Research Article

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A preliminary assessment of potential ecological risk and soil contamination by heavy metals around a cement factory, western Saudi Arabia

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Abstract: Twenty surface soil samples (0-10 cm) and shoots of a perennial shrub *Zygophyllum coccineum* L. were collected around a cement factory on the western coast of Saudi Arabia, in order to assess concentrations of some heavy metals (Cr, Cu, Ni, Pb and Zn). The most noticeable among all heavy metals was Pb that showed an average concentration of $460.15 \pm 86.60 \mu\text{g g}^{-1}$ followed by Cr ($138.67 \pm 30.89 \mu\text{g g}^{-1}$), Zn ($54.41 \pm 43.79 \mu\text{g g}^{-1}$), Ni ($41.22 \pm 12.60 \mu\text{g g}^{-1}$) and Cu ($33.48 \pm 12.52 \mu\text{g g}^{-1}$). Based on biological concentration factor analysis, *Z. coccineum* can be considered as an accumulator only for zinc ($\text{BCF} > 1$). Estimation of various ecological contamination factors revealed the significant impact of Pb in the environmental pollution in the region. It is also understood that the primary contribution to the ecological risk index (RI) mainly originated from various anthropogenic influences such as industrialization and urbanization. The different statistical analysis further revealed the potential effect of soil characteristics on the occurrence and dispersal of heavy metals in the study area.

Keywords: Cement factory; soil; heavy metals; ecological risk index; Saudi Arabia .

1 Introduction

The soil is considered an important natural resources because of its capability to act as a geochemical reservoir for various contaminants, including heavy metals resulting from aerosol deposition through urban and manufacturing activities [1,2]. Soil can also act as a natural buffer and therefore can control the dispersal of chemical contaminants in the air, water and biological components [3]. The soil ecosystems worldwide are significantly influenced by rapid industrialization and urbanization [4]. Anthropogenic activities such as construction, energy production, industrial mining, fossil fuel combustion and waste disposal resulted in the uncharacteristic deposition of heavy metals in urban soil resulting in severe environmental pollution [5,6,7]. Industries involved in cement production are the chief source of environmental pollution due to the emission of dust that contains toxic chemicals, which vary according to the raw materials used [8,9]. These toxic chemicals include heavy metals that accumulate in the surrounding environment including soil [10-13]. Many of the heavy metals produced as a byproduct of cement industrial activities are known to be toxic for living organisms even in minimal concentrations [14]. The level of impact is mainly determined by its potential harmfulness, high tenacity, level of non-degradation and biological accumulation [15]. The wind and rain have a major influence on the distribution of dusts that carry heavy metals [16,17]. Other factors that influence the dispersal of heavy metals are the soil-pH and availability of calcium ions, which eventually can determine the solubility, adsorption, retention and movement of heavy metals [18,19]. Many plant species are known to be sensitive to higher concentrations of heavy metals that adversely affect their growth and physiological activities [20,21]. Higher levels of heavy metals can increase the phytotoxicity that affects human beings by bioaccumulation through the food chains [14,22].

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Ecological risk assessment studies can reveal the possibility of contamination, as well as the potential impact of heavy metals on the ecology of soil [23]. Many geochemical approaches such as contamination factor (CF), ecological risk factor (E_r^i), potential toxicity response index (RI) and geochemical index method are now widely used for evaluating the anthropogenic influence on urban soil. These indices represent the pollution degree and provide detailed information about the soil quality [24].

Rabigh is an actively growing industrial town located on the western coast of Saudi Arabia. In the south of the city center, an active cement factory with capacity of 4000 tons/day is located. The current study is mainly focused on the assessment of various heavy metals concentrations (Cr, Cu, Ni, Pb and Zn) in the surface soil near the cement factory and their potential impact on the perennial shrub *Zygophyllum coccineum* population. It further focused on evaluating the contamination level of the measured heavy metals based on different pollution indices. These results in turn can be helpful to different stakeholders such as urban development planners and environmental risk managers.

2 Material and methods

2.1 Study Area

Rabigh region in Saudi Arabia is considered as one of the most active places in terms of development activities. By having various natural resources (soils with important minerals, natural vegetation of high economic value and tourism related activities), it plays an integral part in the Saudi Arabian economy. The area of Rabigh city is about 14,000 km² and the inhabiting population is almost 93 thousands [25]. It is located in Makkah quadrangles where the Precambrian basement rocks are covered by tertiary sedimentary rocks in the west and by Miocene to Pliocene lavas in the north. The climate is of hot and arid nature with high temperature and humidity during the summer season. The minimum temperature in the study area is normally observed during January (26°C) and the maximum during the period between July-September (45°C). The dominant wind direction is from west to southwestern (with a speed of about 10-30 km/h). The present study area is located around a cement factory and has a distance of 30 km south from Rabigh city center.

Figure 1: Map showing the study area and sampling sites around the cement factory.

2.2 Sampling and analytical procedures

Sampling was carried out during January 25-30, 2018. Twenty composite soil samples and 20 plant samples (*Zygophyllum coccineum*) were collected from the area around the Rabigh cement factory. The sampling sites were selected with a grid system having an equal distance from one another (Figure 1) and it covered an area of 2.0 km² from the active factory zone. From each site, about one kg of soil sample was collected from the surface 0-10 cm soil layer using an auger. In order to increase the accuracy, three subsamples were collected from each site and were mixed to obtain a bulk composite sample. Upon reaching the laboratory, all samples were air-dried and then sieved through <2 mm sieve. Large objects like pebbles, foreign particles, and debris were carefully removed during the sieving. The particle size distributions for soil samples were carried out through the pipette method [26]. The pH was measured in deionized water with 1:2.5 soil to solution ratio using Beckman glass electrode pH meter. Electrical conductivity (EC) was measured in soil paste 1:5 extract [27], while total carbonates were estimated gasometrically using Collins calcimeter and later calculated following the methods of Hesse [28]. In addition, the organic matter (OM) percentage in the soil samples were also determined by the titration method based on the oxidation of organic matter by K₂Cr₂O₇ [28].

In order to remove the heavy metals adhered to fine soil particles, the samples were oven dried at 105°C overnight, sieved mechanically using a 0.5 mm sieve, homogenized and then ground to 0.063 mm fine powder following the protocols mentioned by Madrid et al. [29]. Crushed soil samples were then weighed (1.00 gm±0.01) and digested using 4:1 nitric acid/perchloric acid (HNO₃

Table 1: Recovery analysis of heavy metal concentrations ($\mu\text{g g}^{-1}$) in soil and plant certified reference materials.

Metal	Soil sample (IAEA-433)			Plant sample (CRM-1570)		
	Certified	Measured	Recovery (%)	Certified	Measured	Recovery (%)
Cr	136	131 $\pm$ 3.1	96.3	-	-	-
Cu	30.8	28.5 $\pm$ 2.7	92.5	12.2	11.1 $\pm$ 1.1	91.0
Ni	39.4	37.7 $\pm$ 1.4	95.7	2.14	2 $\pm$ 1.0	93.5
Pb	26	29.7 $\pm$ 2.6	114.2	-	-	-
Zn	101	98.2 $\pm$ 7.6	97.2	82	78.4 $\pm$ 9.2	95.6

and HClO_4) mixture in a Teflon beaker. The samples were later heated initially at 40°C for 1h and the temperature was then subsequently increased to $140\text{--}170^\circ\text{C}$ up to a time of 4h until a clear solution was obtained [30]. The resultant solution after filtration is diluted with deionized water to a total volume of 50 ml. For the plant samples, shoots of *Z. coccineum* were collected and washed with distilled water in order to remove the attached fine sediment particles. The shoots were then homogenized after oven-drying at a temperature of 80°C . About one gram of the homogenized shoot was placed into 125 ml digestion tubes and 5 ml of concentrated perchloric acid was added to each tube. All the tubes were then heated at 120°C for 3h in a block digester and made to total volume of 50 ml [31]. The total heavy metal contents (Cr, Cu, Ni, Pb and Zn) in the soil and the plant samples were estimated with the help of an Inductively Coupled Plasma Optical Emission Spectrometer (Optima 5300 DV with an auto-sampler Model AS 93 Plus/S10, Perkin Elmer, USA). Standards were pre-prepared in order to measure the heavy metals concentration in the digested samples and the obtained values were expressed in $\mu\text{g g}^{-1}$. To ensure accuracy of the analysis, certified reference materials were used for soil and plant samples (IAEA-433, International Atomic Energy Agency and CRM-1570, National Institute of Standards and Technology Standard, respectively). The analysis was carried out in triplicates and the recoveries of the studied metals were 92.5–114.2% and 93.3–105.5% for the soil and plant reference materials, respectively (Table 1).

2.3 Biological concentration factor (BCF)

To find out the distribution and the level of heavy metals uptake, the bio-concentration factor is calculated by the following equation:

$$BCF = C_{shoot}/C_{soil} \quad (1)$$

where, C_{shoot} and C_{soil} are the heavy metal concentrations in the shoot and the soil sample respectively.

2.4 Risk assessment

Different pollution indices were used to assess the metal pollution in this particular study namely; geo-accumulation index (I_{geo}), contamination factor (CF), pollution load index (PLI) and potential toxicity response index (RI)

2.4.1 Geo-accumulation index (I_{geo})

For environmental pollution assessment studies, the geochemical and physico-chemical characteristics of sediments are very much crucial in order to identify the source as well as the intensity of the contamination. I_{geo} is therefore used to determine the progressive variation of heavy metals by comparing the present-day metal concentrations with the geochemical background (pre-civilized background values). Geo-accumulation index, introduced by Müller [32], has been applied in most of the recent pollution studies for assessing the soil contamination by heavy metals and is calculated by the following equation:

$$I_{geo} = \log_2 \left[\frac{C_n}{1.5 \cdot B_n} \right] \quad (2)$$

where, C_n is the concentration of metal n measured in soil and B_n is the geochemical background value in the upper continental earth's crust [33]. The constant 1.5 was used to account for potential variability in reference value due to the influence of lithogenic processes. In this regard, seven classes of I_{geo} were categorized by Müller [34] as shown in Table (S1).

2.4.2 Contamination factor (CF) and pollution index

The contamination factor is a major tool for identifying the pollution and the contamination level in the environmental matrix. CF is considered as the ratio obtained by dividing the concentration of each metal in the sediment by the background value and is obtained by the following formula:

$$CF = C_i / B_i \quad (3)$$

where C_i is metal concentration in soil and B_i is the background value, which refers to the concentration of metal in the soils when there is no anthropogenic input. According to Håkanson [35], the following criteria were applied: $CF < 1$ indicates low contamination; $1 < CF < 3$ is moderate contamination; $3 < CF < 6$ is considerable contamination; and $CF > 6$ is very high contamination. The pollution load index (PLI) is the estimated geometric mean of relative concentration factors of selected heavy metal of a seemingly polluted site. According to Daud et al. [36], PLI is considered as a combined tool used to assess the amount of pollution at a site for a particular set of heavy metals. The PLI value equal to 1 describes the potential absence of pollution, whereas $PLI > 1$ indicates the polluted nature of the site. The following equation is used for calculating the PLI:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n)^{1/n} \quad (4)$$

Where n = number of metals and CF = contamination factors.

The potential ecological risk coefficient (E_r^i) was estimated using the formula mentioned by Håkanson (1980) as follows:

$$E_r^i = T_r^i * C_r^i = T_r^i * C_s^i / C_n^i \quad (5)$$

where T_r^i is the metals toxic response factor ($Cr = 2$, $Cu = 5$, $Ni = 5$, $Pb = 5$ and $Cd = 30$) and C_r^i is the contamination factor, C_s^i is the concentration of heavy metals in the sediment, and C_n^i a background value for heavy metals. The degree of E_r^i can be categorized as shown in Table (S2). The potential toxicity response index (RI) is a method for calculating the sum of different risk factors and is commonly used to evaluate the toxicity of various heavy metals in soil. Håkanson [35] described RI as the index that

determines the heavy metal toxicity and the subsequent environmental response to all five risk factors (Pb, Cd, Cu, Zn and Cr) in soils. The potential ecological risk index (RI) was calculated as follows:

$$RI = \sum E_r^i \quad (5)$$

The classification criteria for RI classes are presented in Table (S2).

2.5 Statistical Analysis

Pearson's correlation coefficient was performed in order to determine the relationships among the physico-chemical properties of soils and the observed heavy metals concentration of each site. Descriptive statistical analysis of the studied parameters was conducted using SPSS software for Windows (version 23.0). Principal Component Analysis (PCA) was performed using factor extraction. The eigenvalue was kept being larger than 1 after Varimax rotation.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and discussion

The range of variations and the obtained descriptive statistical analysis of various physico-chemical properties of the collected soil samples are given in Table 2. The grain size analysis showed that the soil texture of the studied sites was predominantly sandy (81.0%) followed by silt and clay (14.5% and 4.5% respectively). The soil-pH fluctuated in a narrow range (7.7 to 8.5) with an average value of 8.15 that clearly indicated the neutral to sub-alkaline behavior of the examined soil samples. In case of electrical conductivity, it exhibited comparatively higher values at site 16 (20.1 dSm^{-1}), which is located adjacent to the cement factory and the lowest one obtained at site 20 (1.1 dSm^{-1}). The highest organic matter content has been observed from the sites with abundant wild plants. It ranged from a minimum of 0.5 to a maximum of 1.8% (at sites 17 and 16 respectively) with a mean value of 0.9%. The percentage of calcium carbonate in the soil samples varied between 21.4 and 67.9% at sites 11 and 1 respectively (average: 43.9%). The study area is characterized by different geological, morphological, climatological characteristics as well as rapid population growth and urbanization. The present results showed that in the downstream of Rabigh valley,

Table 2: Descriptive statistics of different physico-chemical characteristics of soil samples studied around the cement factory.

Sites	Particle size distribution (%)			pH	EC (dSm ⁻¹)	%OM	%CaCO ₃
	Sand	Silt	Clay				
1	78.6	16.8	4.7	7.7	2.6	0.9	67.9
2	89.3	9.3	1.5	7.9	12.6	1.0	58.9
3	96.7	3.0	0.3	7.8	9.0	1.3	29.5
4	79.0	12.0	9.0	8.2	1.9	0.5	61.6
5	76.4	19.7	3.9	8.0	4.7	0.8	38.4
6	65.4	27.2	7.4	8.4	1.8	0.5	49.1
7	66.4	24.6	9.0	8.0	8.6	1.6	33.9
8	63.3	28.4	8.3	8.1	3.5	0.5	30.4
9	91.6	8.2	0.2	7.9	14.1	1.5	33.9
10	94.8	4.7	0.5	8.4	1.8	0.7	48.2
11	75.0	20.9	4.1	8.4	1.3	0.8	21.4
12	73.4	21.5	5.1	8.4	1.5	0.7	65.2
13	85.4	12.2	2.4	8.1	17.2	0.8	64.7
14	72.2	18.8	9.0	8.2	2.0	0.9	48.2
15	90.5	8.2	1.3	8.5	1.1	0.5	22.3
16	70.8	21.3	7.9	8.0	20.1	1.8	28.6
17	66.1	23.9	10.1	8.3	1.6	0.5	58.5
18	94.9	1.8	3.3	8.3	1.6	0.9	30.4
19	97.7	2.2	0.1	8.1	2.1	0.6	56.7
20	92.5	6.1	1.4	8.3	1.1	0.6	29.9
Minimum	63.3	1.8	0.1	7.7	1.1	0.5	21.4
Maximum	97.7	28.4	10.1	8.5	20.1	1.8	67.9
Average	81.0	14.5	4.5	8.2	5.5	0.9	43.9
Standard error	2.6	2.0	1.8	0.1	1.3	0.1	3.5
Standard deviation	11.8	8.8	3.5	0.2	6.0	0.4	15.6

where significant urbanization is happening, the slope varies from slight to very slight flood risk.

The total concentrations and other descriptive statistics of the analyzed heavy metals from the soil samples around the cement factory are given in Table 3 and Figure 2. The range of each heavy metal in the surface layer of the soil was: 88.33-200.00, 12.30-64.00, 18.30-68.30, 280.40-586.40 and 15.20-89.90 $\mu\text{g g}^{-1}$ for Cr, Cu, Ni, Pb and Zn, respectively. It is worth mentioning that Pb displayed the highest mean concentration ($460.15 \pm 86.60 \mu\text{g g}^{-1}$) followed by Cr ($138.67 \pm 30.89 \mu\text{g g}^{-1}$), Zn ($54.41 \pm 43.79 \mu\text{g g}^{-1}$), Ni ($41.22 \pm 12.60 \mu\text{g g}^{-1}$), and Cu ($33.48 \pm 12.52 \mu\text{g g}^{-1}$) (Table 3). Chromium, copper and nickel are the most

influenced heavy metals by the proximity to the cement factory (Figure 2) and sites, such as 19 and 20 clearly exhibited higher concentrations for the above mentioned heavy metals (200.0, 64.0 and $86.3 \mu\text{g g}^{-1}$ respectively). Even though the maximum concentration of lead ($586.4 \mu\text{g g}^{-1}$) was observed at site 5, there are a few sites (20, 14 and 4), which also showed higher concentrations of this metal. This may be due to the effect of pollution from both the cement factory (sites 20, 14 and 4) and the motor vehicles (at site 5). The high occurrence of lead in such environmental conditions was previously observed by Carreras and Pignata [37], Banat et al. [38], Kakareka and Kukharchyk [39], and Ogunkunle and Fatoba [40]. In

Figure 2: Spatial distribution of heavy metals ($\mu\text{g g}^{-1}$) in the surface soil around the cement factory. The minimum and maximum values are written near to the corresponding bubble.

Figure 3: Biological concentration factor of heavy metals in *Z. coccineum* grown around the cement factory. The minimum and maximum values are written near to the corresponding bubble.

contrary to site 2, which was away from the direct effect of various environmental pollution, showed significant low values for most of the heavy metals (copper, nickel and zinc). Similarly, the minimum concentration of lead ($280.4 \mu\text{g g}^{-1}$) was obtained from site 13, whose location was far away from the factory. Occurrence of the higher concentrations of heavy metals, mainly in the soils north of the cement factory might be linked to different characteristics of the particular soil such as particle size, pH, electrical conductivity and organic matter content. It may also be affected by the direction of the prevailing wind in the region, which is normally north to northwest [41]. Regarding heavy metal concentrations in the shoots of *Z. coccineum*, results showed the following averages: $\text{Zn } (16.56 \mu\text{g g}^{-1} \pm 6.99) > \text{Cr } (7.43 \mu\text{g g}^{-1} \pm 3.22) > \text{Cu } (6.53 \mu\text{g g}^{-1} \pm 2.49) > \text{Ni } (5.47 \mu\text{g g}^{-1} \pm 2.14) > \text{Pb } (1.56 \mu\text{g g}^{-1} \pm 1.16)$.

From the current study, it is clear that, the average concentration of each heavy metal exceeded the background values suggested by Håkanson [35]. Also, the current concentration of lead is considerably higher than the values reported around cement factories as well as in many cities worldwide [13, 24, 38, 40, 57, 60-63, see Table 3] except from Nigeria by Ogunkunle and Fatoba [40]. This high Pb content of the soil might be the result of synergistic deposition from the adjacent cement factory. It is well documented that both Pb and Cu are the principal waste products of the cement production [38,39]. However, chances that the emission of such heavy metals is from the motor transport cannot be written off [42]. The cement factory in the current study is located near various major roads and motor transport activities, which can be significantly contributing to the reported high concentration. The obtaining of higher concentrations of Pb from the surface soil layer in the present study coincides with the findings of many studies [43-45]. It is highly recommended to provide proper attention in order to reduce the lead pollution owing to its negative influence on human health; such as its effect on the central nervous systems and many other disorders [46]. Proper monitoring of residents in Rabigh area can provide detailed information on the impact of such high concentrations of Pb on their health and can be useful in drawing future strategies to curb the pollution.

3.1 Biological concentration factor (BCF)

BCF values for heavy metals is ranked on the following sequence: $\text{Zn} > \text{Cu} > \text{Ni} > \text{Cr} > \text{Pb}$ (Table 4 and Figure 3). Relatively higher bioconcentration factors were observed for Cu (0.58), Ni (0.31) and Zn (1.19) from the plants

Table 3: Range of variation and descriptive statistics for the heavy metal concentrations in the soil comparing with the other countries.

Heavy metals	Concentration ($\mu\text{g g}^{-1}$ soil)					References
	Cr	Cu	Ni	Pb	Zn	
Minimum	88.33	12.30	18.30	280.40	15.20	Current study
Maximum	200.00	64.00	68.30	586.40	89.90	
Average	138.67	33.48	41.22	460.15	54.41	
Standard error	6.910	2.80	2.82	19.36	4.23	
Standard deviation	30.89	12.52	12.60	86.60	18.90	
Variance	953.89	156.86	158.72	7499.73	357.36	
London, UK	-	73.00	-	294.00	183.00	[60]
Bangkok, Thailand	26.00	42.00	25.00	48.00	118.00	[61]
Hong Kong	-	24.80	-	93.40	168.00	[62]
Palermo, Italy	-	63.00	-	202.0	138.0	[57]
Central Jordan	83.93	2.89	-	62.17	146.94	[38]
Canada	64.00	63.00	-	70.00	200.00	[63]
Argentina	41.10	3.84*	2.42*	9.42*	106.00	[10]
Changchun, China	66.00	29.40	-	35.40	90.00	[55]
China	-	68.00	-	55.00	209.00	[13]
Nigeria	186.20	404.40	-	469.20	168.10	[40]
Montenegro	28.59	96.59	-	35.35	92.84	[24]

* Sample was extracted with HCl.

Table 4: Biological concentration factor of heavy metals in *Z. coccinea* grown around the cement factory.

	BCF Cr	BCF Cu	BCF Ni	BCF Pb	BCF Zn
Minimum	0.06	0.21	0.15	0.00	0.36
Maximum	0.11	0.58	0.31	0.01	1.19
Average	0.02	0.08	0.05	0.00	0.14
Standard error	0.025	0.106	0.078	0.004	0.248
Standard deviation	0.005	0.023	0.018	0.000	0.056

collected at site 2, while Cr (0.11) and Pb (0.01) were on the higher side from the plants collected at sites 16 and 7 respectively. Enhanced bioconcentration factors for these heavy metals in the tissues of *Z. coccineum* revealed the weak nature of particular shrub as a bioindicator for heavy metal pollution monitoring programs. The studies of Semhi et al. [11] further corroborated the same finding, who found only minimal differences of heavy metals in *Rhazya stricta* in comparison to the surrounding soil adjacent to a cement factory in Oman. Still, there are many studies pointing out the negative effect of cement dust on the growth and productivity of some wild and

cultivated plants [47-49]. Even though the BCF values of Cu and Zn obtained for *Z. coccineum* in the present study is comparatively higher than those of Cr, Ni and Pb, which may only indicate the less absorption of those elements.

3.2 Geo-accumulation Index

The I_{geo} index for Pb varied from heavily contaminated (HC) to heavily extremely contaminated (HEC) at all the sites with values varying between 3.22 (site 13) and 4.29 (site 5) (Table 5). I_{geo} values of Cr and Cu in turn fluctuated

Table 5: Averages of geo-accumulation (I_{geo}) of the studied heavy metals in all sites.

Sites	Averages of I_{geo} of the studied heavy metals				
	Cr	Cu	Ni	Pb	Zn
1	1.58MC	-0.78UC	0.33UMC	3.71HC	-1.06UC
2	0.78UMC	-1.61UC	-0.71UC	3.84 HC	-2.81UC
3	1.51MC	-0.04UC	0.39UMC	4.04HEC	-0.24UC
4	1.16MC	-1.12UC	-0.35UC	4.22HEC	-1.74UC
5	1.20MC	-0.44UC	0.13UMC	4.29HEC	-0.68UC
6	1.72MC	-0.09UC	0.70UMC	3.69HC	-1.05UC
7	1.08MC	0.45UMC	0.34UMC	3.81HC	-2.18UC
8	1.52MC	0.06UMC	0.95UMC	4.02HEC	-1.10UC
9	0.75UMC	-0.21UC	-0.14UC	3.91HC	-0.71UC
10	1.46MC	0.23UMC	0.73UMC	4.01HEC	-0.78UC
11	1.58MC	0.06UMC	0.97UMC	3.46HC	-0.64UC
12	1.30MC	-0.78UC	0.21UMC	3.40HC	-1.54UC
13	0.93UMC	-0.48UC	0.35UMC	3.22HC	-1.00UC
14	1.79MC	-0.57UC	0.39UMC	4.22HEC	-1.52UC
15	1.66MC	0.36UMC	0.88UMC	4.12HEC	-0.77UC
16	1.20MC	-0.32UC	0.04UMC	3.96HC	-0.41UC
17	1.68MC	-0.59UC	0.25UMC	4.10HEC	-1.11UC
18	1.27MC	0.20UMC	0.70UMC	4.01HEC	-0.60UC
19	1.93MC	0.77UMC	0.48UMC	3.93HC	-1.04UC
20	1.23MC	-0.39UC	1.19UMC	4.28HEC	-0.56UC

within the status of uncontaminated to moderately contaminated level. More importantly, Zn displayed status was at an uncontaminated level (negative) at all sites (Table 5). It is understood that the proximity of an active cement factory together with the presence of an industrial city and petrochemical factory (located 15 Km north of the cement factory) are the main sources of pollution in the current study area. Also, both traffic emissions from local roads and highways, and the direction of the wind play a significant role in transferring pollutants.

3.3 Contamination factor and pollution load index

Results showed that the highest CF value obtained for Pb is a direct indication of the higher contamination of this metal ($CF > 6$), in all studied sites (Table 6). This might be due to the high synergistic deposition of heavy metals from the cement manufacturing [37-39]. Mean contamination

factor indicated moderate contamination ($1 < CF < 3$) for Cr and Cu and low metal contamination for Zn and Ni ($CF < 1$). The following sequence was visible in terms of the average CF values obtained in the present study: $Pb > Cr > Cu > Ni > Zn$. As represented in Table 6, the PLI values were found to be high ($PLI > 1$) in almost all the studied sites indicating the severe nature of pollution and subsequent deterioration of the sediment quality [50]. The PLI values in the present study ranged between 1.04 and 2.65 and the obtained higher PLI value might be directly associated with the higher concentrations of heavy metals in the sites, particularly at the site 15 ($PLI = 2.65$) and site 19 ($PLI = 2.58$). Since PLI obtained in the current observation is > 1 , all sites are considered to be polluted according to the studies of Cabrera et al. [51].

Table 6: Contamination factor, pollution index and degree of pollution of heavy metals in studied soils around cement factory.

Sites	Contamination factor					PL Index
	Cr	Cu	Ni	Pb	Zn	
1	1.89	0.87	0.85	23.08	0.72	1.88
2	1.08	0.49	0.42	25.19	0.21	1.04
3	1.80	1.46	0.90	29.09	1.27	2.44
4	1.41	0.69	0.54	32.99	0.45	1.51
5	1.45	1.10	0.75	34.49	0.94	2.08
6	2.09	1.41	1.10	22.83	0.72	2.22
7	1.34	2.05	0.86	24.76	0.33	1.81
8	1.81	1.57	1.32	28.58	0.70	2.37
9	1.06	1.30	0.62	26.48	0.92	1.83
10	1.74	1.76	1.13	28.49	0.88	2.44
11	1.89	1.57	1.33	19.46	0.96	2.37
12	1.56	0.88	0.79	18.65	0.51	1.59
13	1.20	1.07	0.87	16.49	0.75	1.69
14	2.18	1.01	0.89	32.82	0.52	2.02
15	2.00	1.92	1.26	30.61	0.88	2.65
16	1.45	1.20	0.70	27.42	1.13	2.07
17	2.02	1.00	0.81	30.24	0.69	2.03
18	1.52	1.72	1.11	28.46	0.99	2.41
19	2.41	2.56	0.95	26.86	0.73	2.58
20	1.49	1.15	1.55	34.35	1.02	2.48
Minimum	1.06	0.49	0.42	16.49	0.21	
Maximum	2.41	2.56	1.55	34.49	1.27	
Average	1.67	1.34	0.94	27.07	0.76	
Standard error	0.08	0.11	0.06	1.14	0.06	
Standard deviation	0.37	0.50	0.29	5.09	0.27	

3.4 Potential toxicity response index (RI)

The ecological risk factor (E_r^i) indices for Cr, Cu, Ni and Zn obtained in the study were lower than 40 (Table 7). Lead contributed significantly towards the ecological risk factor closely followed by Cd and Cu. The E_r^i value for Pb ranged from contaminated to moderately contaminated in terms of ecological risk factor. The high content of Pb in surface soil samples observed in this study can be a result of the combined effects of the pollutants from the cement manufacturing. The highest RI value of 176.89 was recorded at site 20, and the lowest value (91.46) from site 13 with an average of 140.73 (Table 7). According to the

standards, most of the sites in the current study placed in low ecological risk level ($RI \leq 150$) except for sites 4, 5, 8, 10, 14, 15 and 20 that showed moderate ecological risk (Table 7).

3.5 Relations between heavy metals and soil characteristics

Pearson's correlation showed negative correlation for soil-pH with both EC ($r = -0.559$, $P < 0.01$) and OM ($r = -0.579$, $P < 0.01$), while positive correlation with Ni ($r = 0.531$, $P < 0.01$) (Table 8). EC showed positive correlation with OM

Table 7: Potential ecological risk index (E_i^p) and potential toxicity response Indices (RI) of heavy metals.

Sampling Sites	Potential ecological risk indices for individual metal (E_i^p)					Potential toxicity response indices (RI)
	Cr	Cu	Ni	Pb	Zn	
1	8.97/L	4.36/L	9.40/L	98.10/C	0.72/L	121.55/LR
2	5.14/L	2.46/L	4.58/L	107.08/C	0.21/L	119.46/LR
3	8.55/L	7.30/L	9.85/L	123.63/C	1.27/L	150.60/M
4	6.70/L	3.44/L	5.90/L	140.23/C	0.45 /L	156.71/M
5	6.90/L	5.52/L	8.23/L	146.60/C	0.94 /L	168.18/M
6	9.89/L	7.06/L	12.15/L	97.03/C	0.72 /L	126.85/LR
7	6.34/L	10.24/L	9.48/L	105.25/C	0.33 /L	131.64 /LR
8	8.60/L	7.84/L	14.48/L	121.48/C	0.70 /L	153.09/M
9	5.05/L	6.48/L	6.83/L	112.55/C	0.92 /L	131.82/LR
10	8.23/L	8.80/L	12.40/L	121.10/C	0.88 /L	151.41/M
11	8.97/L	7.84/L	14.65/L	82.70/C	0.96 /L	115.12/LR
12	7.38/L	4.38/L	8.65/L	79.25/M	0.51 /L	100.17 /LR
13	5.70/L	5.36/L	9.55/L	70.10/M	0.75 /L	91.46 /LR
14	10.36/L	5.06/L	9.80/L	139.48/C	0.52 /L	165.22/M
15	9.50/L	9.62/L	13.83/L	130.08/C	0.88 /L	163.90/M
16	6.90/L	6.00 /L	7.73/L	116.53/C	1.13 /L	138.28/LR
17	9.60/L	4.98 /L	8.90/L	128.50/C	0.69 /L	152.67/LR
18	7.22/L	8.62 /L	12.20/L	120.95/C	0.99 /L	149.98/LR
19	11.43/L	12.80/ L	10.45/L	114.18/C	0.73 /L	149.58/LR
20	7.06/L	5.74/L	17.08/L	146.00/C	1.02 /L	176.89/M
Average	7.92	6.70	10.31	115.04	0.77	140.73
Maximum	11.43	12.80	17.08	146.60	1.27	176.89
Minimum	5.05	2.46	4.58	70.10	0.21	91.46

($r = 0.731$, $P < 0.01$), indicating the influence of high salinity on the organic particles due to the disruption of soil micro-aggregates thereby increasing the solute concentration of organic compounds as mentioned by Morrissey et al. [52]. On the other hand, there were negative correlation for EC with Cr ($r = -0.626$, $P < 0.01$), and Ni ($r = -0.510$, $P < 0.01$). It is known that increasing soil pH can limit the binding capacity of clay compounds, leading to the reduced sorption of metals [53]. A negative correlation was also observed for CaCO_3 percentage with Cu ($R = -0.456$, $P < 0.01$), Ni ($R = 0.522$, $P < 0.01$), and Zn ($R = 0.589$, $P < 0.01$). Also, Pb did not show any correlation with other studied metals, which indicates the different origin or controlling factors of Pb in soil. Changes in the physico-chemical properties, biological activities and distribution of contaminants might have

been attributed to such kind of relations [54]. The statistical results also showed significant positive correlation with the elemental pairs Cr-Cu ($r = 0.439$), Cr-Ni ($r = 0.433$) and Ni-Zn ($r = 0.430$) at a significance level of 0.05. A positive correlation, which was significant at the level of 0.01 was also obtained between Cu and Ni ($r = 0.492$). Generally, a higher elemental pair correlation represents the influence of primary anthropogenic source such as industrialization [55].

3.6 Principal component analysis (PCA)

Principal component analysis provided the information about the possible interactions among the different

Table 8: Correlation coefficients obtained between the soil properties and heavy metals concentration.

	pH	EC	%OM	%CaCO ₃	%Sand	%Silt	%Clay	Cr	Cu	Ni	Pb
EC	-0.559*										
%OM	-0.579*	0.731*									
%CaCO ₃	-0.145	-0.042	-0.327								
%Sand	-0.086	0.048	0.012	-0.083							
%Silt	0.074	-0.019	-0.015	0.055	-0.984**						
%Clay	0.103	-0.113	-0.005	0.140	-0.895**	0.802**					
Cr	0.329	-0.626*	-0.464*	0.013	-0.123	0.106	0.147				
Cu	0.223	-0.199	0.030	-0.456*	0.248	-0.227	-0.264	0.439*			
Ni	0.536*	-0.510*	-0.388	-0.522*	0.061	-0.023	-0.146	0.433*	0.492*		
Pb	0.011	-0.283	-0.121	-0.303	0.141	-0.224	0.085	0.132	0.001	0.073	
Zn	0.012	0.095	0.170	-0.589*	0.356	-0.318	-0.400	0.127	0.280	0.430*	0.179

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

*Correlation is significant at the 0.05 level (2-tailed)

Table 9: Rotated principal component analysis (PCA) with varimax for various parameters in soil samples.

Parameter	PC1	PC2	PC3	PC4
EC dSm ⁻¹	-0.895			
%OM	-0.864		0.310	
pH	0.741			
Cr (μg g ⁻¹)	0.721			
%Sand		-0.986		
%Silt		0.957		
%Clay		0.918		
%CaCO ₃			-0.905	
Zn (μg g ⁻¹)		-0.301	0.733	
Cu (μg g ⁻¹)	0.302		0.657	
Ni (μg g ⁻¹)	0.619		0.644	
Pb (μg g ⁻¹)				0.959
Eigenvalue	3.43	3.20	1.85	1.14
Variance %	28.61	26.66	15.42	9.54
Cumulative %	28.61	55.27	70.69	80.23

The loadings having a greater than 0.60 are marked bold in the table

environmental parameters and the observed heavy metals (Table 9). The PCA ordination of the soil properties and heavy metal concentrations revealed that the first two components accounted for 55.27 % of the total

variance (PC1: 28.61% and PC2: 26.66%). PC1 was mainly characterized by the high loading of Soil-pH, sand along with Cr and Ni (Table 9). This can be mainly due to the impact of natural and anthropogenic sources as proposed by Möller et al. [56]. On the other hand, PC2 was dominated by soil characteristics like silt and clay. This factor implies the physical nature of the soil samples and its impact on the heavy metals. Moreover, PC3 was represented by Zn, Cu and Ni metals with total variance of 15.42%, which are commonly due to anthropogenic sources enriched in the top soils of urban soils [57]. While PC4 accounted for 9.54% of the total variance loaded with Pb. This is a clear indication of the pollutant contribution from various motor vehicle activities [58] and cement emissions [43]. The higher concentrations of Pb in the urban soils may reflect the effect of its long-term contamination in the particular soils as well as its long half-life in soils [59].

4 Conclusions

The distribution of heavy metals (Cr, Cu, Ni, Pb and Zn) in the surface soils around a cement factory in the Rabigh district, Saudi Arabia, indicated that this area has been affected mainly by cement industry and traffic emissions. The studied metals especially lead showed relatively higher concentrations at sites near the factory. From different perspectives of the current study, the average of ecological risk potential is described as a region with

moderate risk. Different multivariate analysis proved that the effect of heavy metal deposition due to the functioning of the cement factory and other anthropogenic sources like motor vehicle emissions are of minimal importance.

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