



## Exploring the Distribution of Microplastics and Heavy Metals in Agricultural Soils and the Evaluation of Risk Indices in Erbil City

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### Abstract

Microplastics (MPs) and heavy metals (HMs) are emerging contaminants that pose potential risks to both environmental and human health. This investigation aims to evaluate the concentration, dispersion, and potential health hazards of microplastics and heavy metals in agricultural soils of Erbil City, Iraq. The quality of microplastics will be assessed by analysing soil samples collected from six agricultural sites using FT-IR spectroscopy. The study sites and plants contained various forms of microplastics, including PET, PA, PE, PS, and PP. Samples from S3–S5 may contain traces of aromatic structures, suggesting either PS contamination or degradation products of PET. The highest concentration of plastic particles per gram of soil was observed in S4 for PET, ranging from  $0$  to  $2.88 \pm 0.55$ . Heavy metals such as Ba, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were evaluated in soil samples and two plant species (*Barbarea verna* and *Anethum graveolens*) using ICP. The concentrations of chromium, manganese, nickel, iron, and zinc in the samples exceeded the FAO's permitted levels. Based on microplastic and heavy metal contamination, sites S2 and S6 were classified as medium risk, while site S4 demonstrated a high ecological risk. According to the data obtained from MPs and HMs, the strongest positive correlation was observed between aluminium and PET (Polyethylene Terephthalate) MPs ( $r = 0.82$ ), while the correlation between Pb and PS was  $r = 0.78$ . Additionally, the study will assess whether MPs and HMs could enter the food chain, posing a risk to human health.

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### 1. Introduction

Microplastics (MPs) have become a worldwide issue, highlighting their link to health problems such as stillbirth, prematurity, congenital anomalies, neurological disorders, allergies, asthma, respiratory illness, and lung malignancies, due to the toxic, mutagenic, and carcinogenic properties of MPs [1].

MPs enter the body of people by several mechanisms, including cutaneous contact, inhalation, and ingestion [2]. In contemporary agriculture, the use of plastics introduces microplastics into soils via many techniques, such as plastic mulching, effluent irrigation, soil amendments, chemical coatings, dumping waste, drainage, and atmospheric release [3]. Since 1950, global plastic output has significantly escalated, with an anticipated total of 348 million metric tonnes of manufactured plastics by 2050, indicating a global yearly increment of 33 billion tons [4]. The predominant, frequently manufactured, and utilised plastic polymers are Polyethylene (PE), Polystyrene (PS), Polypropylene (PP), Polyethylene Terephthalate (PET), and polyvinyl chloride (PVC) [5]. Because plastics are durable, unsustainable, poorly managed, and rarely recycled, they tend to build up significantly in ecological systems [6].

The primary environmental problem nowadays is plastic contamination. Solid particles with regular or irregular shapes and polymeric matrix particles varied from  $1 \mu\text{m}$  to  $5 \text{ mm}$  in size are two distinct forms of microplastics [7]. Furthermore,

microplastics can be categorised depending on their origins as primary or secondary [8]. While the secondary originates from plastic breakdown due to weathering, the primary is already created on the microscale [9]. The soil contains several chemical additions and contaminants that have shown a propensity for interaction with MPs. This relationship helps MPs' negative impacts on plants and animals to be even more enhanced [10]. Various processes in the soil environment degrade the waste plastic residues from plastic mulching operations in agriculture that remain after their use into small particulates, ultimately achieving a size of 5 mm, which is known as microplastics (MPs) [11]. The leftover plastic from mulching degrades into smaller fragments gradually, eventually becoming microplastics through processes like sunlight exposure, erosion from water or air, and the actions of earthworms [12]. The leftover polymers experience a photo-oxidative breakdown, resulting in their transformation into smaller particles [13].

The conversion of plastics to microplastics increases surface adsorption capacity, allowing for the adsorption of many contaminants, such as heavy metals, organic compounds, and antibiotics [14]. As a result, MPs function as vectors for the transmission of these contaminants throughout the food chain [15]. The data indicate that MPs have a significant specific surface area and elevated adsorption capacity, hence possibly exacerbating symptoms of toxicity when present with contaminants such as heavy metals [16].

Heavy metals (HMs) in agricultural soils can serve dual functions, functioning as important micronutrients at low concentrations while being hazardous at elevated levels. Trace elements, including zinc (Zn), copper (Cu), and nickel (Ni), are essential for plant development, enzyme activity, and physiological functions. Nonetheless, when their concentrations beyond crucial limits, they can obstruct nutrient absorption, hinder root development, and affect photosynthesis and protein synthesis. Non-essential heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) lack biological function and exhibit toxicity even at minimal concentrations. Heavy metals constitute a substantial category of pollutants recognised for their harmful impacts on living organisms. The HM ions exhibit a robust propensity for adhesion to the MPs [17].

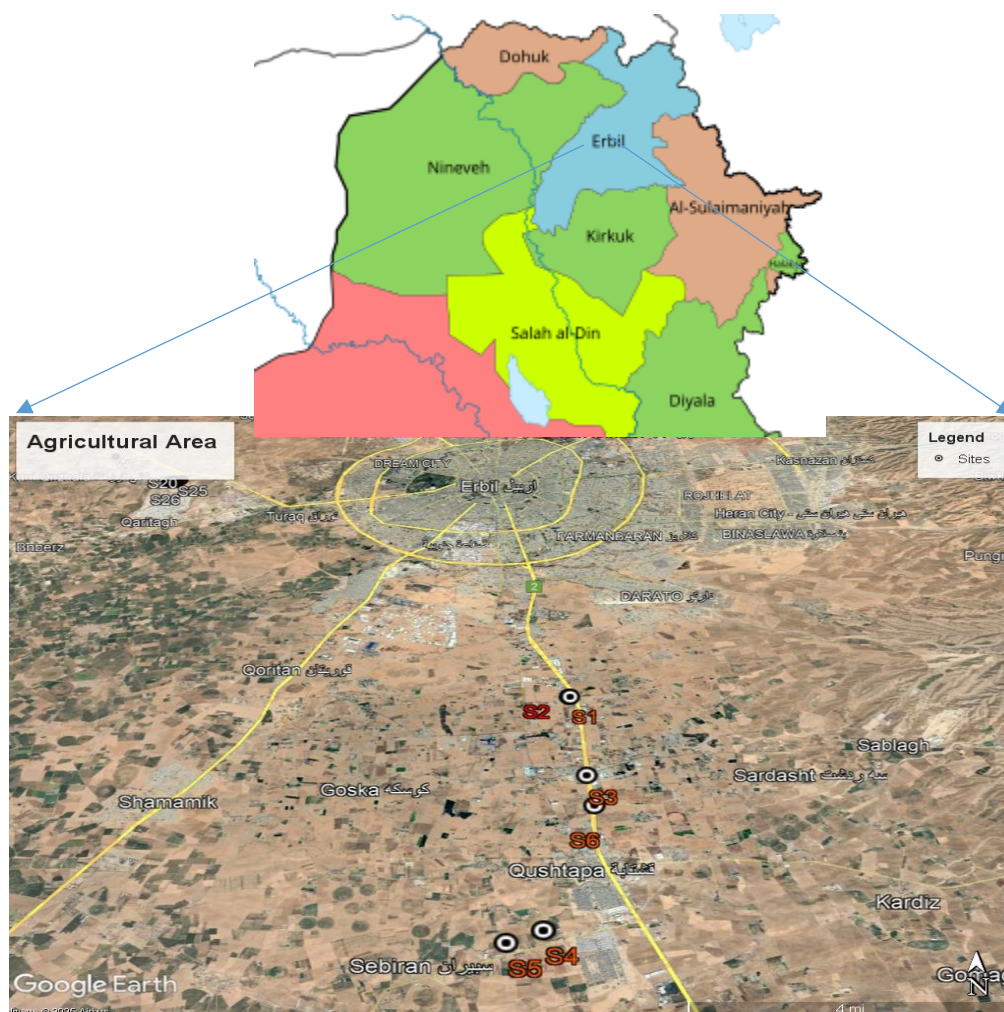
The translocation of HMs into the environment can be facilitated through different chemical, physical, and biological processes, which may be either natural or man-made [18]. Consequently, the growing global apprehension regarding microplastic contamination and its interaction with heavy metals is of considerable significance. Microplastics in soil can influence plant growth through multiple mechanisms, including modifying soil characteristics, delaying germination, disturbing the structure of root systems, and affecting the microbial population vital for plant growth [19]. As collected within plant tissues, HMs disturb several important cellular functions, which finally influence development and production [20]. The reaction of MPs with HMs might aggravate soil conditions and plant metabolism even further.

This research aims to measure the kinds and quantities of heavy metals and microplastics, in addition to possible human health hazards related to MPs and HMs in the agricultural soils of Erbil city. Therefore, investigating the influence of the coexistence of microplastics and heavy metals on agroecosystems becomes essential to guarantee world food security for the increasing population.

## **2. Research Method**

### **2.1 Study Area**

The research locations are placed along the Erbil-Kirkuk road, extending to the Makhmur road within the Qushtapa Sub-District, as illustrated in Figure 1, in Erbil City, Iraq. The coordinates of the location are 36°06'27.72"N latitude and 44°03'36.84"E longitude (Figure 1). Erbil City is a significant agricultural area in Iraq, characterised by intensive farming and plastic-based agriculture methods. Sampling locations will be determined by land utilisation, irrigation techniques, and closeness to urban sources.



**Figure 1:** Map of North Iraq and sites of sample collection.

Map of North

## 2.2 Sample Collection and Processing

We gathered soil samples from multiple depths and locations. Six sites will host the collection of samples. To create a composite sample at each sampling point, soil samples were mixed at a depth of 0–5 cm. Samples were transported to the environmental science and health department lab for examination. Standardised extraction methods (density separation, filtration, and digestion) will be used to isolate MPs.

## 2.3 Soil Analysis

After collecting soil samples and carrying them to the lab for evaluation, the samples were transported to the lab for physicochemical measurements, including pH (pH meter), EC (EC meter), Organic Matter (OM), and Organic Carbon (OC) by the Walkley-Black method. Heavy metals, including Ba, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn, were identified in soil samples using ICP analysis. The **ICP (Inductively Coupled Plasma) method** is a laboratory technique used to **measure metals** (like zinc, lead, cadmium, etc.) in soil, water, or plant samples. The sample is turned into a liquid and sprayed into a very hot plasma (like a small flame at 10,000°C).

**Table 1.** General Features of the studied sites

| Sites | Latitude      | Longitude     | pH   | EC ( $\mu\text{S}/\text{cm}$ ) | OC %  | OM %  |
|-------|---------------|---------------|------|--------------------------------|-------|-------|
| S1    | 36°06'27.72"N | 44°03'36.84"E | 7.75 | 344                            | 0.672 | 1.156 |
| S2    | 36°06'28.23"N | 44°03'32.07"E | 7.50 | 715                            | 0.517 | 0.889 |
| S3    | 36°03'17.80"N | 44°03'67.70"E | 8.27 | 135                            | 0.336 | 0.578 |
| S4    | 35°98'32.66"N | 44°02'39.77"E | 8.12 | 338                            | 1.747 | 3.005 |
| S5    | 35°98'00.01"N | 44°01'53.22"E | 8.01 | 314                            | 2.352 | 4.045 |

|    |               |               |      |     |       |       |
|----|---------------|---------------|------|-----|-------|-------|
| S6 | 36°02'11.79"N | 44°03'81.74"E | 8.23 | 150 | 2.486 | 4.276 |
|----|---------------|---------------|------|-----|-------|-------|

## 2.4 Plant Collection and Analysis

Near the agricultural site, two distinct types of plants were collected. One of these plants is an Upland cress species that is scientifically termed *Barbarea verna*, while the other is a Dill plant that is identified by its scientific name, *Anethum graveolens*. The fresh shoots and root systems of *Barbarea verna* and *Anethum graveolens* species were selected and subsequently oven-dried at 60 °C for 48 hrs. The desiccated samples were pulverised to pass through a 2 mm filter and subsequently processed for chemical analysis following wet digestion. The plant samples were examined for metals such as Ba, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn. The plant samples were digested in a mixture of HNO<sub>3</sub> and HClO<sub>4</sub> (9:1) as outlined by [21]. Subsequently, they were quantified using an ICP (Inductively Coupled Plasma).

## 2.5 Microplastic Identification

### 2.5.1 FT-IR analysis:

To conduct qualitative analysis, a tiny soil sample was collected from an agricultural area with a microplastic distribution exceeding 5000 particles per kilogram. The samples were dried and preserved in petri dishes after filtration using vacuum-filtered sheets (WHATMAN, Ø 25 mm, pore size 0.2 µm). Microplastics of 500 µm or less are examined utilising FT-IR (SHIMADZU Corporation, Kyoto, Japan). A multi-point ultrafast mapping detector was used to take readings with a precision of 16 cm<sup>-1</sup> per scan. This is a rapid mapping technique capable of simultaneously measuring 1024 spectra per scan by constructing a complete infrared spectrum for each pixel of an image. The findings of the experiment were obtained using the instrument's OPUS and MP finder (PIKE Technologies, Miracle ATR). The plant and soil samples were analysed quantitatively and qualitatively for PE, PP, PET, PA, and PS, respectively.

## 2.6 Risk Indices evaluation

The risk indices were calculated by using the equations as follows: -

### 2.6.1 MP Risk Indices

Equations defined by [22] were used to ascertain risk indices of microplastics (MPs) for the soil samples; hazard ratings depend on levels of toxicity as provided by [23]: PP = 1, PET = 4, PE = 3, PA = 50, and PS = 30. The formula shows:

$$\text{Polymer risk indices (pRi)} = \Sigma \left( \frac{\text{Number of individuals MPs (pmi)}}{\text{Total MPs (pT)}} \right) * \text{Hazard score (Si)} \quad (1)$$

$$\text{pRarea} = (\text{pR1} \times \text{pR2} \times \text{pR3} \times \dots \times \text{pRn})^{1/n} \quad (2)$$

### 2.6.2 Potential Ecological Risk Index (RI)

The potential ecological risk index was established by Swedish scientists [24]. It was utilised to evaluate the detrimental impacts of the pollutants on the environment and human health. The equation demonstrates:

$$C_f = \frac{CD}{CR} \quad (3)$$

$$E_R = C_f * TR \quad (4)$$

$$RI = \Sigma E_R \quad (5)$$

CD= represents the quantified amount of heavy metals at each sampling location,

CR= denotes the reference value, indicating the baseline content of each heavy metal in the soil

Cf= denotes the accumulation coefficient of element i,

Tf= represents the toxic response factor of element i, indicating its toxicity degrees and the susceptibility of the bioorganism to it. The hazardous responses of the major metals chromium, copper, lead, zinc, nickel, and cobalt were 10, 5, 5, 2, 5, and 5, respectively [24]. The criteria utilized to denote risk factors and RI are categorized into:

**Table 2.** E<sub>R</sub> and RI classification:

| E <sub>R</sub> Value       | Risk Level       | RI Value       | Risk Level  |
|----------------------------|------------------|----------------|-------------|
| E <sub>R</sub> < 30        | Slight           | RI < 40        | Slight      |
| 30 < E <sub>R</sub> < 60   | Medium           | 40 < RI < 80   | Medium      |
| 60 < E <sub>R</sub> < 120  | Strong           | 80 < RI < 160  | Strong      |
| 120 < E <sub>R</sub> < 240 | Very Strong      | 160 < RI < 320 | Very Strong |
| E <sub>R</sub> > 240       | Extremely Strong |                |             |

## 2.7 Statistical Analysis

Statistical analysis was conducted with IBM SPSS Statistics 19 and Microsoft Office Excel 2016, with Duncan's multiple range test (DMRT) applied to evaluate mean differences. Additionally, GraphPad Prism 10 is used for data curves.

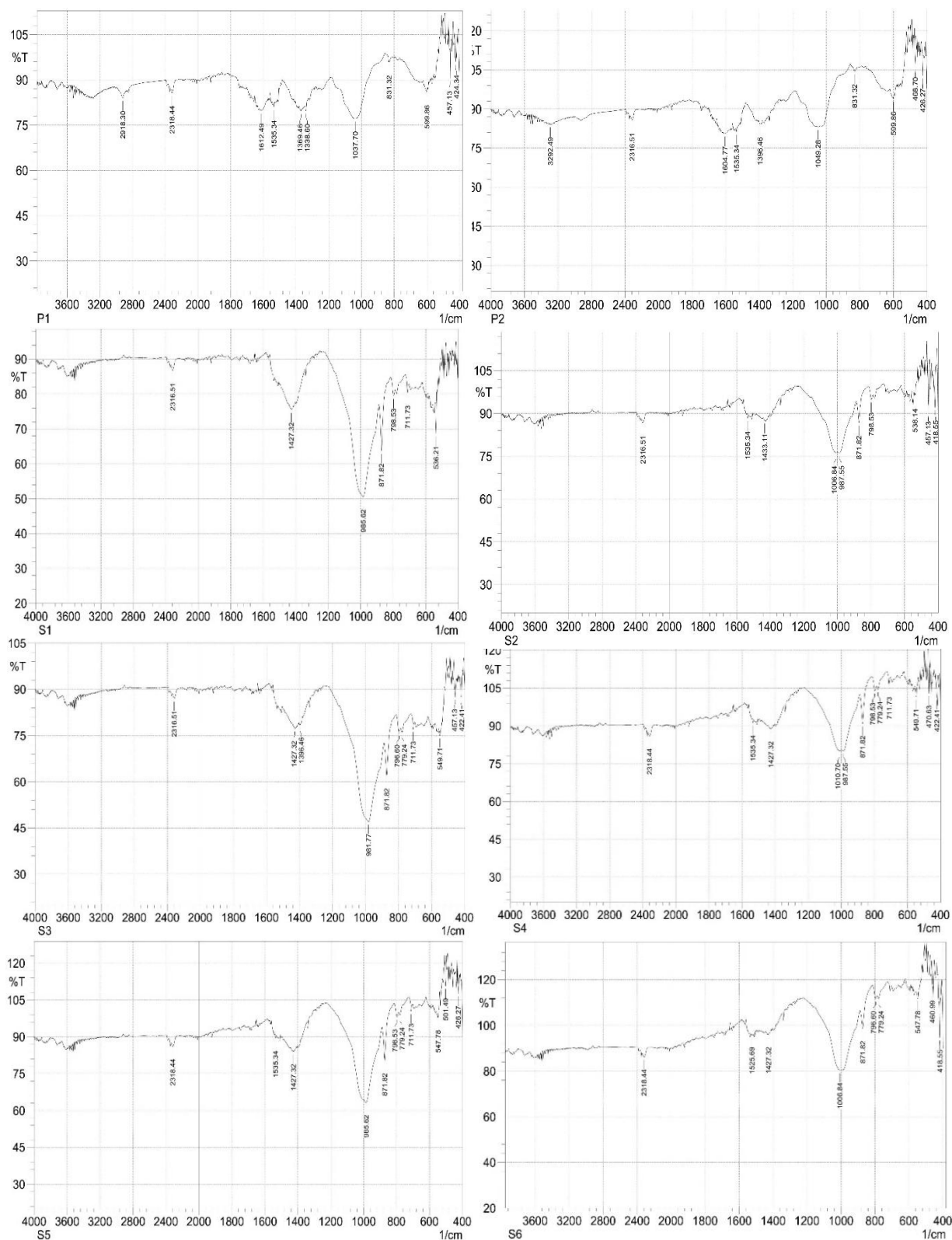


Figure 2: FTIR spectra of the detected particles.

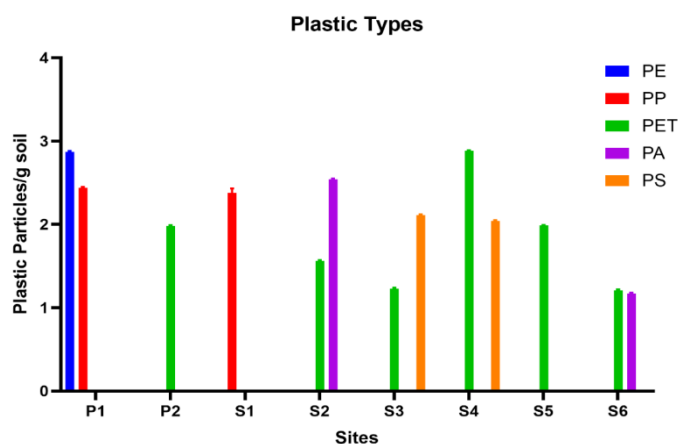
### 3. Results and Discussion

### 3.1 Detection of Types of MPs by FTIR

Figure 2 demonstrates that the infrared spectrum offers significant knowledge about the chemical structure of diverse polymers and their functional groups. PET often shows strong C=O ( $\sim 1710$ – $1740\text{ cm}^{-1}$ ) and C–O ( $1100$ – $1300\text{ cm}^{-1}$ ) stretches. PE/PP are mainly aliphatic, showing C–H stretch/bend and CH<sub>2</sub> rocking at  $720\text{ cm}^{-1}$ . On the other hand, peaks ranging from  $720$  to  $2918\text{ cm}^{-1}$  in P1 and P2 showed CH<sub>2</sub> rocking, CH<sub>3</sub> bending, and C–H stretching, suggesting the presence of PET, PE and PP MPs (Figure 2). S3–S5 samples may contain traces of aromatic structures, suggesting either PS contamination or degradation products of PET [25]. Therefore, in S2, S3, S4, S5, and S6, peaks ranged from  $720$  to  $1725\text{ cm}^{-1}$  with functional groups showing C=O stretches, Aromatic C–H or C=C, and C–O stretches and indicated the persistence of PET, PA, and PS microplastics in soil sites; only in S1 did peak values vary from  $720$  to  $2918\text{ cm}^{-1}$  with functional groups as aliphatic –CH<sub>2</sub>/–CH<sub>3</sub> groups, and the presence of polypropylene plastic (Figure 2). Various forms of microplastics are found in agricultural soil as a result of plastic mulching, irrigation with wastewater, the application of compost or sludge, atmospheric deposition, and the degradation of bigger plastic materials. These sources present many shapes and polymers, including films, fibres, and pieces derived from bags, containers, and synthetic textiles. In addition to mentioning the prevalence of PET microplastics, the researchers of [26] also observed C–H symmetrical stretching, C–O deformation, aromatic ring stretching at  $2908\text{ cm}^{-1}$ ,  $1342\text{ cm}^{-1}$ ,  $1410\text{ cm}^{-1}$ ,  $1453\text{ cm}^{-1}$ , and  $972\text{ cm}^{-1}$ , respectively. Additionally, the FTIR spectra of PP were shown by the authors of [27], with peaks at  $2923.27$ ,  $2838.67$ , and  $1631.29\text{ cm}^{-1}$ .

### 3.2 Microplastics Distribution in Plants and Agricultural Soil

Microplastics are among the most prevalent materials in the soil environment, and their quantity and prevalence are steadily increasing over time. The detrimental effects of microplastics on soil environments and ecosystems must not be disregarded. Due to their extended longevity, they are expected to persist in the soil for subsequent generations [28]. The results show the distribution of microplastics among several kinds of plastic polymers throughout several study sites and plant kinds. It sorts microplastics according to particle counts per gram of soil. The identification of Microplastics is crucial because crop roots are dispersed across various soil sites. The outcomes demonstrated the presence of microplastics at multiple soil locations and in plants, yielding a statistically significant difference ( $p < 0.05$ ). The microplastic concentrations ranged from  $0$  to  $2.88 \pm 0.55$  plastic particles/g soil (Figure 3). The concentration of PET (polyethylene terephthalate) is the highest at site 4, with a value of  $2.88$ , followed by PE (polyethylene) at P1 ( $2.87$ ), the accumulation of microplastics in plants primarily results from the application of contaminated compost and sludge, plastic mulching, wastewater irrigation, air deposition, and soil disturbance. Moreover, their diminutive dimensions and interaction with root systems enable certain microplastics to infiltrate the tissues of plants, presenting potential hazards to food safety and human health. Although PA's highest concentration was found at Site 2, it is also the basis material for nylon, which is extensively employed in many industrial uses, home goods, and clothes [29]. Polyethylene (PE) and polypropylene (PP) are favoured materials extensively utilised for mulching in agricultural fields [30]. Nevertheless, owing to their low density, they can be readily displaced by soil erosion. PS, PE, PP, HDPE (high-density polyethylene), PVC, and PET have been identified in the agricultural soils of Shanxi province [31]. The data indicate that the accumulation and breakdown of plastic polymers within soil sites may be influenced by potential factors, as evidenced by the variations in microplastic dispersion among distinct soils. PP, PA, and PS were identified in the agricultural soil by the authors of [32], whereas PP and PVC were recorded in the soil by [33].



**Figure 3:** Distribution of various microplastic particles in agricultural soils and vegetation. With Significant differences ( $p \leq 0.05$ ).

### 3.3 Heavy Metals Distribution in Plants and Agricultural Soil



Table 3 presents the concentrations of heavy metals in the soils under examination. Overall, the average concentrations of the metals in all the study regions were (31100, 26900, 3780, 661, 391, 119, 91.7, 29.7, and 0.398 mg/kg). The concentrations were arranged in the subsequent pattern: Al > Fe > Zn > Mn > Ba > Ni > Cr > Cu > Co > Pb. The maximum contents of chromium recorded in the S5 were 91.7 (mg/kg), and the high amount of zinc recorded in the S4 was 3780 (mg/kg), as per the results. The increased concentrations of chromium in certain regions may be attributed to trash, industrial pollution, and poor farming methods. The transport of chromium to the soil is also significantly influenced by irrigation water, which accumulates over time, increasing the soil's chromium content [34]. The amounts of Co, Cr, Cu, Mn, Ni, Pb, and Zn in the soil sites were all higher than the safe thresholds set by the FAO, which are 10 mg/kg, 59.9 mg/kg, 38.9 mg/kg, 488 mg/kg, 29 mg/kg, 27 mg/kg, and 70 mg/kg, respectively [35]. Given the growing of human activities that could elevate heavy metal contents in agricultural soil sites, we observe that the amounts of heavy metals in the present research are less than those recorded in earlier research conducted in Saudi Arabia and Basra [36, 37]. Furthermore, it exceeds the levels observed in the Babel region of Iraq [38]. In the study, the maximum concentration of heavy metals, specifically Zn, was found in both plants above allowed limits, while other metals were below detectable levels. Elevated levels of zinc (Zn) in plants cultivated in agricultural soils may arise from a confluence of anthropogenic and environmental influences. The overapplication of zinc-based fertilisers, such as zinc sulphate, is a prevalent issue, especially when utilised frequently or in substantial quantities. Furthermore, soil pH is crucial; in acidic soils, zinc exhibits enhanced solubility and bioavailability, hence elevating the likelihood of plant absorption even at lower soil concentrations.

**Table 3.** Heavy Metals concentration of the studied samples

| Heavy Metals | P1    | P2   | S1    | S2    | S3    | S4    | S5    | S6    | FAO   |
|--------------|-------|------|-------|-------|-------|-------|-------|-------|-------|
| Ba (mg/kg)   | 20.2  | 35   | 145   | 191   | 142   | 146   | 391   | 133   | 520   |
| Co (mg/kg)   | ND    | ND   | 19.4  | 14.1  | 16.1  | 21.8  | 14.2  | 17.1  | 10    |
| Cr (mg/kg)   | ND    | ND   | 83.7  | 75.8  | 83.9  | 82.9  | 91.7  | 90    | 59.5  |
| Cu (mg/kg)   | 29.5  | 17.3 | 28.4  | 29.7  | 23.6  | 27.5  | 17.6  | 22.6  | 38.9  |
| Fe (mg/kg)   | 256   | 170  | 21600 | 21000 | 22700 | 21700 | 26900 | 23100 | 20000 |
| Mn (mg/kg)   | 72.3  | 88.2 | 534   | 543   | 563   | 534   | 661   | 579   | 488   |
| Ni (mg/kg)   | ND    | ND   | 112   | 104   | 109   | 99.5  | 113   | 119   | 29    |
| Pb (mg/kg)   | 0.398 | ND   | 19.6  | 18.7  | 22.3  | 23.3  | 20.4  | 21.9  | 27    |
| Zn (mg/kg)   | 837   | 1240 | 2580  | 1160  | 1210  | 3780  | 408   | 1140  | 70    |

ND= Not Detectable.

### 3.4 Impact of Microplastics on Soil Metal Concentrations

MPs function as a vector that transports harmful substances (e.g., heavy metals) from the ambient environment. As a result, they degrade soil quality by activating the synergistic interaction of MPs-HMs [39]. MPs affect the displacement and modification of HMs through adhesion, rainfall, or the modification of soil physical and chemical characteristics [40]. According to the correlation matrix illustrated in Table 4, the highest positive correlations found between the aluminum and PET (Polyethylene terephthalate) MPs was 0.82, and the correlation of Pb and PS was 0.78; therefore, the moderate correlations were identified between the Cr and PA (0.55) and the PET and each of Ni and Pb (0.57 and 0.51, respectively). While MPs indirectly affect HMs' accessibility by changing the soil properties, including physical, chemical, and biological properties, their unique characteristics, such as small particle size, bulky surface area, lipophilic nature, and specific morphological traits, directly enhance the biological absorption of HMs [39]. The lowest correlation found between CO with PA was -0.48 in the study sites.

**Table 4.** Correlation between Heavy metals and Microplastics of the soil sites

| Heavy Metals | PP | PET | PA | PS |
|--------------|----|-----|----|----|
|--------------|----|-----|----|----|

|                   |       |       |       |       |
|-------------------|-------|-------|-------|-------|
| <i>Al (mg/kg)</i> | -0.26 | 0.82  | -0.22 | 0.44  |
| <i>Ba (mg/kg)</i> | -0.23 | 0.28  | -0.13 | -0.37 |
| <i>Co (mg/kg)</i> | 0.37  | 0.12  | -0.48 | 0.46  |
| <i>Cr (mg/kg)</i> | -0.08 | 0.02  | 0.55  | -0.17 |
| <i>Cu (mg/kg)</i> | 0.38  | -0.18 | 0.40  | 0.11  |
| <i>Fe (mg/kg)</i> | -0.28 | 0.21  | -0.39 | -0.23 |
| <i>Mn (mg/kg)</i> | -0.35 | 0.20  | -0.21 | -0.32 |
| <i>Ni (mg/kg)</i> | 0.18  | 0.57  | -0.07 | 0.57  |
| <i>Pb (mg/kg)</i> | -0.40 | 0.51  | 0.53  | 0.78  |
| <i>Zn (mg/kg)</i> | 0.34  | 0.20  | -0.32 | 0.48  |

### 3.5 Risk Indices Evaluation

#### 3.5.1. MP Polymer Risk Indices (pRi)

Research evaluated microplastic (MP) polymer risk indices (pRi) and comprehensive pollution risk indices, categorised by [28], spanning from low to very high according to pRi values. Hi values ranged from 0.45 to 30.97 throughout the soil sites, indicating minimal hazards for all forms of Microplastics, except for PA and PS MPs, which were classified in the medium-risk category (Figure 4a). Specifically, PS demonstrated a relatively elevated health risk within the medium-risk category (Figure 4b), as polystyrene is frequently regarded as hazardous due to its detrimental effects on the gastrointestinal tract, reproductive system, brain system, and immunological response, as noted in [41]. The existence of high-risk Microplastics in soil sites presents a possible health danger to the farming community. The results are in accordance with those of [42], who indicated low to medium health hazards from Microplastics in dust in Dhaka, Bangladesh.

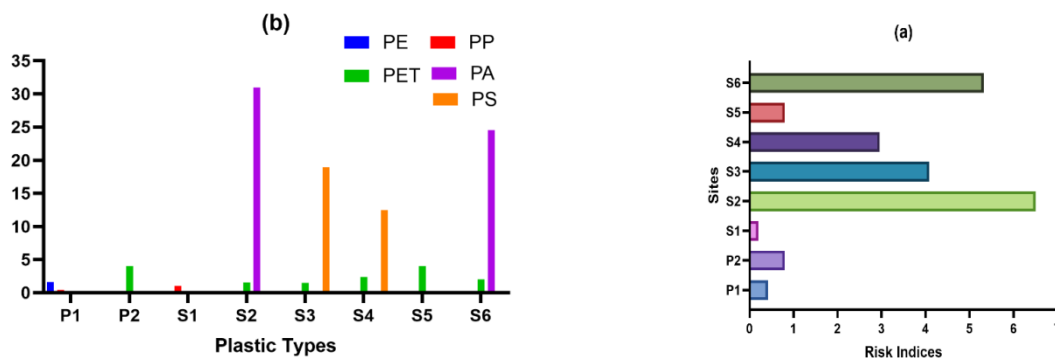


Figure 4: (a) Area-specific risk indices of MPs;  
(b) Individual risk indices of MPs in agricultural soils and vegetation of Erbil.

#### 3.5.2 Potential Ecological Risk Index

Table 5 displays the ecological risk values of a variety of heavy metals in the soil sites of the Erbil agricultural area. It is evident that site S4 had the highest Zn value, 43.20, indicating that the soil is substantially medium due to  $30 < E_r^i < 60$ . Conversely, site S2 had the lowest Pb Er, 1.34, indicating that the site is low contamination due to  $E_r^i < 30$ . In the present investigation, chromium, copper, lead, nickel, and cobalt pollution levels were minimal at all soil locations. All soil sites, except for site S4, which was moderately polluted with zinc, had low pollution levels. The extraordinarily high Zn contamination could be associated with the atmospheric deposition of combustion emissions and the application of pesticides and fertilisers [43]. Depend to Table 5, the soil at site S5 had the lowest RI value of 44.65, indicating that it is medium contaminated, as  $40 < RI < 80$ . Conversely, the soil at site S4 had the greatest RI value of 84.88, indicating that it is strongly contaminated. To limit and minimise the risk of heavy metals, utilise compost and biochar amendments to stabilise metals and enhance soil quality. Cultivate hyperaccumulator crops during non-growing seasons. Restrict vegetable cultivation in areas with high contamination levels.

**Table 5.** The ecological risk factor values and the potential ecological risk index of heavy metals in the surface soil of the research region



| Sites | Potential Ecological Risk Factor (Er) |      |      |       |       |       |       |
|-------|---------------------------------------|------|------|-------|-------|-------|-------|
|       | Cr                                    | Cu   | Pb   | Zn    | Ni    | Co    | RI    |
| S1    | 9.30                                  | 2.84 | 1.40 | 29.49 | 19.31 | 9.70  | 72.04 |
| S2    | 8.42                                  | 2.97 | 1.34 | 13.26 | 17.93 | 7.05  | 50.97 |
| S3    | 9.32                                  | 2.36 | 1.59 | 13.83 | 18.79 | 8.05  | 53.95 |
| S4    | 9.21                                  | 2.75 | 1.66 | 43.20 | 17.16 | 10.90 | 84.88 |
| S5    | 10.19                                 | 1.76 | 1.46 | 4.66  | 19.48 | 7.10  | 44.65 |
| S6    | 10.00                                 | 2.26 | 1.56 | 13.03 | 20.52 | 8.55  | 55.92 |
| mean  | 9.41                                  | 2.49 | 1.50 | 19.58 | 18.86 | 8.56  | 60.40 |

#### 4. Conclusion

Co-contamination of microplastics (MPs) and heavy metals (HMs) poses a significant threat to soil fertility, crop quality, and food safety by disrupting soil microbial communities, impairing nutrient cycling, and facilitating the uptake of toxic substances into edible plant parts. The examination of microplastic (MP) content in agricultural soil identified five forms of MPs: PE, PP, PET, PA, and PS. Organic fertilizer and irrigation practices were recognised as the main sources of PE and PP, while PET, PA, PS, and their additives were linked to irrigation systems. The health risk from MPs in various regions was assessed as medium to low; however, some MPs, particularly PS MPs, presented relatively elevated health hazards. At site 4, the soil's maximum potential ecological risk index (RI) was recorded at 84.88, indicating that the soil is exceedingly high in heavy metals. Conversely, the minimum RI was reported at site 5, with a value of 44.65, indicating moderate pollution at this site. Upon examining all the measurements taken during the research, it was found that the agricultural soils in Erbil City are not contaminated with the elements Ba, Co, Cr, Cu, Fe, Mn, Ni, and Pb. However, zinc was identified as a contaminant, with levels varying from low to significant pollution. Implementing preventative actions to reduce MP and HM contamination from various sources could greatly reduce the entry of MPs into soil ecosystems. Consequently, there is an imperative need to develop biodegradable and eco-friendly mulches to replace traditional plastic film mulches in agricultural soils, as well as to reduce human activity near agricultural areas.

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#### 6. Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication.

#### 7. Funding

The authors declare that they have no known competing financial interests in this paper

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## استكشاف توزيع المواد البلاستيكية الدقيقة والمعادن الثقيلة في التربة الزراعية وتقييم مؤشرات المخاطر في مدينة أربيل

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### المستخلص:

تُعد المواد البلاستيكية الدقيقة (MPs) والمعادن الثقيلة (HMs) ملوثات جديدة تشكل تهديدات محتملة على البيئة والصحة البشرية. يهدف هذا البحث إلى تقييم تركيز المواد البلاستيكية الدقيقة والمعادن الثقيلة وانتشارها والمخاطر الصحية المحتملة لها في التربة الزراعية بمدينة أربيل، العراق. سيتم تقييم جودة المواد البلاستيكية الدقيقة من خلال تحليل عينات التربة المأخوذة من ستة مواقع زراعية باستخدام مطيافية الأشعة تحت الحمراء بتقنية تحويل فورييه (FT-IR). احتوت مواقع الدراسة والنباتات على أشكال مختلفة من المواد البلاستيكية الدقيقة، بما في ذلك PET و PA و PE و PS و PP. قد تحتوي عينات S3-S5 على آثار من هياكل عطرية، مما يشير إلى تلوث بـ PS أو نواتج تحلل PET. لوحظت أعلى كمية من جزيئات البلاستيك لكل جرام من التربة في الموقع S4 من PET، مع نطاق يتراوح من 0 إلى  $0.55 \pm 2.88$ . تم تقييم المعادن الثقيلة مثل Ba و Co و Cr و Cu و Fe و Mn و Ni و Pb و Zn في مواقع التربة ونوعين نباتيين مختلفين باستخدام جهاز ICP. كانت مستويات الكروم والمنغنيز والنيكل والحديد والزنك في العينات المفحوصة أعلى من المستويات المسموح بها من قبل منظمة الأغذية والزراعة (FAO). بناءً على تلوث البلاستيك الدقيق والمعادن الثقيلة، تم تصنيف الموقعين S2 و S6 ضمن فئة الخطورة المتوسطة، بينما أظهر الموقع S4 مستوى خطر بيئي مرتفع. وفقًا للبيانات التي تم الحصول عليها من MPs و HMs، تم الإبلاغ عن أقوى الارتباطات الإيجابية بين الألومنيوم و PET (بولي إيثيلين تيريفثاليت) ( $r = 0.82$ )، بينما كان الارتباط بين الرصاص و PS ( $r = 0.78$ ). بالإضافة إلى ذلك، ستقوم الدراسة بتقييم ما إذا كان من الممكن أن تدخل المواد البلاستيكية الدقيقة والمعادن الثقيلة إلى سلسلة الغذاء وتشكل خطرًا على صحة الإنسان.