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Assessment of heavy metals pollution in roadside Soils Ajdabiya of City, Libya

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تقييم التلوث التربة جوانب الطرق بالمعادن الثقيلة بمدينة أجدابيا، ليبيا

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Abstract:
The assessment of some heavy metals contaminants in roadside soils is important part for controlling any excess in the environment especially if present in high concentration level, as it will affect human and animal health. This study was conducted at 15 different soil sample locations and divided into 4 zones in Ajdabiya city Libya. The study analyzed the eight heavy metals: Pb, Ni, Cu, Co, Cr, Mn, Cd, and Hg in soil samples. The EPA 3050 B (acid digested) method was used, and atomic absorption spectroscopy (AAS) was used to determine the metals. The pH of the soil samples was measured. The study evaluated the contamination factor (CF), the pollution load index (PLI), and the geo-accumulation index (I geo). The results show the mean metal concentration (µg/g) along roadside soils ranged from Pb: (0.0-607.65), Ni: (10.40-28.45), Cu: (208.30-3361), Co: (11.80-169.50), Cr: (215.50-345.35), Mn: (13.60-218.35), cadmium and mercury were not detectable. The result of the PLI in zone C is indicate strong sings of pollution (5.58), Zone B (2.29), Zone D (1.66) and Zone A (1.34) so, the pollution was due to anthropogenic impacted. The pH analysis shows most soil samples were alkaline ranging from (7.50 -9.6), because the pH of soils samples was alkaline that indicated the metals are strongly adsorbed (less soluble) and less mobile (immobilize metals) but can reduce availability of essential micronutrients such as, Cu and Mn.

Keywords: Heavy metals; Roadside soils; Contamination factor; Ajdabiya city.

الملخص :
يُعد تقييم بعض الملوثات بالمعادن الثقيلة في تربة جوانب الطرق جزءاً مهماً للسيطرة على أي زيادة في البيئة، لا سيما إذا كانت متواجدة بمستويات تركيز عالية، لما لها من تأثير على صحة الإنسان والحيوان .
أُجريت هذه الدراسة على 15 موقعاً مختلفاً لعينات التربة، مقسمة على 4 مناطق في مدينة أجدابيا، ليبيا. وحللت الدراسة ثمانية معادن ثقيلة هي: الرصاص(Pb) ، النيكل(Ni) ، النحاس(Cu) ، الكوبالت(Co) ، الكروم(Cr) ، المنجنيز(Mn) ، الكادميوم(Cd) ، والزئبق .(Hg)
استُخدمت طريقة EPA 3050 B (الهضم الحمضي)، واعتُمد على مطيافية الامتصاص الذري (AAS) لتحديد تراكز المعادن، كما قِيس الرقم الهيدروجيني (pH) لعينات التربة. وقومت الدراسة معامل التلوث(CF) ، ومؤشر حمولة التلوث (PLI)، ومؤشر التراكم الجغرافي.(I geo)
أظهرت النتائج أن متوسط تركيز المعادن (ميكروغرام/غرام) في التربة المتاخمة للطرق تراوح كالتالي:
-الرصاص :(Pb) من 0.0 إلى 607.65
-النيكل :(Ni) من 10.40 إلى 28.45
-النحاس :(Cu) من 208.30 إلى 3361
-الكوبالت :(Co) من 11.80 إلى 169.50
-الكروم :(Cr) من 215.50 إلى 345.35

-المنجنيز :(Mn) من 13.60 إلى 218.35
-الكادميوم والزئبق: لم يُكشف عنهما (دون حدود الكشف).
تشير نتائج مؤشر حمولة التلوث (PLI) في المنطقة C إلى مؤشرات تلوث قوية (5.58)، تليها المنطقة(2.29) B ، ثم المنطقة(1.66) D ، والمنطقة(1.34) A ؛ مما يدل على أن التلوث ناتج عن تأثيرات بشرية المنشأ .(Anthropogenic)
أظهر تحليل الرقم الهيدروجيني (pH) أن معظم عينات التربة كانت قلوية، وتراوحت بين (7.50 - 9.6). وكون التربة قلوية يشير إلى أن المعادن ممتزة بقوة (أقل ذوباناً) وأقل حركة (معادن غير متحركة)، ولكن ذلك قد يقلل من تيسّر المغذيات الزهيدة الأساسية مثل النحاس والمنجنيز.

الكلمات المفتاحية: المعادن الثقيلة؛ تربة جوانب الطرق؛ معامل التلوث؛ مدينة أجدابيا.

INTRODUCTION

Heavy metals occur naturally in soils at varying concentrations, originating primarily from the lithosphere through the weathering of parent rock materials during pedogenetic processes. In unpolluted soils, these elements are derived exclusively from the mineral fraction of the Earth's crust and are generally present as trace constituents that are rarely toxic [1,2,3].

However, natural background levels of heavy metals can be exceeded as a result of diverse anthropogenic activities. Soil contamination may arise from emissions associated with rapid industrial expansion, mine tailings, waste dumping, disposal of metal-rich wastes, leaded gasoline and paints, agricultural practices including the application of fertilizers and animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, runoff from terrestrial systems, industrial and domestic effluents, petrochemical spills, accidental leaks, and atmospheric deposition[4,5]. Heavy metals introduced from anthropogenic sources tend to be more mobile and therefore more bioavailable than those derived from pedogenic or lithogenic processes [6, 7].

Unlike organic pollutants, heavy metals do not degrade over time and thus represent a long-term environmental threat. Human activities have disturbed and accelerated the naturally slow geochemical cycling of metals, resulting in the accumulation of one or more heavy metals in both rural and urban soils above defined background levels, potentially posing risks to human health, plants, animals, and ecosystems [1, 4]. The accumulation of heavy metals frequently leads to soil and water degradation and ecosystem dysfunction. Furthermore, heavy metals can enter the food chain through contaminated soil, water, and air, leading to food contamination and associated health risks for humans and animals [8, 7].

In view of these environmental and public health concerns, this study assessed the levels of selected heavy metals in roadside soils of Ajdabiya City, Libya, to evaluate the extent of contamination and its potential ecological implications.

MATERIALS AND METHODS

All the chemical used were analytical grade chemistry.

Study Area: The study was conducted in Ajdabiya city, Libya, where the sample points are situated between30-43-0 N, 30- 48-0 N and 20-11-0 E, 20-17-0 E which has an elevation above the mean sea level of 3 meters.

The coordinate of the sampling points was done using Google Earth Maps and GPS (Global Positioning System) figure (1)

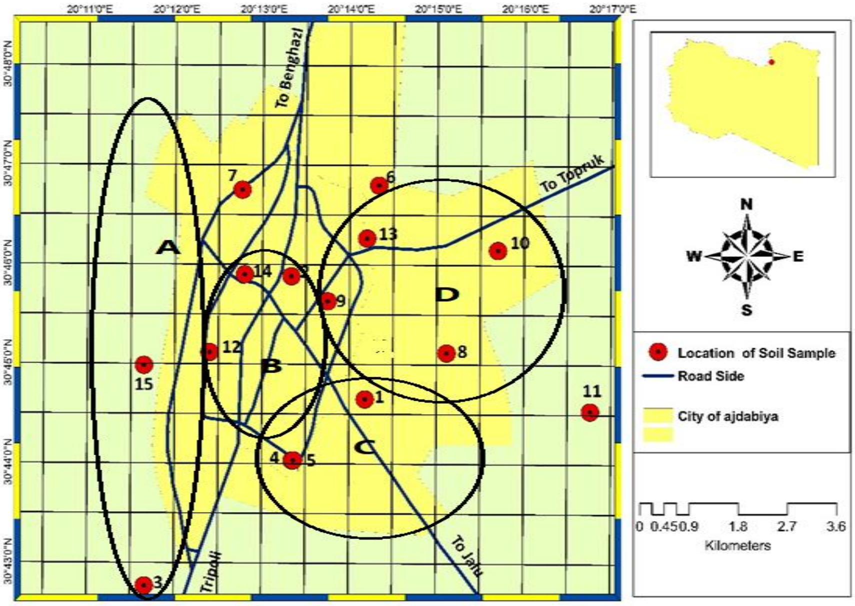

Figure 1: Area of study

Samples Collection and preparation: A total of fifteen (15) soil samples were randomly collected in accordance with commonly applied guidelines in environmental study designs. Sampling was conducted at a depth of 0–20 cm from roadside soils across different locations within the study area. To ensure adequate spatial representation, the area was divided into four zones (A, B, C, and D). Sampling was carried out in July 2022 under dry weather conditions to minimize the potential leaching or redistribution of heavy metals by rainfall.

Soil samples were collected using a plastic spade and hand trowel. The collected samples were subsequently passed through a 2 mm sieve to remove debris and extraneous materials such as stones, straw, and leaves. Each sample was properly labeled according to its designated zone, placed in clean, resealable plastic bags, and transported for laboratory analysis.

Sample Preparation and Analysis

The soil samples were oven-dried at 110°C for one hour and then allowed to cool in a desiccator. Thereafter, 2.0 g of each dried sample was accurately weighed and transferred into a reflux flask for acid digestion following the standard procedure recommended by the Environmental Protection Agency (EPA Method 3050B).

The concentrations of heavy metals in the digested solutions were determined using a Drawell Atomic Absorption Spectrophotometer (Model 320N). Prior to analysis, the instrument was calibrated using standard solutions of known concentrations to ensure accuracy and reliability of the measurements.

RESULTS AND DISCUSSION

Results of pH soil samples on the roadside in Ajdabiya city, Libya

The pH results of soil samples on roadside in Ajdabiya city, Libya are illustrated in figure 2. The values were from (7.50-9.60)

In this slightly basic soil, metals form **insoluble hydroxides, oxides, or carbonates**, and heavy metals become **less available** to plants (immobilized) and the toxicity will be reduced but also essential micronutrients may be locked.

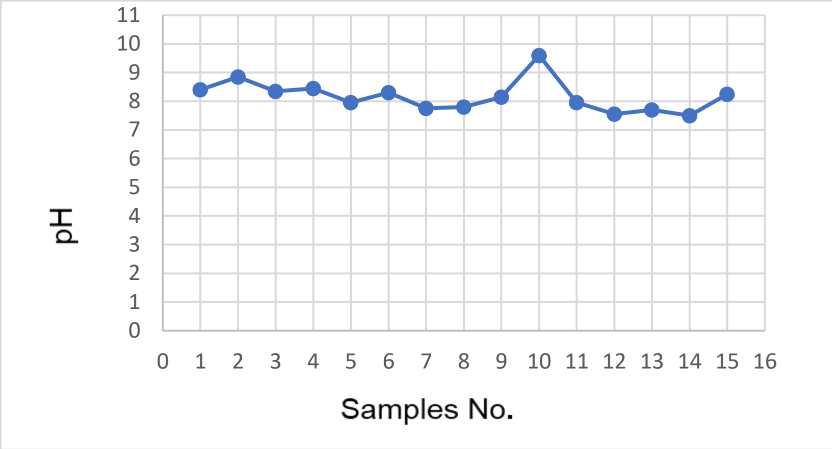

Figure 2: pH values of the samples

Heavy metal concentrations in soils

The mean heavy metal concentrations (in µg/g) along roadside soils ranged from (5.80-38.05) Ni; (169.25-5800) Cu; (10.20-20.95) Co; (186.50-383.00) Cr; (114.95-227.40) Mn; and (0.00-919.5) Pb. Cadmium and Mercury did not detect. Since this study is the first of its kind for Ajdabiya roadside soils, there is no local information in literature available for comparison. Table (1) gives the average concentration of metals in soil samples in the four zones

Table (1): The average concentration of metals in soil samples in the four zones.

Zone/Metal (µg/g)	Pb	Ni	Cu	Co	Cr	Mn	Cd	Hg
A	3.05	17.18	354.55	14.48	264.50	165.74	N.D.	N.D.
B	30.19	19.49	267.17	15.14	276.71	153.66	N.D.	N.D.
C	221.79	13.69	1445.96	15.27	279.11	190.58	N.D.	N.D.
D	7.18	23.09	337.09	13.84	252.89	143.87	N.D.	N.D.

N.D= not detected – Below the detection limit.

The concentrations of heavy metals varied across the four sampling zones (A–D), indicating spatial differences in contamination levels. Zone C consistently recorded the highest concentrations of several metals, suggesting localized anthropogenic influence.

Lead showed substantial variation among the zones, with a markedly elevated concentration in Zone C (221.79 µg/g) compared to Zones B, D, and A. This pronounced increase suggests significant contamination in Zone C, potentially linked to vehicular emissions, roadside activities, or other human-related sources. Given the persistence and toxicity of lead, such elevated levels may pose environmental and public health concerns.

Copper exhibited an exceptionally high concentration in Zone C (1445.96 µg/g), far exceeding the values observed in the other zones. This sharp increase strongly indicates localized contamination, possibly from traffic-related sources, mechanical wear, or industrial inputs. Manganese also showed higher levels in Zone C relative to the other zones, further supporting the influence of anthropogenic activities in this area.

Nickel concentrations were relatively moderate across all zones, with Zone D showing the highest value (23.09 µg/g). The limited variation suggests a combination of natural background contribution and minor localized inputs. Similarly, cobalt levels were fairly uniform across the study area, indicating minimal spatial variability and possibly stronger lithogenic control.

Chromium concentrations were consistently high in all zones, with only slight differences among them. This pattern suggests a more widespread source of contamination rather than a single-point input, potentially reflecting long-term accumulation from traffic emissions, industrial fallout, or other diffuse sources.

Cadmium and mercury were not detected in any of the sampled zones, which is a positive environmental indicator and suggests limited input from sources typically associated with these metals.

Overall, the findings identify Zone C as a contamination hotspot, particularly with respect to lead, copper, and manganese. The generally elevated chromium levels across all zones also indicate a broader environmental concern. Continuous monitoring and appropriate management strategies are therefore recommended to mitigate potential ecological and human health risks.

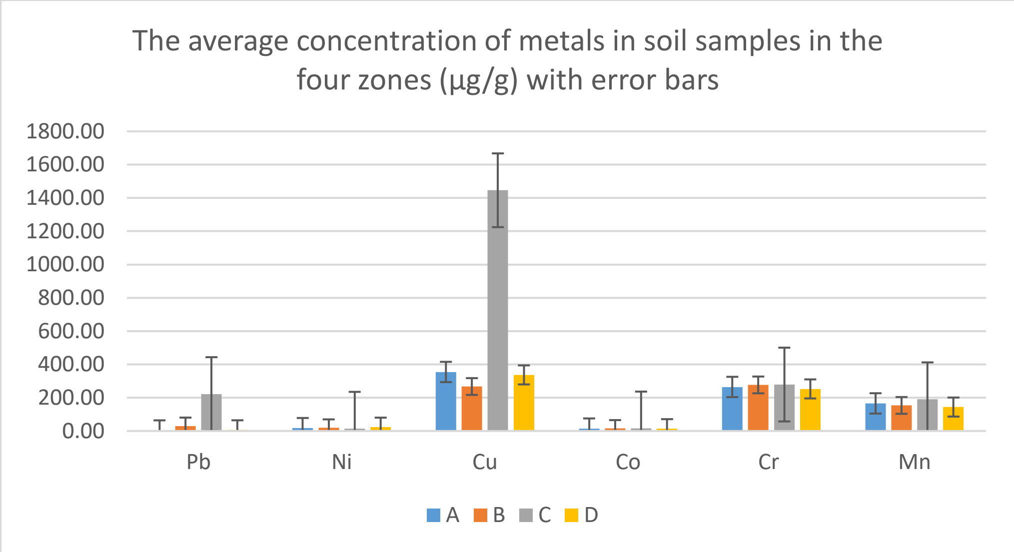

Figure 3: The average concentration of metals in soil samples of four zones (µg/g)

Contamination factor (CF)

The level of contamination of soil by metal is expressed in terms of a contamination factor (CF) calculated as:

$CF = C_m$ Sample $/C_m$ Background … (1)

C_m is the metal concentration.

Where the contamination factor $CF < 1$ refers to low contamination; $1 \leq CF < 3$ means moderate contamination; $3 \leq CF \leq 6$ indicates considerable contamination and $CF > 6$ indicates very high contamination.

Contamination factors of various metals in the roadside soils in sampled zones are presented in Table (2).

Using the contamination factor categories previously described, zone A suffered moderate contamination by all metals except Ni. Zone B show low contamination by Ni, moderate contamination by Co, Cu, Cr, and Mn, but very high contamination by Pb. On the other hand, zone C displayed low contamination by Ni and moderate by Co, Cr, and Mn, but very high contamination by Pb and Cu. Zone D displayed moderate contamination by all metals, and considerable contamination by Pb.

Table (2): Contamination factors for heavy metals along roadside soils for each sampled zone.

Zone/ Metal	Pb	Ni	Cu	Co	Cr	Mn
A	1.61	0.76	1.70	1.16	1.16	1.15
B	15.89	0.87	1.28	1.21	1.21	1.06
C	116.73	0.61	6.94	1.22	1.22	1.32
D	3.78	1.02	1.62	1.11	1.11	1.00

Pollution load index (PLI)

Each site was evaluated for the extent of metal pollution by employing the method based on the pollution load index (PLI) developed by Thomlison [9], as follows:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{1/n} \quad \ldots (2)$$

Where *n* is the number of metals studied and *CF* is the contamination factor calculated as described in Equation 1.

The **Pollution Load Index (PLI)** is a **composite index** used to assess the overall contamination level of the environment based on the contamination factors of multiple metals. The PLI is calculated by multiplying the CF values for each metal in the sample and then taking the nth root, where **n** is the number of metals.

The PLI provides simple but comparative means for assessing a site quality, where a value of PLI < 1 denote perfection; PLI = 1 present that only baseline levels of pollutants are present and PLI > 1 would indicate deterioration of site quality.

To effectively compare whether the four stations suffer contamination or not, the pollution load index, PLI, described in Equation 2, was used. The PLI is aimed at providing a measure of the degree of overall contamination at a sampling site. Figure (4) shows results of the PLI for the metals studied at these zones.

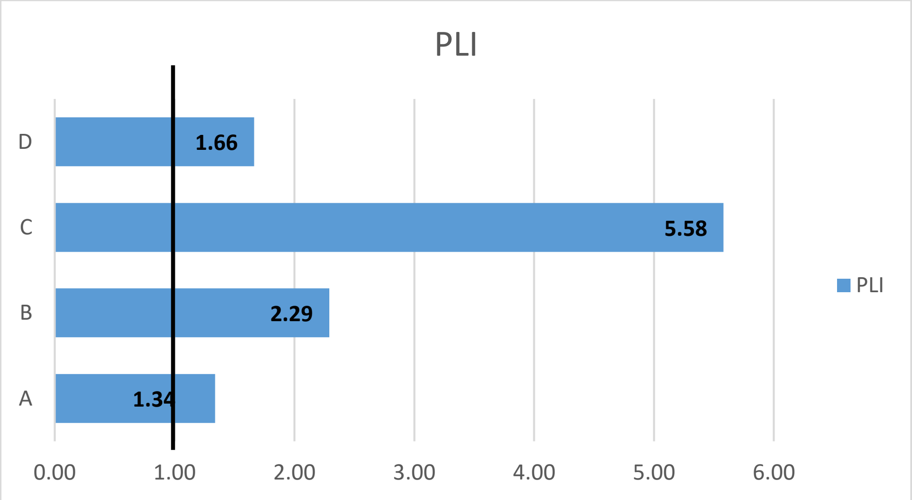

Figure 4: Pollution load index, PLI for all metals studied at all zones.

Based on results presented in Figure (4.4.1) the overall degree of contamination by the all metals is of the order C > B > D > A. Zone C shows strong signs of pollution or deterioration of site quality, whereas B is almost at baseline level. Site C suggests perfection (or no overall pollution). Relatively high PLI values at A, D and, to some degree, B suggest input from anthropogenic sources attributed to increased human activities and/or vehicular emissions. Zone A is the most crowded traffic area in Ajdabiya city including the main entrance of Ajdabiya where a lot of trucks are using this area. The high pollution index in Zone D is attributed to the high level of Cu in road side soil; in this zone there are many low standard oil change stations.

The ***Contamination Factor (CF)*** *and* ***Pollution Load Index (PLI)*** are important indicators used to assess the extent of pollution and contamination in soils. In the following a breakdown of the interpretation of these values will be discussed for each zone separately:

Zone C is the most polluted area, characterized by extremely high contamination of Lead (Pb) and Copper (Cu), as reflected in the very high Pollution Load Index (PLI = 5.58). This zone is severely polluted, likely due to industrial or anthropogenic activities releasing these metals into the environment.

Zone B shows significant contamination from Lead (Pb) (CF = 15.89) but is generally less polluted by other metals. The PLI of 2.29 indicates a moderate pollution level overall.

Zone A has relatively moderate contamination, particularly with Lead (Pb), but the overall pollution is still on the lower side, with a PLI of 1.34, indicating a slightly polluted zone.

Zone D shows moderate contamination with a PLI of 1.66, primarily from Lead (Pb) and Copper (Cu), but overall, it is less contaminated than Zones B and C.

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Geoaccumulation index (Igeo)

Enrichment of metal concentration above baseline concentrations was calculated using the method proposed by Muller [10] termed the geo-accumulation index *(Igeo)*. The values of Igeo were used for a better understanding of each element's spatial variation. The Igeo value not only reflects the spatial variation of the element's concentration but also standardizes the concentration of each element, which is more relevant for discovering the similarities and differences of the changes caused by human activities [11]. This method assesses the metal pollution in terms of seven (0 to 6) enrichment classes ranging from background concentration to very heavily polluted, as follows:

$$I_{geo} = \log_2[\, C_m \text{ Sample} / (1.5 \times C_m \text{ Background})] \qquad \ldots(3)$$

The factor 1.5 is introduced in this equation to minimize the effect of possible variations in the background values, *C*m Background, which may be attributed to lithogenic variations in soils. The seven proposed descriptive classes for *I*geo values are given in table (3).

Table (3): The Igeo classes with respect to soil quality.

Igeo value	*Igeo class*	*Designation of soil quality*
> 5	6	Extremely contaminated
4 - 5	5	Strongly to extremely contaminated
3 - 4	4	Strongly contaminated
2 - 3	3	Moderately to strongly contaminated
1 - 2	2	Moderately contaminated
0 - 1	1	Uncontaminated to moderately contaminated
0	0	Uncontaminated

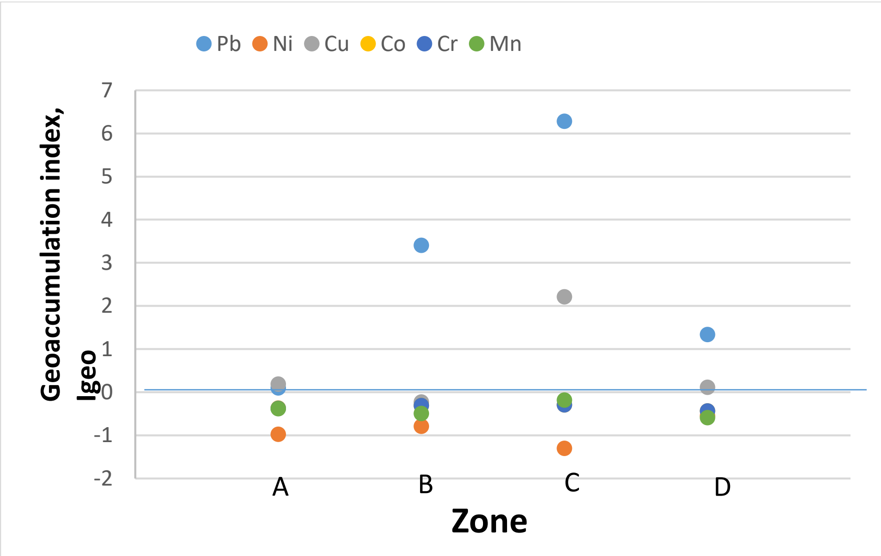

Figure 5: Geoaccumulation indexes of heavy metals along the roadside soils.

The ***Geoaccumulation Index (Igeo)*** is a widely used tool to assess the degree of contamination in the environment, particularly in soils. It compares current concentrations of elements to their natural background levels, and the values give insight into the extent of contamination. Igeo values are classified into categories that describe the level of contamination, ranging from "uncontaminated" to "extremely contaminated."

Zone C stands out as the most contaminated zone, primarily due to high levels of lead and copper. Zone B also exhibits significant contamination from lead, while the other zones show relatively low contamination across all metals. Further investigation in Zones B and C may be needed, especially regarding potential sources of heavy metal pollution.

The calculated geoaccumulation (*I*geo) values are presented in figure (5) It is evident from figure (6) that the uncontaminated to moderately contaminated *I*geo value of '0 to 1' is observed at zone A by Pb and Cu, and strongly contaminated at zone D by Pb. Zone C was extremely contaminated by Pb, while zone D was moderately contaminated by Pb.

As revealed from the three pollution assessment methods; CF, PLI, and *I*geo, roadside soils of all zones are pollution impacted, as compared.

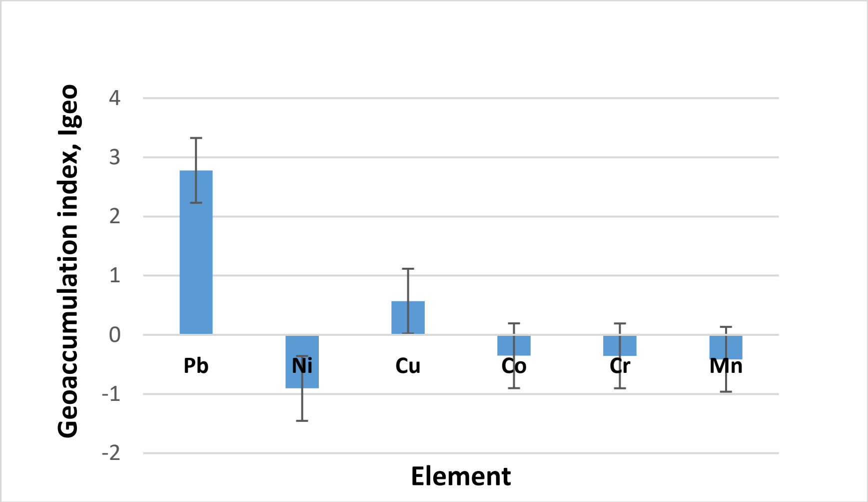

Figure 6: Box plot of the relationship between the geo-accumulation index and heavy metal elements.

The correlation constants, r, between concentrations of the heavy metal in roadside soil of the study area are listed in table (4)

Some of the pollutants have similar sources, but there is no doubt that the town is more affected by the surrounding heavy metal sources than internal sources. This phenomenon implies that in areas with complex geological environments such as the desert, the effect of soil parent material on heavy metals cannot be ignored [11].

Table (4): Correlation coefficient between concentrations of metals in the sampled zones.

	Pb	Ni	Cu	Co	Cr	Mn
Pb	1					
Ni	-0.0561	1				
Cu	0.1181	-0.1752	1			
Co	0.2391	-0.0930	-0.0406	1		
Cr	0.2377	-0.0933	-0.0404	0.9999	1	
Mn	0.2165	-0.2018	0.5307	0.02805	0.0282	1

*Correlation is significant at the 0.01 level (2- tailed)

Table (4) indicated that elemental pair of, Co/Cr (r=0.9999), have a high correlation with each other. Cu/Mn pair (r=0.5307) has moderate relationship, whereas the other elemental pairs show no significant correlation with each other. The results indicated that roadside soil contamination by the metals originated from a common anthropogenic source. It can be assumed that the heavy metals analyzed in the street dust was derived almost exclusively from automobiles and local industries.

CONCLUSION

This analysis suggests that some metals, particularly Lead (Pb) and Nickel (Ni), may originate from similar sources or industrial activities, while others, like Cobalt (Co) and Chromium (Cr), might be more linked due to specific geochemical factors. Further investigation into the environmental sources of these metals would be useful to understand the contamination patterns more clearly.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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