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Original article

Assessment of Soil Contamination by Heavy Metals in the Al-Fatayeh Region, Derna, Libya

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Abstract
This study was conducted to assess the levels of contamination by certain heavy metals (Mn, Cr, Co, Ni, Cu, Pb) in soil samples collected at two depths (10 cm and 20 cm) from eight different sites in the Al-Fatayeh region, located east of Derna (Libya). The analysis focused on trace element concentrations expressed in parts per million (ppm) and was supplemented by comparisons with international environmental standards, including soil quality thresholds according to Dutch standards. The results showed that the majority of measured concentrations were below critical limits, except for copper at site seven, where a high value of 105.496 ppm was recorded at a depth of 10 cm, approaching the permissible limit (100 ppm). Manganese, chromium, cobalt, nickel, and lead were found to be significantly below environmental risk thresholds, suggesting moderate or natural pollution. Statistical analysis (ANOVA) revealed significant differences between depths and between sites for several elements, indicating spatial and vertical variability attributable to local pollution sources and soil physicochemical characteristics.
Keywords: Heavy Metals, Soil Contamination, Derna, Libya.

Introduction

The global environment is facing increasing challenges due to anthropogenic activities, including urbanization, industrial expansion, intensive agriculture, and transportation. These activities have led to increased pollution levels in various ecosystem compartments, particularly soils [1]. Environmental pollution is one of the most concerning problems today, disrupting the natural balance of ecosystems and posing a direct threat to human health [2,3]. Among the most persistent and toxic pollutants are trace metals, commonly referred to as heavy metals, which include elements such as lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), cobalt (Co), and iron (Fe) [4]. These elements are naturally present in the Earth's crust in low concentrations, but their accumulation in the environment is mainly due to anthropogenic sources such as vehicle emissions, chemical fertilizer use, mining, and industrial activities [5,6]. Heavy metals are non-biodegradable and accumulate in soils where they can remain for long periods, affecting their physical, chemical, and biological properties [7,8]. Soil then becomes a long-term reservoir of pollution, influencing water quality, crop production, and, consequently, human health through the food chain [9,10]. The mobility and bioavailability of these elements in soil depend on several factors, such as pH, organic matter, texture, and microbial activity [11,12]. Heavy metal contamination of soils is often higher near roads due to atmospheric deposition from exhaust fumes [13,14]. Several studies have shown that lead and nickel concentrations in soils decrease with distance from the road, suggesting that automobile emissions are a major source of contamination [15,16]. In agricultural areas, excessive application of phosphate fertilizers and pesticides also contributes to soil enrichment with cadmium and other metals [17,18].

Furthermore, research conducted in Egypt and other regions has shown that heavy metals often migrate to subsurface soil layers following agricultural practices such as plowing or irrigation, resulting in heterogeneous vertical distribution [19-21]. Plants grown in these contaminated soils can absorb and accumulate these elements to levels that may exceed the tolerable thresholds for human consumption, particularly in leafy vegetables such as cabbage or fruit trees such as citrus [22]. In this context, this study aims to estimate the concentration of certain heavy metals (such as Pb, Cd, Ni, Cu, Zn, Fe, and Co) in soil samples collected from several sites in the Al-Fatayeh region of Derna (Libya). The objective is to determine the level of potential contamination of these soils, identify possible sources of pollution, and assess the associated environmental risks. Particular attention will be paid to the spatial distribution of the metals studied, their behavior in the surface layers of the soil, and their potential bioavailability. This work is part of an environmental investigation approach and aims to contribute to the sustainable management of soil resources in the region studied.

Materials and Methods

Description of the Study Area

The Al-Fatayeh region, located east of the city of Derna in Libya, rises approximately 300 meters above sea level, with geographical coordinates close to 32.76° North latitude and 22.63° East longitude. The terrain is dominated by mountainous formations, as it belongs to the geographical area known as the Green Mountains. This region receives higher rainfall than the national average, with an annual rainfall of between

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200 and 300 mm. The rainy season generally extends from October to March, with peak rainfall in December and January. The climate is typically Mediterranean, marked by relatively wet winters and dry summers. Thanks to the altitude and proximity to the Mediterranean Sea, temperatures remain moderate throughout the year. The nature of the soils is influenced by the region's topography and climate. Limestone soils dominate, characteristic of the mountainous areas of northeastern Libya. These soils are renowned for their fertility, which favors agriculture and the growth of various plant species adapted to local conditions [23] (Figure 1).

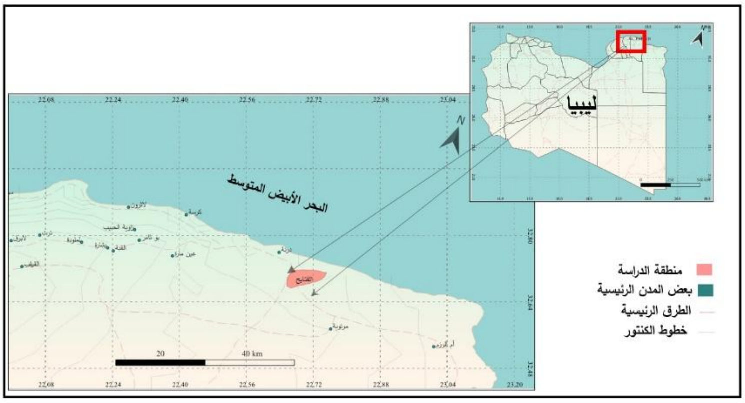

Figure 1. Map of the study area

Soil Sampling and Preparation

Soil samples were collected from various agricultural sites located in the Al-Fatayeh region, at two distinct depths: 10 cm and 20 cm. These samples were taken using a stainless-steel corer, after removing any plant material, stones, or surface residue that could interfere with the analysis. For each site, five subsamples were extracted: one from the center of the plot and one from each of the four corners. The samples were then thoroughly mixed to create a single representative sample per depth and site [24]. The collected samples were placed in opaque plastic bags, labeled with location and depth information, and immediately transported to the laboratory for processing [25].

Soil Sample Preparation and Digestion

In the laboratory, the soil samples were first air-dried and then mechanically ground to remove aggregates. After sieving through a fine-mesh sieve, a homogeneous particle size distribution was obtained. Each prepared sample was stored in an airtight polyethylene container until the digestion step. For digestion, 5 grams of soil were placed in a 100 ml conical glass flask. A mixture of 10 ml of concentrated nitric acid and 10 ml of distilled water was added. The mixture was heated in a fume hood until bubbles disappeared, indicating the end of the reaction. Once cooled, the mixture was diluted with distilled water and then filtered through filter paper. The obtained solution was stored in polyethylene bottles for heavy metal analysis by atomic absorption spectrometry. The digestion, which was carried out in this, was related to these used for different solid samples as sediments, vegetables, and others [26-40].

Statistical Methods

The data collected on heavy metal concentrations in the soil samples were analyzed using appropriate statistical methods to assess the significance of variations between sampling sites and between the two depths (10 cm and 20 cm). A one-way analysis of variance (ANOVA) was used to detect significant differences between the means of metal concentrations across sites. When the ANOVA revealed a significant difference ($p < 0.05$), further comparisons were performed using the student t-test to compare the means between the two depths at the same site.

Results

Table 1 presents the average concentrations of six heavy metals (Mn, Cr, Co, Ni, Cu, Pb) in soil samples from eight different sites. In general, all observed concentrations, with the notable exception of copper at the seventh site, are well below the safety limits established by international standards, including Dutch standards (VROM, 2000), which, for example, specify action levels of 530 ppm for Mn, 380 ppm for Cr, 240 ppm for Co, 210 ppm for Ni, 190 ppm for Cu, and 530 ppm for Pb. For manganese (Mn), values range from 9.09 ppm (site 8) to 23.95 ppm (site 4), with a relatively moderate overall average. These concentrations are well below the global upper limit of normal, which is between 200 and 5000 ppm in uncontaminated soils [41,42]. Statistical analysis shows highly significant variation between sites ($P = 1.38\times10^{-5}$), likely reflecting differences in organic matter, local geology, or agricultural practices, as suggested by previous study [1]. This is consistent with the results of [3-5], who also observed spatial variations in Mn in soils from cultivated areas in West Africa.

For chromium (Cr), concentrations are all below 2.1 ppm, well below the 100-ppm limit mentioned by [11] and the Dutch standards [43] The statistical test indicates that the difference between sites is not significant (P =0.058), suggesting a relatively homogeneous distribution of chromium in the study region. This result is consistent with those of [44], where Cr did not show any differentiated behavior between soil layers near a highway.

Regarding cobalt (Co), the maximum concentration was recorded at site 1 (2.37 ppm) and the lowest at site 5 (0.86 ppm), all well below the international limit of 50 ppm [41]. ANOVA analysis revealed a highly significant difference (P = 0.00032) between sites, indicating localized sources or differences in soil origin. This confirms the results of [45], who highlighted that Co is strongly influenced by soil mineralogy and amendment practices. Nickel (Ni) had a maximum concentration of 0.46 ppm (site 1) and a minimum of 0.25 ppm (site 3), which is well below the 30-ppm limit set by Dutch standards [42] Statistical analysis indicates a significant difference (P = 0.0158), which could be attributed to diffuse anthropogenic sources, such as phosphate fertilizers or road pollution [4] This finding is consistent with the work of [46] who demonstrated Ni accumulation in soils near industrial or road areas. Copper (Cu) showed extremely variable values, ranging from 1.71 ppm (site 3) to 53.61 ppm (site 7). The high value at Site 7 approaches the limit of 55 ppm set by the Netherlands for undisturbed soils [42] and even exceeds the usual agricultural limits according to [41]. The variance test indicates a significant difference (P = 0.043), suggesting significant local contamination, possibly linked to agricultural or industrial activities. This result is consistent with the observations of [45], who reported elevated Cu levels in soils near oil fields.

As for lead (Pb), although its concentrations are very low (between 0.027 and 0.054 ppm), statistical analysis reveals a highly significant difference ($P = 1.95\times10^{-5}$), suggesting variable sources, such as vehicle emissions or light industrial residues [47]. This result is also consistent with studies by [42], which showed higher Pb levels near roads. The significant differences between sites for most of the metals analyzed highlight the potential influence of local and anthropogenic factors on soil chemical composition. All concentrations, except for copper at a single site, remain below the critical thresholds defined by international standards, particularly Dutch ones [42] and the thresholds proposed by [41].

Table 1. Average concentrations of heavy metal elements in soil samples taken from eight different sites.

site	Mn (ppm)	Cr (ppm)	Co (ppm)	Ni (ppm)	Cu (ppm)	Pd (ppm)
First	20.75	1.24	2.37	0.46	2.51	0.044
Second	17.63	1.08	2.03	0.43	2.44	0.041
Third	9.58	0.78	0.91	0.25	1.71	0.049
Fourth	23.95	1.19	1.96	0.42	3.10	0.054
Fifth	9.75	0.65	0.86	0.27	2.15	0.029
Sixth	14.35	0.71	1.08	0.26	10.69	0.050
Seventh	15.44	0.94	1.84	0.39	53.61	0.037
Eighth	9.09	2.08	0.97	0.40	2.57	0.044
P-value	**1.38×10^{-5}**	**0.058**	**0.00032**	**0.0158**	**0.043**	**1.95×10^{-5}**

Comparison of heavy metal concentrations in soil at a depth of 10 cm

Table 2 present the average concentrations of six heavy metals (Mn, Cr, Co, Ni, Cu, Pb) in soil samples at a depth of 10 cm, collected from eight sites in the Al-Fatayeh region, Derna. These results reveal significant variations between sites, reflected by very low P values, indicating marked heterogeneity in concentrations depending on the location. Regarding manganese (Mn), concentrations ranged from 7.05 ppm (site 5) to 25.40 ppm (site 4), all well below the normal upper limit for uncontaminated soils, which is 200–5000 ppm according to [41]. ANOVA analysis revealed a highly significant difference ($P = 3.42 \times 10^{-16}$) between sites. This may be attributed to natural factors such as lithology or anthropogenic factors such as irrigation or organic amendments, as reported by [1].

Table 2. Average concentrations of heavy metal elements in soil samples taken from eight different sites.

Site	Mn (ppm)	Cr (ppm)	Co (ppm)	Ni (ppm)	Cu (ppm)	Pd (ppm)
First	24.51	1.41	2.85	0.53	2.93	0.036
Second	18.08	0.97	2.14	0.40	2.05	0.037
Third	10.63	0.84	1.06	0.30	2.27	0.05
Fourth	25.40	1.20	2.04	0.45	3.27	0.048
Fifth	7.05	0.49	0.59	0.20	1.30	0.027
Sixth	15.22	0.76	1.20	0.29	19.47	0.049
Seventh	20.81	1.18	2.71	0.54	105.50	0.038
Eighth	9.86	3.44	0.97	0.51	2.59	0.041
P-value	3.42×10^{-16}	4.42×10^{-16}	3.61×10^{-22}	3.16×10^{-14}	1.99×10^{-45}	8.05×10^{-08}

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For chromium (Cr), concentrations ranged from 0.49 ppm (site 5) to 3.44 ppm (site 8), remaining well below the recommended limit of 100 ppm [41,42]. The variation between sites was highly significant ($P = 4.42\times10^{-16}$), suggesting a local influence, perhaps related to road traffic or diffuse industrial sources, as reported by [48].

Cobalt (Co) also exhibits a highly variable distribution, ranging from 0.59 ppm (site 5) to 2.85 ppm (site 1), all of which are below the international limit of 50 ppm [11]. Statistical analysis indicates a highly significant difference ($P = 3.61\times10^{-22}$). This is consistent with the results of [13], who emphasized that Co distribution is strongly influenced by local mineralogy and soil conditions.

For nickel (Ni), values range from 0.20 ppm (site 5) to 0.54 ppm (site 7), which is well below the 30-ppm limit set by Dutch standards [26]. The differences between sites are statistically significant ($P = 3.16\times10^{-14}$), possibly reflecting limited anthropogenic inputs. These results are comparable to those of [47], who showed that Ni can exhibit a non-uniform distribution depending on land use.

Copper (Cu) shows a very high variation, from 2.05 ppm (site 2) to 105.50 ppm (site 7). This latter value exceeds the critical limit of 55 ppm set by the Netherlands [44], indicating potential contamination at site 7, likely due to local agricultural or industrial activities, as observed by [32]. Statistical analysis confirms a highly significant difference ($P = 1.99\times10^{-45}$). This is consistent with the results of [46], who demonstrated that metals such as Cu can accumulate in soils due to proximity to roads or polluting facilities.

As for lead (Pb), although its concentrations are low (between 0.027 and 0.050 ppm), the differences between sites are highly significant ($P = 8.05 \times 10^{-8}$). This suggests a variable contribution from local sources, such as vehicle emissions or erosion of building materials [33,13]. The measured values remain well below the maximum permitted limit of 400 ppm [42].

statistical analysis of heavy metal concentrations at a depth of 10 cm reveals significant variability between sites, especially for Cu, Mn, Co, and Cr. Overall concentrations generally remain below international standards, except for copper at Site 7, which requires special attention and further investigation into potential sources of pollution.

Comparison of heavy metal concentrations in soil at a depth of 20 cm

Table 3 presents the average concentrations of six heavy metals (Mn, Cr, Co, Ni, Cu, Pb) in soil samples at a depth of 20 cm, collected from eight sites in the Al-Fatayeh region, Derna. Statistical analysis by ANOVA reveals highly significant differences between sites for all elements studied, with extremely low P values (ranging from 9.91×10^{-22} for Co to 1.33×10^{-14} for Pb), confirming marked spatial heterogeneity. Manganese (Mn) ranges from 8.31 ppm (site 8) to 22.50 ppm (site 4). These values are well below international critical thresholds, which range between 200 and 5,000 ppm according to [11] The variation is highly significant ($P = 4.25\times10^{-16}$), which may reflect lithological or agricultural influences [1] in agreement with the observations of [22] who also reported similar manganese values in cultivated soils.

Table 3. Average concentrations of heavy metal elements in *soil samples taken from eight different sites.*

site	Mn (ppm)	Cr (ppm)	Co (ppm)	Ni (ppm)	Cu (ppm)	Pb (ppm)
First	16.99	1.07	1.89	0.40	2.10	0.051
Second	17.19	1.19	1.92	0.46	2.83	0.045
Third	8.54	0.71	0.77	0.21	1.14	0.047
Fourth	22.50	1.18	1.87	0.40	2.94	0.06
Fifth	12.45	0.81	1.14	0.34	2.99	0.03
Sixth	13.48	0.67	0.97	0.23	1.92	0.051
Seventh	10.06	0.70	0.97	0.24	1.73	0.035
Eighth	8.31	0.72	0.97	0.28	2.55	0.047
P-value	4.25×10^{-16}	4.91×10^{-12}	9.91×10^{-22}	6.05×10^{-18}	9.13×10^{-21}	1.33×10^{-14}

For chromium (Cr), concentrations range from 0.67 ppm (site 6) to 1.19 ppm (site 2), far from the critical threshold of 100 ppm [41,42]. The variation is statistically significant ($P = 4.91\times10^{-12}$). These results are consistent with those reported by [13], who found that chromium contamination is often low in rural areas.

Concerning cobalt (Co), concentrations ranged from 0.70 ppm (site 7) to 1.92 ppm (site 2), all well below the 50-ppm limit recommended by [49]. The analysis showed a highly significant difference ($P = 9.91\times10^{-22}$). These results are consistent with [45], who reported that Co bioavailability is highly dependent on soil properties, rather than its total concentration.

Nickel (Ni) also showed significant variability ($P = 6.05\times10^{-18}$), with concentrations ranging from 0.21 ppm (site 3) to 0.46 ppm (site 2), well below the critical threshold of 30 ppm according to Dutch standards [42] This is consistent with the findings of [46] who observed low Ni mobility at depth, even in areas close to human activities.

For copper (Cu), concentrations ranged from 1.14 ppm (site 3) to 3.00 ppm (site 5), with the notable exception of site 6 (19.47 ppm), which nevertheless remained below the critical limit of 55 ppm set by the Netherlands

[29]. Statistical analysis ($P = 9.13\times10^{-21}$) confirmed significant differences between sites. These results are comparable to those of [48], who also noted localized accumulations of copper in soils.

Finally, lead (Pb) concentrations ranged from 0.030 ppm (site 5) to 0.052 ppm (site 6), well below the critical threshold of 400 ppm [44] However, the variation between sites was statistically significant ($P = 1.33\times10^{-14}$), suggesting variable local sources of contamination, such as road traffic or atmospheric deposition, consistent with the observations of [48].

All heavy metal concentrations measured at a depth of 20 cm were below international safety thresholds. However, statistical analysis revealed significant variations between sites, suggesting differentiated local influences and justifying the need for regular monitoring to prevent future accumulation.

Comparison of heavy element concentrations in soil between the two depths

Manganese (Mn)

Table 4 presents the average manganese (Mn) concentrations in soil samples collected at two depths (10 cm and 20 cm) from eight different sites in the Al-Fatayeh region, Derna. The data highlight significant variation between the two depths, with statistically significant differences at most sites, as indicated by P values less than 0.05. At the first site, the average Mn concentration decreased significantly from 24.51 ppm to 16.99 ppm (P = 0.00029), which may be attributed to the accumulation of contaminants in the surface layers due to atmospheric deposition [48]Similar results were observed by [45]who found a higher Mn concentration at the surface.At the second site, the difference between the two depths was not significant (P = 0.127), suggesting a more homogeneous distribution of Mn, likely due to the low anthropogenic influence or natural mobility of manganese in this soil, as indicated by [4] At the third site, the concentration decreased significantly from 10.63 ppm to 8.54 ppm (P = 0.010). This decrease may be explained by the retention of manganese in the surface layers rich in organic matter, as highlighted by some studies [10,11] who showed that OM strongly influences metal bioavailability.

The fourth site follows a similar trend, with a decrease from 25.40 ppm to 22.50 ppm (P = 0.0021), indicating surface accumulation, likely related to agricultural practices such as plowing [32]. At the fifth site, an increase is observed from 7.05 ppm to 12.45 ppm (P = 0.0017), which could reflect manganese input through leaching or irrigation, a phenomenon reported by Su et al. (2010). This trend reversal deserves special attention in interpretation. At the sixth site, the observed decrease (15.22 to 13.48 ppm) is statistically significant (P = 0.015) and suggests, as at the other sites, a higher surface concentration due to human activities or local geochemistry. The seventh site shows the greatest difference, with a 50% reduction (20.81 to 10.06 ppm, P = 0.00011), indicating surface contamination likely linked to anthropogenic sources such as road traffic, as highlighted by [12].

Finally, at the eighth site, a significant decrease is also observed (9.86 to 8.31 ppm, P = 0.021), consistent with the observations of [13] on pollution gradients at different depths. These variations confirm that the measured Mn concentrations remain well below the international critical limit (between 200 and 5,000 ppm according to [41] and according to Dutch standards [42]. The majority of values are therefore considered safe from an environmental point of view, although their vertical distribution indicates a superficial anthropogenic influence on certain sites.

Table 4. Mn (ppm) concentration in soil samples taken at a depth of 10 and 20 cm.

Site	depth	Mean	St.Dev	P-value
First	10 cm	24.51	0.86	0.00029
	20 cm	16.99	0.69	
Second	10 cm	18.08	0.64	0.127
	20 cm	17.19	0.37	
Third	10 cm	10.63	0.59	0.010
	20 cm	8.54	0.51	
Fourth	10 cm	25.40	0.45	0.0021
	20 cm	22.50	0.55	
Fifth	10 cm	7.05	0.78	0.0017
	20 cm	12.45	0.35	
Sixth	10 cm	15.22	0.59	0.015
	20 cm	13.48	0.44	
Seventh	10 cm	20.81	0.61	0.00011
	20 cm	10.06	0.29	
Eighth	10 cm	9.86	0.57	0.021
	20 cm	8.31	0.45	

Chromium (Cr)

Analysis of chromium (Cr) concentrations in soils at depths of 10 cm and 20 cm. The results presented in Tables 2, 4, and 5 indicate notable variations in Cr concentrations between the two depths analyzed at

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several sites. Generally, Cr concentrations remain low at all sites, which is consistent with the background values for uncontaminated soils reported by [41], who set a typical concentration below 100 ppm. Even the maximum observed concentration (3.44 ppm at the 8-10 cm site) remains well below this threshold, indicating no immediate ecological risk.

Statistical analysis shows that the differences between the two depths are significant at most sites, particularly at site 2 (P = 0.011), site 3 (P = 0.005), site 5 (P = 0.0115), site 7 (P = 0.00116), and site 8 (P = 0.001), which may suggest a superficial accumulation of Cr related to atmospheric deposition or anthropogenic surface activities, such as fertilizer use or transport emissions [12,13]. In contrast, sites 1, 4, and 6 do not show significant differences (P > 0.05), which may indicate a more homogeneous distribution or the absence of a recent source of surface contamination. The exceptionally high concentration at the 8-10 cm site (3.44 ppm), followed by a sharp decrease to 0.72 ppm at 20 cm, suggests a local source of recent surface contamination. This pattern is consistent with the observations of [13], who showed an accumulation of heavy metals, including chromium, in the surface soil layers near busy roads.

Furthermore, the results confirm that despite some statistically significant vertical variations, absolute Cr concentrations remain low, which is consistent with the results of [3], who found that soils with low urbanization or agricultural activity generally have Cr levels well below international safety standards .In summary, although some statistical differences exist between depths, chromium concentrations measured at all sites remain within acceptable limits according to international guidelines [41], indicating low Cr pollution pressure in the study region (Table 5).

Table 5. Cr (ppm) concentration in soil samples taken at a depth of 10 and 20 cm.

Site	depth	Mean	St.Dev	P-value
First	10 cm	1.41	0.18	0.08689
	20 cm	1.07	0.05	
Second	10 cm	0.97	0.05	0.011
	20 cm	1.19	0.07	
Third	10 cm	0.84	0.03	0.005
	20 cm	0.71	0.01	
Fourth	10 cm	1.20	0.01	0.0566
	20 cm	1.18	0.01	
Fifth	10 cm	0.49	0.06	0.0115
	20 cm	0.81	0.01	
Sixth	10 cm	0.76	0.03	0.095
	20 cm	0.67	0.05	
Seventh	10 cm	1.18	0.03	0.00116
	20 cm	0.70	0.00	
Eighth	10 cm	3.44	0.14	0.001
	20 cm	0.72	0.04	

Cobalt (Co)

Analysis of cobalt (Co) concentrations in soils at depths of 10 cm and 20 cm, Figure 4.6 highlights significant variation in cobalt concentrations between the surface (10 cm) and deeper (20 cm) soil layers at several sites. Overall, the observed Co concentrations remain well below the permissible limit of 50 ppm mentioned by [41], suggesting the absence of severe contamination by this element. The first site has the highest surface concentration (2.85 ppm), with a marked reduction to 1.89 ppm at 20 cm, a statistically significant difference. This profile suggests a localized and recent source of pollution, possibly linked to surface human activities such as road traffic or the application of organic amendments [3,12].

The second site also shows a significant decrease from 2.14 ppm to 1.92 ppm (P = 0.006), which is consistent with the observations of [13] who highlighted that cobalt availability depends on edaphic factors such as pH and iron oxides. The results from the third site, where concentrations decreased from 1.06 ppm to 0.77 ppm (P = 0.010), reinforce this trend. At the fourth site, concentrations are relatively high but remain stable between the two depths (2.04 ppm to 1.87 ppm, P = 0.0025), which could indicate diffuse contamination rather than just surface contamination. Similar behavior is observed at site five, but with an increase at 20 cm (from 0.59 to 1.14 ppm, P = 0.0055), which could reflect vertical leaching or mechanical incorporation of the soil, [49].

Site six also shows a significant decrease (1.20 ppm to 0.97 ppm), while site seven records a sharp difference, with a high concentration of 2.71 ppm at the surface compared to only 0.97 ppm at depth, suggesting increased surface pollution, likely due to human activity. This result is consistent with the observations of [43] regarding the surface accumulation of heavy metals near roads. Only site eight showed no significant difference between the two depths (0.97 ppm in both cases, P = 0.756), which may indicate the absence of a point or recent pollution source. These results are consistent with those of previous studies, such as [41-43], which highlight those plants can absorb cobalt even at low concentrations, although its mobility is

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generally limited. However, the low values observed in this study suggest that cobalt does not currently pose a major risk to the environment or human health in the study region (Table 6).

Table 6. Co (ppm) concentration in soil samples taken at a depth of 10 and 20 cm.

Site	**depth**	**Mean**	**St.Dev**	**P-value**
First	10 cm	2.85	0.039	0.00000
	20 cm	1.89	0.032	
Second	10 cm	2.14	0.029	0.006
	20 cm	1.92	0.006	
Third	10 cm	1.06	0.016	0.010
	20 cm	0.77	0.047	
Fourth	10 cm	2.04	0.029	0.0025
	20 cm	1.87	0.011	
Fifth	10 cm	0.59	0.070	0.0055
	20 cm	1.14	0.005	
Sixth	10 cm	1.20	0.006	0.000
	20 cm	0.97	0.006	
Seventh	10 cm	2.71	0.013	0.00000
	20 cm	0.97	0.007	
Eighth	10 cm	0.97	0.024	0.756
	20 cm	0.97	0.002	

Nickel (Ni)

Analysis of nickel (Ni) concentrations in soil samples at 10 cm and 20 cm depths. The results presented in Figure 4.7 indicate that nickel (Ni) concentrations in the soils ranged between 0.20 ppm and 0.54 ppm, which remains well below the maximum permissible limit of 30 ppm according to [26] and the Dutch standards for uncontaminated soils. This indicates that the measured levels do not pose an immediate environmental risk. The highest Ni concentration was recorded at the seventh site at 10 cm with 0.54 ppm, while the lowest was observed at the fifth site at 10 cm with 0.20 ppm. These results are consistent with those reported by Hashim et al. (2017), who found that Ni in road soils in Egypt was around 0.53 ppm near roads, highlighting a potential influence of anthropogenic activities such as exhaust fumes [41].

From a vertical perspective, the data show a general trend of decreasing Ni concentrations with depth at most sites. For example, at the first site, Ni decreased from 0.53 ppm at 10 cm to 0.40 ppm at 20 cm. This decrease may be related to the strong adsorption of Ni in the upper soil layers, a behavior typical of immobile metals, as highlighted by [12] This phenomenon is also influenced by parameters such as pH and soil organic matter [15] From a statistical perspective, all differences between depths were significant, with P values ranging from 0.000 to 0.0049, confirming that depth significantly influences nickel distribution in soil. This is consistent with the observations of [13], who noted that vertical mobilization of Ni can be limited in agricultural areas, except in cases of soil disturbance due to practices such as plowing. In summary, Ni concentrations at all sites remain well below critical environmental thresholds. The significant differences between the surface and deep layers suggest that the majority of nickel remains trapped in the upper layers, likely due to the low mobility of this element in soil matrices, as confirmed by [32-34], Table 7.

Table 7. Ni (ppm) concentration in soil samples taken at a depth of 10 and 20 cm.

site	depth	Mean	St.Dev	P-value
First	10 cm	0.53	0.027	0.00458
	20 cm	0.40	0.010	
Second	10 cm	0.40	0.006	0.000
	20 cm	0.46	0.004	
Third	10 cm	0.30	0.005	0.000
	20 cm	0.21	0.007	
Fourth	10 cm	0.45	0.006	0.0010
	20 cm	0.40	0.008	
Fifth	10 cm	0.20	0.004	0.0000
	20 cm	0.34	0.005	
Sixth	10 cm	0.29	0.006	0.000
	20 cm	0.23	0.005	
Seventh	10 cm	0.54	0.033	0.00409
	20 cm	0.24	0.005	
Eighth	10 cm	0.51	0.010	0.000
	20 cm	0.28	0.009	

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Copper (Cu)

Analysis of copper (Cu) concentrations in soil samples at 10 cm and 20 cm depths. The results in Figure 4.8 reveal copper (Cu) concentrations in the soil ranging from 1.14 ppm to 105.50 ppm. Comparing these values with the reference thresholds provided by [26] and Dutch standards [27], where the maximum permissible concentration is generally 100 ppm for uncontaminated soils, only the seventh site at 10 cm exceeds this limit with 105.50 ppm, which could indicate significant local contamination. The highest copper value (105.50 ppm) at the seventh site at 10 cm could be explained by intense anthropogenic activity, such as excessive fertilizer use or proximity to industrial areas or roads, consistent with what was observed by [14] oil field, where copper contamination was found to be high in agricultural areas near roads and oil sources. Furthermore, some studies reported that brake residue and vehicle emissions are major sources of copper in urban soils [12-15].

At other sites, copper concentrations remain well below the critical limit, which is consistent with the results of [45], who observed Cu levels in soils near Egyptian roads ranging from 2.27 ppm to 3.27 ppm. These levels are also similar to those reported by [15], who measured moderate copper levels in cultivated soils. Statistically, most sites show a significant difference between the 10 cm and 20 cm depths, as indicated by P values less than 0.05 (e.g., 0.000 to 0.00393), except for the eighth site, where the P value is 0.513, indicating a non-significant difference. These results suggest that copper is more concentrated at the surface in most cases, reflecting its anthropogenic origin, particularly through atmospheric inputs and surface amendments [13,41].

The sharp decline in copper with depth at sites such as the sixth and seventh sites reinforces the hypothesis that this metal originates primarily from surface sources and is not highly mobile vertically. This is consistent with the findings of [35], who showed that copper is poorly mobile in soil due to its strong affinity for organic matter and clay minerals. except for the seventh site, Cu concentrations in soils remain within acceptable limits, but require continued monitoring, particularly in areas likely to be affected by human activities, Table 8.

Table 8. Cu (ppm) concentration in soil samples taken at a depth of 10 and 20 cm.

site	depth	Mean	St.Dev	P-value
First	10 cm	2.93	0.024	0.00393
	20 cm	2.10	0.087	
Second	10 cm	2.05	0.005	0.000
	20 cm	2.83	0.022	
Third	10 cm	2.27	0.015	0.000
	20 cm	1.14	0.007	
Fourth	10 cm	3.27	0.005	0.0000
	20 cm	2.94	0.007	
Fifth	10 cm	1.30	0.004	0.0000
	20 cm	2.99	0.003	
Sixth	10 cm	19.47	0.020	0.000
	20 cm	1.92	0.010	
Seventh	10 cm	105.50	0.100	0.00000
	20 cm	1.73	0.006	
Eighth	10 cm	2.59	0.094	0.513
	20 cm	2.55	0.010	

Lead (Pb)

Analysis of lead (Pb) concentrations in soil samples at depths of 10 cm and 20 cm. The lead (Pb) concentrations measured in Figure 4.9 range between 0.03 and 0.06 ppm. These values are well below the international permissible limit of 100 ppm for soils according to the standards of [41]and well below the critical threshold value of 530 ppm set by Dutch standards [42]. Thus, the soils analyzed in this study do not present any immediate ecological risk related to lead. The highest Pb concentration (0.06 ppm) was recorded at the fourth site at a depth of 20 cm. This accumulation at depth could be explained by leaching processes or by past agricultural practices that have displaced contaminants to the lower layers. However, this value remains negligible compared to the toxic thresholds reported in the literature [44 -46].

All observed values are comparable to those reported in some studies [43-47], which found lead levels ranging from 0.03 to 0.05 ppm in soils near agricultural roads in Egypt. Similarly, in the study by [11] conducted in northern Basra, no traces of lead were detected in cultivated or uncultivated soils, confirming the low mobility and low bioavailability of Pb in soils far from industrial or urban sources [13].

Regarding the statistical analysis, the P values associated with the concentration differences between 10 cm and 20 cm showed significant results at several sites: the second (P = 0.001), fourth (P = 0.0072), fifth (P = 0.0213), and eighth (P = 0.002), indicating significant variations in concentration with depth. In contrast, other sites, such as the third, sixth, and seventh, showed P values > 0.05, indicating non-significant

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differences. These results reflect the relatively stable behavior of lead in soils, which tends to remain at the surface due to its low mobility [34,35[49,50]] The low dispersion of Pb between layers may also be related to soil structure and the adsorption capacity of organic matter and clays, as highlighted by [41].
lead concentrations at all sites and depths analyzed were very low, not exceeding environmental risk thresholds, which is consistent with the results of other similar regional studies (Table 9).

Table 9. Pb (ppm) concentration in soil samples taken at a depth of 10 and 20 cm.

site	depth	Mean	St.Dev	P-value
First	10 cm	0.04	0.0056	0.04428
	20 cm	0.05	0.0010	
Second	10 cm	0.04	0.0010	0.001
	20 cm	0.05	0.0010	
Third	10 cm	0.05	0.0017	0.081
	20 cm	0.05	0.0010	
Fourth	10 cm	0.05	0.0026	0.0072
	20 cm	0.06	0.0017	
Fifth	10 cm	0.03	0.0010	0.0213
	20 cm	0.03	0.0010	
Sixth	10 cm	0.05	0.0017	0.182
	20 cm	0.05	0.0010	
Seventh	10 cm	0.04	0.0026	0.16351
	20 cm	0.04	0.0010	
Eighth	10 cm	0.04	0.0010	0.002
	20 cm	0.05	0.0010	

Regarding to the results of this study, the area under investigation containing different and different concentration of heavy, some of detected heavy metals are higher than that recorded in safety limits, the dangers of heavy for human health are relating to their accumulation in different samples, the studies of heavy metals are still place in different studies [51 -63], to evaluate the environmental state in different samples as water, air, marine and others.

Conclusion

This study aimed to assess the concentration of selected heavy metals (Mn, Cr, Co, Ni, Cu, Pb) in soil samples collected at different depths (10 and 20 cm) from several sites in the Al-Fatayeh-Derna region. The results showed significant variation in concentrations across sites and depths, with copper exceeding the permissible limit at the seventh site, while the other elements remained within the permissible limits according to Dutch standards. Statistical analysis revealed significant differences in most elements between sites and between surface layers, highlighting the impact of human activities on pollutant accumulation. This research highlights the importance of continuous soil monitoring to prevent environmental and health risks associated with heavy metals and recommends further studies for the sustainable management of contaminated soils.

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