Accumulation of metals in roadside soil, dust and pine needles in different characteristic traffic areas

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ACCUMULATION OF METALS IN ROADSIDE SOIL, DUST AND PINE NEEDLES IN DIFFERENT CHARACTERISTIC TRAFFIC AREAS

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ABSTRACT

Heavy metal levels and sources of contamination were investigated in different roadside locations from Ankara and Bursa metropolitan cities in Turkey. A state of the art energy dispersive X-ray fluorescence (EDXRF) spectrometry was utilized in the experiments. Contamination factor and contamination degree were calculated using the obtained results. Contamination degrees were calculated to be 10.9 in highway soil, 20.9 in tunnel dust, 11.1 in parking lot dust, 9.9 in bus stations, 39.0 in the city center, 13.8 in industrial soil, and 7.8 in pine needles. General observation for two cities reveals that the contamination degree of Bursa and Ankara by seven heavy metals was found to be 20.6 and 18.7, respectively. According to the results, Ankara has a considerable degree of contamination ($10 \leq C_d < 20$) and Bursa has a high degree of contamination. Contamination was significantly related to Cu, Zn and Pb. Contamination levels of heavy metals from vehicle emission could be related to traffic volume, frequency of vehicle brake stop, vehicle speeds, road type, neighboring environment and meteorological conditions. According to outcome of evaluation, the pollution sources should be minimized in the rates of contamination.

KEY WORDS: traffic, heavy metal, contamination degree, contamination factor, Ankara, Bursa

1. INTRODUCTION

Traffic emission, power plants, coal combustion, metallurgical industry and domestic emission cause anthropogenic heavy metal pollution. One of the most important heavy metal sources is vehicle emission [1-3]. Effective and flexible transport systems are an important part of the world's economy and life quality. Nevertheless, road traffic is an important negative factor regarding air quality, noise and land consumption. Contamination levels of heavy metals from vehicle emission are related to traffic volume, atmospheric dispersion from traffic rotaries, industrial emission, frequency of braking, vehicles coming to a complete stop, vehicle speeds, vehicle types, road types, neighboring environment, and meteorological conditions [1, 4].

Roadside dust makes a significant contribution to the pollution in the urban environment and consists of vehicle exhaust, sinking particles in air, soil dust, house dust, and particles carried by water. Many studies on roadside dust have focused on heavy metal contribution to pollution [5].

The search for suitable new traffic indicators is not simple, and such indicators have been tested with different methods. Further, a waste range of investigations have been looking into processes that are directly connected with the traffic volume but cannot be assigned to the burning process. The release of metals from the car body, the loss of engine, and lubricating oils can be subsumed [6].

The USA EPA (Environmental Pollution Association) highlights 21 substances which have been qualified as toxic emitted by road vehicles. Additionally, it poses a threat to plants and animals, and has direct consequences for human beings [7]. Since roadside dust and soil include a range of toxic elements, they are evaluated from the point of both environmental quality and human health.

The persistence of heavy metals in the environment is a long process [8]. There are many reasons for elemental contamination, such as traffic-derived heavy metal accumulation. Monitoring Pb emission arising from traffic is still a matter of concern for countries which have smaller economies because of less capacity for environmental protection. Most vehicles burn leaded gasoline which is a well-established source of Pb contamination to urban environments.

Several heavy metals are emitted through the abrasion of tires (Zn, Cu), brake pads (Cu), corrosion (Zn, Cu, V, Ni), lubricating oils (V, Cu, Zn,), or fuel additives (V, Zn, Pb) [9]. Ba is present as an additive in catalytic converters and also stated as an important brake component

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[2]. Compilation of traffic-derived elements and their sources are shown in Table 1.

TABLE 1 - Compilation of references for traffic-derived elements and their sources.

Element	Sources	References
V	Traffic-related	[13]
Ni	Diesel	[14]
	Lubricating oil	[15]
Cr	Diesel	[16]
	Brake wear	[9]
Cu	Diesel	[9]
	Brake wear	[15]
	Lubricating oil	[9]
Zn	Diesel	[16]
	Tires	[15]
	Carriage	[17]
	Brake wear	[17]
	Lubricating oil	[15, 17]
Ba	Brake wear	[9]
	Lubricating oil	[15]
Pb	Diesel	[8]
	Brake wear	[17]
	Carriage	[14]

Since the accumulation of metals on or in vegetation may originate from dust raised by motor vehicles and wind, and from their uptake from the soil, pine needles were also collected and analyzed in parallel with soil and dust samples.

The aim of this study is to determine heavy metal levels on roadside soil, dust and pine needle samples in Bursa and Ankara metropolitan cities. The obtained results were evaluated in terms of heavy metal sources and sampling points, and the assessments of soil contamination with elements were carried out using contamination factor and degree.

2. MATERIALS AND METHODS

2.1. Sampling

A major highway, city center, cross road, tunnel, parking lot, and bus station were selected as sampling points in Ankara and Bursa. Traffic densities and speeds of different characteristic traffic sites in the cities are shown in Table 2. At the same time, soil samples from industrial regions, exhaust particles and background samples collected away from the industrial and traffic zones in Bursa were chosen as control points.

The collection of environmental samples was carried out in August, 2010 during dry and warm weather, approximately two weeks after the last rain. A 4-cm-diameter polyethylene tube was used to take the soil samples. The road dust samples were mainly collected by sweeping from specified areas for each location using a clean plastic dustpan and brushes for each sampling site.

Road soil samples of surface layer (0-3 cm) were collected from the city centers, cross roads and highways at a distance of 4 m from the sidewalk with traffic lights. The roadside dust was hand-brushed along the kerb stone from the area of 4×0.5 m. The tunnel wall dust was also hand-brushed from the walls of the city tunnel from an area of 0.5×0.9 m over the ground, up to 1 m. Soil samples of bus stations were collected at a distance of 4 m from the bus platforms, and parking lot dust samples were collected around the edge of the parking lot at a distance of 2 m from the area of 4×0.5 m. The samples were transferred to the laboratory in plastic bags. The soil and dust samples were dried at room temperature for 7 days and sieved through a 2-mm stainless steel sieve to remove the particles with a diameter above 2 mm. A portion of the sieved samples was ground in a porcelain mortar. Then, the samples were homogenized and sieved at a particle size of <63 µm. After that, samples were stored in polypropylene (PP) bottles at room temperature.

Pine needles (*Pinus sylvestris*) were sampled from trees growing near a road with high traffic density in the city center, and from trees growing in the bus station (Bursa). Samples of pine needles were taken at approximately 2-3 m height. At each sampling location, three samples of pine needles were collected in about 10 m distances from the edge of the road along the way. After separation of the brunches, the needles were dried for 96 h at 60 °C to a constant weight. Pine needles were also ground, homogenized, sieved at particle size of <63 µm, and packed into PP bottles.

2.2. Sample preparation

In order to have the elemental composition, all samples were analyzed by energy dispersive X-ray fluorescence spectrometry. For this analysis, thin pellets of 40 mm diameter were prepared. To receive the required substrate

TABLE 2 - Vehicle speeds, densities, and sampling locations.

Sampling Location	Speed (km/h)	Bursa (vehicles/day)	Location (Bursa)	Ankara (vehicles/day)	Location (Ankara)
Parking Lot	-	1500	Uluyol	3000	Mesrutiyet street
Highway	>120	28000	Istanbul-Ankara rood, 4th km	45000	Konya rood 2nd km
Bus Station	-	850	Bursa bus terminal	1250	Ankara bus terminal
Tunnel	<90	13000	İzmir rood 2nd km	30000	M.Kemal street
City Center	<50-60	45000	Heykel street	58000	Akay street
Cross Road	<80	35000	Sırameseler street	-	-
Background Site	<90	80	Demirtas	-	-

TABLE 3 - Measurement parameters of the samples.

Element	Condition	Secondary Target	Studied Line	Measurement time (sec.)	Excited Condition
V, Cr	Mn	Co	K_α	500	50kV-12mA
Ni, Cu, Zn	Ge	Ge	K_α	500	75kV-8mA
Pb	Sr_Y_Pb_U	Mo	K_α, L_α(Pb)	1000	100kV-6mA
Ba	B_4C	B_4C	K_α	1000	100kV-6mA

material, 0.46 g of wax (high purity cellulose binder with 20-µm particle diameters) was pressed (compression of 5 kN), and then, the mixture (0.48 g of specimen and 0.09 g of wax) was pressed together with substrate material (compression of 10 kN). Samples for EDXRF analysis are usually prepared as powder pellets with the use of a binder. The use of powder pellets pressed without a binder eliminates sample dilution and, therefore, increases the sensitivity and lower limits of detection (LLDs) for trace elements. The other advantages of pressed-powder methods are its simplicity and no need of specialized skills for sample preparation. The disadvantages are particle size effect and matrix effects. However, pressed-powder pellets with a suitable binder may be satisfactorily used if the particle size can be kept below 63 µm.

2. 3. Analytical method

The measurement parameters were set up using the EDXRF system's (Epsilon5, PANalytical, The Netherlands) inbuilt software. The system has an X-Y sample changer with a sample spinner. Samples were irradiated by X-rays from Gd tube under a vacuum equipped with a liquid nitrogen cooled PAN-32 Ge X-ray detector having a Be window thickness of 8 µm. The power, current and high voltage of the instrument were 600 W, 6 mA and 100 kV, respectively. The system's software automatically analyzed the sample spectrum and determined the net intensities of element peaks as soon as the measurement was completed. When elements overlap one another, the accuracy is essential for the trace element analysis. A set of secondary standards, available from PANalytical, was used for the calibration of this application. Measurement parameters for the elements are presented in Table 3.

Lower limits of detection (LLDs) were calculated using the following equation [10]:

$$\frac{N_p}{\sqrt{N_b}} \geq 3$$

where, N_p is the number of counts measured on the peak, and N_b is the number of counts measured on the background with low backgrounds. Lower limits of detection and the accuracy of the applied method and obtained calibration curves were checked by the measurement of standards reference materials from IAEA SL-7, SARM 18, SARM 19, SARM 20, IEAE SL-1, SRM 1648, SRM 2711, SRM 1646a, and BCR CRM 277. Lower limits of detection (LLDs) for studied elements (V, Cr, Ni, Cu, Zn, Pb) were determined to be 2.9, 2.0, 1.2, 1.0, 0.7, and 0.9 in the range of mg/kg. The accuracy of the applied method was checked by the measurement of IAEA SL_7 certified reference material. The results for a certified reference material and certified values are given in Table 4.

TABLE 4 - IAEA -7 Top Soil analysis using EDXRF and comparison with certificated values.

Element	Certified reference values	Values measured
V	66 (59-73)	68
Cr	60 (49-74)	66
Ni	9.7 (7.9-11.6)	10.2
Cu	11 (9-13)	11
Zn	104 (101-113)	98
Ba	-	-
Pb	51 (47-56)	55

3. DATA EVALUATION

3. 1. Contamination factor and contamination degree

The assessment of soil enrichment with elements can be carried out in many ways. The most common ones are the contamination factor and degree, and enrichment factors. Despite certain shortcomings [11], the enrichment factor, due to its universal formula, is a relatively simple and easy tool for assessing enrichment degree and comparing the contamination of different environmental media. The contamination factor and degree seem to be more objective tools for assessing contamination, while a discussion about enrichment factors should start with an analysis of the selection of proper reference elements.

Contamination factor and degree of contamination were calculated in accordance to the method reported by Hakanson (1980) [12]. The contamination factor (c_f^i) defined by Hakanson is as follows:

$$c_f^i = \frac{c_{0-i}^i}{c_n^i}$$

where, c_{0-1}^i is the mean content of metal and c_n^i is the concentration of each individual metal in a relatively clean background site. Four classes of c_f^i to evaluate the metal contamination levels are as follows: (c_f^i<1) low, (1≤c_f^i<3) moderate, (3≤c_f^i<6) considerable, and (6≤c_f^i) very high contamination.

The degree of contamination (C_d) is the sum of contamination factors for all of the elements. The degree of contamination by the seven heavy metals in the road dust, soil and pine needles from the study areas was determined as follows [12]:

$$C_d = \sum_{i=1}^{n} c_f^i$$

Four categories of C_d were used to evaluate metal contamination levels as follows: (C_d<5) low, (5≤C_d<10) moderate, (10≤C_d<20) considerable, (20≤C_d) very high degree of contamination [1].

3. 2. Statistics

Data were analyzed by SPSS software, version 11.5. In order to establish inter-element relationships, Pearson correlation coefficients were calculated. For the elemental differences, one-sample Kolmogrow-Smirnov test was applied, and decided for parametric independent t-test because of normal distributed values. Levene statistic was used to test homogeneity of variances.

4. RESULTS AND DISCUSSION

Table 5 shows elemental concentration of samples collected from different characteristic traffic sites in Bursa and Ankara. Although there was no big difference between roadside soil and dust sample concentrations, some disagreement was observed related to sampling point characteristics. Dust and soil samples which were collected from the city center of Bursa indicated significant differences in Zn concentration due to the fact that the dust samples represent only the recent accumulation of pollutants. Also, Zn contamination was higher than that of other sampling points in the city centers where vehicles have to come to a full stop, and then, accelerate very quickly. For pine needles, all results were found to be slightly higher than the background. In comparison with the soil and dust samples, heavy metal concentrations are very low in the pine needles because of rainfall and wind. On the other hand,

TABLE 5 - Average elemental concentrations of samples (mg/kg).

Sampling Points	V		Cr		Ni		Cu		Zn		Ba		Pb	
	Ankara	Bursa	Ankara	Bursa	Ankara	Bursa	Ankara	Bursa	Ankara	Bursa	Ankara	Bursa	Ankara	Bursa
Central soil	70±1	73±1	164±59	189±40	98±19	98±12	613±25	84±7	601±113	987±211	401±35	442±26	76±1	58±1
Highway soil	74±1	73±2	121±32	746±24	25±19	169±5	17±4	33±3	83±22	104±12	567±39	405±23	21±2	7±1
Bus station soil	73±1	75±1	146±34	206±28	90±23	95±19	26±5	59±5	79±17	148±11	530±37	336±19	8±1	15±2
Tunnel dust	69±3	69±1	188±42	330±67	47±18	86±12	151±12	89±7	479±68	437±19	504±59	372±19	43±1	38±1
Parking lot dust	70±2	73±1	205±37	255±58	53±14	129±9	58±5	54±5	195±32	134±3	506±62	367±10	1±1	BDL
Central dust	-	69±1	-	259±31	-	113±9	-	58±4	-	250±19	-	474±1	-	17±2
Cross road soil	-	72±2	-	173±23	-	73±14	-	67±7	-	273±23	-	382±15	-	389±26
Industrial region soil	-	73±1	-	255±49	-	169±10	-	26±3	-	77±6	-	399±27	-	104±13
Central pine needle	-	66±4	-	37±12	-	20±10	-	51±5	-	130±9	-	12±4	-	5±1
Bus station pine needle	-	66±5	-	35±9	-	17±5	-	57±6	-	184±17	-	11±1	-	BDL
Backgrounds and exhaust particle concentrations as a control														
Soil	55±1		212±2		97±14		245±11		54±2		390±14		17±2	
Pine needle	66±7		29±2		20±7		42±3		109±5		16±1		BDL	
Exhaust particle	66±2		46±1		4874±97		ND		379±6		ND		249±4	

BDL: Below Detection Limit, ND: Not Detected

TABLE 6 - Contamination factors (c_f^i) for most traffic-related elements according to sampling location and studied cities.

Sampling Site	V	Cr	Ni	Cu	Zn	Ba	Pb
Highway Soil	1.4	2.1	1.0	1.0	1.7	2.5	1.2
Tunnel Dust	1.3	0.8	0.7	4.9	8.5	2.3	2.4
Parking lot Dust	1.4	1.2	0.9	2.3	3.1	2.2	-
Bus Station Soil	1.4	0.8	1.0	1.7	2.1	2.2	0.7
Central Soil	1.8	0.8	1.0	14.2	15.1	2.2	3.9
Industrial Soil	1.4	1.2	1.7	1.1	1.4	1.0	6.0
Pine Needle	1.3	0.2	0.2	2.0	2.7	1.4	-
Bursa	1.4	1.5	1.1	2.6	6.3	1.0	6.7
Ankara	1.4	0.8	0.7	7.1	5.3	1.3	2.1

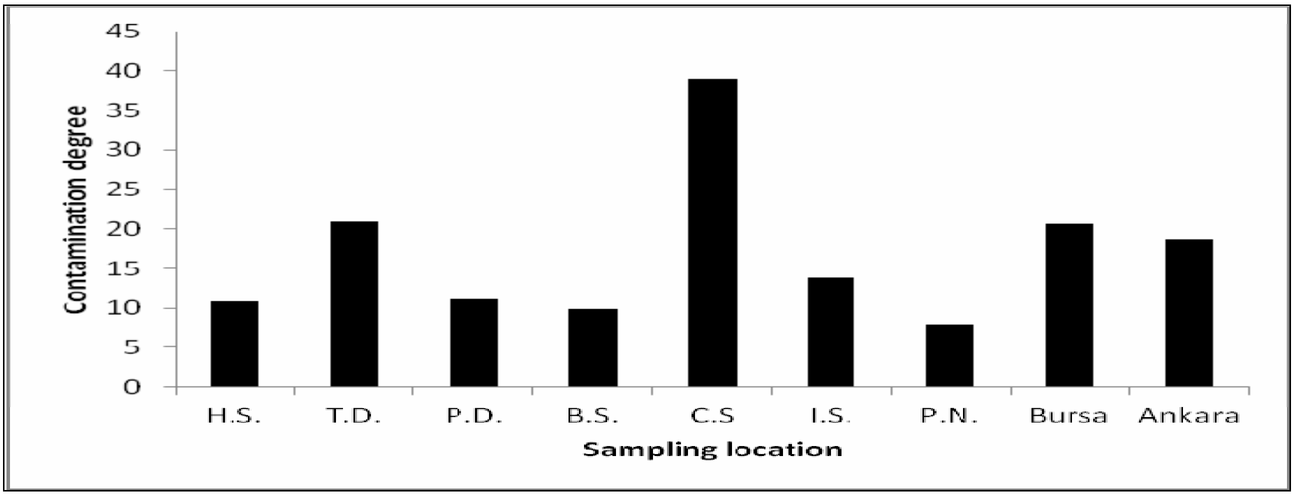

FIGURE 1 - Contamination degrees in the sampling locations (H.S. = highway soil, T.D. = tunnel dust, P.D. = parking lot dust, B.S. = bus station soil, C.S. = city center soil, I.S. = industrial soil, P.N. = pine needle).

analyzes of the exhaust particles gave important sources of contamination after the burning process. The results indicated that exhaust particles include a higher level of Ni, a considerable level of Pb, a moderate level of V and Zn, and a low level of Cr. Cu and Ba were not observed in the exhaust samples.

The heavy metal contamination of the roadside dust, soil and pine needles are shown in Table 6. The values of the contamination degrees due to heavy metals for different characteristic sampling points are shown in Fig. 1.

The contamination factors indicated moderate levels ($1 \le c_f^i < 3$) of V, Cr, Ni, Cu, Zn, Pb, and Ba in the highway soil. The dust from the tunnel wall was categorized with moderate contamination levels of V, Ba, and Pb. While Cr and Ni were categorized as a low level ($c_f^i < 1$), Zn was categorized as a very high contamination level ($6 \le c_f^i$). For the parking lot dust samples, the contamination factors indicated moderate levels of V, Cr, Cu and Ba, low levels of Ni, and considerable contamination by Zn. V, Cu, Zn, and Ba were categorized as moderate levels, and Cr, Pb, and Ni were categorized as low levels of contamination for the bus station soil samples. The roadside soil from the central station had very high contamination levels of Cu and Zn, considerable levels of Pb, moderate levels of V, Ni and Ba, and a low level of Cr. The contamination factors indicated moderate levels of V, Cu, Ba and Zn, but low levels of Cr and Ni for the pine needles. For the soil collected from the industrial region, V, Cr, Ni, Cu, Zn and Ba elements were categorized as moderate contamination, and Pb was categorized as very high contamination.

The results indicated that the tunnel dust is most significantly contaminated by Cu (considerable level) and Zn (very high level), while the parking lot dust was contaminated only by Zn (considerable level). Traffic jams, using brakes over and over again, and corrosion of tires caused a high level of Cu and Zn contamination in closed areas like tunnels. City center soil was contaminated with a very high level of Cu and Zn, and with a high level of Pb. Likewise; these results can be attributed to the traffic density and slow traffic flow. Highway soil, bus station soil and pine needles were contaminated by moderate and low levels of all elements. Contrary to the sampling points mentioned above, low traffic density, fast traffic flow, and weather conditions cause a lower level of contamination for these areas.

The degrees of contamination by seven heavy metals were calculated to be 10.9, 9.9, 39.0, 13.8, 11.1 and 20.9 for soil samples from the highway, bus station, city center, industrial region, parking lot, and tunnel, respectively, and 7.8 for the pine needles. These results indicate that the dust samples from the parking lot and industrial region soil sample have a considerable degree of contamination ($10 \le C_d < 20$). The roadside soil from the city center and dust from the tunnel wall were contributed to increased heavy metal concentrations with a very high contamination degree ($20 \le C_d$). After all, the roadside soil samples from the highway and the bus station were classified as having a moderate degree of contamination ($5 \le C_d < 10$). Since the accumulation of metals on or in vegetation may originate from dust raised by motor vehicles and wind, and from their uptake from the soil, pine needles were also classified as having a moderate degree of contamination ($5 \le C_d < 10$).

According to comparison of the two cities, the contamination factors indicated moderate levels of V and Ba for Bursa and Ankara. Cr and Ni were categorized as a low level of contamination for Ankara, while they were categorized as a moderate level of contamination for Bursa. Cu indicated a moderate and a very high level for Bursa and Ankara, respectively. The contamination factors indicated very high levels of Zn for Bursa and considerable

TABLE 7 - Comparison of measured heavy metal concentrations (mg/kg) in roadside soil and dust with literature data.

Literature	V	Cr	Ni	Cu	Zn	Ba	Pb
SÒo Paulo, Brazil [2]	-	-	-	14	104	159	19
Istanbul Turkey [18]	10-100	10-50	10-50	5-20	10-50	-	1-20
Kompala, Uganda [5]	-	-	-	63-312	100-539	-	245-2540
Several cities, Korea [1]	-	-	13-169	90-182	129-325	-	82-153
Several cities, China [3]	-	109	57	150	656	-	239
Asthma, New Zealand [19]	-	56-80	60-105	22-200	130-480	-	780-2200
Mersin, Turkey [20]	-	-	62-149	29-79	12-29	-	20-328
Kemalpaşa, Turkey [21]	-	-	29-144	-	26-108	-	115-375
Riyad, Saudi Arabia [22]	-	-	44	95	443	-	-
Bursa, Turkey [23]	-	-	67	-	57	-	-
Present study Ankara	69-74	121-205	25-98	17-613	79-601	401-567	1-76
Present study Bursa	69-73	173-746	73-169	33-89	134-987	336-474	7-389
Asthma New Zealand [19]	-	2-4	3-4	13-30	-	-	140-350
Present study (Pine needle)	66	36	18	54	157	11	BDL

BDL: Below Detection Limit

contamination for Ankara. Pb was categorized as a high level for Bursa, and a moderate level for Ankara. Bursa showed higher contamination factors than Ankara due to the heavy industry as well as wind speed and directions.

The contamination degrees of Bursa and Ankara by seven heavy metals were found to be 20.6 and 18.7, respectively. According to the results, Ankara has a considerable degree of contamination ($10 \leq C_d < 20$) and Bursa has a high degree of contamination. Although the traffic density of Ankara is higher than Bursa, both cities have approximately the same contamination degree. This can be attributed to heavy industry and weather conditions which are responsible for carrying the pollutions with high speed wind in Bursa. The elemental concentrations for soil and dust samples were compared with literature data as shown in Table 7. Cr, Cu, Zn and Ba levels were found to be higher than exemplary references in the roadside soil and dust samples. The concentration of Cr was found to be in a range of 121-205 in Ankara and 173-746 in Bursa. Cr values for other cities in various countries are as follows: a range of 10-50 mg/kg in İstanbul [18], mean values of 109 mg/kg in China [3], and a range of 56-80 mg/kg in Asthma [19]. Pb values were observed to be in a range of very higher levels in Asthma [19] and Kompala [5]. Zn concentrations in Ankara and Bursa were higher than compared literature. V and Ba were not compared to literature data, but comparison was done with Istanbul for V. Ni concentrations were in a same range with other studies. According to comparison, Cu values were at the higher levels in Ankara. Most of researchers used the vegetations as sensitive indicator of heavy metal contamination. According to comparison between vegetation samples from traffic-derived areas in New Zealand and pine needles from this study, pine needles showed higher levels of Cr, Ni and Cu; contrary, concentration of Pb indicated a lower level than the excepted values.

Pearson correlation coefficients showed significant inter-element correlations between Cr-Ni ($r=0.591$, $p<0.05$), Cu-Zn ($r=0.545$, $p<0.05$) and Ni-Ba ($r=-0,647$, $p<0.05$). No correlations were observed among others. This result showed that the linked elements came from the same origin, such as diesel, lubricating oil, brake wear etc.

According to the independent t-test using equal variances, there is no difference between the cities in terms of heavy metals ($p>0.05$), except Ba ($t = -3.586$, $p<0.05$). No significant differences were observed between the soil-dust and pine needle samples for Cu, Zn, Pb ($p>0.05$), while the following elements showed significant differences: V ($t = 4.885$, $p<0.01$), Ni ($t = 4.477$, $p<0.01$), Cr ($t = 2.390$, $p<0.05$) and Ba ($t = 14.646$, $p<0.01$). The differences may be attributed to the sources of pollution and accumulation on dust, soil and pine needles.

5. CONCLUSION

According to the results, traffic-related points were significantly contaminated by Zn (30.6% in Bursa and 28.3% in Ankara), Pb (32.5% in Bursa and 11.0% in Ankara) and Cu (12.6% in Bursa and 38.0% in Ankara). They are mostly coming from diesel, brake wear, lubricating oil, tires and carriage. One of the most important results indicated that the contamination degrees were observed to be 39.0 in the roadside soil samples from the city center but 20.9 in the dust samples from the tunnel wall. They contributed to increased heavy metal concentrations with a very high contamination degree ($20 \leq C_d$) due to the high density of traffic, traffic capacity, traffic flow and characteristics of traffic areas, such as closed space.

The amount of metals detected in the samples is only slightly higher to become a health concern, because the elements emitted by road vehicles pose a threat to plants, foods and animals, and have direct consequences for human beings. When viewed from this aspect, the study clearly highlights the necessity of immediate control measures for the exceptionally severe heavy metal pollution in the traffic-derived areas. The pollution sources should be minimized in the rates of contamination, by taking into account traffic area characteristics, traffic flow, type of carriage, type of road, regional climatic characteristics, etc.

On the other hand, EDXRF suffers from matrix and interelement interference issues. With EDXRF, the certified reference material and the sample must be matrix-matched, with respect to both the matrix and the particle size. These results are also important because the Epsilon 5 EDXRF spectrometer is one of the instruments having techniques that can precisely measure heavy metals in soil without requiring aqueous soil extractions.

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