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Research Article

MODELING OF RELATIONSHIPS BETWEEN TRAFFIC PARAMETERS AND VEHICULAR LEAD AND CADMIUM DISTRIBUTION IN URBAN ROADSIDE SOILS

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ABSTRACT

Lead and cadmium are heavy metals and are regarded as traffic generated pollutants scattered in the urban environment through vehicular traffic flow. A total of 13 roads in the city of Isfahan were used for studying the roadside soil pollution amount and determination of effective traffic parameters on soil lead and cadmium amounts. Soil samples were collected and analyzed from 13 sites. An empirical statistical approach was employed for the analysis and modeling purposes. Results suggest that Lead and Cadmium mean concentrations within the distance of 50 m from road curbside are more than background values. These values are well-above the maximum acceptable concentration of heavy metal contents of agricultural soil. Regression analysis of metal concentrations in gutter soil showed that the most effective traffic parameter which affects soil metal concentrations is total traffic volume. It was also observed that Lead and Cadmium concentrations (as independent variables) decreased logarithmically as distance increased from road curbs (as dependent variable), but they decreased exponentially with increment of total traffic volume (as another dependent variable). The regression models developed in this research are used for estimation of Lead and Cadmium concentrations in urban roadside soils on the basis of the distance from road and total traffic volume. The outcomes of this research can be used for mitigation of environmental impacts of roads by using them in urban land use planning, urban design, urban transportation and road traffic management and control.

INTRODUCTION

The disease burden by a population and how that burden is distributed across sub population is important information for defining strategies to improve population health. Global found of the diseases burden from Lead have been introduced for 14 different reasons and different age groups worldwide in developed countries. When Leaded gasoline has usually been phased out, the highest environmental exposure to Lead generally affects children of lower income families. In countries where Lead is still used, Leaded gasoline will likely be a major contributor to exposure directly through air, or indirectly through food and dust of Leaded ceramics (WHO). The evidence for carcinogenicity is stronger in animals, its carcinogenicity in human has recently been questioned [1].

By increasing social needs for transportation and communication, day to day vehicular usage has been increased. There will be more than 950 million vehicles by the year 2020 in the world [2]. Automobiles are known to be the main sources of producing heavy metal pollutions in cities. These pollutions enter the environment from automobile bodies and exhaust as particles. Vehicular pollutions are distributed in roadsides by traffic flow and cause air, water and soil pollution [3, 4].

Lead and Cadmium are parts of vehicular pollutants. These pollutants, because of their poisoning characteristics and because of being dangerous for nature and human body such as blood and nerve system, have been researched by previous researchers [5, 6].

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Lead usually enters the urban environment by using Leaded petrol. Although in recent years, Lead has been omitted from fuel and its entering the environment has been decreased, its pervious effects still persist. Cadmium exists in automobile tires. It partially departs from vehicles and disperses with traffic flow and enters the urban environment [5, 7, 8]. Moreover different parameters affect vehicular pollution in environment, which in large scale contains conditions of road, traffic and environment.

Road parameters related to road physics and design are: length, slope, road canyon and average height, average aspect ratio (i.e. the ratio of height of the building to width of the road), number of lanes, and the type of green cover and its height [9-11]. Traffic flow as one of the most important factors in dispersing vehicular pollution contains speed, traffic volume, traffic congestion and driver behavior in start time and movement, fleet composition ,traffic management method and traffic sign arrangement in roads [12-14]. Environmental parameters contain climatic conditions like temperature, wind direction, speed and also roadside soil characteristics [10, 12, 13].

Past research works have measured heavy metal concentrations in soil, as well as their impacts on distribution trend. Rahmani [15] through soil sampling from different distances in four highway sides in Iran illustrated that sharp decreases exit in lead concentrations as distance increases from the main road. Ward *et al*. [16] in Auckland New Zealand measured Lead and Cadmium concentrations in surface roadside soils in 17 sites. A gradual decrease of heavy metal concentrations has shown in the study as distance increases from roads. Lead content in soil has shown to have a definite relationship with traffic. However, this relationship has been weak for cadmium concentrations. Carlosena *et al*. [17] in Lacrona, Spain studied vehicular traffic effect on heavy metal concentrations and concluded that high load of Lead concentrations and low load of Cd, Cu and Zn concentration were results of traffic distributions. Garsia and Milan [18] measured Cd, Cu, Zn and Pb concentrations at two distances in eight sites experiencing different traffic flow in urban highways of Gipuzequa, Spain. Their results showed Pb and Cd concentration levels changed as distance from highway varied.

This study of vehicular pollutions and their impacts on roadside environment and also impacts of different traffic parameters on distribution amount and trend of pollution is a requirement when urban architecture, design and planning and urban traffic management are of concerns. This study investigates the roadside soil and gutter soil pollution because of Lead and Cadmium. During the course of this research, the impacts of different traffic parameters on the distribution of pollution will be studied and finally the trend of Lead and Cadmium distributions as function of distance and traffic parameters will be analyzed and then modeled.

MATERIALS AND METHODS

Thirteen sites along various roads of varying traffic volumes in the built up areas of Isfahan were selected. Table (1) lists the selected sites and Figure (1) depicts locations of sampling sites in Isfahan. Criteria for the selection of sites were: a) a minimum of 150 m distance from bus stations (terminal) and b) away from any vertical barrier or constraints to prevent trapping from circulation. Most roads in Isfahan are divided and the traffic flows in two directions. Gutters are open drainage channels adjacent to the road stretched along both sides. These gutters have soil apron and concrete wall as well as plants growing in these places.

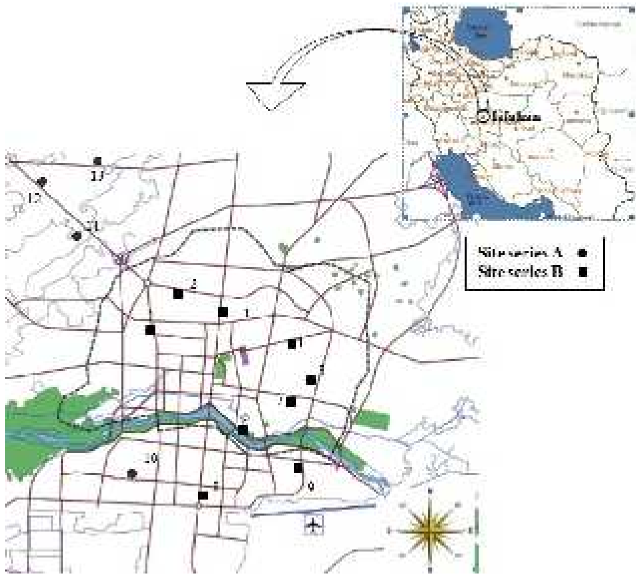

Fig 1 Map of Isfahan and sampling sites

Soil samples were collected from depth of 0-5 cm and distance of 0.5, 1, and 2 m from all roadsides and distances of 4, 6, 8, 10, 15, 20, 30, 40, and 50 m from sites number 10 to 13. Figure (2) presents typical cross sections of roads along sites number 10 to 13. Sampling was carried out using linear soil sampling method. In doing so, samples were taken at a distance of 25 cm from a line parallel to road axis and then mixed. Standard Methods /Techniques [19] were adapted as the basis of sample extraction and measurement of Pb and Cd concentration. These include Atomic Absorption Spectroscopy (AAS) in the sites and laboratories. Data and information were collected on the total traffic volume, daily traffic volume, total (accumulated) traffic volume, total traffic volume to directional road width, total traffic volume to total capacity, vehicular speed and street aspect ratio. Their definitions and calculation methods are as follows: Average annual daily traffic (AADT) is defined as the yearly traffic volume divided by 365. AADT has been used by many researchers in order to compare concentrations in various roads [15-18]. Average daily traffic in year and yearly traffic volume in studied roads were defined from existing data of transportation research center of Sharif University of Technology [20]. Road ages also were defined from their construction documents. On the basis of the vehicular possession coefficients, Isfahan population and age of each road, annual traffic volume in different years for roads were estimated. Information on the construction year of road extraction was extracted from the data base of Isfahan Highway Department and Municipality of Isfahan. Total traffic volume for each road was estimated up to the years 2013. The total traffic volume in all studied roads was about 52 to 520 million vehicles. Total traffic volume was assumed as an effective parameter on extinction of cumulative Lead concentration on the roads under study.

Table 1 Selected streets and sampling sites

sampling site number	site name	location	construction year
1	Chahar Bagh Paeen	100 meters north of Takhti Junction west bound	1937
2	Forougi	500 meters west of Shohada junction south bound	1941
3	Bozorgmehr	200 meters north of Bozorgmehr Square west bound	1961
4	Ahmad Abad	150 meters west of Mehregan street south bound	1937
5	Kashani	30 meters south of Halal Ahmar east bound	1941
6	Moshtag Aval	500 meters east of Khajoo square north bound	1976
7	Kamal Esmaeel	200 meters east of Ferdosi junction north bound	1951
8	Chahar Bagh Bala	300 meters south of Shariati east bound	1956
9	Sajad	200 meters south of Apadana junction west bound	1966
10	Mohtasham kashani	400 meters west of Shariati square north bound	1981
11	Imam Khomeini	150 meters south of Khane Esfahan street east bound	1961
12	Imam Khomeini	1 km north of Ghalamestan park west bound	1961
13	Razmandegan	500 meters west Robat north bound	1991

Total capacity is the maximum number of vehicles that can pass through a point on a road per unit time in a year in both or all directions under the prevailing condition of road and the traffic. Total traffic volume is the demand or number of vehicles that pass through a given point on a road per unit time in both directions. The ratio of (Volume/Capacity) or (V/C) shows the extent to which volume of a road is approaches capacity. It also presents the degree of saturation of a road. Such a ratio has been sought to be another influencing parameter in the amount vehicular heavy metal pollution [10].

Total capacity values were calculated by EMME/2 software. This parameter shows relative value of using roads in their usage age. In each road, by measuring the speed of two types of dominant vehicles in different hours of day, mean speed was defined.

The vehicular mean speed on the vicinity of study sites varied between 30 and 76 kilometers per hour ($km.h^{-1}$). Previous studies have confirmed the influence of street aspect ratio on traffic generated air pollutants distribution. Aspect ratio is defined as the mean height of building along streets to the mean width of streets. Linaritakis (1987) has modeled CO pollution concentrations using data on streets of central London. Models developed based on traffic load was setting and geometry of streets located in central basin districts where high building are set on both sides of roads are known as "Street Canyon models" [21]. Zero height denotes to area where there is no building along streets.

RESULTS

Statistical characteristics of total Lead and Cadmium in street soils up to 50 meters from kerb and background soil are presented in Table (2).

Table 2 Statistical characteristics of total Lead and Cadmium in street soils of up to 50 m from curb and background soil

statistical parameters	gutter		distance up to 50/(m)		background	
	Pb	Cd	Pb	Cd	Pb	Cd
samples number	19	19	40	40	40	40
mean/($mg.kg^{-1}$)	220.86	2.94	126.82	2.41	28.91	2.02
median/($mg.kg^{-1}$)	186.34	3	86.85	2.4	28.65	1.8
standard deviation/($mg.kg^{-1}$)	12.52	0.31	8.77	0.37	1.87	0.15
minimum/($mg.kg^{-1}$)	65.05	2.4	35.78	1.8	7.3	0.6
maximum/($mg.kg^{-1}$)	481.35	3.4	325.26	3.4	57.8	2.7
domain/($mg.kg^{-1}$)	416.3	1	289.48	1.6	50.5	2.1

In Figure (3) relative frequent distribution (probability) of total Lead in roadside soil has been presented. The distribution curve of Lead in background soil is also shown in the Figure (3).

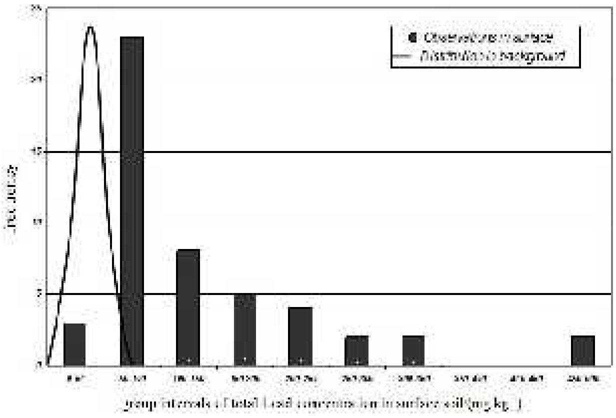

Fig 3 Relative frequency distribution of total Lead concentration in Isfahan urban roadsides

Figure (4) presents relative frequency of total Cadmium in roadside surface soil of Isfahan. This figure also shows background distribution for Cadmium in soil.

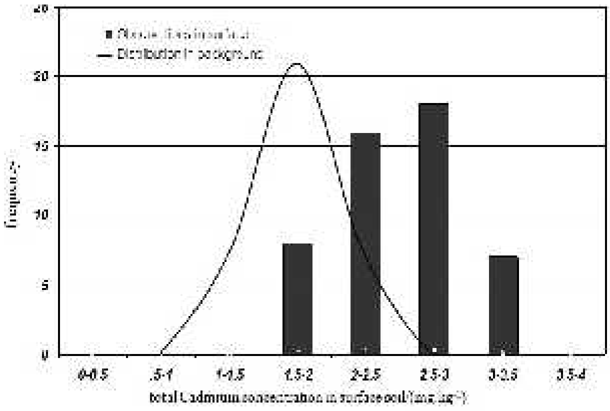

Fig. 4 Relative frequent distribution of total Cadmium concentration in Isfahan urban roadsides

The statistical difference of Lead and Cadmium mean concentrations are investigated by t-student test in significant level of 5% (reliable level 95%) in Table (3).

Table (4) shows results of t-paired test for comparison of Pb and Cd concentrations in soil in different distances.

Table 3 t-test for comparison of Lead and Cadmium concentration in gutter soil and soil until 50 m with background concentrations

situation	number of observations	mean/(mg.kg^{-1})	standard deviation/(mg.kg^{-1})	degree of freedom	t_{cal}	t_{cri}
		Lead				
background	40	28.91	10.87	-	-	-
gutter soil	19	220.86	12.52	57	18.73	2
soil until 50/(m)	40	126.82	12.77	78	6.28	1.66
		Cadmium				
background	40	2.02	0.55	-	-	-
gutter soil	19	2.94	0.31	57	2.2	2
soil until 50/(m)	40	2.41	0.37	78	2.2	1.66

Table 4 results of t-paired test for comparison of Pb and Cd concentrations at different distances traffic lanes

parameter	distance 1 versus 8/(m)	distance 1 versus 15/(m)	distance 1 versus 50/(m)	distance 8 versus 15/(m)	distance 8 versus 50/(m)	distance 15 versus 50/(m)
			Lead			
mean/(mg.kg^{-1})	211.42-120.35	211.42-104.9	211.42-58.7	120.35-104.9	120.35-58.7	104.9-58.7
observations	4	4	4	4	4	4
df	3	3	3	3	3	3
t_{cal}	2.81	2.64	2.58	1.72	2.30	2.40
t_{cri}	2.353	2.353	2.353	2.353	2.353	2.353
significant level	0.05	0.05	0.05	0.05	0.05	0.05
probability	0.021	0.027	0.030	0.120	0.05	0.04
			Cadmium			
mean/(mg.kg^{-1})	2.7-2.4	2.7-2.35	2.7-2.1	2.4-2.35	2.4-2.1	2.35-2.1
observations	4	4	4	4	4	4
df	3	3	3	3	3	3
t_{cal}	2.6	4.03	3.137	1.055	3.48	2.05
t_{cri}	2.353	2.353	2.353	2.353	2.353	2.353
significant level	0.05	0.05	0.05	0.05	0.05	0.05
probability	0.029	0.003	0.012	0.319	0.007	0.071

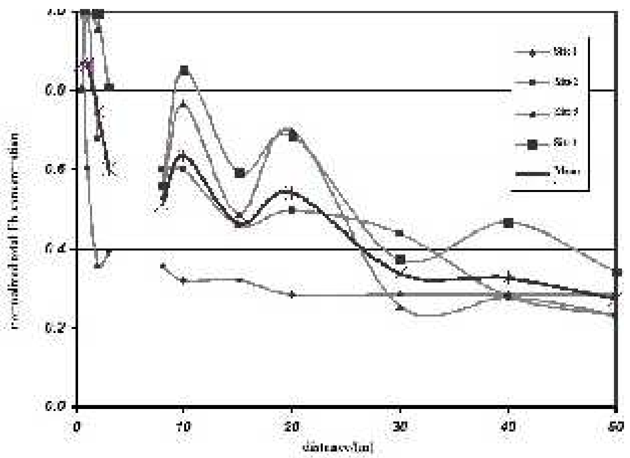

Fig 5 Normalized total Pb concentrations in road side soils of sampling sites of 10 to 13 versus Distance from road curbs

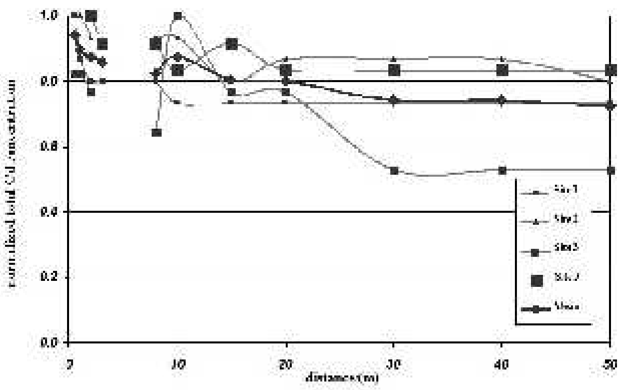

Fig 6 Normalized total Cd concentrations in road side soils of sampling sites of 10 to 13 versus distance from road curbs

Table 5 Traffic data used for modeling

site number	site name	cumulative traffic volume/ (veh)[a]	daily traffic volume/ (veh/d)[a]	total traffic volume to total capacity	total traffic volume to directional road width/ (veh/m)	speed/ (km/h)[b]	street aspect ratio
1	Chahar bagh paeen	323277305	31583	0473	8710723.98	30.2	0.129
2	Forougi	48657845	5470	0.121	11701274.02	30.3	0.3
3	Bozorgmehr	388003251	39686	0.318	7561348	54.3	0.144
4	Ahmad abad	152576141	12325	0.429	20601961.39	33.8	0.198
5	Kashani	520619999	32303	0.390	24067541.65	45.4	0.24
6	Moshtag aval	119352995	18304	0.328	7976695.902	52.2	0.514
7	Kamal esmaeel	285227027	20759	0.638	28787951.13	43	0.106
8	Chahar bagh bala	247895679	23970	0.311	31040260.08	43.3	0.214
9	Sajad	222501183	25358	0.243	34029190	53	0.067
10	Mohtasham kashani	68052132	10600	0.184	18649612.12	54	0
11	Imam Khomeini	68052132	34230	0.192	21133177.71	54	0
12	Imam Khomeini	255499686	29560	0.187	43881081.08	75.8	0
13	Razmandegan	72299009	26205	0.50	32538749.94	54	0

Notes: a) Before the year 2010; b) Year of 2013

With respect to the fact that surveying of heavy metal distribution trend resulted from vehicular factors in roadside soil is one of the research goals, normalized concentrations in versus distances are plotted in Figures (5) and (6). Table (5) shows traffic data, used for modeling which were total traffic volume, daily traffic volume, total traffic volume to directional road width, total traffic volume to total capacity, speed, and aspect ratio.

Table (6) shows the results of "t" paired student test for comparing Pb and Cd mean concentrations in the soil of different sites.

DISCUSSION

Background Lead and Cadmium concentrations are those measured in remote areas of Isfahan regions which were lesser exposed by anthropogenic activities. As shown in Table (2), mean concentrations of metals in the soils of streets and up to distance of 50 m are greater than the background values. Lead distribution in roadside surface soil is more dispersed when compared with lead distribution in background soil. As shown in this Figure 4, cadmium distribution in surface has an outward distribution from its background distribution.

Table 6 Results of t-paired test for comparison of Pb and Cd concentrations in different sites

	sites number					
parameter	10 versus 11	10 versus 12	10 versus 13	11 versus 12	11 versus 13	12 versus 13
Lead						
mean	74.9-181.9	74.79-184.1	74.79-65.92	181.89-184.1	181.89-65.92	184.1-65.92
observations	10-10	10-10	9-9	10-10	9-9	9-9
df	9	9	8	9	8	8
t_{cal}	6.032	4.55	0.559	0.17	5.858	4.908
t_{cri}	2.262	2.262	2.306	2.262	2.306	2.306
significant level	0.05	0.05	0.05	0.05	0.05	0.05
probability	0.001>	0.001>	0.591	0.869	0.001>	0.001>
Cadmium						
mean	2.36-2.7	2.36-2.44	2.36-2.11	2.7-2.44	2.7-2.11	2.44-2.11
observations	10-10	10-10	9-9	10-10	9-9	9-9
df	9	9	8	9	8	8
t_{cal}	6.53	0.497	8	1.816	10	1.664
t_{cri}	2.262	2.262	2.306	2.262	2.306	2.306
significant level	0.05	0.05	0.05	0.05	0.05	0.05
probability	0.001>	0.631	0.001>	0.103	0.001>	0.135

Standardized residual values versus predicted values of models (1) and (2) are shown in Figures (7) and (8), respectively.

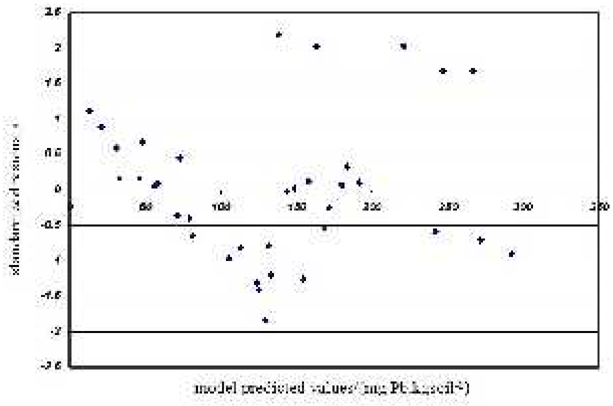

Fig 7 Residual scattering versus model predicted values (Eq. 1) for total Lead

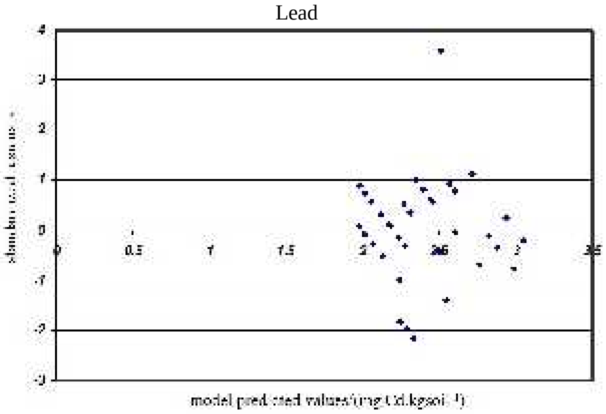

Fig 8 Residual scattering versus model predicted values (Eq. 2) for total Cadmium

Comparison of Figures (3) and (4) shows that Lead is outer than Cadmium from their related background distribution. As a result of planting trees in gutter soil, it is required to use agricultural soil standard for its health measurement. The British and Australian standards were used for Pb is 100 and for Cd is land 5 $mg.kg^{-1}$, respectively. As seen in Table (2), the mean concentration of Pb in gutter soil up to 50 m is greater than maximum allowable concentration. In the case of Cd, mean concentration exceeded the British standard. Such comparison reveals that more attention should be paid to roadside plantation and soil pollution.

One-tailed t-paired student test in significant level of 5 percent was employed to determine the significant effect of distance on metal distribution. One tailed test was selected because it is expected that in nearer distances to streets, concentrations were high. In each site, in ten distance, metal concentrations were measured, but comparison of all is not necessary, and just comparison of concentrations in distances 1, 8, 15 and 50 m will be made.

As Table (4) shows in significant level of 5 percent difference of Pb concentrations in distance of 1 versus 8, 15 and 50 m and distance of 15 versus 50 m are significant because calculated t is greater than critical t. Also at distance 8 m versus 50 m probability level is equal to 5 percent and then differences in these distances are significant. As shown in this table, differences of Cd concentrations in distances of 1 m versus 8, 15 and 50 m and 8 versus 50 m are significant. T-paired student tests may suggest that distance from road curb is an effective parameter in vehicular heavy metal concentrations in roadside soil; and by increasing distance its effect is reduced. Normalized concentration at each point in each site is calculated by dividing the site concentrations to maximum concentration on that site. These values are always between 0 to 1. Using these curves and regarding their amounts, it is more possible to study and compare distribution trend of concentrations.

Figures (5) and (6) show that distribution trends are in wave manner. Wave summits are the same in all sites. This phenomenon relates to size of produced particles by vehicles and happens in the result of traffic flow speed and rotary flow of air near the roads.

Each wave moves to the extent that its movement energy dissipates and concentrations reach background concentrations or any obstacles near the road. Moreover heavy metal distribution is that concentrations in 5 m are less than 1 m from road (Figures 5 and 6). This phenomenon refers (is related to) to road architecture and curb heights (Figure 2) and rotary flow of air. Comparison of Figures (5) and (6) shows that wave manner distribution trend for Pb concentrations is more apparent than Cd concentrations which relates to differences of their particle sizes and weights. Plotting Pb and Cd concentrations versus distances for sites 10 to 13 show that distributions decrease with the increment in distance. In addition to this, the logarithmic models are the best. As Table (6) presents, results of comparison at significant level of 5 percent shows that site 10 versus 11 and 12 with regard to its calculated t and critical t in two tailed test has a significant difference. Also site 13 versus sites 11 and 12 has t_{cal} more than t_{cri}. Results for Cd show that site 10 versus sites 11 and 13 have t_{cal} more than t_{cri} and site 11 versus site 13 has t_{cal} more than t_{cri}. So, it can be concluded that differences between sites are significant and it is clear that this difference relates to various traffic parameters in these sites.

Regression analysis suggests traffic related parameters have influenced heavy metal concentrations and their distribution in road side soil. From fitting different regression models to Pb and Cd concentration data in gutters of all sites versus each one of traffic parameters statute in Table (5), metal concentrations have a good correlation with the total traffic volume. Linear and exponential models explain the relationship between Lead and Cadmium and the explanatory variables well, respectively.
Analysis shows a weak correlation between the Pb and Cd concentrations and the explanatory variable V/C (ratio of total traffic volume to capacity). Moreover, we found a weak relationship between daily traffic volume and concentrations of Pb and Cd, which is the opposite of what was found by other researchers [16-18]. Insignificant correlation between the metal concentration and daily traffic volume can be attributed to the short term nature of daily traffic volume when compared to the cumulative traffic volume. No significant correlation was found between the metal concentration and vehicles speed and street aspect ratio. One may conclude that parameters such as street aspect ratio, vehicles speed and daily traffic volume influence the distribution pattern of gaseous pollutants. Because of this, in this research, a significant relationship was seen between total traffic volume and metal concentration in soil.

The cumulative nature of Pb and Cd concentrations in soil may also explain both operational and prolonged vehicular volume.
To model the changes in metal pollution concentrations of Pb and Cd, various mathematical expressions were tested. Such models examined the relationship between the dependent variables Pb and Cd and explanation variables of total traffic volumes and the distance between the curbside and points where samples were taken.

Models (1) and (2), below, are statistically the most meaningful models resulting from the research analysis (determination coefficient of 0.8).

$$C_{Pb} = 120.83 + (4.92 \times 10^{-7} \times V) - (35.39 \times \ln D) \qquad (1)$$

$$C_{Cd} = 2.25 + (0.29 \times e^{3E-9} \times V) - (0.16 \times \ln D) \qquad (2)$$

Where: C_{Pb} is total Pb concentration as milligram to kilogram dried soil, C_{Cd} is total Cd concentration as milligram to kilogram dried soil, V is total traffic volume as number of vehicles, and D is distances as meter.

As pointed, total traffic volume is not used as independent variable in calculating the metal concentrations in other researches. Therefore, to verify the results, a statistical method standardized residual was used. Standardized residuals are calculated from dividing differences of predicted values and observed values to mean squares of residuals; and they have a mean equal to zero and a standard deviation equal to one and when placed between 2 and -2 show that the selected model is suitable for regression.

As shown in Figures (7) and (8), almost all the residuals placed between 2 and -2 and scattered data has no specific pattern for Pb and Cd. Therefore, regression models presented in model (1) and (2) have a suitable validation.

These are taken from samples using mean concentrations of background samples. One way probability has been employed in this statistical comparison. This is because it is expected that measured Pb and Cd concentrations are greater than background values. In t-student test, the difference between samples will be significant if calculated t (t_{cal}) is more than critical t (t_{cri}). As presented in Table (3), Pb concentrations in all locations have significant difference at significant level 5% with background concentrations. Based on this, total Pb concentrations in sample soil are affected by pollution sources and because of their being in cities, they are anthropogenic. Cd concentrations in gutter soil have significant difference with background values and have affected by external factors. With regard to the fact that these samples are related to road side soils, it can be concluded that traffic flow has caused the roadside to be polluted. This finding is in line with the work of other researchers' [15-18].

CONCLUSIONS

From the review of literature on the related area of heavy metal concentrations and statistical analyses undertaken, the following conclusions can be drawn:

- All of the sites specially gutter soils and soils within 50 m from curbs had Pb and Cd mean concentrations higher than background level and standards of agricultural soil in many countries.
- Statistically, there was a significant difference between Pb and Cd mean concentrations in distances within 50 m of road curb and background level. This difference is

related to the effects of traffic and transportation parameters on roadside soil pollution.

- The significant discrepancy observed between Pb and Cd mean concentrations in different sites can be attributed to the difference shown in their traffic parameters.
- Pb and Cd concentrations in road side soil exhibited more relationship with total traffic volume compared to other traffic parameters.
- Traffic parameters with longer effect such as total traffic volume, total (accumulated) traffic volume, total traffic volume to directional road width, and total traffic volume to total capacity, showed a greater impact on relationship of soil heavy metal concentrations with traffic parameter.
- By increasing distance, Pb and Cd concentrations in roadside soil decrease logarithmically.
- Pb and Cd concentrations of gutter soils increase linearly and exponentially with increment of total traffic volume, respectively.
- The models (models 1 and 2) developed in this research are capable of predicting Pb and Cd concentrations in soil within a distance of 50 m as a function of distance from road side and total traffic volume.

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