCs) 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/Iraq.

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Appendix

Table (A-1). Abundance of MPs in different sites.

Residential					
Site.no	**Duplicate 1**	**Duplicate 2**	**Duplicate 3**	**Total**	**Average**
S1	272	278	274	824	274.67
S2	389	392	393	1174	391.33
S3	285	289	287	861	287
S4	378	379	384	1141	380.33
S5	284	285	290	859	286.33
S6	376	380	382	1138	379.33
S7	317	320	325	962	320.67
S8	382	386	390	1158	386
S9	361	363	367	1091	363.67
S10	282	288	280	850	283.33
S11	908	914	915	2737	912.33
S12	663	665	671	1999	666.33
S13	1720	1730	1725	5175	1725
S14	1046	1040	1054	3140	1046.7
S15	1412	1420	1409	4241	1413.7
S16	904	910	922	2736	912
S17	601	606	612	1819	606.33
S18	825	817	822	2464	821.33
S19	2755	2774	2768	8297	2765.7
S20	2908	2914	2921	8743	2914.3

Table (A-2). 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	49.361	250.140	31.643	40.600	68.892	5.490	0.020	0.126	0.645	0.223	41.867	16783.000
S2		35.210	231.750	47.380	48.900	77.925	5.820	0.052	0.158	1.143	0.248	36.558	13975.000
S3		37.544	219.980	69.356	55.700	74.633	8.220	0.013	0.164	0.396	0.348	52.300	14821.000
S4		56.618	202.755	26.850	53.500	86.933	5.910	0.011	0.145	0.448	0.258	59.575	15137.000
S5		55.776	227.860	63.550	44.500	82.475	7.500	0.014	0.124	1.025	0.346	40.692	16126.000
S6		72.501	276.500	49.967	32.400	87.225	5.820	0.024	0.135	0.745	0.238	55.392	14053.000
S7		38.946	218.770	68.250	3.100	93.950	5.430	0.032	0.142	0.923	0.237	34.567	15862.000
S8		49.926	235.580	58.250	8.500	85.725	8.700	0.052	0.137	0.714	0.233	56.358	16504.000
S9		41.817	228.680	71.840	20.700	94.917	7.500	0.045	0.148	0.483	0.336	43.017	14350.000
S10		33.923	209.530	35.370	9.200	88.150	8.040	0.052	0.152	0.226	0.296	46.133	13752.000
S11	Commercial	67.910	289.500	77.200	67.400	214.000	8.880	0.141	0.632	8.241	0.422	126.325	14204.000
S12		84.323	283.780	68.450	97.800	199.117	27.540	0.092	0.579	9.343	0.597	133.567	16472.000
S13		70.867	319.080	59.650	129.400	263.233	48.720	0.413	0.950	13.857	0.697	167.250	15832.000
S14		109.680	297.570	70.890	150.600	282.317	43.500	0.150	0.648	10.938	0.523	92.825	17367.000
S15		137.890	338.650	74.670	168.300	419.917	56.850	0.210	0.746	7.036	0.665	123.683	15269.000
S16		126.854	348.560	59.780	123.700	307.417	49.500	0.320	0.896	9.032	0.648	103.633	14385.000
S17		117.580	317.340	48.990	101.800	358.133	50.520	0.380	0.684	8.026	0.528	151.900	16440.000
S18		99.610	342.710	68.950	134.500	313.317	89.400	0.415	0.463	10.186	0.564	141.967	17706.000
S19	Industrial	139.467	347.660	70.520	154.600	393.250	59.100	0.389	1.310	21.134	0.897	218.200	16335.000
S20		122.440	336.320	74.660	157.200	439.500	52.500	0.340	2.780	26.363	0.853	240.725	17184.000

Table (A-3). EF values of heavy metals in street dust on a right side of Mosul city.

Site no.	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Sb	Hg	Pb
S1	1.73	1.06	1.00	2.36	2.20	1.87	1.68	0.12	0.75	1.92	6.64	3.12
S2	1.48	1.18	1.00	4.24	3.18	2.53	2.14	0.37	1.13	4.09	8.87	3.27
S3	1.49	1.06	1.00	5.85	3.42	2.29	2.84	0.09	1.11	1.34	11.73	4.41
S4	2.20	0.96	1.00	2.22	3.21	2.61	2.00	0.07	0.96	1.48	8.54	4.92
S5	2.03	1.01	1.00	4.93	2.51	2.32	2.39	0.09	0.77	3.18	10.73	3.15
S6	3.03	1.41	1.00	4.44	2.10	2.82	2.12	0.17	0.96	2.65	8.47	4.93
S7	1.44	0.99	1.00	5.38	0.18	2.69	1.76	0.20	0.90	2.91	7.47	2.72
S8	1.78	1.02	1.00	4.41	0.47	2.36	2.70	0.32	0.83	2.16	7.06	4.27
S9	1.71	1.14	1.00	6.26	1.31	3.01	2.68	0.31	1.03	1.68	11.71	3.75
S10	1.45	1.09	1.00	3.21	0.61	2.91	3.00	0.38	1.11	0.82	10.76	4.19
S11	2.81	1.46	1.00	6.79	4.31	6.85	3.21	0.99	4.45	29.01	14.85	11.12
S12	3.01	1.23	1.00	5.19	5.40	5.49	8.57	0.56	3.52	28.36	18.12	10.14
S13	2.63	1.44	1.00	4.71	7.43	7.56	15.78	2.61	6.00	43.76	22.01	13.21
S14	3.71	1.22	1.00	5.10	7.88	7.39	12.84	0.86	3.73	31.49	15.06	6.68
S15	5.31	1.58	1.00	6.11	10.02	12.50	19.09	1.38	4.89	23.04	21.78	10.13
S16	5.19	1.73	1.00	5.19	7.82	9.71	17.65	2.22	6.23	31.39	22.52	9.01
S17	4.21	1.38	1.00	3.72	5.63	9.90	15.76	2.31	4.16	24.41	16.06	11.55
S18	3.31	1.38	1.00	4.87	6.91	8.04	25.89	2.34	2.61	28.76	15.93	10.02
S19	5.02	1.52	1.00	5.40	8.60	10.94	18.55	2.38	8.02	64.69	27.46	16.70
S20	4.19	1.40	1.00	5.43	8.32	11.63	15.67	1.98	16.18	76.71	24.82	17.51
average	2.89	1.26	1.00	4.79	4.57	5.77	8.82	0.99	3.47	20.19	14.53	7.74
median	2.72	1.23	1.00	5.01	3.87	4.25	3.10	0.47	1.87	13.56	13.29	5.80
max	5.31	1.73	1.00	6.79	10.02	12.50	25.89	2.61	16.18	76.71	27.46	17.51
min	1.44	0.96	1.00	2.22	0.18	1.87	1.68	0.07	0.75	0.82	6.64	2.72
STD	1.32	0.22	0.00	1.20	3.08	3.67	7.89	0.95	3.73	22.32	6.41	4.62
C.V %	0.46	0.18	0.00	0.25	0.67	0.64	0.90	0.96	1.08	1.11	0.44	0.60

Table (A-4). CF values of heavy metals in street dust on a right side of Mosul city

Site no.	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Sb	Hg	Pb
S1	0.83	0.51	0.48	1.09	1.04	0.98	0.80	0.05	0.31	0.96	3.19	1.55
S2	0.59	0.47	0.40	1.63	1.26	1.11	0.85	0.12	0.39	1.71	3.54	1.35
S3	0.63	0.45	0.42	2.39	1.43	1.07	1.20	0.03	0.40	0.59	4.97	1.94
S4	0.95	0.42	0.43	0.93	1.38	1.24	0.87	0.03	0.35	0.67	3.69	2.21
S5	0.94	0.47	0.46	2.19	1.14	1.18	1.10	0.03	0.30	1.53	4.94	1.51
S6	1.22	0.57	0.40	1.72	0.83	1.25	0.85	0.06	0.33	1.11	3.40	2.05
S7	0.65	0.45	0.45	2.35	0.08	1.34	0.80	0.07	0.35	1.38	3.39	1.28
S8	0.84	0.48	0.47	2.01	0.22	1.22	1.27	0.12	0.33	1.07	3.33	2.09
S9	0.70	0.47	0.41	2.48	0.53	1.36	1.10	0.10	0.36	0.72	4.80	1.59
S10	0.57	0.43	0.39	1.22	0.24	1.26	1.18	0.12	0.37	0.34	4.23	1.71
S11	1.14	0.59	0.41	2.66	1.73	3.06	1.30	0.32	1.54	12.30	6.03	4.68
S12	1.42	0.58	0.47	2.36	2.51	2.84	4.03	0.21	1.41	13.94	8.53	4.95
S13	1.19	0.65	0.45	2.06	3.33	3.76	7.13	0.94	2.32	20.68	9.96	6.19
S14	1.84	0.61	0.50	2.44	3.87	4.03	6.37	0.34	1.58	16.33	7.47	3.44
S15	2.32	0.69	0.44	2.57	4.33	6.00	8.32	0.48	1.82	10.50	9.50	4.58
S16	2.13	0.71	0.41	2.06	3.18	4.39	7.25	0.73	2.19	13.48	9.26	3.84
S17	1.98	0.65	0.47	1.69	2.62	5.12	7.40	0.86	1.67	11.98	7.54	5.63
S18	1.67	0.70	0.51	2.38	3.46	4.48	13.09	0.94	1.13	15.20	8.06	5.26
S19	2.34	0.71	0.47	2.43	3.97	5.62	8.65	0.88	3.20	31.54	12.81	8.08
S20	2.06	0.69	0.49	2.57	4.04	6.28	7.69	0.77	6.78	39.35	12.19	8.92
average	1.30	0.57	0.45	2.06	2.06	2.88	4.06	0.36	1.36	9.77	6.54	3.64
median	1.17	0.57	0.45	2.27	1.58	2.10	1.29	0.16	0.76	6.10	5.50	2.82
max	2.34	0.71	0.51	2.66	4.33	6.28	13.09	0.94	6.78	39.35	12.81	8.92
min	0.57	0.42	0.39	0.93	0.08	0.98	0.80	0.03	0.30	0.34	3.19	1.28
STD	0.62	0.11	0.04	0.52	1.44	1.91	3.78	0.35	1.54	11.13	3.07	2.32
C.V %	0.48	0.19	0.08	0.25	0.70	0.66	0.93	0.99	1.14	1.14	0.47	0.64

Table (A-5): 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	1.65	0.51	0.48	5.46	5.22	0.98	8.04	9.22	6.74	127.43	7.75	173.49
S2	1.18	0.47	0.40	8.17	6.29	1.11	8.52	11.56	11.94	141.71	6.77	198.13
S3	1.26	0.45	0.42	11.96	7.16	1.07	12.04	12.00	4.14	198.63	9.69	258.81
S4	1.90	0.42	0.43	4.63	6.88	1.24	8.65	10.61	4.68	147.66	11.03	198.13
S5	1.87	0.47	0.46	10.96	5.72	1.18	10.98	9.07	10.71	197.71	7.54	256.67
S6	2.44	0.57	0.40	8.62	4.16	1.25	8.52	9.88	7.78	136.00	10.26	189.87
S7	1.31	0.45	0.45	11.77	0.40	1.34	7.95	10.39	9.64	135.43	6.40	185.53
S8	1.68	0.48	0.47	10.04	1.09	1.22	12.74	10.02	7.46	133.14	10.44	188.79
S9	1.41	0.47	0.41	12.39	2.66	1.36	10.98	10.83	5.05	192.00	7.97	245.51
S10	1.14	0.43	0.39	6.10	1.18	1.26	11.77	11.12	2.36	169.14	8.54	213.44
S11	2.28	0.59	0.41	13.31	8.66	3.06	13.00	46.24	86.10	241.14	23.39	438.19
S12	2.83	0.58	0.47	11.80	12.57	2.84	40.32	42.37	97.61	341.14	24.73	577.28
S13	2.38	0.65	0.45	10.28	16.63	3.76	71.33	69.51	144.77	398.29	30.97	749.04
S14	3.69	0.61	0.50	12.22	19.36	4.03	63.69	47.41	114.28	298.86	17.19	581.83
S15	4.63	0.69	0.44	12.87	21.63	6.00	83.24	54.59	73.51	380.00	22.90	660.51
S16	4.26	0.71	0.41	10.31	15.90	4.39	72.47	65.56	94.36	370.29	19.19	657.86
S17	3.95	0.65	0.47	8.45	13.08	5.12	73.97	50.05	83.85	301.71	28.13	569.43
S18	3.35	0.70	0.51	11.89	17.29	4.48	130.89	33.88	106.42	322.29	26.29	657.98
S19	4.69	0.71	0.47	12.16	19.87	5.62	86.53	95.85	220.80	512.57	40.41	999.68
S20	4.12	0.69	0.49	12.87	20.21	6.28	76.87	203.41	275.43	487.43	44.58	1132.38
average	2.60	0.57	0.45	10.31	10.30	2.88	40.63	40.68	68.38	261.63	18.21	456.63