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Heavy Metals Concentration in Urban Soils of Fallujah City, Iraq

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Abstract
Twenty samples were collected from the urban soils in Fallujah City in order to determine concentrations, spatial distribution and contamination assessment of heavy metals such as Cu, Zn, Ni, Pb, Ni, Fe, Mn, Cd, Co and Cr. The mean concentrations are as follows : 235.77µg/g for Fe, 24.09µg/g for Mn, 11.59µg/g for Cr, 8.96µg/g for Ni, 5.50µg/g for Zn, 3.82µg/g for Pb, 3.43µg/g for Co , 2.01µg/g for Cu and 0.64µg/g for Cd. To assess metal contamination in urban soils, soil quality guidelines were applied. The mean concentration of Cu, Zn, Ni, Pb, Ni, Fe, Mn, Co and Cr did not exceed and Cd exceeded the USEPA guideline. A similar spatial distribution patterns between the heavy metals were found indicating that these metals were from the same sources. The metal contamination in the soils was also evaluated by appling enrichment factor (EF), pollution load index (PLI), integrated pollution load index (IPLI) and geoaccumulation index (Igeo). Based on enrichment factor (EF) , the urban soils in Fallujah city are extremely high enriched with Cd and Co, very high enriched with Ni and Cr and Pb, Cu and Zn exhibit significant enrichment. to IPLI values, urban soils in Fallujah are lowly polluted with heavy metals. According to Igeo, the urban soils in Fallujah City are uncontaminated to slightly contaminated by Cd. The sources of Cd in soil may be from industrial and anthropogenic activities.
Keywords: Urban soils, Heavy metals, Fallujah city

1. Introduction

Soil is a crucial component of rural and urban environments, and in both places land management is the key to soil quality. Bockheim (1974) gives appropriate and useful definition of urban soil as a soil material having a non – agricultural, man – made surface layer more than 50cm thick, that has been produced by mixing, filling, or by contamination of land surfaces in urban and suburban areas. The characteristics of urban soil are vertical and spatial variability, absence of soil structure leading to compaction, modified soil reaction (in most cases higher pH values), low organic matter content, restricted aeration and water drainage, high content of anthropic materials, modified soil organisms population and activity (Bretzel and Calderisi 2006). When considering different kinds of soil pollutants, heavy metals are especially dangerous because of their persistence and toxicity (Adriano 2001). Soil act as a sink for heavy metals through sorption, complexation, and precipitation reactions (Yong et al. 1992). Due to proximity to humans, accumulation of harmful substances in urban soils is of grat concern (manta et al. 2002; Maas et al. 2010). There are two main sources of heavy metals in soil: (1) naturally background, which represents the heavy metal concentration derived from parent rocks; (2) anthropogenic contamination, including agrochemicals organic amendments, animal manure, mineral fertilizer, sewage sludge and industrial wastes (Li et al. 2009). Heavy metals may be transferred to human bodies by way of ingestion, inhalation and dermal contact, or through the food chain (Biasioli et al. 2006; Vrscaj et al. 2008).

For urban soils, elevated heavy metal concentrations are almost universally reported, although often with high variances (e.g., Wang and Qin 2007; Tume et al. 2008; Ali and Malik 2011; Rizo 2011; Guo et al. 2012; Wang et al. 2012; Li et al. 2013; Cai et al. 2013; Simon et al. 2013). Studies on heavy metals in urban soils in Iraq are very limited. Heavy metals concentrations in surface soils of Hawega area south western of Kirkuk governorate were investigated by Ali (2007). Sulaivany and Mezori (2008) assessted the soil heavy metal content in Dohuk city, north of Iraq. Heavy metal contamination in urban soil within Baghdad city was evaluated by AlObaidy and AlMashhadi (2013). Fayad et al. (2013) analyzed and assessed the heavy metals in soil adjacent to Ishaqi river, north of Baghdad city.

The objectives of this study are to investigate the heavy metals concentrations in urban soils of Fallujah city, spatial variation and to evaluate the soil environmental quality interms of metal contamination.

2. Materials and methods

2.1 Study area

Fallujah city located roughly 69km west of Baghdad on the Euphrates River , 33° 21' 13" N, 43° 46' 46" E, Figure 1. The city grew from a small town in 1947 to a population of 326471 inhabitants in 2010. The region has been inhabited for many millennia. There is evidence that the area surrounding Fallujah was inhabited in Babylonian times.

2.2 Sampling and chemical analysis

The sampling sites were randomly distributed in the study area, (Fig. 1). The soil (0 – 0.9 m) was collected. Each of the soil samples consisted of 3 subsamples obtained in different depths (0 – 0.3m, 0.3 – 0.6m and 0.6 – 0.9m) using a hand auger. Locations of the sampling sites were recorded using Garmon 72 GPS. For each sampling site, a composite sample was made by mixing the three subsamples. The soil samples were kept in plastic bags. They were oven – dried in the laboratory at 105°C for 24 h, sieved through a 2-mm stainless steel sieve to remove large debris, gravel-sized materials, plant roots and other waste materials and they were homogenized with porcelain pestle and mortar. Then these samples Passed through a –0.1 mm stainless steel sieve and stored in closed plastic bags until analysis. Soil samples were digested with a 3: 2 : 2 mixture of HNO_3 - H_2SO_4 – HCl (Salah et al. 2012). The digested solutions were analyzed by Atomic Absorption Spectrometry (AAS Phoenix – 986). All of the soil samples were analyzed for their total concentrations of Cu, Zn, Ni, Pb, Fe, Mn, Cd, Co and Cr. Descriptive statistics and Pearson's correlation analysis were performed using Statistica Release 7 for windows.

2.3 Assessment of soil contamination

To evaluate the degree of contamination in the soils, we used three parameters: Enrichment Factor (EF), Integrated Pollution Load Index (IPLI) and geoaccumulation Index (I_{geo}).

Enrichment Factor (EF)

The enrichment factor (EF) of metals is a useful indicator reflecting the status and degree of environmental contamination (Feng et al. 2004). The EF calculations compare each value with a given background level, either from the local site, using older soils formed under similar conditions, but without anthropogenic impact, or from a regional or global average composition (Cato 1977; Choi et al. 2012). The EF was calculated using the method proposed by Sinex and Helz (1981) as follows:

$$\text{Enrichment Factor (EF)} = (C_x/ C_{Fe})_{sample} / (C_x/ C_{Fe})_{reference\ soil} \qquad (1)$$

Where (C_x/ C_{Fe}) sample is the metal to Fe ratio in the sample of interest; (C_x/C_{Fe})reference soil is the natural background value of metal to Fe ratio. As we do not have metal background values for our study area, we used the values from world average data (Bowen 1979). Iron was chosen as the reference element because it is one of the largest component of soil and the modification of iron by other anthropogenic sources is difficult. Five contamination categories are recognized on the basis of the enrichment factor, where EF < 2 is deficiency to minimal enrichment; EF 2 – 5 is moderate enrichment; EF 5 – 20 is significant enrichment; EF 20 – 40 is very high enrichment, and EF > 40 is extremely high enrichment (Sutherland, 2000).

Integrated Pollution Load Index (IPLI)

Integrated Pollution load index (IPLI) is defined as the mean values for all the pollution indexes (PLI) of all considered metals:

$$(IPLI) = (PLI_1 + PLI_2 + PLI_3 + \dots\dots\dots PLI_n) / n \qquad (2)$$

Where, n is the number of metals. The PLI is defined as a ratio of heavy metal concentration in the soil and the background concentration of the metal (Chen et al. 2005; Faiz et al. 2009):

$$PLI = C_n / B_n \qquad (3)$$

Where C_n is the measured concentration and B_n is the background concentration. The following contamination categories are used (Chen et al. 2005): PLI ≤ 1 is low contamination; 1≤ PLI < 3 is moderate contamination and PLI > 3 is high contamination. The background concentrations of the elements were used from the world average data (Bowen 1979). The IPLIs were classified as: IPLI ≤ 1 is low contamination; 1 < IPLI ≤ 2 is moderate contamination and IPLI > 2 is high contamination (Chen et al. 2005; Wei and Yang 2010).

Geoaccumulation index (I_{geo})

Enrichment of metal concentration above baseline concentrations was calculated using the method proposed by Muller (1969), termed the geoaccumulation index (Igeo). Geoaccumulation index is expressed as follows:

$$I_{geo} = \log_2 (C_n/B_n \cdot 1.5) \qquad (4)$$

Where Cn is the measured concentration of element n in the sediment sample and Bn is the geochemical background value [world average data given by Bowen (1979)]. The factor 1.5 is introduced to include possible variation of the background values due to lithogenic effect. Muller (1981) proposed seven grades or classes of the geoaccumulation index. These classes are : class 1($I_{geo} \leq 0$) is unpolluted; class 1(I_{geo} = 0 -1) is unpolluted to moderately polluted; class 2 (I_{geo} = 1-2) is moderately polluted; class 3 (I_{geo} = 2-3) is moderately to strongly polluted; class 4 (I_{geo} = 3-4) is strongly polluted; class 5 (I_{geo} = 4-5) is strongly to extremely polluted) and class 6 (I_{geo} = 5-6) is extremely.

3. Results

3.1 Concentrations of heavy metals

Table 1 presents the descriptive statistics of the heavy metals concentrations of the urban soils in Fallujah city and the world average data, EPA soil quality guidelines and Canadian soil quality guidelines. The concentrations of Cu, Zn, Ni, Pb, Mn, Cd, Co and Cr varied between 0.87 and 4.97, 2.75 and 10.40, 5.57 and 12.22, 2.62 and 5.30, 145.02 and 417.70, 10.22 and 36.30, 0.47 and 0.87, 2.27 and 4.72, and 7.90 and 21.22 µg/g , respectively, with mean concentrations of 2.01, 5.50, 8.68, 3.82, 235.77, 24.09, 0.64, 3.43, and 11.59 µg/g.

3.2 Correlation coefficient analysis

The results of the Pearson's correlation coefficients and their significant levels ($P < 0.05$) are shown in Table 2. The concentration of Pb showed a high significant positive relationship with Cu (0.76), Co (0.76), Mn (0.62), Zn (0.58), Ni (0.54), and Cd (0.47). The Cu concentration has a significant positive relationship with Co (0.71), Mn (0.67), and Zn (0.54). Zn expressed a strong positive correlation with Co (0.58), Ni (0.54), Mn (0.53), and Cd (0.51). The concentration of Ni expressed a significant positive relation with Mn (0.67), Cd (0.66), and Co (0.56). The Co and Cr concentrations showed very high significant positive correlation with Mn (0.84) and Fe (0.87), respectively.

3.3 Spatial distribution of heavy metals

Golden software surfer 8 was used to construct spatial distribution maps and to assess the potential sources of enrichment and to identify hotspots with high metal concentrations in the urban soils of the study area. The spatial distribution maps of Cu, Zn, Pb, Ni, Fe, Mn, Cd, Co, and Cr are presented in Figure 2.

3.4 Enrichment factor (EF)

The EF for Cu ranged from 3.96 – 33.08 with mean value of 12.58. The EF of Zn ranged from 5.69 – 23.05 with a mean of 10.87. The EF for Ni ranged from 15.04 – 58.88 with a mean of 31.88. The EF of Pb ranged from 12.44 – 37.03 with mean of 19.62. The range of EF for Mn was from 1.38 to 10.01 with a mean of 4.44. The EF of Cd ranged from 184.16 – 396.14 with a mean of 287.13. The EF of Co ranged from 38.38 – 145.66 with a mean of 78.13. The range of EF for Cr was from 20.64 to 37.62 with a mean of 28.31. The spatial variation of EF for the heavy metals in soil of the study area are shown in Figure 3.

3.5 Integrated pollution load index (IPLI)

The mean values of PLI for all metals in the study area soils were less than 1 except for the Cd it was more than 1 (1.614). The IPLIs for all sampling sites ranged from 0.220 – 0.372 with a mean of 0.294. Figures 4and 5 show the spatial variation of the PLI and IPLI, respectively.

3.6 Geoaccumulation index (I_{geo})

The mean values of I_{geo} for all metals were less than zero except for the Cd it was more than zero. The spatial variation of the I_{geo} is shown in Figure 6.

4. Discussion

4.1 Concentrations of heavy metals

The result of the descriptive statistics of the heavy metals concentrations of urban soils in Fallujah showed that all of the mean values of the heavy metals were lower than their background values except of Cd was less than its background value. Due to the lack of an official Iraqi guideline for healthy concentrations of heavy metals in urban soils, metal concentrations are compared with EPA soil quality guideline and Canadian soil quality guideline. In comparison with soil quality guideline, the mean value for all metals did not exceed the limits except Cd exceeds slightly the EPA soil quality guideline, and this result shows that the urban soils in Fallujah city are polluted only by Cd. Concentrations of the heavy metals in urban soils of Fallujah city were compared to the urban soils from other cities in Iraq and the world, Tables 3. Lower concentrations of Cu, Zn, Ni and Pb were reported in the current study as compared to the urban soils in Baghdad, Dohuk and Haweja. Concentrations of Fe and Mn recorded in current study were more than reported in Baghdad and less than recorded in Haweja. Concentration of Cd (0.54 µg/g) reported in Baghdad (Al Obaidy et al. (2013) was within range recorded in current study. Higher concentration of Cd was reported in Baghdad and Dohuk as compared to that reported in urban soils of Fallujah. Concentrations of Co and Cr recorded in current study were more than reported in Baghdad and less than in Haweja. This variation in concentrations of heavy metals in the different cities reflects the influence of different factors, e.g.type of a parent material, traffic density, microclimatic condition and nature of anthropogenic inputs (Ward, 1990). Because the urban soils in Fallujah is polluted by Cd as mentioned above, a detailed discussion bout Cd is given below:

Cadmium (Cd)

Cadmium is highly mobile and toxic, which means that the few maxima found are critical values (Bloemen et al., 1995). Exposure to certain forms and concentrations of cadmium is known to produce toxic effects on humans. Long-term occupational exposure to cadmium at excess concentrations can cause adverse health effects on the kidneys and lungs. Van Assche (1998) estimated that the relative importance of various cadmium sources to human exposure is as follows: phosphate fertilizer (41.3%), fossil fuel combustion (22 %), iron & steel production (16.7 %), natural sources (8 %), none – ferrous metals (6.3 %), cement production (2.5 %), cadmium products (2.5 %) and incineration (1.0 %). Clearly, of the anthropogenic sources of cadmium, phosphate fertilisers, fossil fuel combustion, and some industrial activities contribute far more to human cadmium exposure than production, use and disposal of cadmium products and incineration of all cadmium-containing materials. Humans normally absorb cadmium into the body either by ingestion or inhalation. Dermal exposure (uptake through the skin) is generally not regarded to be of significance (Lauwerys 1988). Cadmium in soils is derived from both natural and anthropogenic sources. Natural sources include underlying bedrock or transported parent material such as glacial till and alluvium. Anthropogenic input of cadmium to soils may be of different sources, such as agricultural amendents, aerial deposition and sewage sludge (Alloway, 1995). The industrial uses of Cd are Ni – Cd batteries pigments, stabilizers, coatings and electronic compounds, and the The major classes of products where cadmium is present as an impurity are non-ferrous metals (zinc, lead and copper), iron and steel, fossil fuels (coal, oil, gas, peat and wood), cement, and phosphate fertilisers (Cook and Morrow 1995). The high Cd concentration in urban soil of Fallujah can be caused from a variety sources, phosphate fertilizer, fossil fuel combustion and atmospheric deposition.

4.2 Correlation coefficient analysis

Correlation analysis provides an effective way to reveal the relationships between multiple variables and thus have been helpful for understanding the influencing factors as well as the sources of chemical components (Li et al., 2013). The relationship between heavy metals can provide important information on heavy metal sources and pathways (Manta et al., 2002). The high significant correlation between Pb and Cu, Co, Mn, Zn, Ni and Cd suggests that these heavy metals may originates from a common pollution source. The concentration of Cd showed a significant positive relationship with Zn, Ni and Pb suggesting that these metals come from similar sources. Cd Cadmium is found principally in association with zinc sulfide based ores and, to a lesser degree, as an impurity in lead ores. Cadmium is utilised as one of the two principal electrode materials in Ni-Cd batteries. A significant positive correlations were found among Ni and Mn and Co suggesting that these metals may have a common pollution source.

4.3 Spatial distribution of heavy metals

The estimated maps of Cu, Zn, Ni, Pb, Fe, M, Cd, Co and Cr are presented in Figure 2. Several hotspots (positive anomalies) of metal concentration were identified by the geochemical maps. In these metals, Cu, Pb and Cd showed a similar spatial patterns, with positive anomalies located in the west of study area, indicating that they were from the same sources. This result was in good agreement with the result of the statistical analysis in which high significant relationship were found between these metals. Other similar spatial distribution patterns were found between Fe and Cr suggesting that they were from the same origins. This result confirmed the results of the correlation coefficient analysis, in which Cr showed very high significant correlation with Fe. The similar spatial distribution of the heavy metals in the study area indicated that anthropogenic activities played an important role in the heavy metals concentrations .

4.4 Enrichment factor (EF)

The enrichment factor (EF) was used to quantify the level of pollution and the potential anthropogenic effects in urban soils of Fallujah city. Basically, as the EF values increase, the contributions of the anthropogenic sources also increase. If an enrichment factor is greater than unity, this indicates that abundance of the heavy metals in soil may not come from the local soil background but other natural and/or anthropogenic sources in urbanized areas, including vehicle emissions, industrial discharge and other activities (Gibson and Farmer, 1986;Thornton, 1991). However, enrichment factors less than 5 may be not considered significant although they are an indicator of metal accumulation, because such small enrichments may arise from differences in the composition of local soil material and the reference background value used in the EF calculations (Wang and Qin, 2007). If the EF values are greater than 5, they are considered to be soil contamination for related metals (Tokalioglu, et. al., 2003). The mean values of enrichment factors are greater than 5 for Cd (287.13), Co (78.13), Ni (31.88), Cr (28.31), Pb (19.62), Cu (12) and Zn (10.87).The results of EF indicated that the urban soils in Fallujah city were extremely high enriched with Cd and Co, very high enriched with Ni and Cr and Pb, Cu and Zn exhibit significant enrichment. The EF value for Mn shows moderate enrichment. It can be concluded that Cd followed by Co was the most serious enriched heavy metals in the urban soil of Fallujah. The sources of Cd in soil may be from industrial and traffic emission by fossil fuel, atmospheric deposition, deposition of plastic soild wastes and application of Cd containing phosphate fertilizer. The significant sources of Co in soils are derived from the deliberate applications of Co salts or Co treated phosphate fertilizers (Smith and Paterson, 1995). The spatial distribution of EF values showed that high enrichment for heavy metals occurs at sampling sites (7 and 13 – 19) located in the built – up area of the old city, which can be attributed to intensive anthropogenic activities in these sites.

4.5 Integrated pollution load index (IPLI)

The PLI value of Cd in urban soils of Fallujah varied from 1.18 to 2.18 which indicated moderate contamination level with mean of 1.64 for all soil sampling sites indicating moderate contamination level. The PLI value for Cu, Zn, Ni, Pb, Fe, Mn, Co and Cr was less than 1 indicating low contamination level. Table 5 shows that IPLI is less than 1 for all heavy metals and for all sampling sites. According to IPLI values, urban soils in Fallujah are lowly polluted with heavy metals. The spatial distribution of PLIs and IPLIs is presented in Figures 4 and 5. Most of the urban soil samples from the older urban areas of Fallujah city have LPI values higher than those in the newer urban areas. The spatial distribution of IPLIs showed a similar pattern to the LPI spatial distribution.

4.6 Geoaccumulation index (Igeo)

The geoaccumulation index (I_{geo}) mean values for Cu (-4. 664), Zn (-4.709), Ni (-3.107), Pb (-3.817), Mn (-6.026), Co (-1.832) and Cr (-1.832) showed that the urban soils in Fallujah city are uncontaminated by these metals. The mean value of Igeo for Cd is 0.085 indicating that urban soils in Fallujah city are uncontaminated to slightly contaminated by Cd as a result of anthropogenic activities.

5. Conclusion

To investigate the status of metal contamination of the urban soils in Fallujah city, Cu, Zn, Ni, Pb, Fe, Mn, Cd, Co and Cr concentrations were estimated in twenty sampling sites. The order of the mean concentrations of tested heavy metals: Fe> Mn> Cr> Ni> Zn> Pb> Co> Cu> Cd. The correlation analysis of mean concentrations showed good to strong positive correlations among Pb, Cd, Zn, Ni, Co, Fe, Mn, Cu and Cr, suggesting that these metals have common sources. The heavy metals in soils of study area showed similar spatial patterns indicating that they were from the same origins. International soil quality guidelines (world average data, USEPA and CCME), enrichment factor (EF), pollution load index (PLI), integrated pollution load index (IPLI) and geoaccumulation index (Igeo) were applied for assessment of contamination. According to sediment quality guidelines, urban soils in Fallujah city were polluted by Cd. The high concentration of Cd revealed the impact of industrial and anthropogenic activities on Cd accumulation in the soil of study area. The results of EF indicated that the urban soils in Fallujah city were extremely high enriched with Cd and Co, very high enriched with Ni and Cr and Pb, Cu and Zn exhibit significant enrichment. It can be concluded that Cd followed by Co was the most serious enriched heavy metals in the urban soil of Fallujah. According to IPLI values, urban soils in Fallujah are lowly polluted with heavy metals. The mean value of Igeo for Cd is 0.085 indicating that urban soils in Fallujah city are uncontaminated to slightly contaminated by Cd as a result of anthropogenic activities. We recommend to investigate distribution of Cd and the potential sources to increase its concentration in details.

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Table 1. Statistics summary of metal concentrations of soil of the study area , reference value and soil quality guidelines in µg/g.

Parameter	Cu	Zn	Ni	Pb	Fe	Mn	Cd	Co	Cr
Minimum	0.87	2.75	5.57	2.62	145.02	10.22	0.47	2.27	7.90
Maximum	4.97	10.40	12.22	5.30	417.70	36.30	0.87	4.72	21.22
Mean	2.01	5.50	8.96	3.82	235.77	24.09	0.64	3.43	11.59
Standard deviation	1.09	2.05	2.14	0.81	66.29	6.81	0.12	0.70	3.13
Standard Error	0.34	0.64	0.67	0.25	20.96	2.15	0.03	0.22	0.98
World average data	30	90	50	35	40000	1000	0.4	8	70
EPA soil quality guidelines	16	110	16	40	-	-	0.6	-	25
Soil quality guidelines of Canada	64	140	200	140	-	-	10	-	63

Table 2. Pearson's correlation coefficient of heavy metals in urban soils in Fallujah city.

	Cu	Zn	Ni	Fe	Mn	Cd	Co	Cr	Pb
Cu	1.00								
Zn	**0.54**	1.00							
Ni	0.37	**0.54**	1.00						
Fe -	0.30	0.23	0.33	1.00					
Mn	**0.67**	**0.53**	**0.67**	**-**0.28	1.00				
Cd	0.29	**0.51**	**0.66**	0.37	0.41	1.00			
Co	**0.71**	**0.58**	**0.56**	-0.09	**0.84**	0.41	1.00		
Cr -	0.17	0.43	0.41	**0.87**	-0.02	0.34	0.19	1.00	
Pb	**0.76**	**0.58**	**0.54**	0.16	**0.62**	**0.47**	**0.76**	0.21	1.00

Marked correlations are significant at $p < 0.05$.

Table 3. Mean concentrations of heavy metals in urban soils from different cities in the world.

City	Cu	Zn	Ni	Pb	Cd	Co	Cr	Reference
Fallujah (Iraq)	2.01	5.50	8.96	3.82	0.64	3.43	11.59	Present study
Shenyang (China)	41.6	234.80	NA	116.76	1.10	NA	67.90	Li et al. (2013)
Guangzhou (China)	11	277	11.1	65.4	0.23	NA	22.4	Cai et al. (2013)
Wien (Austria)	56.35	75	NA	54	0.3	6.5	31	Simon et al. (2013)
Yibin (China)	31.9	138.88	NA	61.23	NA	NA	NA	Guo et al. (2012)
Beijing (China)	17.73	92.9	24.0	23.3	0.13	NA	61.0	Wang et al. (2012)
Islamabad (Pakistan)	101	1638.97	92.47	212.34	3.54	16.98	NA	Ali & Malik (2011)
Havana (Cuba)	29.7	240	66	101	NA	13.9	NA	Rizo et al. (2011)
Beijing (China)	5.4	92.1	26.7	35.4	0.21	NA	61.9	Chen et al. (2010)
Teresina (Brazil)	29.2	29.8	1.3	7.7	NA	NA	7.8	Moura et al. (2010)
Andhra Pradesh (India)	35.36	77.1	27.3	28.3	NA	15.0	67.8	Dantu (2010)
Talcahuano (Chile)	38.2	227	26.8	25.7	NA	NA	26.0	Tume et al. (2008)
Xuzhou (China)	35.7	144.1	34.3	43.3	0.54	11.7	78.4	Wang & Qin (2007)
Haweja (Iraq)	85.96	51.33	152.3	NA	NA	36.29	310.5	Ali (2007)
Tuscany (Italy)	16.41	127.65	59.03	218.58	NA	NA	NA	Bretzel & Calderisi (2006)
Poznan (Poland)	NA	72.98	NA	30.59	0.75	NA	NA	Grzebisz et al. (2002)
Baghdad (Iraq)	NA	NA	80.44	113.98	0.54	NA	NA	Al Obaidy et al. (2013)
Baghdad (Iraq)	5.25	33.06	46.31	8.34	1.58	1.08	0.84	Fayad et al. (2013)
Dohuk (Iraq)	35.36	NA	32.24	35.36	1.54	NA	NA	Sulaivany & Mezori (2008)
Haweja (Iraq)	35.7	51.33	152.3	NA	NA	36.29	310.5	Ali (2007)

NA: Not Available

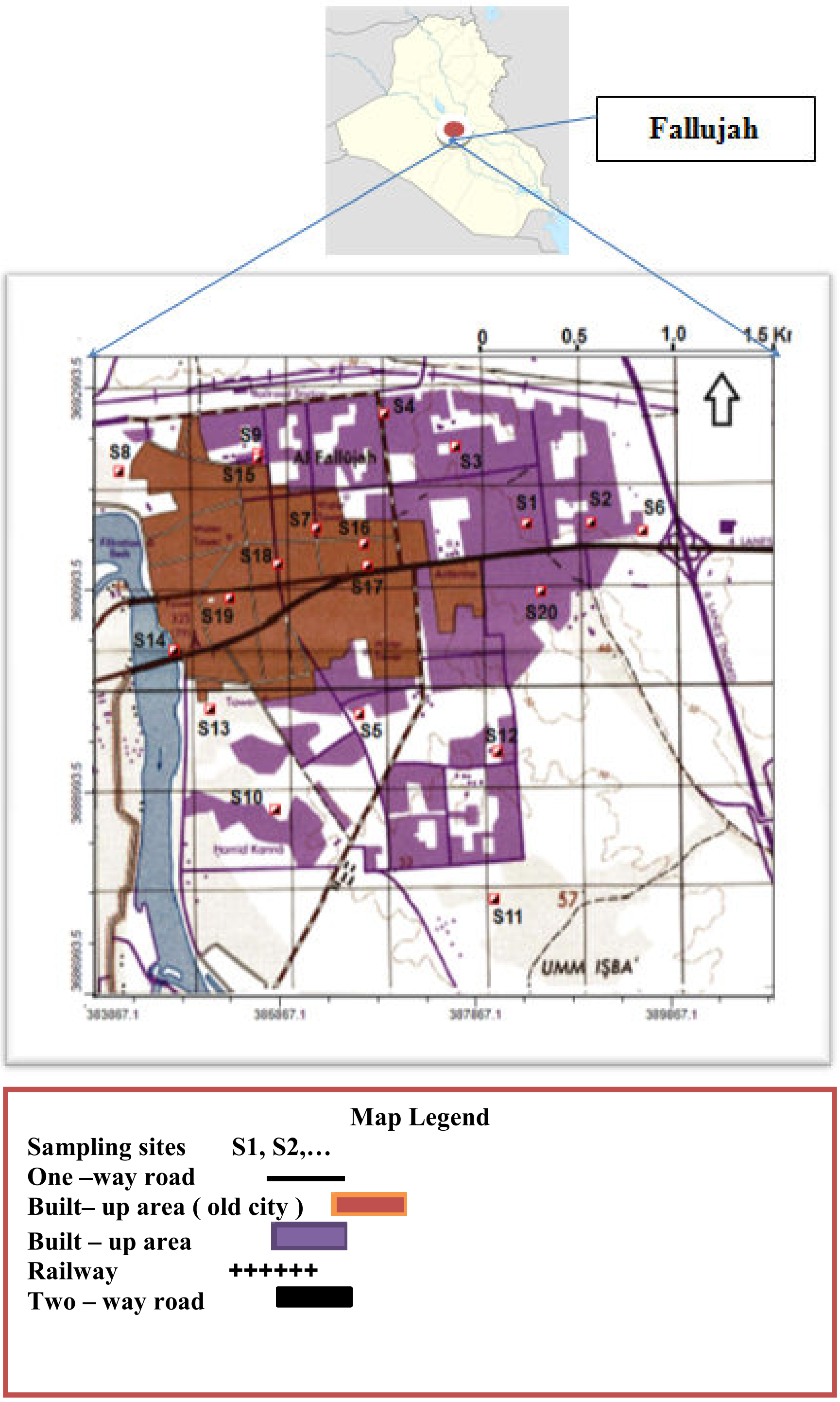

Figure 1. Map of the Fallujah city with location of sampling site of soil.

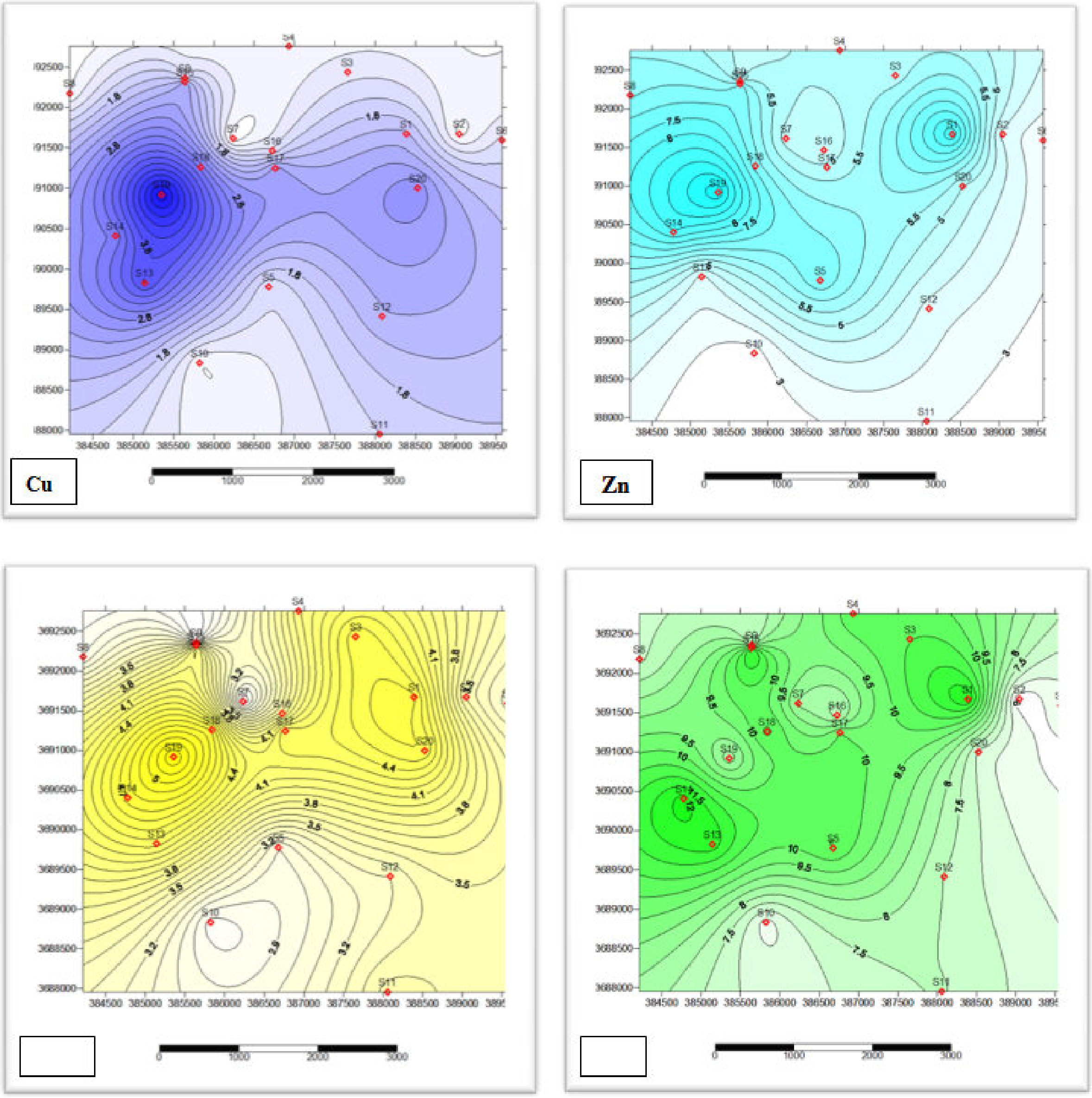

Figure 2. Spatial distribution maps of concentrations of heavy metals in the urban soils in Fallujah City.

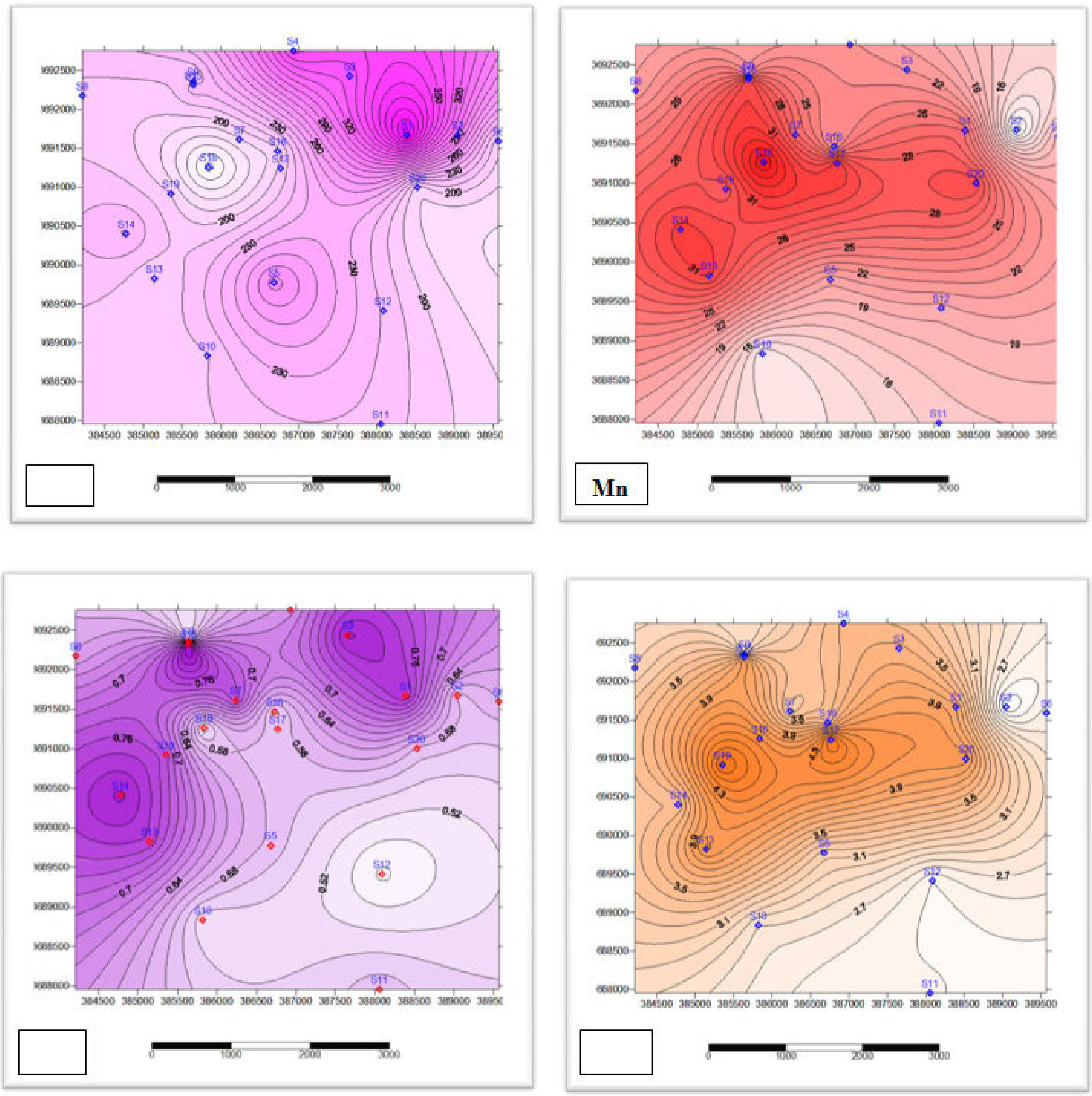

Figure 2. Continued.

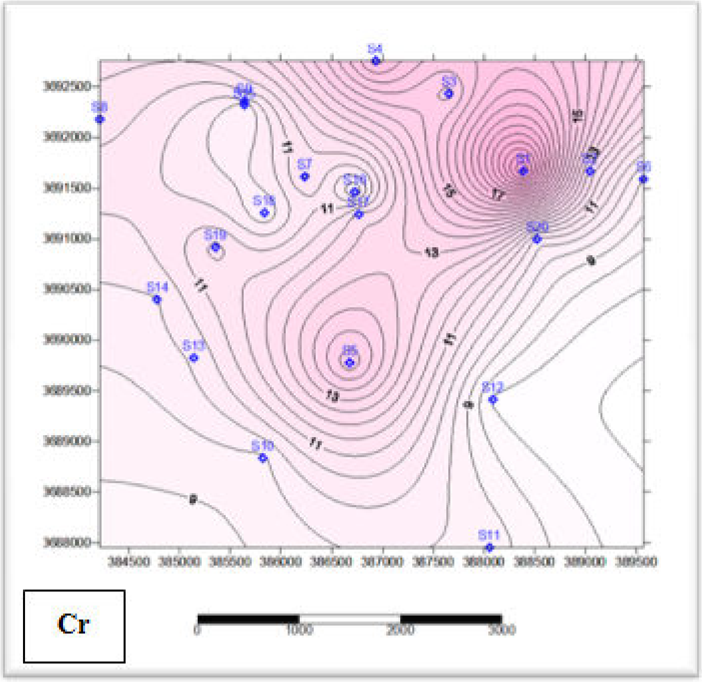

Figure 2. Continued.

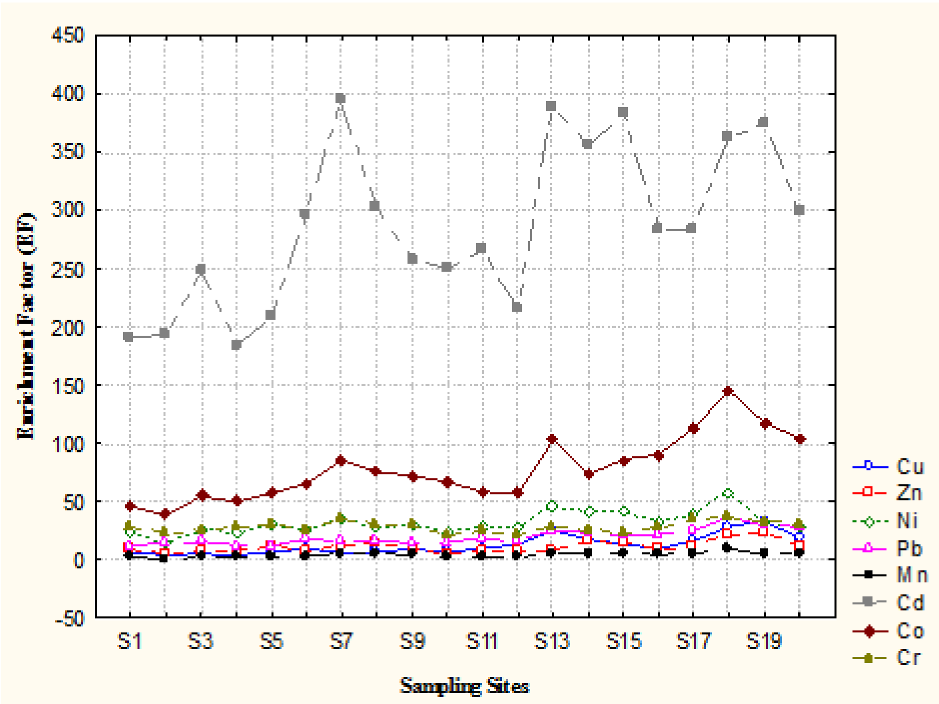

Figure 3. Enrichment factor (EF) values of heavy metals in urban soils in Fallujah city.

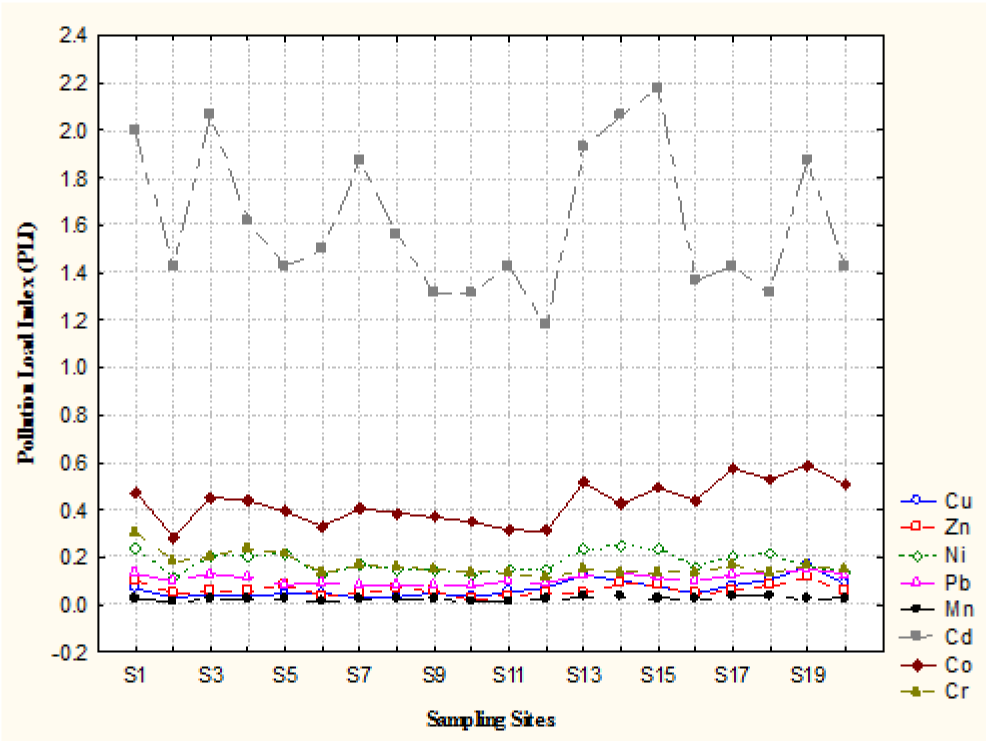

Figure 4. Pollution load index (PLI) values of heavy metals in urban soils in Fallujah city.

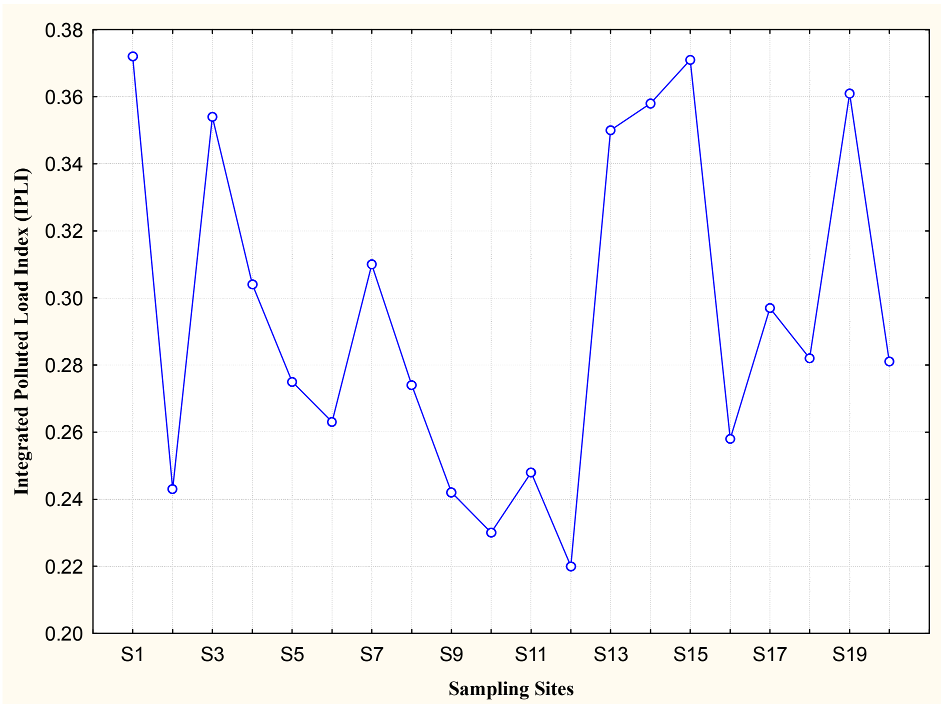

Figure 5. Spatial variation of integrated Pollution load index (IPLI) values of heavy metals in urban soils in Fallujah city.

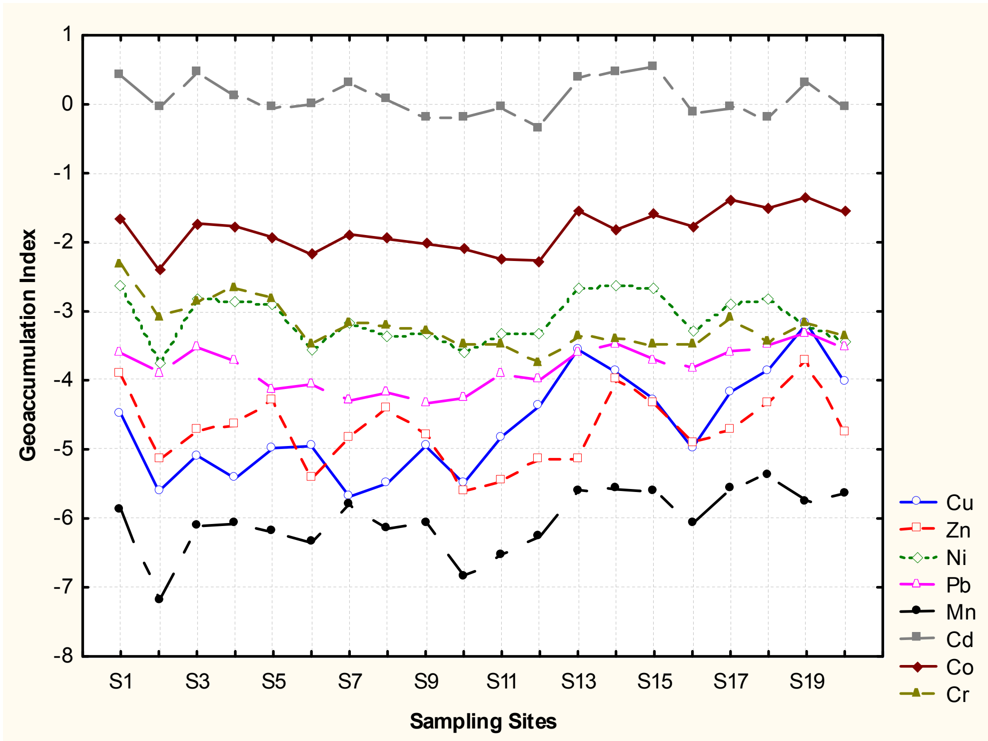

Figure 6. Geoaccumulation index (Igeo) values of heavy metals in urban soils in Fallujah city.