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A statistical and support vector machine approach for assessing heavy metal contamination in soil, dust and rainwater from the Arak city, Iran

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ABSTRACT: This investigation was performed to provide heavy metal signatures of urban soils, dusts, rainwater and to evaluate potential sources in Arak, Markazi Province. Thirty-one samples of urban soils, 29 dust and16 rainwater samples were collected in Arak city. Then, Pb, Cu, Zn, As and Ni concentrations were determined by using atomic absorption spectrophotometry. Application of discriminant analysis, correlation matrix, cluster analysis and support vector machines showed that Pb, Cu, As and Ni in soils, dust and rainwater have similar source and Zn has different source. Contaminations in soils, dusts, rainwater were classified as enrichment factor (EF). EF values indicate that heavy metal pollution levels of soils, dusts, rainwater collected from industrialization sites are greater than those of distal parts of industrialization. Spreading of hazardous wastes from industrial activities in the study area is the main sources of soils, dusts, rainwater pollution. In addition, agricultural wastes and traffic-related metal pollution is also observed.
Keywords: Contamination, heavy metals, natural and anthropogenic sources, enrichment factor, Arak

INTRODUCTION

The study of heavy metals in soils, dusts and rainwater has increased in the last decades because of their adverse environmental and human health effects (Umeobika et al., 2013; Maas et al., 2010; Wei and Yang, 2010; Shaofei et al.,2011; Zhao and Zhao, 2012).With rapid development in industrialization, contamination has become a serious problem in many countries. Contamination and negative impact on the quality of air, water and soil by population growth, rapid urbanization, and industrial activities have been stated by several works (Jickells et al., 2012; Zamani et al., 2012; Ghadimi and Ghomi, 2013; Ghomi et al.,2013; Ren and Yang, 2014; Li et al.,2014). Among the most significant soils, dusts and rainwater contaminants resulting from both natural and manmade sources, heavy metals are of prime importance due to their longterm toxicity effect(Beasley and Kneale, 2004;Sharma et al., 2007; Sun et al., 2010). Metal content in soils, dusts and rainwater is the combination of metals arising from human activities and natural processes. The release of anthropogenic metals to the soils, dusts and rainwater is much greater than contribution of metals from natural sources (Lu et al., 2010; Maas et al., 2010; Zhao et al., 2010; Wang et al., 2012;Ghomi et al., 2013; Manzano et al., 2014). Increase in metal content in soils, dusts and rain is generally observed in areas of intense industrial activities. Metal accumulation in these areas is a few times higher than uncontaminated sites. However, due to long-distance atmospheric transport, high metal concentrations may also be detected in distal parts of industrial centers (Shaofei et al., 2011; Garcia et al., 2009; Hou et al., 2005; Mullaugh et al., 2013; Li et al., 2014). The most important impact of soil pollution on environmental health is that contaminants in soil can be introduced into the food chain by plants and by their direct use or consumption by animals feeding on them (Zamani et al., 2012). Therefore, metal pollution in areas of industrial activities is of great concern (Ghadimi and Ghomi, 2013).

Arak is one of the regions affected by soils, dusts and rainfall contamination of industrial origin. The region is one of the industrial regions in Iran where the impact of rapid population growth and industrialization on limited natural sources and agricultural lands is progressively high and as a result, the size of uncontaminated areas is getting diminished. Due to expanding industrialization and urbanization in Arak and the unrestrained disposal of factory wastes to soils, dusts and rainfall, it is thought that heavy metal contents in this region are high. Therefore, monitoring of this change and determination of contamination in soils, dusts and rainfall has gained importance.

The objectives of this study were (1) to determine average concentrations of five heavy metals(Pb, Cu, Zn, As and Ni) in urban soils, dusts and rainfall; (2) to identify heavy metal sources by multivariate analysis; and (3) to gauge the degree of anthropogenic influence on heavy metal contamination in Arak city.

MATERIALS AND METHODS

Study area

Arak City is located in the center of Iran and is one of the biggest industrial cities in Iran. Economy of the district is mainly based on industry and it is one of the rapidly growing and developing regions in Markazi province (Figure1). The rapid expansion of industrial activities, particularly, after the 1990s has given rise to a jump in the population of the city as well hosting several plants belonging to various industrial sectors. There are several organized industrial small towns in Arak. Industrial facilities including paint, plastic, electric, metal, automotive supply industry, food, cosmetics, packing, machinery, and chemical sectors are currently in operation in these organized industrial area. Furthermore, it was estimated that over 50 thousand motor vehicles in the city from 2012 and people want to know, that is any pollution due to heavy metals in air and soil of Arak city and which of element polluted air and soil. The city is located in a semi-arid zone, with the annual mean air temperature 18°C while the annual rainfall is 250mm.

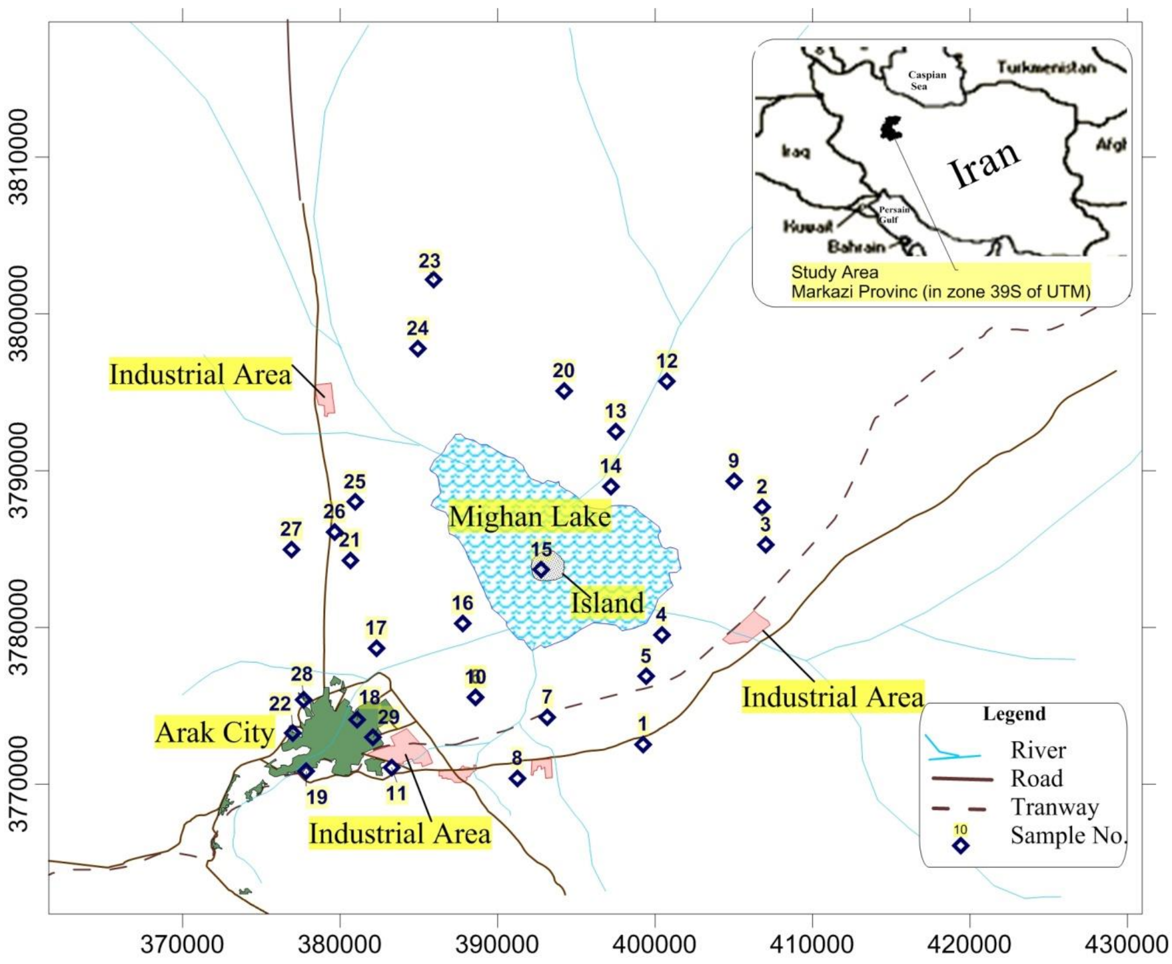

Figure1. Location of the collected samples in Arak city

Sampling and analysis

A series of investigations over soil, dust and rainwater were conducted during September 2012.A total of 31 soil and 29 dust samples were collected. Plastic spatula was used for sample collection. Samples were dried at room temperature and ground before analysis. The materials under 80-mesh sieve were sent to laboratory for analyses.

During the analysis, 1 g of soil and dust sample was left in 2 ml HNO_3, 2M solution for 1 h. The samples were then added to 6 ml of 2:2:2 HCl–HNO_3–H_2O solutions, dissolved at 95 °C for 1 h, and analyzed with ICP-MS. 16 samples of rainwater were collected on the roof of the general buildings. The samplers used for collection contained a 20-cm diameter funnel made of high-density polyethylene, which was set at 1.2 m above the roof. The funnel was connected with a 20 L high density polyethylene container. The filtered samples (0.45 μm) were acidified to pH less than 2 using HCl 6N. The samples were stored at 4 °C for later analysis. The samples were analyzed using Potentiometer (ION^3) for heavy elements. 16 samples of rainwater were collected on the roof of the general buildings. The samplers used for collection contained a 20-cm diameter funnel made of high-density polyethylene, which was set at 1.2 m above the roof. The funnel was connected with a 20 L high density polyethylene container. The water volume was measured in situ. The filtered samples (0.45 μm) were acidified to pH less than 2 using HCl 6N. The samples were stored at 4 °C for later analysis. The samples were analyzed using Potentiometer (ION^3) for heavy elements. The precision and bias of the analysis for major ions and trace metals were determined from quality control check samples prepared in the laboratory. Five replicate measurements of each element were made. The precision and bias of the analysis for major ions and trace metals were determined from quality control check samples prepared in the laboratory. For soil, dust and rainwater samples, standard samples and duplicated samples were simultaneously performed in the two analyses as quality control.

Statistical analysis

A multivariate statistical analysis of discriminate analysis, correlation matrix and cluster analysis were performed to identify the factors that could explain the correlation model between the data variables (Idris, 2008; Sielaff and Einax, 2007). Discriminate analysis is an exploratory statistical procedure that determines how well it is possible to separate two or more groups based on the values of several variables for those groups. It uses Mahalanobis distances to calculate how far individual cases are from the group means for the variables, and assigns the case to the group with the closest mean. Using the large set of metal data collected through analysis of the soil, dust and rainwater samples, it is possible to see if certain metals are more characteristic of different sources of pollution by using discriminant analysis. If this occurs, then the predicted major source of contamination for each soil, dust and rainwater sample can be confirmed, and future soil, dust and rainwater samples can be entered into the discriminant analysis equation to determine the source of pollution. In order to analyze and confirm the relationship among heavy metal content in soil, dust and rainwater samples, a Pearson's correlation analysis was applied to dataset. Cluster analysis was also used to find homogeneous groups of samples based on their geochemical compositions (Lambrakis et al., 2004) The Single linkage method was applied and the Euclidean distance was used for the regrouping of samples and to identify distribution model of the metal content in the soils, dust and rainwater. The variables with reduced distance are more similar than those with longer distances and therefore, could be grouped within the same cluster. The results obtained can be represented in a dendogram, which shows the levels of similarity between the different variables (Zupan et al., 2000). Statistica software package has been used for the data processing.

Support Vector Machines

Support Vector Machines (SVM), formally described by Vapnik (1998), has the ability to define non-linear decision boundaries in high-dimensional variable space by solving a quadratic optimization problem (Hsu et al., 2010; Karatzoglou et al., 2006). Basic SVM theory states that for a non-linearly separable dataset containing points from two classes, there are an infinite number of hyper-planes that divide classes. The selection of a hyper-plane that optimally separate two classes (i.e. the decision boundary) is carried out using only a subset of training samples known as support vectors. The maximal margin M (distance) between the support vectors is taken to represent the optimal decision boundary. In non-separable linear cases, SVM finds M while incorporating a cost parameter C, which defines a penalty for misclassifying support vectors. High values of C generate complex decision boundaries in order to misclassify as few support vectors as possible (Karatzoglou et al., 2006). For problems where classes are not linearly separable, SVM uses an implicit transformation of input variables using a kernel function. Kernel functions allow SVM to separate non-linearly separable support vectors using a linear hyper-plane. Selection of an appropriate kernel function and kernel widths, are required to optimize performance for most applications (Hsu et al., 2010).

Enrichment Factor

The enrichment factor (EF) can be utilized to differentiate between the metals originating from human activities and those from natural procedure, and to assess the degree of anthropogenic influence. One such technique that has often been applied is normalization of a tested element against a reference one. Here a question arose about which element can be chosen as a reference element. A reference element is often a conservative one, such as the most commonly used elements: Al, Fe, Me, Mn, Sc, Ti etc (Sutherland, 2000). Therefore, Fe is expected to be a conservative element and may be chosen as the reference element. The value of the enrichment factor was calculated by the modified formula suggested by Buat-Menard and Chesselet (1979) (Eq. 1):

$$EF= [C_{n(Sample)}/C_{ref(Sample)}]/[B_{n(Baseline)}/B_{ref(Baseline)}] \qquad \text{Eq. 1}$$

Where, $C_{n(Sample)}$ is the concentration of the examined element in soils and urban dusts, $C_{ref(Sample)}$ is the concentration of the reference element in soils and urban dusts, $B_{n(Baseline)}$ is the content of the examined element in upper continental crust(UCC) (Taylor and McLennan 1995), $B_{ref(Baseline)}$ is the content of the reference element in UCC. EF can give an insight into differentiating an anthropogenic source from a natural origin. EF close to 1 shows a crustal origin while those greater than 10 are considered to have a non-crustal source (Nolting et al., 1999). Further, EF can also assist the determination of the degree of metal contamination. Five contamination categories are recognized on the basis of the enrichment factor (Sutherland, 2000).
EF<2: deficiency to minimal enrichment
2≤ EF<5: moderate enrichment
5≤ EF<20: significant enrichment
20≤ EF<40: very high enrichment
40 ≤ EF: extremely high enrichment

But for rainwater, $EF_{natural}$ is source estimators of heavy metal and have been used to estimate anthropogenic, natural origins in rainwater (Chabas and Lefevre, 2000). Fe is selected as a reference element for calculation of EF_{crust} by Equ. 3 :

$$EF_{natural}X = [(X/Fe)_{rain}]/(X/Fe)_{natural} \qquad (3)$$

The $(X/Fe)_{natural}$ is taken from Keene et al. (1986), and Taylor and McLennan (1985). $EF_{natural}$ fall in a range of 1– 10 which suggests crust or natural sources, 10– 500, moderate enrichment, and >500, extreme enrichment, respectively (Poissant et al., 1994). A severe contamination caused by human activities can be indicated by extreme EF enrichment. Using the UCC (Taylor and McLennan, 1985) concentrations of each trace metal in Arak, the $EF_{natural}$ factors were calculated using the Fe concentration determined in the rainwater samples.

RESULTS AND DISCUSSION

Heavy metal concentrations of soil samples

Descriptive statistics for five elements used in this study are shown in Table 1. Reference values (upper continental crust) (UCC) of the studied metals (Caritat and Reimann, 2012; Taylor and McLennan, 1995) are also included this table. Most of the elements have a wide range of variations of several magnitudes. Lead concentrations in Arak soils are between 3.01 and 17.36 mg/kg with an average of 8.05 mg/kg which is noticeably lower than values upper continental crust (Table 1). Based on the average value, Arak soils are uncontaminated while the maximum value implies also that soils are uncontaminated. Copper content of soils in the Arak region are between 9.60 and 195mg/kg with an average 37 mg/kg which is applicably greater than that in uncontaminated soils. The minimum Zn concentration in Arak soils is 0.85 mg/kg and the maximum value is 68 mg/kg. The average Zn concentration is 12 mg/kg which is lower than Zn concentrations reported in the literature (47 mg/kg, Table 1). The minimum As concentration in Arak soils is 1.41 mg/kg and the maximum value is 4.50 mg/kg. The average As concentration is 2.48 mg/kg which is lower than As concentrations reported in the literature (5 mg/kg) (Table 1). Nickle concentrations in Arak soils are between 12 and 63 mg/kg with an average of 39 mg/kg which is noticeably higher than values reported in the literature.

The mean concentrations of Pb, Cu, Zn, As and Ni in dusts are 43, 45, 9.28, 7.05and 28 mg/kg and the maximum concentrations of Pb, Cu, Zn, As and Ni are 104, 285, 98, 10 and 43 mg/kg, respectively. Compared with upper continental crust, the heavy metal mean concentrations of urban dusts in Arak are much higher (except Zn). This suggests that heavy metal may have mainly an anthropogenic source and Zn has natural source.

The most abundant heavy metal in rainwater was followed by Pb (0.18 mg/kg), Cu (0.09 mg/kg), Zn (0.18 mg/kg), As (0.26 mg/kg) and Ni (0.93 mg/kg) (Table 1). Such a large amount of all above metals in rainwater has been found in many polluted sites worldwide (Ozsoy and Ornektekin, 2009; Farahmandkia et al., 2010). Information for As limited. The metal concentrations in rainwater, cited from literature, were compared with our data (Table 1). The concentration of Ni in Arak was comparable to the values cited in Turkey (Ozsoy and Ornektekin, 2009), and Cu was also in agreement with Paris district (Garnaud et al., 1999).However, our data for Zn and Pb were near the Dutch delta area (Nguyen et al., 1990) whereas those for Fe were near the minimum. Among the rare metals, As was almost lower than in concentration to the cited values by Andreae (1980).

Table1. Concentrations of heavy metals in the soil, dust and rainwater samples around the Arak city (all concentration in mg/kg).

Variables	Parameter	Valid N.	Mean	Minimum	Maximum	Upper continental crust(UCC)
	Soil	31	8.99	3.01	17.36	
Pb	Dust	29	43	16	104	17
	Rainwater	16	0.18	0.01	0.80	
	Soil	31	37	9.60	195	
Cu	Dust	29	45	3.12	285	13
	Rainwater	16	0.09	0.001	0.65	
	Soil	31	12	0.85	68	
Zn	Dust	29	9.28	1.14	98	47
	Rainwater	16	0.18	0.07	0.62	
	Soil	31	2.48	1.41	4.50	
As	Dust	29	7.05	3.50	10	5
	Rainwater	16	0.26	0.03	0.83	
	Soil	31	39	12	63	
Ni	Dust	29	28	14	43	18
	Rainwater	16	0.93	0.02	6.56	

Statistical analysis

Discriminant analysis

It should be noted that parametric statistical tests require the data to be normally distributed. Therefore, it was checked, the data came from a population with normal distribution by applying Shapiro-Wilk's test (significance level, = 0.05).We employed the discriminant analysis to determine whether three investigated sampled groups (soil, dust and rainwater) differed significantly in terms of heavy metal concentration. For this purpose, we first entered the three sampled groups as grouping variables. The five heavy metal concentrations were also entered as the independent variables. The obtained results presented in Table 2 clearly indicate that soil, dust and rainwater groups exhibit similar concentrations of heavy metals (except for Zn). It is evident that for each metal under investigation, a low degree of variations among groups exist. Canonical correlation has values between 0.0001 to 0.0007 and Wilk's lambda statistic range from 0.0013 to 0.0018 for Pb, Cu, As and Ni, therefore, there is a few lower degree of variations within-groups and three groups of soil, dust and rainwater have similar variations and similar source of contamination in Arak city. Generally, the larger the canonical correlation statistic, the greater between groups variation as a proportion of the total variation and the larger the Wilk's lambda statistic, the greater is the within-group variation as a proportion of the total variation(Idris, 2008). The scatter plot illustrates the similarity between groups in terms of the frequency concentrations of the various heavy metals (Figures 2, 3).

Table 2. Discriminant analyses results for the three investigated groups.

	Wilks' - Lambda	Canonical correlation
Pb	0.0014	0.0007
Cu	0.0014	0.0001
Zn	0.9999	0.8791
As	0.0018	0.0001
Ni	0.0013	0.0002

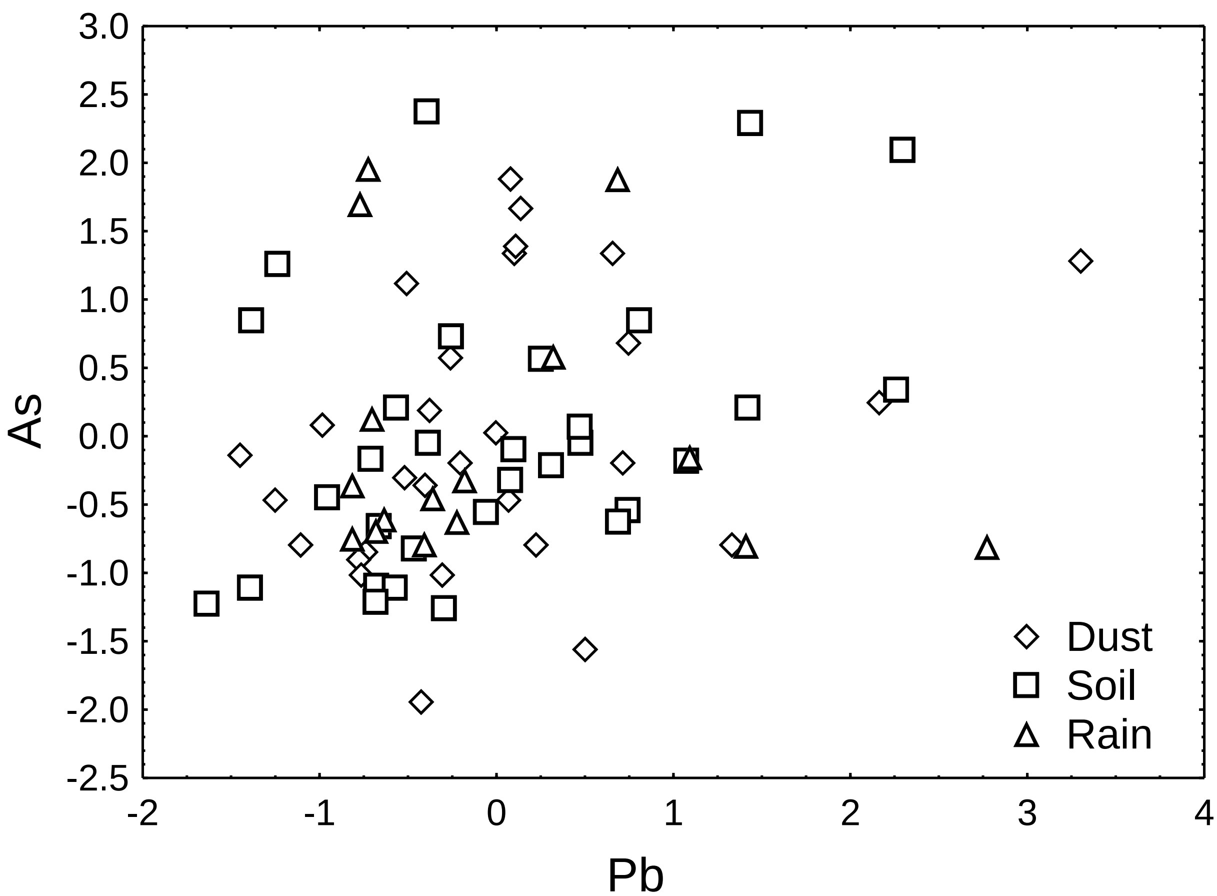

Figure2. Scatter plot of Pb against As in soil, dust and rainwater of Arak.

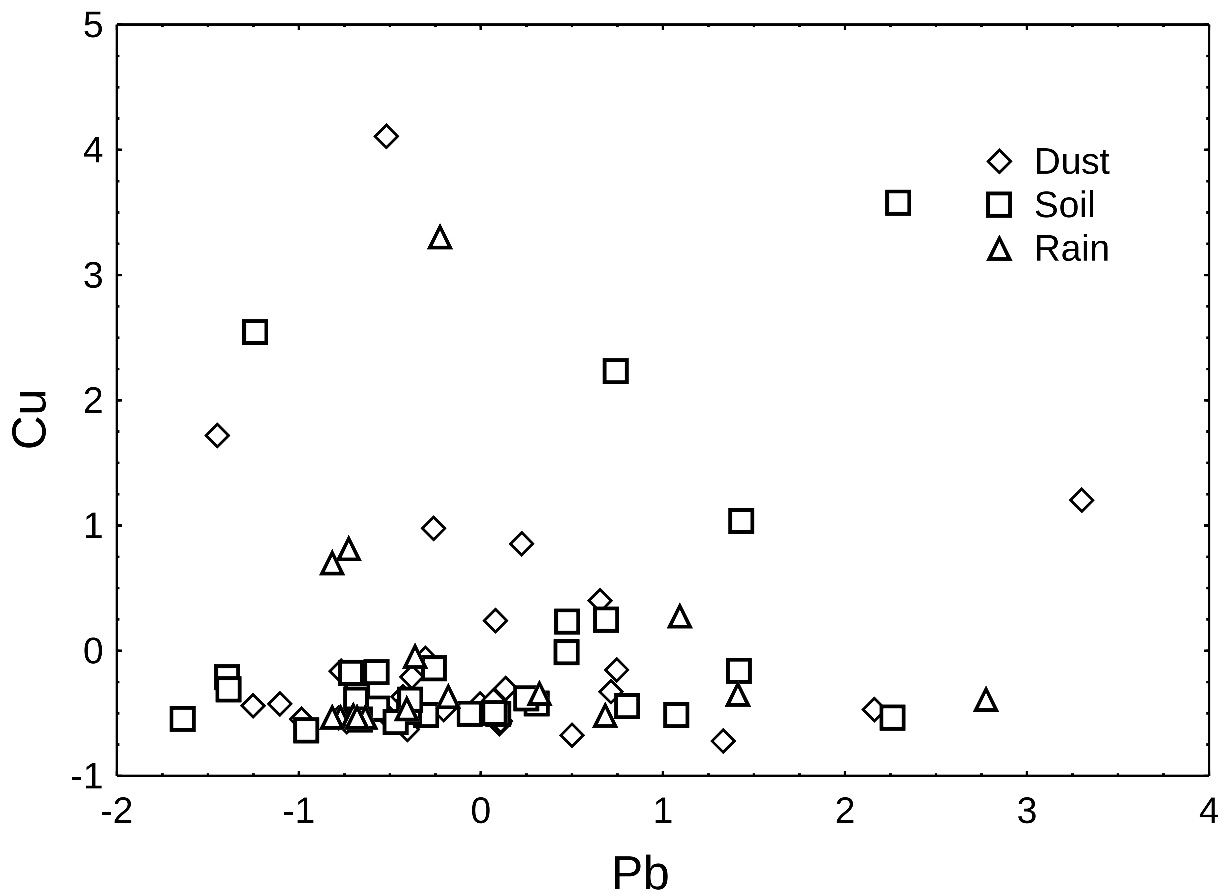

Figure3. Scatter plot of Pb against Cu in soil, dust and rainwater of Arak.

Canonical correlation has values 0.8791 and Wilk's lambda statistic 0.9999 for Zn, thus, three groups of soil, dust and rainwater have different variations and different contamination source in Arak city. The scatter plots of Pb,As,Cu and Ni with Zn illustrate the significant differences between the three groups in terms of the frequency concentrations(Figures4.5).

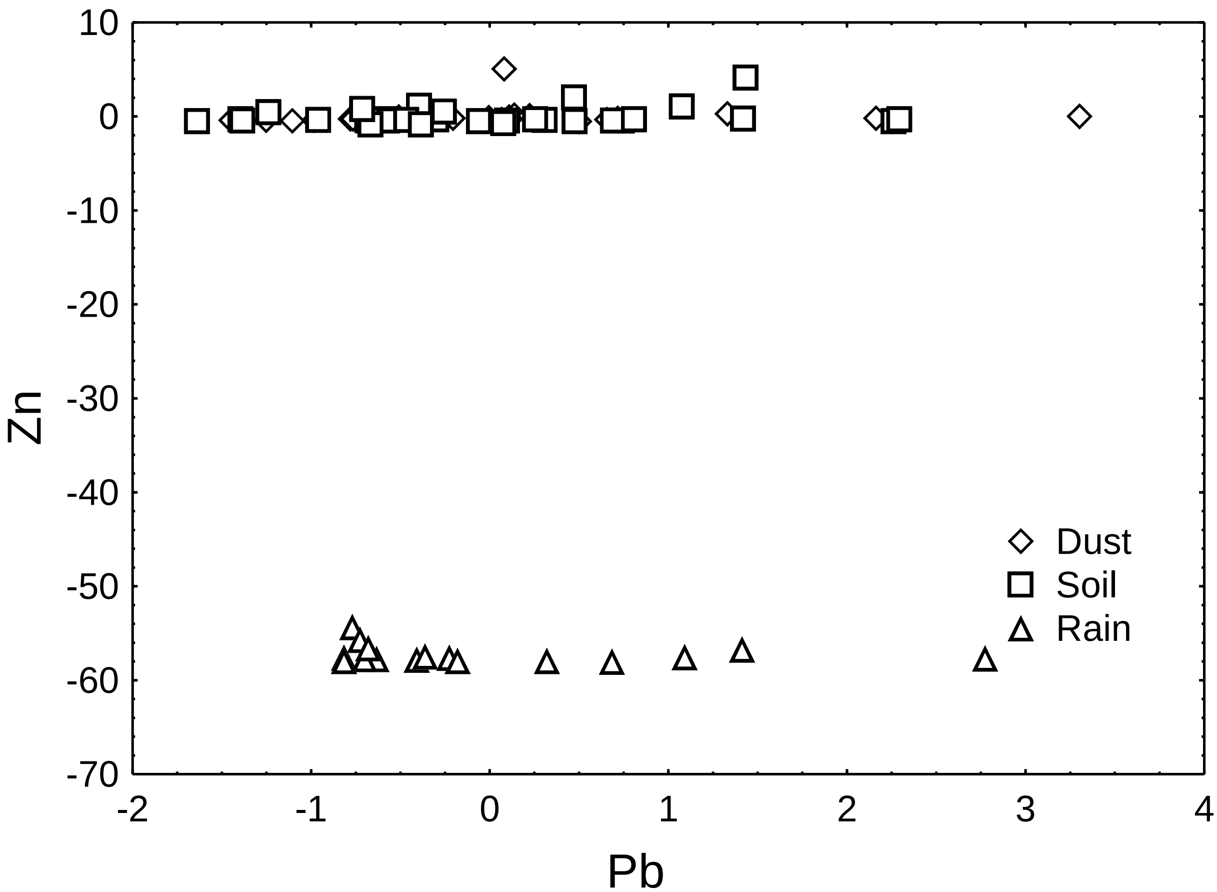

Figure4. Scatter plot of Pb against Zn in soil, dust and rainwater of Arak.

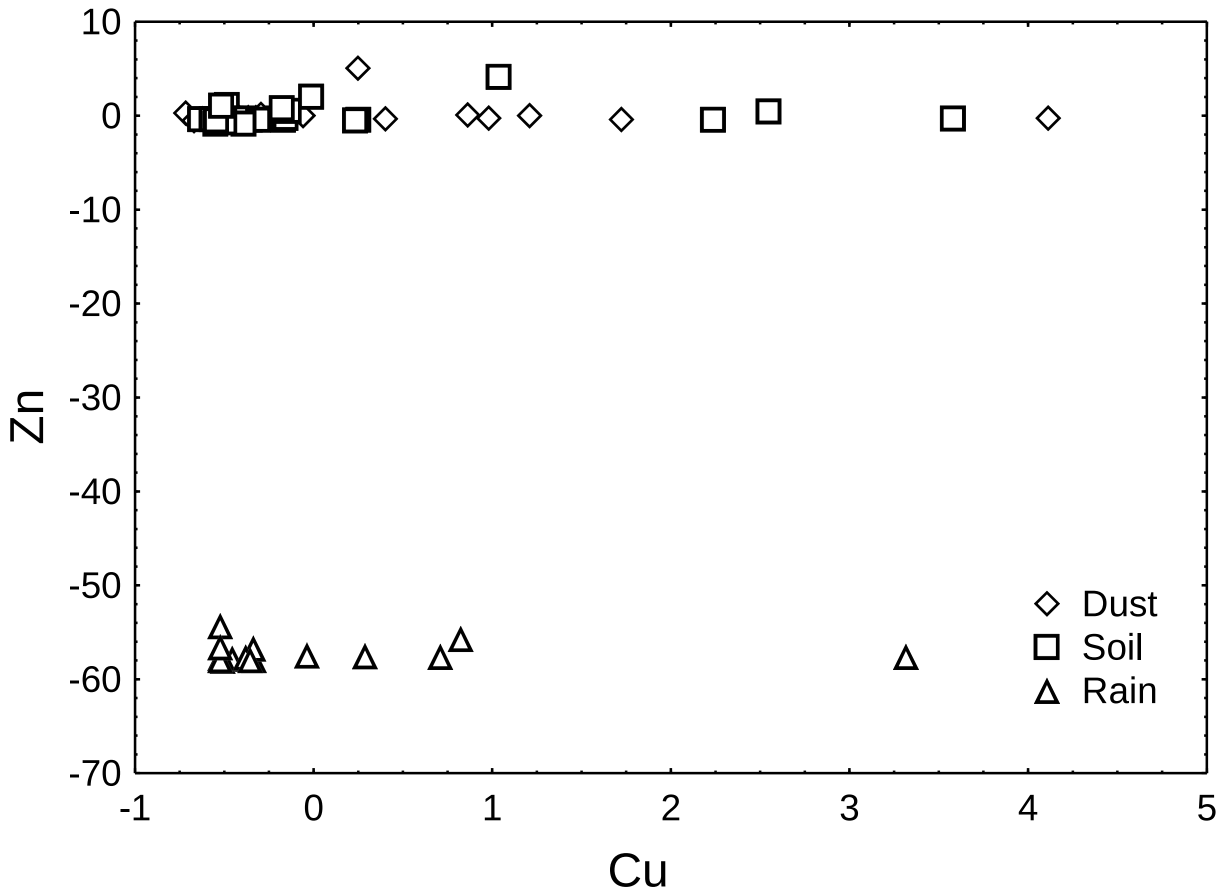

Figure5. Scatter plot of Cu against Zn in soil, dust and rainwater of Arak.

Correlation between heavy metals

Correlation analysis for the studied elements in soil, dust and rainwater samples is very useful for determination of multi-element relations. Pearson correlation analysis between all the variables was performed. Heavy metals such as Pb, Cu, As, Ni (except Zn) are closely associated with each other. Table 3 shows that all elements except Zn under investigation are significant at a level of $p \leq 0.01$. Significant correlations between these metals indicate that contaminants and hazardous metals in the Arak soil, dust and rainwater have a similar source and Zn has weakly correlated with other elements at a significance level of $p \leq 0.01$ and has different source.

Table3. Pearson correlation coefficient matrix for elements in the soil, dust and rainwater samples ($p \leq 0.01$).

Variables	Pb	Cu	Zn	As	Ni
Pb	1.00				
Cu	0.12	1.00			
Zn	0.01	0.00	1.00		
As	0.26	0.21	0.02	1.00	
Ni	0.12	0.14	0.00	-0.10	1.00

Cluster analysis

In order to reveal relationship between elements and element groups, cluster analysis was performed. Using Single-linkage and Pearson's correlation coefficients cluster analysis (hierarchical cluster analysis) was carried out and the results are given in a dendogram (Figure6). Results of cluster analysis indicate that the elements comprise two main groups. The first group is composed Zn and the second group is composed of Pb, As, Cu and Ni with similar source and is different with Zn source. Both groups coincide with results of discriminant analysis and correlation matrix.

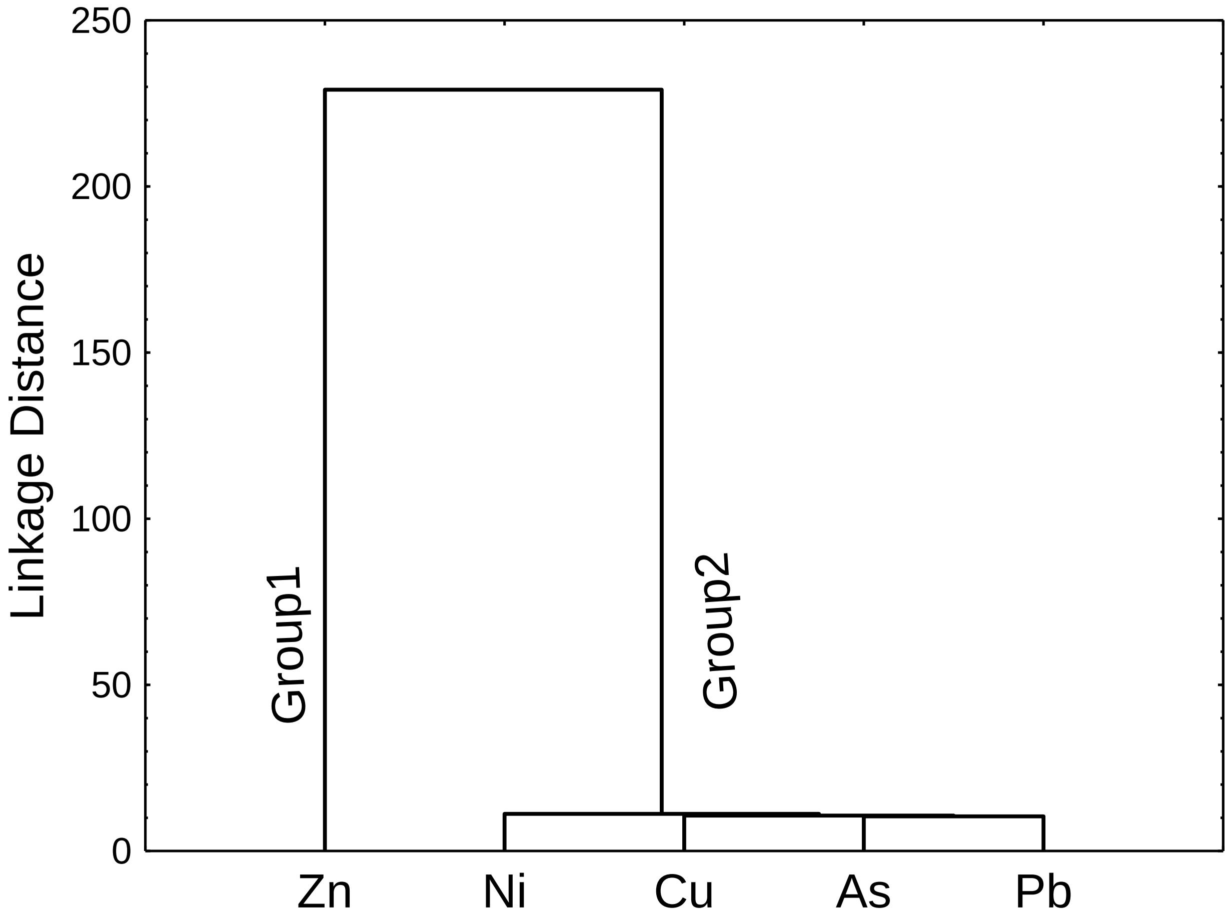

Figure6. Dendogram of heavy metals in soil, dust and rainwater samples.

Application of the Support Vector Machines

To apply the Support Vector Machines method, 5 information layers of heavy metals were considered as key criteria. The concentrations of Pb, Cu, Zn, As and Ni were examined to classify them into three classes (soil, dust and rainwater). The separate class identifies an extremely good qualitative class. But, if samples belong to similar class, there is similar source. The main objective of this study was to determine whether the sources of heavy metals in soil, dust and rainwater are or are not similar in the study area. The polynomial kernel function is used to prepare the best discrepancy between soil, dust and rainwater samples. Applying this function requires the determination of the degree of a polynomial (D), capacity constant(C) (Karatzoglou et al., 2006). After testing several degrees and capacity constant, the optimal D equal 3 and C equal 150 is obtained (Fig.7). The correct classification was calculated by above degree of a polynomial (D), capacity constant(C) is shown in confusion matrix. The confusion matrix was obtained by dividing the summation of diagonal elements by overall samples. This matrix function allowed the comparison of the three parameters (soil, dust and rainwater) classes (Table4). Confusion matrix indicates a correct classification for rainwater (100%), but correct classification for soil and dust is 90% and 21%, respectively (Table 4). Confidence level and prediction scatter plots were carried out to evaluate the classifier method in most classification problems (Figures7,8,9,10,11).Above figures show the classification of the heavy metals using the Support Vector Machines for soil, dust and rainwater. All of samples have overlap in above figures based on Pb and As. Scatter plots of heavy metals show that, there is not classification among soil, dust and rainwater samples and above metals has similar source and the source of pollution in soil, dust and rainwater samples are similar based on Pb, Cu, As and Ni. Soil, dust and rainwater samples separate to three groups based on Zn metal (Figures 7,8,9,10, 11) and the source of contamination is difference relative to other heavy metals. The results of this method coincide with results of statistical method such as discriminant and cluster analysis.

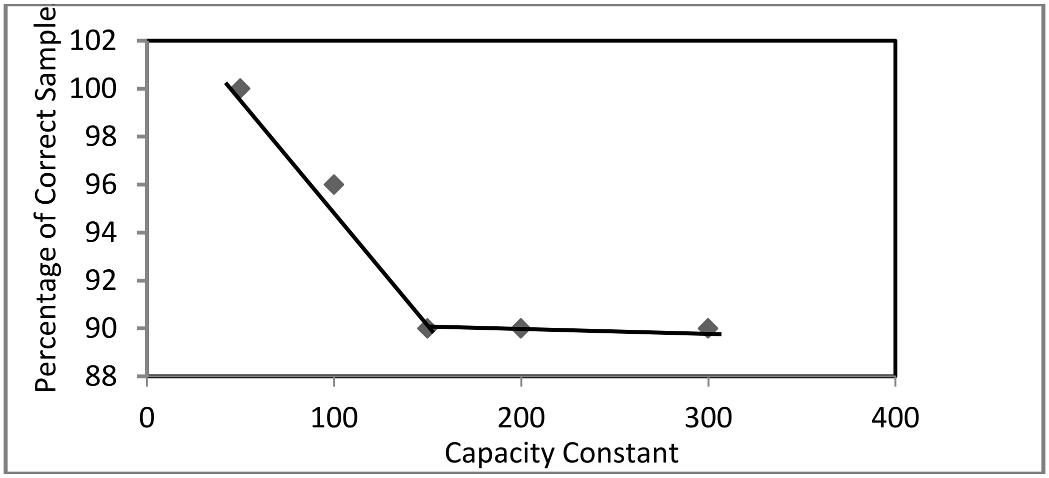

Figure7. Optimization of the capacity constant the polynomial kernel function for dust.

Table4. Confusion matrix for overall samples (Polynomial kernel)

	Total samples No.	Correct samples No.	Incorrect samples No.	Percentage of Correct samples	Percentage of incorrect samples
Soil	31	28	3	90	10
Dust	29	6	23	21	79
Rainwater	16	16	0	100	0

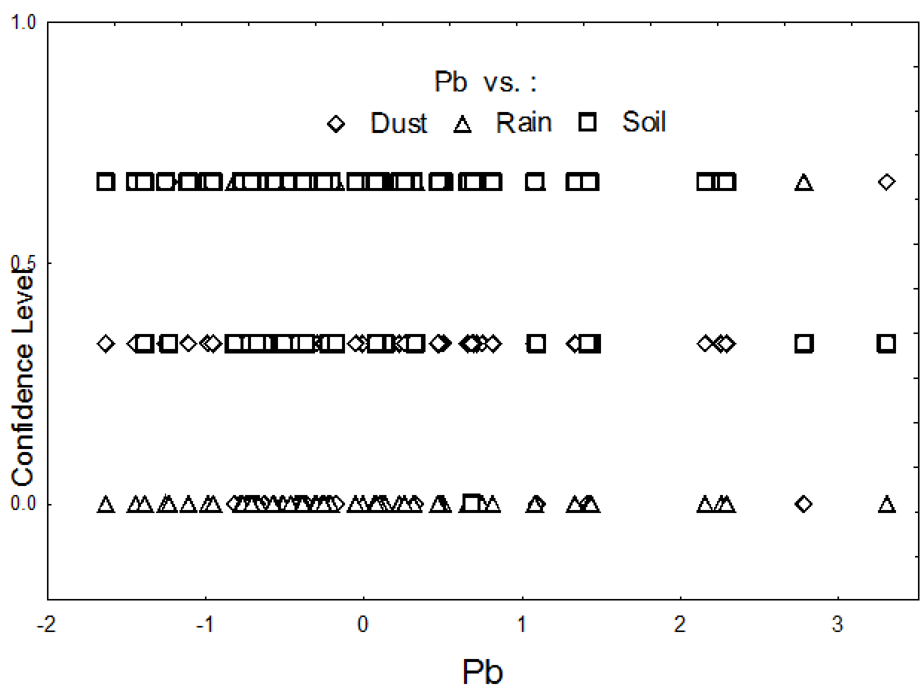

Figure8. Scatter plot of Pb against confidence levels in soil, dust and rainwater samples.

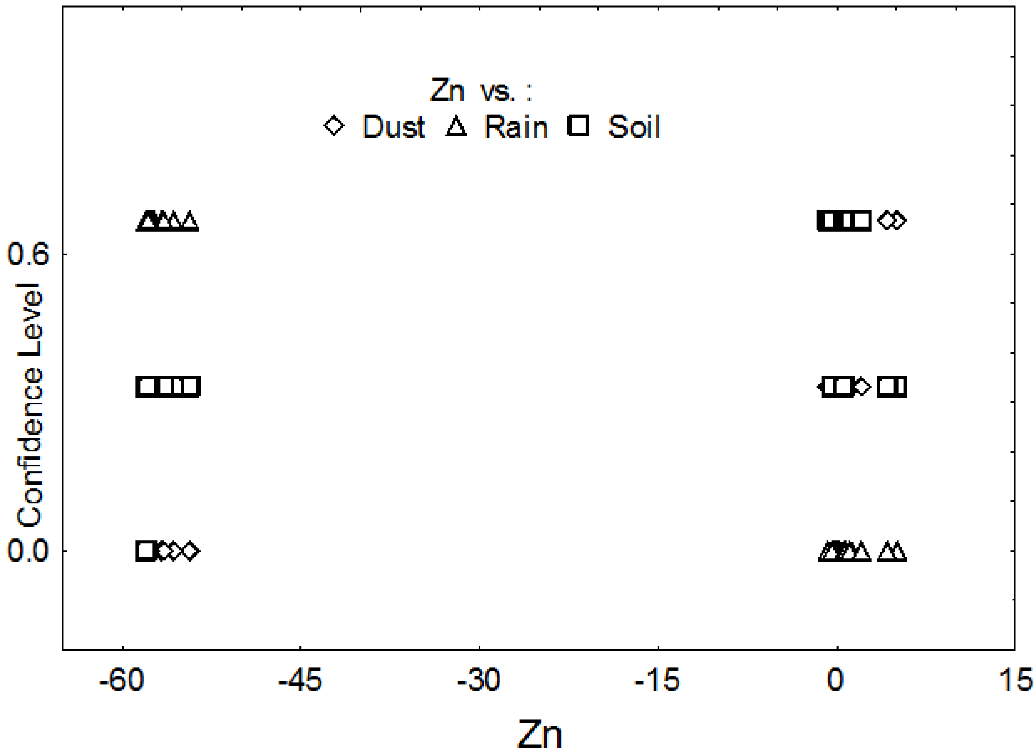

Figure9. Scatter plot of Zn against confidence levels in soil, dust and rainwater samples.

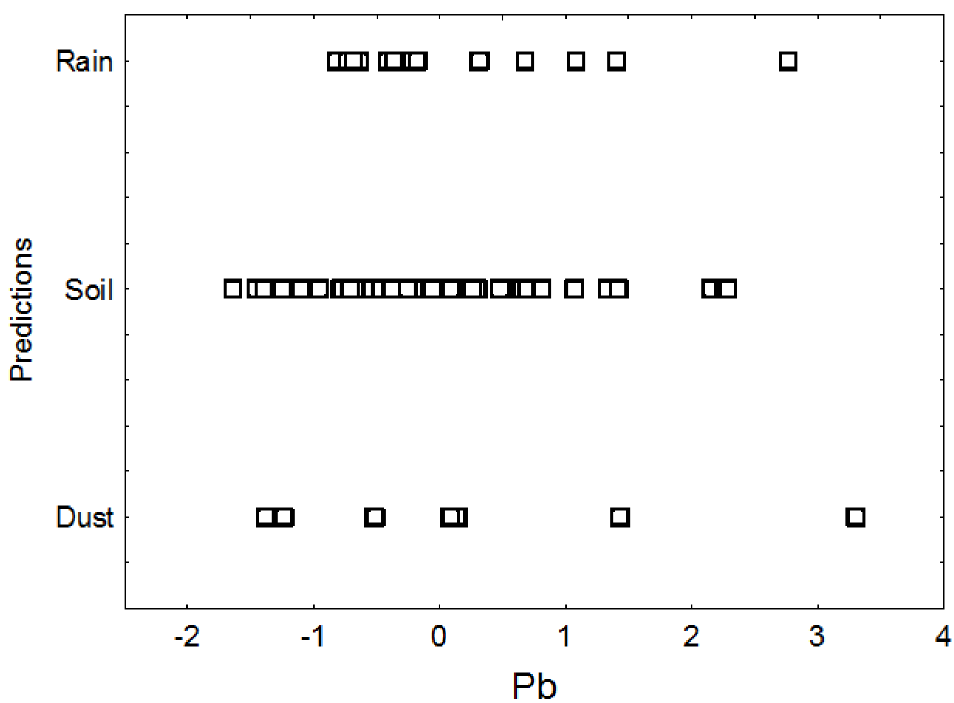

Figure10. Scatter plot of Pb against prediction in soil, dust and rainwater samples.

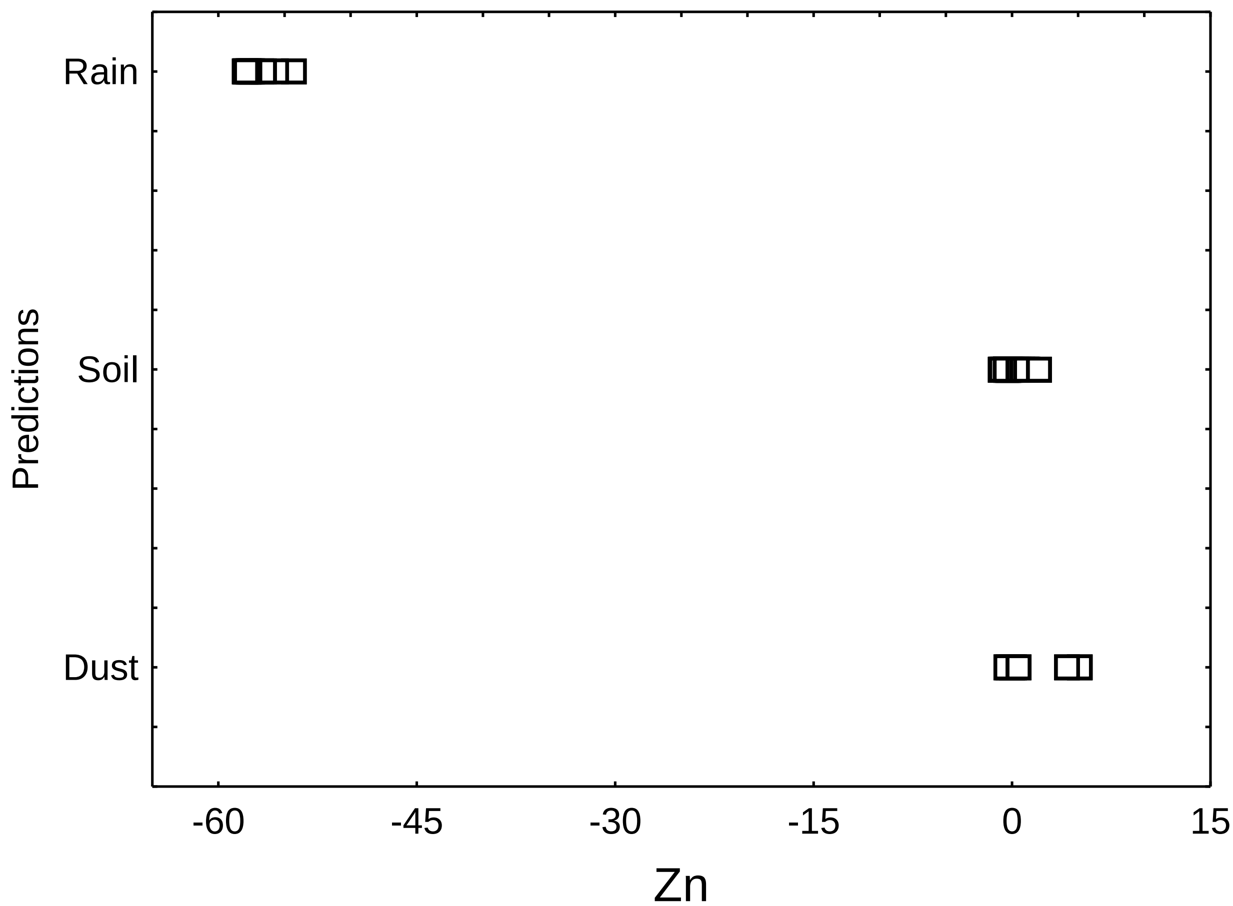

Figure11. Scatter plot of Zn against prediction in soil, dust and rainwater samples.

Enrichment factor analysis

Fe determined a conservative element in the studied environment for soil, dust and rainwater. The average EF value for soils are 0.50 indicating that soils collected from the study area correspond to deficiency to minimal enrichment (Figure12).The EF values for Cu range from 0.50 to 15.60 with a mean value of 2.10 which falls under the class of moderately enrichment. The average EF value for Zn is 0.50, which indicates deficiency to minimal enrichment. The EF for As ranges from 0.10 to 1.80 (Figure 12). The minimum and maximum values imply to deficiency to minimal enrichment. The average EF value is 2.20 indicating that soils collected from the study area correspond to moderately enrichment.

In dust, it is clear from Figure13, Pb and Cu only in some of samples have mean EF higher than 3, were considered to originate mainly from anthropogenic sources. Ni, Zn, and As have an EF close or less to unity, further confirming its mainly natural source. It seems, therefore, that EF can also be an effective tool to differentiate a natural origin from anthropogenic sources in this study. The mean EF decrease in the order of Pb, Ni, Cu, As and Zn, which can also be seen as the decreasing order of their overall contamination degrees of urban dusts in Arak. All of elements have mean EF lower than 2, which mean deficiency to minimal enrichment; while some of samples of Pb and Cu, with their mean EF more than 5 as significant enrichment and Pb and Cu between 2 and 5, were classified as moderately contaminated.

The mean $EF_{natural}$ values for atomospheric trace metals in rainwater collected in Arak are: Pb: 339, Cu: 135, Zn: 202, As: 122 and Ni: 192. Figure12 shows the box-whisker graph of the $EF_{natural}$ of the heavy elements. The high values of $EF_{natural}$ found for all of the metals show that these metals in rainwater are non-natural and indicated anthropogenic sources. However, these values may be different due to the chemical composition of local industrial activity.

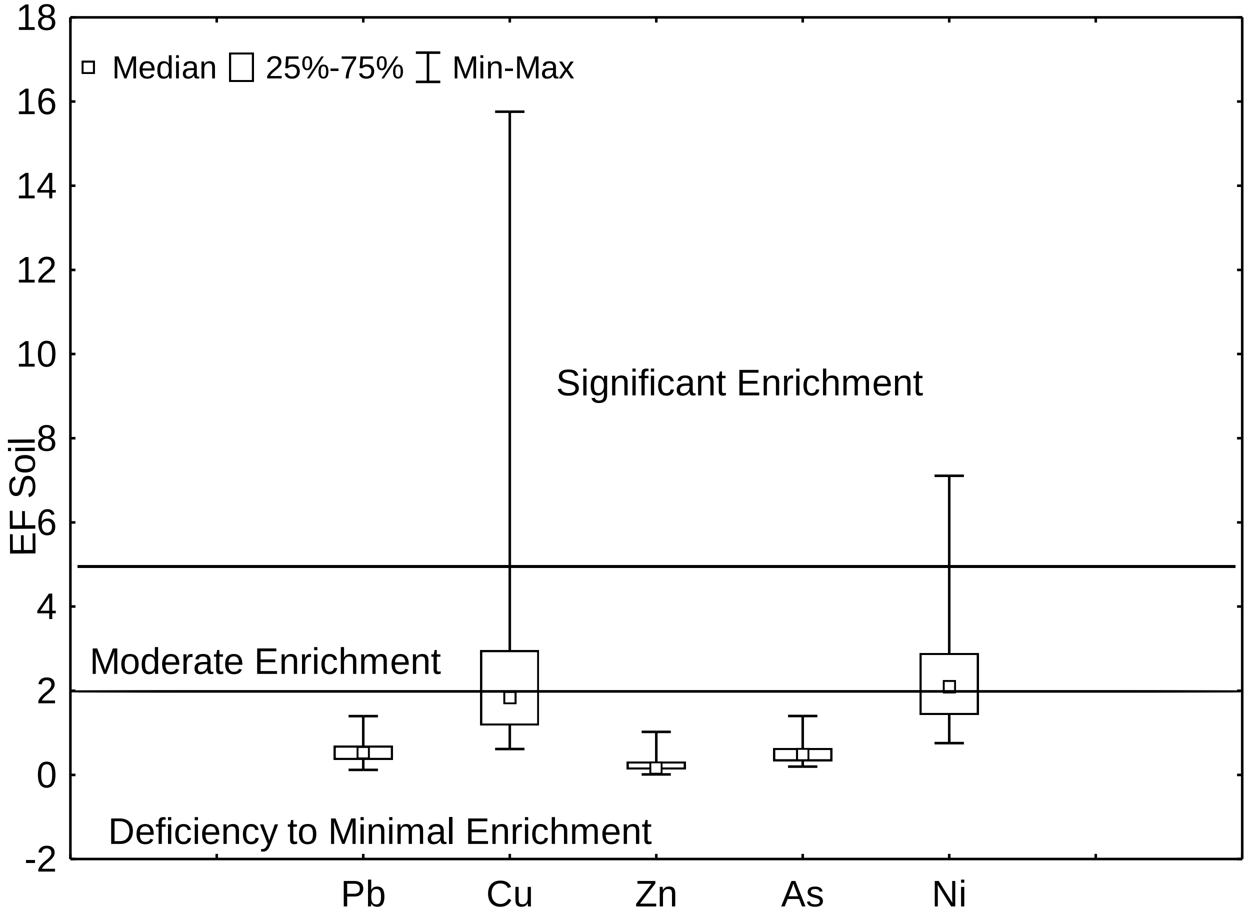

Figure12. Enrichment factors for metals in soil of Arak.

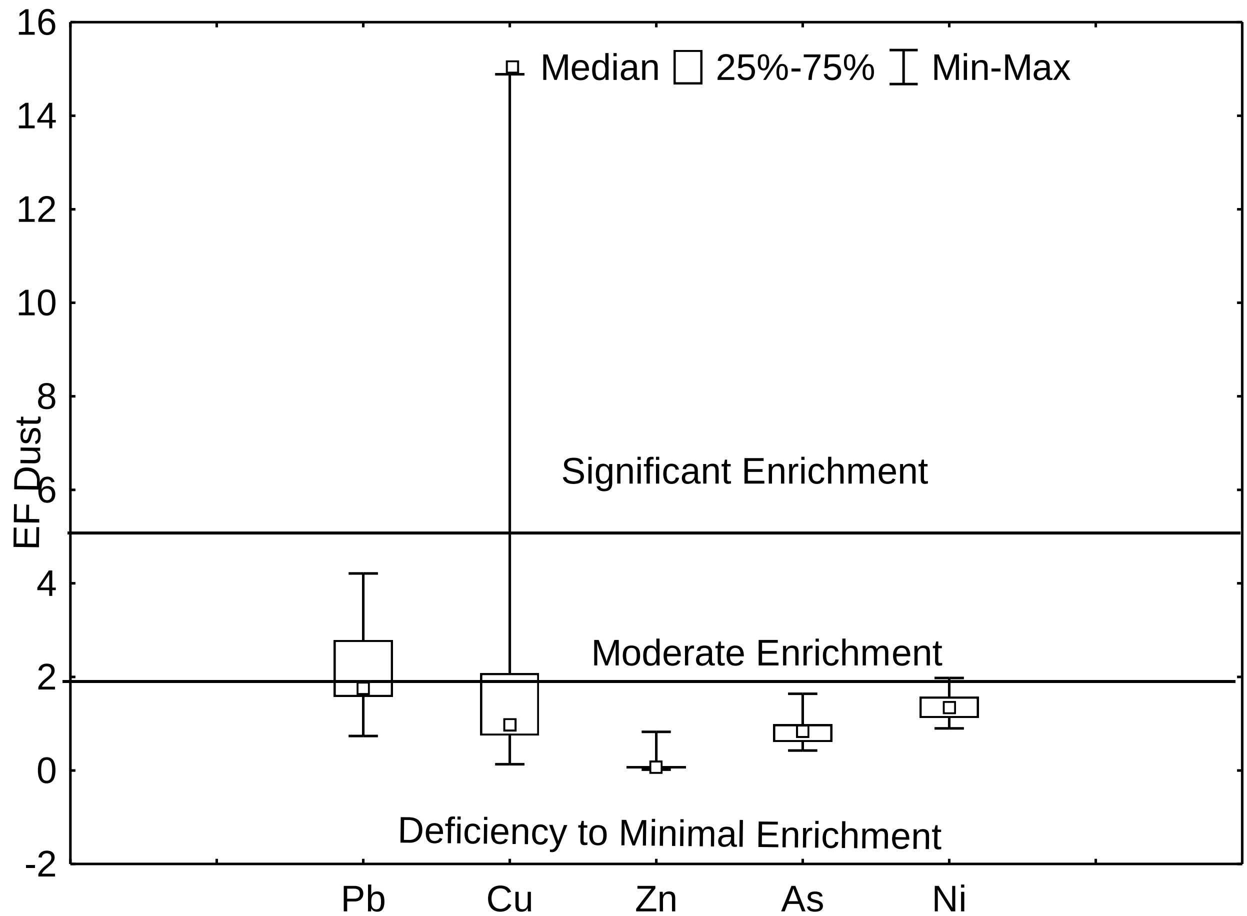

Figure13. Enrichment factors for metals in dust of Arak.

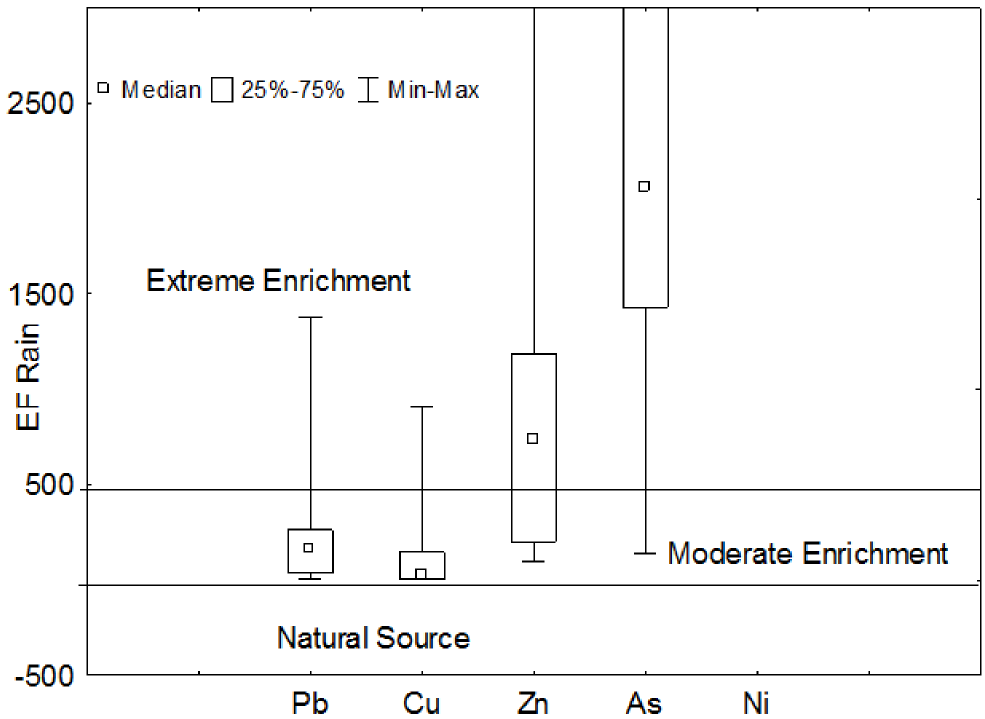

Figure14. Enrichment factors for metals in rainwater of Arak.

Percentage of contamination class of heavy metal elements in urban dusts in Arak are summarized in Table 5. From Table 5, Pb in the most of soil samples has natural source but, for some of the samples in dust and rainwater has anthropogenic source. Copper has natural and anthropogenic source in soil, dust and rainwater. Zinc and As has only anthropogenic source in rainwater. All of samples in rainwater have anthropogenic source for Ni and in soils has both of source. Nickel has natural source in dust.

Table 5.Percentage of contamination class for soils, dust and rainwater samples.

Variables	parameter	Class1	Class2	Class3
Pb	Soil	100	0	0
	Dust	58	42	0
	Rainwater	7	75	18
Cu	Soil	55	35	10
	Dust	72	17	11
	Rainwater	44	50	6
Zn	Soil	100	0	0
	Dust	100	0	0
	Rainwater	0	43	56
As	Soil	100	0	0
	Dust	100	0	0
	Rainwater	0	6	94
Ni	Soil	49	48	3
	Dust	100	0	0
	Rainwater	0	0	100

*For soil and dust; Class1: deficiency to minimal enrichment; Class2: moderate enrichment and class3: significant enrichment

*For rainwater; Class1: natural sources; Class2: moderate enrichment, and Class3: extreme enrichment

Lead contamination is seriously emphasized in recent years since this metal is very toxic for humans and animals. Lead enters to human or animal metabolism either via food chain or by intake of dust and rainwater. Gasoline vehicles are the main source of lead pollution. Lead production and operation facilities without waste-gas treatment system, battery production and scrap battery recovery facilities, thermal power plants, and iron–steel industries in Arak city are the other lead sources. Copper contamination in soil, dust and rainwater is due to fertilizers, sprays, or agricultural or municipal wastes and industrial emissions as well. Small-scale and local Cu contamination in soil, dust and rainwater originates from corrosion of construction materials with Cu alloys (e.g. electric cables) in Arak city. The anthropogenic sources of Zn in rainwater are related to the non-ferric metal industry and agricultural practice (Kabata-Pendias, 2000; Öbornand and Linde, 2001;Samura et al., 2003). Zinc is a most readily mobile element. High doses of zinc show toxic and carcinogenic effects and result in neurologic complications, hypertension, and kidney and liver function disorders (Roa, 2001). The anthropogenic sources of Zn in rainwater are related to the non-ferric metal industry and agricultural practice (Kabata-Pendias, 2000).Zinc is a most readily mobile element. High doses of zinc show toxic and carcinogenic effects and result in neurologic complications, hypertension, and kidney and liver function disorders (Roa, 2001). High As concentrations in rainwater are due to industrial activities. Significant anthropogenic sources of As are related to industrial activities such as metallurgical and chemical industries and the use of arsenical sprays. Nickel mostly originated from coal combustion in soils and rainwater of Arak city.Nickel toxicity, which is usually associated with serpentine soils, sewage-sludge application, or industrial pollution.

CONCLUSIONS

The application of multivariate statistical techniques and support vector machines combined with element concentration analysis has been proved to be an effective tool for source identification of heavy metals in soil, dust and rainwater of Arak. Based on the comparison of heavy metal concentrations of urban soil, dust and rainwater and background values of upper continental crust, the examined elements were classified into two main groups according to their sources: natural and anthropogenic. Then, discriminant analysis and cluster analysis, support vector machines coupled with correlation analysis, were used to gain additional insight into the origins of different elements in urban samples. Two main sources for these studied elements were identified. Heavy metals such as Pb, Cu, As and Ni are attributed to an main origin. Furthermore, Zn is also associated with another source. As a result of the enrichment factor, degree of contamination is difference in soil, dust and rainwater samples. For most of samples in rainwater, class of contamination is moderate enrichment to extreme enrichment. Some of soil and rainwater samples have class of moderate enrichment to significant enrichment. High concentrations of heavy metals in soil, dust and rainwater of Arak city originate from industrial activities which are associated with unrestrained solid and fluid wastes of industry facilities, heavy traffic and agricultural wastes. Based on environmental health criteria, the Arak city needs a remediation.

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