HEAVY METAL DETERMINATION IN ROADSIDE SOILS AND HIGHWAY DUST FROM THE MAJOR HIGHWAYS OF ISTANBUL

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HEAVY METAL POLLUTION DETERMINATION OF ROADSIDE SOILS AND HIGHWAY DUST FROM THE MAJOR HIGHWAYS OF ISTANBUL

Overland transportation is the most widespread solution to the conveyance of humans and goods. However, many environmental issues and problems are being developed as a result of these activities and have to be seriously considered. One of the most important problems is the heavy metal pollution generated by highway traffic.

Most common heavy metals found in environment near areas with intense traffic of vehicles are Pb, Zn, Cu, Ni, Cr and Cd. These metals are released to the environment through different mechanisms such as emissions from fuel burning, abrasions and leakage from the parts of vehicles. This study aims to determine the level of heavy metal pollution through the Anatolian District of city of Istanbul. For 20 critical points in highway intersections scattered around the city, surface soil, 20 cm deep soil and highway dust samples were collected. Selected heavy metals were determined by “EPA 3050 Soil Digestion Method” and Atomic Absorption Spectrophotometry (AAS). Data were evaluated by GIS programs to comment on the overall pollution through the peninsula. Also a portion of the O – 1 highway, which was the most polluted among others, was handled for detailed investigation with elemental analysis experiments to determine soil properties for interpreting better results. The results were given by GIS maps and statistical graphs together with useful comments to determine the severity of problem.

İSTANBUL'UN ANA ARTERLERİNDEKİ YOL KENARI TOPRAKLARI VE TOZLARINDAKİ AĞIR METAL KİRLİLİĞİNİN BELİRLENMESİ

Karayolu ulaşımı, insan ve mal taşımacılığında ülkemizde ve dünyanın pek çok yerinde kullanılan en yaygın yöntemdir. Fakat bu aktiviteler esnasında ciddi boyutta ele alınması gereken çevresel sorunlar da ortaya çıkmaktadır. Bu sorunların en önemlilerinden biri, trafik tarafından yaratılan ağır metal kirliliğidir.

Yoğun araç trafiğinin olduğu bir çevrede en fazla karşılaşılan ağır metaller Pb, Zn, Cu, Ni, Cd ve Cr'dir. Bu maddeler çevreye yakıt emisyonları, araç aşınmaları ve sızıntılar gibi bir çok yoldan yayılır. Bu çalışmanın amacı, İstanbul'un Anadolu Yakası'nda trafik sonucunda ortaya çıkan ağır metal kirliliğini belirlemektir. Bu amaçla şehrin bu bölgesinde ana arterler ve otoyol kenarlarında 20 farklı noktadan toprak yüzeyinden, 20 cm derinlikten ve yol kenarı tozlarından örnekler alınmıştır. Bu numunelerdeki seçilmiş ağır metallerin düzeyleri "EPA 3050 Toprak Yakma Metodu" ve Atomik Absorpsiyon Spektrofotometri (AAS) cihazı kullanılarak belirlenmiş, elde edilen veriler "Coğrafi Bilgi Sistemleri" (GIS) programları ile işlenerek tüm yarımadadaki kirlilik dağılımı elde edilmiştir. Ayrıca çalışmada en kirli kısım olarak bulunan O – 1 otoyolu için organik karbon deneyleriyle toprak yapısı belirlenerek, bu bölge için daha detaylı sonuçlar elde edilmiştir. Sonuçlar GIS haritaları ve çeşitli istatistik grafikleri üzerinde sunularak kirlilik düzeyinin bölgesel dağılımı ve durumun ciddiyeti ortaya çıkarılmıştır.

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1. INTRODUCTION

The aim of this study is to determine, monitor and interpret the heavy metal pollution created by the transportation activities in the “Anatolian District” of the city of Istanbul. For the study, soil and highway dust samples taken from the selected points were collected and analyzed not only to obtain pollution levels for the selected metals but also to get some common soil properties in order to make a better understanding for the mechanisms affecting the nature of the pollution.

Istanbul is the biggest city in Turkey with a population of 10 018 735 at year 2000, which corresponds to 14.8 % of country’s total population. Furthermore, neighbour cities surrounding Istanbul are densely populated and they have enormous industrial and commercial activities which create dense import, export and trade events. The selected part of the city holds mainly residential areas, as well as numerous commercial and industrial zones are included within the boundaries. Transportation network is not well planned and major highways that are mainly responsible for the pollution is either too close to critical facilities or sometimes completely inside the urban areas. The highway of TEM (Trans-European Motorway), which connects Europe to Asia and plays a major role in intercontinental transportation, makes the situation worse since most of the transportation activities in the country are achieved by TEM.

For the study, sampling locations were decided around the Anatolian District. They were located on major highways where high levels of pollution due to transportation activities are expected. Within the scope of study, soil and dust samples from the pre-determined sample locations were collected and analyzed for selected heavy metals (Pb, Zn, Cu, Cr, Cd and Ni). These heavy metals were encountered in high amounts in soils where contamination occurs due to the transportation activities; hence they are selected for determination within the scope of this research. “EPA 3050b – Acid Digestion of Soils, Sediments and Sludges” method was used for the laboratory experiments in order to achieve extraction of heavy metals from the soil to solution. The extracts were analyzed by using FLAAS (Flame Atomic Absorption Spectrophotometry) device to obtain concentrations of selected heavy metals. For the most polluted arterial highway O – 1, elemental analysis for carbon and nitrogen determination was held. pH experiments were also conducted for all soil samples. Data from these experiments were used to understand and explain the relationship between these parameters and levels of pollution.

To develop a better understanding on the expansion of the pollution and the relationship between the soil properties and the levels of pollutants, a GIS study has been run. Many GIS-based maps are included in this thesis, focusing on distribution of metals over the area and threshold exceeds.

2. THEORETICAL BACKGROUND

2.1. Studies on Behaviour of Heavy Metals in Soil

"Heavy metals" is a group name for the metals and semimetals with certain properties. Although there is no perfect and completely clear classification for the term, a metal is generally assumed as "heavy metal" if it has a mass per unit volume of five times of water or more. Other than the specific gravity classification widely accepted, there are numerous other definitions based on relative atomic mass, atomic number, chemical properties and toxicity (Duffus, 2002). Within the scope of this study, heavy metals are considered as substances with following properties:

- Have common metal or metalloid properties
- Have high density in atomic form
- Mostly emitted by anthropogenic sources, but also found in environment inherent
- Found both in element and substance forms in environment
- Have biologically toxic properties for exceeded specific levels

Heavy metals found in soils can be from natural sources (inherent concentrations from bedrock mineralogy) or from anthropogenic sources. All metals naturally contain metals in different amounts, which is not a sign for contamination. Common ranges of selected heavy metals in soils were given in Table 2.1. Heavy metal concentrations in soils should not exceed certain limits. Maximum allowable concentrations specify the acceptable limits to protect human and ecological health, and allowable limits for selected heavy metals in soils were given in the following Table 2.2. The table represents data according to both European Union and Turkish regulations.

In soil, metals are found in one or more of several states (Shuman, 1991):

- Dissolved in the soil water
- Occupying exchange sites on inorganic soil constituents

- Specifically adsorbed on inorganic soil constituents
- Precipitated as pure or mixed solids
- Present in the structure of minerals

Table 2.1. Common ranges for metals in soils (Fabis, 1987)

Metals	Common Range in Soils (mg/kg)
Lead (Pb)	0.1 – 20
Zinc (Zn)	10 – 50
Copper (Cu)	5 – 20
Cadmium (Cd)	0.1 - 1
Nickel (Ni)	10 – 50
Chromium (Cr)	10 - 50

Table 2.2. Allowable limits for metals in soils (EU and Turkish Regulations)

Metals	Allowable limits (mg/kg) (EU, 2002)			Allowable limits (mg/kg) (Turkish Regulation, 2001)	
	pH 5 - 6	*pH 6 - 7*	*pH > 7*	*pH < 6*	*pH > 6*
Lead (Pb)	70	70	100	50	300
Zinc (Zn)	60	150	200	150	300
Copper (Cu)	20	50	100	50	140
Cadmium (Cd)	0.5	1	1.5	1	3
Nickel (Ni)	15	50	70	30	75
Chromium (Cr)	30	60	100	100	100

Soil is a heterogeneous medium formed by solid phase (organic and inorganic constituents) and fluid phase (water and air) with a complex interaction between these (Alloway, 1995). Heavy metals are accumulated in soils by adsorption mechanisms which is a major process (Bradl, 2004). The most important parameters controlling heavy metal adsorption and their distribution between soil and water are soil type, metal speciation, metal concentration, soil pH, solid to solution mass ratio, and contact time. Inorganic minerals of clay, metal oxides, hydroxides, metal carbonates and phosphates mainly dominate other inorganic constituents as adsorption interfaces, (Bradl, 2002; Apak, 2002) organic matter and organisms living in soil also have complex adsorption mechanisms and are responsible for the accumulation of heavy metals. pH and type of metal play important role in adsorption and mobility, where specific behaviours for different metals in different soils are observed.

Lead (Pb) in soluble form reacts with clays, phosphates, sulphates, carbonates, hydroxides, and organic matter such that Pb solubility is greatly reduced. At pH values above 6, Pb is either adsorbed on clay surfaces or forms lead carbonate. Carbonate content in soils plays an important role in controlling Pb behaviour. Zinc (Zn) is readily adsorbed by clay minerals, carbonates, or hydrous oxides. The greatest percent of the total Zn in polluted soils and sediments was associated with Fe and Mn oxides. Precipitation is not a major mechanism for Zn in soils because of the relatively high solubility of Zn compounds. Zn adsorption increases with pH. For pH values larger than 7.7 hydrolyzed species are strongly adsorbed to soil surfaces.

Zinc forms complexes with inorganic and organic ligands that will affect its adsorption reactions with the soil surface (McLean and Bledsoe, 1992). Copper (Cu) also shows a strong affinity for soil organic matter and is absorbed to a greater extent by soils and soil constituents than the other metals except Pb. Cu, however, has a high affinity for soluble organic ligands and the formation of these complexes may greatly increase Cu mobility in soils.

Nickel (Ni) does not form insoluble precipitates in unpolluted soils and retention for Ni is through adsorption mechanisms, which is a quite different characteristic from the other metals mentioned. Nickel will be adsorbed by clays, iron and manganese oxides, and organic matter; thus it is found removed from the soil solution. The formation of complexes of Ni with both inorganic and organic ligands will increase Ni mobility in soils. (McLean and Bledsoe, 1992)

Cadmium (Cd) may be adsorbed by clay minerals, carbonates or hydrous oxides of iron and manganese or may be precipitated as cadmium carbonate, hydroxide, and phosphate.

The greatest percentage of the total Cd was associated with the exchangeable fraction. Cd solubility increases and very little adsorption of Cd by soil colloids, hydrous oxides, and organic matter takes place. At pH values greater than 6, cadmium is adsorbed by the soil solid phase or is precipitated, and the solution concentrations of cadmium are greatly reduced. Cadmium forms soluble complexes with inorganic and organic ligands, in particular with Cl. The formation of these complexes will increase Cd mobility in soils.

Chromium (Cr) exists in two possible oxidation states in soils: the trivalent chromium, Cr (III) and the hexavalent chromium, Cr (VI). Cr in soils is controlled by a variety of factors and complex mechanisms such as redox potential, oxidation state, pH and soil mineral structure. (McLean and Bledsoe, 1992; Bradl, 2004) Chromium has different chemical properties from other metals within the scope of study. It is found in environment in two ionic forms, chromate ($CrO_4{}^{2-}$) and dichromate ($Cr_2O_7{}^{2-}$) which are both negatively charged unlike most of the other metal ions. This unique difference affects the adsorption behaviour of chromium especially against negatively charged soil minerals such as clays, where adsorption and chemical complexation is rare due to the repellent forces between the chromates and clay particles.

Annual yearly rainfall affects the behaviour of heavy metals in soils. In the regions where precipitation is not high, the effect is negligible. However, in sites with high precipitations (more than 930 mm/yr) variations were observed depending on the type of metal. Pb was found enriched with high precipitation, where Zn was depleted. Cu did not show a significant change. The level of enrichment/depletion is higher for the metals mentioned as precipitation increases (Teutsch et al. 1999).

Among natural elements such as mineral structure, pH and types of organisms live in the soil media; there are also artificial factors which affect the behaviour of heavy metals in soils. For example, high amounts of NaCl in soils was found to make Pb, Zn and Cu vulnerable to leaching either by displacing the Ca^{++} ions of the base cations from the exchange sites of the soil or by lowering the pH, which is an important factor that controls mobility/retaining mechanisms of most metals (Norström and Jacks, 1998). The common source for artificial NaCl in roadside soils is de-icing salts used in cold seasons. Especially, the leaching of Pb to the groundwater may violate the drinking water quality standards since limiting values are low with respect to the Zn and Cu. Pb was affected most among three where total organic carbon was also found having direct relationship with the mobilization mechanism. Zn and Cu were affected by Cl^- complexes, pH and ionic exchange (Norrström, 2005). Cadmium concentrations were also found to increase under the presence of NaCl in soils as a response to ion exchange and formation of chloride complexes (Backström et al. 2003). Sepiolite, a mineral with low cost and high production, was found useful to retain cadmium and zinc when used as an additive to the soil and can be used together with de-icing salt to diminish the effects of salt mobilization. Acid rains will also likely to affect the entire soil structure and properties together with heavy metal behaviour, first by lowering the pH of the surface soil (and contributing the heavy metal mobilization) where most of the pollution is observed, then altering the complex ion equilibriums within the soils, and lastly affecting microorganisms and plants which play important role in determination of soil parameters and in retaining of heavy metals.

Cu and Pb were found strongly-sorbing and would remain in nature over centuries to millennia under suitable soil conditions (high organic content and pH). Weakly-sorbing metals of Ni, Zn and Cd will respond to small changes in decades to a century (Tipping et al. 2005). However, entrapment of pollution in the soil is not guaranteed since numerous natural and artificial changes in soil structure and properties would likely to occur with the time as mentioned above.

Heavy metals in soils have interactions with organisms living in soil also. For those organisms that have survived and adopted theirselves to the situation, accumulation and adsorption behaviours are encountered. The plant of *Graminaceae* and a species of snails, *Helix Aspersa,* accumulate high amounts of Pb, Zn and Cd in their biomass (Viard et al. 2004). *Nerium Oleander*, a common plant around Mediterranean, can accumulate Pb, Zn, Cd and Cu in its leaves, which makes it a useful biomonitor for the metals mentioned (Aksoy and Öztürk, 1997). Also *Phacelia* and cress was found accumulating Zn, Cd and Cu; and spinach and stinging nettle collecting Zn and Cu in their parts (Schafer et al. 1998). Literature study supports the positive correlation between the concentrations of pollutants in contaminated street dust and in plants. *Taraxacum officinale, Plantago lanceolata, Lolium multiflorum, Rhytidiadelphus squarrosus* and *Vascellum pratense* establishes positive relationships between concentrations (Djingova et al. 2002).

For the microorganisms, high surface area-to-weight ratio creates very large contact area; hence microorganisms are able to fully interact with the pollutants within the environment. Adsorption, precipitation, complexation and active transport are common mechanisms for the interaction with heavy metals. However, heavy metal polluted soils are toxic to most organisms. Pb and Cd contamination cause a significant decrease in soil biomass microbial carbon within the 28 days following the contamination. Under excess contamination, where Pb concentration is larger than 600 mg/kg of soil or Cd exceeds 100 mg/kg of soil, soil biomass microbial carbon continues to decrease in the next 28 days. High Pb and Cd contamination significantly inhibits soil microbial community structure (Akmal et al. 2005). Furthermore, enzymatic activity of soil microorganisms diminishes with increasing heavy metal pollution linked with the decreasing carbon biomass. This is assumed as a result of increase in carbon use as energy source rather than assimilation processes under unfavourable conditions (Mikanov, 2005). The contribution of adverse effects of polyaromatic hydrocarbons emitted during transportation activities should be noted, though, since the effects may not be result of a single parameter (Tuhackova, 2001). For the microorganisms which are able to survive within the soil environment, the behaviour of heavy metals is affected by (Ledin, 2001):

- Transformation of metals by redox and alkylation
- Accumulation through passive and active methods within the cells
- Enzyme release which results in sudden changes in the chemistry of media
- Participation to organic carbon cycle which is a very important parameter describing heavy metal behaviour in soils
- Influencing other soil parameters which have significant effects on retaining/mobilization mechanisms, such as soil pH.

Acceptable upper limits for heavy metals in the soils were given in Table 2.2. European Union and Turkish regulations represent maximum allowable heavy metal concentrations in soils; and indicated that exceeded levels threaten human and ecological health seriously, resulting in side effects on human health and environmental imbalances.

2.2. Studies on Determination of Heavy Metals

Numerous studies have been performed in order to measure the heavy metal pollution due to the transportation activities; however a few have been studied in Turkey and Istanbul. The main lead (Pb) source of pollution is from the leaded gasoline which includes tetraethyl or tetra methyl lead used to increase octane rate of fuel. Roadside soils have been shown containing high amounts of Pb which is determined mainly originating from petroleum combustion. Also deep layers were found both including natural and artificial Pb content together. Natural Pb content was found associating with carbonate iron oxides, where artificial Pb associates with alluminosilicates mainly and this property was used to separate natural and artificial Pb from each other (Teutsch et al. 2001).

Zinc (Zn) has been shown coming mainly from the tyre abrasion and corrosion of safety fences (Blok, 2005). In the Netherlands, Zn release by corrosion of safety fences was estimated as 44 tons/yr and release from tyre abrasion was calculated as 140 tons/yr (Blok, 2005). Cu deposition to environment was found mainly due to the abrasion of brake linings. Wear of brake linings also contributes to Zn pollution as well as Cu and Pb. A typical brake lining includes 11.7% Cu, 2.3% Zn and 0.9% Pb (Jonsson, 2001). Also leakage from parts of vehicles continuously contributes to pollution created by various heavy metals.

Sezgin et al (2003) examined the region over the most loaded highway in European District of Istanbul. During the studies, Pb levels up to 555.4 mg/kg, Cu levels as high as 1358.5 mg/kg and Zn concentrations of 1502.5 mg/kg have been measured in the street dusts representing very high levels of pollution that can be related to transportation activities. Turer et al (2000) had a wider study in Cincinnati, Ohio in the U.S. covering heavy metal concentrations of top soil and different depths from the soil surface, detailed soil composition, soil mineralogy and sequential extraction of metals. Experiments have shown that the pollution concentrated within the first 10 cm of the soil for the Pb, Zn and Cu, however there was no clear relationship for the Ni and Cr. Levels of Pb, Zn, Ni, Cr and Cu have been found directly related with the organic carbon content of the soil. The researched site has exposed no emissions of unleaded fuel for 12 years; however pollution levels were found very high which represents heavy metals, especially lead in particular, are very persistent within the environment.

Chen et al (2005) have studied the parks of Beijing in China for heavy metal contamination and obtained critical pollution levels for some parks, where children who are most vulnerable to diseases and effects of heavy metal pollution would be affected from the pollution by skin contact. With respect to the background levels of soils, 12 times higher Cu concentrations and seven times more Pb concentrations were measured. Another study made in parks of Seville, Spain indicated surface Pb, Zn and Cu concentrations up to 557, 388 and 290 mg/kg respectively. Similarly, some of the parks was found critically contaminated. Surprisingly, the soil under the surface was determined carrying more pollution which gave Pb, Zn and Cu contaminations of 1080, 876 and 698 mg/kg respectively. Traffic-related sources were found as the main source of the heavy metal contamination in this study, as well (Madrid et al. 2002).

Li et al (2001) have conducted a similar study for parks, urban soils and street dusts in Hong Kong and found elevated concentrations for Pb, Zn, Cu and Cd. Cd had the most exchangeable fraction among the other metals. Highest pollution levels were obtained in street dusts and pollution levels in soil were found decreasing after the use of unleaded fuel. A case study performed in urban soils of Palermo, Italy indicated maximum concentrations for Pb, Zn, Cu, Ni, Cr and Cd as 682, 433, 344, 39, 100 and 1.86 mg/kg respectively over 70 topsoil samples. Nearly all of the samples were found containing Pb levels over the acceptable limits (Manta et al. 2002).

Lee and Touray (1998) researched contamination characteristics and leaching behaviour of highly contaminated soils collected from the edge of a highway where they have obtained average concentrations of 1460 mg/kg for Pb, 2830 ppm for Zn and 2.8 ppm for Cd. They have found the mobility of metals was in the order of Cd > Zn > Pb. Pb and Zn were found highly soluble under acidic conditions. Another study in Ogbornoso, Kenya gave similar characteristics to other studies such as very high peak values in some samples and highly varying results, but it also expressed that there was no correlation between concentrations and distance from the road for Ni, Cu and Cr (Olajire and Ayadele, 1996). There is no such behaviour for Pb and Cd, as expected. Where atmospheric dispersion of the emitted pollutants is high, this might be possible.

Highway runoff was also studied since it contains eroded material from topsoils and highway dust. Critical limits of pollution in runoffs were obtained immediately after the rainfall and different soils act differently under the runoff contamination, where high organic carbon and pH values provide larger retention capacities (Barbosa and Jacobsen, 1999). Turer et al (2000) also studied highway runoff in their studies and obtained very high event mean concentrations for Zn, Cu and Pb which violate EPA discharge criteria. Especially, Zn mean concentrations were found extremely larger than the discharge acceptable limits (4 to 130 times higher). This is followed by Cu and Pb concentrations, respectively.

2.3. GIS-applied Studies

GIS applications are used in environmental sciences where it is needed to understand, represent and combine results of various researches over a geographical area. In example, by using GIS software, point measurements done for a specific purpose over an extended area can be used to estimate overall distribution schematics. GIS applications have various extensions including one where point results may be distributed and evaluated over an extended area, which is called spatial analysis tool. Kriging and IDW (Inverse distance weighing) methods are the most commonly used interpolation techniques. They are useful to obtain statistically unbiased estimates of surface elevations from a set of control points. By using these methods, heavy metal distribution over entire area can be estimated from the experimental data received from point samples. Also source identification is made more precise in studies where GIS extensions are used. Furthermore; monitoring of variables, calculating the future trends and estimating expectancies are successfully achieved with the help of these applications, if needed.

GIS-involved studies on heavy metals and soils generally aim to represent source determination and distribution of pollution. Liu et al (2005) have tried to characterize the heavy metal pollution in paddy fields in Zhejiang, China, and examined an area over 6390 km^2 by taking samples from 450 points. Results were converted to filled contours maps, where highly contaminated areas and potential point and area sources can be identified easily. Heavy metals with high risk for environment pollution and human health, and areas those may need agricultural cultivation adjustments were determined from the GIS maps.

Mitsios et al (2003) have also conducted a three year study for the evaluation of heavy metal pollution in the agricultural areas of Thessaly, Greece, where tobacco is mainly cultivated. An extensive area of 287.5 km^2 has been studied and spatial distribution of the different heavy metals has been determined by using Kriging analysis with different suitable spatial analysis parameters. After applying the GIS analysis, highly polluted zones were revealed for each metal.

Facchinelli et al (2000) made a preliminary study for the determination of soil contamination in Piemonte, Italy. Using geostatistics and GIS applications, study aimed to determine heavy metal concentrations over the area, to find the variability of the pollution and to predict natural and artificial point and area sources. Point concentrations found by experiments were distributed over the area by GIS applications and converted to area values by using contour lines. Also main sources and variability are associated with factors by using geostatistics and GIS. Cr, Co and Ni concentrations were found to be controlled by parent rock. Pb was also found showing anomalies and has been shown related with road transport, urban and industrial areas.

Urban, suburban and country parks in Hong Kong were subject to a research of heavy metal contamination study supported by GIS application. Over an area of 80.3 km^2 was studied for determining the pollution in surface and 15 cm deep soil. Pb, Zn, Cu and Cd were found in excessive amounts in some locations. Spatial distribution of heavy metals, soil pollution index and annual average daily traffic was done by using GIS software. Pb isotopic composition analysis has shown that dense traffic load over the urban area was the primary source of pollution. Severely polluted areas were also obtained by GIS application over the research area (Lee et al, 2005).

Li et al (2004) also concentrated in a highly urbanized part of Hong Kong, called Kowloon area. The researchers have conducted an extensive GIS study and found that Ni, Cu, Pb and Zn contamination over the district had common sources. Old industrial and residential areas, road junctions, major roads and existing industrial facilities were decided as the potential sources of contamination. The decisions were based on geochemical and soil metal index maps created by the GIS operations and hot spots were found as a result of these analyses.

3. SITE SELECTION AND SAMPLING

Six major highways were selected as sampling locations in the Anatolian District of Istanbul. These highways form a network over the district, which includes more than half of the residential areas of city of Istanbul and a considerable amount of commercial and industrial activities. Sampling points were selected according to meet the following criteria listed:

- They have similar distances between them, and scattered evenly over the research field in order to see distribution better over the site.
- Locations which are near to critical places such as water basins, densely used bus stops and highly populated urban zones were sought.
- Intersections were considered first, if they exist, where mostly polluted areas were expected near the crossings of two or more highways. Also data taken from the intersections was used in detailed investigation of both intersecting arterials.

All of the major highways in Anatolian District of Istanbul were subjected to sampling operations. Soil and dust from following arterials were sampled for the study:

- O – 1 Highway
- O – 2 Highway
- O – 4 Highway
- D – 100 Highway
- D – 020 Connection
- O4 – D100 Connection

List of locations for sampling points is given in Table 3.1. along with the names of the belonging arterials. Figure 3.1. includes a map of Anatolian District with sampling locations. Also, a simplified GIS map for highways and sampling locations is given in Figure 3.2.

Table 3.1. Sampling Locations

Sampling Point	Sampling Location	Sample ID	Arterial(s)
1	Beylerbeyi	SP01	O – 1
2	Altunizade	SP02	O – 1 & D – 020
3	Çamlıca	SP03	O – 1 & O – 4
4	Göztepe	SP04	O – 1 & D – 100
5	Fenerbahçe	SP05	O – 1
6	Kavacık	SP06	O – 2
7	Kazım Karabekir	SP07	O – 2
8	Ümraniye	SP08	O – 2 & D – 020
9	Ataşehir	SP09	O – 2 & O – 4
10	Kozyatağı	SP10	O – 2 & D – 100
11	Haydarpaşa	SP11	D – 100
12	Altıntepe	SP12	D – 100
13	Cevizli	SP13	D – 100
14	Kartal	SP14	D – 100 & D100 – O4 Connection
15	Yakacık	SP15	D100 – O4 Connection
16	Samandıra	SP16	O – 4 & D100-O4 Connection
17	Kayışdağı	SP17	O – 4
18	Kısıklı	SP18	D – 020
19	Çekmeköy	SP19	D – 020
20	Sarıgazi	SP20	D – 020

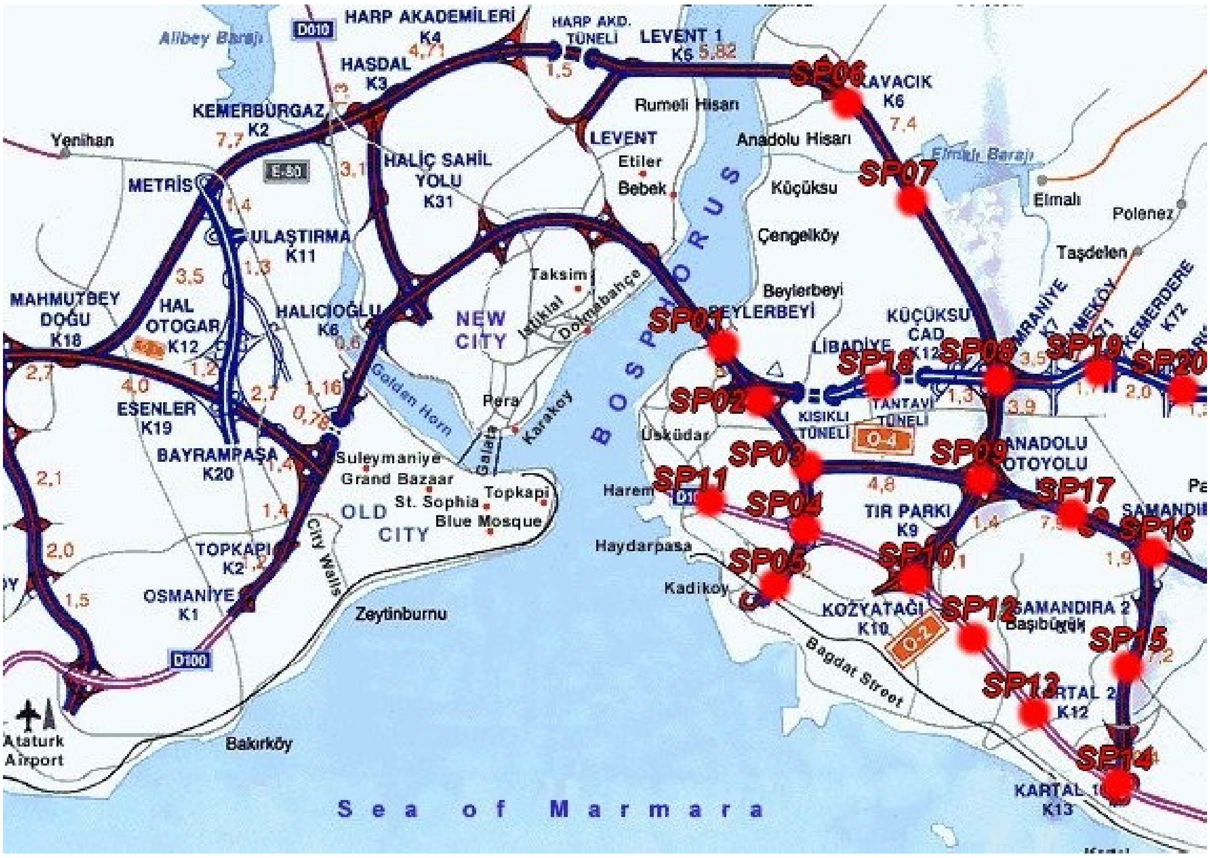

Figure 3.1. Sampling Locations

From each sampling point, three samples were collected:

A. Surface soil: Top soil was taken next to road to determine heavy metal concentrations, pH, salinity, conductivity for each sampling point. Also additional samples were collected for elemental analysis.
B. Soil from 20 cm deep: These soil samples were taken next to road in order to reveal same information determined for surface soils. The obtained data were evaluated as an indicator of impact of surface pollution to background conditions.
C. Highway dust: Dust samples were collected from each sampling point from the road pavement to determine heavy metal concentrations. Dust is mobile where wind and/or rainfall present, and assumed as most direct pathway threatening human health and nearby ecology.

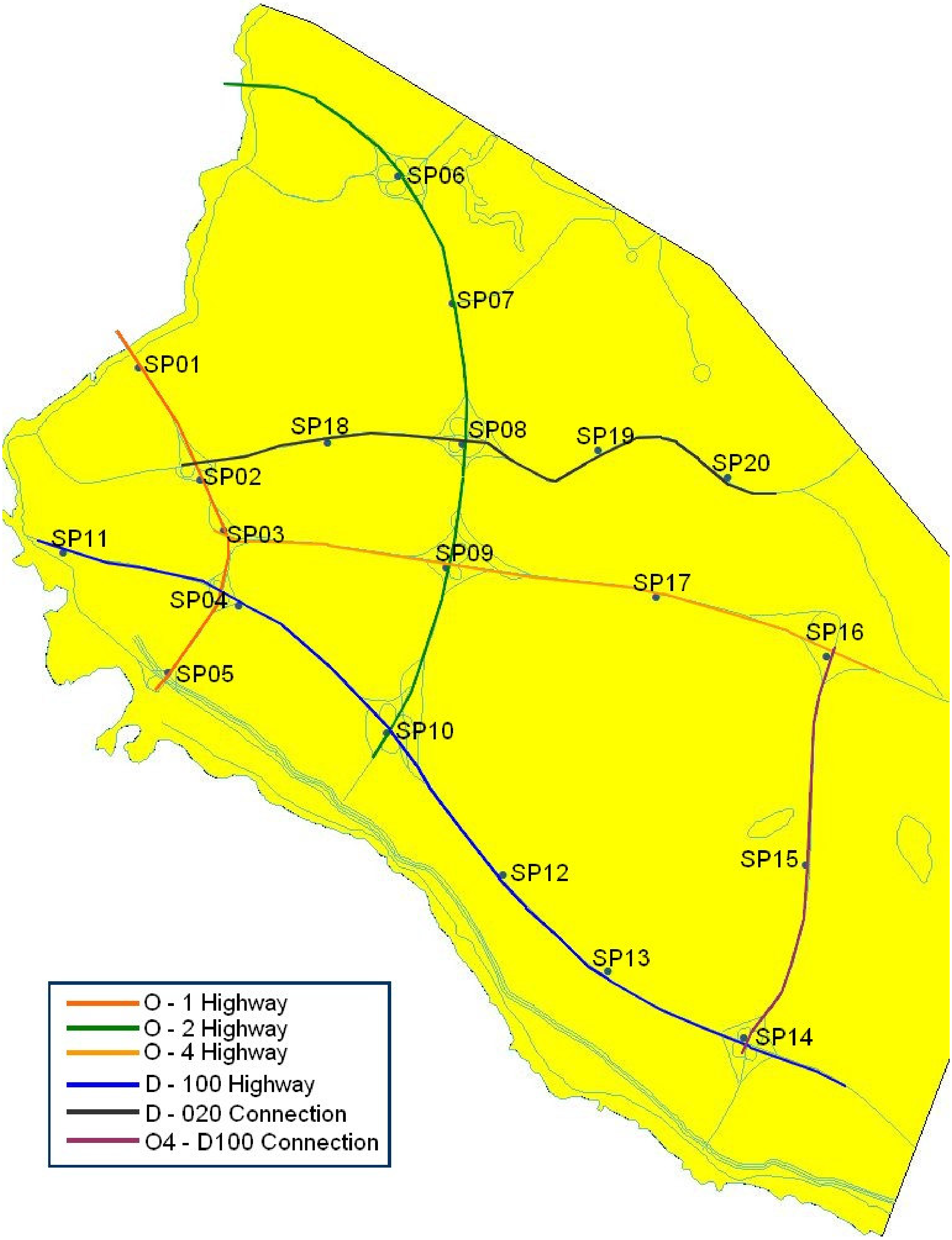

Figure 3.2. Sampling Locations and Highways

4. MATERIALS AND METHODS

4.1. Sampling Procedure

For the sampling operations, a sampling device was manufactured specially (See Figure 4.1.). The device was inspired from the widely used cylindrical sampling device "Shelby Tube", which is a common instrument used to obtain undisturbed soil samples for the laboratory experiments. To get soil samples, the device was driven into the ground with a steel hammer or by hydraulic pumps.

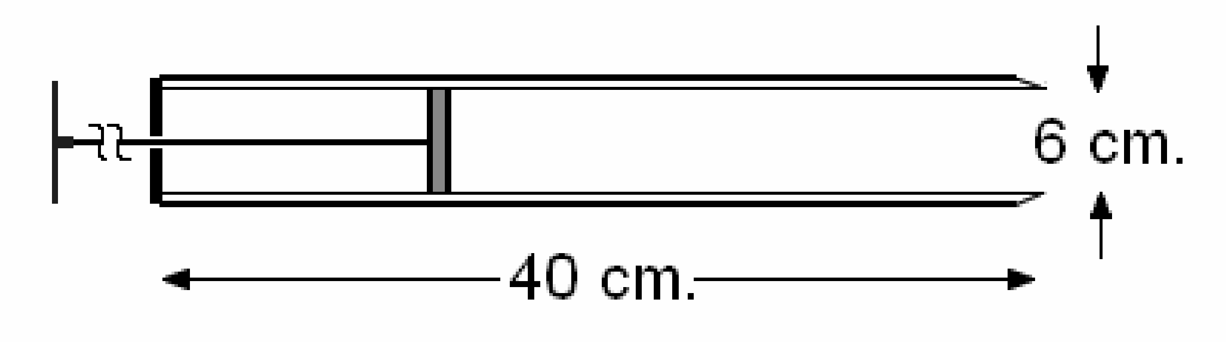

Figure 4.1. Sampling Device

The sampling device was designed according to meet some specific purposes. To minimize fundamental errors and variations for the laboratory experiments, the tube should have a diameter large enough so that it is possible to take necessary amount of soil (Shefsky, 1997). On the other hand, it becomes impossible to penetrate the device through soil due to the resistant shear forces when diameter is too wide. By considering these points, the diameter was chosen as six cm. The tube was also manufactured to get into the necessary sampling depth easily, which resulted of a selection for 40 cm as the length.

A piston was added inside of the device in order to take soil easily out of the pipe. The tube was prepared from a suitable type of steel with a specially forged mouth part to make it resistant against cracking and bending during the operation. A total of three identical sampling devices were manufactured and used during the sampling operations.

Soil samples were taken from the surface and from the 20 cm depth for each sampling point. By driving the device with the help of a steel hammer, soil was picked with minimum disturbance and was taken out from the tube with the use of piston. Since soil samples were used in different laboratory experiments, multiple samplings were done for each point to get necessary amount of soil for the use in experiments. The samples were put in plastic bags and experiments were conducted as soon as possible. Figure 4.2. shows how a sampling is done with the tube.

Highway dust samples were also collected from each sampling point with the help of a brush and a dustpan. Similarly, collected dusts were put into and hold in plastic bags and analyzed as soon as possible.

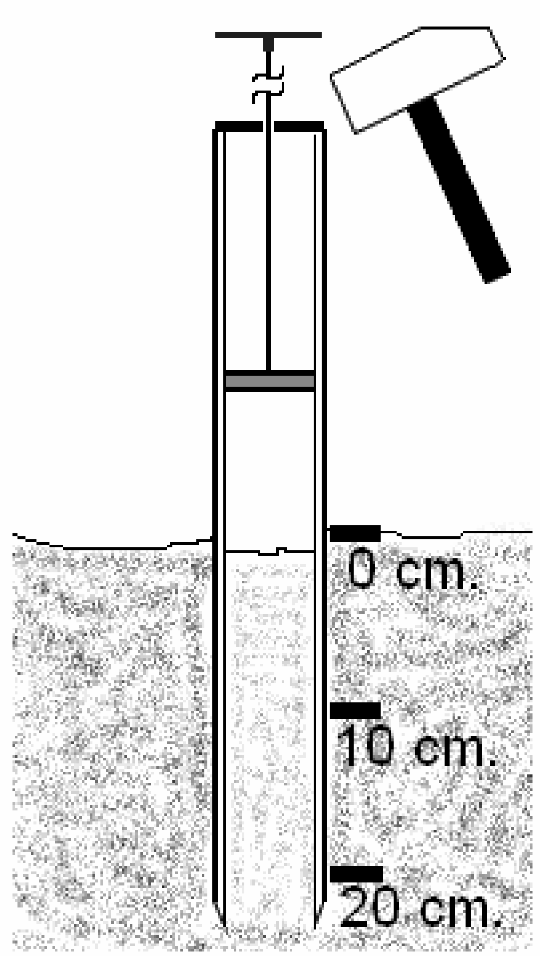

Figure 4.2. Schematics of Sampling Operation

4.2. Determination of Metal Concentrations

Heavy metal concentrations for surface soils, 20 cm deep soils and highway dust were determined for all of the sampling points within the scope of this study. Measurement of the pollutants becomes possible when all the desired metals are extracted from the soil media to aqueous phase. For this reason, to determine the heavy metal concentration of samples they were digested by strong acids in order to set metals free into a certain amount of liquid solution. During the digestion, organic part of the soil is completely destroyed, leaving the metal ions bound to it.

To achieve this, laboratory experiments were conducted. EPA method of “Acid Digestion of Sediments, Sludges and Soils – Method Number 3050B” was used during the laboratory studies (USEPA, 1996). All of the six metals within the scope of this research can be effectively and precisely determined after using FLAAS (Flame Atomic Absorption Spectrophotometry) device by using this method. The approximate limits for the metals that can be determined by the EPA method for 2 g of sample are as follows;

- Lead (Pb): 200 000 mg / kg
- Zinc (Zn): 1 000 000 mg / kg
- Copper (Cu): 1 000 000 mg / kg
- Nickel (Ni): 1 000 000 mg / kg
- Cadmium (Cd): 1 000 000 mg / kg
- Chromium (Cr): 1 000 000 mg / kg

These limits for the method are far beyond the pollution levels to be expected to get from the soil samples, which means pollution values can be determined with precision by using EPA 3050b.

All samples were crushed with a plastic hammer and dried after collection from the site and sieved using a USS #10 sieve with openings of two mm in order to achieve homogeneity of sample needed for the experiment, and to isolate impurities that may be available within the soil (rubbles, cobbles, parts of plants and trash). Samples were properly labelled, placed in plastic containers and analyzed as soon as possible.

Procedure followed is given in detail below:

- For each dried sample, 1 g of dry soil was weighed with a high-sensitive scale and put into special Teflon vessels.
- For initial digestion of soil sample, 1:1 HNO_3 solution was added. The slurry was mixed and covered with a watchglass of appropriate size. Vessel was put on the heat source, allowing it to reflux at 90 – 95 ^oC without boiling for 10 – 15 minutes. Then sample was allowed to cool.
- Concentrated HNO_3 was added to the vessel and slurry was heated to 90 – 95 ^oC to reflux for 30 minutes with watchglass on top of the vessel, maintaining a covering solution at the bottom of the vessel. If brown fumes were generated, indicating high organic content and reaction with HNO_3 in the slurry, this step was repeated until no fumes were generated anymore. The solution was evaporated to 5 mL continuing heating at 90 – 95 ^oC without boiling, which generally took two hours. Sample was left for cooling after this step.
- Two mL of water and three mL of 30% H_2O_2 were added to vessel and slurry was heated. Care must be taken to avoid losses during excessive peroxide reaction. 30% H_2O_2 was continuously added in one mL aliquots until no reaction is observed. Up to 10 mL of 30% H_2O_2 was allowed to add to vessel. The solution was allowed to evaporate to 5 mL continuing heating at 90 – 95 ^oC without boiling, which generally took about two hours. Sample was cooled after this step.
- 10 mL of concentrated HCl was added to vessel and solution was refluxed for 15 minutes without boiling with a watchglass on top of it. Cooled solution was filtered through Whatman No. 41 filter paper and diluted to 100 mL in volumetric flask.

All experiments were conducted in parallel samples and average of results for two duplicate experiments was taken for further use in the study. All the experiments were done under a fume hood to avoid toxic smokes and the necessary safety precautions were taken during the laboratory work.

“Selecta – Plactronic” model hot plate with Teflon coating was the heater used during the experiments. Flame atomic absorption device of “Perkin Elmer AAnalyst 300” was used for heavy metal concentrations reading. Atomic spectroscopy detection limits for this device are given in Table 4.1.

Table 4.1. Detection Limits for FLAAS Device

Metal	Detection Limit (µg/L)
Pb	15
Zn	1.5
Cu	1.5
Cd	0.8
Ni	6
Cr	3

4.3. pH, Salinity and Conductivity Measurements for Soil

pH and salinity are important parameters controlling heavy metal pollution in soils. Numerous different relationships for pollution characteristics and mechanisms have been defined between pH and different heavy metals. Also salinity and conductivity have been shown to affect metal behaviour in soils primarily causing change in pH of the media, as shown in the literature review. For this study, pH, salinity and conductivity values of soil samples taken from surface and 20 cm depth were determined. No measurements were done for highway dust samples.

pH determination in soils was done by using EPA method of “Soil and Waste pH – Method Number 9045C” (USEPA, 1995). The method is based on the measurement of the pH of solution which is a mixture of sample and reagent water by using a pH meter. The method is not suitable for samples which have very high or low pH values (pH<1 or pH>10). In these cases, experiment should be held by using a low-sodium electrode or by repeating experiment in a diluted media. Fortunately, soil samples rarely had very high or very low pH values.

Model of pH meter used in the experiments is “WTW pH330 pH/mV meter”. Device is able to measure the pH, salinity and conductivity of an aqueous solution.

It is important to keep the electrode clean during the operations. If it becomes coated, it must be cleaned by using proper ways. Also pH meter should have temperature correction feature, or temperature correction must be applied to the results in order to get accurate results by recording the ambient temperature.

The detailed procedure for the pH measurement of the soil samples used during this study is as follows:

- Calibration of the testing equipment was done by using appropriate method to get accurate readings. For each different model of pH meter, different methods were used most of the time.
- 20 g of soil for each sample was put in a 50 mL e beaker and 20 mL of reagent water was added. Suspension was stirred for five minutes. When suspended particles settled after one hour or aqueous phase was separated from the suspension by means of filtering, glass electrodes were inserted to the aqueous medium ensuring good electrical contact and constant pH values.
- Results were reported together with the temperature values of solution. If needed, correction was applied.

4.4. Determination of Carbon, Nitrogen and Sulphur Contents

Heavy metals can react with soil constituents through different mechanisms. Chemical binding to elements and compounds by forming complexes and adsorbance behaviour can be better understood when elemental composition is when known.

Since O – 1 Highway was found as the most polluted highway, elemental analysis was conducted to investigate soil pollution in detail. Surface and 20 cm deep soil samples belonging to O – 1 Highway were analyzed for this purpose and carbon, nitrogen and sulphur content of samples were measured.

“Thermo Finnigan Flash EA 1112 Series” elemental analysis instrument was used in the experiments. Any homogenous solid, liquid or gas sample can be analyzed for the determination of elements. Carbon, hydrogen, nitrogen and sulphur percentages in a sample can be obtained in a single experiment. The device is composed of four integrated sections:

- Chromatography column
- Adsorption filters
- Reactors
- Autosampler

For the experiment, soil samples were dried, sieved and crushed to achieve homogeneity needed for the instrument to perform accurately. During the experiment, two mg of sample was burned at 950 – 1000 ^{o}C inside the instrument. Oxygen (O_2) was used as incinerator, and helium was the carrier gas of the burned constituents in the system. At the beginning, sample which was put in a Stannic capsule (Sn) was oxidated by burning and mixed with helium gas. Then, gas mixture was sent through chromatography column for the separation of gas mixture. All gas compounds were converted to N_2, CO_2, H_2O and SO_2 by redox reactions in reduction zone where reactions with copper (Cu) occurred. Quantities of these gases were measured by Thermoconductive Detector (TCD) and percentages of carbon, nitrogen, hydrogen and sulphur are obtained as percentages.

4.5. Data Evaluation in GIS

ArcView GIS 3.3 program was used to perform data evaluation. By using the program, one is able to:

- View, create and edit any form of geographical data. Usable data include feature, grid and image data files. Also a wide variety of files can be exported including database files and AutoCAD drawings.
- Create and process tables and charts. A bunch of files can be exported and edited for use with geographical data.

- Add, modify and merge layers. Layers are the basic datasets for use with program and a layer can be used with any digitized data if proper coordinates are defined on it. Supported layers are in form of points, lines and polygons. Any kind of data can be assigned to a layer member by editing the attribute table belonging to the layer.
- Perform complex analyses. Distance, histogram, query, statistics and various interpolation analyses are examples.
- Create layouts customized for any kind of use. Layouts are simply digital maps and they can be prepared for any purpose.

For the thesis, a digitized map of Istanbul taken from General Directorate of Turkish Highways (TCK) was used. The map contained simple topographic data and main arterials in the city. First, the area where sampling operations were done was clipped. Then, coordinates of the sampling locations were defined by using a point layer. Values of heavy metal concentrations found from the experiments were added to the attribute tables of the point layer.

To obtain distribution of the pollution over the study area, grid interpolation with inverse distance weighing method was used. Inverse distance weighing method assumes a pollution value in a point affects neighbour points inversely proportional to distance. The method works according to the following formula;

$$C = \frac{\sum_{i=1}^{n} \frac{m_i}{d_i^2}}{\sum_{i=1}^{n} \frac{1}{d_i^2}} \tag{4.1}$$

where m is the pollution value in a predefined point (which corresponds to pollution values in sampling locations for this study), i is the total number of predefined points and d is the distance between a point on the map and predefined point.

After inverse distance weighing grid interpolation analysis completed, layout maps were created separately for the metal concentration distribution. Legends were added to each map to represent the severity of the pollution distribution.

5. RESULTS AND DISCUSSION

5.1. Heavy Metal Pollution in Sampling Locations

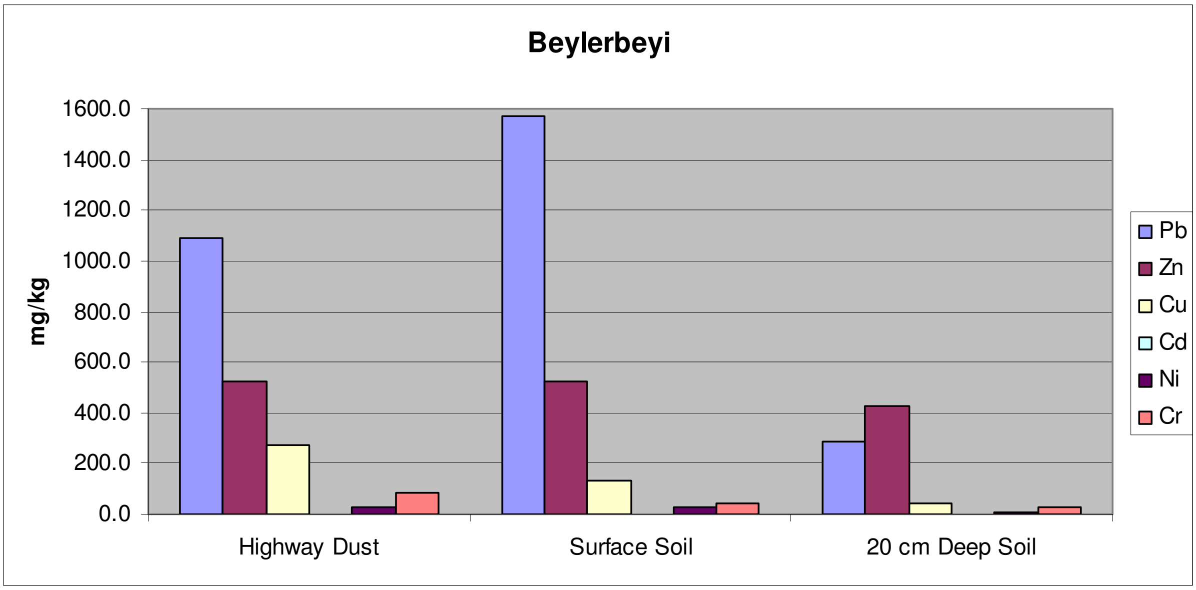

Figure 5.1. Pollution Distribution in Beylerbeyi

This sample point is on the O – 1 Highway. Soil and highway dust samples taken from this sample point were found very highly contaminated. Lead concentrations exceeded EU limits (which is 100 mg/kg for soils with pH>7) 11 times in highway dust, nearly 16 times in surface soils and three times in 20 cm deep soil. Zinc concentrations also violated EU standards (200 mg/kg for soils with pH>7) in highway dust, surface soil and 20 cm deep soil samples. Moreover, copper content of highway dust and surface soils were found above the EU limitations (100 mg/kg for soils with pH>7).

For this sample point, it is possible to say excess pollution in soil surface has penetrated to deeper layers of soils to some extent. 20 cm deep soil samples gave lower contamination values than the surface soils; however, the results were still very high.

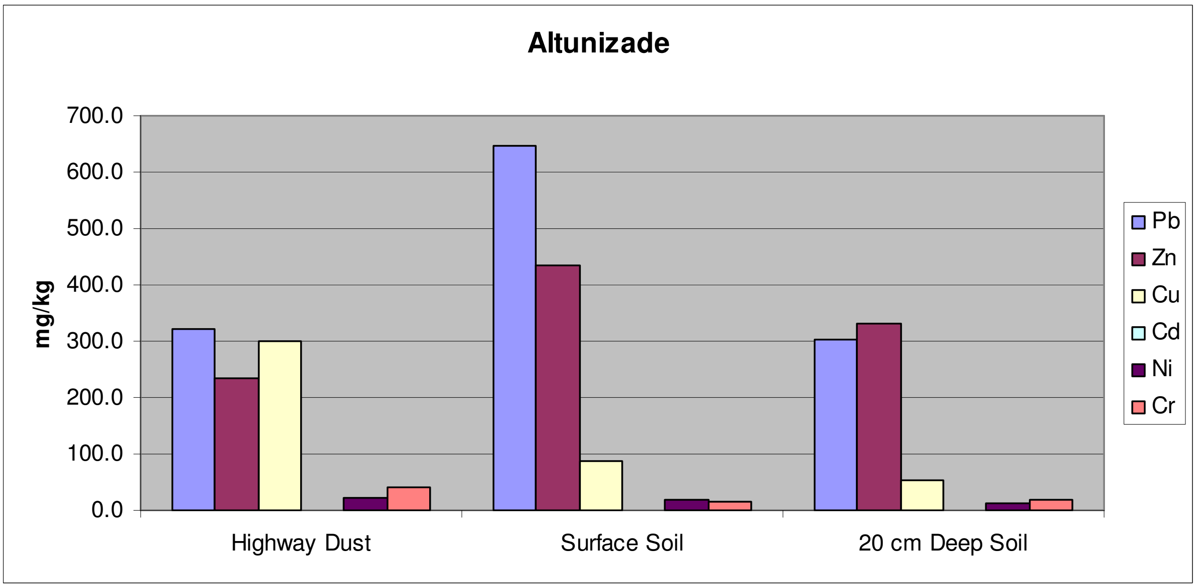

Figure 5.2. Pollution Distribution in Altunizade

This sample point is on an intersection between O – 1 Highway and D – 020 connection. Soil and highway dust samples taken from this location were highly contaminated with lead, zinc and copper. Lead concentrations were found three times higher than EU regulations in highway dust, six times more in surface soil and three times higher in 20 cm deep soil. Zinc pollution exceeded EU limits in all samples. Copper exceeded limits in highway dust and found close to limits in surface and 20 cm deep soil samples. Copper values were above the common range in all samples (5 – 20 mg/kg), which is a sign for contamination.

Pollution in soil surface was found reaching to deeper soil layers partially. 20 cm deep soil samples had pollution values near to surface soils.

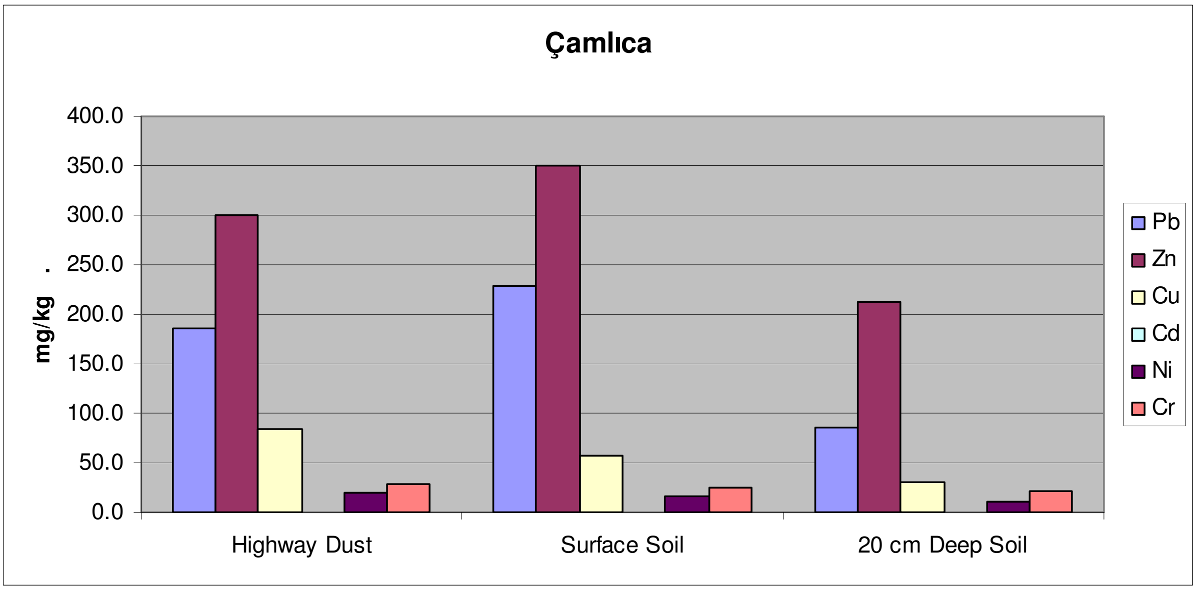

Figure 5.3. Pollution Distribution in Çamlıca

This sample point is on an intersection between O – 1 Highway and O – 4 Highway. Soil and highway dust samples belonging to this location were found highly contaminated with lead and zinc. Lead concentrations exceeded EU regulations two times in highway dust and surface soil samples. Also, 20 cm deep samples were found containing lead much more than the common range (0.1 – 20 mg/kg). Zinc pollution exceeded EU limits in all samples. Copper did not exceeded limits in highway dust; however values were found exceeding common range in surface and 20 cm deep soil samples.

Pollution in soil surface affected deeper soil layers to some extent. Samples from 20 cm depth had slightly lower pollution values than the surface soils at this location.

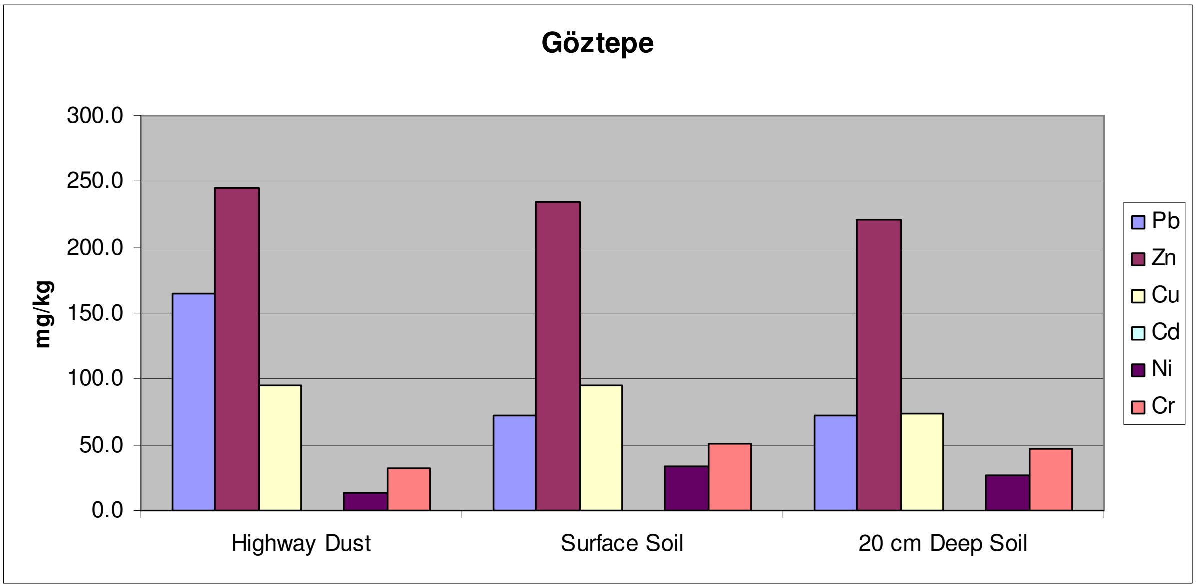

Figure 5.4. Pollution Distribution in Göztepe

This sample point is on an intersection between O – 1 Highway and D – 100 Highway. Soil and highway dust samples collected from this location were found considerably contaminated with lead, zinc and copper. Lead concentrations exceeded EU regulations in highway dust, but not in surface and 20 cm deep soil samples. However surface and 20 cm deep soil samples were found containing lead more than the common range. Zinc pollution exceeded maximum allowable values in EU regulations in all samples. Copper did not exceed limits in any samples; however values were found very close to maximum allowable limits and also exceeded common range for surface and 20 cm deep soil samples.

Pollution in soil surface was found highly penetrated to deeper soil layers. Laboratory experiments for 20 cm deep soil samples gave pollution values very close to values for surface soils in this location.

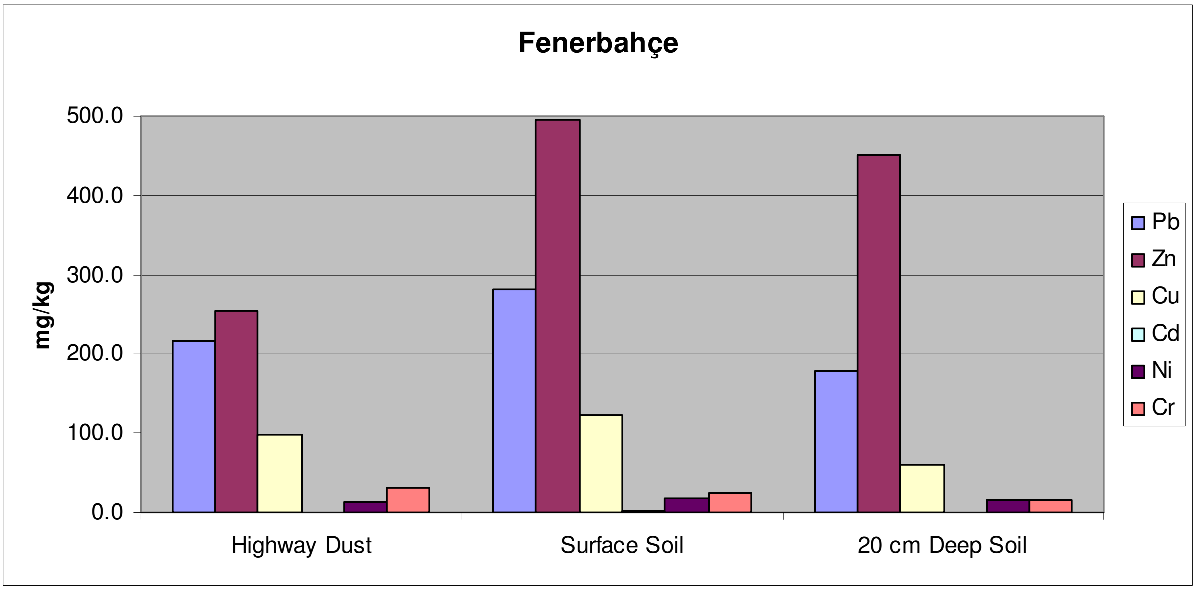

Figure 5.5. Pollution Distribution in Fenerbahçe

This sample point is at the end of the O – 1 Highway, where it is connected to smaller urban arterials. Soil and highway dust samples collected from this location were found highly contaminated with lead, zinc and copper. Lead concentrations was found two times more than EU regulations in highway dust, three times more for surface soils and two times more for 20 cm deep soil samples. Zinc pollution exceeded maximum allowable values in EU regulations for highway dust, and was found near two times of that value in surface and 20 cm deep soil samples. Copper also exceeded limits in surface soil samples; moreover values were found very close to maximum allowable limits and also exceeded common range for highway dust and 20 cm deep soil samples.

Pollution in soil surface was found affecting deeper soil layers also. 20 cm deep soil samples was found having pollution values close to concentrations of surface soils in this location.

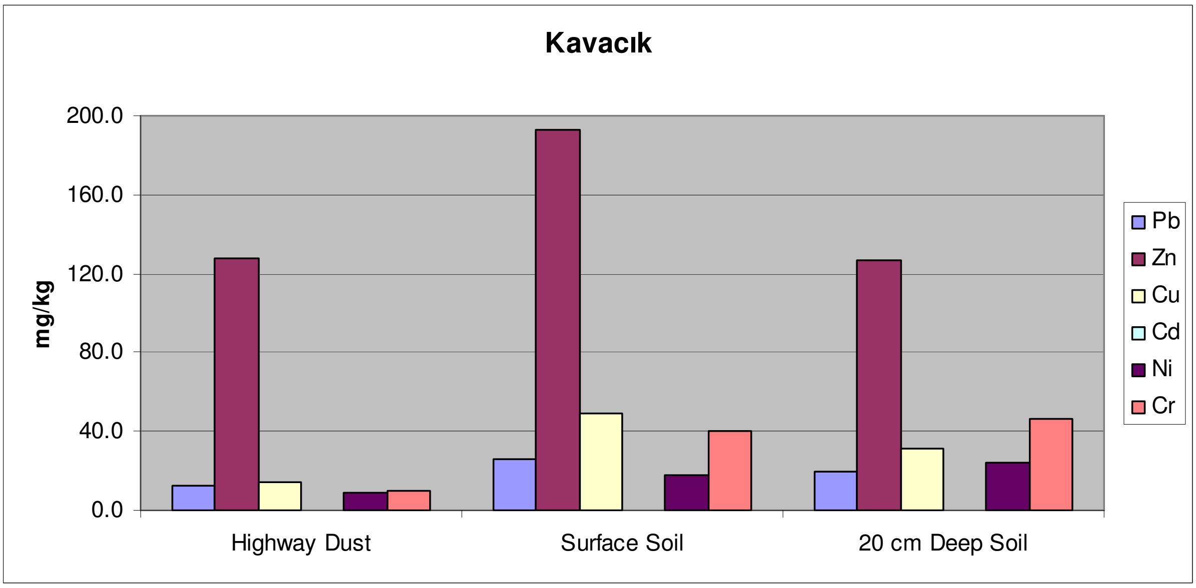

Figure 5.6. Pollution Distribution in Kavacık

This sample point is on the O – 2 Highway. Contamination in soil and highway dust samples taken from this sample point was found falling in acceptable ranges except surface concentrations of zinc and copper, where acceptable ranges are 150 mg/kg and 50 mg/kg respectively for soils with a pH between 6 and 7. Other than these two values, no concentrations exceeded maximum allowable limits in EU regulations. The point which samples were collected is on an intersection which was built two years ago. All the contaminated soil was screened during the construction operations and soil was renewed after the intersection was completed. This is probably why the results were found lower than expected.

On the other hand, all metals were found exceeding common ranges in soils. Especially zinc concentration highly exceeded the common range, which was found very close to limiting values in EU regulations.

For this sample point, it is still possible to say pollution in soil surface has penetrated to deeper layers of soils because common range values are exceeded. 20 cm deep soil samples give lower values than the surface soils; however, results violate common ranges.

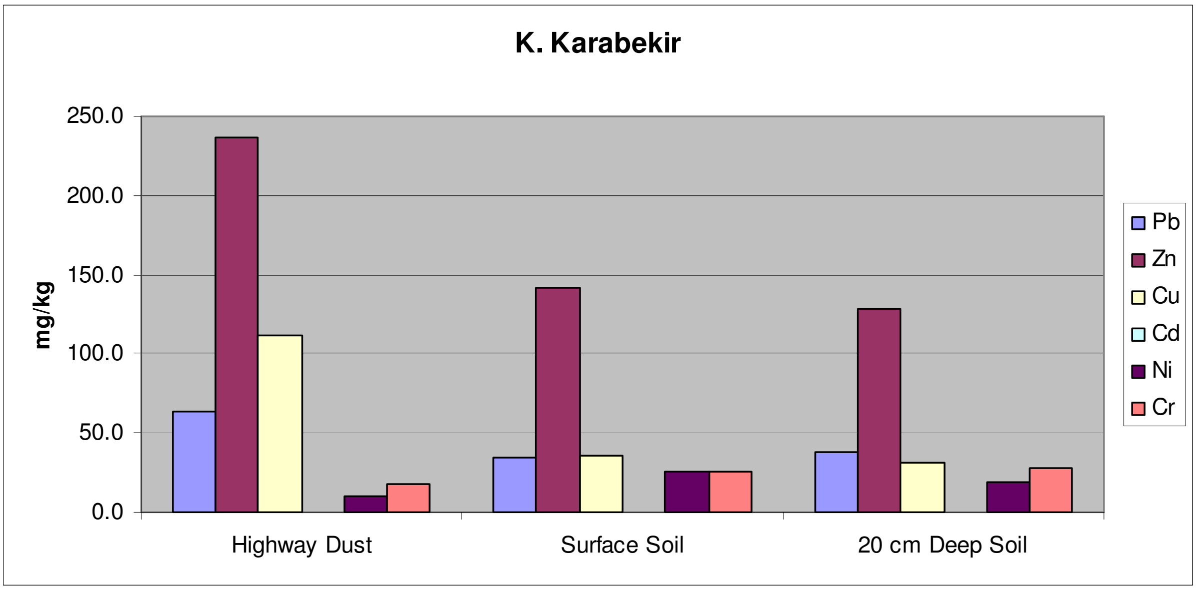

Figure 5.7. Pollution Distribution in K. Karabekir

This sample point is on the O – 1 Highway and it is very close to Elmalı water reservoir. Soil and highway dust samples taken from this location were found considerably contaminated with lead, zinc and copper. Lead concentrations did not exceed EU regulations in any sample but was found above the common range. Zinc pollution exceeded EU limits in highway dust samples and was found very close to allowable values in surface and 20 cm deep soil samples. Copper also exceeded limits in highway dust but did not found close to EU limits in surface and 20 cm deep soil samples. Copper values were above the common range in those samples, which is an indicator for the contamination.

Pollution in soil surface was found reaching to deeper soil layers in high amounts. 20 cm deep soil samples had pollution values very close concentration values for surface soils.

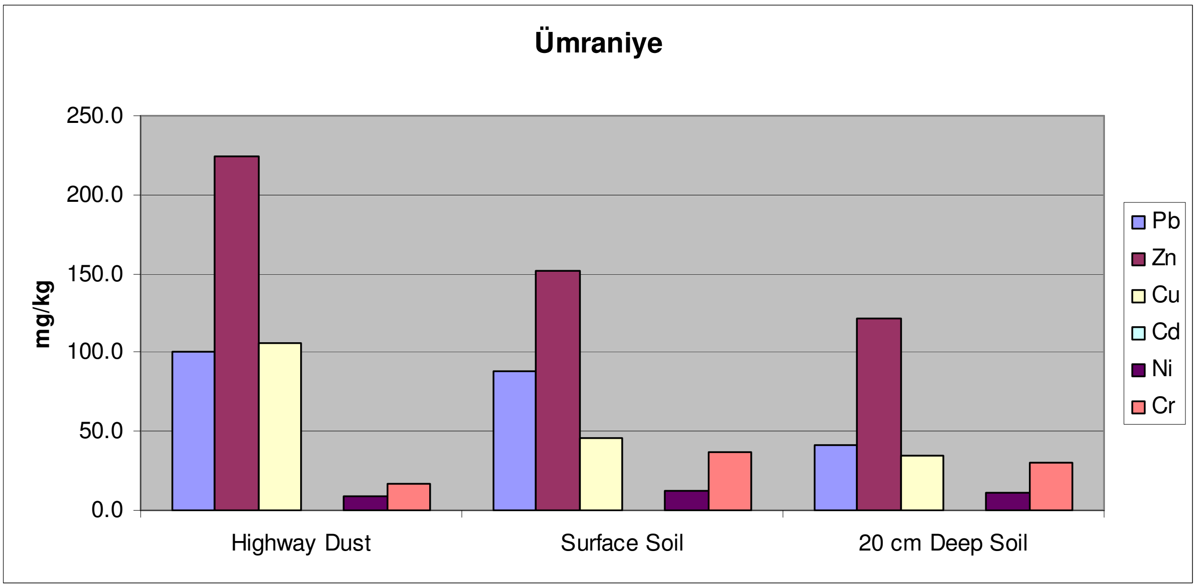

Figure 5.8. Pollution Distribution in Ümraniye

This sample point is on an intersection between O – 2 Highway and D – 020 intersection. Soil and highway dust samples belonging to this location were found partially contaminated with lead, zinc and copper. Lead concentrations exceeded EU regulations in highway dust. Also, 20 cm deep samples were found containing lead much more than the common range. Zinc pollution exceeded EU limits in highway dust samples and concentrations belonging to surface and 20 cm deep soil samples were found close to allowable concentrations. Copper concentrations exceeded EU limits in highway dust; however values was not found exceeding the EU regulations for surface and 20 cm deep soil samples.

Pollution in soil surface was found affecting deeper soil layers to some extent. 20 cm deep soil samples had pollution values slightly lower than the surface soils for this location.

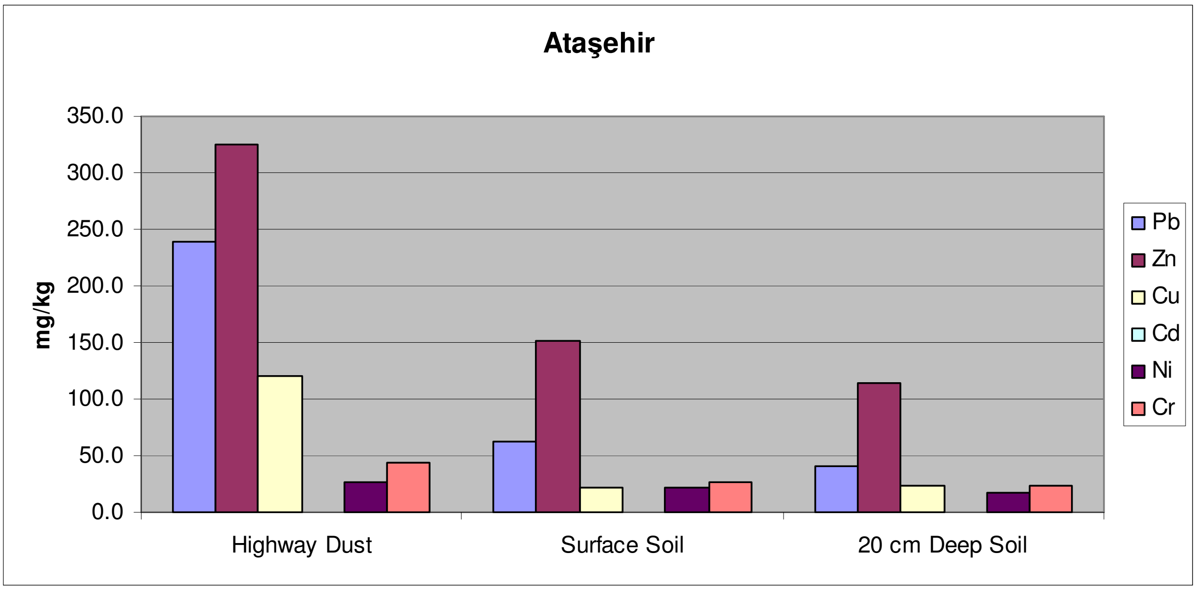

Figure 5.9. Pollution Distribution in Ataşehir

This sample point is on an intersection between O – 2 Highway and O – 4 Highway. Soil and highway dust samples collected from this location were found considerably contaminated with lead, zinc and copper. Lead concentrations exceeded EU regulations two times in highway dust. Zinc and copper values also violated EU limits for dust samples. Contamination for surface and 20 cm deep soil samples fell within acceptable limits. However these soil samples were found containing lead and zinc more than the common range.

Pollution in soil surface was found penetrated to deeper soil layers in some extent. Laboratory experiments for 20 cm deep soil samples resulted with pollution values close to values for surface soils in this location.

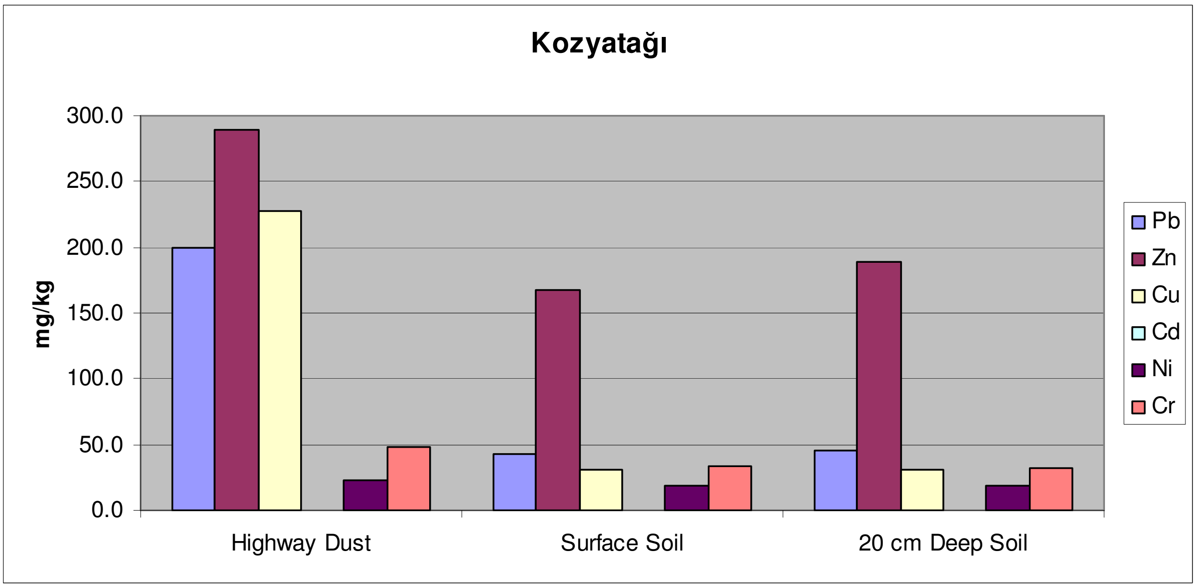

Figure 5.10. Pollution Distribution in Kozyatağı

This sample point is on the intersection of O – 2 Highway and D – 100 Highway. Soil and highway dust samples collected from this location were found contaminated to some extent with lead, zinc and copper. In highway dust, lead, copper and zinc concentrations was found exceeding critical values denoted in EU regulations. None of the metals exceeded maximum allowable values in EU regulations for surface and 20 cm deep soil samples. However, lead and zinc values were found above the common range. Especially zinc values was very close to EU limitations for soil in surface and 20 cm deep soils samples.

Pollution in soil surface was found highly affecting deeper soil layers. 20 cm deep soil samples had pollution values nearly same as concentrations of surface soils in this location.

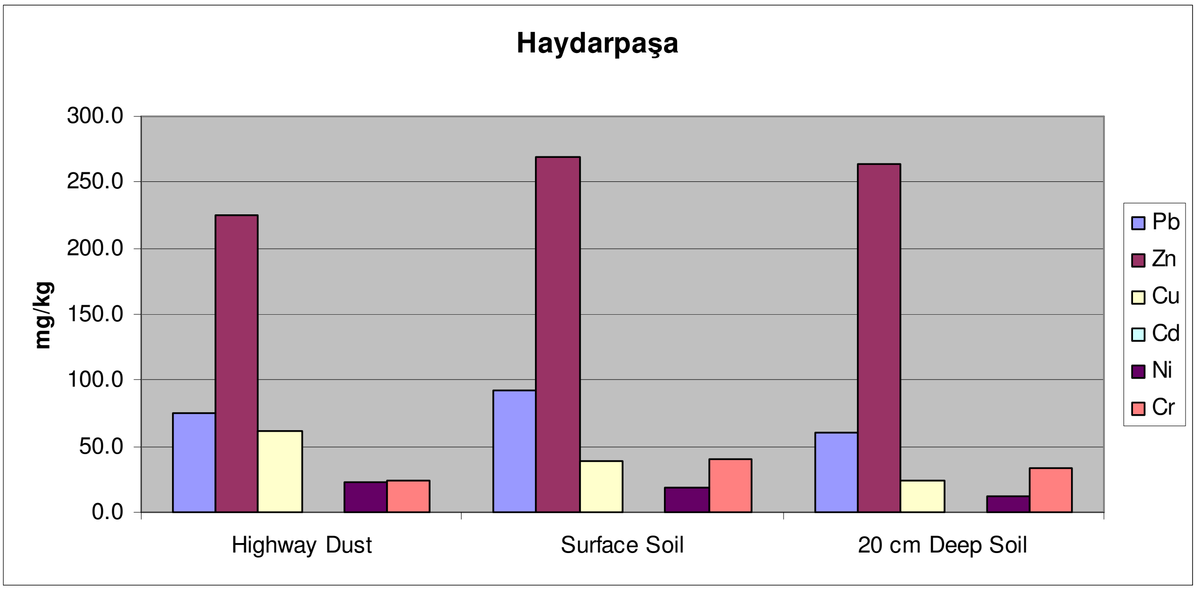

Figure 5.11. Pollution Distribution in Haydarpaşa

This sample point is on the D - 100 Highway. Soil and highway dust samples taken from this sample point were found considerably contaminated. Lead concentrations did not exceed EU maximum allowable limits in any samples. However, zinc concentrations violated EU standards in highway dust, surface soil and 20 cm deep soil samples. Copper content of dust and soil samples was found below the EU limitations, but exceeded common range in soils.

For this sample point, it is possible to say pollution in soil surface has highly penetrated to deeper layers of soil. 20 cm deep soil samples nearly had the same values with the surface soils.

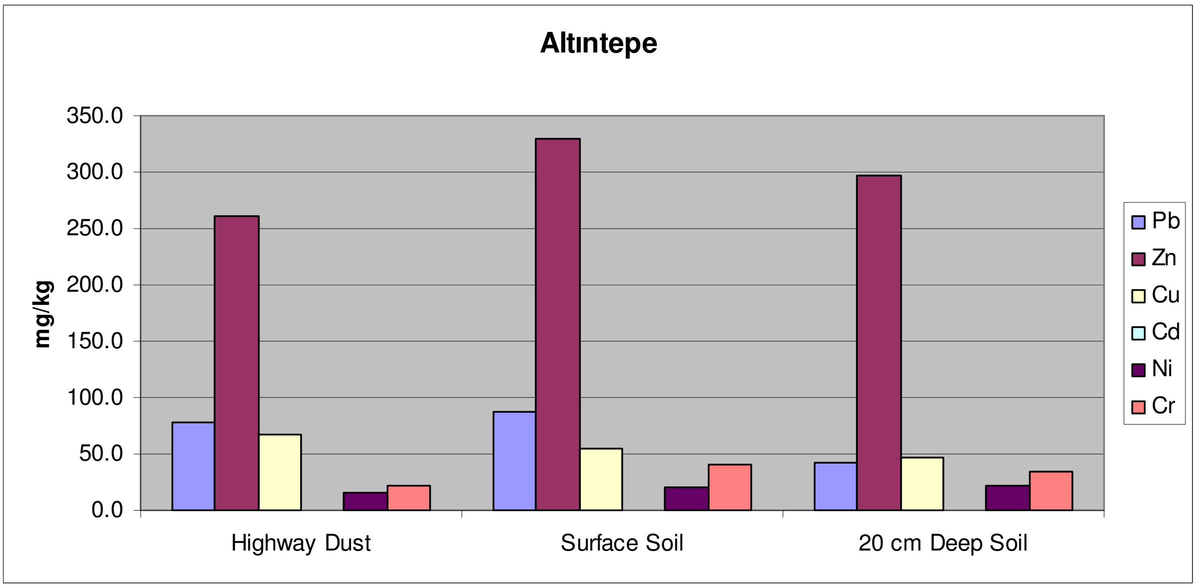

Figure 5.12. Pollution Distribution in Altıntepe

This sample point is on the D - 100 Highway. Soil and highway dust samples taken from this sample point were found considerably contaminated with lead and zinc. No lead concentrations exceeded EU maximum allowable limits in any samples. However, zinc content of highway dust, surface soil and 20 cm deep soil samples was found higher than the standards. Copper concentrations of dust and soil samples were found below the EU allowable limits, but exceeded common range in soils.

Pollution in soil surface was found reaching to deeper soil layers in high amounts. 20 cm deep soil samples had pollution values very close to surface soils.

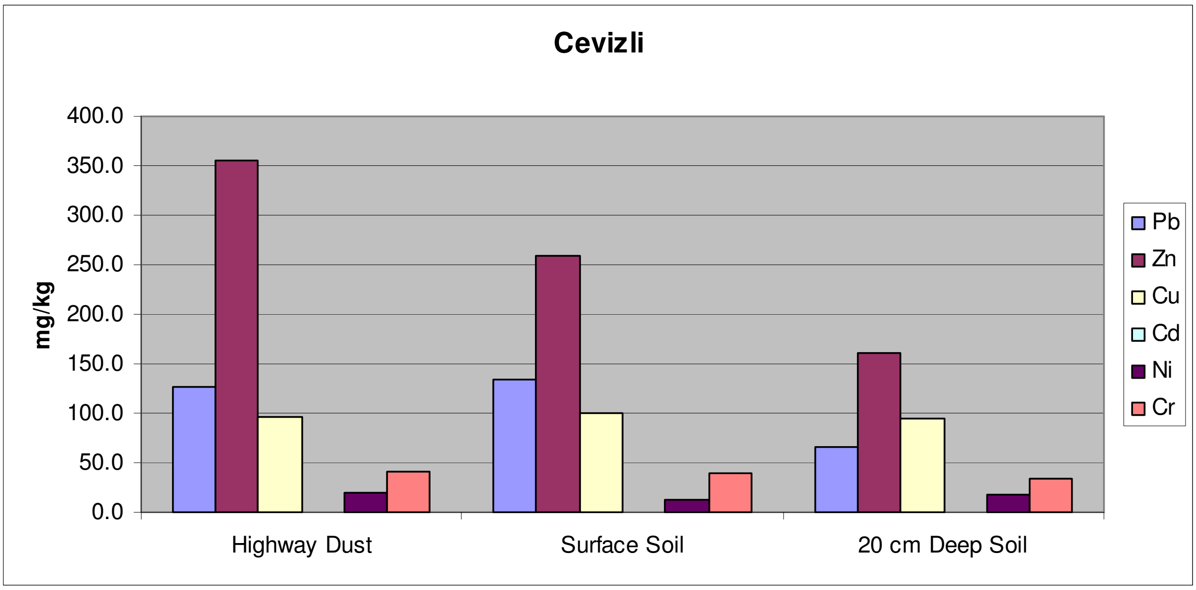

Figure 5.13. Pollution Distribution in Cevizli

This sample point is on D – 100 Highway. Soil and highway dust samples belonging to this location were found highly contaminated with lead, zinc and copper. Lead concentrations exceeded EU regulations in highway dust and surface soil samples. Also, 20 cm deep samples were found containing lead more than the common range. Zinc pollution exceeded EU limits in highway dust and surface soil samples. Copper was found very close to the EU maximum allowable limits in highway dust, surface soil and 20 cm deep soil samples.

Pollution in soil surface affected deeper soil layers to some extent. 20 cm deep soil samples had pollution values lower than the surface soils for this location, but concentrations exceeded common range.

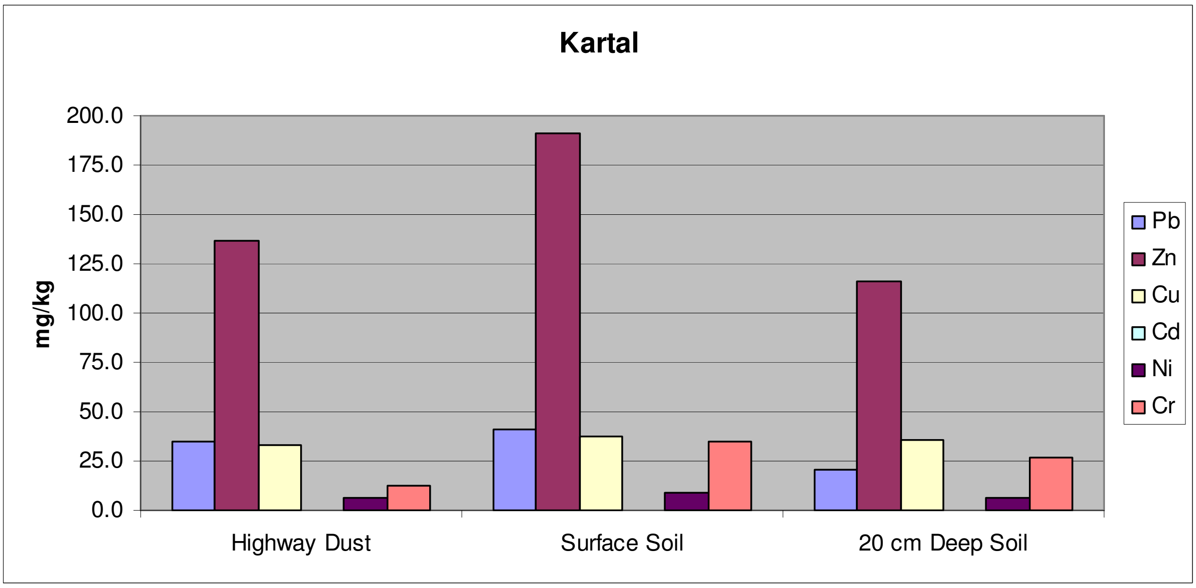

Figure 5.14. Pollution Distribution in Kartal

This sample point is on an intersection between D – 100 Highway and O4 – D100 connection. Pollution values of soil and highway dust samples collected from this location fell within the acceptable ranges for EU regulations. Since traffic load on this point is not too high, obtained results were expected. However lead, zinc and copper concentrations were still found exceeding common range, especially zinc values were close to maximum allowable limits of EU. This is a sign of contamination.

Pollution in soil surface was found penetrated to deeper soil layers to some extent. Laboratory experiments for 20 cm deep soil samples gave pollution values close to values for surface soils in this location.

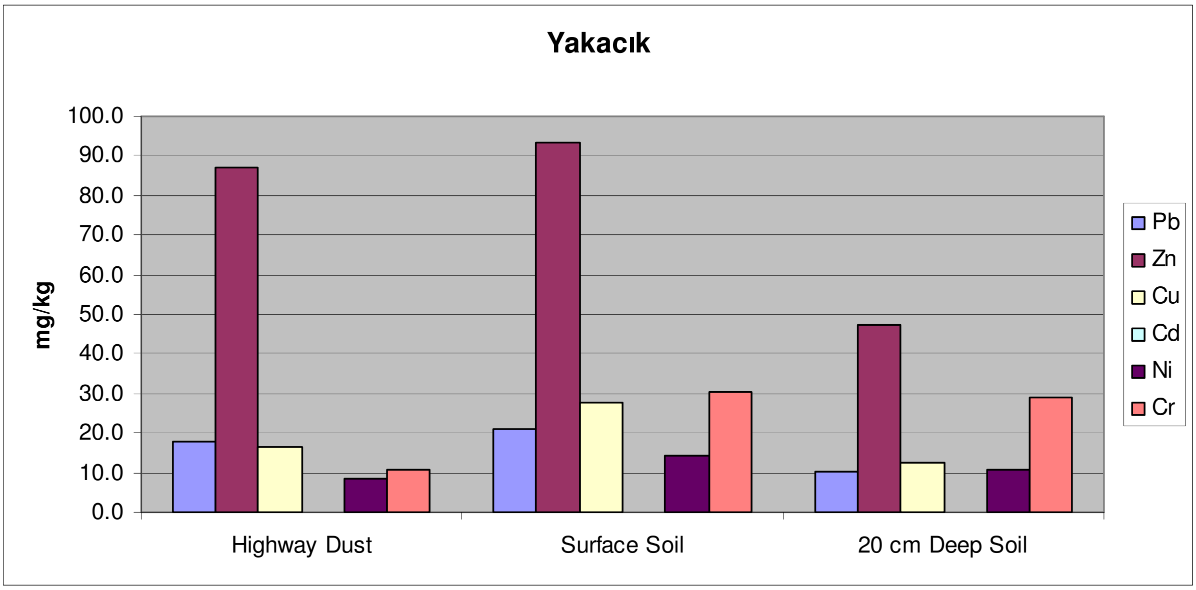

Figure 5.15. Pollution Distribution in Yakacık

This sample point is on O4 – D100 connection, which is not a densely used arterial. Pollution values of soil and highway dust samples collected from this location was found between the acceptable ranges for EU regulations. Because traffic load on this point is low, results are not extraordinary. However lead and copper concentrations were still exceeding common range in surface soil samples. Also zinc values were found higher than common range in highway dust and surface soil samples, which is a sign of contamination.

Pollution in soil surface was not found penetrated to deeper soil layers. Laboratory experiments for 20 cm deep soil samples did not give any pollution values above the common range.

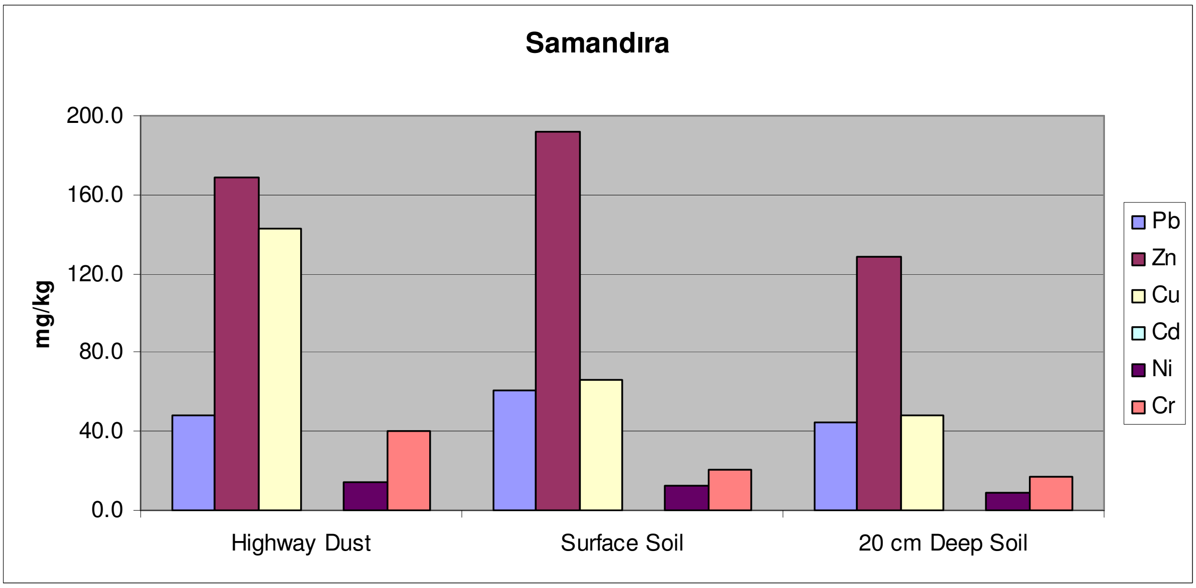

Figure 5.16. Pollution Distribution in Samandıra

This sample point is on an intersection between the O – 4 Highway and O4 – D100 connection. Soil and highway dust samples taken from this sample point were found slightly contaminated by lead, zinc and copper. Only copper concentrations in highway dust exceeded EU limits. However, zinc concentrations were found close to EU standards in highway dust, surface soil and 20 cm deep soil samples. Moreover, lead, zinc and copper content of all samples were found above the common range.

For this sample point, it is possible to say pollution in soil surface has penetrated to deeper layers of soils to some extent. 20 cm deep soil samples gave lower values than the surface soils; however, results were found still high with respect to the common ranges.

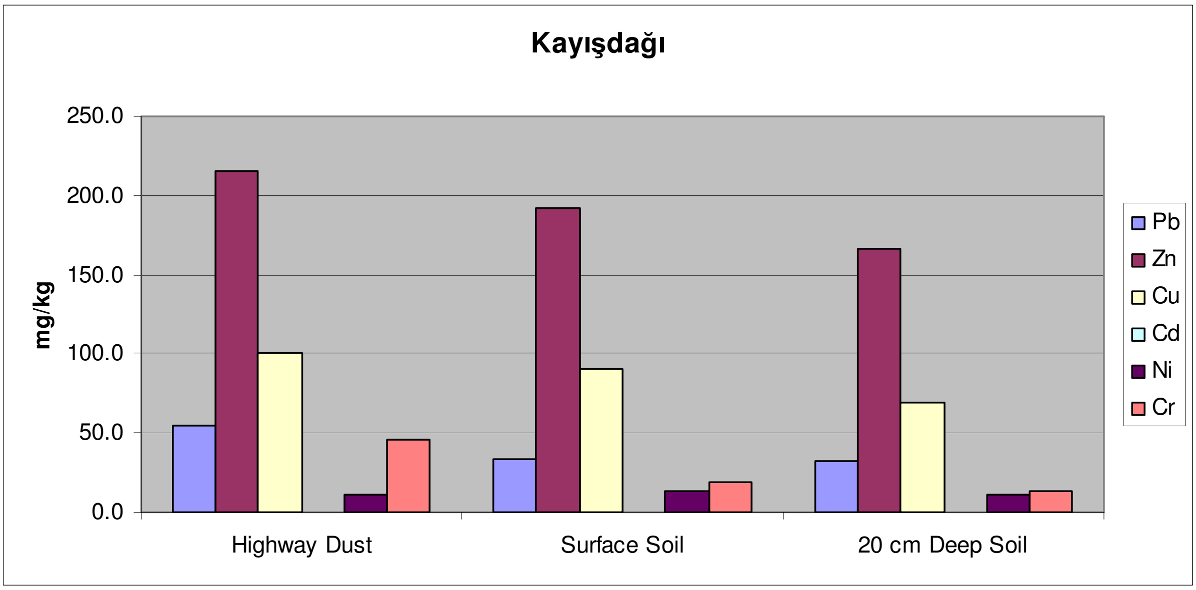

Figure 5.17. Pollution Distribution in Kayışdağı

This sample point is on O – 4 Highway, which is most used for travels between major cities and it is not much disturbed by urban traffic. Soil and highway dust samples taken from this sample point were found slightly contaminated by lead, zinc and copper. Zinc and copper concentrations in highway dust exceeded EU maximum allowable limits. Zinc concentrations were found close to EU standards in surface soil and 20 cm deep soil samples. Moreover, lead, zinc and copper content of all samples were found above the common range.

Pollution in soil surface was found reached to deeper soil layers partially. 20 cm deep soil samples had pollution values near to those of surface soils, exceeding common range.

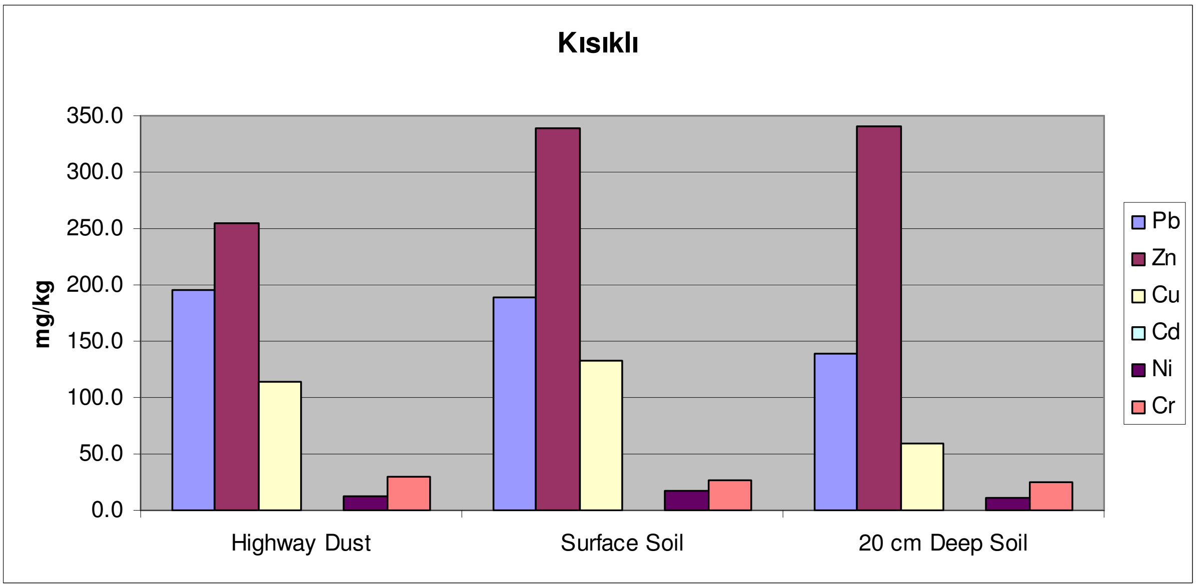

Figure 5.18. Pollution Distribution in Kısıklı

This sample point is on D – 020 connection. Soil and highway dust samples belonging to this location were found highly contaminated with lead, zinc and copper. Lead concentrations exceeded EU regulations two times in highway dust and surface soil samples. Also, 20 cm deep samples were found containing lead more than the EU allowable limits. Zinc pollution exceeded EU limits in all samples, where it was found two times of limit value for surface and 20 cm deep soil samples. Copper also exceeded limits in highway dust and surface soil samples, where values were also found above common range in 20 cm deep soil samples.

Pollution in soil surface affected deeper soil layers in high amounts. 20 cm deep soil samples had pollution values very close the concentrations of surface soils for this location.

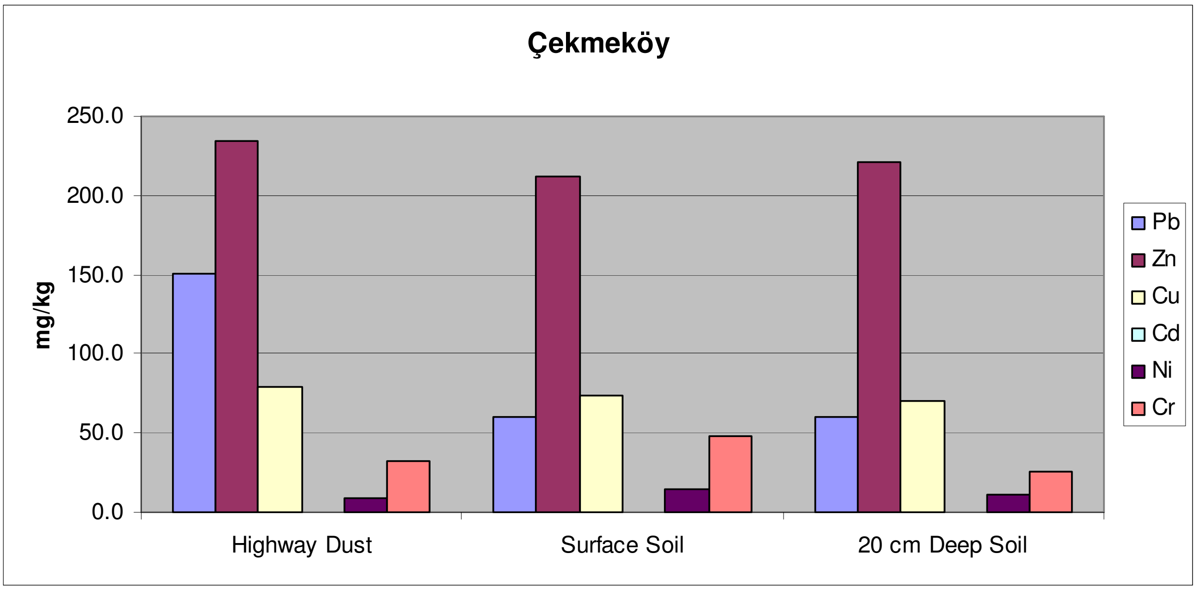

Figure 5.19. Pollution Distribution in Çekmeköy

This sample point is on D – 020 connection. Soil and highway dust samples collected from this location were found considerably contaminated with lead and zinc. Lead concentrations exceeded EU regulations in highway dust, but not in surface and 20 cm deep soil samples. However surface and 20 cm deep soil samples were found containing lead more than the common range. Zinc pollution exceeded maximum allowable values in EU regulations in all samples. Copper did not exceed limits in any samples; however values were found very close to maximum allowable limits for EU and also exceeded common range in all samples.

Pollution in soil surface was found highly penetrated to deeper soil layers. Laboratory experiments for 20 cm deep soil samples gave nearly same pollution values with concentrations in surface soils in this location.

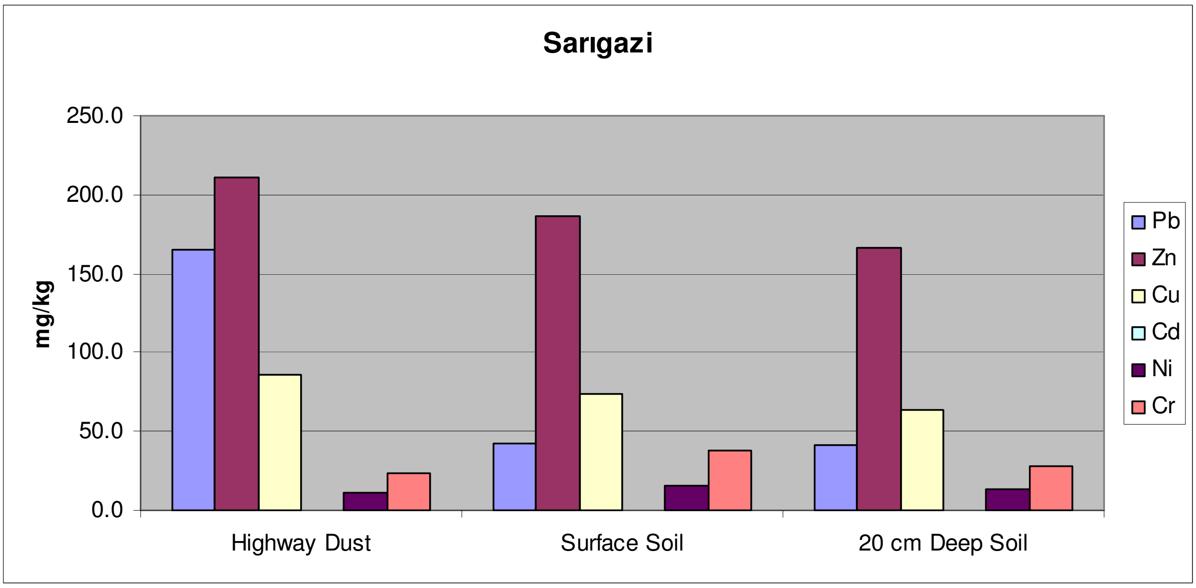

Figure 5.20. Pollution Distribution in Sarıgazi

This sample point is on the D – 100 connection. Soil and highway dust samples collected from this location were found considerably contaminated with lead and zinc. Lead concentrations was found more than allowed values in EU regulations for highway dust, and beyond common range for surface soils and 20 cm deep soil samples. Zinc pollution exceeded maximum allowable values in EU limits for highway dust, and was found near to that value in surface and 20 cm deep soil samples. Copper values did not violate EU regulations but exceeded common range for highway dust, surface soil and 20 cm deep soil samples.

Pollution in soil surface was found affecting deeper soil layers also. 20 cm deep soil samples was found having pollution values close to concentrations of surface soils in this location.

A summary of experiment results for highway dust samples were given in Table 5.1. As shown from the figures above and Table 5.1., major pollutants entering to the environment from transportation activities are lead, zinc and copper.

Table 5.1. Summary of Experimental Results for Highway Dust Samples

	Pb	Zn	Cu	Cd	Ni	Cr
Maximum (mg/kg)	1086.5	520.7	299.6	0.4	29.8	84.8
Minimum (mg/kg)	12.5	87.0	14.0	0.0	6.2	9.9
Average	176.7	245.2	111.3	0.1	15.3	31.9
Median	138.4	235.6	97.8	0.0	13.5	30.6
Standard Deviation	229.57	91.63	75.46	0.11	6.78	17.18

Street and highway dust is an environmental pollution indicator for urban areas. It is a mixture of particles coming from different sources mainly transported by wind. Contaminated dust seriously threatens health since it is easily remobilized by wind from the roadside to air, cars and residences, and easily comes into contact with humans by inhalation and skin contact. Moreover, highway dust can be easily carried by the stormwater runoff which results in massive transport of contamination to environmentally critical places such as water reservoirs, rivers and seas.

Experimental results summary for surface soils were given in Table 5.2. As shown from the figures above and from Table 5.2. the principal pollutants affecting the surface soils coming from transportation activities are lead and zinc, and also copper to some extent.

Heavy metal pollution created by transportation activities incorporates the environment by several mechanisms. Lead is principally released to the environment bound to particulate matter after the combustion by-products of leaded gasoline is exhausted to open atmosphere. Tyre abrasion and corrosion of roadside safety fences contribute to most of the zinc pollution present within the roadside soils. Wearing of brake linings (brakepads) and other leakages, abrasions and spills from the vehicles are major sources of pollution for other heavy metals, especially for copper.

Table 5.2. Summary of Experiment Results for Surface Soil Samples

	Pb	Zn	Cu	Cd	Ni	Cr
Maximum (mg/kg)	1572.5	522.1	136.0	1.2	33.0	50.9
Minimum (mg/kg)	21.1	93.4	21.4	0.0	9.0	15.7
Average	190.7	255.3	68.7	0.2	17.7	32.8
Median	67.5	202.5	61.4	0.0	16.7	34.1
Standard Deviation	355.1	120.0	35.3	0.37	5.6	9.58

All of the pollutants carried to environment by different mechanisms mentioned above first reach and contaminate surface soils near the roads. Surface soils may also receive pollutants from wind – blown highway dust, rain and stormwater runoff. Microorganisms and plants are directly affected from this pollution and they are either completely destroyed on high levels of pollution or a few adapt and survive under unfavourable conditions. Exposure pathways to animals and humans are skin contact and feeding with plants and animals which get contamination from soil.

The summary of experimental results for 20 cm deep soils can be shown in Table 5.3. The principal pollutants affecting the 20 cm deep soil layer by penetrating the soil were found as lead and zinc. Copper pollution was also found transported to deeper layers of soil, but did not reach to dangerous levels.

Table 5.3. Summary of Experiment Results for Soil Samples from 20 cm Depth

	Pb	Zn	Cu	Cd	Ni	Cr
Maximum (mg/kg)	302.1	449.9	94.1	0.5	26.5	47.5
Minimum (mg/kg)	10.1	47.2	12.6	0.0	6.6	13.8
Average	81.2	211.4	47.0	0.1	14.5	27.8
Median	44.8	177.8	45.9	0.0	12.4	27.8
Standard Deviation	82.7	109.0	20.7	0.14	5.4	8.94

Heavy metal pollution created by transportation activities affects the environment in several ways and pollutants first contaminate surface soils near the roads. While soil surface is first affected at the instance of disposal, contamination may settle in deeper parts of soils with time.

Heavy metal pollution in soils mostly stays in first 20 – 30 cm of top layer. Unless very porous media such as calcareous or sandy soils are present, penetration to lower layers are limited, but possible. Soil pollution under the top layer is an indicator of intensity of contamination and its ability of penetration through deeper layers.

A set of complete results of heavy metal determination experiments was given in Appendix A.

5.2. Distribution of Soil Parameters

5.2.1. pH, Salinity and Conductivity of Soil Samples

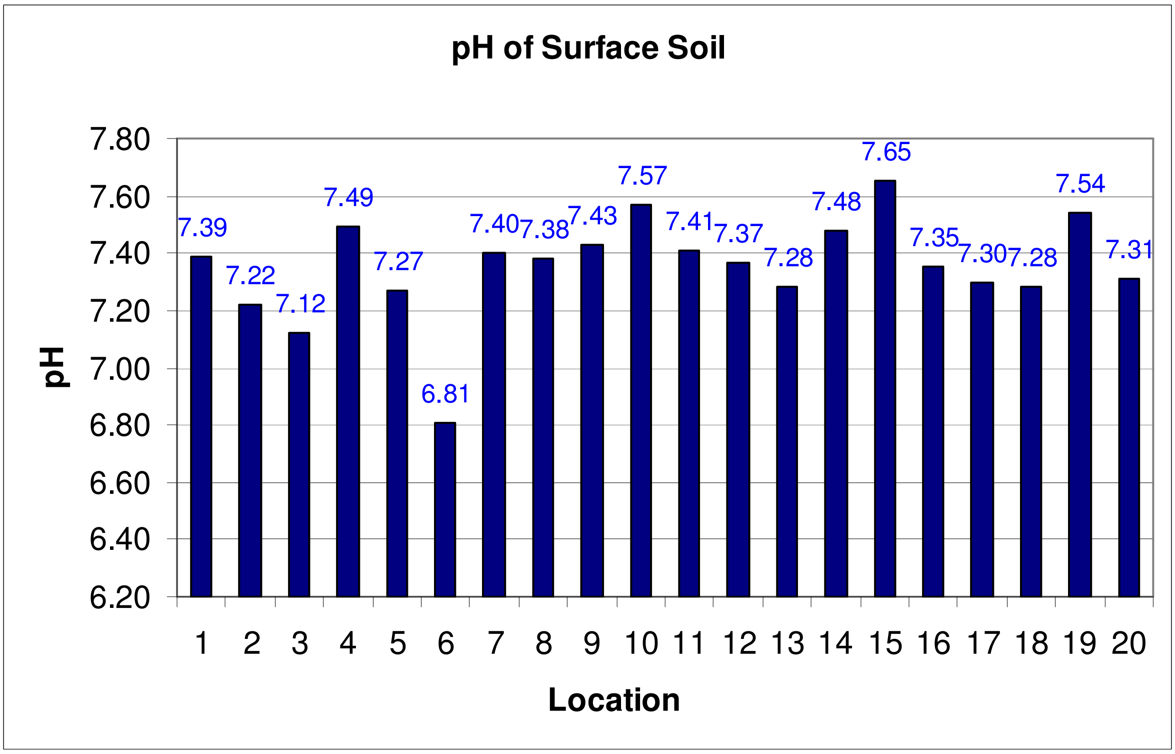

Figure 5.21. pH Values of Surface Soil Samples

In surface soils, pH values were given in Figure 5.21. pH values were found in the range of 6.81 – 7.65 and only one sample had a pH lower than 7 where three samples had pH values over 7.50. In general, soil samples collected from the site were slightly alkaline.

Average of pH values was 7.35 and the standard deviation was 0.179. Variance of pH values over the study field was low and distribution of pH of soil samples was close to uniform.

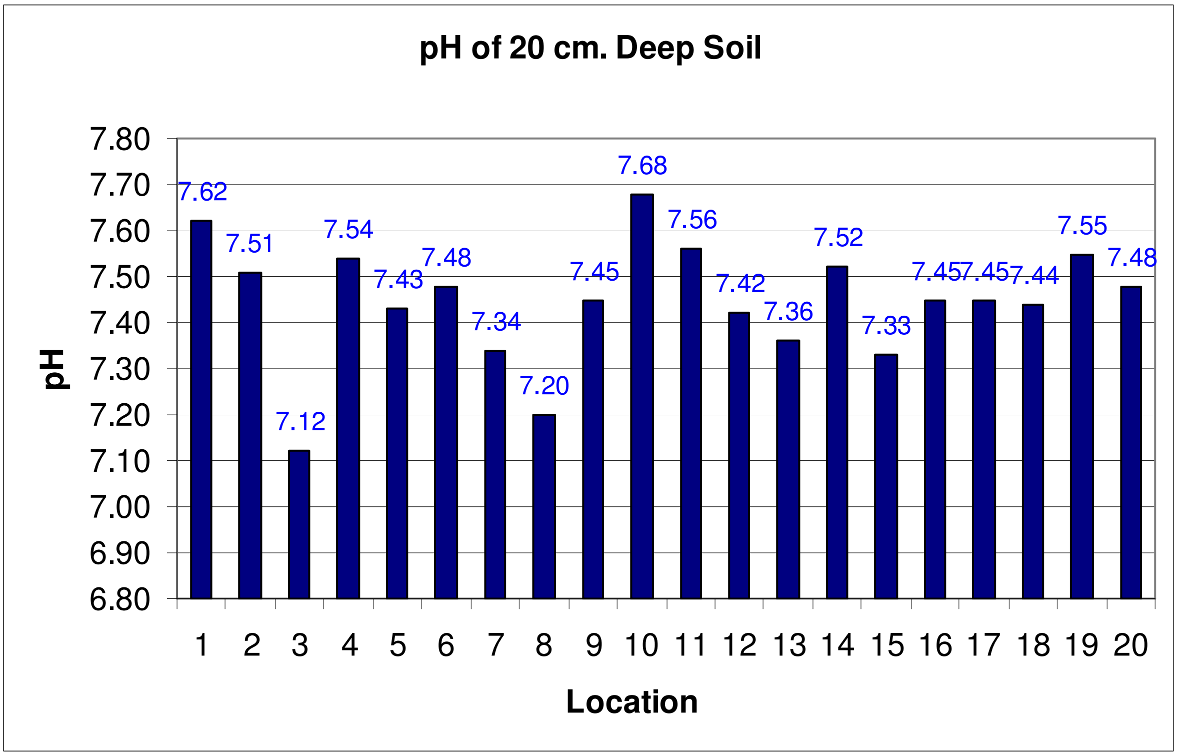

Figure 5.22. pH Values of 20 cm deep Soil Samples

Figure 5.22. shows the summary of experiment results of pH values for 20 cm deep soil samples. pH values were found in the range of 7.12 – 7.68 where no soil sample had the pH lower than 7. Experiments for six of 20 samples gave a pH value over 7.50. General tendency for 20 cm deep soil samples collected from the study area was found as slightly alkaline.

Average of pH values for 20 cm deep soil samples was found as 7.45, which is larger than the average for surface soil samples. Standard deviation was found as 0.132. Variance of pH values over the study field is low. Distribution of pH of soil samples over the area can be interpreted as very close to uniform.

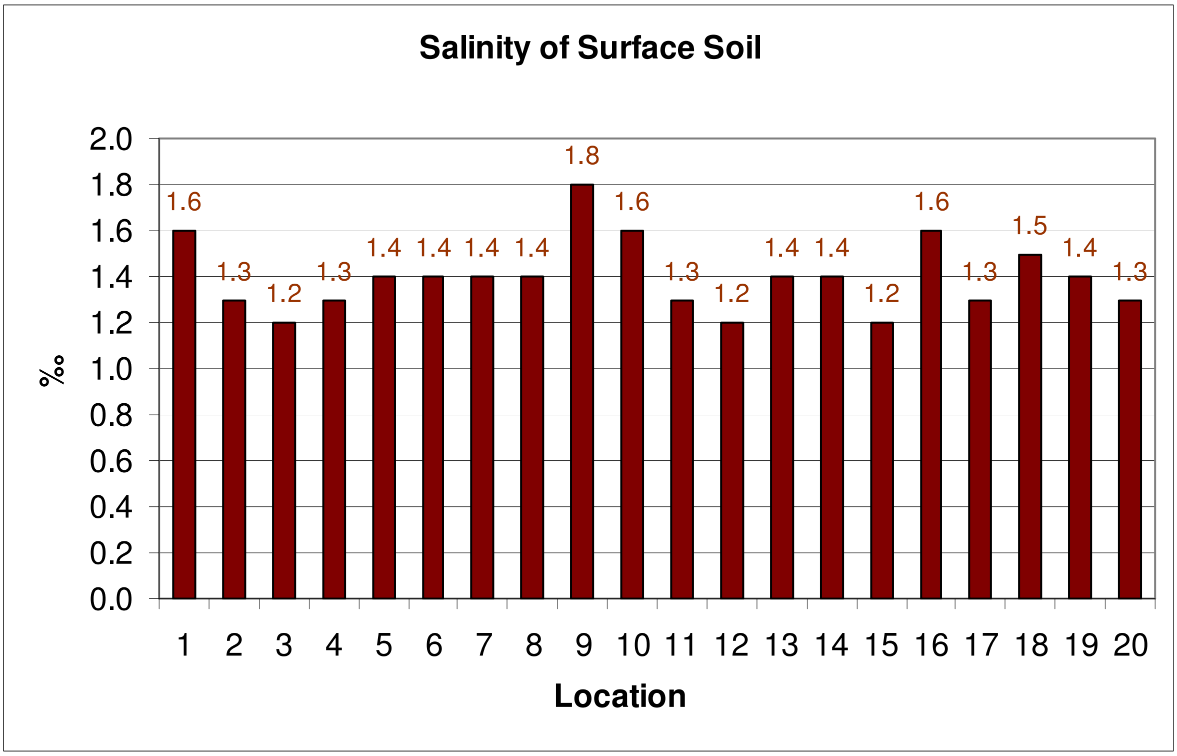

Figure 5.23. Salinity Values of Surface Soil Samples

Results of salinity experiments for surface soil samples were given in Figure 5.23. Salinity values were found changing from 1.2 to 1.8 per thousand. Average of salinity values was 1.40 per thousand, and standard deviation was found as 0.156.

Change in salinity values over the study field is relatively low and distribution of salinity of soil samples can be interpreted as near to uniform. Overall results for salinity are found high, which can be denoted to the effect of de-icing salts spred to road pavement in winter season.

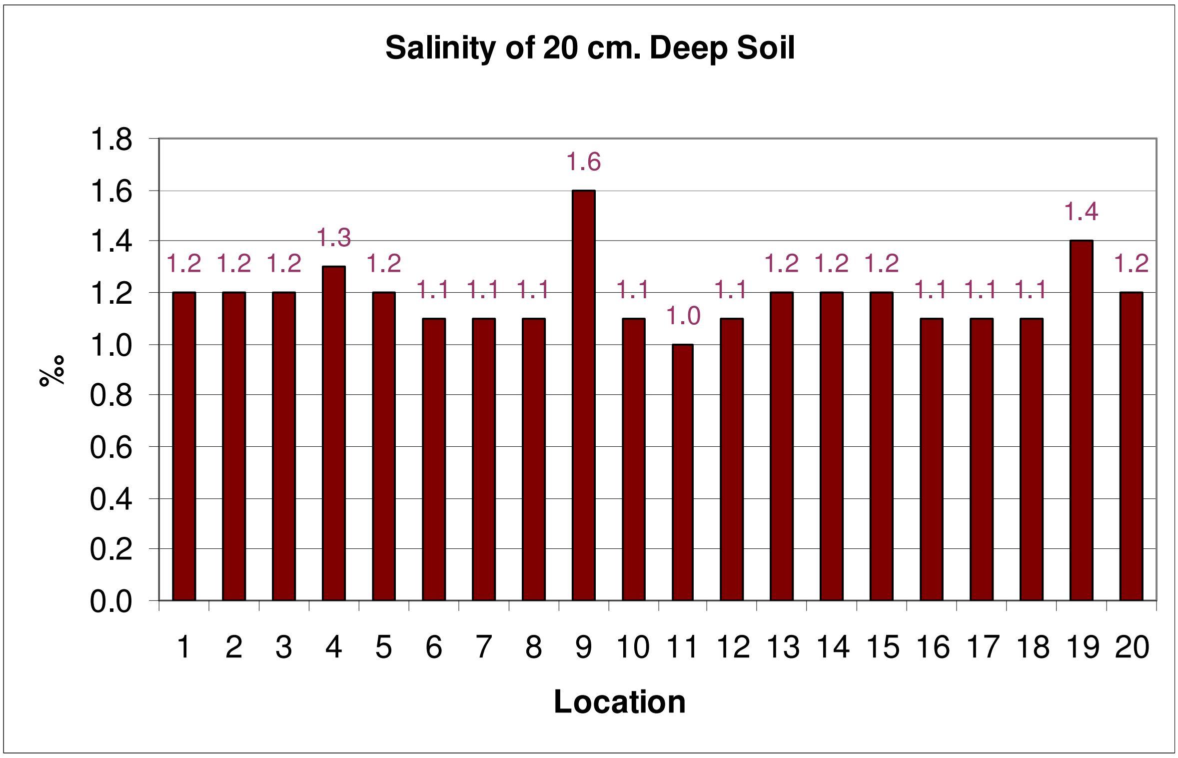

Figure 5.24. Salinity Values of 20 cm deep Soil Samples

Results of salinity experiments for 20 cm deep soil samples can be seen in Figure 5.24. Salinity values were found in the range of 1.0 - 1.6 per thousand. Average of salinity values was 1.19 per thousand, and standard deviation was found as 0.131, both were being lower with respect to the values for surface soil samples.

Change in salinity values over the study area was found low, and distribution of salinity of 20 cm deep soil samples can be interpreted as very close to uniform. Results for salinity were found still high, although they were lower than the surface values, which is probably because of the effect of de-icing salts frequently used in road pavement in winter season.

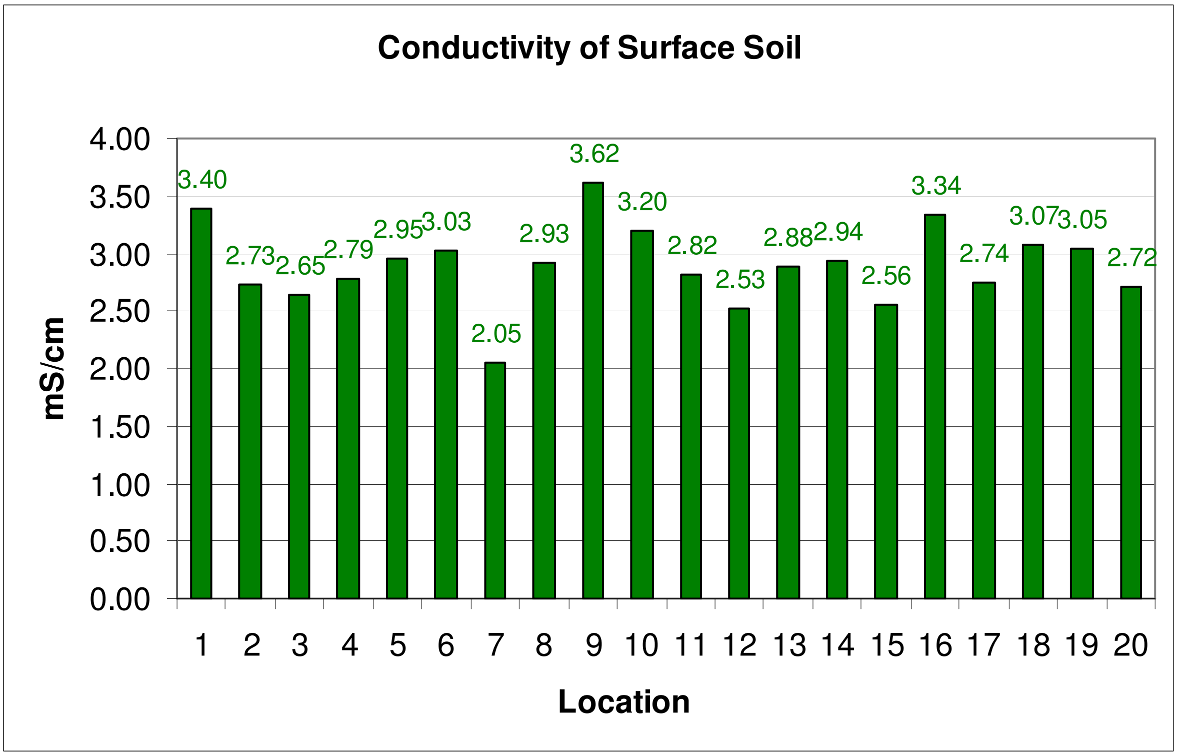

Figure 5.25. Conductivity Values of Surface Soil Samples

Experimental results of conductivity values for surface soils samples are shown in Figure 5.25. Conductivity values were found in the range of 2.05 – 3.62 mS/cm. Seven samples had a conductivity higher than 3 mS/cm. Only one soil sample had a conductivity below 2.50 mS/cm.

Average of conductivity values for surface soil samples was 2.90 mS/cm, and standard deviation was found as 0.346. Variance of conductivity values over the study field is relatively high, and distribution of pH of soil samples can be interpreted as scattered.

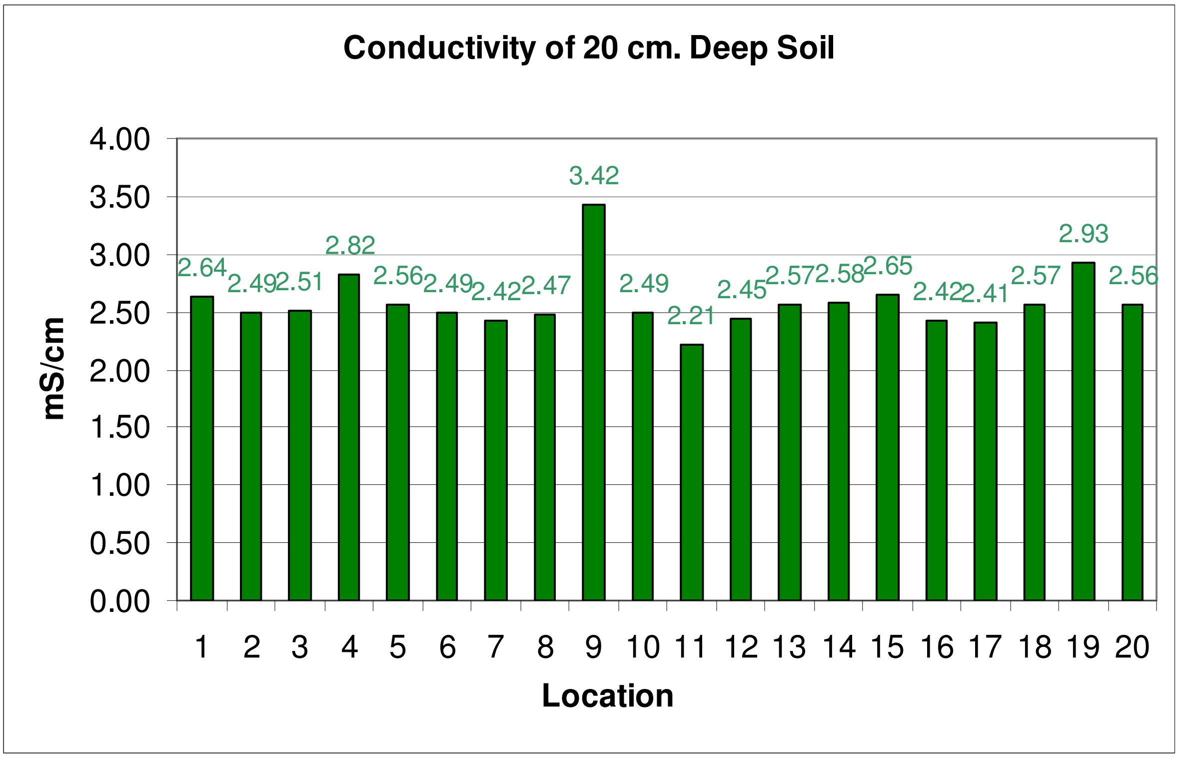

Figure 5.26. Conductivity Values of 20 cm deep Soil Samples

Results of experiments for conductivity analysis in 20 cm deep soil samples are shown in Figure 5.26. Conductivity values were found changing from 2.21 to 3.42 mS/cm. Only one sample had a conductivity value higher than 3 mS/cm. Nine of 20 soil samples had a conductivity below 2.50 mS/cm.

Average conductivity value for 20 cm deep soil samples was 2.58 mS/cm, and standard deviation was found as 0.248. Both values for 20 cm deep soil samples were smaller than the values for surface soil samples. Variance of pH values over the study field is moderate, and distribution of conductivity of 20 cm deep soil samples can be interpreted as moderately scattered.

Experimental results are represented in statistical form in Table 5.4. and Table 5.5. for surface soil samples and 20 cm deep soil samples, respectively. These tables include maximum, minimum and average values for the corresponding data as well as the median and standard deviation. Also a set of complete results of pH, salinity and conductivity determination experiments were added to the Appendix B, which can be found at the end of the thesis.

Table 5.4. pH, Salinity and Conductivities of Surface Soil Samples

	pH	Salinity (‰)	Conductivity (mS/cm)
Maximum	7.65	1.80	3.62
Minimum	6.81	1.20	2.05
Average	7.35	1.40	2.90
Median	7.38	1.40	2.91
Standard Deviation	0.179	0.156	0.346

Table 5.5. pH, Salinity and Conductivities of Soil Samples from 20 cm Depth

	pH	Salinity (‰)	Conductivity (mS/cm)
Maximum	7.68	1.60	3.42
Minimum	7.12	1.00	2.21
Average	7.45	1.19	2.58
Median	7.45	1.20	2.54
Standard Deviation	0.132	0.131	0.248

pH of a soil medium is controlled by very complex mechanisms. However, this research aims to describe the effects of soil pH on mechanisms and quantity of heavy metal pollution in soils, not to understand the pH behaviour itself. In most soils, lead, nickel, zinc and cadmium were found mobilized in lower pH values, which is also true to some extent for other cationic metals. In alkaline ranges, however, solubility decreases and these metals become largely immobile. However, generalization may not be possible since dissolved organic matter, when available, is easily mobilized in increased pH values, which also makes heavy metal ions bound to them by complexation also mobile. pH also affects the structure of the complexes formed within the soil boundaries, which primarily influences the sorption mechanisms.

Roadside soils generally contain artificial salinity if road pavement is subjected to sprinkling of de-icing salts during cold season. Salinity and conductivity experiments were performed because all of the highways within the scope of this study receive de – icing salts in winter time. Excess salinity in roadside soils generally causes pH values of the soil to decrease about one unit due to the effects of salt in ion exchange mechanisms of soil. As a result, mobility of heavy metals in soils is expected to rise with increased salinity whereas retention in soil falls. Conductivity is principally related to salinity in soils especially receiving de – icing salts.

A set of complete results of pH, salinity and conductivity determination experiments was added to Appendix B.

5.2.2. Carbon and Nitrogen Content of Soil Samples

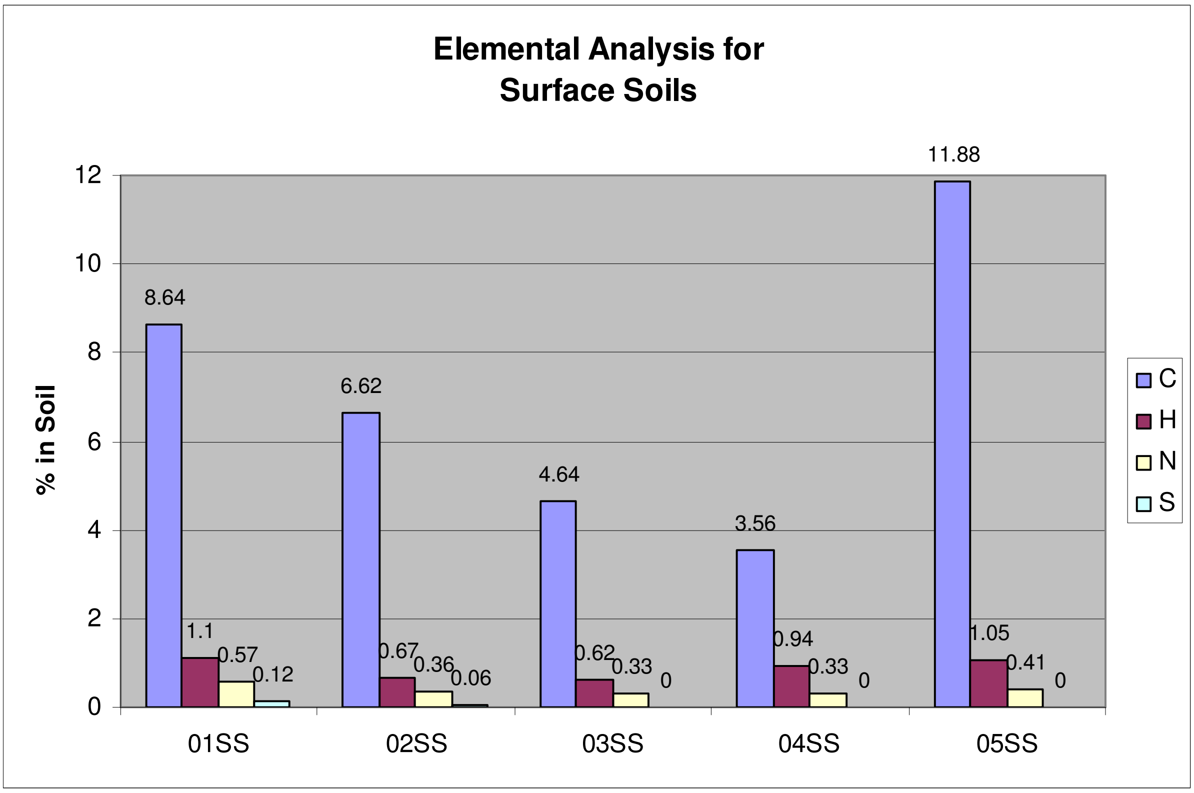

Figure 5.27. Elemental Analysis Results for Surface Soil Samples from O – 1 Highway

Surface soil samples collected from sampling locations in O – 1 Highway were analyzed for their carbon, hydrogen, nitrogen and sulphur contents. The samples had very high levels of carbon, ranging from 3.56 % to 11.88 % with an average of 7.07 %. Hydrogen percentage was between 0.62 and 1.10 where 0.88 % was found as the average value.

Nitrogen content was found in range of 0.33 – 0.57 % where average was found as 0.40. No sulphur was detected in three samples and two samples were determined having very small amounts of sulphur.

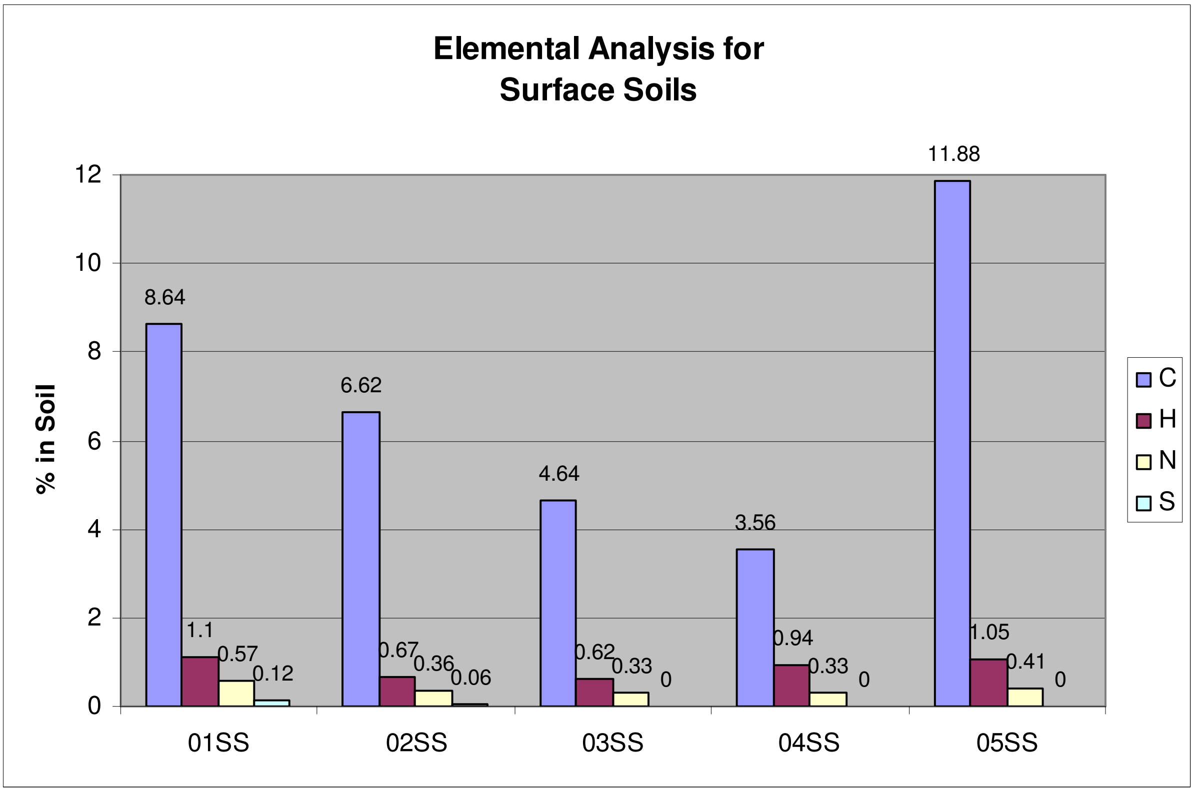

Figure 5.28. Elemental Analysis Results for 20 cm deep Soil Samples from O – 1 Highway

Analyses for carbon, hydrogen, nitrogen and sulphur contents of 20 cm deep soil samples from sampling locations in O – 1 Highway has shown that samples were having high levels of carbon in the range of 1.56 % to 4.75 %, with an average of 3.14. Hydrogen percentage was found between 0.26 and 0.72 and 0.46 %t was the average content. Nitrogen content was changed from 0.09 % to 0.25 % where average was 0.19. No sulphur was detected in any samples.

Samples from 20 cm deep soils had lower carbon, nitrogen, hydrogen and sulphur content than the surface soil samples. This is probably due to the presence of the contamination in top soil by organic pollutants (such as non-combusted petroleum hydrocarbons from emissions and oils coming from leaks from vehicles) and higher biological activity in the soil surface.

The results of experiments were given as a summary in Table 5.6. and Table 5.7. with minimum, maximum, average and median values, and standard deviations. All experimental data can be viewed in Figure 5.27. and 5.28.

Table 5.6. Summary of Elemental Analysis for Surface Soil Samples

	C (%)	H (%)	N (%)	S (%)
Maximum	11.88	1.10	0.57	0.12
Minimum	3.56	0.62	0.33	0.00
Average	7.07	0.88	0.40	0.04
Median	6.62	0.94	0.36	0.00
Standard Deviation	3.318	0.219	0.100	0.054

Table 5.7. Summary of Elemental Analysis for Soil Samples from 20 cm Depth

	C (%)	H (%)	N (%)	S (%)
Maximum	4.75	0.72	0.25	0.00
Minimum	1.56	0.26	0.09	0.00
Average	3.14	0.46	0.19	0.00
Median	3.25	0.42	0.22	0.00
Standard Deviation	1.152	0.193	0.064	0

For this research, surface soil and 20 cm deep soil samples collected from O – 1 Highway were analyzed for carbon, sulphur, nitrogen and hydrogen contents, because the corresponding highway was determined as the mostly polluted arterial among the others within the scope of this research.

Non-metals such as carbon, hydrogen, nitrogen, sulphur, oxygen and phosphorus are mostly found in forms of organic compounds over the earth. One of the most important mechanisms that affect metal behaviour in soils is the complexation with organic substances within the soil. These complexes retain heavy metal pollutants in the soil, increase the carrying capacity for contamination and affect mobility under different conditions such as pH. Determination of the percentages of these elements is certainly helpful when explaining the amount and mechanisms of heavy metal pollution in the soil media.

The full set of results for elemental analysis can be seen in Appendix C.

5.3. Relationship Between Soil Parameters and Metal Concentrations

5.3.1. pH and Metal Concentrations

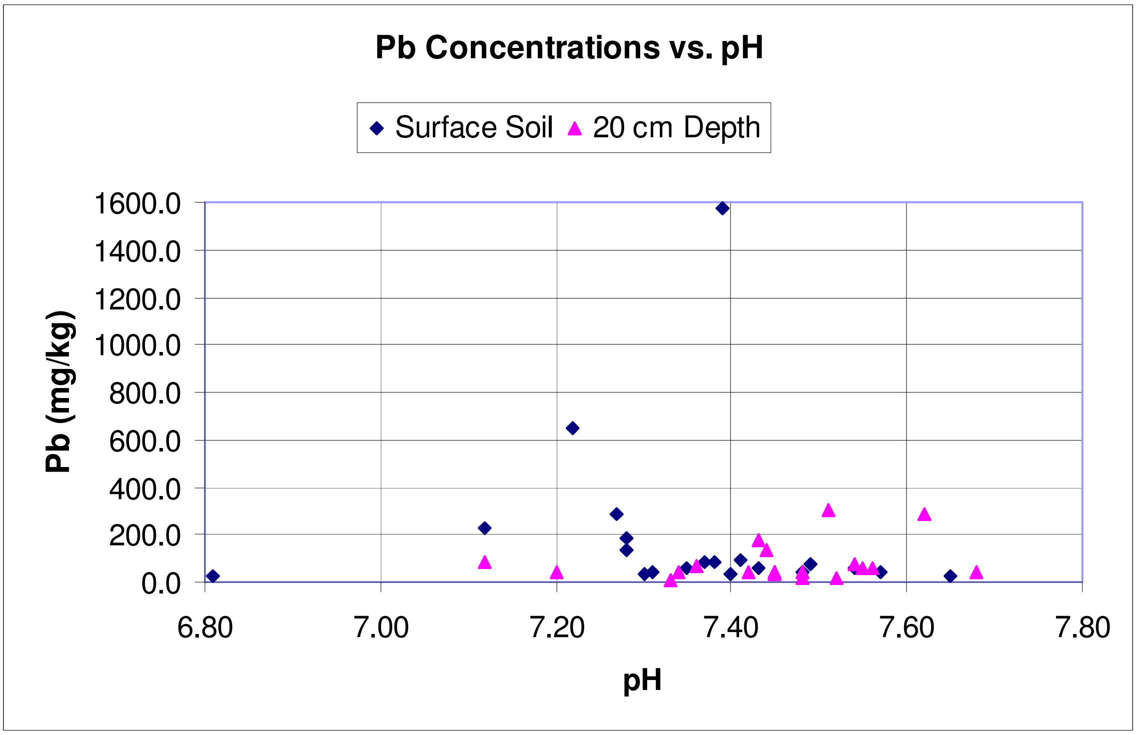

Figure 5.29. Pb Concentrations vs. pH

pH versus lead concentrations distribution for surface and 20 cm deep soils is given in Figure 5.29. There is a tendency of slight increase in metal concentrations as pH values rise as shown in the graph. Data are moderately scattered over the graph area.

From the graph, it is possible to comment that soils with larger pH values retain more lead than the soil media with smaller pH.

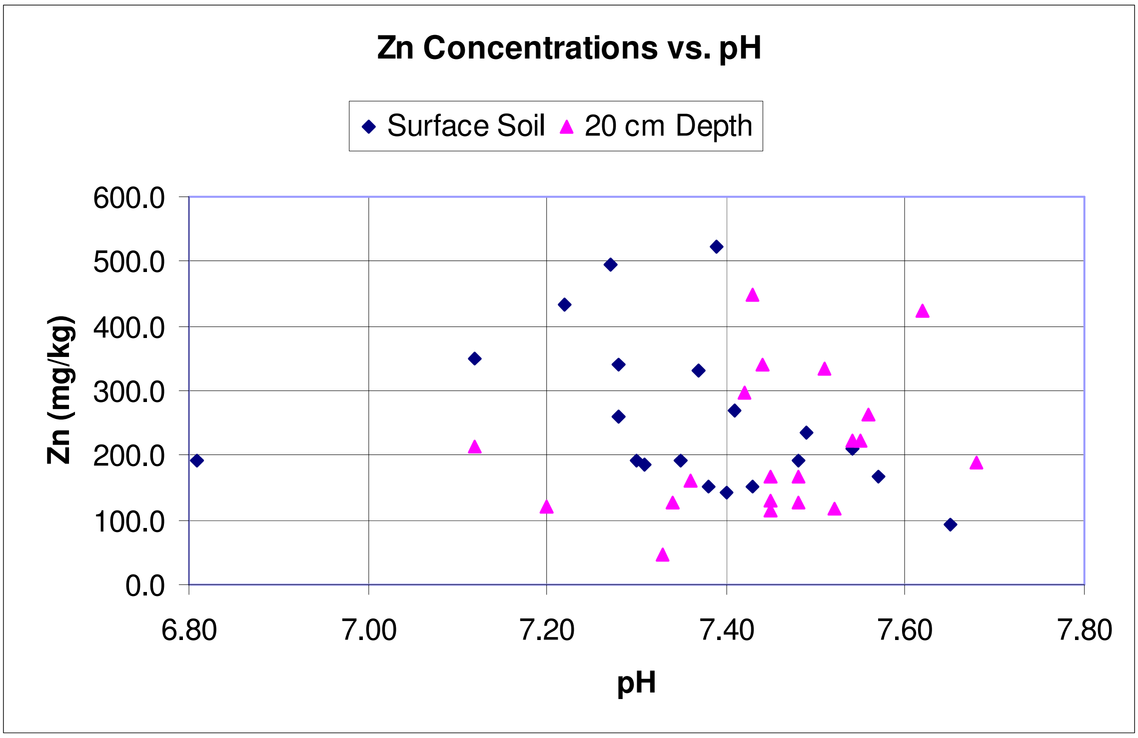

Figure 5.30. Zn Concentrations vs. pH

In Figure 5.30. distribution of pH versus zinc concentrations for surface and 20 cm deep soils is given. A tendency of slight increase in metal concentrations as rise with pH values is shown; however, highly scattered data distribution was obtained in the graph.

Soil media falling in high pH intervals tend to retain more zinc in their structure than the soils having lower pH. On the other hand, it is not possible to comment on pH – zinc concentrations very clearly from the figure because of the scattered distribution.

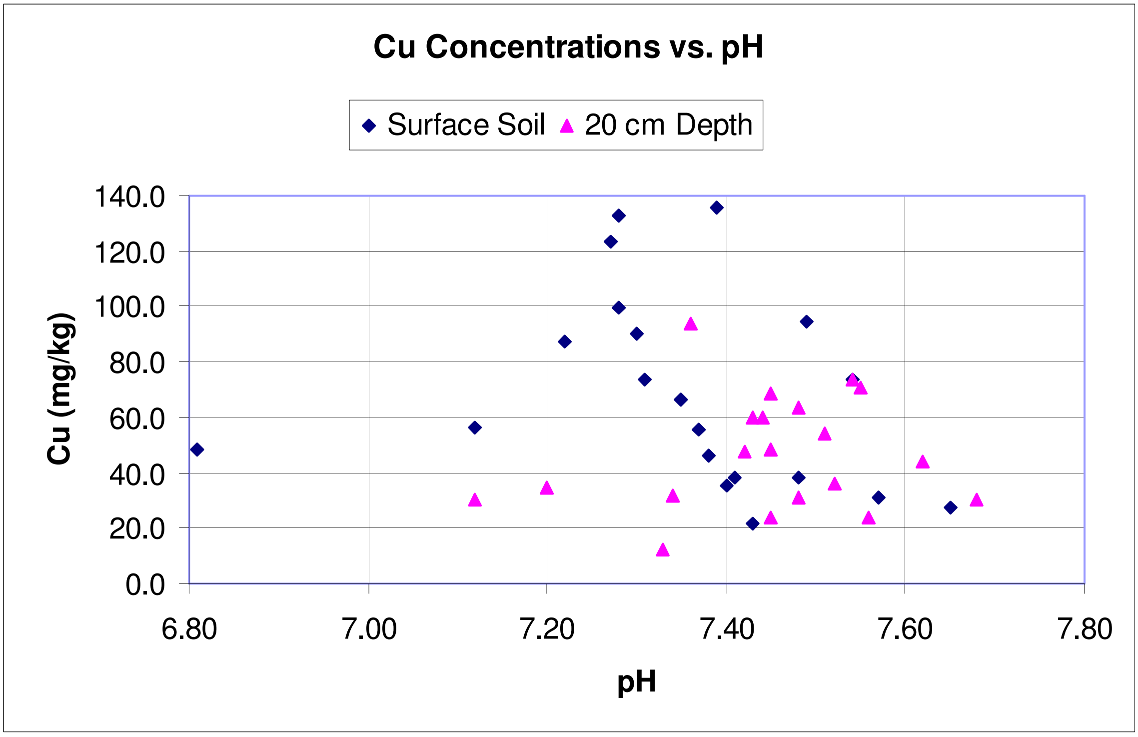

Figure 5.31. Cu Concentrations vs. pH

The graph in Figure 5.31. shows the distribution of pH versus copper concentrations for surface and 20 cm deep soil samples. A slight increase in metal concentrations as pH values of soil media rises was obtained. The processed data are highly scattered over the entire graph area.

Where soil media have high pH values, they are able retain more copper than the soils having lower pH, as shown in the figure, but the decision is not very clear because of having highly scattered data.

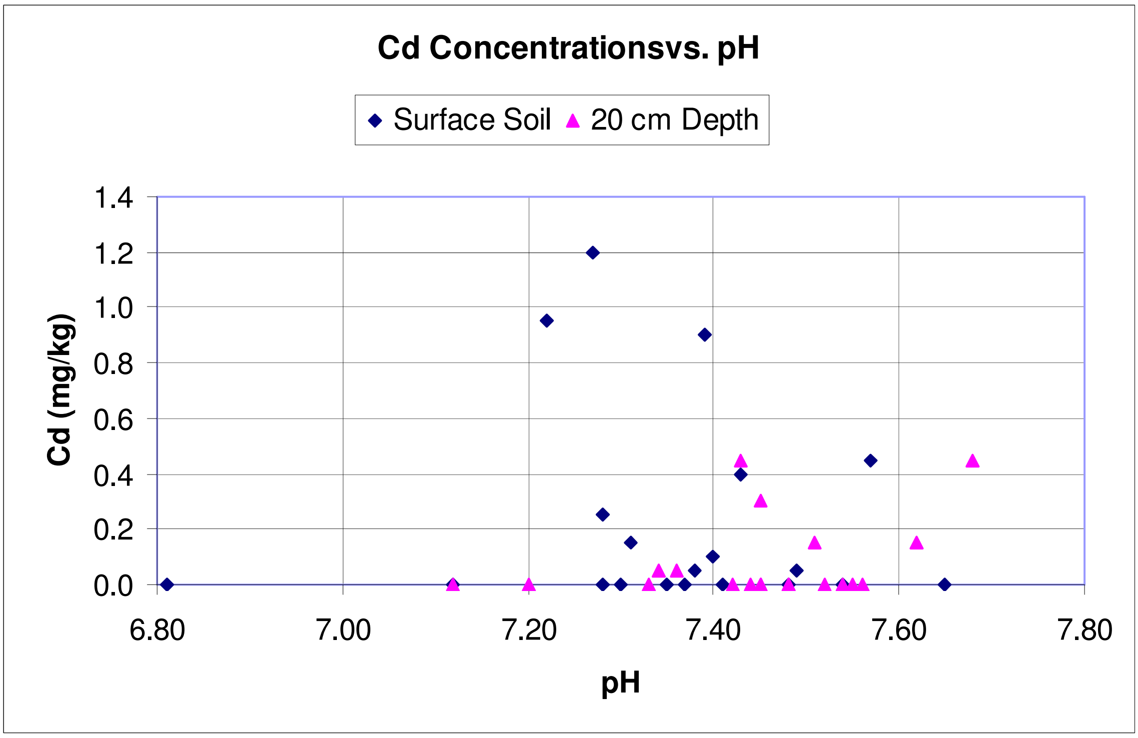

Figure 5.32. Cd Concentrations vs. pH

The graph above explains the distribution of pH versus cadmium concentrations of samples from surface and 20 cm deep soils. An obvious rise in metal concentrations together with increase of pH values of soil media were obtained where only a few points do not fit to this trend. The cadmium concentrations versus pH values are found moderately scattered over the graph.

There are few non – zero concentration data available on the graph than other graphs for pH versus metals; however, it is possible to comment that soils having high pH values retain more cadmium in soil structure than the soils with lower pH values.

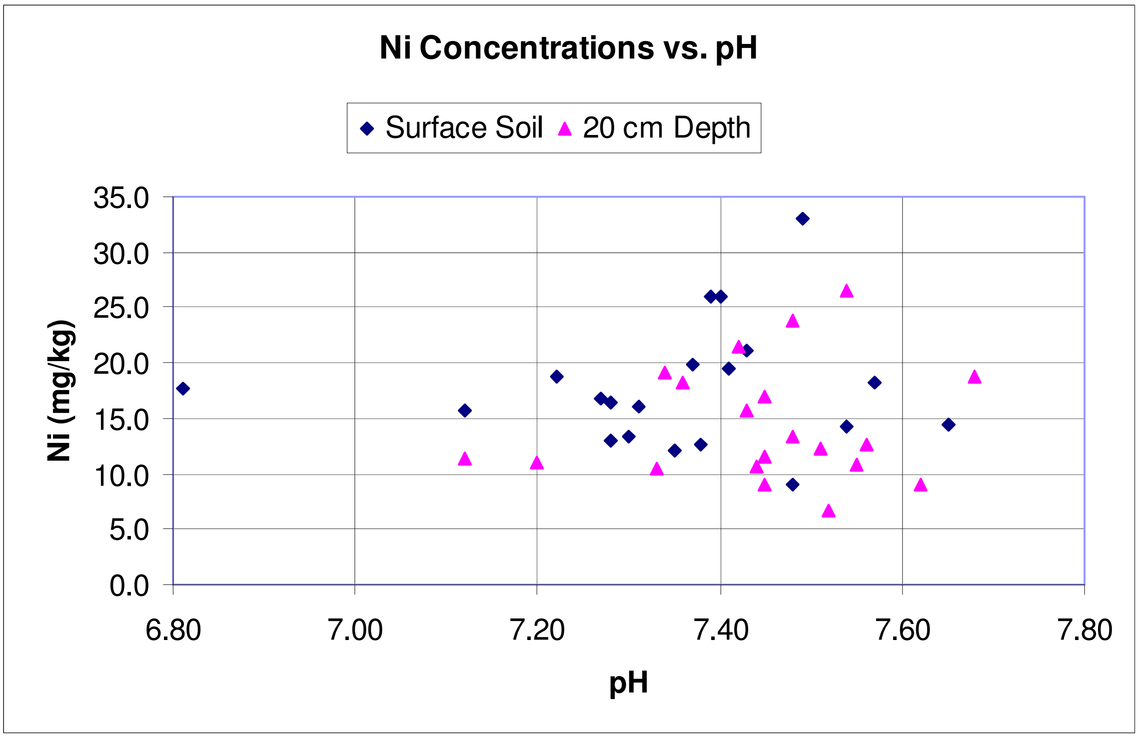

Figure 5.33. Ni Concentrations vs. pH

Figure 5.33. explains the distribution of pH against nickel concentrations for surface and 20 cm deep soil samples. An increase in metal concentrations was obtained as pH values of soil increases. The nickel concentrations were moderately scattered over the graph where especially results for samples from 20 cm depth give more clear increase behaviour.

It is possible to say that soils having high pH values retain more nickel in soil media than the soils with lower pH. Data over the graph was found moderately scattered.

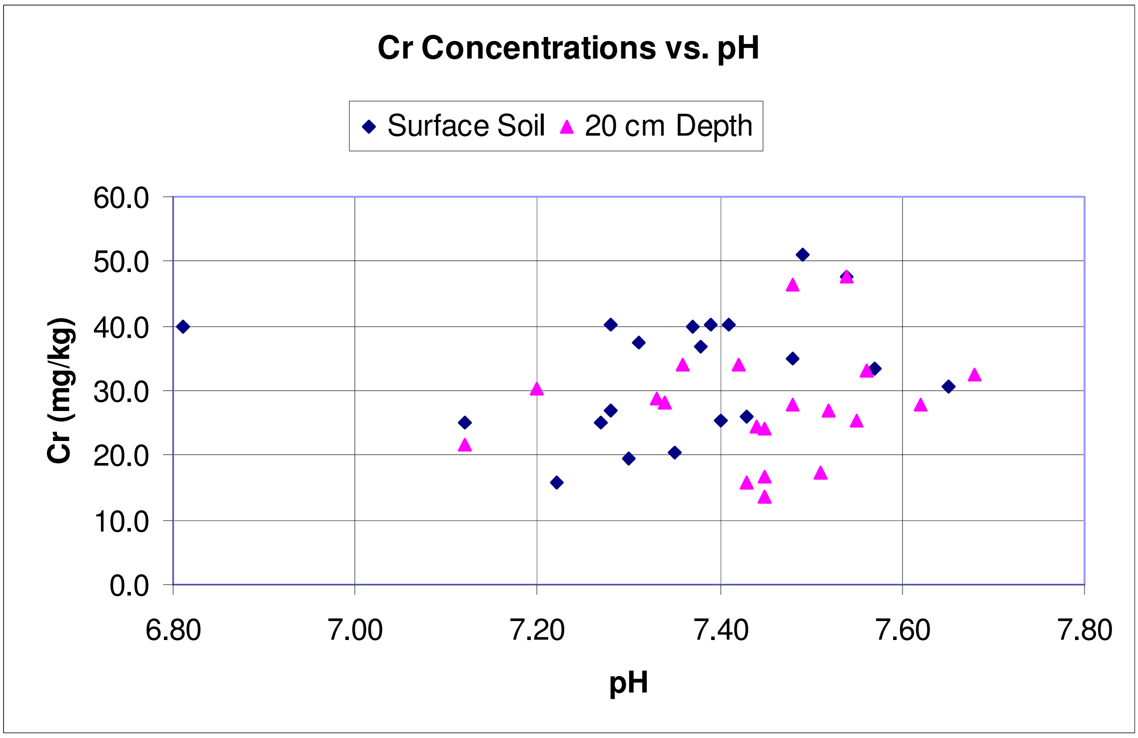

Figure 5.34. Cr Concentrations vs. pH

In Figure 5.34. the distribution of pH against chromium concentrations for soil samples from surface and 20 cm depth is projected. There is an obvious increase in metal concentrations as soil pH rises. The chromium concentrations are moderately scattered over the graph.

Soils with higher pH values tend to retain more chromium in their structure than the soils having lower pH values. The relationship is shown clearly for samples from both surface and 20 cm deep.

As mentioned in theoretical background and in results part of the thesis, heavy metals tend to be retained in the soil media at higher pH values. On the other hand, metals are more mobile at soils with lower pH. This certainly affects the amount and characteristics of the pollution in soils.

At higher pH values, soil is able to retain very high amounts of pollutants, but mobility of metals is less. However soils with lower pH retain less pollutant while metals escape easily to other media by mobilization, which may be more dangerous in cases where high pollution loads are present. Results of the experiments support this information. All metals show a slight tendency to increase as pH rises. For chromium, this tendency is more clearly seen.

Although heavy metal concentrations for surface soil samples and samples from 20 cm deep largely differ where surface soils was found having contaminated in greater extent, similar relationships were obtained and above explanations apply to both types of samples.

5.3.2. Salinity and Metal Concentrations

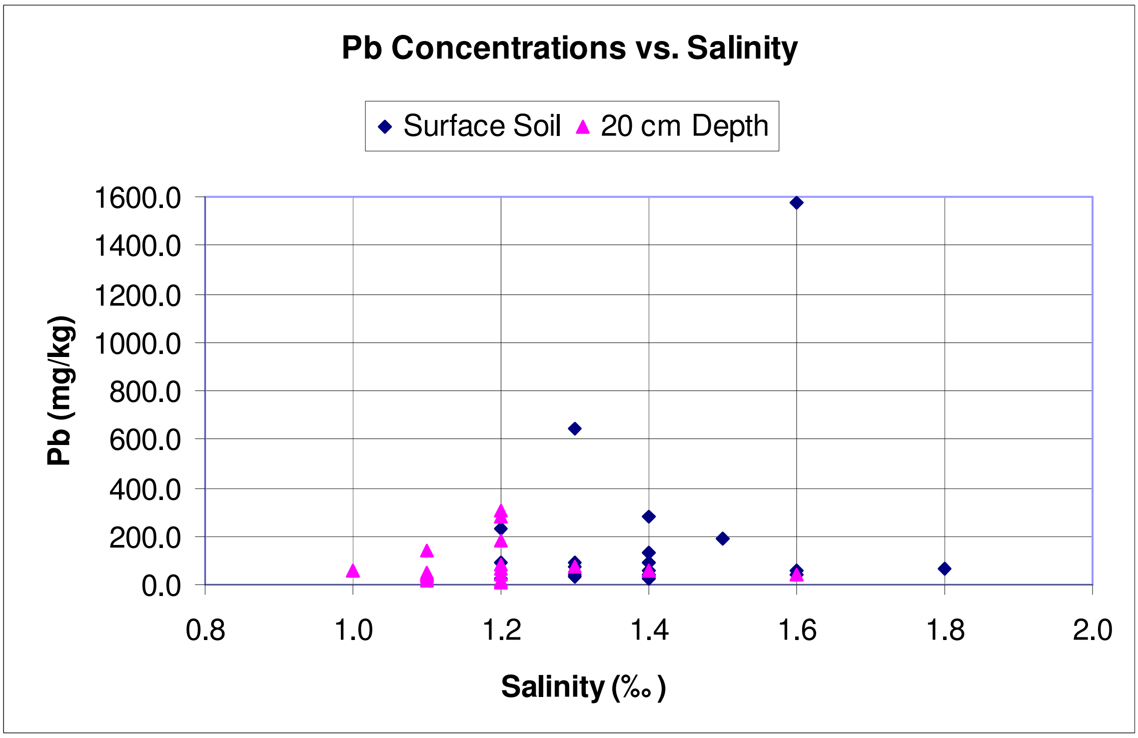

Figure 5.35. Pb Concentrations vs. Salinity

In Figure 5.35 salinity versus lead concentrations distribution for surface and 20 cm deep soils is given. As shown from the figure, there is a tendency of slight increase in metal concentrations as salinity values decrease. But the relationship between the parameters is not very clear since a few data points are highly scattered over the the graph area.

It is possible to say that soils with larger salinity values retain lesser amounts of lead than the soil media with smaller salinity. However, more detailed investigation may be needed.

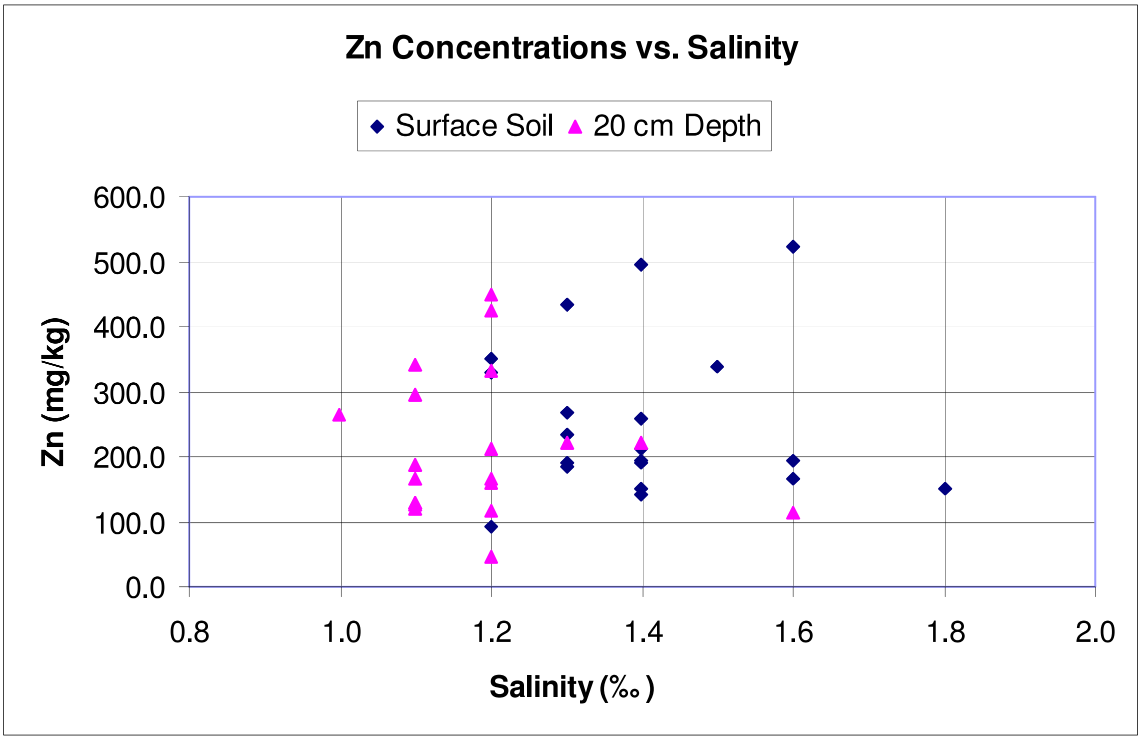

Figure 5.36. Zn Concentrations vs. Salinity

In Figure 5.36. distribution of salinity against zinc concentrations for surface and 20 cm deep soils is shown. An increase in metal concentrations as salinity values fall can be obtained; however, some points in moderately scattered data do not fit the trend.

Soil samples in high salinity intervals are likely to retain less zinc concentrations in soil structure than the soils having lower salinity. It is possible to comment on the behaviour of zinc concentrations with respect to the salinity from the figure, although moderately scattered distribution exists.

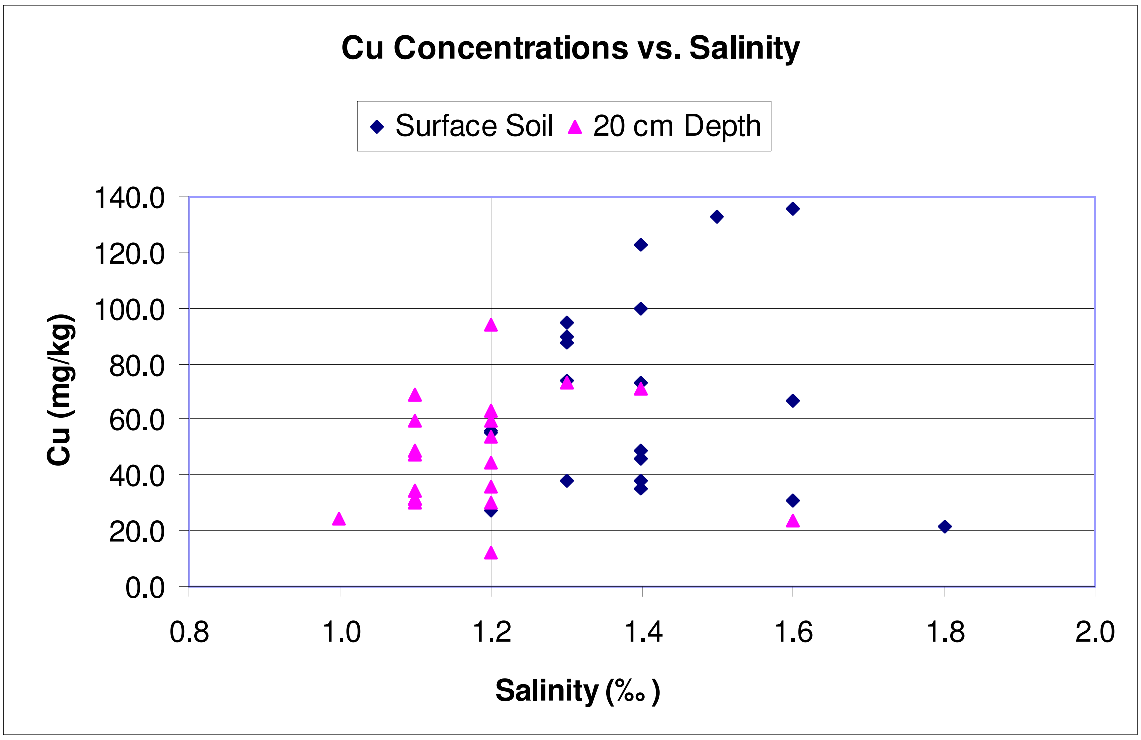

Figure 5.37. Cu Concentrations vs. Salinity

The graph shown in Figure 5.37. gives the distribution of salinity versus copper concentrations for surface and 20 cm deep soil samples. No obvious increase or decrease in metal concentrations with changes in salinity values of soil media can be seen. The processed experimental data were found moderately scattered over the graph.

From the experimental data, it is not possible to say soil media with high salinity values are whether able retaining more copper than the soils having lower salinity or less.

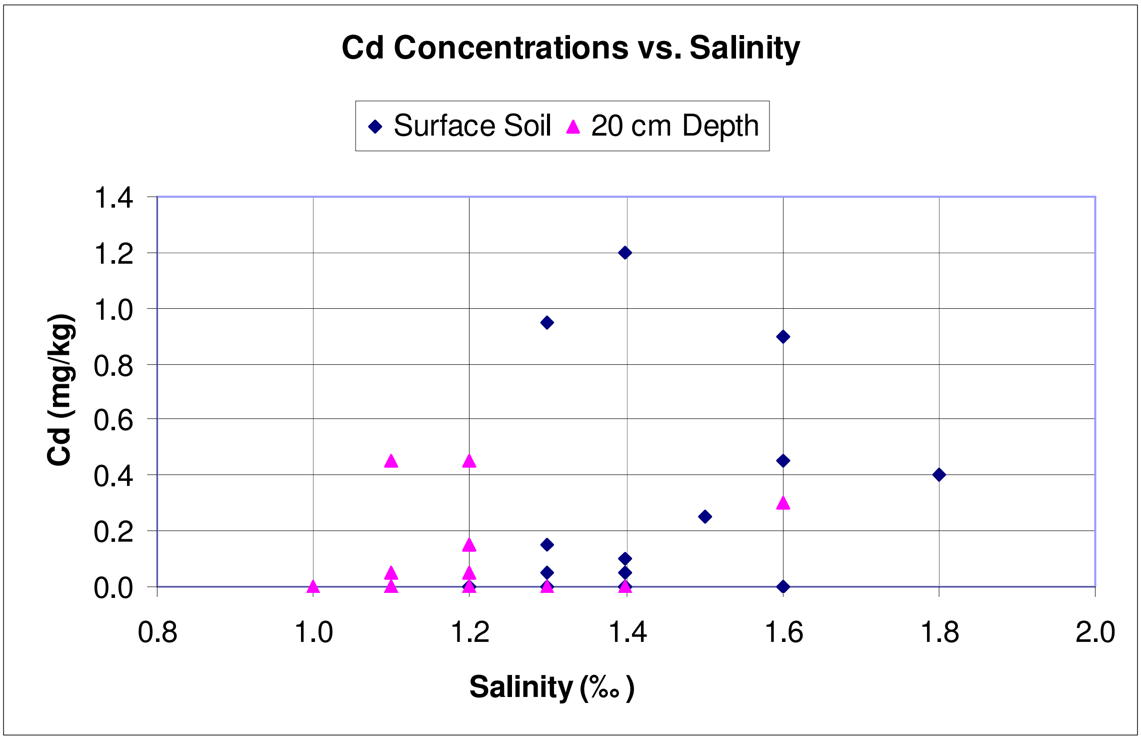

Figure 5.38. Cd Concentrations vs. Salinity

Figure 5.38 explains the distribution of salinity versus cadmium concentrations of samples from surface and 20 cm deep soils. No clear comment between metal concentrations and salinity values of soil media is obtained because there were some zero values in the plot. Experimental data for cadmium concentrations versus salinity values were found moderately scattered over the graph.

Since fewer non – zero concentration data was available on the graph than other graphs for salinity; it is not possible to say that soils with high salinity values retain more or less cadmium than the samples with lower salinity.

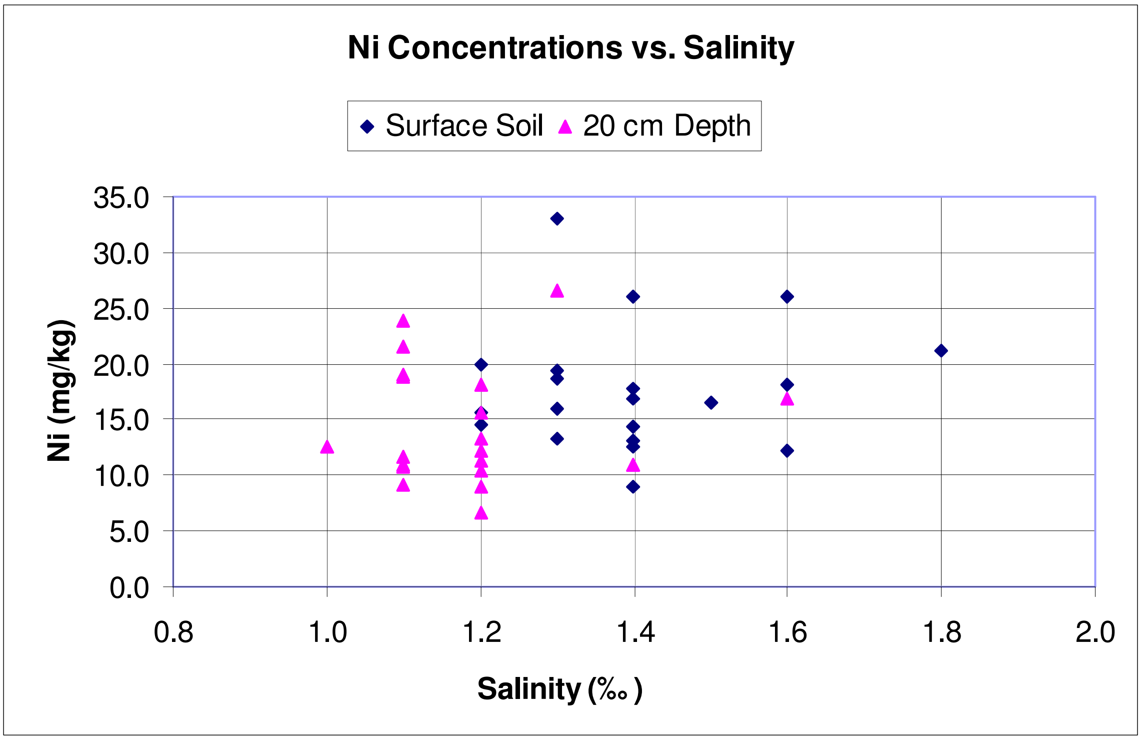

Figure 5.39. Ni Concentrations vs. Salinity

Figure 5.39. represents the distribution of salinity versus nickel concentrations for surface and 20 cm deep soil samples. A trend of increase in metal concentrations can be seen in the graph as salinity values of soil decreases if surface and 20 cm deep soils are examined separately. The nickel concentrations were found moderately scattered over the graph.

Soils having high salinity values retain less nickel in soil media than the soils with lower salinity, where most of the points were found fitting to this comment.

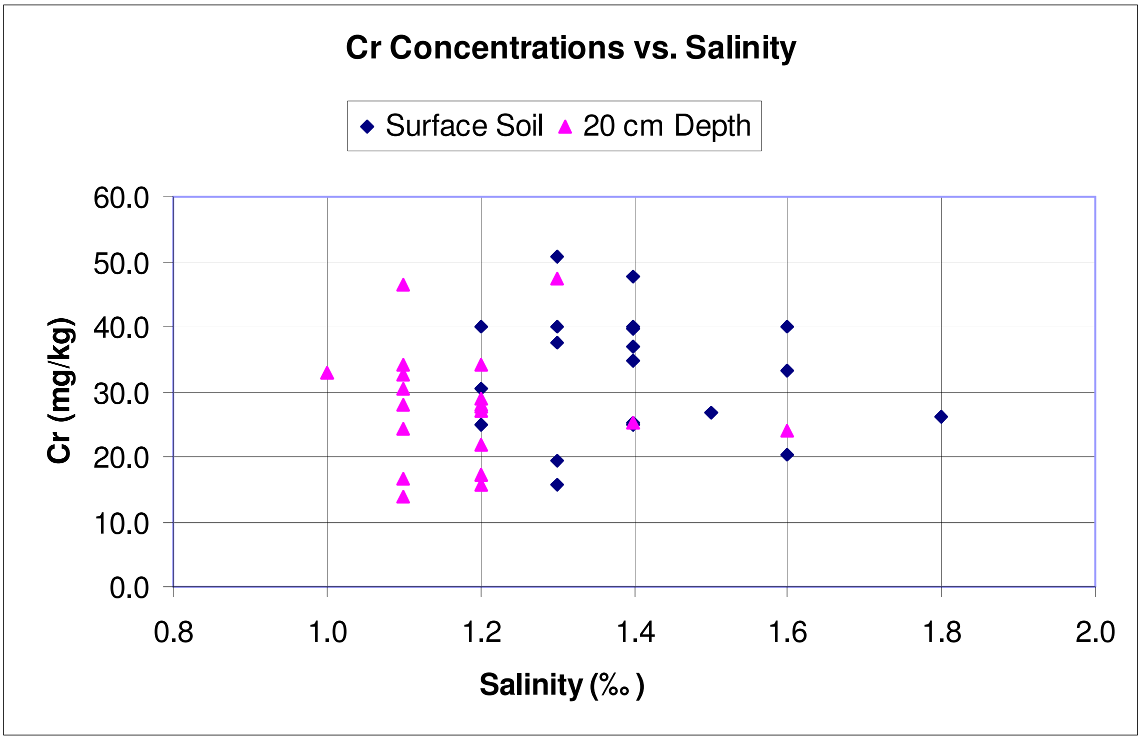

Figure 5.40. Cr Concentrations vs. Salinity

The distribution of salinity against chromium concentrations for soil samples from surface and 20 cm depth is projected in Figure 5.40. No change in metal concentrations is observed with soil salinity change for surface soils, but there is an inverse proportion between salinity values and chromium concentrations for 20 cm deep soils. The chromium concentrations are highly scattered over the graph.

Soils with higher salinity values were found retaining more chromium than the soils having lower salinity values. The relationship is only visible for 20 cm deep soil samples, not for surface soils since highly scattered data is available in the graph.

Artificial salinity in roadside soils mostly comes from the salt sprinkling operations to the road pavement during winter in cold regions. De-icing salts quickly form an aqueous solution with snow and water in the pavement, and the mixture is spreaded to roadside soils as vehicles pass. The aqueous solution comes to contact with roadside soils and the salinity of the soil media is increased.

Increased salinity is hazardous for the roadside environment. First of all, highly saline soils support a narrow variety of microorganisms and plants. Also increase in salinity generally results in a lowered pH value for soil media, which means a rise in mobility of heavy metals. As a result, a decrease in metal concentrations in soils would be expected as salinity of the soil is increased as a result of pH alteration due to the salinity.

As shown in the figures above, concentrations of lead and zinc are inversely proportional to the salinity values found for soil samples, which is not an unexpected result. Concentrations of copper and cadmium, however, had no relationship with salinity and no connection was found. Very low cadmium concentrations should be noted for the reason why no relationship appeared. Nickel and chromium concentrations were also found having an inverse relationship with salinity of soil, as expected; however further investigation may be needed.

5.3.3. Conductivity and Metal Concentrations

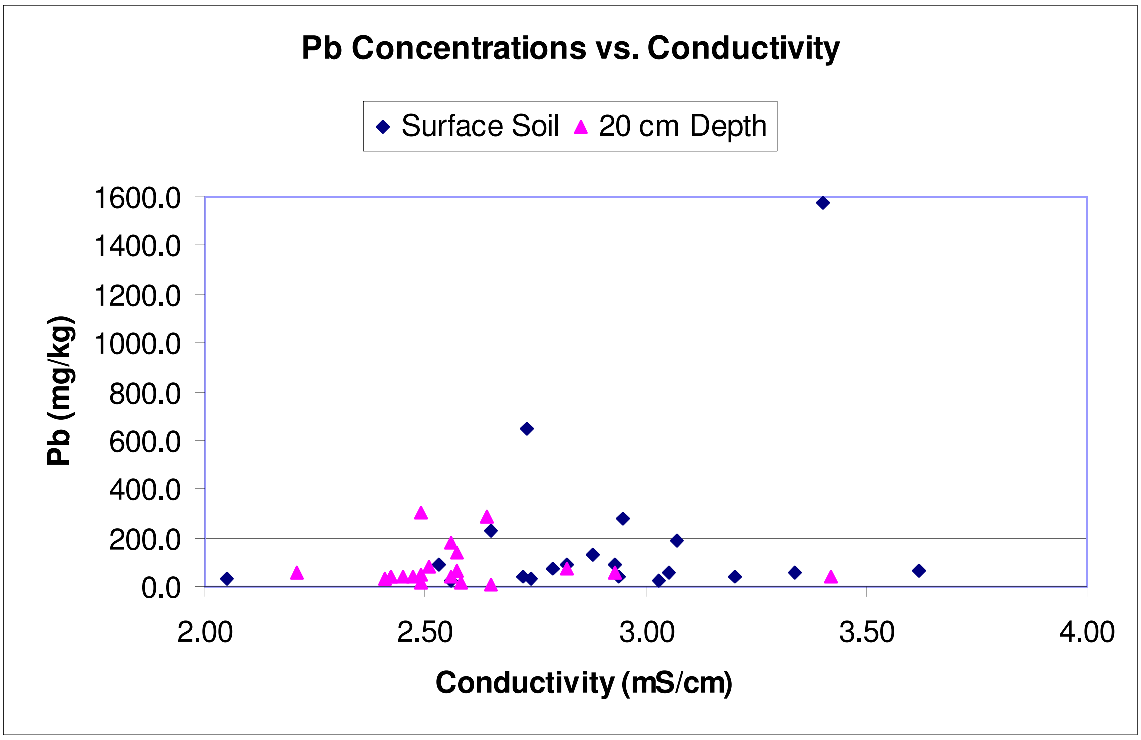

Figure 5.41. Pb Concentrations vs. Conductivity

Conductivity versus lead concentrations distribution for surface and 20 cm deep soils is given in Figure 5.41. As shown in the graph above, metal concentrations slightly increase as conductivity values rise. Data are moderately scattered over the graph area, especially in regions where very high concentrations occur.

It is possible to comment soils with larger conductivity values retain more lead than the soil media with smaller conductivity; however, further investigation may be needed.

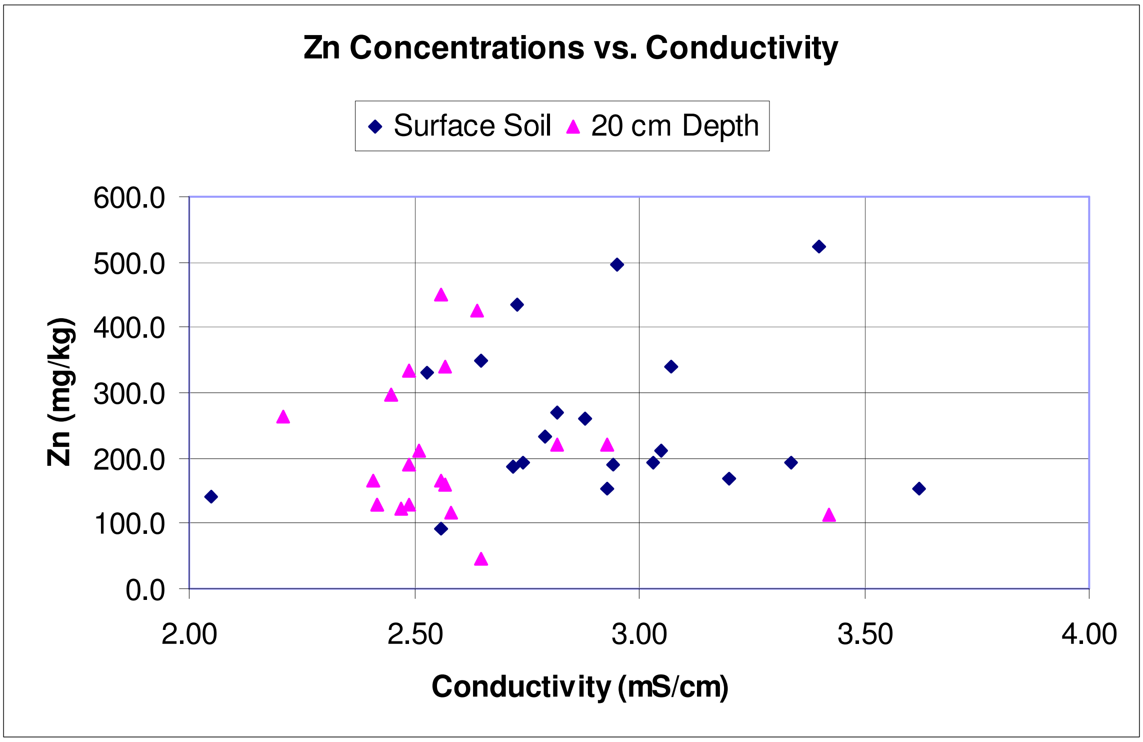

Figure 5.42. Zn Concentrations vs. Conductivity

Distribution of conductivity versus zinc concentrations for surface and 20 cm deep soils is given in Figure 5.42. A trend of increase in metal concentrations with a rise in conductivity values was obtained. Highly scattered data distribution was shown in the plot.

Soil media with high conductivity values tend to retain more zinc in their structure than the soils having lower conductivity values. It is possible to comment on conductivity – zinc concentrations from the figure in spite of the scattered distribution.

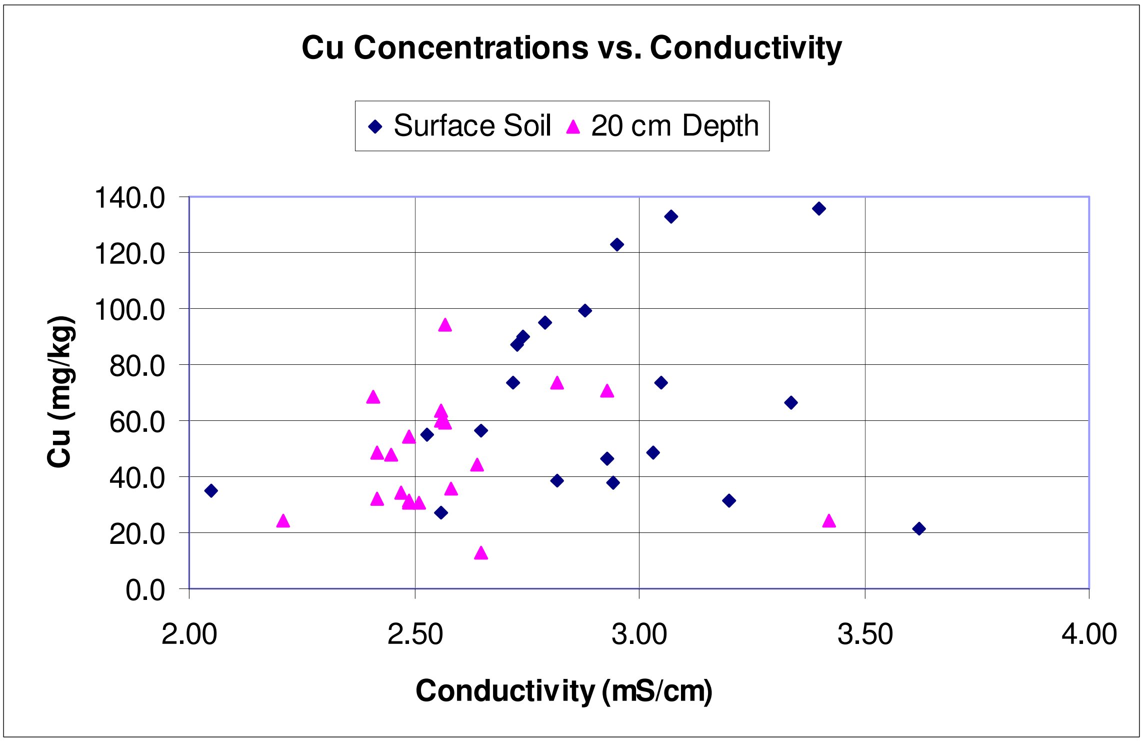

Figure 5.43. Cu Concentrations vs. Conductivity

The plot on Figure 5.43. gives the distribution of conductivity against copper concentrations for surface and 20 cm deep soil samples. A clear increase in metal concentrations as conductivity values of soil media rises was obtained. The processed data are moderately scattered over the plot area.

When soil media have high conductivity values, retainment of higher copper concentrations were seen, as shown in the figure. The connection is clear despite of availability of scattered data.

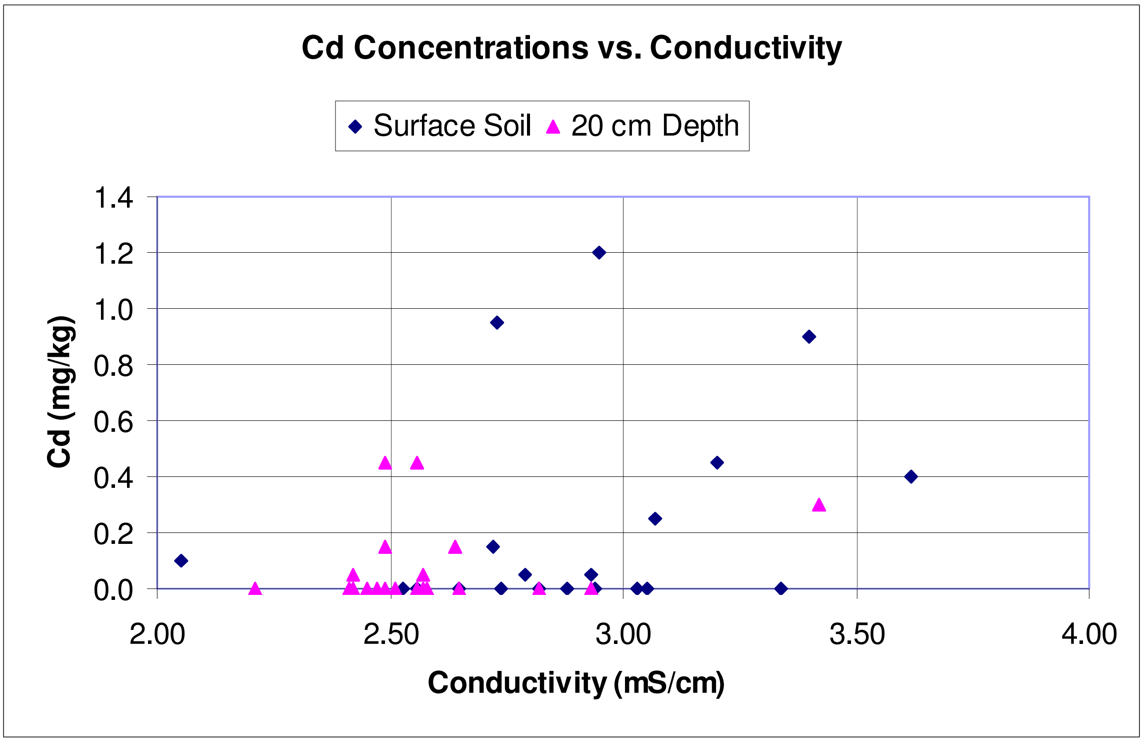

Figure 5.44. Cd Concentrations vs. Conductivity

Figure 5.44. explains the distribution of conductivity versus cadmium concentrations of samples from surface and 20 cm deep soils. A rise in metal concentrations with increase of conductivity values of soil media was obtained. The cadmium concentrations versus conductivity values were found highly scattered over the graph.

The number of non – zero concentration points available on the above graph is less than number of points in other graphs for conductivity versus metals; however, it is still possible to comment that soils having high conductivity values retain more cadmium in soil structure than the soils with lower conductivity.

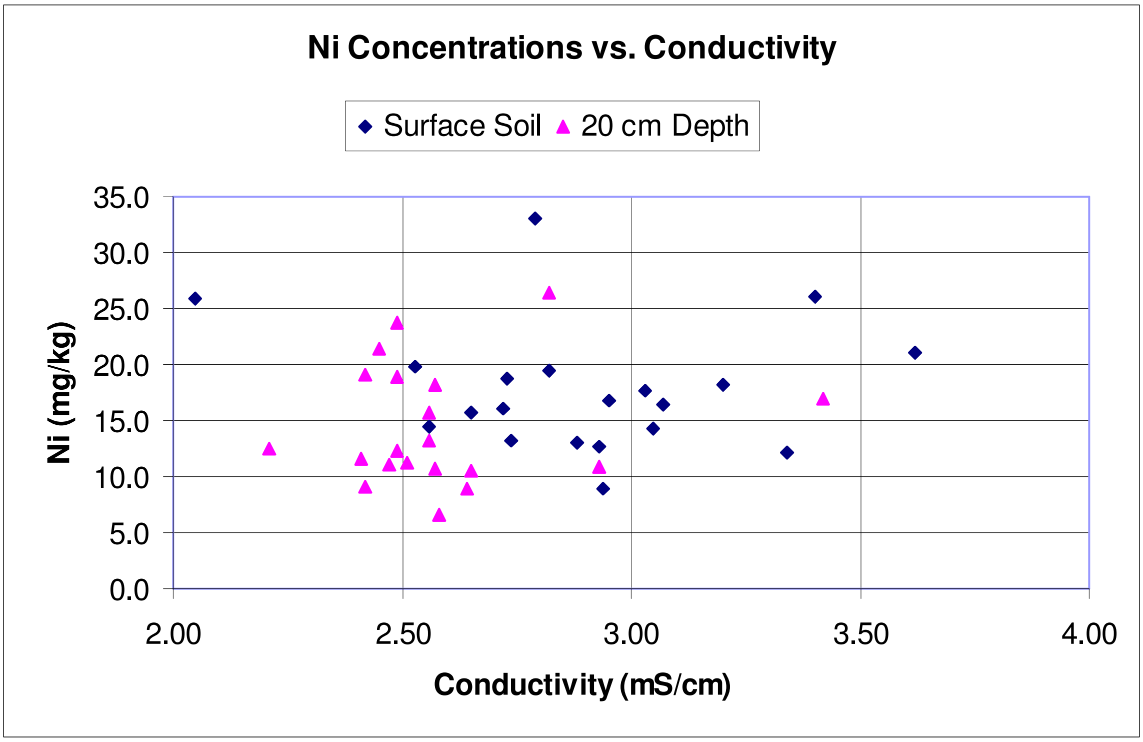

Figure 5.45. Ni Concentrations vs. Conductivity

Figure 5.45. shows the distribution of conductivity against nickel concentrations for surface and 20 cm deep soil samples. A slight increase in metal concentrations as conductivity values of soil rises was obtained. The nickel concentrations are moderately scattered over the graph where few points do not fit in the behaviour of proportional increase mentioned.

It is possible to comment that soils with high conductivity values are likely to retain higher nickel concentrations in soil media than the soils with lower conductivity. Data over the graph was found highly scattered.

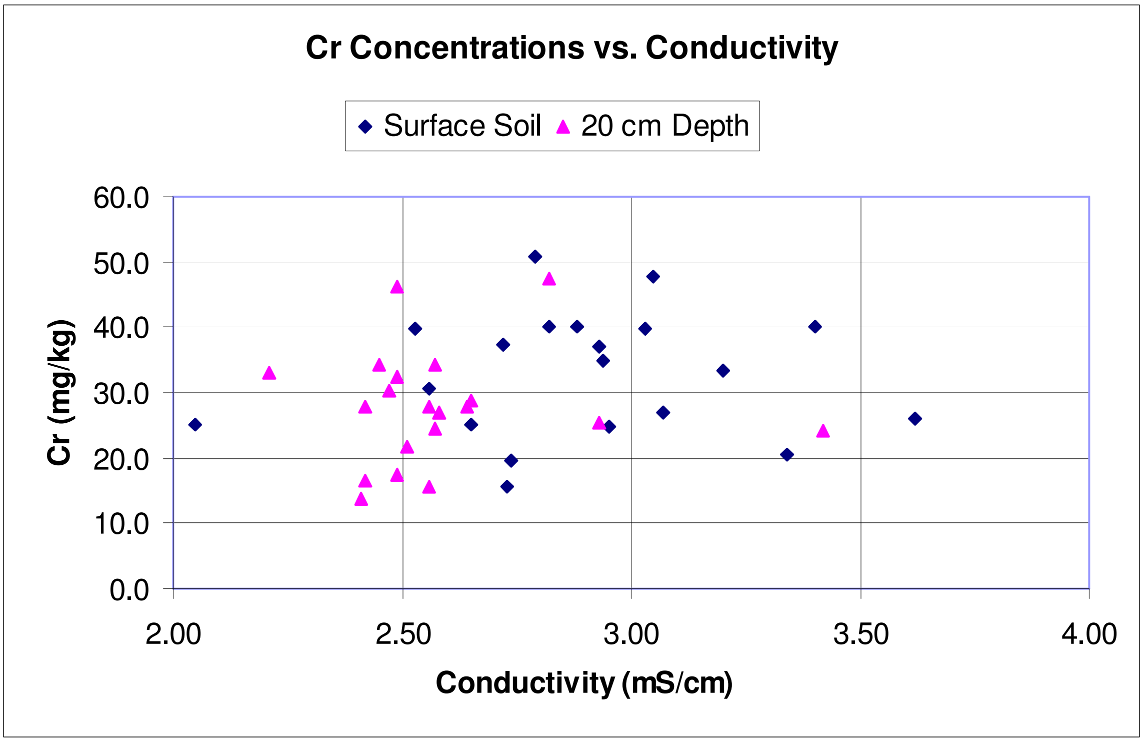

Figure 5.46. Cr Concentrations vs. Conductivity

In Figure 5.46. the distribution of conductivity against chromium concentrations for soil samples from surface and 20 cm depth is plotted. There is an increase in metal concentrations as soil conductivity rises. The chromium concentrations are moderately scattered over the graph.

Soils with higher conductivity values retain larger concentrations of chromium in their structure than the soils having lower conductivity values. The relationship can be seen clearly although there is scattered data in plot.

For all of the metals within the scope of this research (Pb, Zn, Cu, Cd, Ni and Cr), concentrations in soils show a direct relationship with conductivity values of the soil samples. However, for the cadmium, results are not so precise since determined values are near to or equal to zero in most points. On the other hand, a good relationship can be seen for lead, zinc, copper, nickel and chromium between conductivity and metal concentrations, and conductivity is an indicator for levels of heavy metal concentration in contaminated soils.

5.3.4. Carbon Content and Metal Concentrations

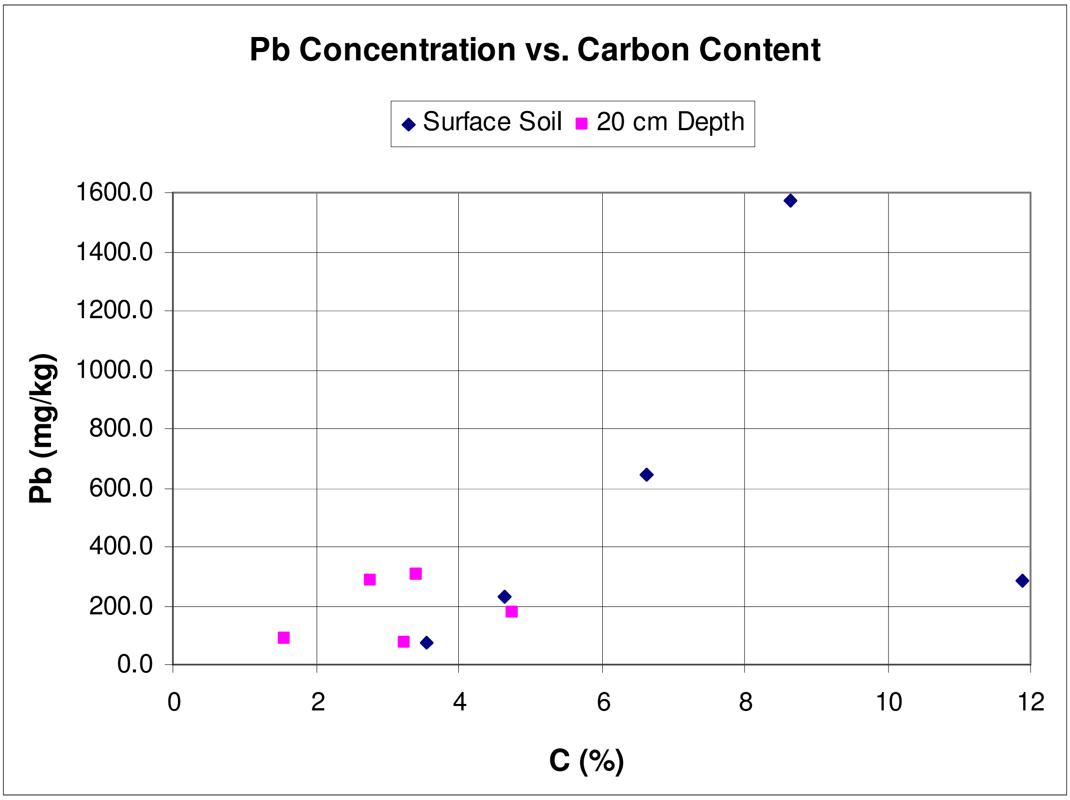

Figure 5.47. Pb Concentration vs. Carbon Content for Soils of O – 1 Highway

Carbon content versus lead concentrations distribution for surface and 20 cm deep soils of O – 1 Highway is shown in Figure 5.47. There is an obvious increase in metal concentrations as carbon content rises as shown in the graph. Data points are moderately scattered over the graph area.

It is shown that soils with higher carbon content retain more lead than the soil media with smaller carbon percentage as can be seen from the plot.

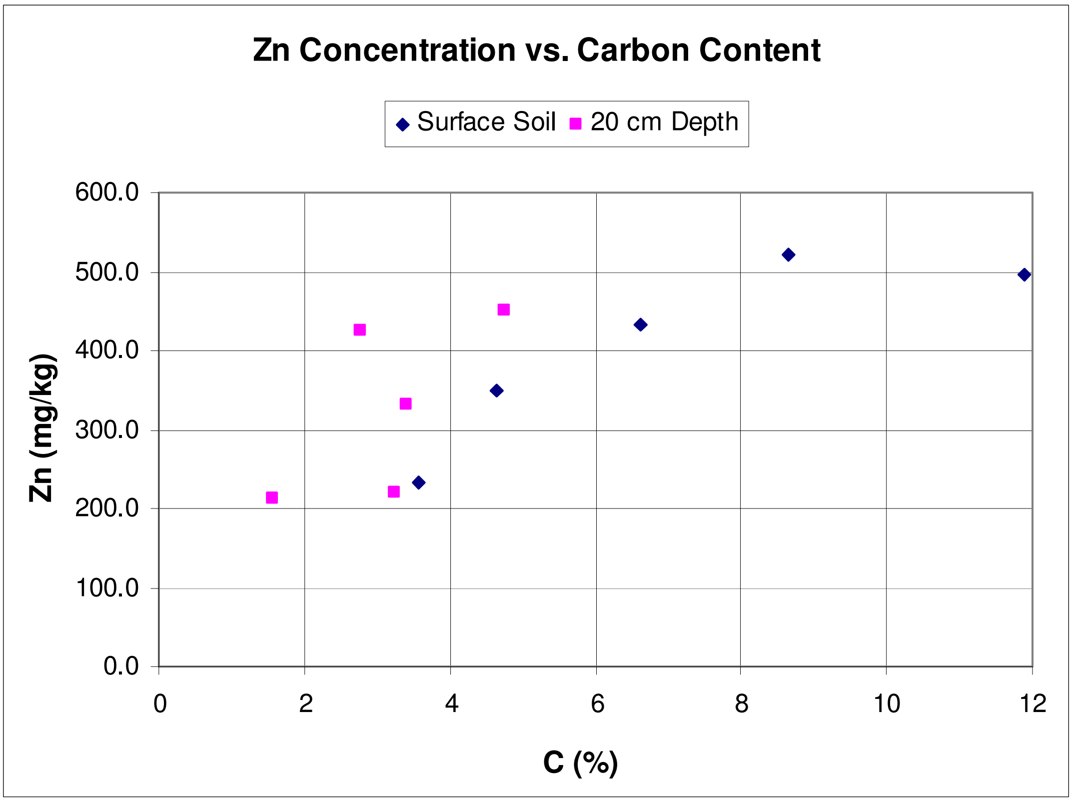

Figure 5.48. Zn Concentration vs. Carbon Content for Soils of O – 1 Highway

In Figure 5.48. distribution of carbon content versus zinc concentrations for surface and 20 cm deep soils of O – 1 Highway is given. A clear behaviour of increase in metal concentrations as carbon content rises is shown. Less scattered data distribution was obtained in the graph.

Soil media with high carbon content tend to retain larger concentrations of zinc in their structure than the soils having a lower carbon percentage. Carbon content – zinc correlation is very clear.

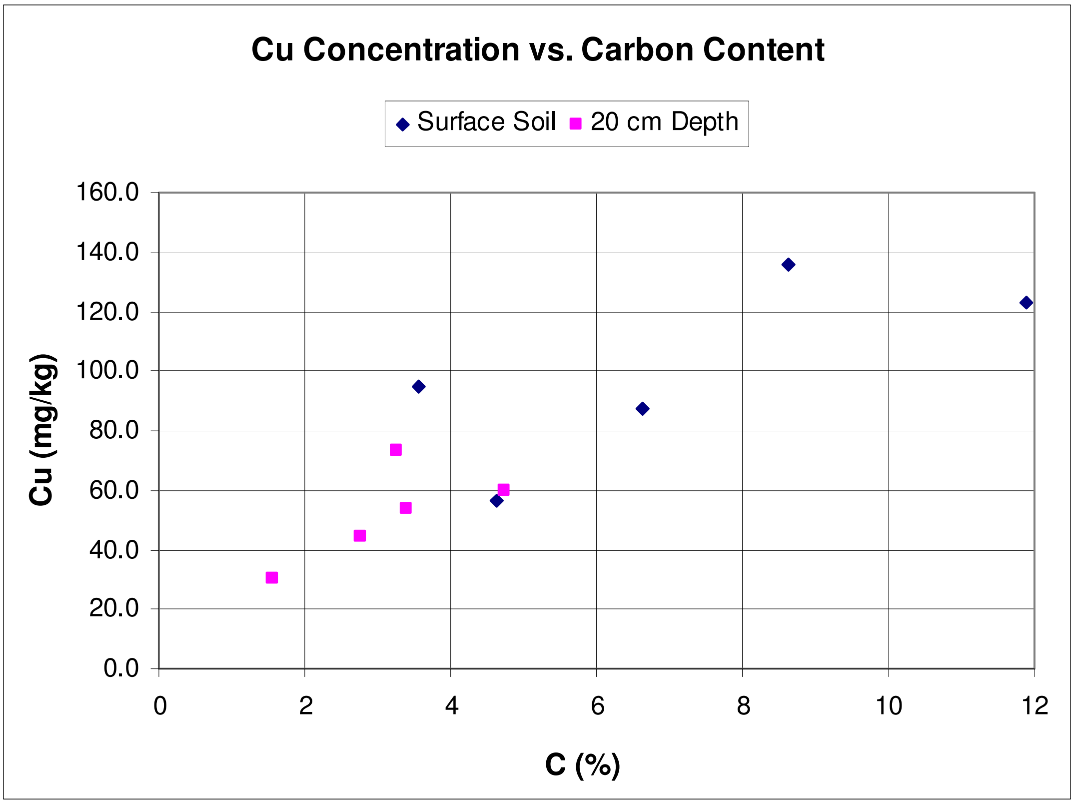

Figure 5.49. Cu Concentration vs. Carbon Content for Soils of O – 1 Highway

The graph in Figure 5.49. represents the plot for distribution of carbon content versus copper concentrations for surface and 20 cm deep soil samples from O – 1 Highway. Linear increase in metal concentrations together with carbon content rise of soil media was obtained. The processed data are moderately scattered over the entire plot area.

It is shown that soil samples with high carbon content are able retain more copper than the soils having lower carbon content, as shown in the figure. The relationship is very clear and linear behaviour exists within the range of graph.

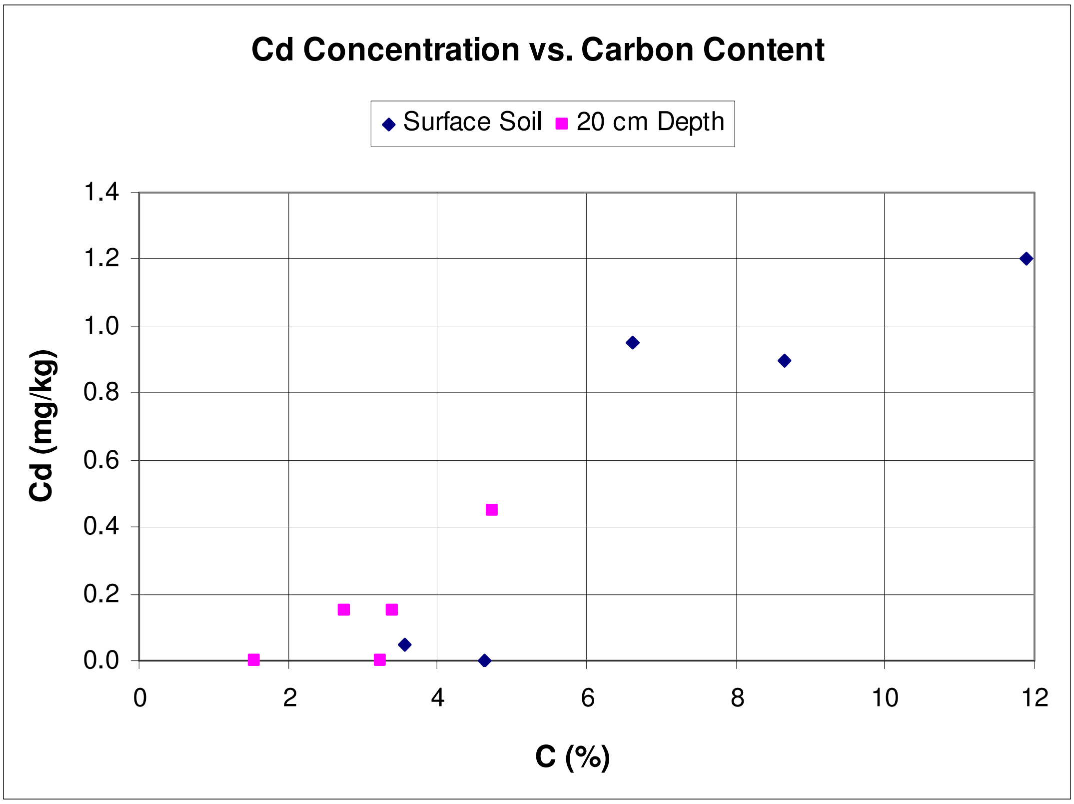

Figure 5.50. Cd Concentration vs. Carbon Content for Soils of O – 1 Highway

The graph in Figure 5.50. explains the distribution of carbon content versus cadmium concentrations of samples from surface and 20 cm deep soils of O – 1 Highway. An obvious linear rise in metal concentrations together with increase of carbon content of soil media was obtained where processed points were found slightly scattered over the graph.

Although there are some points of zero concentration data available on the plot area, it is possible to comment that soils having high carbon content retain more cadmium in soil structure than the soils with lower percentages of carbon.

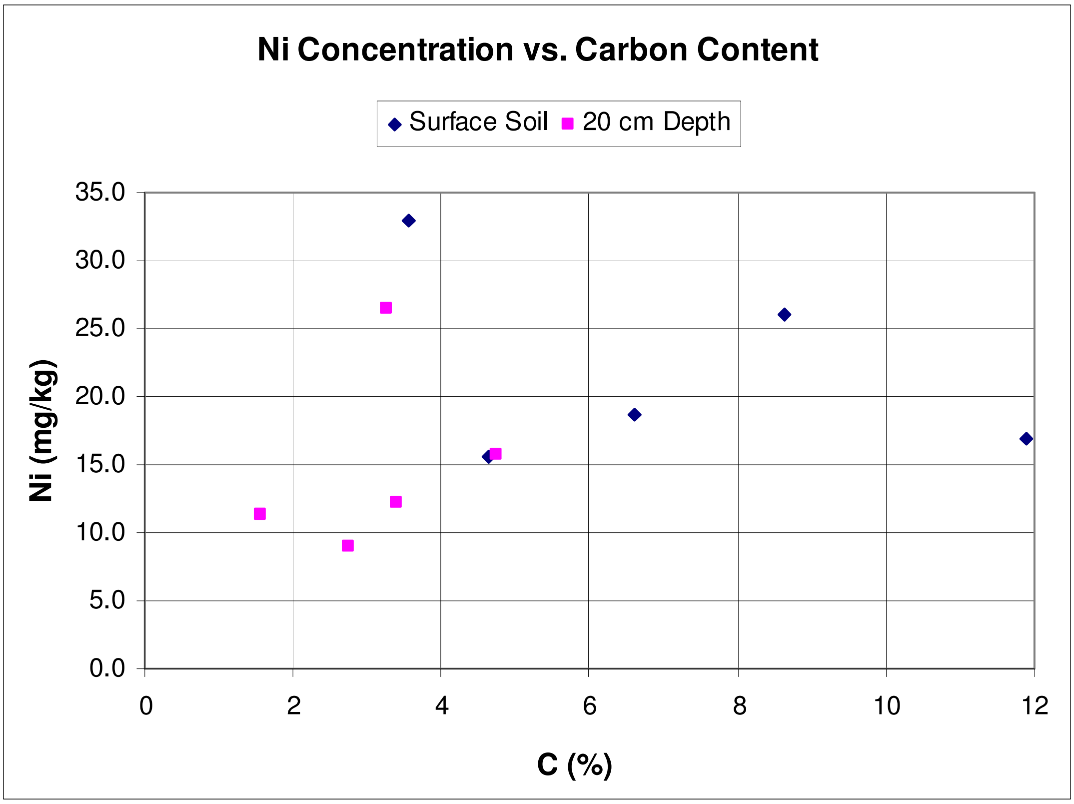

Figure 5.51. Ni Concentration vs. Carbon Content for Soils of O – 1 Highway

In Figure 5.51. the distribution of carbon content against nickel concentrations for surface and 20 cm deep soil samples of O – 1 Highway is given. An increase in metal concentrations was obtained as carbon content of soil increases. The nickel concentrations are moderately scattered over the graph and especially results for samples from 20 cm depth have behaviour of linear increase.

It is possible to say that soils having high carbon content retain higher nickel concentrations in soil media than the soils with lower carbon content. Data over the graph was found highly scattered.

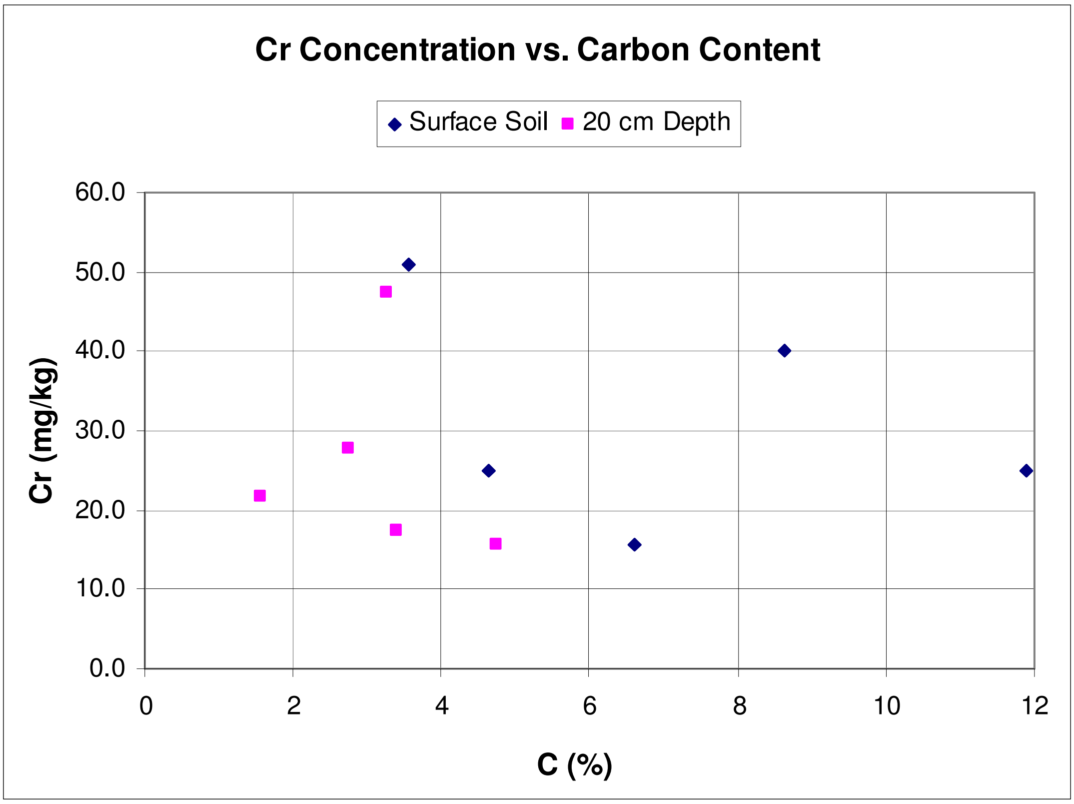

Figure 5.52. Cr Concentration vs. Carbon Content for Soils of O – 1 Highway

In Figure 5.52. distribution of carbon content against chromium concentrations for soil samples of O – 1 Highway from surface and 20 cm depth is plotted. There is an increase in metal concentrations as carbon content rises. However chromium concentrations were found highly scattered over the graph area and relationship is not very clear.

Soils with higher carbon content tend to retain more chromium in their structure than the soils having lower percentages of carbon; on the other hand, further investigation may be needed for more clear decision.

Carbon is the main part of the complex organic material that may be present in numerous different molecular structures. Retaining of heavy metals in soils mainly depends on the adsorption mechanisms to soil grains and complexation reactions with organic substances. For this reason, carbon content determination for soil is important and it was determined for the samples collected from O – 1 Highway, which was found as the most polluted highway among others.

There is a positive correlation expected between the carbon content and heavy metal concentrations since carbon percentage is likely to increase with increased organic content. The relationship between total carbon and organic carbon needs not to be perfectly accurate; however, there is a certain connection between these parameters.

Increased carbon content leads higher heavy metal concentrations in polluted soils as mentioned in the theoretical background part of the report, and the graphs of carbon percentage versus heavy metal concentrations goes parallel with pre-work. There is a strong proportion between these parameters, especially true for the heavy metals of lead, zinc, copper and cadmium. For nickel and chromium, however, the correlation is not very clear, but, clues for such a connection still exist. If more samples would be analyzed for carbon determination, it would be possible to see whether the link between carbon content and heavy metal concentrations is stronger or not for the nickel and chromium.

5.3.5. Nitrogen Content and Metal Concentrations

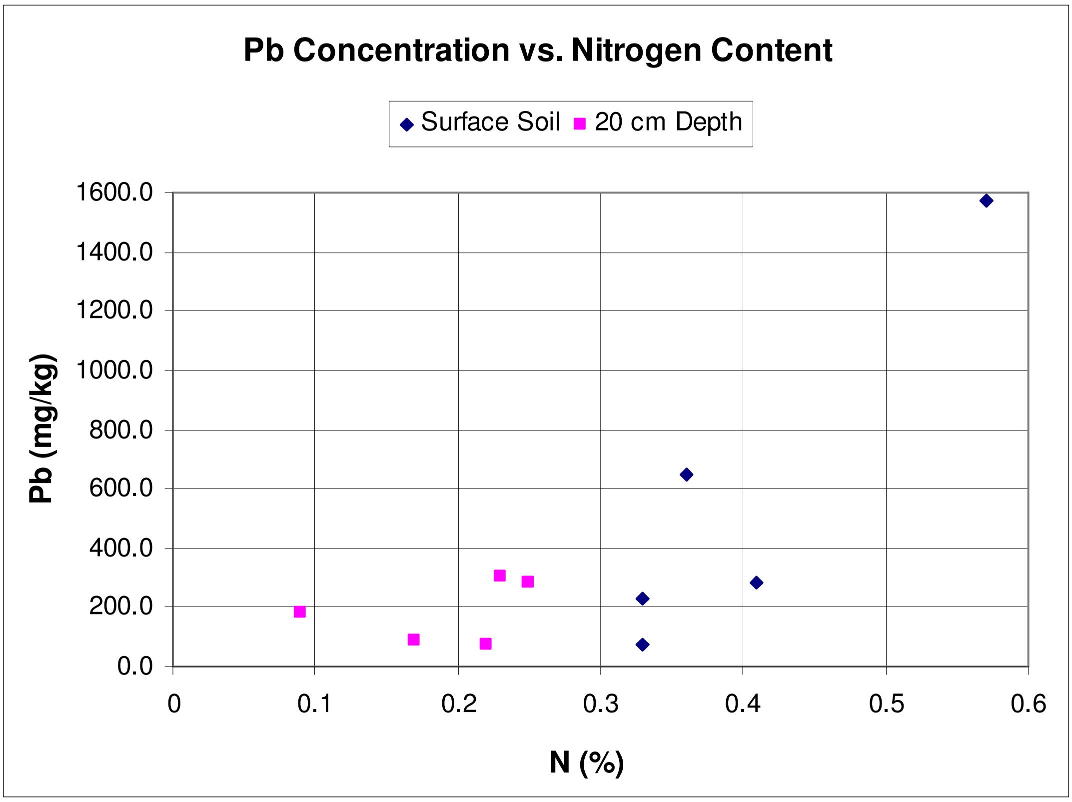

Figure 5.53. Pb Concentration vs. Nitrogen Content for Soils of O – 1 Highway

In Figure 5.53 the plot of nitrogen content versus lead concentrations distribution for surface and 20 cm deep soils of O – 1 Highway is shown. A clear increase in metal concentrations was obtained as nitrogen content rises as shown in the graph. Data are moderately scattered over the graph.

It is evident that soils with higher nitrogen content retain more lead than the soil media with smaller nitrogen percentage as shown in the graph.

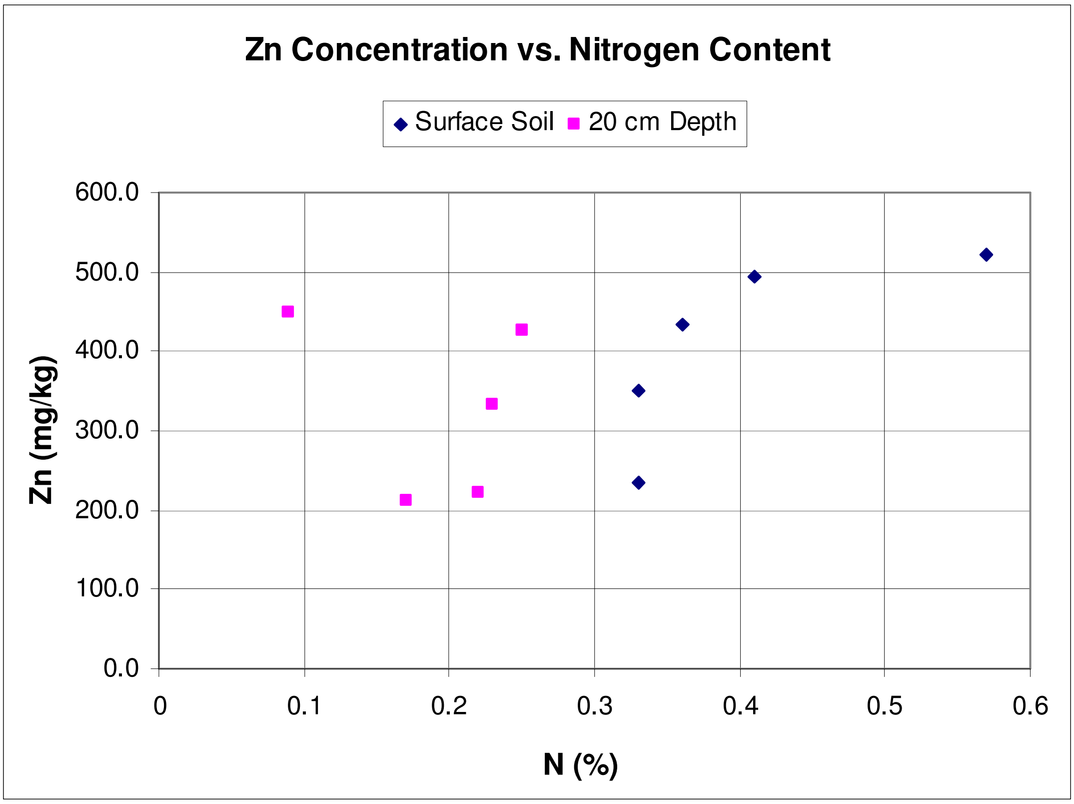

Figure 5.54. Zn Concentration vs. Nitrogen Content for Soils of O – 1 Highway

In Figure 5.54. distribution of nitrogen content versus zinc concentrations for surface and 20 cm deep soils of O – 1 Highway is given. A clear behaviour of increase in metal concentrations as rise with nitrogen content was shown, where scattered data in some locations were obtained on the plot.

The graph shows soil media with high nitrogen content retain larger concentrations of zinc in their structure than the soils having lower nitrogen percentage. The proportion between nitrogen percentage and zinc concentration is clear.

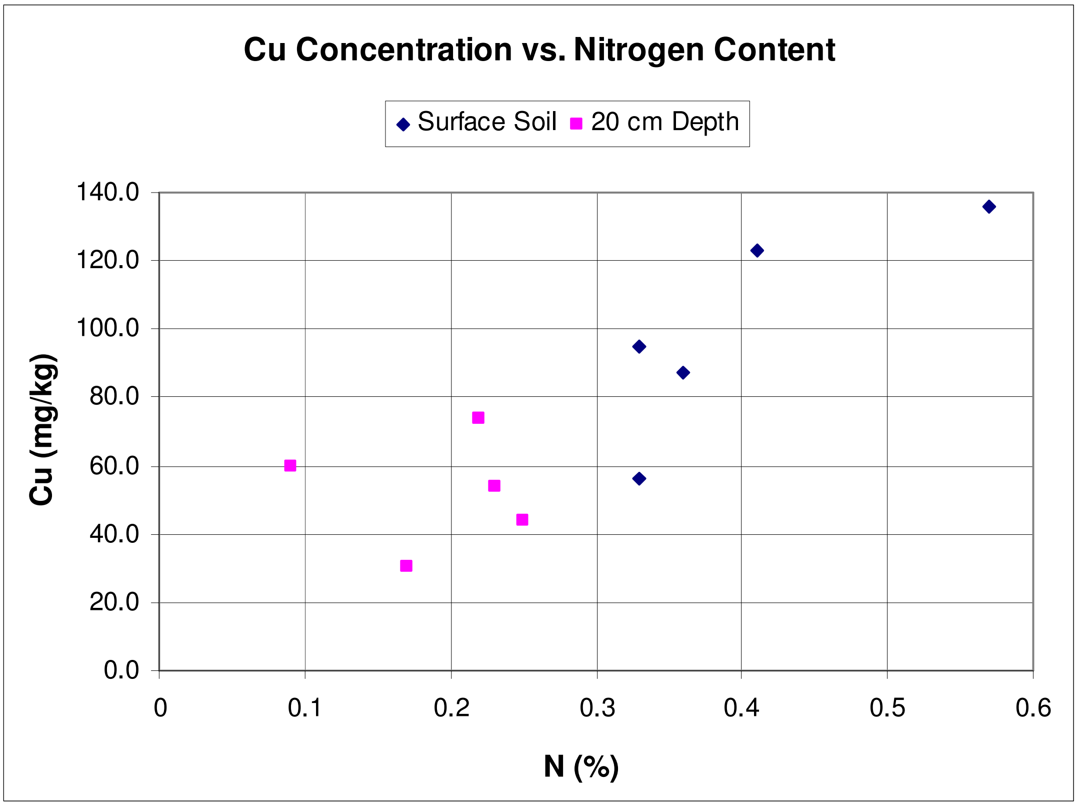

Figure 5.55. Cu Concentration vs. Nitrogen Content for Soils of O – 1 Highway

Figure 5.55. represents the graph of plot for distribution of nitrogen content versus copper concentrations for surface and 20 cm deep soil samples from O – 1 Highway. An increase close to linearity in metal concentrations together with nitrogen content rise of soil media was obtained. The data points are scattered to some extent over the plot area.

The graph shows that soil samples with high nitrogen content are able retain higher copper concentrations than the soils having lower nitrogen percentages. The relationship is shown very clearly especially for experimental results of surface soils, and linear behaviour between the parameters exists for the graph range.

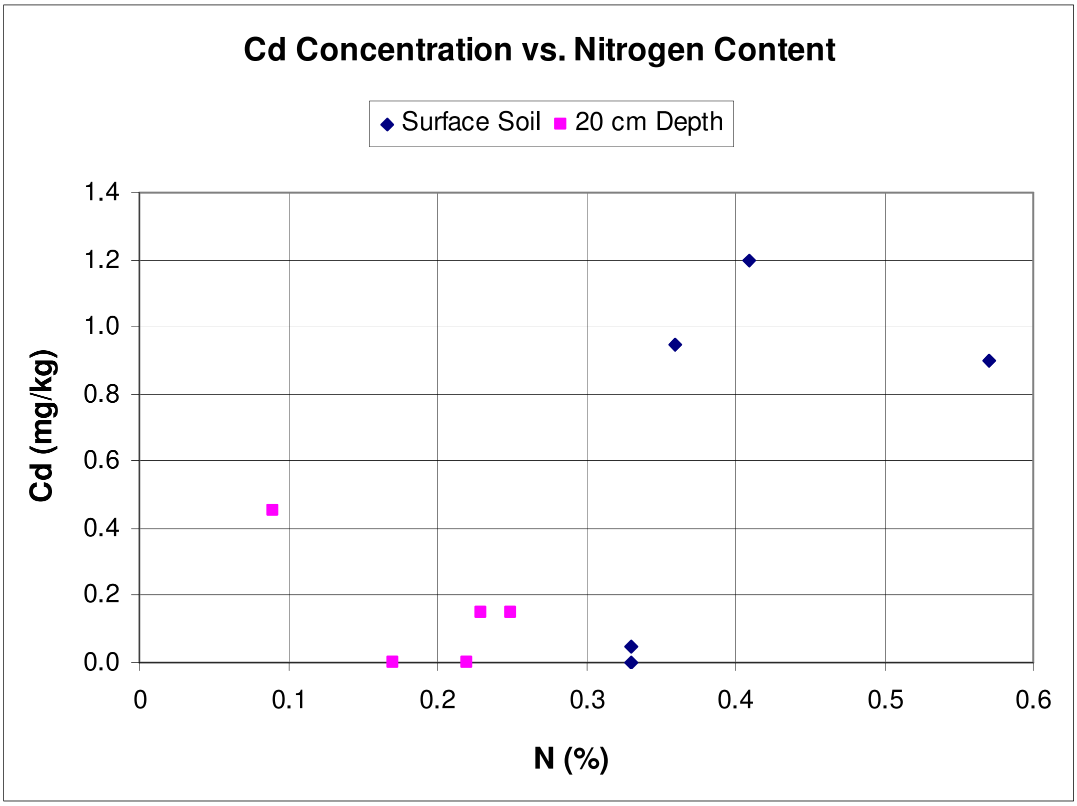

Figure 5.56. Cd Concentration vs. Nitrogen Content for Soils of O – 1 Highway

The graph in Figure 5.56. shows the distribution of nitrogen content against cadmium concentrations of samples from surface and 20 cm deep soils of O – 1 Highway. A non-linear rise in metal concentrations with increase of nitrogen content of soil media is obtained, however some points were found scattered over the plot area.

It is possible to comment that soils having high nitrogen content retain more cadmium in soil structure than the soils with lower percentages of nitrogen, although there are some points with zero concentration and some values are scattered.

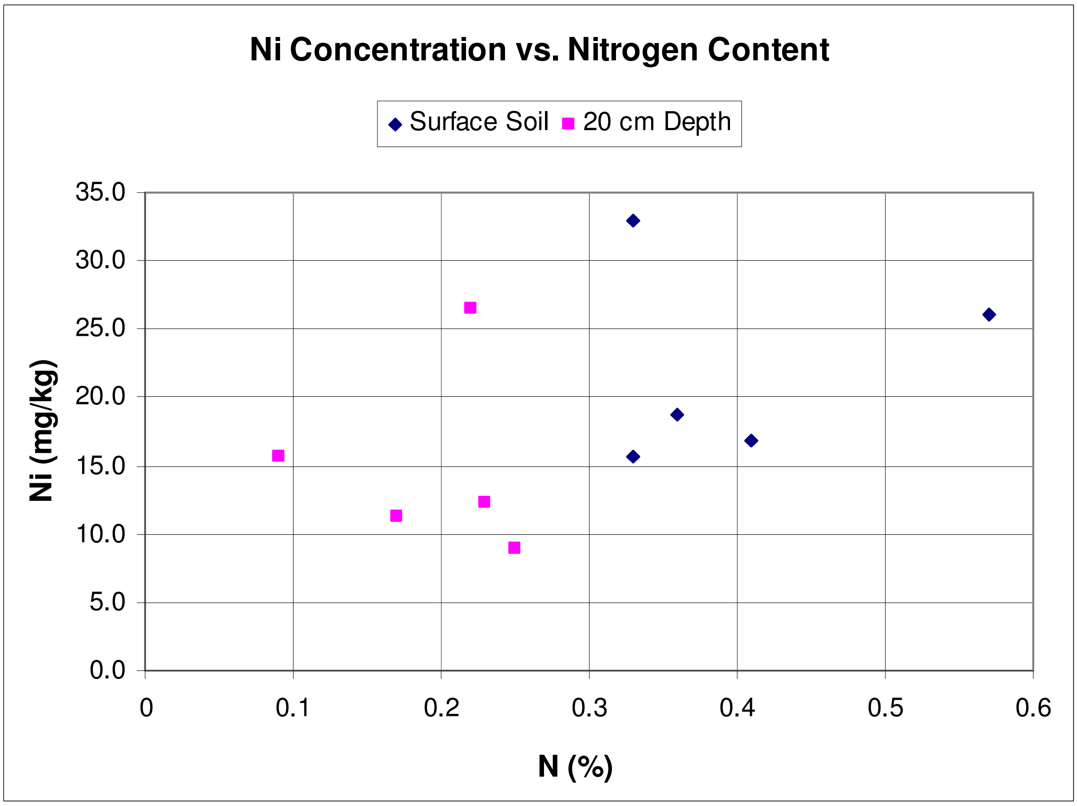

Figure 5.57. Ni Concentration vs. Nitrogen Content for Soils of O – 1 Highway

The distribution of nitrogen content against nickel concentrations for surface and 20 cm deep soil samples of O – 1 Highway is given in Figure 5.57. Rise in nickel concentrations was obtained as nitrogen content of soil increases. The nickel concentrations are moderately scattered over the graph.

From the graph, it is possible to say that soils having high nitrogen content retain higher nickel concentrations in soil media than the soils with lower nitrogen content although data plot over the graph was found scattered to some extent.

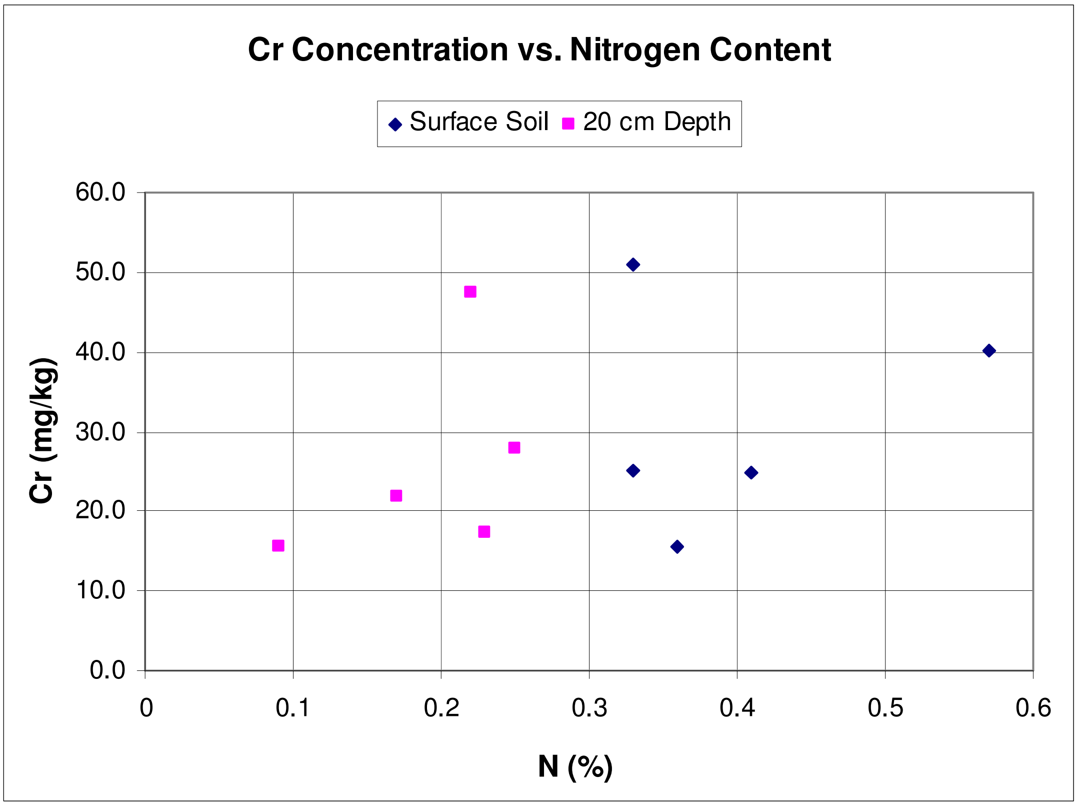

Figure 5.58. Cr Concentration vs. Nitrogen Content for Soils of O – 1 Highway

In Figure 5.58. distribution of nitrogen content against chromium concentrations for soil samples of O – 1 Highway from surface and 20 cm depth is given. There is an increase in metal concentrations as nitrogen percentage of soil rises. Chromium concentrations were found highly scattered over the graph area.

Soils with higher nitrogen content tend to retain more chromium in their structure than the soils having lower percentages of nitrogen. Although data points are scattered, the relationship can be seen separately for both surface soil and 20 cm deep soil samples.

Nitrogen is a major part of many complex organic compounds. Although an organic molecule does not always necessarily contain nitrogen, it is mostly present in a wide variety of organic molecules, adding key properties to the substance. Since heavy metals retention in soils largely depends on the complexation reactions with organic substances, the determination of nitrogen content for soil is important for understanding the characteristics of pollution. For this reason, surface and 20 cm deep soil samples collected from O – 1 Highway were analyzed to determine the nitrogen percentage of the soil media.

Nitrogen percentage is likely to increase with increased organic content. Hence, there is an expected positive relationship between the nitrogen content and heavy metal concentrations retained in the soils. The relationship between total nitrogen and organic nitrogen may not be perfect since considerable amounts of inorganic nitrogen may be present in a soil media. However, high total nitrogen percentage in a soil media refers to high organic nitrogen content most of the time.

As shown from the detailed plots above, a relationship exists between nitrogen content and retained metal concentrations. This fact holds true especially for the heavy metals of lead, zinc and copper. For nickel, cadmium and chromium, the correlation is not much clear as for the lead, zinc and copper, but it still exists. If more samples were analyzed for nitrogen determination, a more solid proof would be obtained.

5.4. Evaluation of Results by GIS

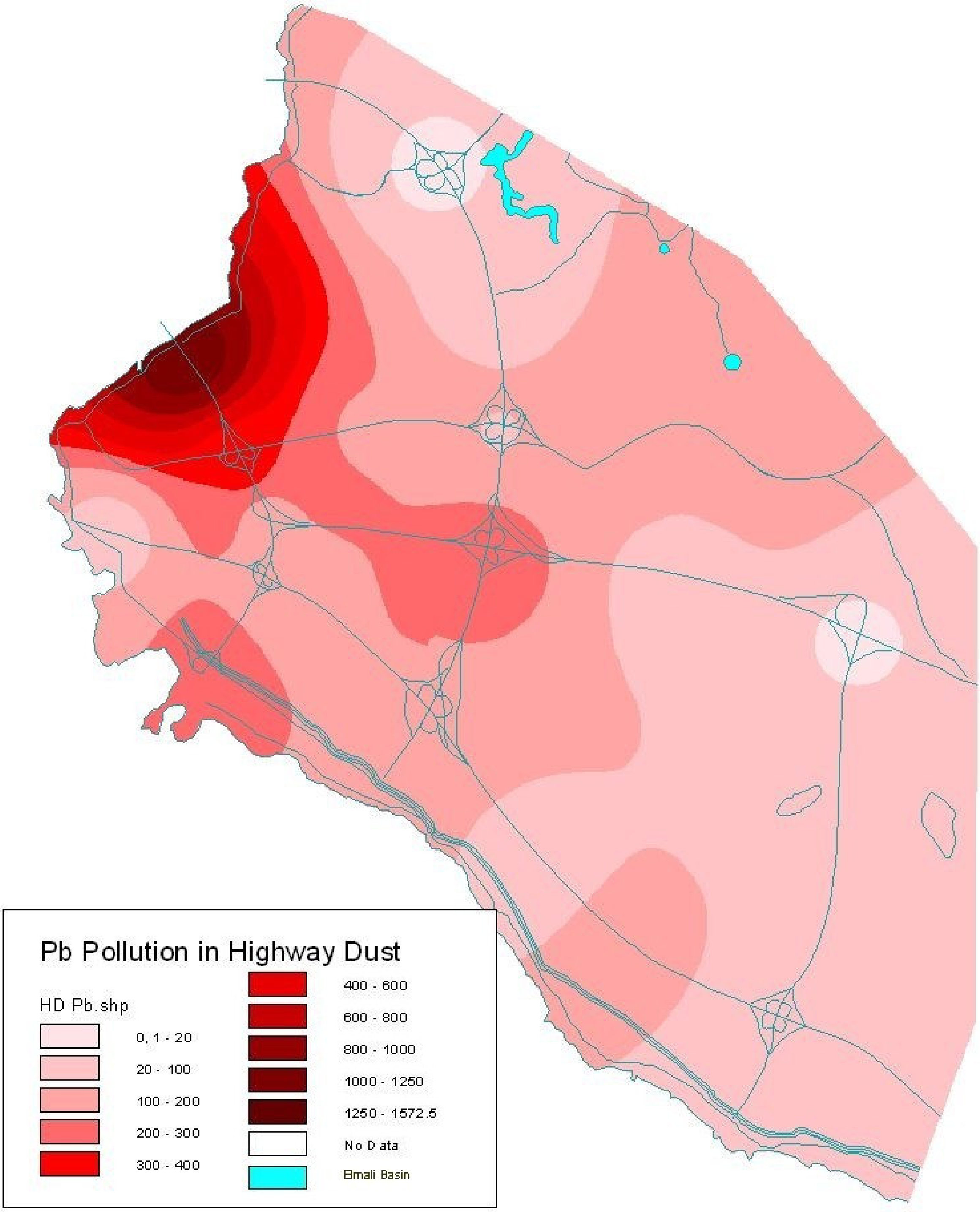

Figure 5.59. Spatial Distribution of Pb Pollution in Highway Dust

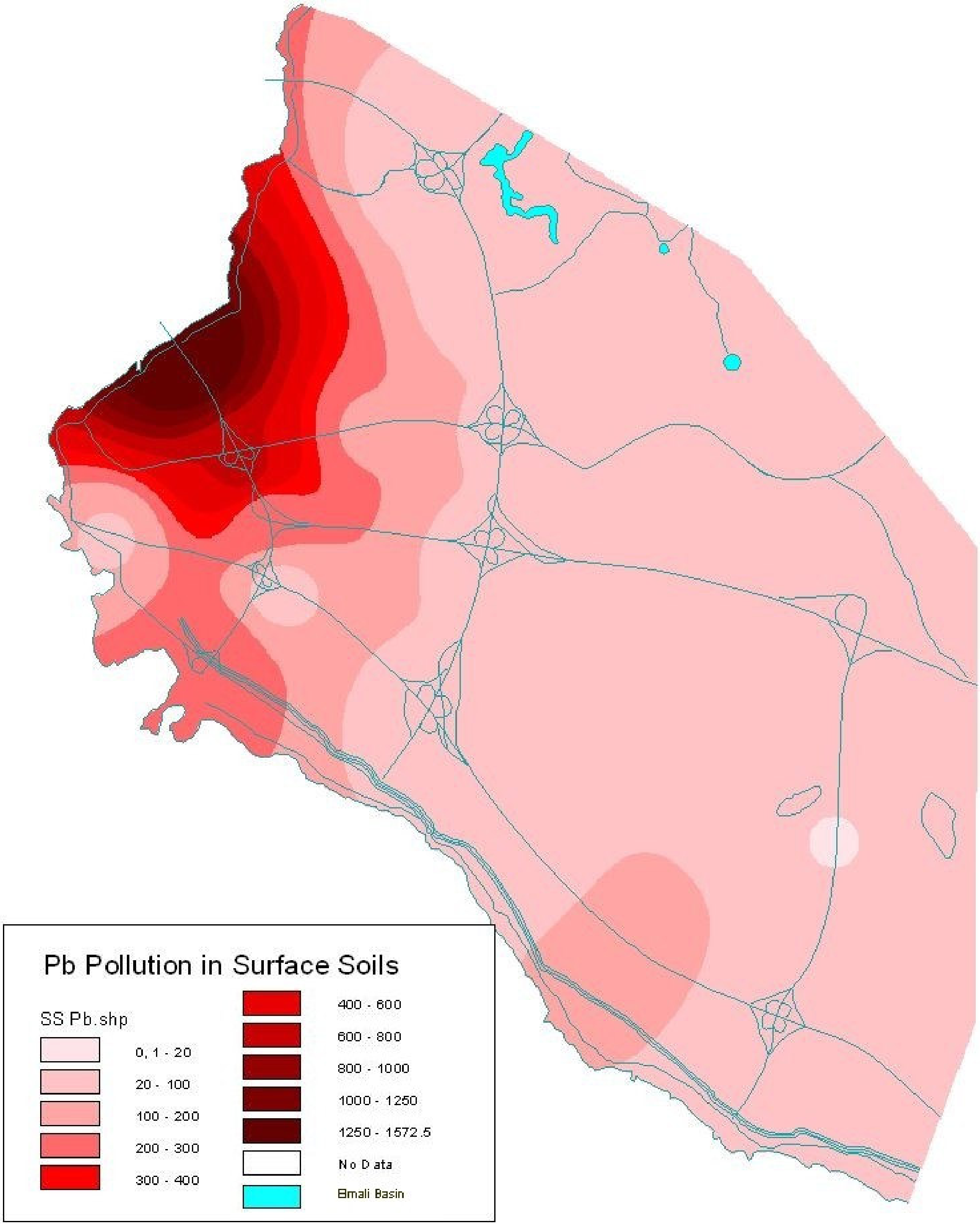

Figure 5.60. Spatial Distribution of Pb Pollution in Surface Soils

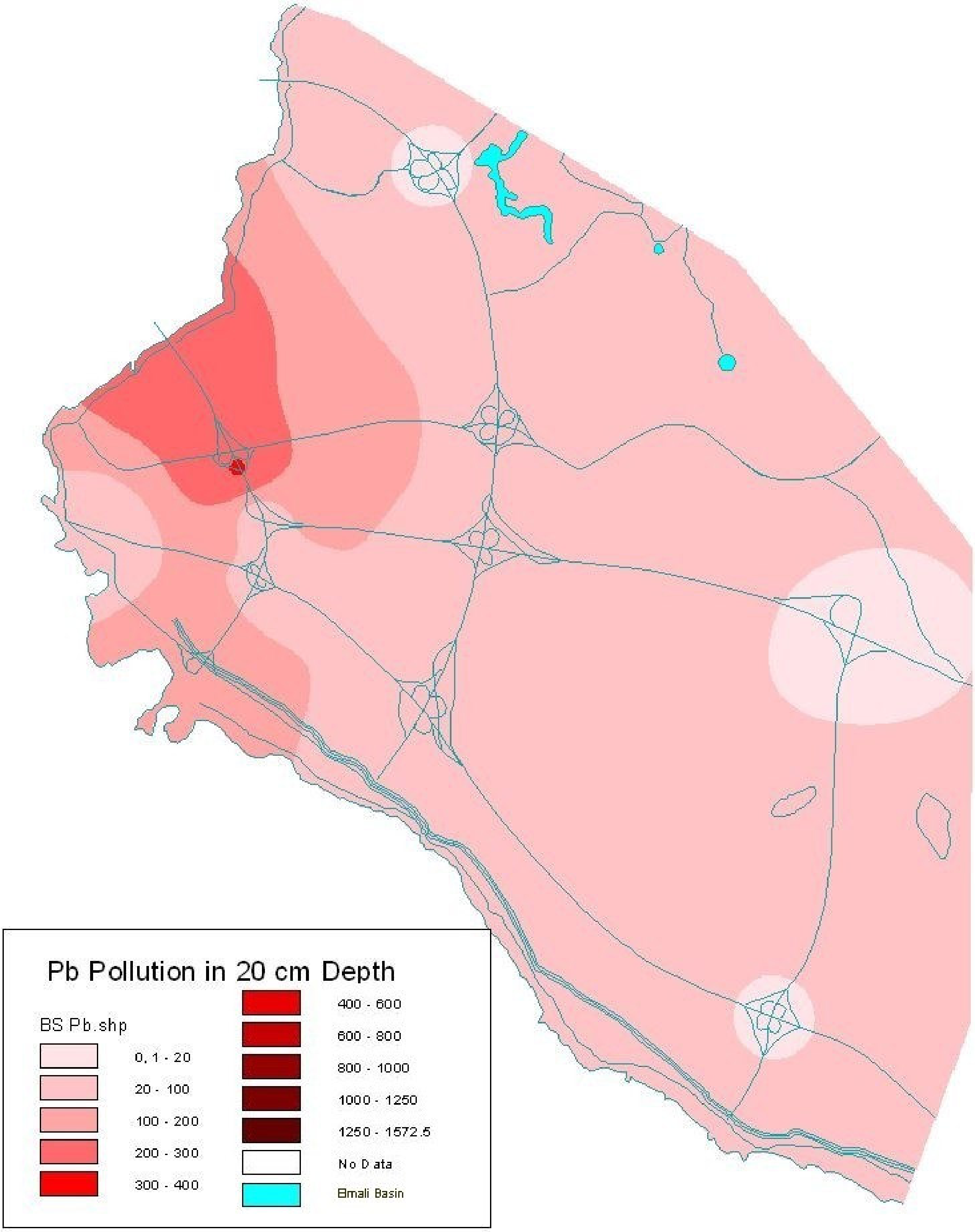

Figure 5.61. Spatial Distribution of Pb Pollution in 20 cm Depth

As shown from Figure 5.59, Pb concentration distribution over the area for highway dusts indicates very critical pollution levels. Over the entire study area, dust samples from only two small regions had lead levels within the common range (0.1 – 20 mg/kg). Highway dusts in more than half of the total study field had lead contamination over the acceptable limits of EU (100 mg/kg for soils with pH>7). Dusts from O – 1 Highway were found mostly polluted by lead, where all of the areas around the arterial were found containing concentrations larger than the EU maximum allowable values.

The severity of lead pollution is represented in Figure 5.60 and it was higher for surface soils. All of the study area except a very small spot in Yakacık region was found containing lead concentrations in their topsoil above the common range for soils, which is a sign of serious spatial pollution. Lead contamination in soil surface was concentrated around the O – 1 Highway and neighbour arterials, where results more than 16 times of EU limitations were obtained. The regions around O – 2 Highway and D – 100 Highway were also found under threat since contamination levels may become more critical in future.

Figure 5.61 shows that lead pollution in highway dusts and surface soils has also penetrated to deeper layers of soil. Studies for 20 cm deep soils collected from the study area shown that only a small extent of overall region had typical common lead concentrations, while background soils in a very large portion of the map was contaminated with lead. Some locations around the O – 1 Highway and D – 020 Connection were determined having excess contamination values with respect to the EU regulations where concentrations over four times of limits were available. Moreover, pollution around Elmalı water basin reached critical levels in some locations for highway dust, and exceeded common range for surface and background soils.

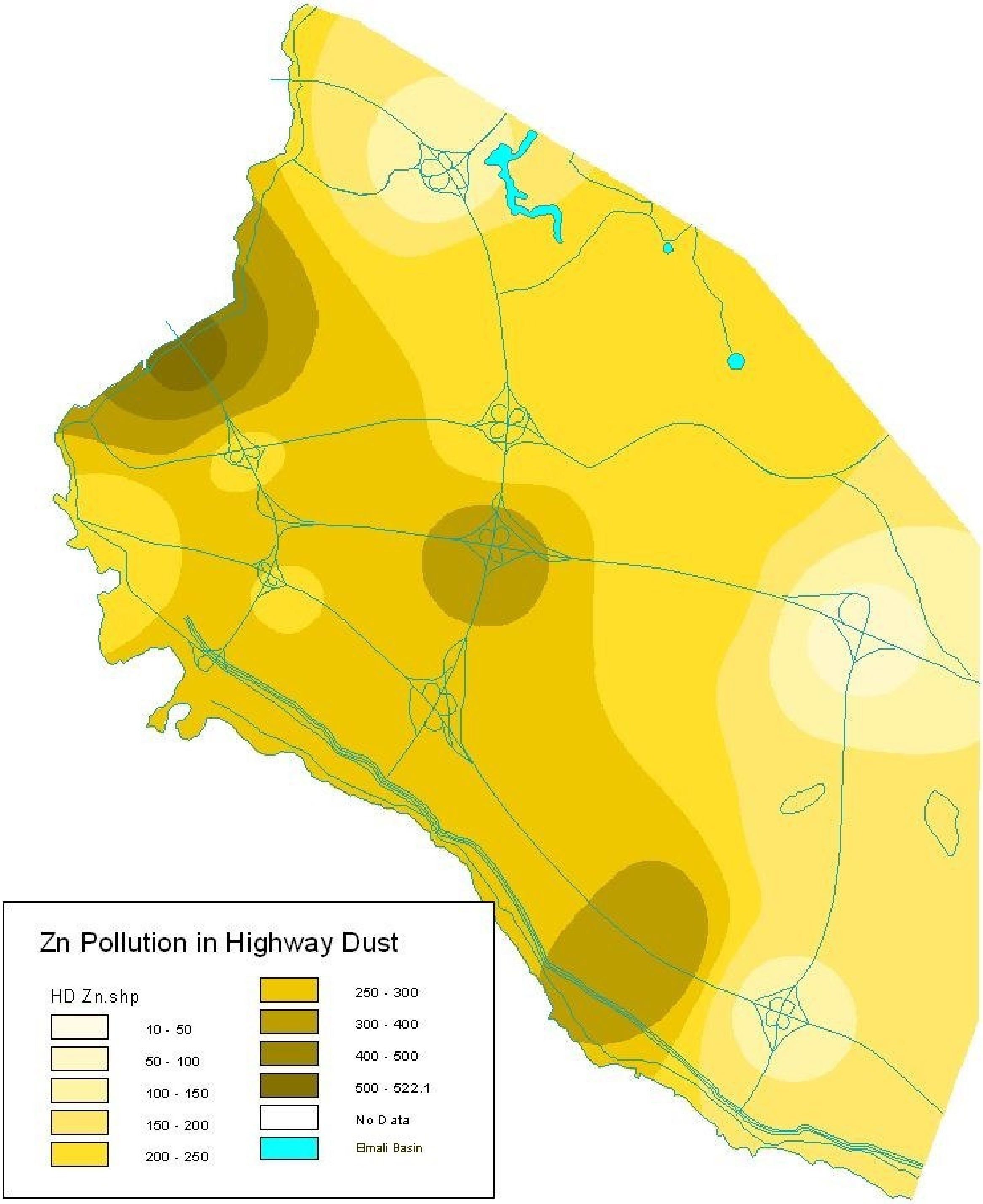

Figure 5.62. Spatial Distribution of Zn Pollution in Highway Dust

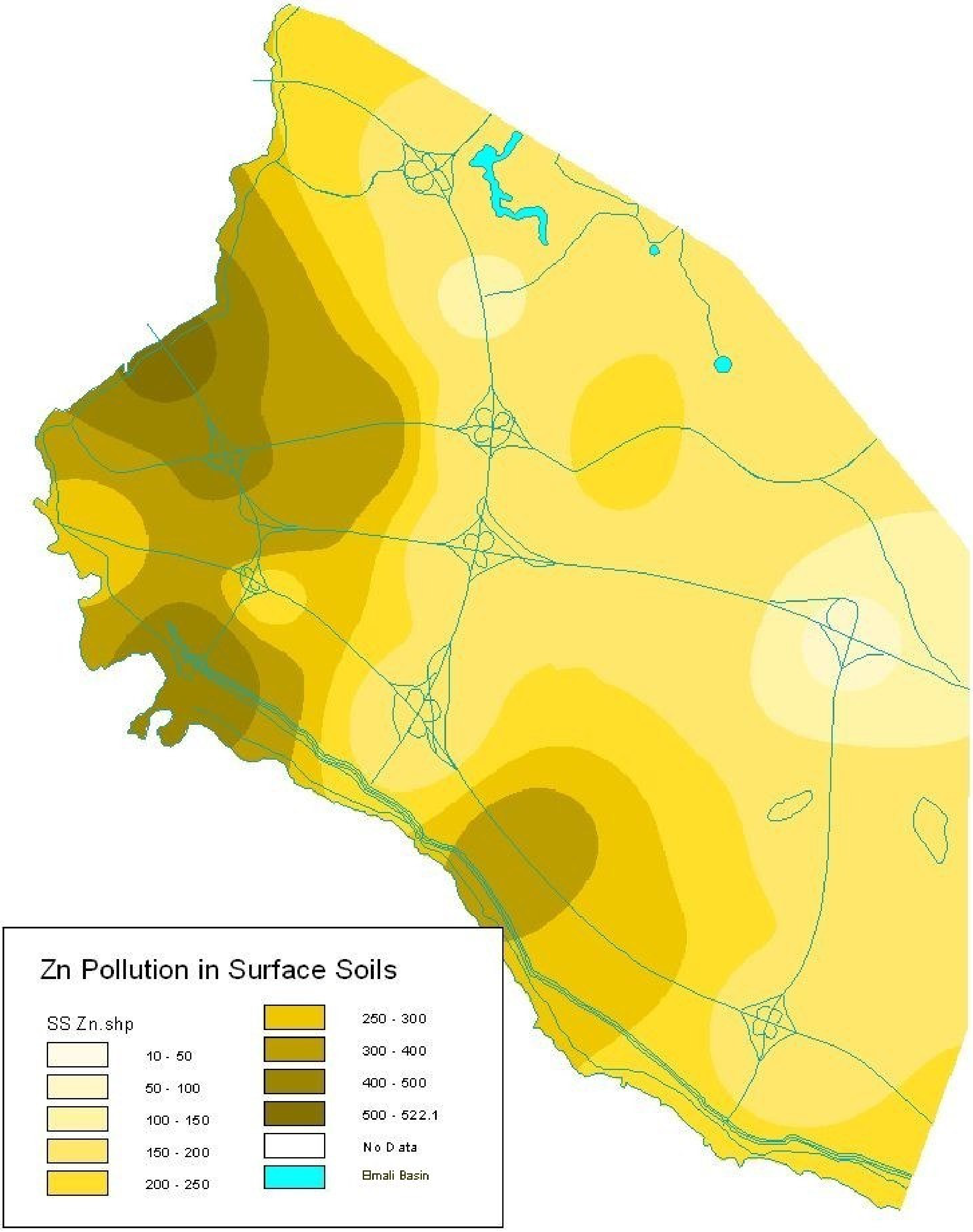

Figure 5.63. Spatial Distribution of Zn Pollution in Surface Soils

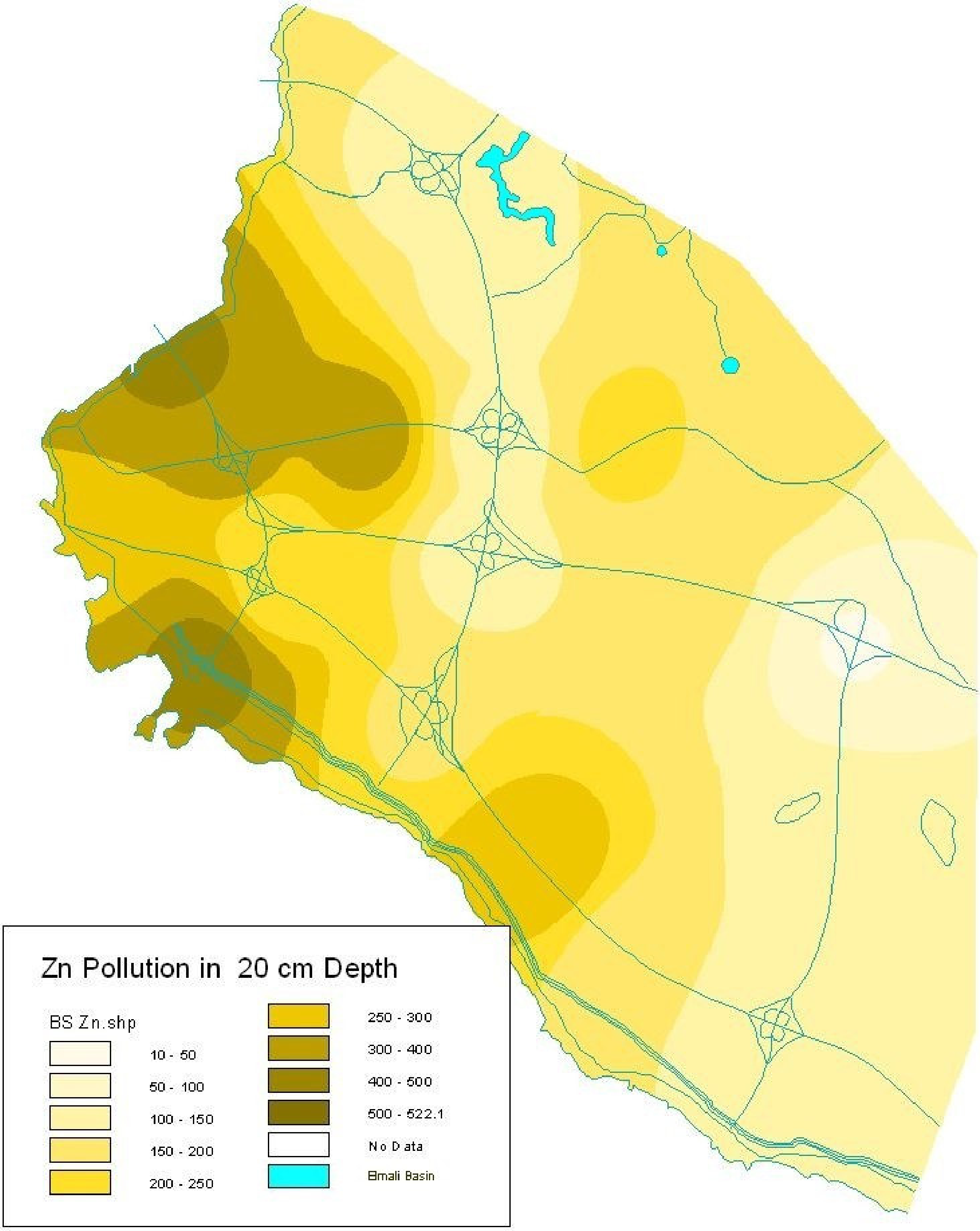

Figure 5.64. Spatial Distribution of Zn Pollution in 20 cm Depth

Figure 5.62. represents zinc concentration distribution for highway dusts over the study area. The map shows critical pollution levels. Zinc pollution in dust was within the common range (10 – 50 mg/kg) for only one small area on O – 4 Highway. Highway dusts in nearly the 80% of study field were found having zinc contamination over the acceptable maximum concentrations determined by EU (200 mg/kg for soils with pH>7). Dusts of O – 1, O – 4 and D – 100 Highway was found mostly polluted. D – 020 Connection and O – 2 Highway also had wide areas around them with zinc concentrations exceeding the EU maximum allowable values.

Surface soils of O – 1 Highway, D – 020 Connection and D – 100 Highway and surrounding areas were also critically polluted by zinc as shown in Figure 5.63. Common range was exceeded in nearly entire map area. Moreover, more than half of the entire study field was found containing zinc concentrations in surface soil above the EU maximum limitations. Zinc contamination in soil surface had its maximum values around the O – 1 Highway and neighbour areas, where values exceeding EU regulations two times were shown. D – 020 connection and D – 100 Highway also had areas where contamination levels were critical.

Figure 5.64 indicates zinc pollution in highway dusts and surface soils penetrated to deeper soil layers. Distributed experimental results for 20 cm deep soils shown that only a small portion of the map had zinc concentrations in common range. 20 cm deep soils from many locations on the O – 1 Highway, D – 020 Connection and D – 100 Highway were contaminated with zinc. Also excess pollution was detected in neighbour areas, where maximum values were found around the O – 1 Highway. Furthermore, zinc pollution around Elmalı water basin has been shown exceeding EU regulations in some areas for highway dust. The pollution levels exceeded common range for surface and background soils, which is a sign of contamination.

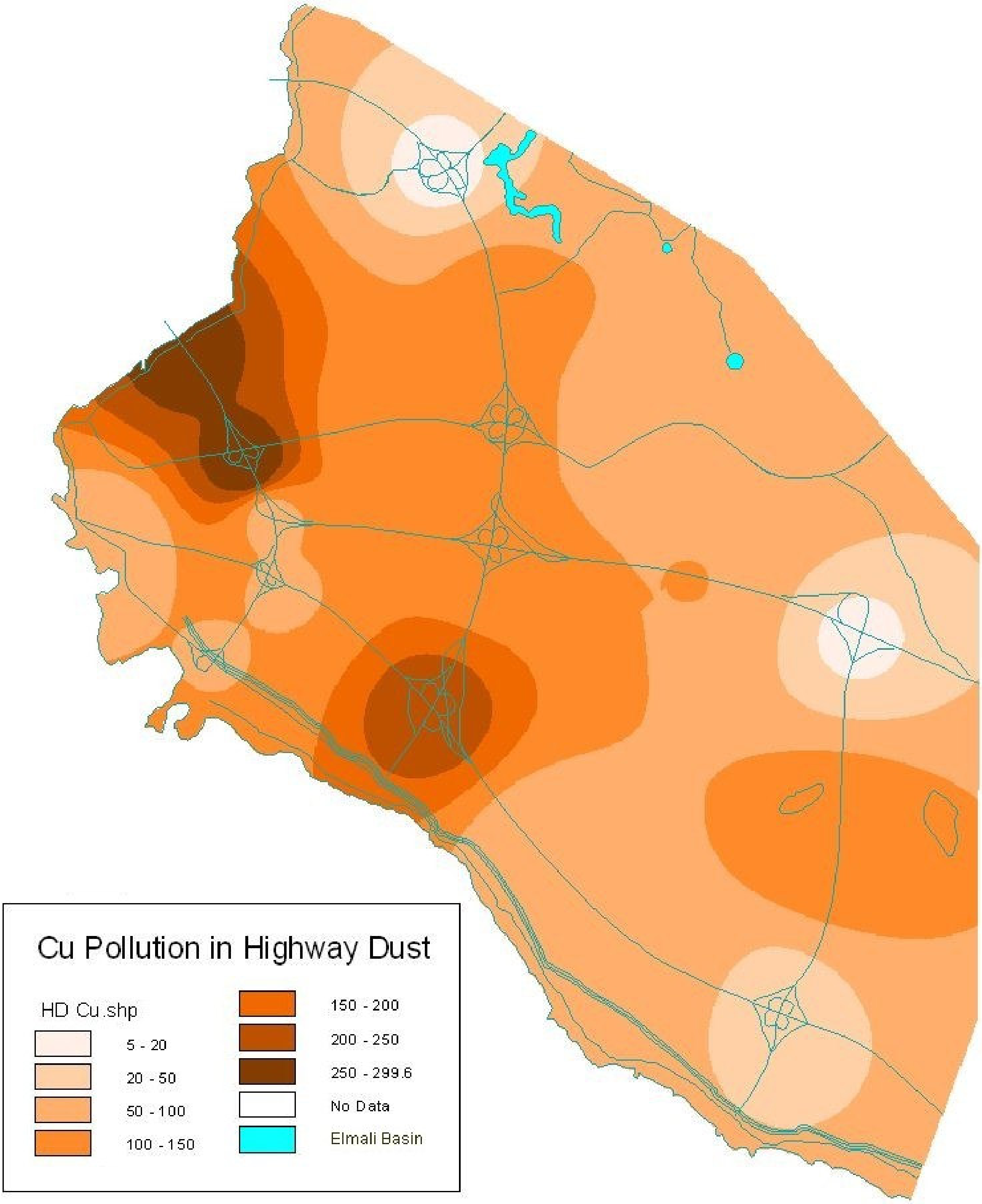

Figure 5.65. Spatial Distribution of Cu Pollution in Highway Dust

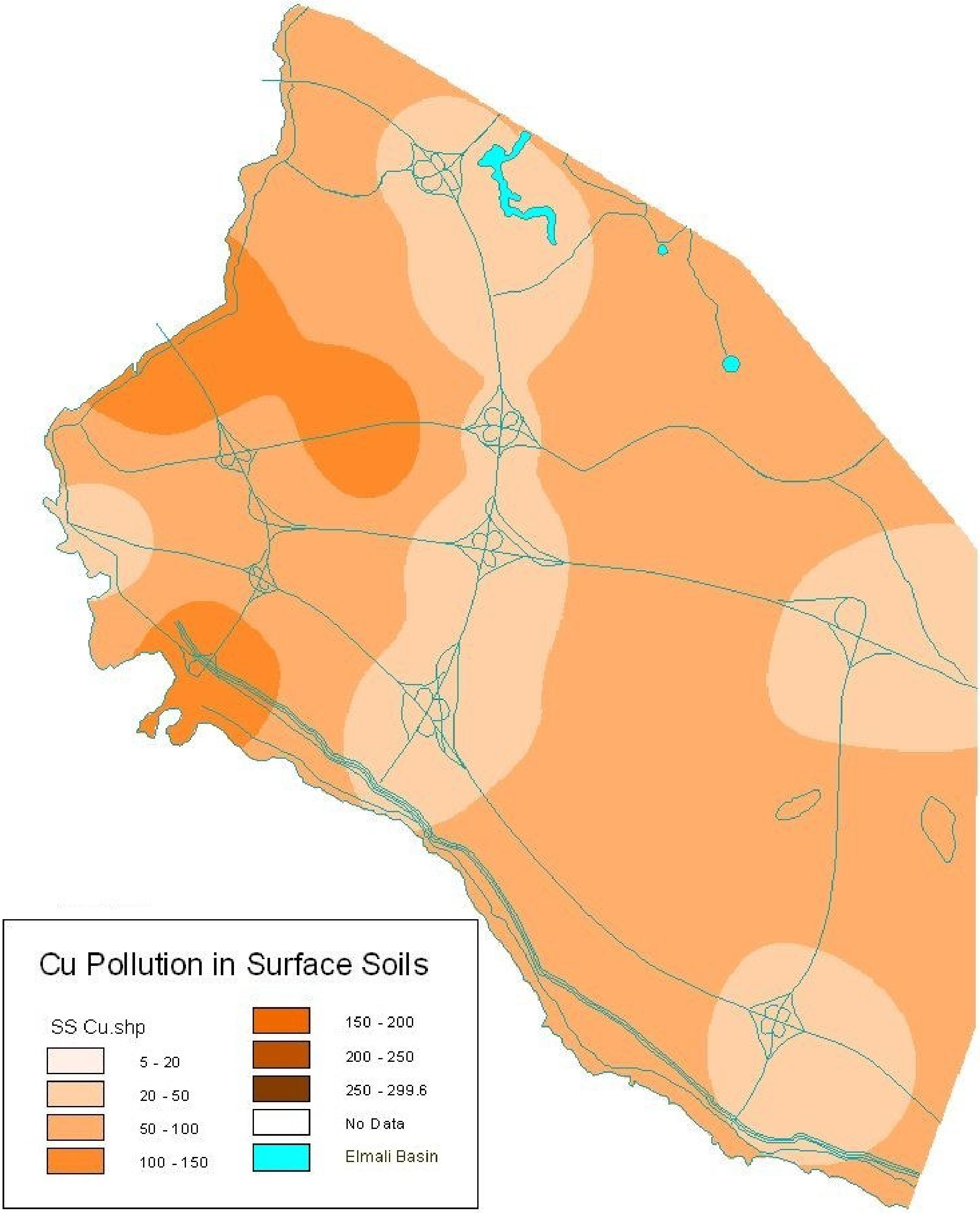

Figure 5.66. Spatial Distribution of Cu Pollution in Surface Soils

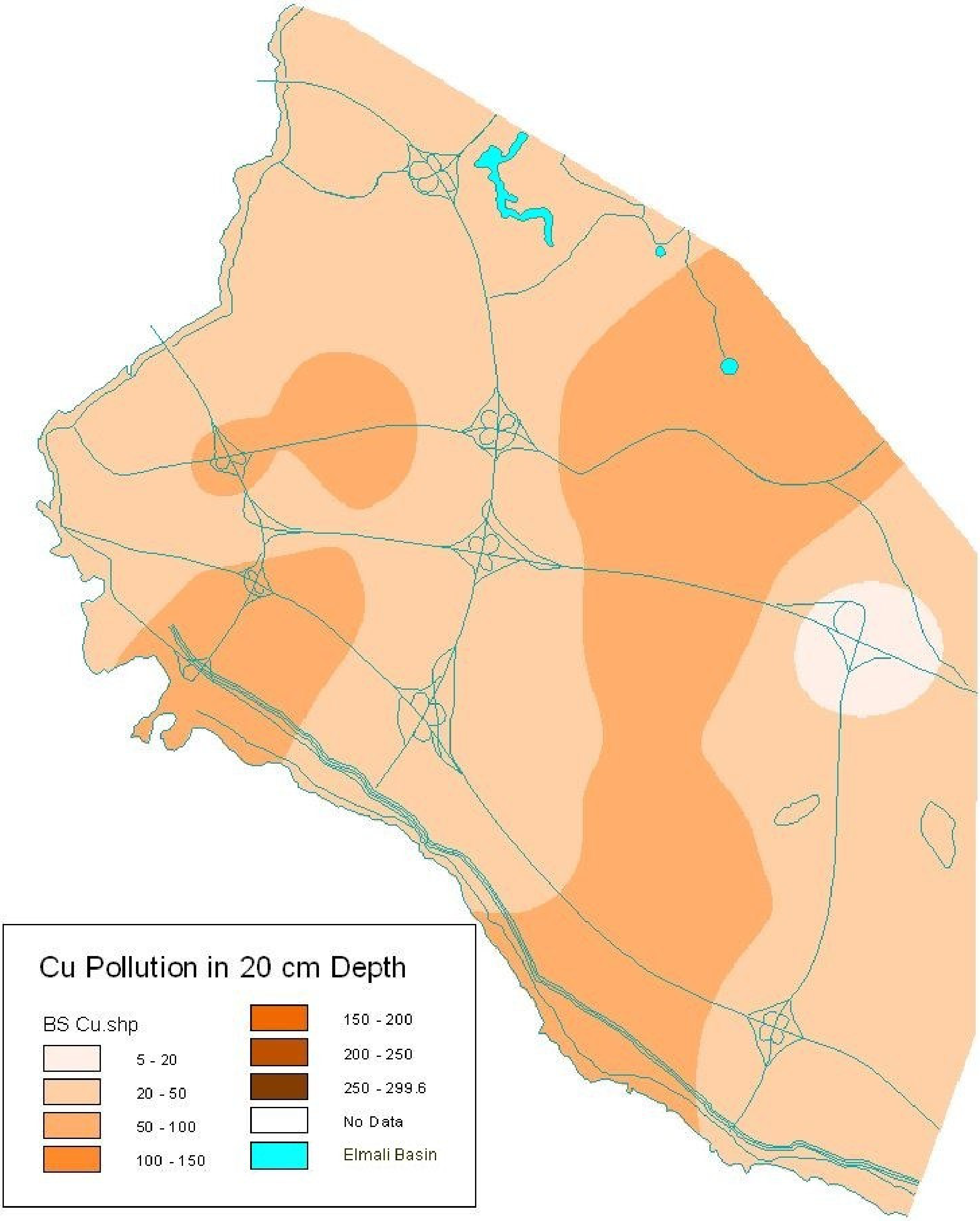

Figure 5.67. Spatial Distribution of Cu Pollution in 20 cm Depth

As shown from the figure 5.65, copper concentration distribution for highway dusts over the study area indicates critical pollution levels in many areas. Copper pollution in street dusts was found within the common range (5 – 20 mg/kg) for only two small spots on O – 1 and O – 4 Highway. The contamination in highway dust was found exceeding maximum concentrations in EU regulations in more than half of study field (100 mg/kg for soils with pH>7). Dusts of O – 1, O – 2 and O – 4 Highway were found highly polluted. All other arterials also had critically contaminated areas around them with copper concentrations exceeding the EU maximum allowable limits.

Surface soils of O – 1 Highway were found critically polluted by copper in some locations as shown in Figure 5.66. Surprisingly, copper concentrations exceeded common range (5 – 20 mg/kg) in entire study field. Maximum values of copper contamination in soil surface were obtained around the O – 1 Highway and neighbour areas, fortunately they were the only areas where contamination levels were critical and exceeding EU maximum concentrations. Copper contamination in surface soils certainly exists, but values are mostly in acceptable ranges.

Copper pollution in highway dusts and surface soils did not penetrate much to deeper soil layers. As shown from Figure 5.67; although only a small portion of the study field had copper concentrations in common range for the 20 cm deep soils, no critical levels of pollution was encountered in any area. The site is absolutely polluted by copper; however penetration to the deeper soil layers is low. Also copper pollution around the Elmalı water basin exceeded EU limits in some areas for highway dust and levels of pollution was above common range for surface and background soils, which proves the existence of contamination.

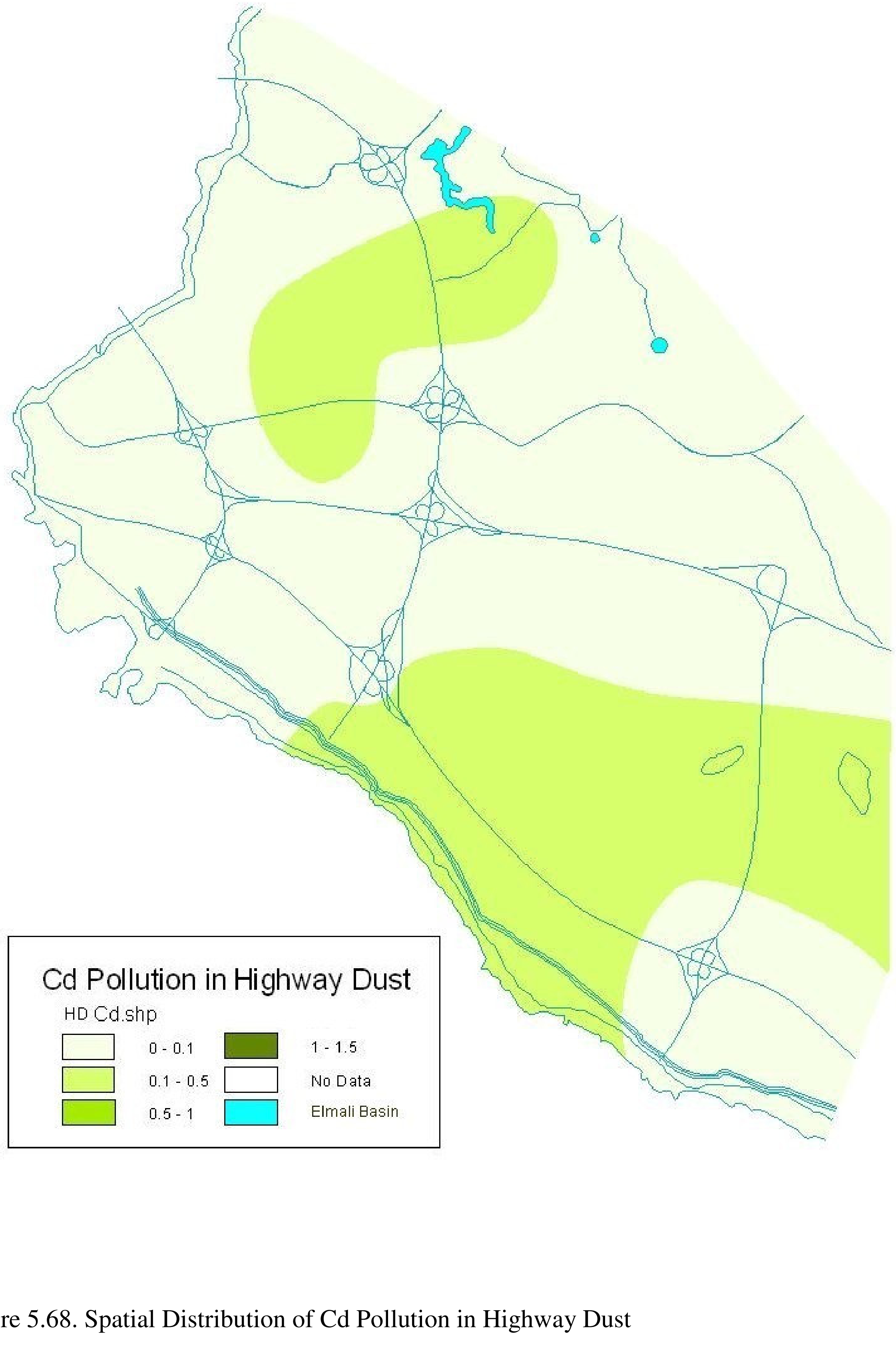

Figure 5.68. Spatial Distribution of Cd Pollution in Highway Dust

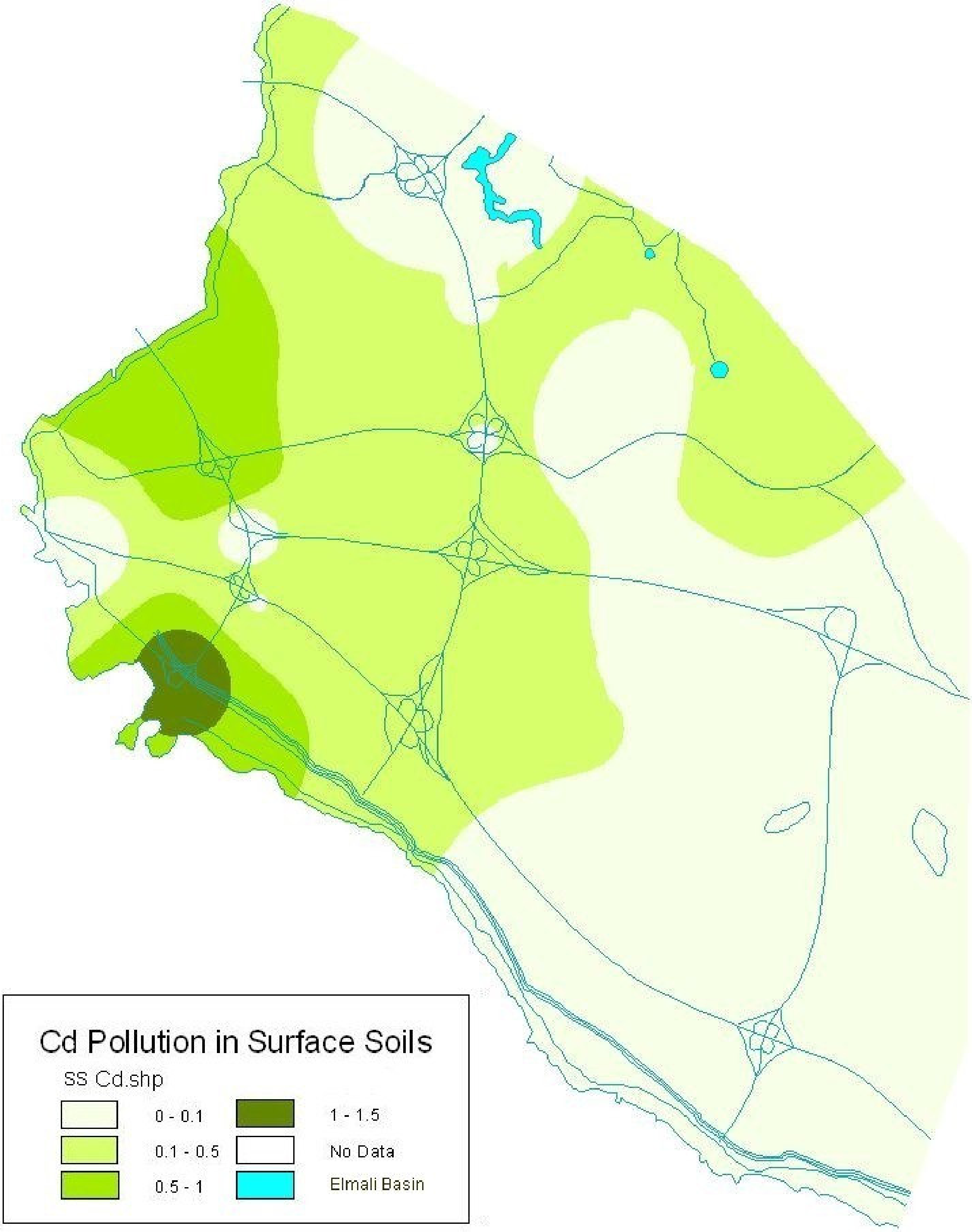

Figure 5.69. Spatial Distribution of Cd Pollution in Surface Soils

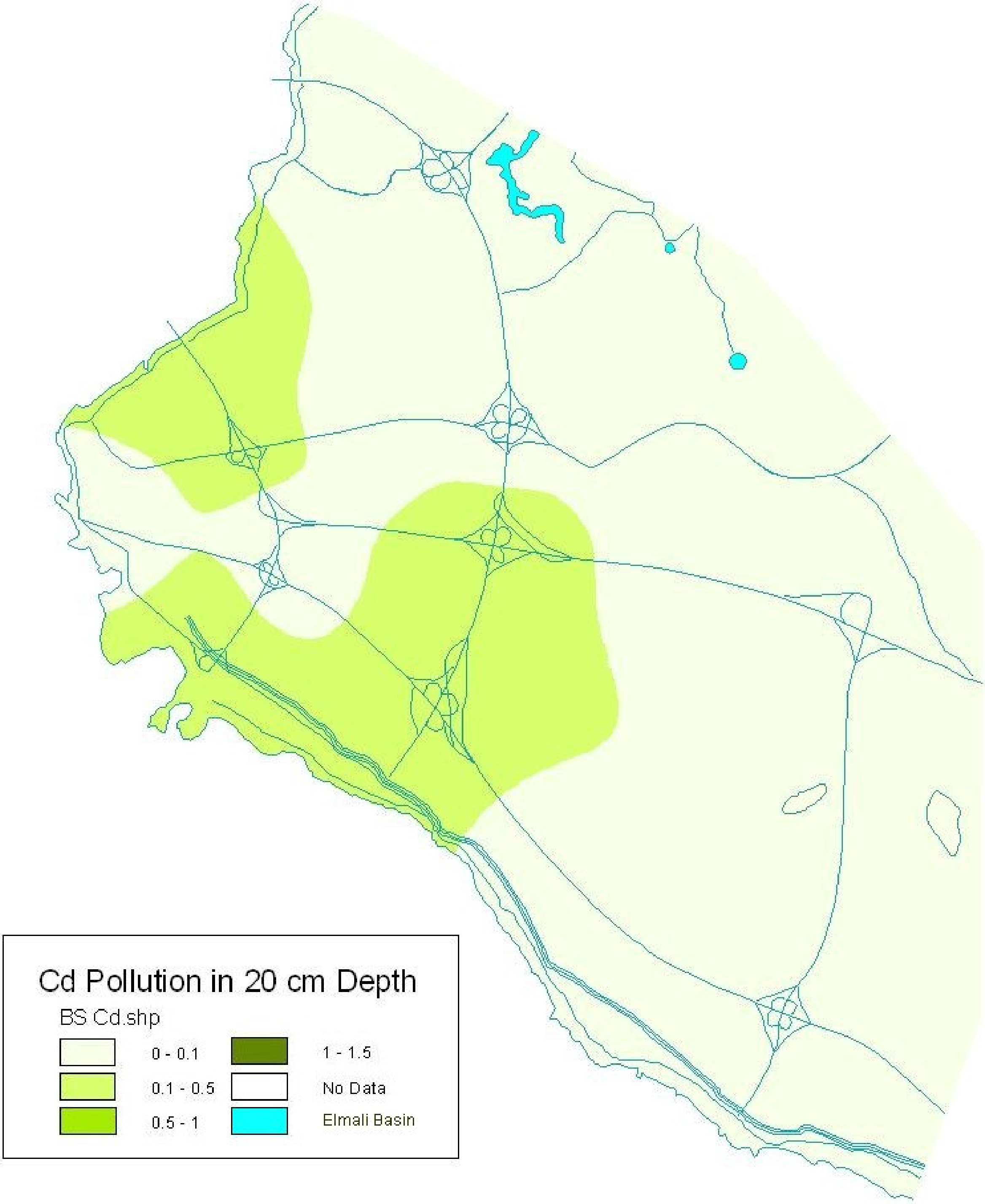

Figure 5.70. Spatial Distribution of Cd Pollution in 20 cm Depth

As shown from the Figure 5.68, concentrations of cadmium in highway dusts did not exceed common range for soils (0.1 – 1 mg/kg). The entire study area has ordinary values of cadmium concentrations and no pollution was determined in any locations for the highway dusts.

In Figure 5.69, area distribution of cadmium pollution for surface soils is given. As shown from the figure, there is a small area where the common range for cadmium (0.1 – 1 mg/kg) was exceeded. However, the maximum cadmium concentration in the study area was in compliance with the EU maximum allowable limits (1.5 mg/kg for soils with pH>7). Also no critical pollution of cadmium was observed for the 20 cm deep soils, which is represented in Figure 5.70.

Cadmium pollution was not observed over the study area for highway dusts and soils.

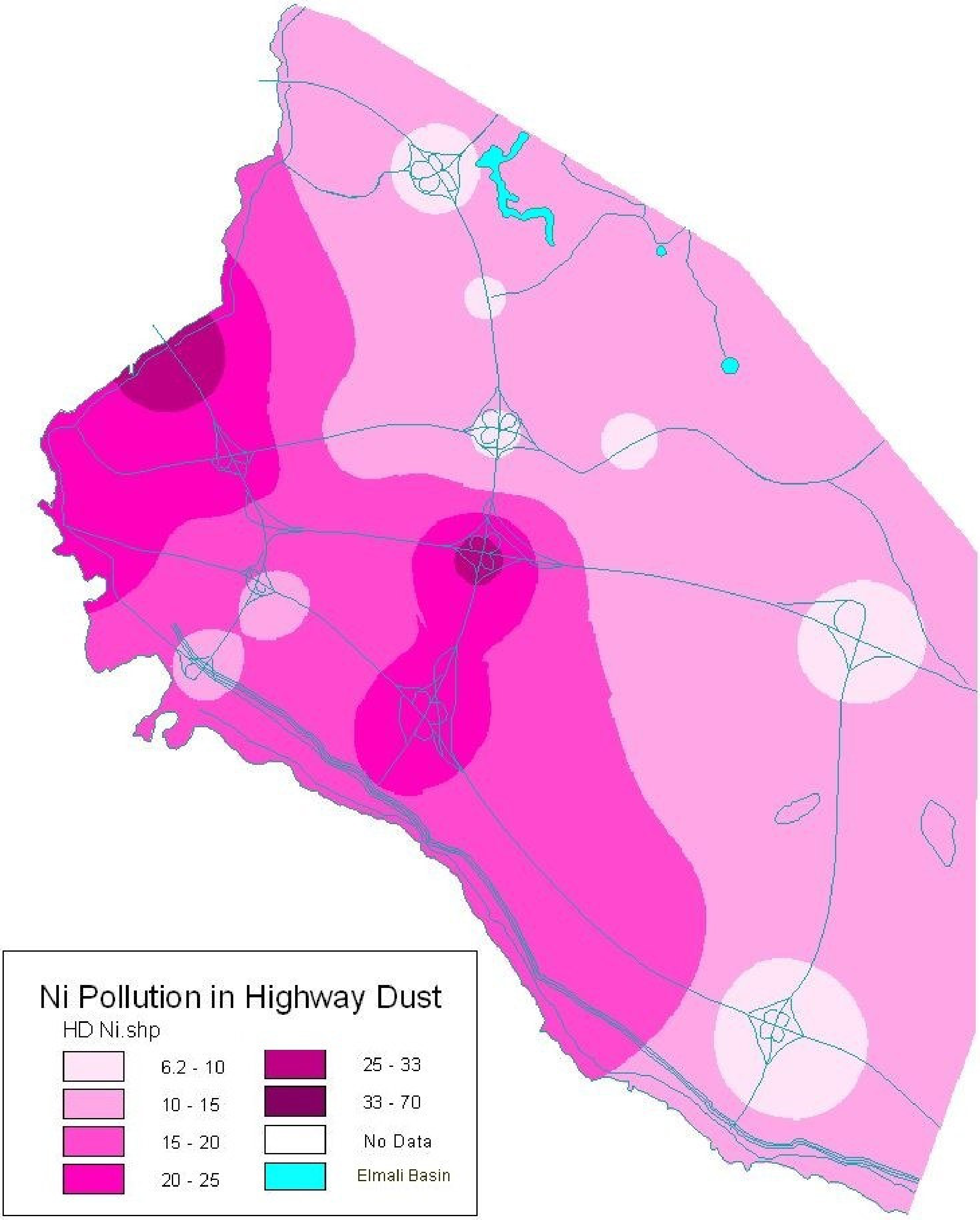

Figure 5.71. Spatial Distribution of Ni Pollution in Highway Dust

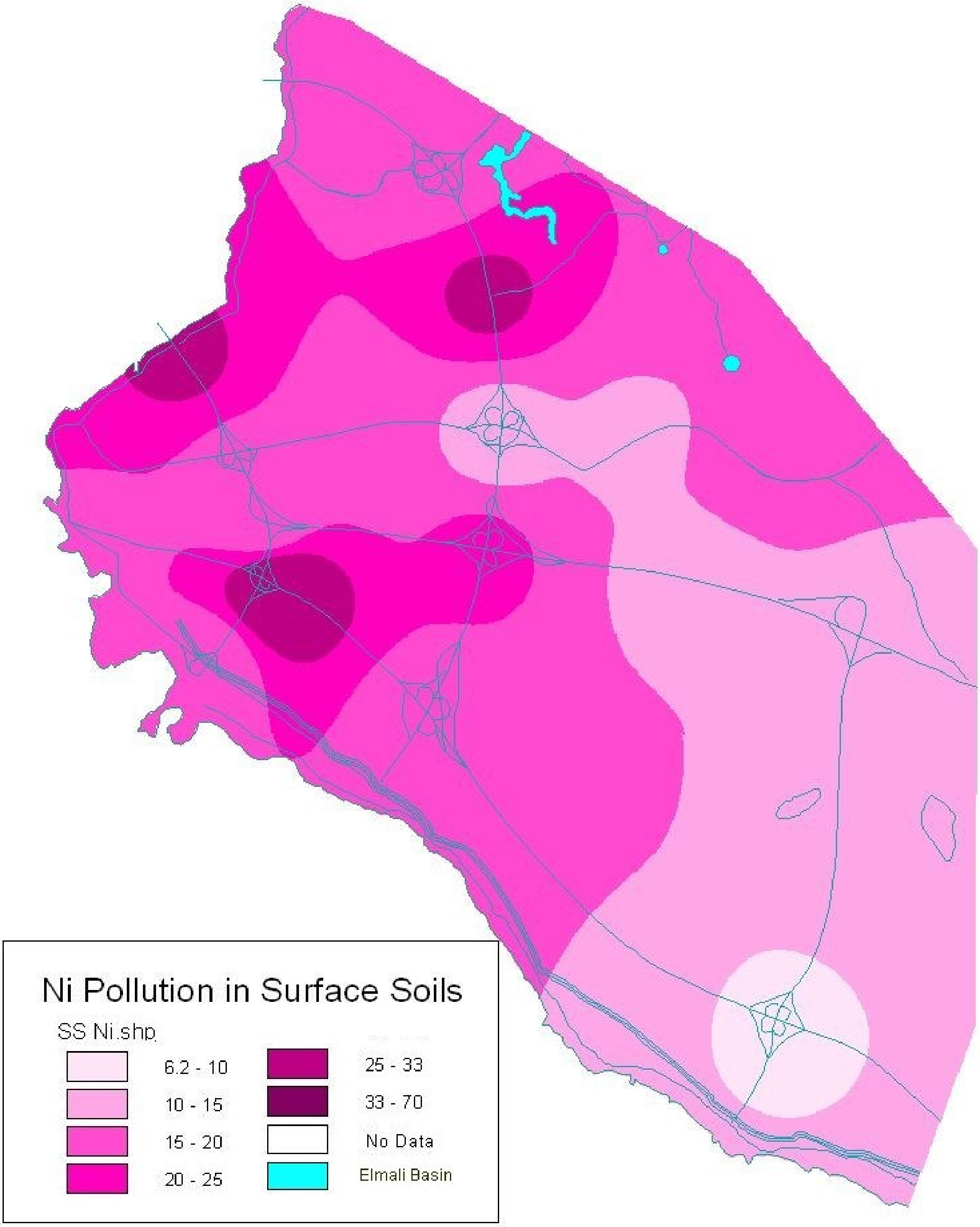

Figure 5.72. Spatial Distribution of Ni Pollution in Surface Soils

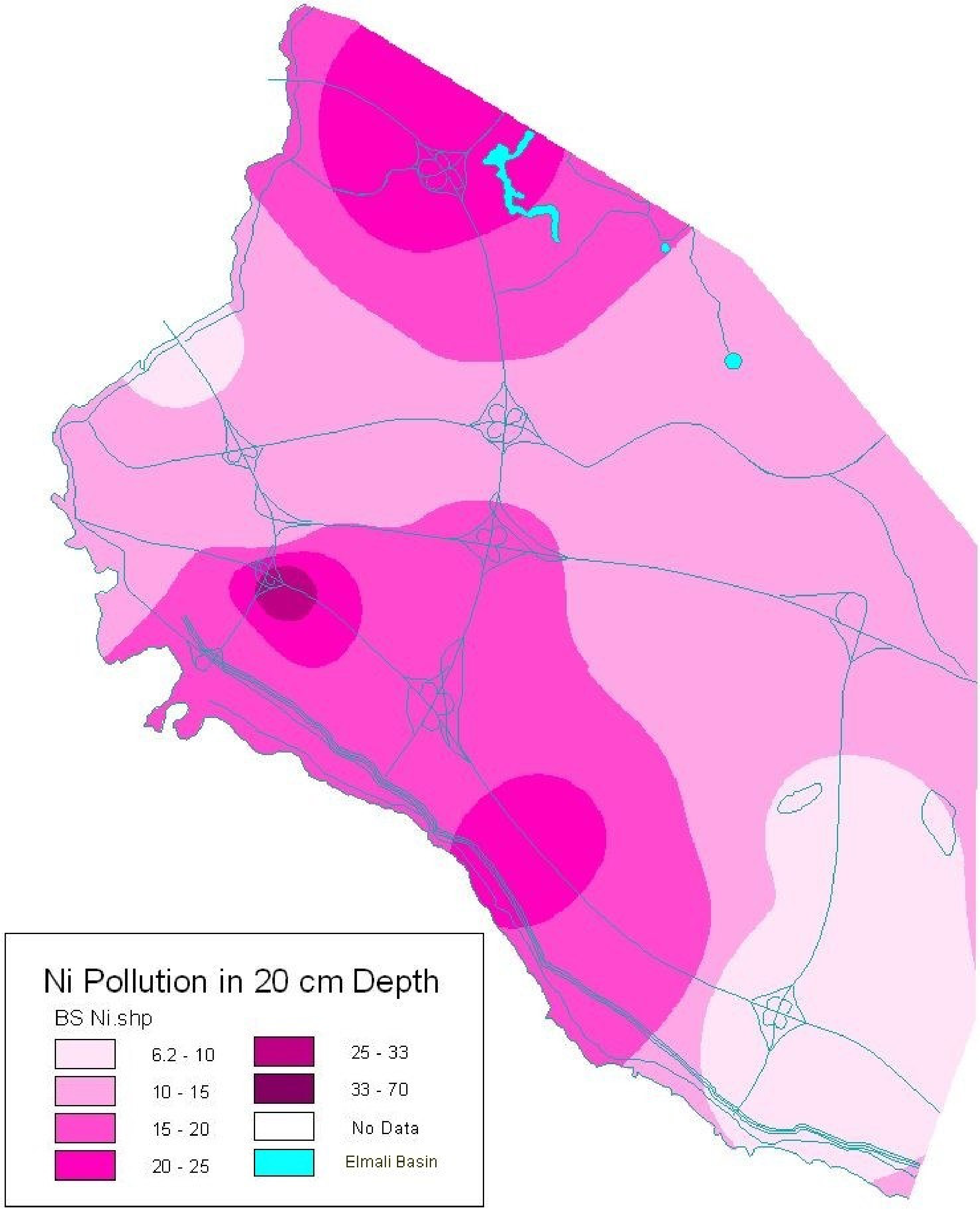

Figure 5.73. Spatial Distribution of Ni Pollution in 20 cm Depth

Nickel concentrations of highway dusts did not exceed common range for soils (10 – 50 mg/kg). The overall study area had no critical values of nickel concentrations. Highest pollution values were obtained in O – 1 and O – 2 Highways for the highway dusts, as shown from Figure 5.71.

In Figure 5.72, distribution of nickel pollution for surface soils on the research area is shown. Common range for nickel was not exceeded and nickel concentrations in the study area satisfied the allowable values in EU regulations (70 mg/kg for soils with pH>7). As shown from the Figure 5.73, no critical pollution of nickel was determined in the 20 cm deep soils.

Nickel pollution was not present over the study area for highway dusts and soils.

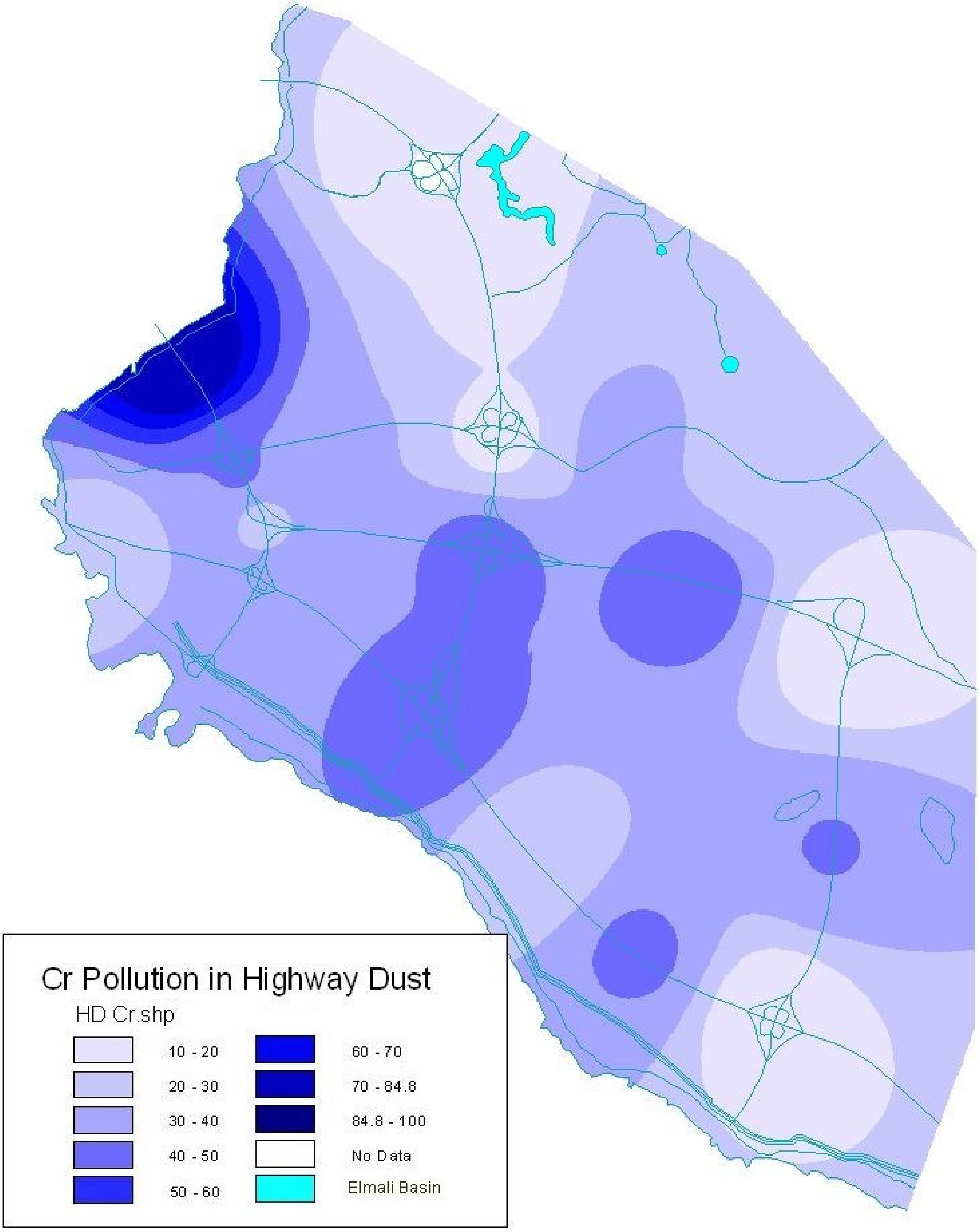

Figure 5.74. Spatial Distribution of Cr Pollution in Highway Dust

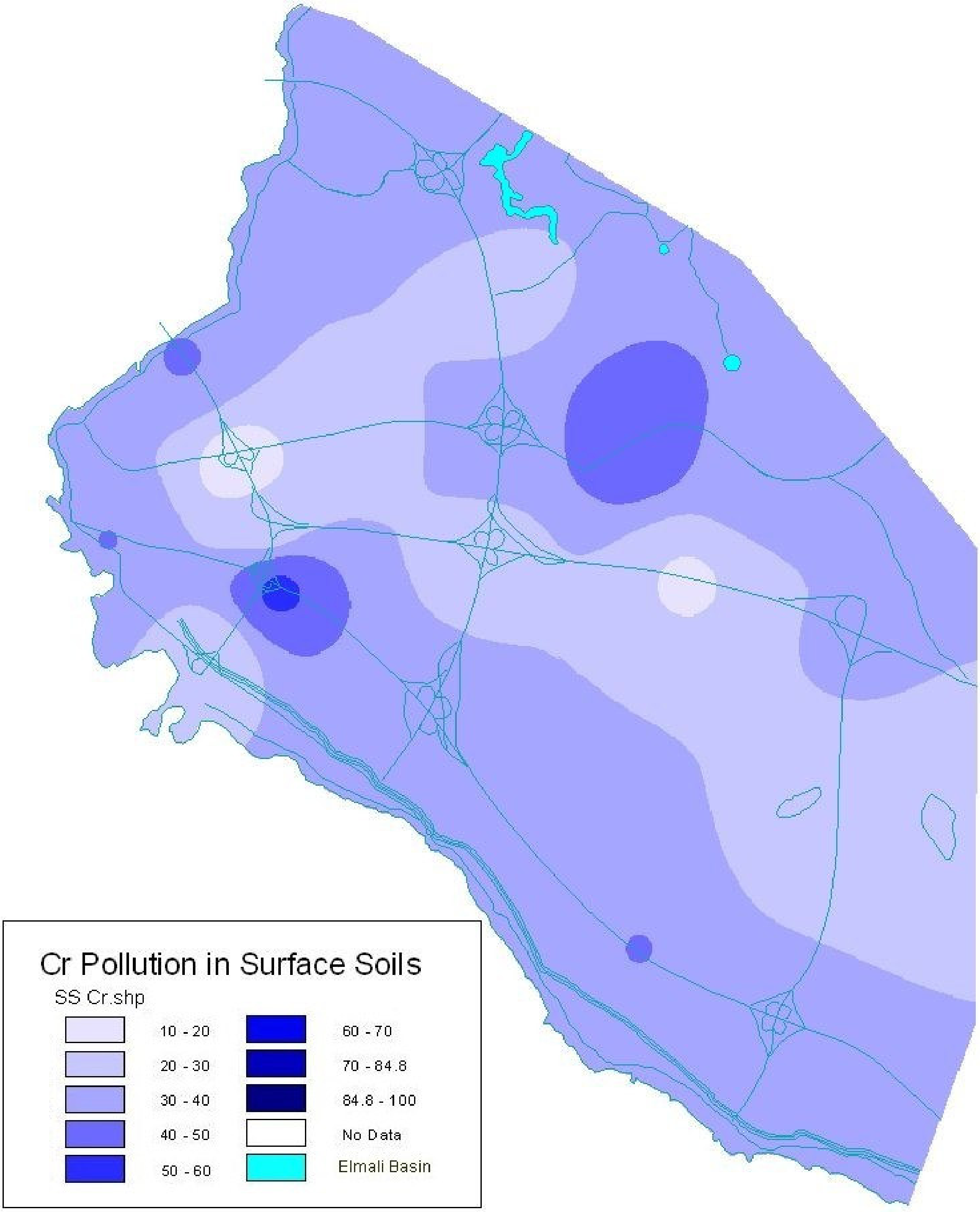

Figure 5.75. Spatial Distribution of Cr Pollution in Surface Soils

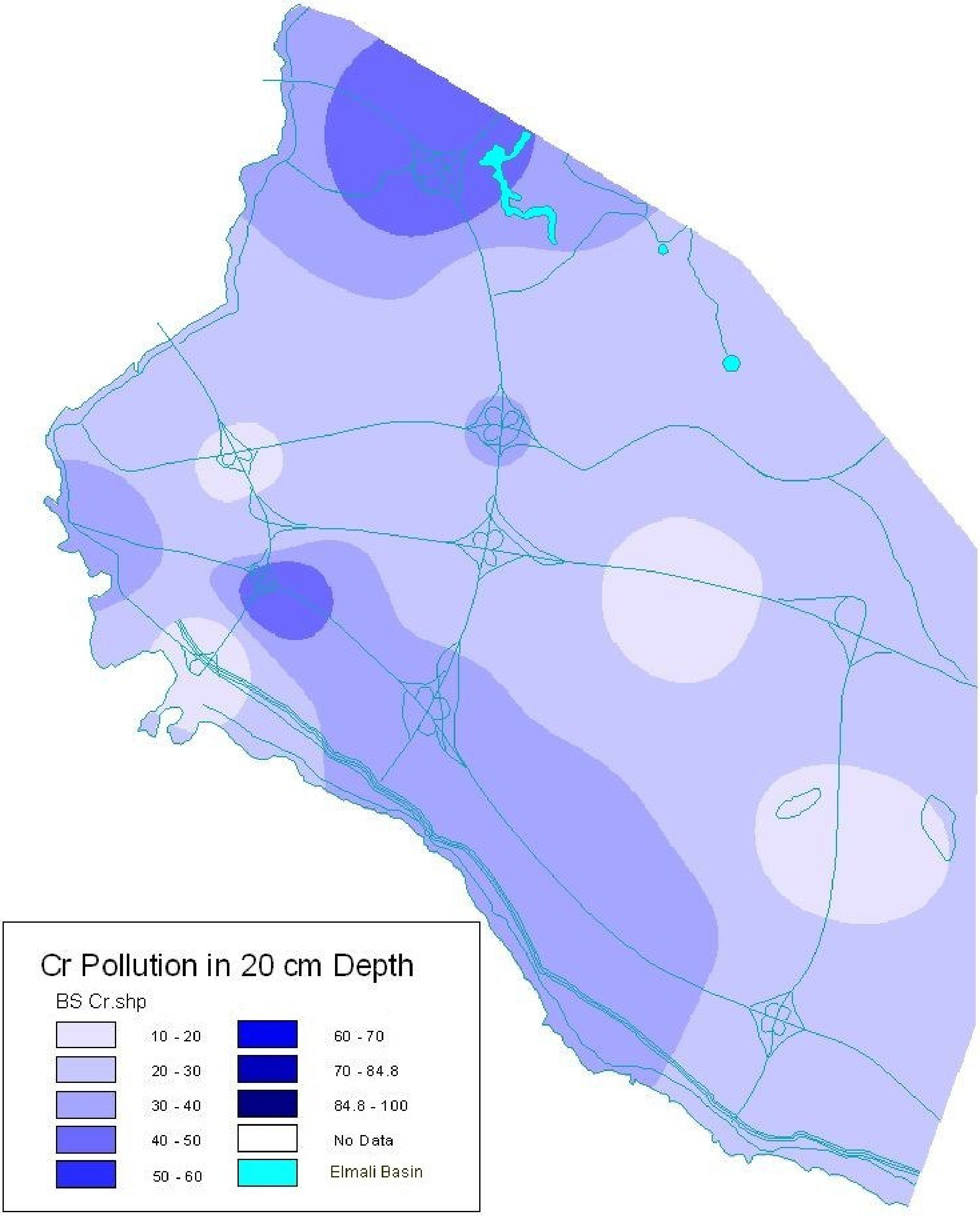

Figure 5.76. Spatial Distribution of Cr Pollution in 20 cm Depth

As shown from Figure 5.71, chromium concentrations of highway dusts exceeded common range for soils (10 – 50 mg/kg) only in one point on O – 1 Highway. The remaining study area had no critical values of chromium concentrations. Highest values were obtained in O – 1 and O – 2 Highways for the highway dusts; however, EU regulations were satisfied for chromium (100 mg/kg for soils with pH>7).

Distribution of chromium concentrations for surface soils on the research area is shown in Figure 5.72. Common range for chromium (10 – 50 mg/kg) was not exceeded except for one location, and chromium concentrations in the study area are suitable with the maximum allowable values in EU regulations (100 mg/kg for soils with pH>7). As shown from the Figure 5.73, no critical pollution of chromium was determined in the 20 cm deep soils for the study area.

Chromium pollution was not found over the field for highway dusts and soils.

6. CONCLUSIONS

- Experimental results have shown that heavy metal contamination due to the transportation activities in the Anatolian District of Istanbul is a serious environmental problem. Lead, zinc and copper were found as the most dangerous pollutants from transportation activities. Cadmium, nickel and chromium concentrations were within the acceptable ranges.

- Lead was found in excessive amounts in highway dusts and surface soil samples, and it may be noted as the most dangerous pollutant where seriously violated maximum allowable concentrations in EU and Turkish regulations. Maximum concentrations were encountered in surface soils, followed by dust samples. Lead pollution also reached deeper layers of soils.

- Zinc concentrations also exceeded EU and Turkish regulations in highway dust, surface soil and soil samples from 20 cm depth. Highest zinc concentrations were found in surface soils, followed by dust samples. Zinc pollution reached to deeper soil layers very easily, where concentrations for surface and 20 cm depth samples were close to each other.

- Copper pollution was highest in highway dust. Also surface soils were found polluted with copper to some extent, where values exceeded EU limits in both cases. Soils from 20 cm depth were affected from dust and surface soil pollution, but did not contain amounts exceeding values in regulations.

- Cadmium concentrations did not exceed EU maximum allowable limits and common range in soils. Highest values were obtained in surface soil samples.

- No critical nickel pollution over the site was found. Surface soils had higher nickel concentrations than 20 cm deep soils and highway dust.

- Chromium concentrations were in the common range and highest amounts of chromium were detected in dust samples. Surface and 20 cm deep soils contained chromium very close to each other.

- Soils with higher pH values tend to retain higher amounts of metal concentrations, where relationship between parameters was most clearly seen for chromium.

- High salinity values in soils were linked to lower heavy metal retention capacity. Clear correlations were obtained for lead and zinc. However, further investigation may be needed to prove the judgement for copper, cadmium, nickel and chromium.

- Higher conductivity values were obtained in soil samples where concentrations of metals were high. The correlation was clear for all metals within the scope of the study except cadmium.

- Very high levels of carbon and high amounts of nitrogen were detected in soil samples. This is probably due to the hydrocarbon pollution in roadside environment. It is a result of gas emissions which contain hydrocarbons and other pollutants because of the partial combustion of fuel in engines.

- Increased carbon content of the soil media was linked with the metal retaining capacity of the soil. Where continuous pollution over time is present, it is evident that soils with high carbon percentages are able to retain higher concentrations of heavy metals in the soil structure. Very clear proof was obtained for lead, zinc, copper and cadmium and clues exist for nickel and chromium.

- The relationship between increasing nitrogen content and high concentrations of metals in soils proved true for the metals within the scope of the study. The connection is very clear for lead, zinc and copper. However, further investigation might be needed for cadmium, nickel and chromium.

- GIS study has shown that O – 1 Highway and surrounded areas were the mostly polluted arterial among the others. Soils and dusts of D – 100 Highway were also highly contaminated. Pollution in O – 2 Highway and D – 020 connection was less critical. However, there were locations on these motorways where pollution reached critical levels.

- According to the results of the GIS study, O – 4 Highway and O4 – D100 connection was found as the least polluted arterial among the others. Critical levels of pollution were obtained in limited areas. However, metal concentrations exceeded common ranges for soils in most places, which show the existence of contamination.

- Elmalı basin was found under the threat of heavy metal pollution. Results of GIS analysis showed that soils around the basin were found critically contaminated with lead, zinc and copper where EU limits were violated for pollution distribution in highway dust, and common ranges were exceeded for all sample types. Existence of continuous heavy metal load over the basin area and Elmalı Dam due to the nearby transportation activities was suspected. Fortunately, cadmium, nickel and chromium pollution was not observed near the basin. Further study should be conducted to estimate the pollution carried to the reservoir by runoff water and other mechanisms.

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APPENDIX A

EXPERIMENTAL RESULTS
FOR
HEAVY METAL DETERMINATION

Table A.1. Contents of Heavy Metals in Highway Dust Samples

				Extractable Content (mg/kg)											
Location	**Sample Type**	**Sample ID**	**Set**	Pb	**Pb (Avg)**	Zn	**Zn (Avg)**	Cu	**Cu (Avg)**	Cd	**Cd (Avg)**	Ni	**Cr (Avg)**	Cr	**Cr (Avg)**
Beylerbeyi	Highway Dust	01HD	A	1171	**1086.0**	522.3	**520.7**	269.2	**272.8**	0	**0.1**	30.1	**29.8**	96.9	**84.8**
	Highway Dust		B	1002		519		276.3		0.2		29.4		72.7	
Altunizade	Highway Dust	02HD	A	272.0	**321.9**	368.2	**234.0**	207.4	**299.6**	0.0	**0.0**	19.9	**22.8**	37.5	**40.8**
	Highway Dust		B	371.7		99.7		391.7		0.0		25.6		44.1	
Çamlıca	Highway Dust	03HD	A	157.0	**185.1**	336.3	**299.3**	78.9	**83.6**	0.0	**0.0**	19.3	**19.5**	30.2	**29.0**
	Highway Dust		B	213.2		262.2		88.2		0.0		19.7		27.8	
Göztepe	Highway Dust	04HD	A	197.2	**164.2**	253.6	**245.3**	92.3	**95.7**	0.1	**0.1**	14.0	**13.0**	27.0	**32.2**
	Highway Dust		B	131.1		237.0		99.0		0.0		12.0		37.3	
Fenerbahçe	Highway Dust	05HD	A	197.2	**217.3**	237.6	**254.0**	112.0	**99.0**	0.0	**0.0**	16.1	**14.0**	36.8	**30.8**
	Highway Dust		B	237.4		270.4		86.0		0.0		11.8		24.8	
Kavacık	Highway Dust	06HD	A	13.1	**12.5**	126.6	**127.8**	14.9	**14.0**	0.0	**0.0**	10.8	**9.0**	11.0	**9.9**
	Highway Dust		B	11.9		128.9		13.0		0.0		7.1		8.8	
K. Karabekir	Highway Dust	07HD	A	45.0	**63.4**	238.3	**236.6**	126.9	**111.3**	0.3	**0.2**	10.6	**9.7**	19.6	**17.6**
	Highway Dust		B	81.7		234.9		95.6		0.1		8.7		15.5	
Ümraniye	Highway Dust	08HD	A	101.1	**100.3**	222.4	**224.5**	108.8	**105.6**	0.0	**0.0**	7.8	**9.0**	20.4	**17.2**
	Highway Dust		B	99.5		226.6		102.3		0.0		10.1		13.9	
Ataşehir	Highway Dust	09HD	A	186.6	**239.0**	361.4	**325.7**	118.0	**119.6**	0.0	**0.0**	27.7	**26.9**	21.2	**43.7**
	Highway Dust		B	291.4		289.9		121.2		0.0		26.0		66.2	
Kozyatağı	Highway Dust	10HD	A	212.4	**199.2**	334.6	**288.8**	356.0	**227.4**	0.2	**0.1**	33.2	**23.1**	56.3	**48.6**
	Highway Dust		B	185.9		243.0		98.7		0.0		13.0		40.9	

Table A.1. Contents of Heavy Metals in Highway Dust Samples (Continued)

				Extractable Content (mg/kg)											
Location	**Sample Type**	**Sample ID**	**Set**	Pb	**Pb (Avg)**	Zn	**Zn (Avg)**	Cu	**Cu (Avg)**	Cd	**Cd (Avg)**	Ni	**Cr (Avg)**	Cr	**Cr (Avg)**
Haydarpaşa	Highway Dust	11HD	A	87.7	**74.6**	221.2	**224.9**	82.6	**62.0**	0.0	**0.0**	21.1	**22.6**	31.3	**24.5**
	Highway Dust		B	61.4		228.5		41.4		0.0		24.1		17.7	
Altıntepe	Highway Dust	12HD	A	67.4	**77.9**	261.0	**260.3**	65.5	**67.6**	0.3	**0.4**	14.9	**15.3**	22.3	**22.4**
	Highway Dust		B	88.4		259.5		69.7		0.4		15.7		22.5	
Cevizli	Highway Dust	13HD	A	121.1	**126.6**	330.3	**355.5**	101.1	**96.7**	0.3	**0.3**	18.8	**19.3**	44.0	**41.5**
	Highway Dust		B	132.1		380.6		92.2		0.3		19.8		38.9	
Kartal	Highway Dust	14HD	A	37.7	**34.9**	141.4	**136.2**	21.7	**33.1**	0.0	**0.0**	6.6	**6.2**	10.1	**12.7**
	Highway Dust		B	32.1		131.0		44.4		0.0		5.7		15.3	
Yakacık	Highway Dust	15HD	A	18.1	**17.9**	86.8	**87.0**	14.4	**16.4**	0.0	**0.0**	6.9	**8.4**	10.4	**10.6**
	Highway Dust		B	17.7		87.2		18.4		0.0		9.9		10.8	
Samandıra	Highway Dust	16HD	A	46.1	**48.0**	166.1	**168.5**	88.8	**142.5**	0.1	**0.2**	12.1	**14.3**	66.1	**40.3**
	Highway Dust		B	49.9		170.8		196.1		0.3		16.4		14.4	
Kayışdağı	Highway Dust	17HD	A	60.8	**54.8**	208.1	**215.1**	80.6	**100.5**	0.0	**0.0**	12.1	**11.2**	64.0	**45.6**
	Highway Dust		B	48.8		222.0		120.3		0.0		10.3		27.2	
Kısıklı	Highway Dust	18HD	A	201.1	**194.7**	240.4	**254.3**	128.4	**114.5**	0.3	**0.2**	14.3	**12.5**	29.9	**30.3**
	Highway Dust		B	188.2		268.1		100.6		0.0		10.7		30.7	
Çekmeköy	Highway Dust	19HD	A	162.2	**150.2**	220.6	**234.7**	86.7	**79.1**	0.0	**0.1**	10.1	**9.4**	28.8	**32.6**
	Highway Dust		B	138.1		248.7		71.4		0.1		8.6		36.3	
Sarıgazi	Highway Dust	20HD	A	140.4	**164.8**	206.1	**211.1**	80.6	**85.7**	0.0	**0.0**	12.3	**11.2**	26.2	**23.3**
	Highway Dust		B	189.2		216.0		90.7		0.0		10.1		20.3	

Table A.2. Contents of Heavy Metals in Surface Soil Samples

				Extractable Content (mg/kg)											
Location	**Sample Type**	**Sample ID**	**Set**	Pb	**Pb (Avg)**	Zn	**Zn (Avg)**	Cu	**Cu (Avg)**	Cd	**Cd (Avg)**	Ni	**Cr (Avg)**	Cr	**Cr (Avg)**
Beylerbeyi	Surface Soil	01SS	A	1612	**1572.5**	524.1	**522.1**	133.4	**136.0**	1.1	**0.9**	26.0	**26.1**	36.8	**40.2**
	Surface Soil		B	1533		520.1		138.6		0.7		26.1		43.5	
Altunizade	Surface Soil	02SS	A	690.4	**645.8**	443.0	**433.6**	88.5	**87.3**	1.0	**1.0**	20.2	**18.8**	17.1	**15.7**
	Surface Soil		B	601.2		424.2		86.1		0.9		17.3		14.2	
Çamlıca	Surface Soil	03SS	A	242.5	**227.8**	340.8	**350.3**	56.6	**56.3**	0.0	**0.0**	16.7	**15.7**	25.8	**25.1**
	Surface Soil		B	213.1		359.8		56.0		0.0		14.6		24.3	
Göztepe	Surface Soil	04SS	A	71.7	**73.0**	245.9	**233.9**	78.7	**94.7**	0.0	**0.1**	29.2	**33.0**	46.4	**50.9**
	Surface Soil		B	74.2		221.9		110.6		0.1		36.7		55.4	
Fenerbahçe	Surface Soil	05SS	A	270.3	**282.2**	498.4	**495.3**	125.2	**123.1**	1.2	**1.2**	17.8	**16.9**	24.7	**24.9**
	Surface Soil		B	294.0		492.1		120.9		1.2		15.9		25.1	
Kavacık	Surface Soil	06SS	A	20.8	**25.6**	226.0	**193.2**	59.6	**48.7**	0.0	**0.0**	17.8	**17.7**	40.8	**39.8**
	Surface Soil		B	30.4		160.4		37.8		0.0		17.6		38.8	
Kazım Karabekir	Surface Soil	07SS	A	36.5	**34.4**	143.4	**142.2**	35.9	**35.3**	0.1	**0.1**	25.4	**26.0**	24.8	**25.3**
	Surface Soil		B	32.3		140.9		34.6		0.1		26.5		25.7	
Ümraniye	Surface Soil	08SS	A	87.6	**88.1**	163.7	**151.9**	52.9	**46.3**	0.0	**0.1**	12.6	**12.6**	36.7	**36.9**
	Surface Soil		B	88.5		140.1		39.6		0.1		12.6		37.1	
Ataşehir	Surface Soil	09SS	A	62.6	**62.1**	142.7	**152.1**	21.1	**21.4**	0.3	**0.4**	21.0	**21.1**	25.6	**26.1**
	Surface Soil		B	61.6		161.4		21.7		0.5		21.2		26.6	
Kozyatağı	Surface Soil	10SS	A	41.8	**42.4**	186.9	**167.0**	30.6	**31.1**	0.9	**0.5**	18.5	**18.2**	33.3	**33.3**
	Surface Soil		B	43.0		147.1		31.6		0.0		17.9		33.3	

Table A.2. Contents of Heavy Metals in Surface Soil Samples (Continued)

				Extractable Content (mg/kg)											
Location	**Sample Type**	**Sample ID**	**Set**	Pb	**Pb (Avg)**	Zn	**Zn (Avg)**	Cu	**Cu (Avg)**	Cd	**Cd (Avg)**	Ni	**Cr (Avg)**	Cr	**Cr (Avg)**
Haydarpaşa	Surface Soil	11SS	A	92.6	**92.0**	266.3	**268.6**	38.3	**38.4**	0.0	**0.0**	19.2	**19.4**	38.6	**40.1**
	Surface Soil		B	91.4		270.8		38.5		0.0		19.6		41.6	
Altıntepe	Surface Soil	12SS	A	100.7	**87.9**	336.0	**330.1**	54.9	**55.3**	0.0	**0.0**	19.6	**19.9**	38.7	**39.9**
	Surface Soil		B	75.0		324.1		55.6		0.0		20.2		41.0	
Cevizli	Surface Soil	13SS	A	141.4	**133.7**	261.0	**259.8**	100.5	**99.5**	0.0	**0.0**	10.4	**13.1**	38.6	**40.1**
	Surface Soil		B	126.0		258.5		98.5		0.0		15.7		41.6	
Kartal	Surface Soil	14SS	A	41.1	**40.7**	201.1	**190.9**	38.1	**37.9**	0.0	**0.0**	8.1	**9.0**	35.4	**34.9**
	Surface Soil		B	40.3		180.7		37.7		0.0		9.9		34.3	
Yakacık	Surface Soil	15SS	A	20.2	**21.1**	90.6	**93.4**	26.1	**27.5**	0.0	**0.0**	20.1	**14.5**	32.3	**30.6**
	Surface Soil		B	22.0		96.1		28.9		0.0		8.8		28.8	
Samandıra	Surface Soil	16SS	A	60.0	**60.3**	202.0	**192.4**	66.7	**66.5**	0.0	**0.0**	12.6	**12.2**	20.2	**20.4**
	Surface Soil		B	60.6		182.7		66.2		0.0		11.7		20.6	
Kayışdağı	Surface Soil	17SS	A	30.6	**33.9**	192.2	**192.2**	90.2	**90.0**	0.0	**0.0**	13.4	**13.3**	20.4	**19.5**
	Surface Soil		B	37.2		192.2		89.8		0.0		13.2		18.6	
Kısıklı	Surface Soil	18SS	A	187.6	**188.7**	338.8	**339.2**	135.2	**133.0**	0.0	**0.3**	16.6	**16.5**	26.8	**26.8**
	Surface Soil		B	189.8		339.6		130.8		0.5		16.4		26.8	
Çekmeköy	Surface Soil	19SS	A	60.6	**59.8**	211.8	**211.7**	73.3	**73.4**	0.0	**0.0**	14.4	**14.3**	49.6	**47.8**
	Surface Soil		B	58.9		211.6		73.4		0.0		14.2		45.9	
Sarıgazi	Surface Soil	20SS	A	42.2	**42.4**	186.1	**186.1**	81.2	**73.6**	0.2	**0.2**	16.1	**16.1**	37.7	**37.4**
	Surface Soil		B	42.6		186.0		66.0		0.1		16.0		37.1	

Table A.3. Contents of Heavy Metals in Samples from 20 cm Depth

				Extractable Content (mg/kg)											
Location	**Sample Type**	**Sample ID**	**Set**	Pb	**Pb (Avg)**	Zn	**Zn (Avg)**	Cu	**Cu (Avg)**	Cd	**Cd (Avg)**	Ni	**Cr (Avg)**	Cr	**Cr (Avg)**
Beylerbeyi	Background Soil	01BS	A	282.4	**284.4**	376.1	**425.3**	44.1	**44.2**	0.3	**0.2**	8.8	**9.0**	26.9	**27.8**
	Background Soil		B	286.4		474.4		44.3		0.0		9.1		28.6	
Altunizade	Background Soil	02BS	A	328.5	**302.1**	344.6	**332.8**	56.9	**54.0**	0.0	**0.2**	13.3	**12.3**	18.7	**17.4**
	Background Soil		B	275.7		320.9		51.0		0.3		11.2		16.0	
Çamlıca	Background Soil	03BS	A	80.0	**85.9**	206.9	**212.7**	30.0	**30.5**	0.0	**0.0**	10.0	**11.3**	21.4	**21.8**
	Background Soil		B	91.8		218.5		30.9		0.0		12.6		22.2	
Göztepe	Background Soil	04BS	A	71.7	**73.0**	214.5	**221.2**	73.8	**73.6**	0.0	**0.0**	27.4	**26.5**	49.5	**47.5**
	Background Soil		B	74.2		227.8		73.3		0.0		25.6		45.5	
Fenerbahçe	Background Soil	05BS	A	179.2	**179.2**	445.9	**449.9**	58.5	**59.7**	0.5	**0.5**	15.0	**15.7**	15.9	**15.7**
	Background Soil		B	179.1		453.9		60.8		0.4		16.4		15.4	
Kavacık	Background Soil	06BS	A	17.2	**19.3**	127.0	**127.2**	30.7	**31.3**	0.0	**0.0**	22.1	**23.8**	40.3	**46.4**
	Background Soil		B	21.3		127.3		31.8		0.0		25.5		52.4	
Kazım Karabekir	Background Soil	07BS	A	38.8	**38.5**	117.0	**128.1**	31.7	**31.8**	0.1	**0.1**	22.6	**19.1**	32.3	**28.0**
	Background Soil		B	38.2		139.1		31.9		0.0		15.6		23.7	
Ümraniye	Background Soil	08BS	A	41.4	**41.5**	123.6	**121.3**	40.2	**34.5**	0.0	**0.0**	11.4	**11.0**	32.3	**30.5**
	Background Soil		B	41.6		118.9		28.8		0.0		10.6		28.6	
Ataşehir	Background Soil	09BS	A	41.3	**40.3**	121.0	**114.8**	24.4	**24.0**	0.6	**0.3**	16.6	**16.9**	24.1	**24.1**
	Background Soil		B	39.3		108.5		23.6		0.0		17.2		24.0	
Kozyatağı	Background Soil	10BS	A	42.7	**45.5**	158.0	**189.2**	30.2	**30.5**	0.9	**0.5**	18.6	**18.9**	31.9	**32.6**
	Background Soil		B	48.2		220.4		30.8		0.0		19.1		33.2	

Table A.3. Contents of Heavy Metals in Samples from 20 cm Depth (Continued)

				Extractable Content (mg/kg)											
Location	**Sample Type**	**Sample ID**	**Set**	Pb	**Pb (Avg)**	Zn	**Zn (Avg)**	Cu	**Cu (Avg)**	Cd	**Cd (Avg)**	Ni	**Cr (Avg)**	Cr	**Cr (Avg)**
Haydarpaşa	Background Soil	11BS	A	60.0	**60.4**	302.0	**264.2**	26.6	**24.2**	0.0	**0.0**	12.6	**12.6**	34.5	**33.0**
	Background Soil		B	60.8		226.4		21.7		0.0		12.5		31.5	
Altıntepe	Background Soil	12BS	A	41.0	**41.9**	307.1	**296.3**	47.7	**47.6**	0.0	**0.0**	22.1	**21.5**	34.0	**34.2**
	Background Soil		B	42.8		285.4		47.5		0.0		20.8		34.3	
Cevizli	Background Soil	13BS	A	62.2	**65.3**	138.3	**160.2**	96.1	**94.1**	0.0	**0.1**	16.6	**18.2**	32.3	**34.2**
	Background Soil		B	68.3		182.1		92.1		0.1		19.7		36.0	
Kartal	Background Soil	14BS	A	20.7	**20.2**	120.6	**116.2**	36.1	**35.9**	0.0	**0.0**	6.5	**6.6**	25.0	**27.0**
	Background Soil		B	19.6		111.8		35.6		0.0		6.7		28.9	
Yakacık	Background Soil	15BS	A	10.6	**10.1**	48.2	**47.2**	10.0	**12.6**	0.0	**0.0**	10.6	**10.5**	28.6	**28.9**
	Background Soil		B	9.6		46.1		15.1		0.0		10.4		29.1	
Samandıra	Background Soil	16BS	A	40.7	**44.2**	120.9	**128.5**	48.4	**48.5**	0.0	**0.0**	8.9	**9.1**	16.5	**16.6**
	Background Soil		B	47.7		136.0		48.6		0.0		9.3		16.7	
Kayışdağı	Background Soil	17BS	A	32.2	**32.0**	166.1	**165.9**	67.6	**68.8**	0.0	**0.0**	11.6	**11.6**	16.7	**13.8**
	Background Soil		B	31.8		165.7		69.9		0.0		11.6		10.8	
Kısıklı	Background Soil	18BS	A	138.3	**138.5**	340.6	**340.8**	60.9	**59.6**	0.0	**0.0**	12.6	**10.7**	26.1	**24.4**
	Background Soil		B	138.7		341.0		58.2		0.0		8.8		22.6	
Çekmeköy	Background Soil	19BS	A	58.8	**60.8**	222.4	**221.3**	71.6	**70.9**	0.0	**0.0**	10.6	**10.9**	22.3	**25.4**
	Background Soil		B	62.7		220.2		70.1		0.0		11.2		28.4	
Sarıgazi	Background Soil	20BS	A	41.4	**41.1**	166.7	**166.3**	67.7	**63.3**	0.0	**0.0**	13.2	**13.3**	27.9	**27.9**
	Background Soil		B	40.7		165.9		58.9		0.0		13.4		27.8	

APPENDIX B

EXPERIMENTAL RESULTS
FOR
pH, SALINITY AND CONDUCTIVITY

Table B.1. pH, Salinity and Conductivity Values of Soil Samples

Location	**Sample Type**	**Sample ID**	**pH**	**Salinity (‰)**	**Conductivity (mS/cm)**
Beylerbeyi	Surface Soil	01SS	7.39	1.6	3.40
	Background Soil	01BS	7.62	1.2	2.64
Altunizade	Surface Soil	02SS	7.22	1.3	2.73
	Background Soil	02BS	7.51	1.2	2.49
Çamlıca	Surface Soil	03SS	7.12	1.2	2.65
	Background Soil	03BS	7.12	1.2	2.51
Göztepe	Surface Soil	04SS	7.49	1.3	2.79
	Background Soil	04BS	7.54	1.3	2.82
Fenerbahçe	Surface Soil	05SS	7.27	1.4	2.95
	Background Soil	05BS	7.43	1.2	2.56
Kavacık	Surface Soil	06SS	6.81	1.4	3.03
	Background Soil	06BS	7.48	1.1	2.49
Kazım Karabekir	Surface Soil	07SS	7.40	1.4	2.05
	Background Soil	07BS	7.34	1.1	2.42
Ümraniye	Surface Soil	08SS	7.38	1.4	2.93
	Background Soil	08BS	7.20	1.1	2.47
Ataşehir	Surface Soil	09SS	7.43	1.8	3.62
	Background Soil	09BS	7.45	1.6	3.42
Kozyatağı	Surface Soil	10SS	7.57	1.6	3.20
	Background Soil	10BS	7.68	1.1	2.49

Table B.1. pH, Salinity and Conductivity Values of Soil Samples (Continued)

Location	**Sample Type**	**Sample ID**	**pH**	**Salinity (‰)**	**Conductivity (mS/cm)**
Haydarpaşa	Surface Soil	11SS	7.41	1.3	2.82
	Background Soil	11BS	7.56	1.0	2.21
Altıntepe	Surface Soil	12SS	7.37	1.2	2.53
	Background Soil	12BS	7.42	1.1	2.45
Cevizli	Surface Soil	13SS	7.28	1.4	2.88
	Background Soil	13BS	7.36	1.2	2.57
Kartal	Surface Soil	14SS	7.48	1.4	2.94
	Background Soil	14BS	7.52	1.2	2.58
Yakacık	Surface Soil	15SS	7.65	1.2	2.56
	Background Soil	15BS	7.33	1.2	2.65
Samandıra	Surface Soil	16SS	7.35	1.6	3.34
	Background Soil	16BS	7.45	1.1	2.42
Kayışdağı	Surface Soil	17SS	7.30	1.3	2.74
	Background Soil	17BS	7.45	1.1	2.41
Kısıklı	Surface Soil	18SS	7.28	1.5	3.07
	Background Soil	18BS	7.44	1.1	2.57
Çekmeköy	Surface Soil	19SS	7.54	1.4	3.05
	Background Soil	19BS	7.55	1.4	2.93
Sarıgazi	Surface Soil	20SS	7.31	1.3	2.72
	Background Soil	20BS	7.48	1.2	2.56

APPENDIX C

RESULTS OF ELEMENTAL ANALYSIS

Table C.1. Carbon, Hydrogen, Nitrogen and Sulphur Contents of Samples from O - 1 Highway

Location	**Sample Type**	**Sample ID**	**Carbon (%)**	**Hydrogen (%)**	**Nitrogen (%)**	**Sulphur (%)**
Beylerbeyi	Surface Soil	01SS	8.64	1.1	0.57	0.12
	Background Soil	01BS	2.76	0.6	0.25	0
Altunizade	Surface Soil	02SS	6.62	0.67	0.36	0.06
	Background Soil	02BS	3.4	0.42	0.23	0
Çamlıca	Surface Soil	03SS	4.64	0.62	0.33	0
	Background Soil	03BS	1.56	0.32	0.17	0
Göztepe	Surface Soil	04SS	3.56	0.94	0.33	0
	Background Soil	04BS	3.25	0.72	0.22	0
Fenerbahçe	Surface Soil	05SS	11.88	1.05	0.41	0
	Background Soil	05BS	4.75	0.26	0.09	0