SINET: Ethiop. J. Sci., 35(2):81–94, 2012
 ISSN: 0379–2897

DETERMINATION OF THE LEVELS OF LEAD IN THE ROADSIDE SOILS OF ADDIS ABABA, ETHIOPIA

Endale Teju [1, 2], Negussie Megersa [1], * B.S. Chandravanshi [1] and Feleke Zewge [1]

[1] Department of Chemistry, College of Natural Sciences, Addis Ababa University, PO Box 1176, Addis Ababa, Ethiopia. E-mail: megersane@yahoo.com or negussie.megersa@aau.edu.et
[2] Department of Chemistry, Haramaya University, PO Box 138, Dire Dawa, Ethiopia

ABSTRACT: Contamination of the roadside soils of Addis Ababa city by lead, most likely originationg from vehicular exhaust, has been investigated. To this end, soil samples were collected from 14 roadside sites; *i.e.,* 2 samples for shorter and 5 samples for longer roads. Determination of lead was carried out on a total of 45 samples and a control sample collected from a relatively remote area of the city, Entoto Mountains, which was assumed to be free of anthropogenic lead sources. The levels of lead in all the samples were determined using flame atomic absorption spectrometer. The concentration of lead obtained from majority of the sample sites surpassed the maximum limit of the metal in soil recommended by WHO (100 µg/g). The average concentrations of lead in the roadside soils were found to be 418.6 ± 3.4 µg/g. Similarly, the concentration of lead in the control soil sample was 18.8 ± 0.5 µg/g. Although at present the lead content of the gasoline used in the country is 0.013 g/L, the use of leaded gasoline during the past decades is thought to be responsible for the high concentration of lead in the roadside soils of Addis Ababa.

Key words/phrases: Addis Ababa, contamination factor, gasoline lead, traffic density, vehicular emission

INTRODUCTION

Anthropogenic activities are known to cause heavy metals, such as lead, to be concentrated in the compartments of the urban environment and posing toxicity as they may be inadvertently or deliberately released. Human exposure to these toxins may inevitably result in adverse effects on health that may be either acute or chronic (Louella *et al.*, 2006).

Lead is neither essential nor beneficial to living organisms (Tsuji *et al.*, 1997). It is a neurotoxin metallic element that can be absorbed by the body, primarily through the lungs and stomach. It can replace calcium in bones (Wayne and Ming-Ho, 2004). Lead can pass the placental barrier and may reach the foetus, resulting in miscarriages, abortions and stillbirths (Opeolu *et al.*, 2010). Excessive amounts of lead in the body can cause disorders in the metabolism of other microelements, *e.g.,* iron, which may be manifested as anaemia, copper or zinc, which has a negative effect on the function of heart and kidneys. Children may be particularly vulnerable to lead exposure because they spend a significant part of their time on the streets, put everything into their mouths and often lack proper nutrition that may also increase their susceptibility to lead poisoning (Jankiewicz *et al*., 2001).

Lead has been recognized as a poison for millennia and has recently been the focus of public health regulations in most of the developed world (Zaki *et al*., 2010; Bjerregaard *et al*., 2004). Although lead naturally occurs in soils in relatively low concentrations, its concentration in the environment has been increasing for several decades due to human activities particularly the use of lead additives to gasoline (Sharma and Prasad, 2010).

Reduction of lead additives in gasoline drastically lowered the metal contamination in the roadside environment in Hong Kong, China (Ho, 1990). In Watford and South Mimms sections of London Orbital Motorway, the rate of lead contamination in vegetation, surface soil, dust and air born fractions was studied since its

* Author to whom all correspondence should be addressed.

opening, in late 1986. In 12 months period, elevated lead levels extended to distances of greater than 100 m from the motorway. Moreover, the average lead contents of motorway verge dust changed from 85 to 7200 μg/g in Watford and 64 to 3472 μg/g in South Mimms (Ward, 1990).

Moreover, the high concentration of lead and cadmium contained in soils and vegetables from 12 towns of Poland were attributed to vehicular emissions (Gzyl, 1990). Similarly, studies on the concentration of lead in roadside soils and plants from the metropolis of Pune, Maharashtra, India, have shown that the accumulation of lead in the dust and plants were closely related to the density of vehicular traffic (Bharati *et al*., 1992). According to a study done in Venezuela, in the year 2003, the concentration of lead in the leaves and roots of plants sampled at a heavy traffic roadside was higher than in samples from a lighter traffic site (Elizabeth, 2003).

A study carried out in Jordan (Jaradat and Moman, 1999) has also shown that roadside soils and plants had significantly high concentrations of lead and other heavy metals. Furthermore, the levels of these metals increased with increasing traffic densities (Akbar *et al*., 2006). Similarly, a study done in Brisbane, Australia, had shown that vehicular emissions were the major sources of lead in roadside soils (Abdul Sahib and Darryl, 2000). A study in Ohio, Canada, had also verified that the main source for lead in roadside soils was the use of leaded gasoline in highway vehicles (Turer *et al*., 2001). Moreover, in Ogbomso, Nigeria, the high pollution parking lots showed higher levels of lead and other heavy metals in leaf and bark tree samples (Olagire and Ayodele, 2003). Besides, a strong correlation was observed for the concentration of lead in soil and plants along Islamabad highway, Pakistan (Pirzada *et al*., 2009).

As shown in the aforementioned studies, the principal source of atmospheric lead has been the combustion of alkyl lead additives in motor fuels and this airborne lead can be deposited in soil and water, thus reaching humans through the food chain and in drinking water. Currently, in Addis Ababa, there are no primary or secondary lead processing and refining factories, no lead alkyl manufactures, no lead oxide and inorganic pigment products or grey iron foundries. Hence, the main source of lead in the atmosphere in the city is likely to originate from the use of leaded gasoline. The Ethiopian Petroleum Enterprise imports and distributes petroleum products in the country; the types of petroleum products currently imported for domestic consumption are: liquefied petroleum gas (LPG), motor gasoline, jet fuel, kerosene and fuel oil. The motor gasoline imported and distributed was not lead free (with 0.6 g/L of lead) until July 2003, when the Government promulgated new specifications for unleaded gasoline (ULG) and decided that all the gasoline imported into Ethiopia shall be unleaded gasoline (WB, 2003).

Due to the high traffic density in parts of Addis Ababa and the use of leaded gasoline, incisors of children from Addis Ababa had statistically significant lead concentration than the rural areas of the country (Fantaye Wondwossen, 2003). In Addition, studies have revealed that lead is one of the heavy metals accumulated at a maximum concentration in leafy vegetables such as Swiss chard and lettuce grown in Kera area of Addis Ababa (Fisseha Itana, 2002). Moreover, soils at Akaki area, which is the oldest industrial site, was found to contain about 4 to 5 times more total lead, nickel, copper, chromium, mercury and cobalt than the soils from Hawassa (Fisseha Itana, 1998).

Generally, vehicular traffic is the main and the largest source of lead in many urban areas, often accounting for more than 90 percent of all atmospheric emissions (WB, 1998). In this regrd, there are no studies carried out in the past years in Addis Ababa dealing with the determination of lead in roadside soils aiming at knowing the effect of leaded gasoline combustion on the accumulation of lead around highways and lead variation with traffic densities of the roads. Hence, this study was designed to investigate the extent to which the roadside soils in Addis Ababa are polluted due to lead accumulation.

MATERIALS AND METHODS

Instrumentation

The instrument used in this work for the determination of the abundance of lead in roadside soils was BUCK Scientific 210VGP Atomic Absorption Spectrophotometer (Norwalk, USA) at the Department of Chemistry, Addis Ababa University. For the determination of the soil pH, WTW Inolab pH/ION Level 2 pH meter (Germany), was used. Similarly, the determination of electrical conductivity was carried out using a Thermo Orion Conductivity meter, Model 145 (Germany).

Chemicals and reagents

All chemicals used in this study were of high-purity analytical grade reagents. Concentrated HCl (36–38%, Hopkins and Williams, UK), concentrated HNO_3 (69–72%, Spectrosol BDH, UK) and H_2O_2 (21–31% Alvetra GmbH, Germany) were used for digestion of the soil samples. Standard lead solution (1000 ppm) used for instrumental calibration was obtained from (PuroGraphic^{tm} calibration standard, Buck Scientific, USA). Working standard solutions were prepared by proper dilution of the 1000 ppm standard solution with distilled-deionized water.

Study area

The city of Addis Ababa is located between 9°1′48″N 38°44′24″E/ 9.03°N 38.74°E/ 9.03; 38.74 coordinates and lies at an altitude of about 2,300 masl and is a grassland biome. The city lies at the foot of Entoto mountains. From its lowest point, at 2,326 masl in the southern periphery, the city rises to over 3,000 masl around the Entoto mountains to the north. Addis Ababa, the capital and largest city of Ethiopia has an estimated population of over 3 million inhabitants in 2012 (CSA, 2011). With 2.1% annual population growth (CSA, 2008) and constantly increasing industrial activities, the city is currently facing environmental pressure from urbanization and industrialization. According to Fisseha Itana (1998), the city covers an area of 500 km^2 and harbours about 65.3% of all industrial and commercial activities of the country.

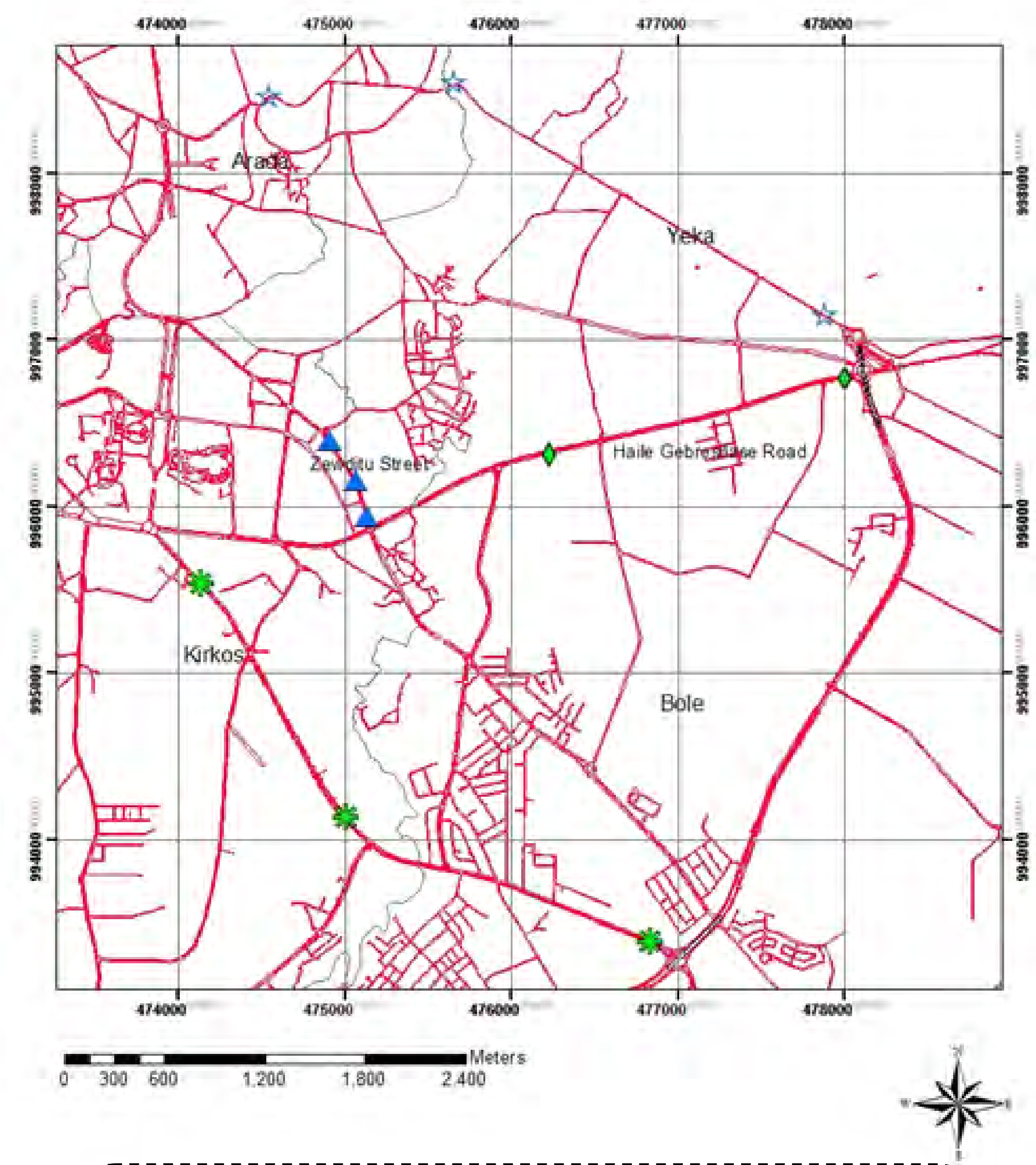
Moreover, a large number of different types of vehicles travel daily in the 2814 kilometres of the road network in the city of which 1,280 km (45.5%) is asphalt and the rest 1534 km (54.5%) is gravel road (AACG, 2009).This can be considered high for the land area occupied by the city and could be responsible for the pollution of air in the city through emitting gaseous lead compounds from the leaded gasoline vehicle use as fuel. Therefore, to get the necessary information regarding the extent of lead pollution in the roadside soils of Addis Ababa, sampling sites were selected from the major roads in the city. A number of the sampling sites in each road were chosen based on the length of the respective roads. A site outside Addis Ababa, 10 kms north from the urban activities was chosen as a background site (control). All the sampling sites are located in predominately residential or residential/commercial areas with no industrial activities. Hence, analyzing soil samples from these sites could indicate the associated lead pollution of the roads in Addis Ababa as a result of vehicular emission.

Sample sites

The roadside soils were collected along 14 selected streets/roads in the city. In this regard, the city was divided into four sectors and the roads were identified from these four sectors. The four divisions, together with the respective roads within them are as follows: Eastern Sector: Africa Avenue, Queen Elizabeth Street – Fikremariam Aba Techan Street, Haile Gebresilase Avenue and Zewditu Street (Figure 1); Northern Sector: Algerian Street, Adwa Avenue, Russia Street and Belay Zeleke Street (Figure 2); Central Sector: Arbegnoch Street, Churchill Avenue, Fitawrari Habte Giyorgis Street, Chad Street and Taitu Street (Figure 3); South and South Western Sector: Alexander Pushkin Street, Debre Zeit Road and Akaki Main Road (Figure 4). The division of the city is only for convenience of handling the large area of the city, which was found difficult to clearly show the representative sampling points in a single map.

Sample collection and treatment

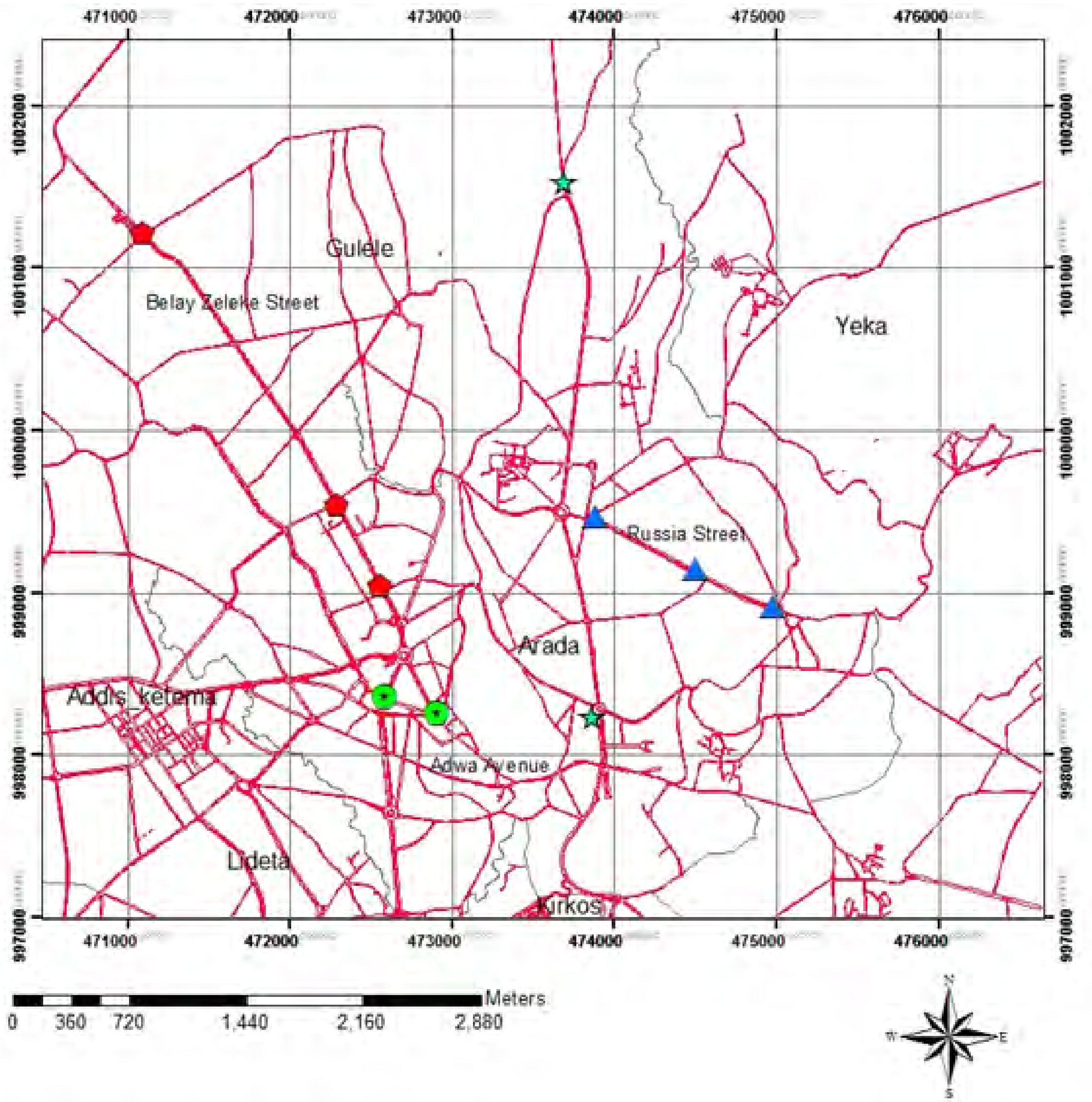
Soil samples were collected from mid-January to end of February, 2008. From each sample site, three 30 cm^2 holes were dug and about ½ a kilogram of soil was taken using a hand driven stainless steel shovel after removing the upper 1 cm surface layer (Chimuka *et al*., 2005). The samples were taken from each hole by cutting cross-sectionally, (1–15 cm) which was then pooled together to give a composite sample. Finally, the samples were packed in polyethylene bags and brought to the laboratory. In the laboratory, all samples were air dried for two days. The dried samples were then divided into quarters and one portion of each sample was ground using mortar and pestle. The samples were then sieved with a 0.09 mm mesh sieve and kept packed until further analysis. In a similar way, soil samples for the control group, which served as pollution-free reference point were brought from Entoto Mountain.



LEGEND

Africa Avenue	Queen Elizabeth Str. – Fikremariam AT Str.
CETU (S-3)	Angelican Church (4M-1)
Dembel City Center (S-4)	Kebena (4M-2)
Bole Ring Road (S-5)	Yeka Michael (4M-3)
Zewditu Street	***Haile Gebresilasie Road***
Menilik II Mau. (Z-1)	Plasa Hotel (M-3)
Kasanchis (Z-2)	Road Transport Authority (M-4)
St. Urael Church (Z-3)	

Fig. 1. Map of the Eastern part of Addis Ababa showing 4 roads with 11 sampling sites.



LEGEND

Algerian Street

- Shiromeda (S-1)
- Arat- kilo (S-2)

Russia Street

- Sidst-kilo Total (R-1)
- Sidist-kilo Tele (R-2)
- Menilik- II Hospital (R-3)

Adwa Avenue

- Charles de Gaulle Square (AD-1)
- City Council (AD-2)

Belay Zeleke Street

- St. Giyorgis Church (B-1)
- Semen Hotel (B-2)
- Adissu Gebeya (B-3)

Fig. 2. Northern part of Addis Ababa containing 4 roads with 10 sampling sites.

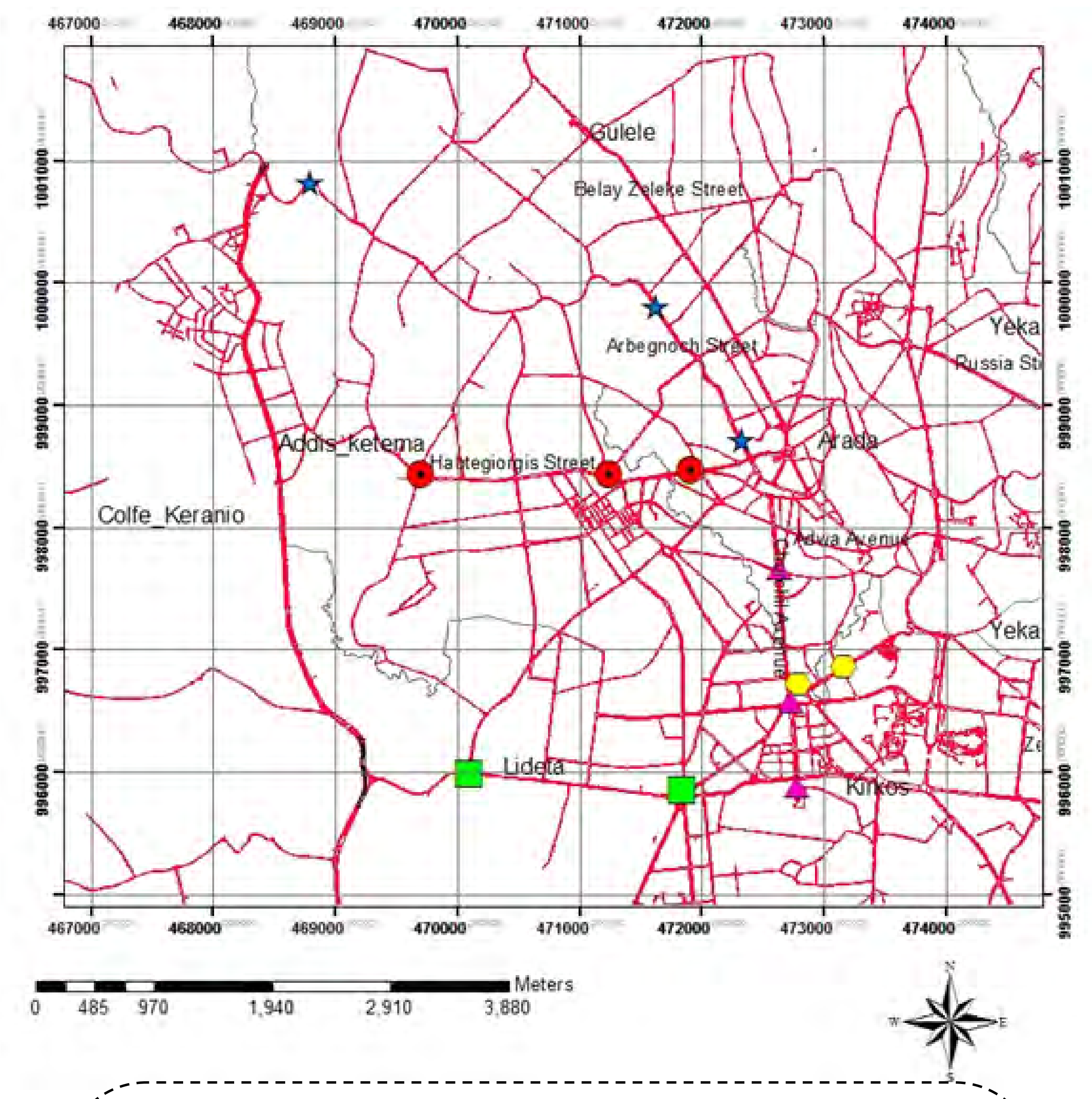


Fig. 3. Central part of Addis Ababa containing 5 roads with 13 sampling Sites.

LEGEND

Arbegnoch Street

- Abune Petros Square (A-1)
- Ras Desta Hospital (A-2)
- Asko Ring Road (A-3)

Ft. Habtegiyorgis Street

- Kelifa Business Centre (H-1)
- Gojam Berenda (H-2)
- Mesalemia (H-3)

Churchil Avenue

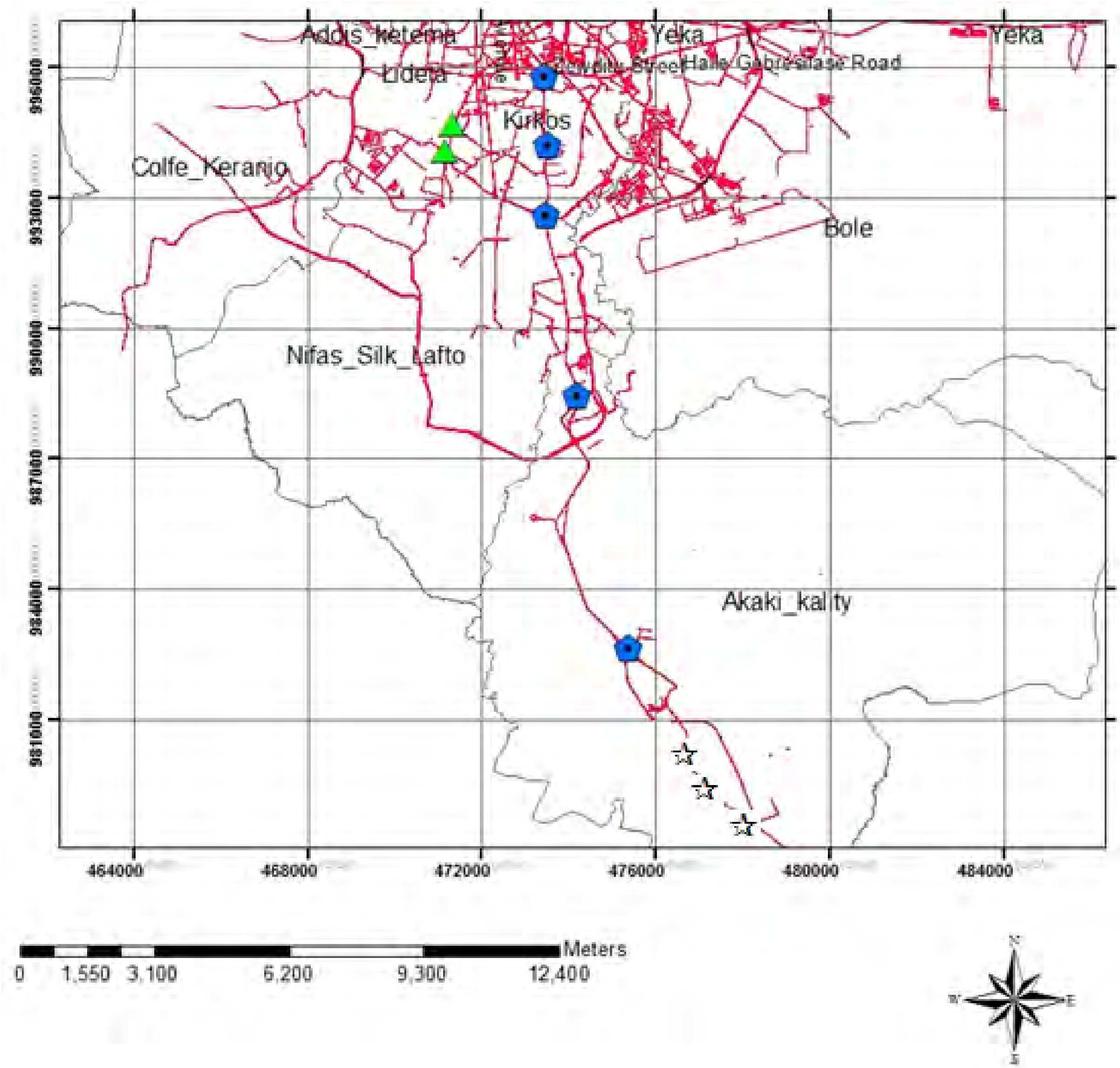
- Railway Station (C-1)
- National Theater (C-2)
- Tewodros Square (C-3)

Chad Street

- Awash Winery (M-1)
- Mexico Square (M-2)

Taitu Street

- Sheraton Square (SS-1)
- Harambe Hotel (SS-2)



LEGEND

Alexander Pushkin Street

▲ Alexander P. Street (AP-1)

▲ Kera (AP-2)

Akaki Main Road

☆ Akaki Total (AK-1)

☆ Akaki Bank (AK-2)

☆ Akaki Korkoro (AK-3)

Debre Zeit Road

⬟ St. Joseph School (SK-1)

⬟ Global Hotel SK-2)

⬟ Gotera (SK-3)

⬟ FAFA (SK-4)

⬟ Kality Total (SK-5)

Fig. 4. South and South West part of Addis Ababa containing 3 roads with 10 sampling sites.

Soil digestion procedure

A 0.5 g sample of each laboratory soil sample was weighed into 100 mL Erlenmeyer flasks. Then, each soil sample was wetted by 5 mL of distilled-deionised water. Next 3 mL HNO_3 and 10 mL HCl were added into each digestion flask. The samples were mixed with the acid mixture and digested over boiling water bath, at 92°C, for two hours. After cooling, the digestion mixture was treated with 2 mL of H_2O_2 and was filtered through Whatman No 41 filter paper. The filtrate was transferred into a 100 mL flask and was diluted to the mark. Finally, all the solutions prepared in this way were kept in the refrigerator for subsequent metal determination (VanLoon, 1985; Vandecasteele and Block, 1993).

Procedure for determination of soil pH

A 10 g laboratory soil sample was weighed into five 50 mL beakers and 25 mL distilled-deionised water was added to form 1:2.5 soil/water mixtures. Then, the beakers containing the mixture were placed on an automatic stirrer and stirred for 30 minutes; the samples were then kept to stand for about 5 minutes for the soil particles to settle. Finally, the pH meter electrodes were immersed into the soil/water mixture and the pH was measured on the upper part of the suspension (Sertse Solomon and Taye Bekele, 2000).

Procedure for determination of electrical conductivity of soil

To determine the electrical conductivity of the soil samples, a 10 g laboratory soil sample was weighed into four 100 mL beakers. Then, 50 mL of distilled-deionised water was added and the mixture was stirred using an automatic stirrer for 30 minutes. Finally, the conductivity of each sample was measured, from the upper part of the mixture, after the suspensions settled (Sertse Solomon and Taye Bekele, 2000). The temperature during this measurement was displayed by the instrument automatically.

RESULTS AND DISCUSSION

Instrumental parameters and the calibration curve

During the use of the Flame Atomic Absorption Spectrometer, the wavelength and the slit width were selected and adjusted and were kept constant until the end of the analysis. The same procedure was followed throughout the study period. Then the instrument response was plotted as a function of concentration of the analyte over the concentration range of 1 to 6 ppm, at five points. Normally, the calibration curve should be linear over a given range of analyte concentration (Fifield and Kealey, 2000). Accordingly, the calibration curve was observed to be linear with a coefficient of determination (r^2) of 0.9999. The instrumental parameters of the Flame Atomic Absorption Spectrometer (FAAS) during the determination of concentration of lead were all the same throughout the study and are described in Table 1 below.

Table 1. Instrumental parameters of FAAS during analysis of lead.

Instrumental parameters	Corresponding value (condition)
Energy	3.65×10^{-7}J
Wavelength	283.1 nm
Slit width	0.7 nm
Fuel	Air-acetylene (99 % purity)
Flam type	Lean blue
Detection limit	0.1 ppm
Sample introduction system	Direct aspiration (8 mL/min)
Radiation source	Hollow- Cathode Lamp (HCL)

Method detection limits (MDL)

The method detection limit is the lowest concentration level of the analyte of interest that can be determined to be statistically different from a blank (98% confidence). For the method used in the present study, the detection limit was calculated using the data obtained by analyzing the reagent blank. In this regard, five reagent blanks were analyzed in triplicate and the standard deviation was calculated from 15 determinations. The detection limit was obtained by multiplying the standard deviation of the blank by three, (Lovei, 1996; Fisseha Itana, 1998). Accordingly, the method detection limit obtained for the method used in the present study was 0.12 ppm while the detection limit for the instrument is 0.1 ppm.

Recovery of lead in soil samples

Soil samples were digested with HNO_3-HCl mixture followed by treatment with H_2O_2 and the filtered solutions were analyzed for lead. To evaluate the performance of this procedure, to quantitatively extract lead from the soil samples, known amounts of the standard solutions of the element were spiked into the soil sample followed by digestion, filtration, dilution and final determination by FAAS. The percentage recoveries of the spiked soil samples were found to be in the range 88.7–91.6% with an average value of 90% and the corresponding RSD values were also in the range 2.9–6.8% signifying the reliability of the method used in this study. The spiking level of lead in the soil samples, the amount measured, %R and RSD values are given in Table 2.

Table 2. Recoveries obtained in the determination of lead in spiked soil samples (*n*=3).

Spiked [Pb] (μgL^{-1})	Measured (μgL^{-1})	Recovery %	RSD %
0	18	-	
25	40.3	89.2	6.8
50	62.3	88.7	4.7
100	108.7	90.7	3.9
150	155.3	91.6	2.9
200	196.7	89.3	5.0

Lead in roadside soils of Addis Ababa

The concentrations of lead together with some soil properties of Addis Ababa city from the 14 roads and from the site for the control group are given in Table 3. The concentrations of lead were observed to vary from 70.3 ± 0.5 to 1079.9 ± 7.7 µg/g dry weight. The highest concentrations of the metal were determined for samples collected from Charles de Gaulle Square (1079.9 ± 7.7 µg/g) and Kera areas (1062.4 ± 54.1 µg/g). Data in Table 3 show that the levels of lead in roadside soils of Addis Ababa city are significantly higher than the background lead concentration (18.8 ± 0.5 µg/g dry weight). This indicates the contribution of vehicular emission to lead in roadside soils considered in the present study.

More importantly, out of the total 14 roads, 13 (92.31%) of them have shown an average lead concentration greater than the maximum value recommended by WHO, that is 100 µg/g (Louella *et al*., 2006). In addition, the sample sites with the highest lead concentrations are located in busy residential/commercial areas frequented by young children and adults. This may aggravate the exposure of the children to be intoxicated by lead. Moreover, lead is not biodegradable and when it gets contact onto soil, it usually sticks to soil particles and retained in the top few centimeters due to its interaction with soil colloids (McBride, 1994). Hence, it is likely to be quite persistent in the areas where it was found to be at higher concentrations.

pH of the soil samples

The availability of lead in soil is directly dependent upon the pH of the soil. Under oxidizing conditions, the lead(II) ions become less soluble as the soil pH is raised. Complexation with organic matter, chemisorption on oxides and silicate clays, and precipitation as carbonates, hydroxide or phosphate are all favoured at higher pH. However, in alkaline soils, solubility may increase by formation of soluble lead-organic and lead-hydroxy complexes. In near-neutral soils (pH 6–8) lead is strongly bound to soil particles and may not be available for plant uptake. It becomes more soluble in acidic soils (pH less than 5). Lead is the least mobile heavy metal in soils, especially under non acid conditions (McBride, 1994).

In order to understand the ease of accessibility of lead in the roadside soils to plants and animals of the surrounding, the pH of all the soil samples, whose lead content has been investigated, were determined. Accordingly, the pH values of the soil samples ranged from 5.62 ± 0.16 to 8.11 ± 0.26. These values show that most of the soil samples are within the neutral pH range (6–8). The observations on the pH values may signify that the lead in the soil is tightly bound and may not be accessible, especially for plants (McBride, 1994).

Table 3. Concentration of lead expressed in µg/g with 95% confidence interval obtained for the soil samples collected from 14 selected roads in Addis Ababa with their respective sample sites, *n* = 3.

Street name	Sample code	Distance (m)[a]	Traffic volume/hr Mean (range)	pH (25^0C)	Cond.(µS) $\overline{X}$ ± ts√N	[Pb] $\overline{X}$ ± ts√N	Average[Pb] $\overline{X}$ ± ts√N
Algerian Street –	S-1	0.5	1846 (1720–1984)	7.66±.24[b]	686±9.9[b]	265.2±11.4[b]	
Africa Avenue	S-2	0.75	2684 (2579–2767)	7.16±.14	618±7.9	778.0±54.4	
	S-3	1	2908 (2881–2947)	7.33±.21	1116±6.0	664.8±95.1	
	S-4	2	3755 (3562–3874)	7.00±.11	162.5±8.9	336.9±22.3	474.6±12.3[b]
	S-5	0.5	2240 (2159–2286)	5.90±.25	265±3.2	328.1±53.1	
Equatorial	M-1	0.75	1938 (1897–1969)	7.19±.15	3900±2.7	307.5±7.0	
Guinea Street –	M-2	0.8	3913 (3874–3958)	7.41±.19	553±8.4	705.2±15.1	
Chad Street	M-3	0.75	2864 (2789–2961)	7.57±.33	370±9.9	664.4±9.7	483.7±3.7
	M-4	0.5	2914 (2878–2952)	7.48±.24	338±5.7	887.5±11.9	
Zewditu Street	Z-1	0.75	2250 (2172–2294)	7.50±.18	1135±8.4	560.1±50.1	
	Z-2	0.5	2115 (2072–2141)	7.60±.27	282±6.6	629.4±18.6	
	Z-3	0.5	4933 (4878–4999)	7.29±.16	1180±3.2	919.8±15.9	703.1±18.6
Russia Street	R-1	0.75	1393 (1380–1418)	6.96±.11	416±12.7	160.4±14.9	
	R-2	0.5	700 (628–742)	7.00±.15	539±10.4	117.6±8.4	141.6±6.0
	R-3	1	473 (421–609)	6.97±.19	546±5.7	146.7±6.0	
Dej. Belay	B-1	0.5	2255 (2197–2328)	7.18±.12	970±15.1	259.0±4.5	
Zeleke Street	B-2	0.5	1920 (1875–1954)	7.18±.14	750±10.9	457.2±29.3	
	B-3	1.5	600 (549–627)	5.62±.16	830±17.6	71.2±3.0	262.6±9.9
Arbegnoch	A-1	0.5	1629 (1517–1718)	7.30±.21	888±13.2	638.5±79.4	
Street	A-2	0.5	1507 (1482–1517)	7.19±.17	549±8.4	836.6±26.8	
	A-3	1.5	1228 (1180–1265)	6.33±.11	1760±5.2	476.2±59.6	650.4±34.3
Fit. H/Gyiorgis	H-1	0.5	2109 (2069–2134)	7.70±.23	505±11.2	151.3±9.4	
Street	H-2	0.5	2232 (2186–2256)	7.16±.19	1609±12.9	215.6±36.7	231.3±19.4
	H-3	0.5	2062 (2009–2111)	7.49±.14	625±6.5	327.0±76.5	
Adwa Avenue	AD-1	0.5	2735 (2672–2839	7.62±.23	206±3.0	1079.9±7.7	
	AD-2	0.5	2372 (2315–2439)	7.55±.19	467±6.2	865.9±3.5	972.9±39.5
Debre Zeit Road	SK-1	0.5	2905 (2867–2924)	7.53±.20	258±5.7	450.3±3.5	
	SK-2	0.5	2968 (2811–3095)	7.88±.14	515±10.2	345.2±10.9	
	SK-3	0.5	4471 (4442–4487)	8.11±.26	335±8.9	373.3±14.4	293.6±2.0
	SK-4	1.5	2763 (2640–2867)	7.74±.16	596±6.7	146.1±5.9	
	SK-5	1	2286 (2190–2336)	7.50±.12	2490±3.0	153.1±5.9	
Alexander	AP-1	0.5	3545 (3472–3639)	7.69±.11	160±3.2	1062.4±54.1	
Pushkin Street	AP-2	0.75	2825 (2751–2913)	7.73±.17	970±6.0	134.5±8.9	598.5±98.8
	C-1	1.5	3883 (3812–3942)	6.45±.15	352±8.2	517.8±44.7	
Churchill	C-2	0.5	1934 (1894–2011)	7.54±.18	534±11.4	560.8±9.9	
Avenue	C-3	0.5	2730 (2683–2790)	7.43±.21	490±6.9	413.3±23.1	497.3±17.1
Queen Elizabeth	4M-1	1	1298 (1248–1324)	7.23±.13	659±8.4	144.5±5.0	
Street – Fikre-	4M-2	0.75	1245 (1208–1311)	7.45±.14	650±6.5	112.4±5.0	
mariam Aba	4M-3	2	877 (784–931)	7.64±.22	216±4.7	82.7±1.5	113.2±2.5
Techan Street							
Taitu Street	SS-1	0.5	2045 (2000–2112)	6.24±.16	900±3.5	260.7±9.9	
	SS-2	0.75	3510 (3455–3584)	6.61±.11	2380±0.7	458.9±65.3	359.8±28.7
	AK-1	0.5	1654 (1629–1701)	6.98±.13	745±10.4	81.5±1.5	
	AK-2	0.75	832 (761–893)	7.05±.22	1195±15.6	70.3±0.5	
Akaki Main Road	AK-3	1.5	657 (621–678)	7.20±.19	234±4.0	82.6±1.0	78.1±0.5
Control	Co	-	-	6.70±.17	34±4.2	18.8±0.5	18.8±0.5

[a]*The distance is measured from the main road to the sample site in meters.*
[b]*Results are calculated at 95% confidence interval from the pooled standard deviation for the mean of a triplicate analysis.*

Electrical conductivities (EC) of the soil samples

Salinity or the concentration of dissolved salts of a given solution is most conveniently measured by electrical conductivity. This is based on the principle that the conductivity or ease with which an electric current is carried through a solution is proportional to the quantity of ions (actually, the quantity of ionic charge) in the solution (McBride, 1994). Moreover, conductivity is a numerical expression of the ability of a solution to carry an electric current and it is usually expressed in µS (micro Siemens). Thus, EC depends on the presence of ions, on their total concentration and on the temperature of the measurement. Soluble salts are determined in an extract of known quantity of solids or liquids. For soils, the methods commonly used are the EC on a soil/water mixture of 1:1, 1:5 and 1:10 (Sertse Solomon and Taye Bekele, 2000).

The conductivities of the soil samples collected from all the sampling sites, in this study, were determined and are reported at 25°C (Table 3), which was done automatically by the conductivity meter. The values obtained fall within the range 160 ± 3.2 to 3900 ± 2.7 µS. The lowest values for the electrical conductivity were obtained for those sampling sites with the maximum (above 1000 µg/g) lead concentrations and the corresponding conductivities were: 160 ± 3.2 µS for Kera and 206 ± 3.0 µS for de Gaulle Square. This implies that the soils in these sampling sites might have the possibility of containing higher concentration of the loosely bound lead particulates.

Comparison of roadside lead among the selected roads

The average values for triplicate measurements of the lead concentration obtained from all streets considered in Addis Ababa are shown in Figure 5. Except for the soil samples from Akaki Main Road, all the 13 roads were found to contain average lead levels above 100 µg/g. The average lead concentrations of all the roads considered in Addis Ababa in decreasing order were: 972.9 ± 39.5, 703.1 ± 18.6, 650.4 ± 34.3, 598.5 ± 98.8, 497.3 ± 17.1, 483.7 ± 3.7, 474.6 ± 12.3, 359.8 ± 28.7, 293.6 ± 2.0, 262.6 ± 9.9, 231.3 ± 19.4, 141.6 ± 6, 113.2 ± 2.5, 78.1 ± 0.5 and 18.8 ± 0.5 µg/g for Adwa Avenue, Zewditu Street, Arbegnoch Street, Alexander Pushkin Street, Churchill Avenue, Equatorial Guinea Street – Chad Street, Algerian Street – Africa Avenue, Taitu Street, Debre Zeit Road, Dej. Belay Zeleke, Fit. Habte Giyorgis Street, Russia Street, Queen Elizabeth Street – Fikremariam Aba Techan Stret, Akaki Main Road and the control from Entoto Mountain, respectively.

Variation of the roadside lead levels with traffic density

To correlate the lead content of roadside soils with the traffic density of the road, investigation was done by counting the number of all types of vehicles that pass a point at a given road for one hour (9–10 am) for three successive working days and the average was taken. Results of this study are shown in Table 3. At sites located in relatively enclosed areas of higher atmospheric stability, lead contents increased markedly with increasing traffic density. However, in the absence of such atmospheric stability, the distribution of lead in roadside soils revealed different patterns, which were attributed mainly to the effect of meteorological factors such as wind (Enayatzamir *et al.*, 2012; Farooq *et al.*, 2008).

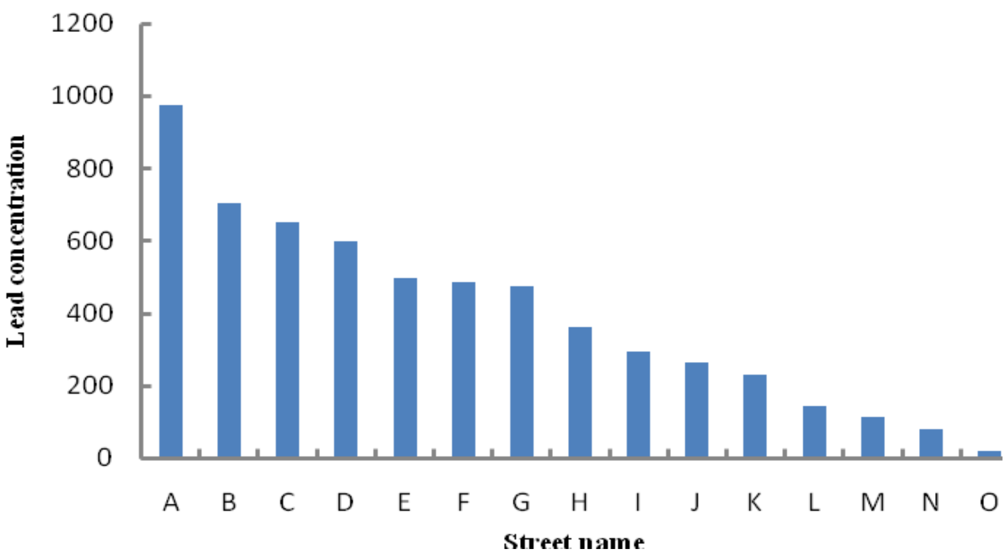


Fig. 5. Average concentrations of lead with respect to sampling streets in Addis Ababa city: A (Adwa Avenue), B (Zewditu Street,), C (Arbengoch Street), D (Alexander Pushkin Street), E (Churchill Avenue), F (Equatorial Guinea Street – Chad Street), G (Algerian Street – Africa Avenue), H (Taitu Street), I (Debre Zeit Road), J (Dej. Belay Zeleke Street), K (Fit. H/Gyiorgis Street), L (Russia Street), M (Queen Elizabeth Street – Fikremariam Aba Techan Street), N (Akaki Main Road) and O (Control), *n* = 3.

Moreover, the correlation between lead concentrations of the roadside soils and the traffic density of the corresponding roads was evaluated using the Pearson Coefficient of Correlation. Using this method, the correlation between the two variables (the lead concentration and traffic density) was found to be r (13) = 0.66, $p < 0.05$. This means that there is a strong positive or direct correlation between the two variables (Miller and Miller, 2005). The relationship between the traffic densities of the streets and the corresponding average lead levels of the streets is given in Figure 6 below. The lead concentrations are given in µg/g.

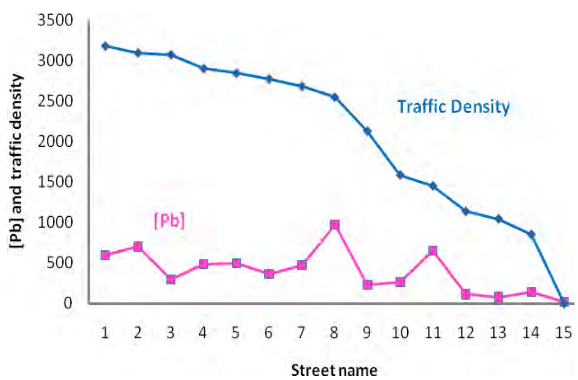


Fig. 6. Variation of lead concentrations with traffic densities. 1 (Alexander Pushkin Street), 2 (Zewditu Street), 3 (Debre Zeit Road), 4 (Equatorial Guinea Street – Chad Street), 5 (Churchill Avenue), 6 (Taitu Street), 7 (Algerian Street – Africa Avenue), 8 (Adwa Avenue), 9 (Fit. H/Gyiorgis Street), 10 (Dej. Belay Zeleke Street), 11 (Arbegnoch Street), 12 (Queen Elizabeth Street – Fikremariam Aba Techan Street), 13 (Akaki Main Road), 14 (Russia Street), 15 (Control).

Comparison of the average lead concentration in Addis Ababa with cities of other countries

The average concentration of lead obtained, in this study, for the roadside soils of Addis Ababa has been compared with the levels of lead in the roadside soils of other cities around the world. The levels of lead in roadside soils of these cities are shown in Table 4. It is noted that slightly higher quantities of lead were obtained for the soil samples of Addis Ababa, comparing to the accumulation levels determined for most of the other selected cities. This could probably be due to the longer time since the use of leaded gasoline was phased out in the other countries and the variations in their traffic densities.

Table 4. Comparison of average lead concentration obtained in Addis Ababa with other studies.

Country or City	[Pb] µg/g	References
Northern England	1198	(Akbar *et al.*, 2006)
Dares Salaam, Tanzania	152.5	(Luilo and Othman, 2006)
Aurangabad, India	65.5	(Asif *et al.*, 2011)
Jos metropolis, Nigeria	12.10	(Abechi *et al.*, 2010)
Jordan	188.8	(Jaradat and Momani, 1999)
Ljubljana, Slovenia	516	(Plesnicar and Zupancic, 2005)
Riyadh, Saudi Arabia	72	(Al-Shyeb and Seaward, 2001)
Elazig, Turkey	45	(Bakirdere and Yaman, 2008)
Addis Ababa	418.63	The current study

Contamination factor (CF)

The level of contamination of soil by metal is expressed in terms of a contamination factor (CF), and the values were calculated using the following equation:

$$CF = \frac{C_m Sample}{C_m\ Background}$$

where CF is the contamination factor, C_m Sample is the concentration of the metal in the samples analyzed and C_m Background is the metal concentration in the control sample.

The contamination factor, CF < 1 refers to low contamination; $1 \leq CF < 3$ means moderate contamination; $3 \leq CF \leq 6$ indicates considerable contamination and CF > 6 indicates very high contamination (Mmolawa *et al.*, 2011). Accordingly, the contamination factor for the average lead concentration of Addis Ababa was found to be 22.3 which indicate that the city is highly contaminated by lead.

SUMMARY AND CONCLUSIONS

The extent to which lead has been accumulated in the roadside soils of Addis Ababa was investigated by collecting soil samples from 14 representative sampling sites. Following the physical pretreatment for size reduction, the soil samples were acid digested for final determination using atomic absorption spectrometry. The contents of lead determined in the roadside soil samples of Addis Ababa were generally higher than 100 µg/g. Moreover, the contribution of vehicular emission for lead in roadside soils of Addis Ababa was indicated from the observed difference in lead levels between the sites that are exposed to vehicular emission and the background site (control).

Except for those sample sites with recently incorporated new soil cover to the roadside and those with windy meteorological conditions, in most of the sample sites the concentration of lead observed is directly correlated with the traffic density of the roads near the sample sites. Hence, the major source of lead in road side soils is the use of lead additives in gasoline and the high concentration of lead in almost all of the sampling sites of Addis Ababa city may be attributed to the previous use of leaded fuel for automotives. Although at present the lead content of the gasoline imported and distributed by the Ethiopian Petroleum Enterprise is low (0.013 g/L), the lead from previous use has persisted in the soils and can have long term effects. Moreover, the level of lead determined in the roadside soil samples of this study was also compared with the levels determined in similar studies in the other cities around the world. It has been recognized that slightly higher quantities of lead were obtained for the soils of Addis Ababa, compared to the accumulations determined for many other cities around the world.

ACKNOWLEDGEMENTS

The authors are grateful to the Swedish International Development Agency and the Department for Research Cooperation (SIDA/SAREC) for the financial support made through the Pesticide Research Project. The Department of Chemistry of Addis Ababa University is also greatly acknowledged for availing the experimental facilities during the whole period of the research work.

REFERENCES

1. AACG (2009). Urban development indicators, 2009. Addis Ababa City Government (AACG), Finance and Economic Development Bureau, Addis Ababa, 56 pp.
2. Abdul-Sahib, A. and Darryl, H. (2000). Distribution of vehicular lead in roadside soils of major roads of Brisbane, Australia. *Water Air Soil Pollut.* **118**:299–310.
3. Abechi, E.S., Okunola, O.J., Zubairu, S.M.J., Usman, A.A. and Apene, E. (2010). Evaluation of heavy metals in roadside soils of major streets in Jos metropolis, Nigeria. *J Environ Chem Ecotoxicol.* **2(6)**:98–102.
4. Akbar, K.F., Hale, W.H.G, Headley, A.D. and Athar, M. (2006). Heavy metal contamination of roadside soils of Northern England. *Soil Water Res.* **1(4)**:158–163.
5. Al-Shyeb, S.M. and Seaward, M.R.D. (2001). Heavy metal content of roadside soils along the ring road in Riyadh (Saudi Arabia). *Asian J Chem.* **13(2)**:407–423.
6. Asif, S., Abed, S. and Farooqui, M. (2011). Presence of lead in the roadside soil of Aurangabad City. *Adv Appl Sci Res.* **2(4)**:371–373.
7. Bakirdere, S. and Yaman, M. (2008). Determination of lead, cadmium and copper in roadside soil and plants in Elazig, Turkey. *Environ Monit Assess.* **136(1–3)**:401–410.
8. Bharati, P.D., Dnyan, P.N. and Venkat, G.R. (1992). Lead in roadways dust and roadside plants: A case study of the metropolis of Pune, Maharashtrta, India. *Biologia Indica.* **1(2)**:43–48.
9. Bjerregaard, P., Johanson, P., Mulvad, G., Pederson, H.S. and Hansen, J. C. (2004). Lead sources in human diet in Greenland. *Environ Health Perspect.* **112(15)**:1496–1498.
10. CSA (2008). Summary and statistical report of the 2007 population and housing census. Central Statistical Agency (CSA) , Population Census Commission, Federal Democratic Republic of Ethiopia, Addis Ababa, 113 pp.
11. CSA (2011). Statistical Abstract, Population 2011. Central Statistical Agency (CSA), Federal Democratic Republic of Ethiopia, Addis Ababa, 70 pp.
12. Chimuka, L., Mugwedi, R., Moboladisoro, B.H. and Odiyo, O.J. (2005). Metals in environmental media: A study of trace and platinum group metals in Thohoyandou, South Africa. *Water SA.* **31(4)**:581–588.
13. Elizabeth, O. (2003). The effect of lead on the phytochemistry of tithonia diversifolia exposed to roadside automotive pollution or grown in pots of Pb-supplemented soil. *Braz J. Plant Physiol.* **15(3)**:149–158.
14. Enayatzamir, K., Amini, M., Savaghebi, G. and Abbaspour, K.C. (2008). Quantifying the effect of traffic on lead accumulation in soil: a case study in Iran. *Caspian J. Env. Sci.* **6**:11–17.
15. Fantaye Wondwossen (2003). *Lead in Human Primary Teeth from Rural and Urban Ethiopia.* International Association for Dental Research, Alexandria, USA.
16. Farooq, H., Jamil, Y., Ahmad, M.R., Khan, M.A.A., Mahmood, T., Mahmood, Z., Haq, Z. and Khan, S.A. (2012). Lead pollution measurement along national highway and motorway in Punjab, Pakistan. *J. Basic Appl. Sci.* **8**:463–467.

17. Fifield, F.W. and Kealey, D. (2000). The evaluation of results and methods. **In**: *Principles and Practice of Analytical Chemistry*, pp. 23–30. Fifth Edition, Blackwell Science Ltd, London.
18. Fisseha Itana (1998). Comparative study on soil pollution with toxic substances on farm lands close to old and new industrial sites in Ethiopia. *Bull. Chem. Soc. Ethiop*. **12**:105–112.
19. Fisseha Itana (2002). Metals in leafy vegetables grown in Addis Ababa and toxicological implications. *Ethiop. J. Health Dev*. **16**:295–301.
20. Gzyl, J. (1990). Lead and cadmium contamination of soil and vegetables in the Upper Silesia Region of Poland. S*ci Total Environ*. **96(1–2)**:199–209.
21. Ho, Y.B. (1990). The effect of lead reduction in petrol on the lead content of kerb side dust in Hong Kong, dust contamination and transport at highway surfaces. *Sci Total Environ*. **93**:411–418.
22. Jankiewicz, B., Ptaszyński, B. and Wieczorek, M. (2001). Spectrophotometric determination of lead in the soil of allotment gardens in Łódź. *Pol. J Environ Stud*. **10(2)**:123–126.
23. Jaradat, Q.M. and Moman, K.A. (1999). Contamination of roadside soil, plants, and air with heavy metals in Jordan; A comparative study. *Turk. J. Chem*. **23**:209–220.
24. Louella, F.O., Annie, M.P.A., Jacqueline, A.P. and Gilbert, C.S. (2006). Levels of lead in urban soils from selected cities in a central region of the Philippines. *Environ. Sci. Pollut. Res.* **13(3)**:177–183.
25. Lovei, M. (1996). *Why Lead Should be Removed from Gasoline*, World Bank, Vol. **4**(2), pp. 1–70.
26. Luilo, G.B. and Othman, O.C. (2006). Lead pollution in urban roadside environments of Dares Salaam City. *Tanz. J. Sci.* **32(2)**:61–67.
27. McBride, M.B. (1994). Lead. **In**: *Environmental Chemistry of Soils*, 1st edn, pp. 336–337. Oxford University Press, New York.
28. Miller, J.N. and Miller J.C. (2005). *Statistics and Chemometrics for Analytical Chemistry*, 5th edn, Pearson Education Limited, Harlow, England, pp. 215–250.
29. Mmolawa, K.B., Likuku, A.S. and Gaboutloeloe, G.K. (2011). Assessment of heavy metal pollution in soils along major roadside areas in Botswana. *Afr. J. Environ. Sci. Tech*. **5(3)**:86–196.
30. Olagire, A.A. and Ayodele, E.T. (2003). Study of atmospheric pollution levels by trace elements analysis of tree bark and leaves. *Bull. Chem. Soc. Ethiop*. **17**:11–17.
31. Opeolu, B.O., Adebayo, K., Okuneye, P.A. and Badru, F.A. (2010). Physicochemical and microbial assessment of roadside food and water samples in Lagos and Environs. *J Appl Sci Environ Manage*. **14(1)**:29–34.
32. Pirzada, H., Ahmad, S.S., Rashid, A. and Shah, T. (2009). Multivariate analysis of selected roadside plants (Dalbergia Sissoo and Cannabis Sativa) for lead pollution monitoring. *Pak. J. Bot*. **41(4)**:1729–1736.
33. Plesnicar, A. and Zupancic, N. (2005). Heavy metal contamination of roadside soil along Ljubljana-Obrezje highway. *RMZ- Mater and Geoenviron*. **52(2)**:403–418.
34. Sertse Solomon and Taye Bekele (2000). *Procedures for Soil and Plant Analysis.* National Soil Research Centre, Ethiopian Agricultural Research Organization, Addis Ababa, pp. 25–60.
35. Sharma, S. and Prasad, F.M. (2010). Accumulation of lead and cadmium in soil and vegetable crops along major highways in Agra (India). *E-J. Chem*. **7(4)**:1174–1183.
36. Tsuji, L.J.S., Nioboer, E., Karagatzides, J.D. and Kozlovich, D.R. (1997). Elevated dentine lead levels in adult teeth of First Nation People from an isolated region of Northern Ontario, Canada. *Bull. Environ. Contam. Toxicol.* **59**:854–860.
37. Turer, D., Maynard, J.B. and Sansalone, J.J. (2001). Heavy metal contamination in soils of urban highways, comparison between runoff and soil concentrations at Cincinnati, Ohio, *Water, Air and Soil Pollution*. **132**:293–314.
38. Vandecasteele, C. and Block, C.B. (1993). Lead Analysis. **In**: *Modern Methods for Trace Element Determination*, pp 1–74. John Wiley and Sons, Chichester.
39. VanLoon, J.C. (1985).). Lead determination. **In**: *Selected Methods of Trace Metal Analysis-Biological and Environmental Samples*, pp 84–110. John Wiley and Sons: New York.
40. Ward, N.I. (1990). Lead contamination of the London Orbital (M25) motorway (since its opening in 1986), air quality and dispersion modelling. *Sci Total Environ*. **93**:277–283..
41. Wayne, G.L. and Ming-Ho, Y. (2004). Heavy Metals, Lead. **In**: *An Introduction to Environmental Toxicology*, 3rd edn, pp. 219–224. Lewis Publishers, Washington DC.
42. WB (1998). *Phasing Out Lead from Gasoline, World Wide Experience and Policy Implications,* Technical Paper, World Bank (WB), No.397. pp. 1–57.
43. WB (2003). Phase-out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa, the Case of Ethiopia Action Plan, the International Bank for Reconstruction and Development, World Bank (WB), No. 038/03. pp. 1–60.
44. Zaki, M.S., Mostafa, S. and Awad, I. (2010). Some studies on lead toxicity in Marino Sheep. *J Am Sci*. **6(4)**:128–131.