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Distribution of Lead Accumulation in Roadside Soils: A Case Study from D 100 Highway in Sakarya, Turkey

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ABSTRACT

In this study, it was aimed to determine the lead accumulation that causes significant environmental problems. It indicated that spatial variability of Pb accumulation depended on the distance from the D100 highway alongside agricultural soils in the border of Erenler, a town of Sakarya. In the reasearch area, 160 soil samples were collected from 10 cm depth on ten transects separated by 500 m intervals and perpendicular to the road at distances of 1,5,10,25,50,100,250 and 500 m on the north and south side of the highway within 4.5 km² area. The content of Pb in soil samples was determined by ICP- OES. The results of the analysis were evaluated by SPSS 18 package programme in terms of statistical analysis. Spatial distribution of lead accumulation was mapped by enterpolation technique in the Geostatistical Analyst tool of ArcGIS 10.1 software. According to the results of the study, Pb contents of soil samples taken from the south side of the road were higher than the others collected from the north side. This caseindicated that the effect of predominant wind direction prevailing from the northwest within the research area. Moreover, there was a significant negative relationship between the Pb contents and the distance from the road and that direction. Pb contents tended to decrease as further away from the road and Pb contents in 1, 5, and 10 meters had considerably higher concentrations than the other distances.

Keywords: Lead accumulation, soil pollution, spatial distribution

INTRODUCTION

Heavy metal contamination of soils can do great damages to the environment create very important problems currently. Heavy metal pollution has a negative impact on plant, animal and human health because of the emissions from the vehicles on the highways and industrial organizations as well as wrong agricultural practices (fertilizer, pesticides, etc.). Heavy metals accumulate in the soil through colloidal adsorption and ion exchange. The removal of heavy metals retained by the soil colloids is quite difficult (Kızıloğlu and Bilen 2005). Evaluation of the soil pollution and to examine it in accordance with the acceptable heavy metal limit values is very important factor for the ecological function of the soil and sustainable agriculture (Kabata-Pendias 1995).

Lead accumulation in soils is mainly caused by road traffic, and it derives from the use of gasoline. Gasoline is added tetraethyl lead in order to prevent pinking in motor vehicles, and its accumulation on the soil surface occurs by means of air (Öztürk 2004). Since this situation changes the biological activity of the soil significantly it has great importance ecologically (Kabata-Pendias 2001). It leads to the accumulation of Pb considerably, in particular, in some tuber plant such as radishes and lettuce and in other cultivated plant grown in the fields near to highway and it is known that it may cause phytotoxic cases which can be fatal in other lives consuming these plants (Mater 2004). Many researchers have studied Pb accumulation in the soils and plants along the roadsides (Rodriguez et al 1982; Bingöl et al 2010; Osma et al 2013; Pivić et al 2013). There are also many studies indicate that amount of Pb decreases as moving away from the road in the samples taken from the surface soils nearthe roadsides with heavy traffic, therefore the pollution may be sourced mainly from the motor vehicles (Haktanır et al 1995; Jaradatand Momani 1999; Şişman et al 2002; Viard et al 2004; Kluge and Wessolek 2012; Bilge and Çimrin 2013). In a similar study made in Niğde, it was determined that zones of the first 20 m from roads are considerably risky areas,in particular, in terms of Pb(Manzak 2006). In a study performed in Galway city of Ireland, high levels of Pb accumulation had been

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detected in the roadside with heavy traffic and it was stated that this pollution would be a threat for the health of people living in the city(Zhang 2006). There are also many studies in which spatial distribution of the pollution is demonstrated by the method of GIS (Geographic Information Systems) (Güney 2006; Zhang 2006; Guagliardi et al 2010; Ölgen and Gür 2012).

In this study, it was aimed to determine the possible Pb contamination and spatial distribution of the pollution caused by the motor vehicles and agricultural practices in the agricultural lands located in sides of D100 highway having a high volume of traffic density at the boundaries of Erenler district of Sakarya province.

MATERIALS AND METHODS

Sampling Site

The study area is located in the division from the east of Sakarya River to Mudurnu Creek, between the Nakışlar and Hasanbey Quarters of Erenler township, around the D100 highway and between the coordinates of 40º44´ N - 40º45´N and 30º27´E - 30º30´E. The field available to take samples from the soils along the highway; and covering an area of 4.5 km^2 including settlements, some industrial areas and also agricultural areas were designated as sampling site. The predominant wind direction which is effective in D100 highway and around, subjected to our study and the sampling site are shown in the following location map (Figure 1).

In order to perform Pb analysis total of 160 soil samples were taken from the points determined in accordance with the grid system, from the distances of 1, 5, 10, 25, 50,100, 250 and 500 m parallel to the road at 10 transects created with the intervals of 500 m perpendicular to the road and from the 0-10 cm depths of surface soils in both sides of D100 highway in the study area after the harvest between September and October. For the physical and chemical analysis of the soil samples were taken from total of 48 points on the 1st, 4th, 7thand 10thtransects, following the packaging and labeling process these soils were dried and passed through 2 mm sieve and prepared for the analysis.

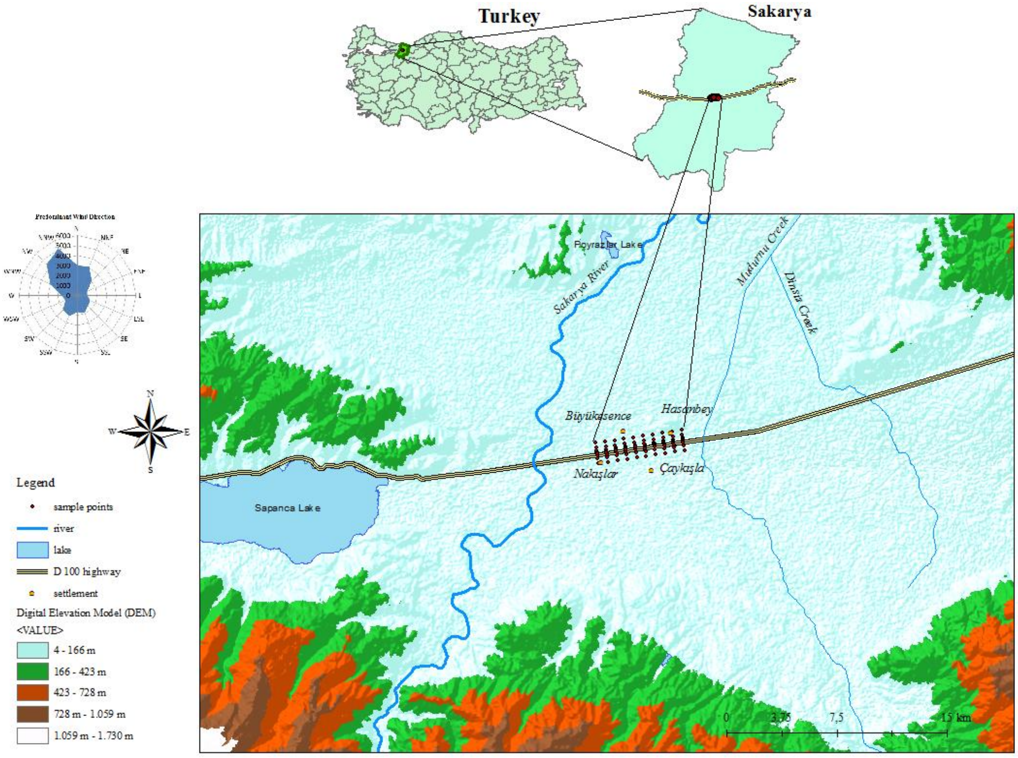

Figure1. *Location map of the study area*

Analysis Methods

Physical analysis of the soil samples was determined according to Bouyoucos-hydrometer method (Bouyoucus 1951). Soil reaction (pH) of the sampleswas determinedby the pH-meter with glass electrode using a soil to water ratio of 1:2.5 (Richards 1954),lime ($CaCO_3$) contents were determined by "Scheibler calcimeter" method (Allison and Moodie 1965), organic matter (OM) contents were determined by "Walkley-Black" method (Walkley 1947) and cation exchange capacity (C.E.C.) was made in accordance with Chapman and Pratt (1961) and quantification of Na was done using an Inductively Coupled Plasma Optical Emission (ICP-OES). Electrical conductivity of the samples (EC) were measured by a soil to water ratio of 1:2.5 solution (Dellavalle N B 1992). Pb analysis of the soil samples were extracted in accordance with Lindsay and Norwell (1978) and quantification wasdetermined by ICP-OES. The average vehicle density data of the General Directorate of Highways in the boundaries of 17^{th} Region at Erenler D 100 are given in the Table 1. Regression, correlation and variance analysis of the data obtained in the study were performed by using the SPSS 18 software package.The spatial distribution of Pb in the study area is obtained with the tool of Inverse Distance Weighting – IDW which is the most appropriate interpolation method in the Geostatistical Analyst module of the ArcGIS 10.1 software.

Table1. *Erenler D100 highway traffic density and the number of vehicles in 2013(KGM)*

Vehicles	*Number*
Automobile	15536
Medium commercial vehicle	1478
Bus	98
Truck	2104
Trailer truck	1584
Total	*20800*

RESULTS

Soil Properties of the Study Area

Physical and chemical properties of the soil samples taken from both sides of D100 highway at the boundaries of the study area are given in the Table 3**.** With reference to this table, clay contents of the soil within the study areavarried from 20% to 76%, silt contents were between 12% and 50% and sand contents were between 0% and 62% and they are usually fine textured. It was observed that the soils within the study area aregenerally distributed homogenously in terms of texture. Organic matter contents ranged between 1.08% and 7.63% and classified as "less" and "more".Lime ($CaCO_{3)}$contents of the soils varried between 6.2% and 27.8% and classified as "medium" and "more". Electrical conductivity (EC) of the examined soils ranged between 0.17and 1.09mS/cm and generally classified as "salt-free"; pH value was between 7.44 and 8.24 and almost all wereare featured as "slightly alkaline". Cation exchange capacity (CEC) in the soil samples varried between 14.26and 64.8 meq$100g^{-1}$(Table 2).

Table2. *The maximum and minimum values of some physical and chemical properties of the research area soils*

Sample point		Sand (%)	Silt (%)	Clay (%)	pH (1:2.5)	EC (1:2.5)	$CaCO_3$ (%)	OM (%)	CEC (meq $100g^{-1}$)
North 1	Maximum	20	44	50	8.19	0.26	14.4	3.31	50.22
	Minimum	6	32	36	8.07	0.19	12.5	1.78	36.36
North 4	Maximum	16	50	59	8.24	0.29	13.2	6.08	61.71
	Minimum	3	26	44	7.75	0.17	7.9	2.43	50.29
North 7	Maximum	46	26	68	8.02	0.5	20.8	4.91	6.8
	Minimum	6	22	28	7.69	0.2	6.2	2.71	27.46
North 10	Maximum	46	40	76	8,02	0.35	20.8	6.51	50.6
	Maximum	0	22	36	7.64	0.2	13.5	1.08	30.04
South 1	Maximum	36	40	60	8.15	1.09	16.9	7.63	58.56
	Minimum	6	24	30	7.44	0.2	10.8	2.11	31.05
South 4	Maximum	62	38	58	8.17	0.72	27.8	5.4	55.15
	Minimum	10	12	20	7.52	0.2	8.9	2.37	14.26
South 7	Maximum	30	46	68	8.16	0.63	19.6	6.91	59.67
	Minimum	6	20	42	7.6	0.2	8.7	2.58	40.1
South 10	Maximum	10	34	68	8.15	0.38	20.9	4.64	51.18
	Minimum	2	26	60	7.94	0.18	10.8	2.97	41.6

Lead Contents in the Study Area

In order to determine whether a relationship between the levels of lead measured in the study and the direction (north and south of the highway), transect number of the soil samples and the distance from the road; in case of presence of any relation, to determine the direction of this, correlation analysis method was performed. According to the obtained results, a significant ($P<0.05$) and negative correlation was found between the measured Pb contents and distance from the road (Table 3).

Table3. *Correlation matrix between the lead contents and the independent variables*

		Transect no	Direction	Distance (m)
Lead content (mg kg $^{-1}$)	r	-0.117	-0.292	-0.267
	P	0.141	0.000	0.001

It was determined that measured levels of lead tended to decrease as moving from the south towards the north of the road as well as moving away from the road. The variability of Pb accumulation in the investigation area according to the distance from the highway is shown in the following (Figure 2).

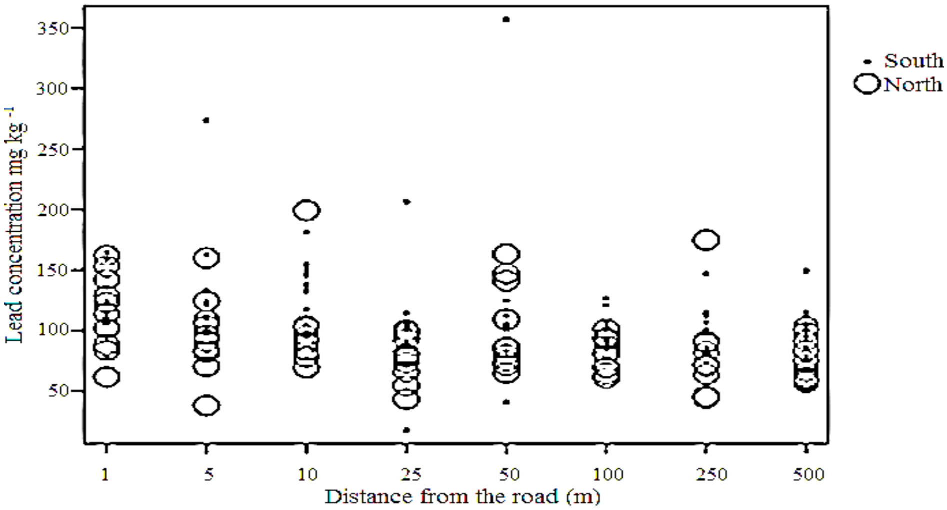

Figure2. *Variability of the lead contents with the distance from the road and the directions*

Relationship Between the Lead Contents and the Distance from the Road and Direction

Variance analysis was carried out in order to determine whether there were differences between the Pb values measured in different distances in the study. It was found that the amounts of Pb measured in different distances were significantly different from each other ($P<0.05$). In the post-hoc analysis carried out, it was found that the measurements made in 25, 100, 250 and 500 m had very low levels of lead concentrations compared to the other distances ($P<0.05$). In addition, it was determined that the average amount of lead determined in the measurements in 1, 5 and 10m was quiet high compared to the other distances ($P<0.05$). Obtained results of analysis and descriptive statistics are given in Table 4

Table4. *Variability of the lead contents with the distance from the road*

Distannce from the road (m)	Sample number	Arithmetic mean	Standart deviation	P value
1 m	20	120.1382	29.11496	0.01327
5 m	20	114.4134	47.23987	
10 m	20	116.8054	34.81771	
25 m	20	89.2919	36.67286	
50 m	20	110.8525	64.99906	
100 m	20	89.5368	17.34064	
250 m	20	91.7675	30.80350	
500 m	20	90.0057	22.17133	
Total	160	102.8514	39.43402	
Total	160	0.8016	0.35222	

The accepable limit values for Pb in the soil in accordance with Soil Pollution Control Regulation (2005) are given in the Table 5.

Table5. *Maximum permitted concentrations of lead in soil (Official Gazette of the Republic of Turkey, 2005)*

	pH 5- 6 Oven dry soil (mg kg $^{-1}$)	pH>6 Oven dry soil (mg kg $^{-1}$)
Lead	50	300

Almost all amount of Pb determined in the study was identified below the maximum limit and in the southern sectionthe 4th transect the amount of Pb was found above the maximum acceptable value (Figure 2 and Figure 3). It was thought that increasing in Pb emissions depending on the intensity of vehicles and carrying the Pb in the direction of dominant wind were effective in the highest level of Pb found around the gas station located in this part of the D100 highway.

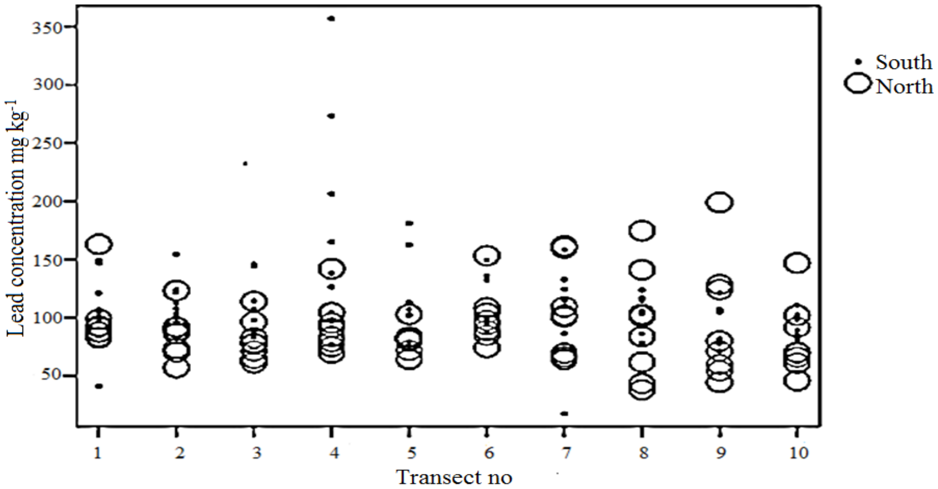

Figure3. *Comparison of the lead contents in the north and south of the road depending on the transects*

Spatial Distribution of Lead Accumulation in the Study Area Soils

In order to examine the relationship between the Pb concentration in the soil and the direction independent single variable testing method was used. According to the obtained results, measured Pb concentrations were found in different levels in southern and northern sides of the road ($P<0.05$). It is determined that the amount of Pb measured from the southern side of the road is quite highly compared to the measured ones from the northern side (Table 6).

Table6. *The average lead concents in northern and southern sides of the road*

	Direction	Sample number	Arithmetic mean	Standart deviation	P value
Lead content (mg kg $^{-1}$)	South	80	114.32	43.60	0.000
	North	80	91.38	31.01	

Regression analysis was performed to determine the relationship between the measured Pb contents, transects and the direction (Figure 4). In order to examine whether the model obtained as a result of analysis is meaningful statistically and mathematically, variance analysis was carried out and the obtained mathematical model was found meaningful ($P<0.05$). For the aim of increasing the R^2 value in the model, in order to determine the mathematical transformations of the independent variables and the interactions with each other, multiplications were included in the model (Table 7).

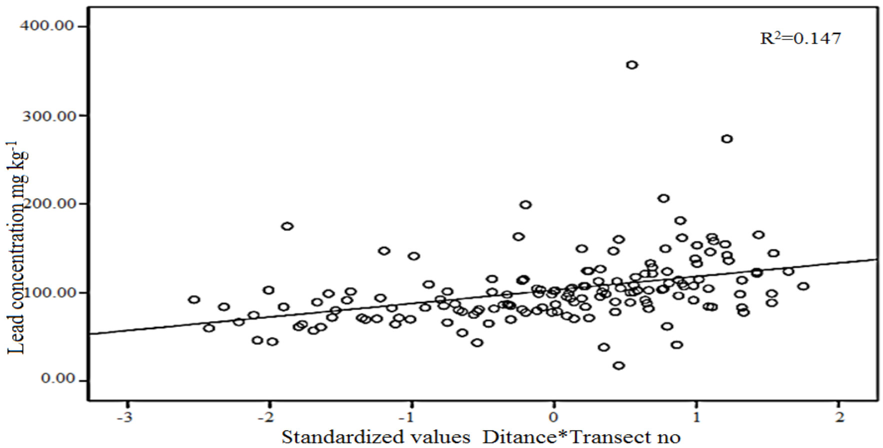

Figure4. *Regression grafic of relations between the lead contents and the distance from the road and the direction*

Table7. *Modelling of the relations among the variables*

Dependent value	Testing of the model			Independent values		
Lead content (mg kg $^{-1}$)	R^2	Coefficients	Model*	Transect no	Distance (m) x Direction	Distance (m)
	0.147	(P<0.05)	(P<0.05)	0.149	-0.368	__*

**Model: Lead content (Y) = - 0.368 (Distance from the road ^{X} Direction) – 0.149 (Transect no)*

Absent in model

When the map was examined presenting the spatial distribution of Pb accumulation, it was seen that the pollution was higher in the southern side of the road (Figure 5). According to the Figure 5, considering the prevailing wind with the direction of northwest which is effective in the field and location of the highway (in southwest-northeast direction) the significant effect of the dominant wind direction was found as the reason for this difference. In addition, according to the variance analysis examined whether the contents of Pb measured in 10 different transects in the study were different in terms of these transects, the levels of Pb measured in different transects were determined significantly different from each other (P<0.05).In the post-hoc analysis carried out, it was found that the transects of 3-8-9-10 had extremely low level of Pb value compared to the other transects (P<0.05). In addition, it was determined that the amount of Pb identified in transect 4 was considerably higher than the other transects (P<0.05) (Figure 3).

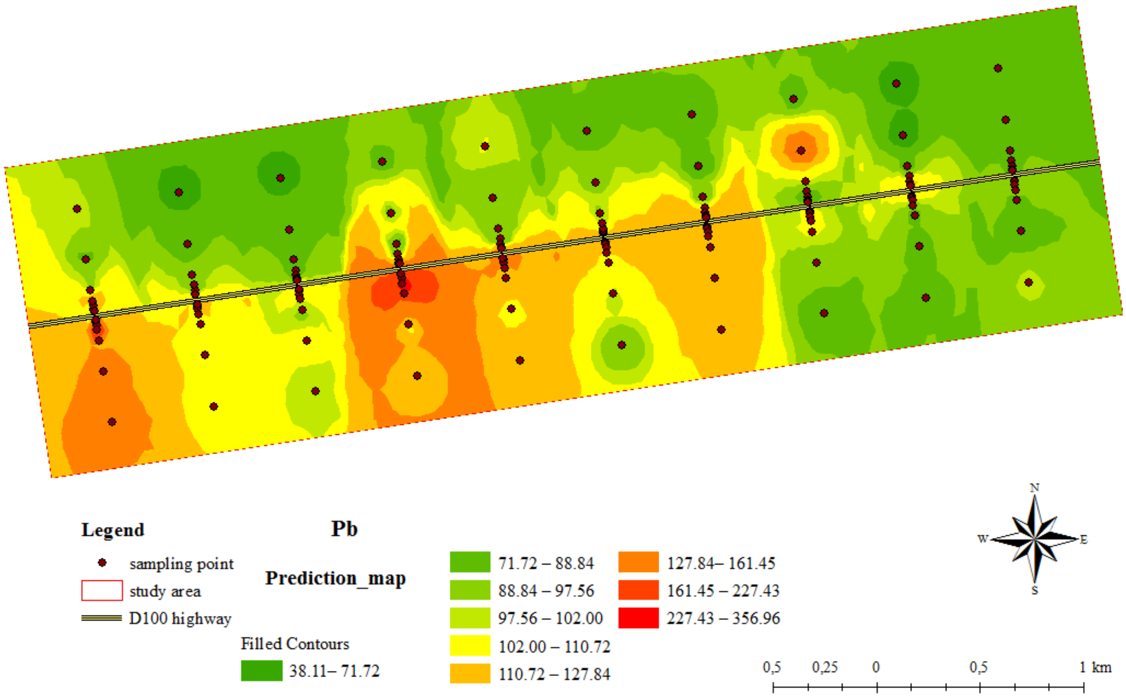

Figure5. *Spatial distribution of the lead accumulation within the study area*

DISCUSSION

Today, in parallel to develop of industrialization, heavy metal pollution in environment and soil has reached a high level. The heavy metals such as Pb emitted to the environment from the exhausts of vehicles in traffic have negative impacts on both humans, plants and animals. Since the Pb which is the first metal damaging the ecological system as a result of human activities and emitted to the atmosphere as a metal or compound has toxic properties, it is the most important heavy metal that creates environmental pollution (Kahvecioğlu et al 2003 and Alloway 2013**)**. In particular, in cultivated plants such as cabbage and parsley grown in the lands near to highways, there are significant amount of lead accumulation.Osma et al (2013) determined the highest concentrations of Pbin cabbage (72.48 µg/g dry weight), parsley (79.89 µg/g dry weight), and chard (87.00 µg/g dry weight) was found near the roadside in their research. In the soils of study area, agricultural activities are started from the roadsides and mainly lettuce, spinach, cauliflower and sugar beet are grown. This situation carries the risk of causing serious health problems in people consuming these foods. Pb and its compounds have a characteristic of accumulation in the soil and therefore the property of remaining in the soil for a long time (Alloway 2013). Especially at pH values above 6, Pbis either adsorbed on clay surfaces or forms lead carbonate. Lead has also a strong affinity for organic ligands and retained by soil (McLean ve Bledsoe, 1992).Total heavy metal amount which can be found in a hectare of agricultural lands must not exceed a certain limit and the maximum value determined by the European Union in this regard 300 mg kg^{-1} for Pb and maximum increasing value in a decade is 15 kg ha^{-1} (Gündüz 2012). The highest values in the research area are identified around the gas station on the 4thtransect (356 mg kg^{-1}). Heavy metal contamination degrees of the soils in the roadside depend on the factors such as traffic density, wind force and direction, distance from the road, plant cover and rain (Şişman 1999). In the study area, it was also found that the amount of Pb decreases with the distance from the road and the amount of Pb in the soils taken from the south of the highway is higher than the soils taken from the north. When considering the effect of prevailing wind in the direction of northwest in the study area and location of the highway, effect of the prevailing wind in this difference was clearly visible (Figure 5). An important source of the heavy metal accumulation in the agricultural lands are phosphorous fertilizers. Applying the phosphorous fertilizers to the soil increases the toxic heavy metal accumulation particularly in the upper parts of the soil (Köleli and Kantar 2005; Sönmez et al 2008). Sludge disposal application on soils is another source of toxic metals today (Rowell 1994). Pb accumulation in the research area was resulted from the existence of operating small industries such as metal processing, washbasin production, etc. besides intensive agricultural activities using the chemicals such as fertilizers and pesticides in order to increase the yield and to get rid of pests as well as the effects of D100 highway and settlement crossroads and also prevailing wind direction. According to analysis results, the lower levels of Pb accumulation were found especially around the 9th and 10th transects where traffic is rare but agricultural fields are more and woodlands which are bariers to the pollution. On the other hand, the obviously higher contents of Pb were found at the around of settlements where vehicle traffic is intensive (1st transect) and in the places where there is a gas station (4th transect) indicated that Pb contamination in the soils was manily affected by the trafic in the research area despite the exsistence of all the industrial activities and the chemicals in agriculture causing Pb contamination. Similarly, Hamzeh et al (2011), in the study in which they were examined the potential effect of traffic and motor vehicles in Pb accumulation along the streets with heavy traffic in Iran, they were determined the gas stations, road junctions and shopping centers where vehicles pass intensively as dense contaminated areas. In another similar study, Güney et al (2010) examined the Pb accumulation in roadside dusts and soils in Istanbul, they had concluded that the main pollutant element was traffic although there were also industrial areas in the study area. Pivić et al (2013) examined the Pb accumulation in the soil and plant samples taken from distances of 10, 30, 50 and 400 m perpendicular to the road and the intervals of 8 km from both sides of E75 highway which is the most important international highways of Europe in 400 km length, they had reached the conclusion that in addition to the anthropogenic pollution, overuse of pesticide, fertilizers and the air pollution generated by the motor vehicle had the effect on the Pb accumulation.

In addition, in several studies in which dedected the relationship between the Pb contamination in roadside surface soils and distance from the road, depth of soil and dominat wind direction; the prevailing wind direction was stated as significant effect on the Pb accumulation (Rodriguez et al 1982; Öztas and Ata 2002; Özkul 2008; Métransect et al 2011; Ölgen and Gür 2012).

Previous studies clearly had indicated that the amount of Pb decreased as moving away from the road and the pollution was mainly sourced from the traffic (Rodriguez et al 1982; Jaradat and Momani 1999; Sezgin et al 2003; Massadeh et al 2004; Kluge and Wessolek 2012). In addition, there were many studies mentioning the effects of Pb pollution on human health (Furman and Laleli 1999; Yapıcı et al 2002; Mormontoy et al 2004; Bakar and Baba 2009).

In conclusion, the results of this study indicated that, the presence of the settlement in the immediate surroundings of the highway carries significant health risks on the people living here especially on the children in adolescence. Therefore, agricultural activities must be started at least 20 m away from the roadside with a heavy traffic. The most effective measure that can be taken in the current study area will be allowing the natural vegetation to create a barrier on the roadsides to prevent the pollution. The pollution in roadside agricultural lands is an issue that should be emphasized in terms of the health problems might be occurred in the living beings today and in the future. Therefore, analysis of heavy metals such as Pb in the soils around the highways with similar traffic intensity must be performed at regular periods and the number of studies on this issue should be increased.

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