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Spatial Distribution and Environmental Implications of Lead and Zinc in Urban Soils and Street Dusts Samples in Al-Hashimeyeh Municipality

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Abstract

The state of heavy metal pollution and mobility of both Pb and Zn were investigated in selected urban soils and street dusts samples in Al-Hashimeyeh Municipality. A total of 43 selected sites were sampled, using composite sampling technique derived from four sub-samples. Sequential extractions were implied to predict the percentages of Pb and Zn present in each soil geochemical phases. Results indicated that street dust samples in Al-Hashemiya have elevated concentrations of Pb (115.3 mg/kg) and Zn (228 mg/kg). Very little amounts of Pb and Zn were retrieved from the exchangeable phase, the readily available for biogeochemistry cycles in the ecosystems. The hydroxide-bound fraction of Pb dominated in almost all soils and dust with highest percentages (69%, 77%, respectively) indicating that this metal is strongly bounded to the solid. Zinic mostly occurred in hydroxide bound fraction in street dust (65%) while the highest percentages of Zn, in urban soils, were found in the hydroxide bound fraction and mineral structure (residual fraction) with 44% and 51.2%, respectively. Furthermore, the concentrations of Pb in urban and street dust samples pose a low risk to the environment with 8% and 9% respectively, existing in exchangeable and carbonate fractions. While the results show that Zn in street dust poses a medium risk with 15% exists in exchangeable and carbonate fractions. The chemical results were intensively investigated using spatial and statistical modeling techniques to predict heavy metal loads and distribution in space. The analyses suggest the presence of heavily contaminant zones allocated at, or close to, industrial activities at the area, suggesting that the major contamination sources might be attributed to both traffic emissions and industrial activities. The paper also provides prediction models for both heavy metals spatial behavior using stepwise regressions and varigogram techniques.

Keywords: Heavy Metals; Spatial Variability; Sequential Extraction; Lead; Zinc

1. Introduction

Generally, urban systems are highly sophisticated and complex. In these systems, top soils and roadside dusts are indicators of several environmental pollutants [1-2]. Levels of contaminants associated with street dusts have received a great interest in the previous decades, because elemental composition and concentrations in these dusts reflect the characteristics of the activities going on in a particular area. These systems have the potential to provide considerable loadings of several contaminants to the receiving water and water bodies, particularly with changing environmental conditions [3].

Heavy metals (particularly Pb, and Zn) are good indicators of contamination in urban soils and street dust. They appear in gasoline, car components, oil lurbicants, industrial, incinerator emissions, municipal wastewater discharges [4,5]. Contamination with the heavy metals is of major concern because of their toxicity and threat to human life and environment, particularly in light of the impact of high blood–Pb levels in children living in urban areas and the likelihood of this being caused by unintentional hand–mouth contamination while children play in a city street [2,6].

Since 40 years ago, one of the largest chemical and petrochemical industrial complexes in Jordan is located in Al- Hashimeyeh at Zarqa Governorate. The presence of a highway and several roads with heavy traffic influences enormously the environment of this area. There have been a number of previous studies on the distribution of heavy metal in road dust and soils in Jordan [7-10]. However, these studies focused only on limited locations, particularly road dusts from traffic areas collected from the urban part of Amman and total levels of these contaminants.

Environmental and health effects of trace metal contaminants in dust are initially dependent on the mobility and availability of the elements. Mobility and availability of these contaminants are functions of their chemical speciation and partitioning within or on dust

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matrices. However, there is little information available; most studies on trace elements in street dust have concentrated on total levels with little emphasis on chemical forms. The identification of the main binding sites, phase associations of trace metals in soils, and sediments help in understanding the bioavailability of an element and the signature of multiple sources [11]. Most commonly, the sequential extraction procedures (SEP) are applied for solid phase speciation [12].

Recently, environmental concerns are growing and sustainable use of natural resources and risk and impact assessments are becoming increasingly important to avoid any human health impacts. A common approach to determine the origin of contamination is to identify the spatial relationships among environmental variables. Many recent studies were concerned with the identification of the sources of contamination either in soil, groundwater, rivers, streams, lakes, seas, or oceans [e.g.13], while other studies were focused on assessing the impact of industrial and agricultural uses on soil and groundwater quality [e.g.14].

Considering the above discussed facts, the primary objectives of the present study are to: (1) Determine average concentrations of heavy metals (Zn and Pb) in the urban soil and street dusts. (2) Define their natural or anthropogenic origin, and (3) Assess their mobility and bioavailability by solid phase speciation of these metals using sequential extraction.

2. Materials and Methods

2.1. Study Site

Al- Hashimeyeh is the most major industrial region at Zarqa Governorate in Jordan. It is located about 5 km eastern north of Zarqa city and 37Km to the east of the capital Amman (Figure1). The area of study is mainly consisting of highly dissected rocks with very gently undulating limestone parent material of Wadi esSir Limestone Formation, which represents the upper most of the Ajlun Group Formation [15].

Al- Hashimeyeh area is considered the vital part of Zarqa Governorate holding the largest industrial zones [16]. Since 40 years ago, the largest chemical and petrochemical industrial complexes in Jordan were built at the study area. At the same time, the presence of a highway and several roads with heavy traffic influences enormously the environment of this area.

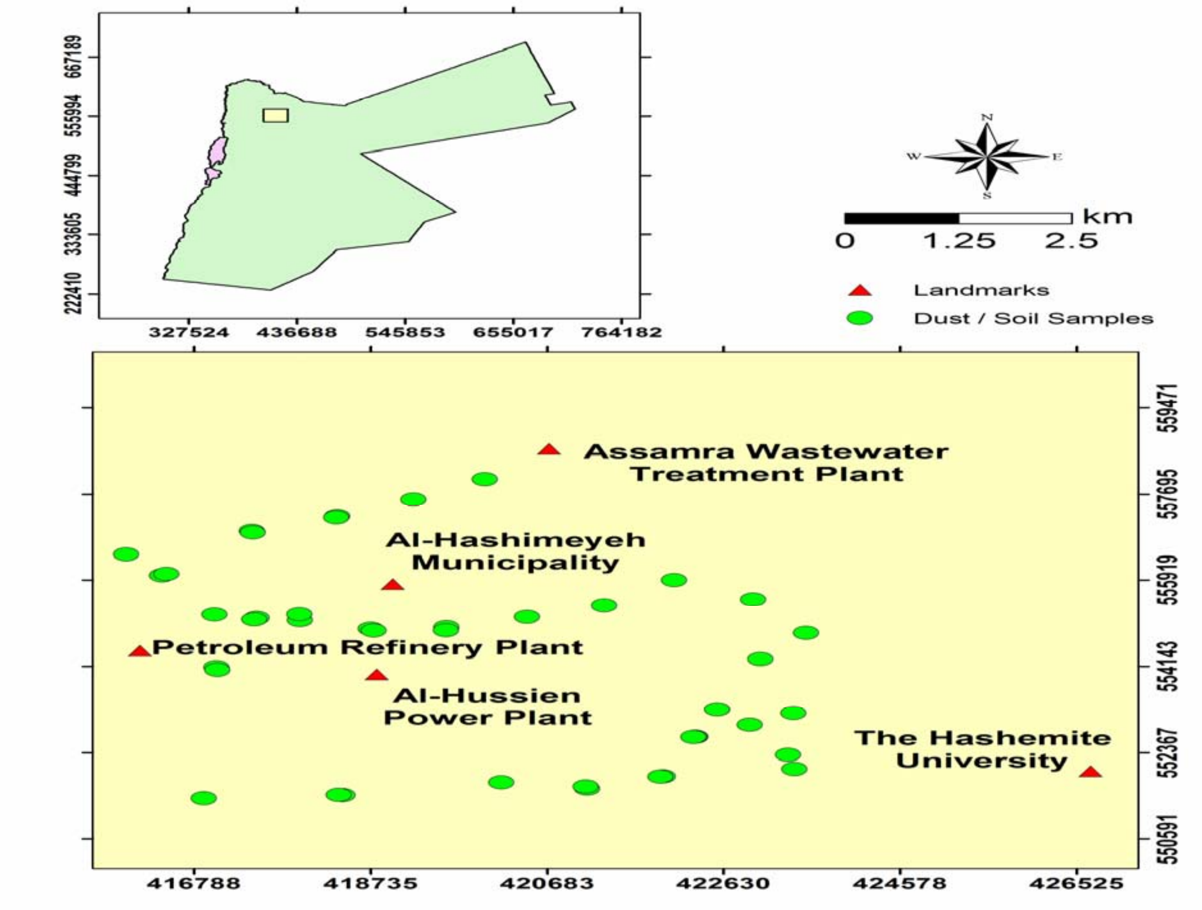

Figure 1. Study Area at the Al-Hashimeyeh Municipality.

2.2. Sample Collection and Preparation

Twenty six street dust samples were collected from both sides of the major streets in Al-Hashimeyeh in November 2005 (Figure1). Another seventeen topsoil samples were collected at a depth 0-15 cm. These urban soils were around one hundred meters away from the main streets (Figure1). The sampling was done using a plastic sweep and stored in mouth-closed polyethylene bags. In the laboratory, all the samples were air-dried, ground, and passed through a 2 mm sieve. The sampling procedure was intended to obtain a representative average sample made of mixing sub-samples from 4 points taken on the corners of a $1m^2$.

2.3. Soil Analyses

Several chemical analyses were conducted using appropriate analytical procedures which are reported in Methods of soil analysis, part 3 [17] as follow: Soil pHe and ECe were determined using soil past extraction. The Walkley- Black wet combustion method was used to determine the total soil organic carbon. Calcium carbonate ($CaCO_3$) was determined, using calcimeter method. Exchangeable cations and soil cation exchange capacity (CEC) were determined, using ammonium acetate. Active or amorphous iron oxide was determined by Tamm's Reagent. All chemicals were of analytical reagent grade unless otherwise indicated.

2.4. Sequential Extraction

Heavy metals of both Pb and Zn in all samples were fractionated by the sequential extraction procedure adopted by Tessier et al. [12] in duplicate. This procedure was selected because it is well documented, widely used, and it has been adapted to the study of soils and dusts [18]. Extractions were conducted in 50 ml polypropylene centrifuge tubes. Between each successive extraction, the supernatant was centrifuge at 6000 rpm for 15 min, and filtered. The chemical reagents, extraction conditions, and corresponding fractions used were as follows:

1. Exchangeable (EXC): 1 g of soil sample is shaken with 8 mL of 1 mol L^{-1} $MgCl_2$ at pH 7 for 1 h at room temperature.
2. Bound to carbonate (CA): the residue from the exchangeable is shaken with 8 mL of 1 mol L^{-1} CH_3COONa, adjusted at pH 5.0 with CH_3COOH for 5 h, at room temperature.
3. Bound to Fe–Mn oxides (Fe–Mn oxides): 20 mL of 0.04 mol L^{-1} NH_2OH . HCl in 25% CH_3COOH, pH 2.0, is added to residue and heated 96 ˚C in water bath for 6 h, with occasional shaking.
4. Bound to organic matter (OM): 3 mL of 0.02 mol L^{-1} HNO_3, 30% H_2O_2 (adjusted to pH 2.0), are added to the residue from the Fe-Mn oxide and heated at 85 ˚C in water bath, for 5 h. another 3.2 mol L^{-1} CH_3COONH_4 in 20% (v/v) HNO_3, is added and agitated for 30 min.
5. Residual (RES): 3 mL of HNO_3+$HClO_4$+HF is added to the residue from bound to OM under high pressure and heated at 170 ˚C.

The atomic absorption spectrophotometer was used for the determination of Pb, and Zn contents in all analyzed soil samples in both street dust and urban soils.

2.5. Statistical Analyses

Arithmetic means (AM) of the duplicate extraction results were calculated as well as the standard deviations (Std.). All the chemical responses, including both Pb and Zn heavy metals, were statistically investigated using JMP 5.01 program [19] platforms for multivariate correlations and regressions basing upon the direct and indirect effect of other independent soil chemical properties as pH, ECe, Cl^-, HCO_3^-, SO_4^{-2}, Na^+, Mg^{2+}, Ca^{2+}, $\%CaCO_3$, %Organic Matter, CEC, and Fe concentration.

Both multivariate and partial multivariate analyses were adopted to investigate the direct and indirect effects of each independent chemical property on Pb and Zn concentrations. Multivariate analyses represent the strength of the linear relationships between each pair of responses. However, the partial multivariate analysis refers to the effect of each independent response on the heavy metals concentration, taking into account the presence of all other responses being constant (i.e. computes correlations using all the values for a given pair of variables in multi-linear regressions).

At the same time, for better understanding of the exact variability of both heavy metals and their relations to other chemical responses, multiple regression analyses were investigated for both heavy metals, using the stepwise regression technique as a critierion to eliminate the colinearity between responses and selecting a subset of effects for best prediction model. The technique is adopted when theory is modest and can not guide the selection of terms for a model especially in complex models that are regulated by many factors.

2.6. Spatial Analyses

The geospatial analyses performed in this study were achieved in three stages. The first stage involved the characterization of spatial distribution of both heavy metals at the study area, using geostatistical tools within the ArcMap within ArcGIS 9.2 program [20]. This stage was achieved by computing the semivariance clouds in all directions using Eq. 1 [21] and tested for isotropy.

$$\gamma_h = \frac{1}{2N}\sum_{i=1}^{N}\left[Z(x) - Z(x+h)\right]^2 \qquad (1)$$

where γ_h is the semivariance, Z(x) the regionalized variable, and N(h) the number of pairs of sample data taken a distance (h) a part.

The second stage dealt with the modeling algorithm that involved the selection of the best empirical fit to represent the actual Pb and Zn spatial variations according to minimum Root Mean Square Error (RMSE). Parameter estimation of the final variogram model was implemented in this stage according to; (1) an independent range (distance of independency) for isotropical cases or major and minor ranges for non-isotropical cases, (2) a sill that represents the ordinary sample variance, and (3) a nugget representing the measurement error due to micro-regionalization. Generally, there are several theoretical models (e.g., linear, spherical, Gaussian or exponential) which were tested to represent spatial semivariance distribution. The selection of the best empirical semivariance model was based on both cross-validation test and provided smallest nugget value [22].

The final stage involved the estimation or prediction of Pb and Zn concentrations at unknown locations using kriging technique. Kriging is a simple linear weighted-interpolation scheme that assumes a weighing fraction for each point associated by each semivariance allocated at a known distance to the point under consideration by which the sum of all weight are set to be one.

3. Results and Discussion

3.1. Ordinary Statistics of Heavy Metal Concentrations

The mean concentrations and standard deviations of chemical properties and heavy metal (Pb and Zn) concentrations for all studied samples are shown in Table 1. The mean total concentrations of Pb and Zn in the street dust samples (115.3 and 228.2 µgg^{-1}, respectively) are much higher than the upper limits of their typical soil concentrations, 20 [23] and 90 µgg^{-1} [24], respectively. This likely reflects an anthropogenic source, especially derived from traffic and industrial activities at the study area. As Zn is used as a vulcanization agent in vehicle tires [25], the higher wearing rate at the high temperature in Al-Hashimeyeh may contribute to the high Zn content in the street dust. Tetraethyland tetramethyl-lead have been added to gasoline from the mid-1920s to increase the octane rating of the fuel, but early 2008 production of leaded gasoline was stopped and all gasoline, at present, is unleaded. The lead is converted to PbO and PbO_2 which are then transformed into volatile $PbCl_2$, $PbBr_2$ and PbBrCl by addition of dichloro- or dibromo-methane to the gasoline [26].

In urban soils, the mean total concentration of Pb and Zn were 98.8 and 86.8 µgg^{-1}, respectively. In comparison to dust samples, the urban soil samples have lower Pb and Zn concentration. The high standard deviation values, and thus standard error means associated with most of the chemical properties, are indications of the complexity of the system. This huge variation in the data is an indication of spatial dependence attributed to either inherited conditions from human interferences with nature and/or induced by various sources of contaminations at the area.

3.2. Sequential Extraction

The distribution of heavy metals Zn, and Pb in the five fractions: exchangeable (EXC), carbonate (CA), Fe–Mn oxides, organic matter (OM) and residual (RES) fractions for all studied samples are summarized in Figure. 2. The results obtained show that the amounts of heavy metals extracted from each fraction vary widely. As with Pb, Zn distribution among the various solid phases depended on the soils characteristics (Figure 2). Total Zn concentrations in urban soils were particularly variable (49.3-185.2 mg kg^{-1}).

Significant amounts of Zn were associated with the residue and the Fe oxides fractions. The 44.0% of the total Zn was found in the Fe-Mn oxide fraction, whereas residual-Zn accounted for 51.3%. These Zn fractions are considered to be occluded inside the crystalline structures and not readily available for plant absorption. The findings are in agreement with those of Shuman [27], who reported that soil Zn was mainly associated with crystalline Feoxides and with the non-extractable residual fraction.

Table 1. Descriptive basic statistics of the chemical properties and heavy metal (Pb and Zn) in the studied samples.

Parameter	Sample	Mean	S.D.	Mean (S.E.)
pHe	Street dust	7.5	0.36	0.07
	Urban soil	7.7	0.42	0.10
ECe	Street dust	16.4	16.8	3.30
	Urban soil	13.5	12.2	3.00
Cl^- (meq/L)	Street dust	127.4	150.4	29.50
	Urban soil	114.8	127.4	31.00
HCO_3(meq/L)	Street dust	22.2	16.0	3.10
	Urban soil	8.7	1.8	0.43
SO_4^{2-} (meq/L)	Street dust	51.7	36.10	7.1
	Urban soil	21.6	12.44	3.0
Na^+ (meq/L)	Street dust	98.6	136.1	26.70
	Urban soil	95.9	148.45	36.00
K^+ (meq/L)	Street dust	8.7	22.6	4.4
	Urban soil	2.0	1.5	0.35
Ca^{2+} (meq/L)	Street dust	62.83	37.4	7.3
	Urban soil	64.0	71.97	17.5
Mg^{2+} (meq/L)	Street dust	44.0	56.5	11.1
	Urban soil	28.7	36.6	8.9
%$CaCO_3$	Street dust	52.8	7.2	1.4
	Urban soil	37.0	8.9	2.2
%OM	Street dust	3.0	3.1	0.61
	Urban soil	1.3	0.50	0.12
CEC (cmol/kg)	Street dust	3.7	1.3	0.25
	Urban soil	7.8	3.0	0.71
Fe (mg/kg)	Street dust	2105.2	315.4	61.86
	Urban soil	721.9	333.4	80.85
Pb (mg/kg)	Street dust	115.3	95.2	18.67
	Urban soil	98.8	105.6	25.60
Zn (mg/kg)	Street dust	228.1	197.7	38.78
	Urban soil	86.86	34.7	8.43

Zinc associated with the chemically reactive fractions such as the Zn in exchangeable and adsorbed forms generally represented less than 10% of the total Zn in the studied soils. Similarly, Hseu [28] reported that Zn associated with the exchangeable and carbonate fractions in native tropical soils varied from approximately 2% to 6% of total Zn.

The greater the amounts of active sites for Zn sorption (mainly Mn and Fe oxides), the less Zn was found in the exchangeable fraction. Usero et al. [29] using also the Tessier method on four marine sediments found that Zn is bound to iron–manganese oxides. Maskall and Thornton [30] indicate that in contaminated soils, Zn is mainly found in the residual fractions. The results for dust street are similar, but with less association with the residual fraction and a higher percentage with the Fe oxides (65%).

Lead in the street dust and urban soil samples are mainly associated with the Fe-Mn oxides with 82.1, and 68.5% respectively. A study by Flores-Rodriguez et al.[31]

on the bioavailable and stable forms of roadside dust and soils found that the Fe-Mn crystalline hydroxides and carbonate fractions of suspended solids are the most important in terms of metal binding, irrespective of the heavy metal. This finding is in general agreement with the results of this study for lead. Studies on the fractionation of roadside soils have suggested that lead has a high affinity for carbonates or iron– manganese oxides [32]. As such, lead is generally considered to be immobile within the soil profile, primarily as a result of its small soluble component. It seems that the same fractionation profile exists for lead in street dust and urban soils.

Environmental risks of Pb and Zn were evaluated using the risk assessment code (RAC). The RAC assesses the availability of metals in solution by applying a scale to the percentage of sediments that can reduce metals in the adsorptive and exchangeable and bound to carbonate fractions [33]. These fractions are considered to be weakly bonded metals, which may equilibrate with the aqueous phase, and thus become more rapidly bioavailabile [34]. The results of the present study show that Zn in street dust poses a medium risk with 15% exists in exchangeable and carbonate fractions. While the percentage of urban Zn in exchangeable and carbonates fractions is 1%, posing a low environmental risk. The concentrations of Pb in urban and street dust samples pose a low risk to the environment with 8% and 9% respectively, exists in exchangeable and carbonate fractions. It is possible to suggest the sequence of mobility for Pb, Zn, in the street dust samples is as the following Zn>Pb while in urban soil it is as the following Pb>Zn.

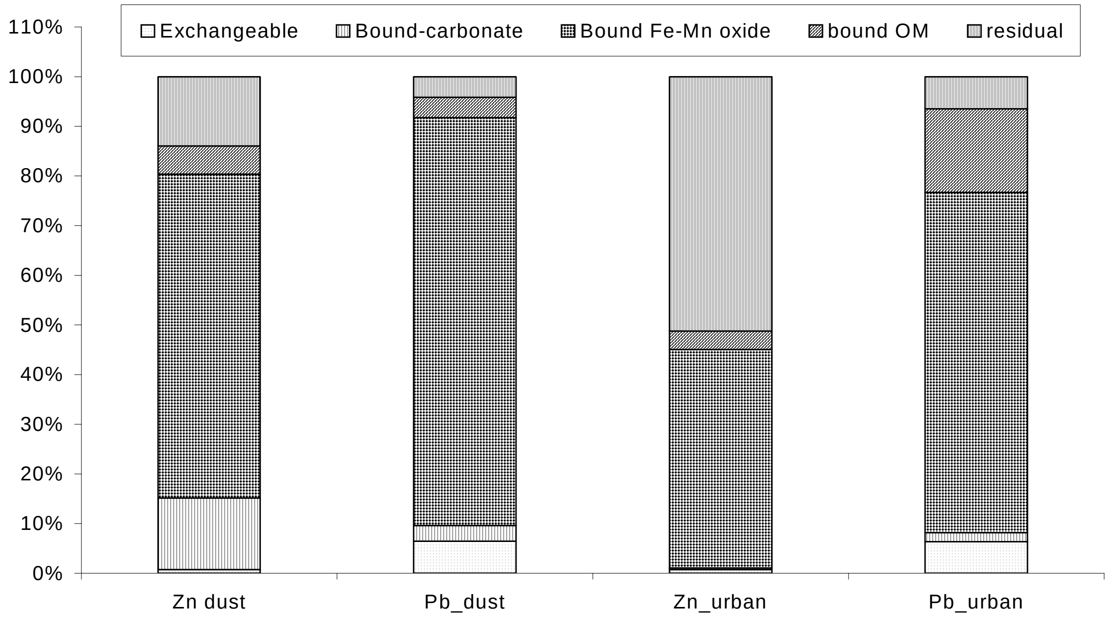

Figure 2. Percentage distributions of Zn and Pb in the studied soils .

3.3. Multivariate Analyses

Processes of metal mobilization–inmobilization are affected by a variety of soil properties [35]. To examine this influence, correlations between pH, carbonate, organic matter and contents of Zn and Pb in the five chemical phases of the sequential extraction have been established for all soils.

According to multivariate correlation analysis (Table 2), Pb concentration actually has a positive significant correlation with Zn of about 51% and inversely correlated to CEC with correlation coefficient of 34%. At the same time, Zn shows a high correlation with organic matter, hydrocarbonates and Fe with correlation coefficients of 58%, 46%, and 43%, respectively. Those relations represent the coefficient of determinations of single pair linear relations. The inter relations between the independent variables agree with the chemical analyses perspective such as the correlations of EC with Cl, SO_4^{2-} with EC, and Na^+ with Cl^-.

On the other hand, the partial multivariate correlation analysis (Table 3) represents the correlation corresponding to the presence of all chemical factors together as a multiple regression. The partial analysis indicates that sulfate, followed by Mg^{2+}, and CEC have a significant negative effect on Pb, while pHe, Cl^-, and HCO_3^- have significant positive effects of Pb. Also, Zn concentration is highly correlated to organic matter with correlation coefficient of 75% followed by K^+ content with a negative correlation coefficient of 59% which proves that Zn is highly associated with organic sources and competes by presence of potassium on the exchangeable sites.

3.4. Prediction Modeling

According to stepwise analysis using the backward strategy (Figure 3), the final effective significant linear prediction model for Pb concentration (R^2 of 56.2%, RMSE of 71.40 ppm) was as follows:

$$Pb(= -512.85 + 82.46\, pH + 0.85\, Cl^- + 4.25\, HCO_3^- - 2.62\, SO_4 - 1.44\, Mg - 10.65\, CEC + 0.23\, Zn. \quad (2)$$

This model suggests that the colinearity between chemical responses was removed, ending by the major significant individuals of pHe, Cl^-, HCO_3^-, SO_4, Mg, CEC, and Zn. Therefore, Pb contamination at the study area can

Table 2: Multivariate correlation analysis for some chemical response.

	pHe	ECe	Cl^-	HCO_3^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}	% $CaCO_3$	%OM	CEC	Fe mg/kg	Pb mg/kg	Zn mg/kg
pHe		-0.46	-0.45	-0.01	-0.22	-0.46	-0.04	-0.49	-0.32	-0.22	0.06	0.25	-0.26	0.23	0.28
ECe	-0.46		0.97	0.29	0.63	0.93	0.32	0.65	0.78	0.20	0.21	-0.24	0.07	0.12	-0.08
Cl^-	-0.45	0.97		0.28	0.63	0.91	0.32	0.65	0.83	0.16	0.19	-0.21	0.02	0.11	-0.10
HCO_3^-	-0.01	0.29	0.28		0.74	0.15	0.78	0.09	0.58	0.31	0.83	-0.40	0.49	0.18	0.46
SO_4^{2-}	-0.22	0.63	0.63	0.74		0.48	0.48	0.28	0.63	0.49	0.49	-0.42	0.40	0.03	0.20
Na^+	-0.46	0.93	0.91	0.15	0.48		0.20	0.75	0.70	0.13	0.11	-0.15	0.03	0.11	-0.11
K^+	-0.04	0.32	0.32	0.78	0.48	0.20		-0.01	0.69	0.08	0.88	-0.21	0.20	0.11	0.25
Ca^{2+}	-0.49	0.65	0.65	0.09	0.28	0.75	-0.01		0.53	-0.04	-0.07	-0.09	0.13	0.06	-0.11
Mg^{2+}	-0.32	0.78	0.83	0.58	0.63	0. 70	0.69	0.53		0.08	0.54	-0.20	0.19	0.06	0.07
%$CaCO_3$	-0.22	0.20	0.16	0.31	0.49	0.13	0.08	-0.04	0.08		0.18	-0.68	0.65	0.01	0.13
%OM	0.06	0.21	0.19	0.83	0.49	0.11	0.88	-0.07	0.54	0.18		-0.28	0.37	0.21	0.58
CEC	0.25	-0.24	-0.21	-0.40	-0.42	-0.15	-0.21	-0.09	-0.20	-0.68	-0.28		-0.62	-0.34	-0.33
Fe conc.	-0.26	0.07	0.02	0.49	0.40	0.03	0.20	0.13	0.19	0.65	0.37	-0.62		0.09	0.43
Pb conc.	0.23	0.12	0.11	0.18	0.03	0.11	0.11	0.06	0.06	0.01	0.21	-0.34	0.09		0.51
Zn conc.	0.28	-0.08	-0.10	0.46	0.20	-0.11	0.25	-0.11	0.07	0.13	0.58	-0.33	0.43	0.51	

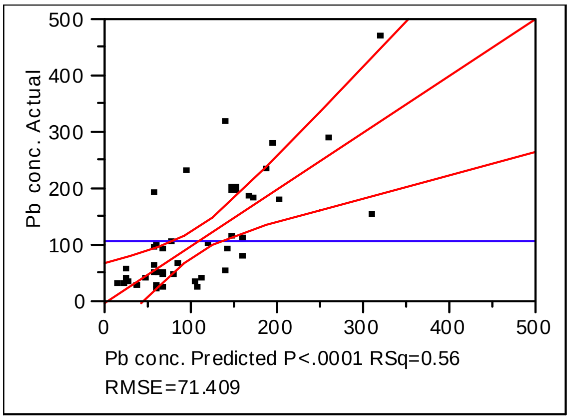

Figure 3. Predicted Model of Pb concentration using the Stepwise linear regression .

be predicted using the former multi-regressive model with negligible error.

On the other hand, Zn contaminants prediction model (Figure 4) estimated using stepwise regression (R^2 of 78.7%, RMSE of 83.12 ppm) suggests the effectiveness of K, $CaCO_3$, OM, Fe, and Pb as inter-related to Zn loads.as follows:

$$Zn = 4.66 - 9.91\ K - 2.72\ CaCO_3 + 91.47\ OM + 0.05\ Fe + 0.56\ Pb \qquad (3)$$

It is important to remark that the presence of both heavy metals in both prediction models is a clear indication of the direct correlation of both metals and approves the assumption of being both related to same subjected pollutant sources..

3.5. Spatial Modeling

According to spatial analysis, the Pb contamination at the study area appeared to have a nonisotropic behavior that is skewed due to heavy weight tail. However, the variability of Pb concentration was exponentially behaved in space with a major range (range of independence) of 78.6 km in 22.5 degree direction, minor range (perpendicular to major range) of 12.1 km and a partial sill (variance at which the semivariogram levels) of 0.21 ppm holding a nugget (smallest error that can not be detected due to smallest sampling spacing or zero separation distance) of 0.23 ppm as described in the following equation:

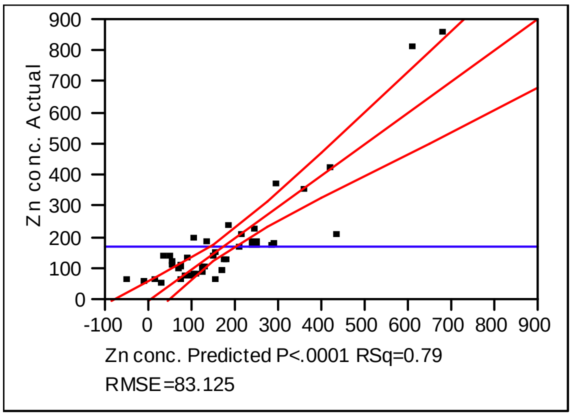

Figure 4. Predicted Model of Zn concentration using the Stepwise linear regression.

$$\gamma(h) = C_0 + C\,[1-\exp(-h/A)] \qquad (4)$$

where

h = lag class interval,

C_0 =0.23= nugget variance

C = 0.21 =structural variance

A = $A_1^2[\cos 2(\theta - \phi)] + A_2^2[\sin 2(\theta - \phi)]$

A_1 =78.6 km = range parameter for the major axis (ϕ)

A_2 = 12.1 km = range parameter for the minor axis ($\phi + \pi/2$)

ϕ = 22.5 = angle of maximum variation

θ = angle between pairs

Using point kriging with 5 neighbors surrounding technique, the final krigged map is given at Figure 5 with a

RMSE of 66.78. Final krigged map for Pb distribution in space indicates that Pb contamination is concentrated at the southern east territory of the study area and decreases towards the main Al-Hashemyiah city; and started again to rise near by the northern west of the study area near the power sanitation plant. The high Pb levels at the southern east territory was mainly due to the presence of the high way that is mainly used to transport and ship petroleum across the kingdom.

Similarly, Zn contamination is behaving nonisotropiclly with a high skweness which was exponentially distributed in space with a major range of 78.6 km in 289 degree direction, minor range of 12.1 km and a partial sill of 0.27 ppm holding a nugget of 0.18 ppm (Figure 6) as described by the following equation:

$$\gamma(h) = C_0 + C[1-\exp(-h/A)] \tag{5}$$

where

h = *lag class interval,*
$C_0 = 0.18$ = *nugget variance*
$C = 0.27$ = *structural variance*
$A = A_1^2[\cos 2(\theta - \phi)] + A_2^2[\sin 2(\theta - \phi)]$
$A_1 = 78.6$ km = *range parameter for the major axis* (ϕ)
$A_2 = 12.1$ km = *range parameter for the minor axis*
$\phi = 289$ = *angle of maximum variation*
θ = *angle between pairs*

According to the final krig distribution maps, Zn is behaving similarly to Pb in space by which both have a very high spatial dependence reflected by having high similar major and minor ranges. However, the differences in the non-iostropical variance directions in both spatial distributions of the heavy metals may not be attributed to differences in pollution sources, but rather may indicate the variability in the interactions with nature as explained by the sequential analyses.

4. Conclusion

This study served to evaluate the distribution, retention, and release of Zn and Pb in selected street dust and urban soil samples of the Al-Hashimeyeh municipality. The results obtained are a first approach to assess the environmental levels of these metals in function of their availability to the ecosystems.

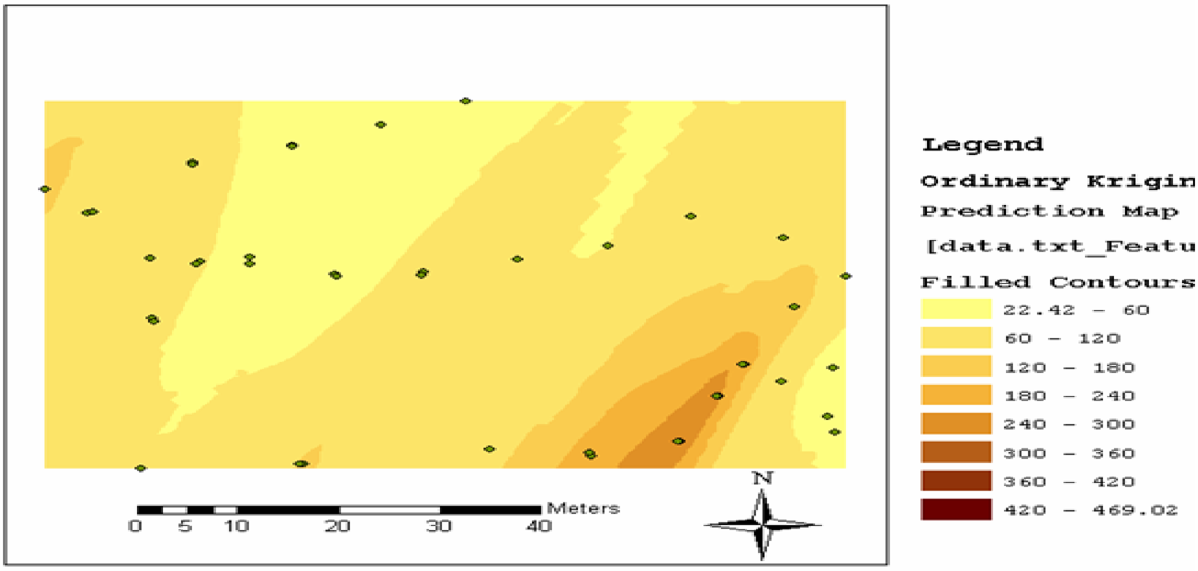

Figure 5. Spatial Kriging for Pb concentration of the studied samples in Al-Hashimeyeh.

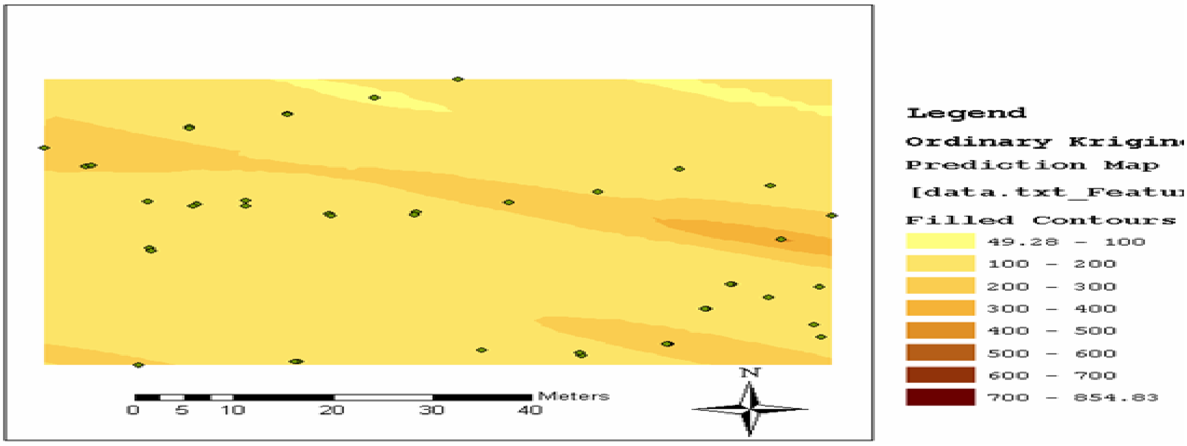

Figure 6. Spatial Kriging for Zn concentration of the studied samples in Al-Hashimeyeh.

Of the total amounts of Zn and Pb only very small proportions were extracted in a readily mobile form. Therefore, these low amounts suggest that metal migration downwards would be limited. The largest proportions for Zn and Pb were extracted in the iron oxide fraction, in which metals are strongly retained in the soil minerals. Nevertheless, this is not expected in the agroecosystems of our region because soil conditions are highly alkaline with a high buffering capacity due to carbonates that can also contribute to retain heavy metals. Further, the high metal loads allocated at or close to industrial zones suggest that major contamination sources were traffic emissions from heavy vehicles along the highways and the industrial activities allocated within the study area.

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