Original Article

Lead Contamination and Pollution Indexes in Roadside Soil in Tehran, Iran

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Abstract

Background and purpose: In the process of rapid urbanization and industrialization in developing countries, environmental pollution is a major concern. One of the fastest growing problems of environmental pollution is an excessive intake of lead in urban soils. Lead concentrations in urban soil may result from human activities such as vehicle emissions and industrial activities. This study aimed to determine of lead contents in roadside soil samples in Tehran city, Iran.

Materials and Methods: One of Tehran municipality's subsections was selected for the collection of 21 samples from seven stations along a main urban highway. In this study, samples were taken over a period of 3-month in the dry season. Sampling was performed in the order of 100 m long, perpendicular to the roadside at 0, 50, and 100 m from the road. Lab measurements were performed on the physical and chemical properties of samples. The extraction was performed using four kinds of acids (HCL, HNO_3, HF, and $HCLO_4$).

Results: Lead concentrations were measured by a spectrophotometer with an average concentration of lead in soil samples of roadsides standing at 112.21 part a million (PPM), and the average lead bio-accessibility at 14.19 PPM.

Conclusion: Lead concentrations showed a linear decrement in proportion to the distance from center line of the road. Human cultural activities were sources of lead pollution by examine soil contamination indexes.

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Key words: Bio-Accessibility, Lead, Pollution Indexes, Soil Contamination, Urban Roadside

1. Introduction

Lead concentration in soil collected from urban areas around the world has many different patterns. It reflects differences in terms of urban pollution, land use, population density, social and economic development, environmental regulations, and local weather conditions. Lead concentrations in urban soil may result from human activities such as vehicle emissions and industrial activities in the surrounding areas which can be specified (1). This type of pollution is one of the fastest growing problems of environmental pollution in the process of rapid urbanization and industrialization. Excessive intake of lead in urban soils can impose a constant burden on bio-geochemical cycles in urban ecosystems as a result of soil degradation and changes in soil properties.

Although urban soils are not used for farming, pollutants in urban soils can be easily transferred into humans through ingestion, inhalation, or dermal routes, etc., and they pose a health risk to urban residents (2). The excessive input of heavy metals into urban soil can impose a long-term burden on the biogeochemical cycle in the urban ecosystem by causing effects such as soil function deterioration, changes in soil properties and other environmental problems (3). The heavy metals in urban soil have a direct influence on public health (4). The concentrations of Cu, Pb and Zn, in general, are considered to be affected by traffic sources (5,6). Previous studies have revealed that human exposure to metals such As, Pb and Hg will lead to their accumulation in the fatty tissues and affect the central nervous system (7). The pollutants in soils with different types of land use may exert different impact on public health (8,9). As a result of anthropogenic influence of human activities in urban topsoil, Pb, Cu, and Zn enjoy the highest concentrations in urban topsoil (4,10,11). A study on the heavy metal concentrations in different types of urban soils land use would be desirable. Health Effects Institute (12) has recently reviewed a large number of health studies and concluded that close contact with roads will cause public health concerns. Although the association between adverse health and proximity to the road is certain, yet there is not a full understanding of how lead contamination interacts with type and size of roads, distance from roads, road transportation, and fleet activities.

Different parameters effect emission of vehicle pollutants in the environment, especially with regard to lead in the roadside soils and pollution resulting from it. On a large scale, the concentration depends on the conditions of the road, traffic, and the environment. Road parameters that are related to physical and architectural conditions of roads include length, slope, age of street and the surrounding buildings, pavement width, and the presence of trees or noise barriers. Traffic parameters include speed and a current density of cars. Environmental parameters include weather conditions such as temperature, speed and direction of the wind, and rainfall. In addition, certain geometric conditions of road, topography and conditions of the surrounding land, amount and direction of wind in site area, existence of lead emission sources in the area such as mines, factories and industries (13), materials used on exterior surfaces of buildings, traffic volume (14), presence or absence of traffic signs on the road (15), types of materials used in road surface such as concrete or asphalt (16), spatial characteristics such as land use (17), and legislation banning the use of lead as well as conditions before and after the restriction (18) are other factors that any change in their condition can affect the amount of lead in roadsides. During last decade, the rapid increase in the use of vehicles for day to day transportation in most developing countries, coupled with a lack of emission standards in these countries, has contributed a great deal of concern over vehicular pollution (19,20).

Vehicular emission is at its peak when there is an increase in population, together with an increase in the number of vehicles on roads (21). Most of car byproducts comprise of different fraction particles. These fractions include the ultrafine particles which are formed in the engines and tailpipes, fine particles produced mainly by chemical reactions, and coarse particles which are produced mechanically through the abrasion of road materials, tires and brake linings (22).

Pollution control has failed in the developing countries due to lack of reliable information and research and the complexity of the factors contributing to vehicular pollution. From viewpoint of regulations, the State Environmental Protection Agency and the Federal Environmental Protection Agency, now the National Environmental Standards and Regulations Enforcement Agency are charged with the responsibility of enforcing environmental laws, regulations and standards in order to prevent people, industries and organizations from polluting and degrading the environment. However, these responsibilities were restricted to the control of air, water, and noise pollution, waste disposal and oil spillage. No consideration was given to soil pollution, especially due to its major threat to environmental health. Soils are seen to be contaminated as a result of anthropogenic activities, and vehicular emission has been found to constitute a major source of soil pollution. Several studies have been carried out on roadside soils because they contain heavy metals. These heavy metals have adverse environmental and health effects (23,24). As a consequence of various observations, different sections of the government's environment control agencies are interested in the effects of vehicular emissions on soil and on the environment as a whole. In this study, the concentration of lead in the soil around a road near a junction in the commercial and industrial hub of Tehran, Iran has been evaluated.

2. Materials and Methods

To examine the lead concentration in roadside soil, Simon Bolivar Boulevard and Eshraghi Street in Tehran were chosen for case study and testing. The area is located in the northern part of Tehran's District 5 and is connected to three main north-south expressways, namely, Ashrafi Esfahani Expressway in the east, Sattari Expressway in center and Bakeri Expressway in west. The length of the path chosen was 3.7 km and the eastern half of the route was allocated to Bus Rapid Transit system. The western part of Farahzad, Morad Abad, Hesarak, North Jannatabad and the northern part of Shahran neighborhoods are located between longitudes 51° 17′ E and 51° 20′ E and latitude 35° 46′ N. Figure 1 shows the map of the study area. This region on average stands 1650 m above the sea level. The prevailing wind direction is west-to-east. The maximum air temperature is 21.8° C while minimum temperature stands at 11.5° C with an average humidity of 41.3%, an average precipitation of is 363.4 mm/year. Annual average frost days has been estimated at 61 and the annual average of sunny hours is 2953.

To obtain information about the status of the soil pollution, soil survey of the roadsides was accomplished. As a result, 21 samples were collected from seven stations following a transect parallel to the road and at distances of 0, 50, and 100 m from it. All topsoil samples were collected at a depth of 0-20 cm. At each sampling point, topsoil samples were taken using a stainless steel trowel. Foreign objects and stones were removed by hand. Systematic grid sampling method was used for soil sampling (25). In this method, three similar samples were collected and mixed on a line parallel to the axis of the main street with the main point as the center and at a distance of 25 cm from each other. The samples were stored in plastic bags for subsequent sample preparation and analysis. Sampling was conducted in the northern part of the streets and carried out in September 2012.

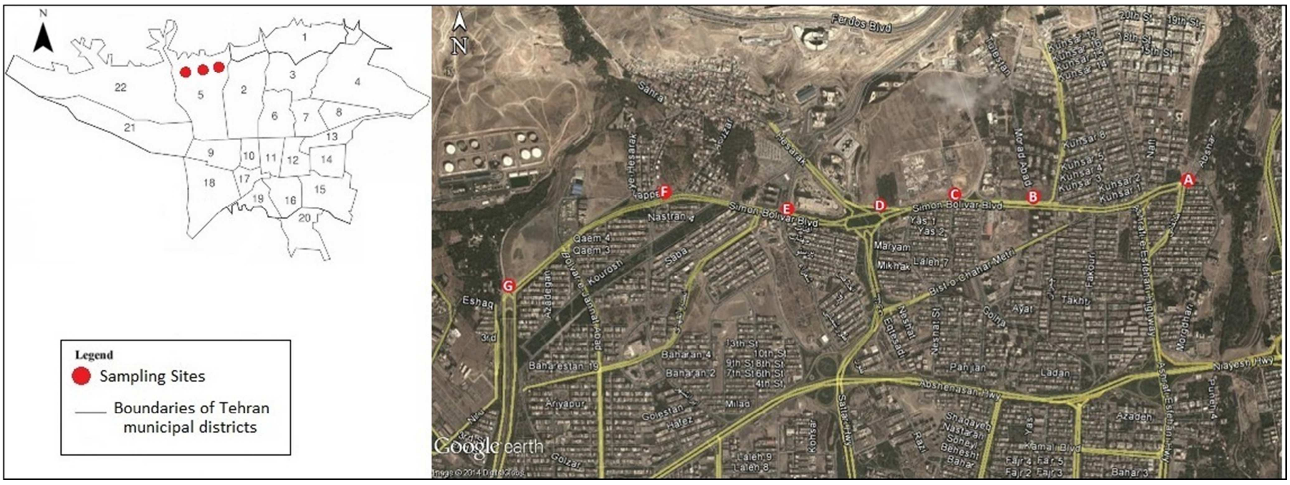

Figure 1. Location of sampling sites along the east-west highway (GoogleEarth, V.6.2.2.6613, Google Inc.)

After transferring samples to the laboratory for chemical analysis, samples were firstly air-dried at Soil Environmental Laboratory, Khajeh Nasir Toosi University of Technology. Then, after grinding, the soil samples passed through a 2 mm sieve. In the laboratory, all samples were dried in an oven overnight at 70° C. After this step, all samples need to be extracted. Hence, samples were grounded by an agate mortar to form a uniform sample so that decomposition by acids became easier to accomplish. Then, 0.5 g of dried soil was weighed by a sensitive microbalance 0.001 g before it was isolated.

To prevent simmering of carbonate, two drops of 0.1 normal hydrochloric (HCL) acids were poured into Teflon sample beaker. Then, 5 ml of hydrofluoric acid were added to decompose the soil silicates. The sample was heated up to 125° C. Then, according to the procedure presented by American Public Health Association, 7 ml of concentrated nitric acid and concentrated HCL acid mixture (3:1 ratio) was added to each sample to decompose nitrates and carbonates in soil before heating it up to 125° C. Afterward, 3 ml perchloric acid was added to it to decompose organic material and again it was heated up to produce dry samples. Finally, by adding 0.1 normal HCL acid, the sample volume in the volumetric flask was increased to reach 50 ml. The resultant solution was used to measure concentration. Lead concentrations in the provided samples were tested using an atomic absorption device (26).

The analysis of each heavy metal was carried out by devices used in this study within the specific wavelength range of 330-900 nm (Lovibond Spectrophotometer SectroDirect). The wavelength of lead is 520 nm. Calibration device with distilled water (Sample Blank) was set on zero. In addition to the total amount of lead, bio-accessibility of lead in the environment is also required to complete information. Bio-accessibility is part of a material that is available for uptake by an organism. To gain access to biological levels, first, 5.7 ml of acetic acid was added to 500 ml of distilled water. In the second stage, 64.3 ml of sodium hydroxide solution was added. Then, to adjust the pH of the resultant solution in the range of 4.93 ± 0.05, the volume was increased to 1 l by adding distilled water. Then 1 g of each sample was combined with 10 ml of the resultant solution. After the solution was shaken well, the atomic absorption device was used for lead measurement. After the concentration was measured, statistical analyses were carried out using SPSS software (version 19, SPSS Inc., Chicago, IL, USA) and the average concentration of soil lead and other input data were compared with one other in different conditions using variance analyses.

Soil contamination is often evaluated by comparing metal concentrations with related environmental guidelines or on the basis of the indexes and values of the field concentration. Based on Enrichment Factor, the value of elements can be assessed relative to their normal value. This factor is calculated using the following equation (27):

$$EF = \frac{C_{sample}}{C_{background}} \qquad (1)$$

Where EF is the enrichment factor, C_{sample} is the lead concentration of the surface soil and $C_{background}$ represents the reference concentration of lead which is background concentration in the region or the world average level. When EF approaches one, lead is derived mainly from a natural source in the Earth's crust or the soil in the area and if EF > 10 then the source of lead is mainly human activities. Enrichment factor is classified according to its degree. It means that when enrichment factor is less than 2, between 2 and 5, in the range of 5-20, 20-40 or > 40, the respective levels of enrichment are considered the minimum, average, significant, high, and very high (Li et al. 2012).

Another indicator that can determine the degree of soil pollution is called geo-accumulation index which was introduced by Muller in 1979 and is calculated using the following equation (28):

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \qquad (2)$$

Where I_{geo} is the geo-accumulation index, $\log_2$ is logarithm base two, C_n is concentrations in sediment and soil and B_n represents the background concentration or the average shale concentration. The coefficient of 1.5 has been used in this relation to correct the effects of soil parent material and content of natural fluctuations and very little changes in the environment caused by human activities. On the basis of this index, Mueller classified the degree of soil contamination in six groups. According to this classification, a geo-accumulation index of less than zero is for uncontaminated soil, between zero and one corresponds to uncontaminated to slightly contaminated soil, between one and two is for slightly contaminated soil, between two and three, corresponds to contaminated soil to very low contaminated soil, between three to four is for very contaminated areas, between four and five is for highly contaminated to extremely contaminated areas while extremely contaminated soil is defined by an index greater than 5.

There is another index defined as compliance index which is somehow similar to enrichment factor. It can be calculated using the following equation (29):

$$I_c = \frac{S_c}{R_c} \qquad (3)$$

Where I_c is the compliance index, S_c is the element concentrations in soil and R_c is the concentration of elements in reference material. For lead concentrations in the reference material, the average lead concentration of shale or 20 mg/kg can be used. According to this index, soil contamination is divided into four groups. Smaller than 0.7 shows insignificant pollution, between 0.7 and one in potentially significant pollution, one to five shows significant pollution level 1, and from 5 to 10 represents significant pollution level 2. Lead concentration is equal to 20 mg/kg in shale and equal to 14 mg/kg in the Earth's crust while average lead concentration of soils around the world is equal to 27 mg/kg (30).

3. Results

Pb concentrations in roadside soils

This section of the paper presents the results of: (1) measurement of the Pb concentration in roadside soil from urban highways in Tehran area, (2) evaluation of the lead contamination using pollution indexes, (3) correlation of Pb concentration found in contaminated soil along the roadsides, (4) exploration of possible and potential sources of Pb and the result of Pb phase-out regulation on the existence of lead in roadsides, and (5) discussion and comparison between the current Pb contamination in soil with historical average total Pb from different roadside studies from 1980s up to the present time.

To measure soil texture, Hydrometer method and seed testing based on Stokes law (effective mass and particle fall time) were used. After calculation of the percentage of particles with soil texture triangle, the fabric of the samples was determined. Soil pH was determined by mixing fresh soil with distilled water (1:5 w/v) (31). Soil texture is sandy loam soil in all samples. The pH level of the samples ranged between 7.06 and 8.03, with a mean equal to 7.44, which shows that the soil is neutral to slightly alkaline. The average percentage of gravel, sand, silt, and clay in the samples was equal to 42.82, 40.47, 8.24, and 8.47, respectively. The results of total Pb concentration in the investigated soil samples have been summarized in Table 1.

The lead concentration in this study ranged from 32.4 mg/kg in site G to 205.5 mg/kg in site D, with the mean of 112.21, the geometric mean of 101.4, standard deviation of 48.85, mode of 68.00, and median of 104.00 mg/kg (Skewness: 0.376; Kurtosis: -0.731). This range of observed lead was lower than European Union standard's upper limit of 300 mg/kg and was at lower concentrations than the maximum tolerable levels proposed for agricultural soil at 90-300 mg/kg (30).

The highest lead concentration corresponds to the station number four (site D) at 0 m distance from University Square. This point is located at the intersection of four streets and on side of the Islamic Azad University Square with Sattari Expressway on the south, Simon Bolivar Boulevard on the west and the east, in addition to University Avenue and Hesarak road on the northwest.

The high concentrations of lead observed could be attributed to lead particles from gasoline combustion which consequently settles on roadside soils. In the same way, vehicles in high traffic areas often move slowly as a result of traffic jams in some areas, and this may account for the high level of lead. This is in line with (32) report that traffic junctions and crossroads record higher levels of metals. Furthermore, it is not surprising that the high level of lead is associated with Site D because it has junctions that serve as a small garage for buses and passenger vehicles. This is in addition to the auto mechanic workshops that dominate the business in the area. The observed highest lead concentration of Site D suggests a long accumulation of some level of lead, most likely from vehicle emissions, since there are no industrial activities within the selected research area. Although the concentration in Site D was close to 205.5 mg/kg, the lead obtained in the present study did exceed reported background values of 25 mg/kg of lead in soil (33).

The station number seven (Site G) has the least concentration value for lead, and this could be expected because of the least volume of vehicles recorded on the road. The station number seven is located in the west of the

Table 1. Average Pb concentration in surface soil samples (ppm) collected along urban roadside sites (mg/kg)

Distance from roadside (m)	Number of stations						
	1	2	3	4	5	6	7
0	165.0	191.0	164.0	205.5	183.0	138.0	146.0
50	88.2	108.0	105.5	104.0	121.4	98.9	68.0
100	53.2	81.4	85.5	68.0	100.3	49.0	32.4

study area, at a distance of 100 m from the main street, and there is not any other street in its vicinity. Distance, prevailing wind direction, slope toward the street, sandy soil and low vegetation are all factors that affect the low degree of measured concentrations in this point relative to other areas.

In examining sampling sites, station number five is an exception because of its overlapping points on the north with the sampling sites on Hesarak road. In fact, the distances between 50 and 100 m from the main street may have interfered with the emissions generated on the northern part of the street. Because of the overlap among various source of pollution, concentrations in this station and at distances of 50 and 100 m, were the highest concentrations compared to other stations in these sampling sites.

3.2. Statistical analysis of Pb contamination in roadside soil samples

The mean concentration of lead obtained from this assessment is lower than the concentration obtained from that conducted in Iwo, Nigeria Bull (126 mg/kg) (34). The coefficients of skewness of Pb were close to zero, indicating that it followed normal distribution. Sampling was conducted on non-agricultural areas, but roadside plants required that the standard for lead in plants and agricultural soils be observed. Comparison of the mean lead concentration in soil in this study with allowed level of lead in soil in Canada agriculture standard, which is equal to 70 ppm, and British agriculture standard, which is equal to 100 ppm, indicates that 57.14% of the surface soil samples along the streets contain lead in excess of the standard limits of these countries. Figure 2 illustrates the frequency distribution of lead soil concentrations in the study area. Also distribution curve, which shows how lead is distributed in different intervals, and denotes the normal distribution of concentrations is plotted. Kolmogorov–Smirnov test also carried out with a P = 0.707 at the 95% significance level confirms the assumption that data distributions are normal. The concentration of samples is classified in seven ranges with the highest frequency related to 100-140 ppm range and the minimum value standing at less than 40 ppm.

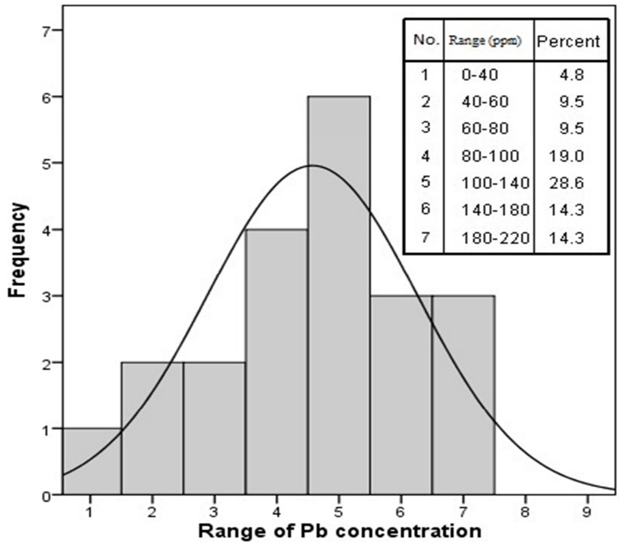

Figure 2. Histogram of the concentration values of lead

Values of the Enrichment Factor, the Geo-accumulation Index and the compliance index of average lead concentration in soils are presented in Table 2. The degrees of concentrations which were listed in Table 1 and equations 1-3, were employed to calculate these indexes. For enrichment calculation, global average lead concentrations were used to normalize the degree of concentrations. If the average concentration of lead in the Earth's crust is taken as the base of enrichment comparison, it can be observed that all samples are enriched relative to it. In general speaking, high enrichment factor shows the impact of human activities on the soil lead levels and low enrichment factor indicates that the existing lead is of natural sources with no interference from unnatural factors. The average concentration of lead in shale is used to calculate the geo-accumulation and compliance indexes.

To find out the impact of distance from

roadside on lead concentration in samples, Student's t-test (paired test or two pairs of variables) was used to compare mean lead concentrations among sampling sites. The results of these tests are presented in Table 3 (statistical significance was computed using Paired Sample t-test with a significant level of $P < 0.050$).

The correlation coefficient between 100 and 50 is a higher than other couples and closer to number one that indicates more impact of this couple on lead concentration in samples. In fact, the mean concentration of lead in the samples is more likely to change by increasing distance from roadside from 50 to 100 m. As shown in table 4 for all paired samples, decision value is smaller than 5% of the significance level and 95% of the confidence interval related to the difference between the upper and lower bounds. It does not include zero and the absolute value of T-statistic is > 2. As a result, in 5% significance level, the difference between lead concentrations at distances of 0 versus 50 m, 0 versus 100 m and 50 versus 100 m from the roadside is significant. Significant difference at this level expresses the impact of distance factor on the soil Pb concentration and the role of human activity on increased amount of lead in soil.

Figure 3 shows the soil lead concentration plotted against the distance from the roadside by fitted regression models. This curve makes it possible to do a quick visual assessment of the appropriateness, balance, and accuracy of each model for the observed values. Points marked with a circle in figure 3 represent the data obtained from the measurement of lead concentrations at various distances from roads, and other lines represent the observation data that are fitted to models. To realize the best curve fitted to the data, a total of seven models of linear, logarithmic, quadratic, compound, power, exponential and logistics curve views were considered.

The results of fitted regression equations are presented in Table 4. Calculating equations based on an allowable error of 0.0001 and the missing data patterns have been taken into consideration when calculating the equations. The distance from the roadside is considered as the independent variable that is determined using the coefficient X in the equation. The lead concentration in soil samples indicated that the coefficient C is also considered as the dependent variable. R^2 statistic indicates the strength of the correlation between the observed data and the predicted pattern of the dependent variable. Therefore, the closer it is to one, the greater is the chance of having a better fit for the data. Data in columns F, df1, df2, and significant indicate the F-test results that determine the validity and accuracy of the model.

Table 2. Comparison among contamination indexes of average lead concentration in soil samples

Distance from roadside (m)	Contamination indexes					
	Pb enrichment factor	EF category	Average I_{geo}	Geo-accumulation category	I_C [Pb]/20	Contamination type
0	6.31	Significant	2.49	4	8.52	PS2
50	3.67	Moderate	1.70	3	4.96	PS1
100	2.49	Moderate	1.07	3	3.36	PS1

Table 3. Paired sample test of lead concentration in roadside soil

Distance (m)		Paired differences					T	df	P (2-tailed)
		Mean	Standard deviation	Standard error mean	95% confidence interval of the difference				
					Lower	Upper			
Pair 1	D0-D50	71.21	20.08	7.59	52.65	89.78	9.38	6	< 0.001
Pair 2	D0-D100	103.24	20.94	7.92	83.87	122.61	13.04	6	< 0.001
Pair 3	D50-D100	32.03	10.41	3.94	22.40	41.66	8.14	6	< 0.001

sd: Standard deviation; Df: Degree of Freedom

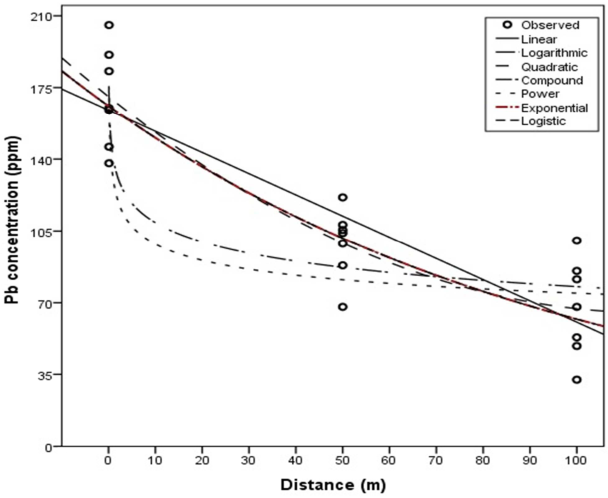

Figure 3. Regression models for estimating the distribution of Pb concentration in roadside soil

A significance level of F statistic is < 0.005 in all models, which indicates that the distribution described by the pattern is not achieved by chance. In the linear model, number 1.03, which is greater than one and negative, proves that there is either an inverse relationship between the dependent or independent variables or the distance from the road causes a sharp decrease in concentration. The remainder shows differences between the predicted values of models and observed data of the dependent variable. In this way, as the number gets smaller, the model will better fit the data. Survey of the residual data shows that the exponential model has the lowest value, which makes it a suitable model with higher correlation coefficient to fit the data.

The intensity and strength of the relationship between the model and the dependent variable is derived from multiple correlation coefficients (R^2) coefficient of determination, adjusted coefficient of determination and standard error of the estimates. These coefficients in relation to the exponential model are equal to 0.854, 0.728, and 0.714, respectively. Standard error for the estimate of the exponential model is 0.258, which is the lowest among all models. Multiple correlation coefficients show the linear correlation between the observed data and the predicted model for independent variable. The coefficient of determination is the squared multiple of correlation coefficient and the exponential model, which shows that 72.8% of the variance or transformation of the variable of distance from the road has been considered in the model. Given all this, we can consider the exponential model as the most appropriate model compared to other models.

Pearson's coefficient for correlation between Pb concentration and soil properties such as distance from the roadside, clay percentage of soil, bio-accessibility and pH of soil samples has been presented in Table 5. One-tailed correlation coefficient test has been used to draw this table 5. There is a significant correlation among the data, especially in those cases where the decision criteria are less than 0.01 or 0.05. Where the correlation coefficient is positive, there is a

Table 4. Results of fitted regression models derived from regression analysis

Model	Summary results					Models
	R^2	F	df1	df2	P	
Linear	0.781	67.95	1	19	< 0.001	$C = -1.03x + 163.91$
Logarithmic	0.781	67.89	1	19	< 0.001	$C = 140.31 - 13.57\log(x)$
Quadratic	0.819	40.78	2	18	< 0.001	$C = 170.54 - 1.82x + 0.008x^2$
Compound	0.728	50.98	1	19	< 0.001	$C = 165.9 \times 0.99^x$
Power	0.637	33.32	1	19	< 0.001	$C = 130.3x^2 - 0.12$
Exponential	0.728	50.98	1	19	< 0.001	$C = 16.94 \exp(-0.009x)$
Logistic[a]	0.667	38.03	1	19	< 0.001	$C = 1/ (0.005 + 0.001 \times 1.26^x)$

[a]For all dependent variables, the theoretical upper limit of 210 is considered

direct relationship among the data and where it's negative, the relationship among the data is the opposite. The closer to one is the value of correlation coefficient; the higher is the correlation between the measured components of the environment and their impact on each other. The results of Pearson's correlation coefficients for lead concentration in urban soils in Tehran are summarized in Table 5.

Accordingly, the correlation between lead concentration and distance from the roadside ($R^2 = -0.884$) was significant and negative. Correlation coefficient was −0.808, which indicates that as distance from the road increased, the lead concentration in soil samples was greatly reduced, proving that traffic activities were the generally the primary source for lead contamination. Due to its small correlation coefficient, soil pH has no significant correlation to the concentration of lead in this area. Soil pH was in the range of 7.06-8.03, which is the range of neutral to slightly alkaline. Hence, it was of little importance in relation to the distribution of lead in this environment. There was a negative correlation between pH and the bio-accessibility, which means that as pH increases, availability is reduced.

The results of the Pearson correlation also indicated that there is high correlation among between percentages of soil particles, because any increase the percentage of sand, will reduce percentages of silt and clay. There is also a correlation between percentages of particles and distance from the road: as distance from the edge of the road increases, percentages of clay and silt decrease while percentages of sand increase. No correlation was found between percentage of clay and concentration of lead. Considering the above facts, it can be deduced that there is a direct correlation between the lead concentration and the absorbable amount by the organism because as the level of soil lead increases, the absorbable amount by the plants, especially in their root, can increase. This issue was observed in this study as well. Therefore, there is a significant relationship between the amount of bio-accessible Pb and the Pb concentration at the 0.01 level of significance which is equal to 0.692. There is also a significantly inverse correlation between the distance and bio-accessibility which is equal to 0.608. In fact, the bio-accessibility of lead in soil is reduced as the distance from the roadside increases.

The average bio-accessibility is equal to 14.19 part a million, which by considering metal toxicity thresholds for the soil for plants, cannot cause poisoning and prevent plant growth in this area. The bio-accessibility value of any sample divided by lead concentration of the same sample gives the percentage of bio-accessibility for that sample. Evaluation of the percentage of bio-accessibility of the samples indicates that the least value for lead bio-accessibility equals 6% which related to the second station and the maximum value is 19.6% for the fourth station. Samples were collected 100 m away from the roadside.

Table 5. Pearson's correlation matrix for the lead concentration and soil properties

	Concentration	Distance	Clay	Silt	Sand	Bio-accessibility	pH
Concentration	1						
Distance	-0.884**	1					
Clay	0.041	-0.220	1				
Silt	0.477*	-0.465*	-0.008	1			
Sand	-0.391*	0.498*	-0.647**	-0.758**	1		
Bio-accessibility	0.692**	-0.608**	0.185	0.124	-0.215	1	
pH	-0.046	-0.015	0.091	0.035	-0.086	-0.306	1

**Correlation is significant at the 0.01 level (1-tailed). *Correlation is significant at the 0.05 level (1-tailed)

Figure 4 illustrates the lead bio-accessibility of soil samples that were collected from the roadside. The concentration and bio-accessibility values were used to draw the graph. The horizontal axis represents total soil lead, and the vertical axis represents the percentage of bio-accessible soil lead levels measured by dividing the value of the lead bio-accessibility at any point to total lead value at the same points. Data were categorized into three groups according to the distance from the edge of the road. The lowest value for the percentage of bio-accessible Pb was 6%, related to the second station while the maximum equaled 19.6%, which was related to the fourth station at a distance of 100 m from the roadside.

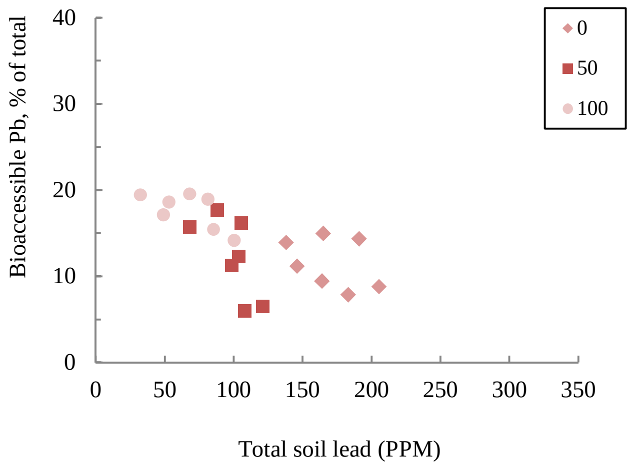

Figure 4. Soil lead bio-accessibility in the roadside soil of the sampling site in Tehran

At the distance of 100 m from the roadside, which has the lowest concentration of lead in soil, the bio-accessibility is in the range of 14.2-19.6%. In roadside soils, which have the maximum lead concentration, the bio-accessible Pb is in the range 7.9-15%. In fact, as the distance from the edge of the road increases, the bio-accessibility of lead rises in soil samples. Testing of the soil lead bio-accessibility in the laboratory is a simple and inexpensive way and its results can be particularly used in relation to urban soils and roadside areas where plants and trees grow. Lead concentrations in soil and thereby the amount of bio-accessible Pb in vegetable farms and gardens along the road can be important due to the absorption of lead by plants' roots, stems, and leaves.

3.3. Comparing roadsides lead concentration and those in other cities

To directly compare the results of soil lead concentration measurements with other available cases in this field, it is necessary to consider some points, including the sampling strategy (single or composite samples), sampling location (open areas or near buildings), the number and depth of the samples, types of pollution sources (point or non-point) and digestion of the samples (partial or full). In some cases, air temperature, amount and speed of wind, sampling season, and coverage of the area can change the measured levels of soil lead. Therefore, for comparison in ideal conditions it is necessary to pay attention to these points. In a related global study, the lowest concentration of lead obtained by this assessment was a higher than the lowest concentration recorded for assessments conducted in the United States (4.62 mg/kg), China (9.95 mg/kg), Ethiopia (20.3 mg/kg) and Poland (7.1 mg/kg) (35). The highest concentration of lead obtained through this study is lower than the highest concentration recorded for studies conducted in Ethiopia (325.4 mg/kg) and India (623.95 mg/kg) (34).

Atuanya and Oseghe (36) showed that higher lead concentration in soils has toxic effect on microorganisms inhabiting the soil, which consequently alters the flora and fauna of a location.

In figure 5, mean lead concentration in surface soil of Tehran, which has been measured in this study, is compared with values obtained from other cities in the world (17,37-65). The data for this comparison are related to the last three decades, and 30 different cities have participated in this comparison. Conditions, procedures, and location of sampling in these cities were as similar as possible. Time interval for measurement of concentrations has been divided into four decades. As seen here, the highest concentration was recorded in the 1980s, and as time goes by, recorded concentrations are decreased.

Selection of these time intervals is important because each country, relative to its concern for human health and protection of the environment, has established restrictions on the use of lead in car fuel. Regardless of the time of sampling, the degree of industrialization, population density, number of vehicles and motor traffic, public transportation mode, age of vehicles, erosion of tires and brake pads, and corrosion of vehicle's bodies, sampling conditions, geometric properties and the quality of the streets, and fuel additives are among the main factors that influence the amount of lead in the soil. The presence of factories and industries in the vicinity of streets or the surrounding areas can also contribute to lead contamination.

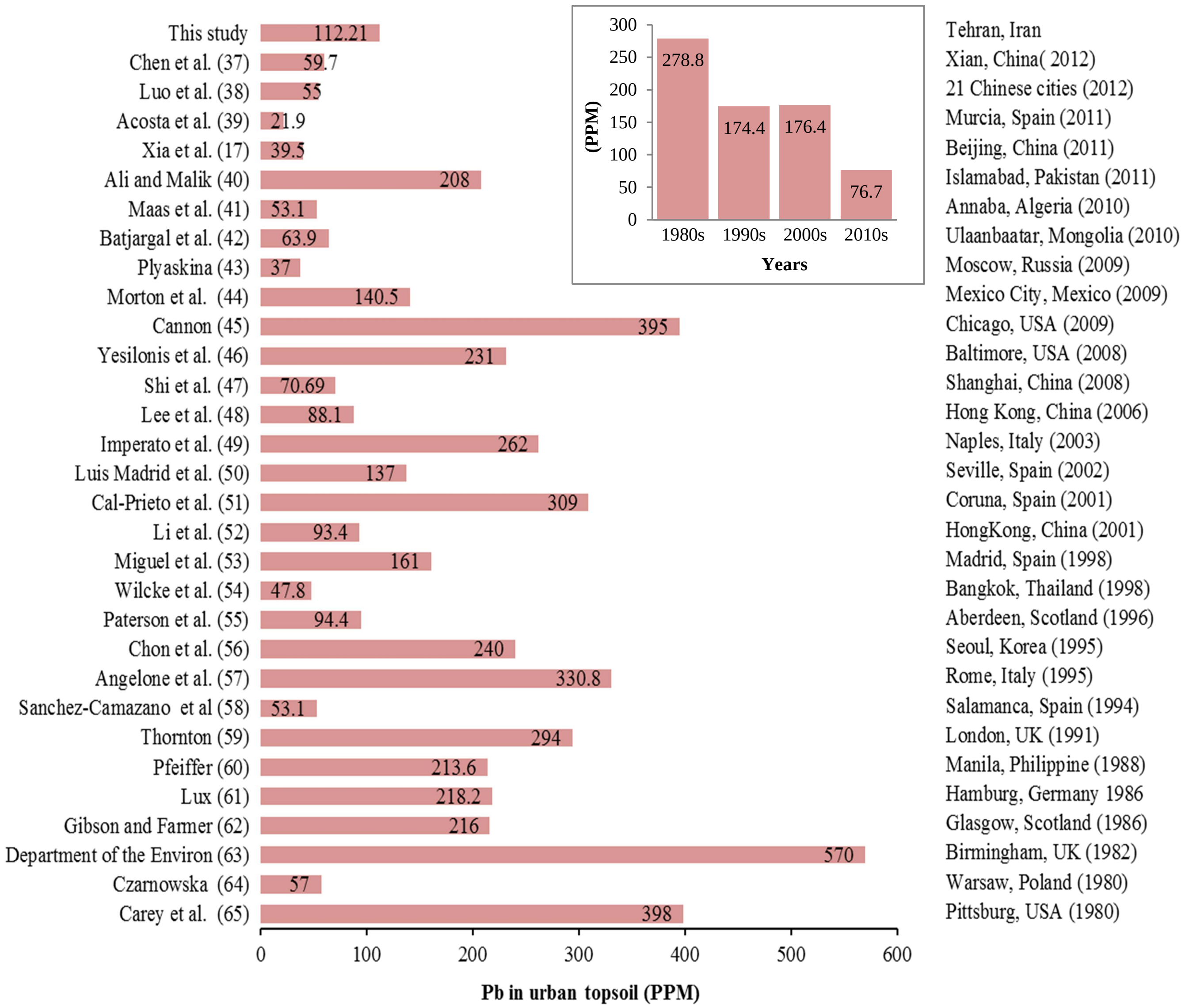

Figure 5. Comparison of historical average lead concentrations in urban soil samples from collected in different cities (mg/kg) from 1980s to present time

4. Discussion

Comparison of lead concentration in surface soil of the study region, along distances of up to 100 m perpendicular to the roadside, revealed that the soil contamination rate decreases as the distance from the roadside increases. It could be concluded that soil contamination is a result of particles emitted from vehicles' exhaust pipes and the volume of motor traffic, which plays an important role in soil contamination.

Assessment of the level of pollution using pollution indices revealed that Pb enrichment level along the roadsides is significant. Analyses show an average enrichment level for enrichment level indices at distances of 50-100 m from the roadside. As the distance from the roadside increases, the average enrichment factor decreases, this shows the effect of distance from the road and severity of contamination as a result of motor traffic in this area. On the basis of geo-accumulation factor, soil located along the roadside is in the range of slightly contaminated to highly contaminated, while for distances of 50-100 m, samples are categorized as slightly contaminated. This indicator also shows the degree of lead contamination, which is reduced by distance from the road. On the basis of compliance factor, soil located close to the roadside shows significant pollution, but when the distance increases to 50-100 m, there is no significant pollution, which indicates decreased pollution as distance from the road increases. Study of the results of pollution indices shows that 20 samples have low-level contamination while one sample is considered as uncontaminated soil.

In relation to other populated cities mentioned above, lead concentration levels in the soil obtained from Tehran roadsides in studied regions shows a reasonable rate. Therefore, in case gardens or vegetable planting sites exist along the roadside or in case such buildings such as kindergartens, schools and hospitals, which are sensitive to lead pollution, are to be constructed there, it is necessary to consider the actual level of lead contamination and the potential rate of soil contamination in the area of study.

Conflict of Interests

The Authors have no conflict of interest.

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