AIR POLLUTANTS SOURCE TRACKING

By

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CERTIFICATION OF THESIS WORK

We the undersigned, glad to certify that **Sk. Salahuddin Ahammad** candidate for the degree of **Master of Science in Engineering (Chemical)** has presented his thesis work on the subject **"Air Pollutants Source Tracking"**. The thesis is acceptable in form and content. The student demonstrated a satisfactory knowledge of the field covered by this thesis in an oral examination held on **August 09, 2008.**

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ABSTRACT

The air quality of Dhaka city is regarded as polluted. Previous air quality research works found Al, As, Br, Ca, C, Cd, Cl, Co, Cr, Cu, Fe, K, Mn, Ni, P, Pb, S, Si, Ti, V and Zn in the air borne particles of Dhaka city. Some of these elements are highly toxic and sources of these pollutants were not tracked extensively for Dhaka city. The aim of this thesis work was to track some significant sources of air pollutants in Dhaka city to know their characteristics in terms of concentrations of some major elements and some environmentally significant trace heavy metals.

Eleven samples were collected from five types of sources such as agricultural soil, brickfield coal, road dust, stone crushing dust and industrial cement dust. Sampling locations of soil were Joynabari in Hemayetpur and Basta in Keraniganj and road dust were Mohakhali, Farmgate, Gulistan, Jatrabari and Rayerbagh in Dhaka city. Coal samples were collected from HMB and HNB brickfield at Aminbazar, Dhaka and rock dust sample was taken from stone crushing zone near Kachpur Bridge. Cement sample was collected from Scan Cement produced at Rupganj. Major elements in the samples were identified by EDX analysis and some major (Fe, Mg, Ca and K) and trace (Cd, Cr, Co, Cu, Pb, Ni, Mn, V, Zn) elements were quantified using AAS, ICP-MS and Flame-photometer.

Observing the EDX spectrums O, C, Fe, Al and Si were identified as the most common major elements in the samples and Na, K, Ca and S were also recognized in the samples. Concentrations of trace heavy metals in the samples revealed some vital information. Levels of heavy metals such as Cr, Cu and Ni in soil samples exceeded the guideline values for common soil. Moreover, contents of Cd and Pb in Joynabari soil sample also overtook the permissible limits for common soil. Elemental concentrations of road dust revealed that Cd, Cu and Pb in Mohakhali, Farmgate, Jatrabari and Rayerbagh road dust samples crossed the acceptable limits for common soil. Moreover, significantly high levels of Cu and Cr were located in Gulistan and Rayerbagh road dust samples. Furthermore, levels of Mn in Jatrabari and Rayerbagh road dust samples were detected remarkably high. Significant levels of various heavy metals were also tracked down in coal, rock dust and cement samples. Elevated levels of trace heavy metals in soil and road dust may be due to rapid urbanization, industrialization and increased vehicular emissions. This study could be helpful scientific source of information for industrial communities and regularity bodies to minimize and control emission to improve air quality.

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CHAPTER 1

INTRODUCTION

Air quality is one of the major environmental and health concerns for Bangladesh. There is a scarcity of fresh air at Dhaka city. as various air pollutants sources are increasing day by day. Although some deadly sources of air pollutants have been abolished by banning leaded gasoline and two-stroke baby taxies from Dhaka city, but still ambient particulate matters do not meet the air quality standards set by government of Bangladesh as well as by WHO (World Health Organization). As population of this city raise at a high rate compare to the facilities for sustainable living environment. the life supporting utilities like air, water, and foods are being polluted by various sources.

Air pollutants can be defined as the substances present in the air, which have harmful impacts on humans and environment. Air pollutants may attribute to natural or man-made sources and may take the form of solid, particles, liquid droplets or gases. The US EPA listed 188 toxic air pollutants in The 1990 Clean Air Act Amendments, which were required to control. These pollutants are divided into various groups such as particulate matter, volatile organic compounds and halogen compounds and also include are more commonly–known pollutants such as lead, mercury and asbestos [1]. Trace heavy metals contamination in the environment is a major concern because of their toxicity and threat to human and environment [10]. The status of air borne heavy metals in Dhaka city air has been reported by various researchers [2-8]. Trace heavy metals like arsenic. cadmium, chromium, cobalt. copper, lead, mercury, manganese, nickel, vanadium and zinc along with many other elements were found in the ambient air of Dhaka city [7-8].

From the literature it has been revealed that soil dust, road dust, coal fly ash, rock dust, cement and vehicular emissions are some remarkable sources of particulate air pollutants. However, it should be mentioned that there is a scarcity of knowledge on the heavy metals status in these sources of particulate air pollutants at Dhaka city as very limited number of research works have been done regarding this issue for Dhaka city as well as for Bangladesh. In the past a study on concentrations of trace elements in road dust of Dhaka city were performed to know the air environmental conditions and significant amount of arsenic, chromium, copper, lead, nickel, vanadium and zinc were found [9-10]. Moreover, few reports on trace elements in soil and coal were also found [26, 28]. However, there are many other effective air pollutants sources, which may have toxic heavy metals and some of the environmentally significant trace elements did not get proper attention in the past studies. To fulfill this gap of knowledge on the air pollutants sources new and innovative research works are very essential.

Detail characteristics of air pollutants sources are vital to understand the severity of the sources and to establish proper abatement plans. One of the main difficulties in air pollution management is to determine the quantitative relationship between ambient air quality and pollutant sources. Moreover, Particulate air pollution sources and their pollution mechanisms are difficult to predict. Often much pollution related data are required to determine the state of air pollution and their possible sources. This project was designed to track some potential sources of particulate air pollutants to know the status of some major elements and toxic trace elements in those sources.

At the initial stage of this study five types of significant particulate air pollutants sources were selected and eleven representative samples were collected within and around Dhaka city. The selected sources were agricultural soil, brickfield coal, road dust, stone crushing dust and industrial cement dust. Sampling locations of soil were Joynabari in Hemayetpur and Basta in Keraniganj and road dust were Mohakhali, Farmgate, Gulistan, Jatrabari and Rayerbagh in Dhaka city. Coal samples were collected from HMB and HNB brickfields at Aminbazar. Dhaka and rock dust sample was taken from stone crushing zone near Kachpur Bridge. The cement sample (as a surrogate industrial fugitive cement particles emission sample) collected from Scan Cement produced at Rupganj.

The collected samples were preserved and analyzed both in internal and outside laboratories. To identify major elements in the source samples EDX analysis was performed in the laboratory of Material and Metallurgical Department, BUET. Twelve elements were commonly searched in the samples .The elements were Ca. Cd, Cr, Co. Cu, Fe, K. Mg, Mn, Ni. Pb and V. The elemental concentrations of the samples were determined in BCSIR Laboratory. Dhaka using ICP-MS (Inductively Coupled Plasma-mass Spectrometer), AAS (Atomic Absorption Spectrophotometer) and Flame Photometer. Moreover, levels of zinc were determined for coal samples.

From the EDX analysis most common major elements found among the samples were O. C, Fe. Al and Si. In addition to this Na. K. S and Ca were also detected in the samples.

Concentrations of Fe, Ca. K and Mg in soil, road dust. rock dust and cement samples were found much higher than other elements. A comparative study on distribution of trace heavy metals such as cadmium, chromium, cobalt, copper, manganese, nickel, lead. and vanadium in the samples was done. Levels of some trace metals in the sources were found remarkably high compared to the average levels of Bangladeshi soil and guideline values for common soil. The highest levels of various trace metals observed in the samples are provided in Table 1.1 below.

Table 1.1. The highest levels (mg/kg) of trace heavy metals found in the samples

Elements	The highest level	Source type	Location
Cadmium	8.28	Road dust	Farmgate
Chromium	267.4	Cement	Rupganj
Cobalt	36.4	Cement	Rupganj
Copper	216	Road dust	Jatrabari
Lead	238	Road dust	Rayerbagh
Manganese	1338	Road dust	Rayerbagh
Nickel	165.1	Scan cement	Rupganj
Vanadium	155.7	Soil	Basta

It was revealed from the concentrations of the trace metals that levels of cadmium, chromium, copper, lead and nickel in Joynabari soil sample crossed the maximum tolerable limits for common soil. Moreover, chromium, copper and nickel levels in Basta soil sample also exceeded the standard values. Levels of cadmium, copper, lead in Mohakhali, Farmgate, Jatrabari and Rayerbagh road dust were found higher than acceptable limits for common soil. Moreover, copper level in Gulistan and chromium level in Rayerbagh road dust samples also overtook the permissible limits. The highest level of manganese was found in Rayerbagh road dust sample. Coal samples were enriched with chromium. copper, lead. nickel, vanadium and zinc. Significant amounts of cadmium, copper, lead. nickel and vanadium were tracked down in rock dust sample. In cement sample remarkable amounts of chromium, cobalt. copper, lead and nickel were noticed. The findings would be used to propose possible methods to reduce air pollution from these sources and the analytical data can be used as reference for future remedial applications.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Introduction

Fundamental knowledge on air pollution is prerequisite to deal with any research work related to air pollution and control. As a basic concept air pollution can be defined as the introduction of chemicals, particulate matter and biological materials into the atmosphere which may have harmful effects on human beings or other living organism or natural ecosystem[11]. According to US EPA there are six criteria air pollutants namely carbon monoxide, sulfur oxides, nitrogen oxides, ozone, lead and particulate matter [1]. Dhaka city air is being polluted predominantly with these criteria pollutants. Particulate matter is recognized as the most important air pollutant in the Dhaka city [4]. A sound knowledge of the sources and health effects of particulate air pollutants is required to discriminate sources according to their importance for human health which permit a more efficient risk management [16]. Many toxic heavy metals have found in the ambient particulate matters of Dhaka city [7, 8]. Sources of these toxic heavy metals in the ambient air should be identified and characterized. This chapter is designed to provide information on different features of particulate air pollutants along with characteristics of some toxic heavy metals, predominantly found in ambient particulate matters of Dhaka city.

2.2 Characterizations of Particulate air pollutants

Particulate air pollutants are very complex pollutants. Particulate matter can be defined as a mixture of microscopic solids and liquid droplets suspended in air [12]. It is made up of various number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles, and allergens (such as fragments of pollen or mold spores) [12, 13]. Some particles are large or dark enough to be seen as soot or smoke with unaided eye. Others are so small that they can only be detected with an electron microscope [14]. Some particles are directly emitted directly into the air from a variety of sources such as vehicles, factories, construction sites, farming, unpaved reads, burning wood, and blowing sand and dust in desert environments. Other particles may be formed in the air when gases from burning fuels chemically react with sunlight and water vapor. The gases originate from fuel combustion sources such as motor vehicles, power plants and other industrial processes [22]. Particle pollution also varies by time of year and by location and is affected by several aspects of weather, such as temperature, humidity, and wind [14]. The nature of the particulates varies depending on their sources. Smaller particles in atmosphere can be removed by coagulation and larger particles undergo rapid settling under the influence of gravity. However, fine particles can stay suspended in atmosphere for several years [7]. A full description of atmospheric particles not only requires specifications of their concentration but also their size, chemical composition, phase (liquid or solid), and morphology [15].Different features of particulate air pollutants are discussed in the subsequent sub-sections.

2.2.1 Types of particulate matters

Particulate matter can be classified in several ways. Firstly, they can be classified into primary and secondary particles based on the formation process. Primary particles are emitted directly as particles. Secondary particles are formed from precursor gases in the atmosphere via gas-to-particle conversion. Secondly, particles can be classified by their physical size [16]. Particle size is normally given as the aerodynamic diameter, which refers to the diameter of a unit density sphere of the same settling velocity as the particle in question. Particles greater than 2.5 µm in diameter are generally referred to as coarse particles, and particles less than 2.5 µm and 100 nm in diameter as fine particles and ultra fine particles, respectively. Particulate matrers can be classified in various categories based on their size distributions and properties such as dust, smoke, fume, mist and fog particles. Brief descriptions of these types of particles are given below.

Dust particles

Dust particles made up of solid particles, larger than those found in colloids. Generally, dust particles generate from civil constructions, earthworks, chemical or mechanical processes. These particles are produced through pulverization or mechanical disintegration of solid matters following crushing, grinding and drilling. Dust particles are in the range of 1 to 200 µ or even larger. Dust particles are usually irregular in shape [15, 17].

Smoke particles

Smoke particles are small gas-borne particles produced from incomplete combustion. It consists predominantly of carbon particles and other combustible materials. Generally, the of the particles is less than 1 µ .The size of coal smoke particles range from 0.2-0.01 µ and oil smoke particles from 1.0-0.03 μ [19]. Smoke could be of either in liquid or solid form. If solid then the particles are usually spherical in shape and if liquid (or tarry) then the shape could be irregular. Smoke particles may remain suspended in air for long time and exhibit Brownian motion in air medium [15, 17].

Fume particles

Fume particles are solid particles generated by condensation from the gaseous state, generally after volatilization from molten substances, and often accompanied by chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce. Fume particles are in the range of 1 to 0.1 μ in size [15, 17].

Mist particles

Mists particles are low concentration dispersion of liquid particles of large size. In meteorology, it means a light dispersion of minute water droplets suspended in the atmosphere. Natural mist particles formed from water vapors in the atmosphere are rather large ranging from 500 to 40 μ in size. Mist particles may coalesce [15, 17].

Fog particles

Fog particles are visible aerosols in which the dispersed phase is liquid. Formation by condensation is usually implied. In meteorology, it refers to dispersion of water or ice in the atmosphere near the earth's surface reducing visibility to less then 1/2 km. In natural fog the size of the particles ranges from 40-1.0 μ [15, 17].

2.2.2 Dispersion of particulate matters

Particulate air pollutants escape from their sources into the atmosphere. The escape and retention of these particles depends on their sizes. The smaller the size the higher the escape and longer it stays in atmosphere as suspended particles. The lengths of suspension and concentration levels are dependent on the meteorological condition in the area. Meteorological factors such as wind speed and direction, temperature, amount of precipitation, and the height of the atmospheric boundary layer, are most important in governing the concentration variations of particulate matter [16]. The highest particulate matter concentrations are often reported during stable meteorological conditions such as inversion with low wind speeds.

2.2.3 Effects of particulate air pollutants

Particulate air pollutants have serious impacts on human health and environment. A brief description of various effects of particulate air pollutants is given below.

Human health effects

Latest epidemiological research suggests that there is no threshold at which health effects do not occur from particulate matters [18]. Severe health effects of ambient particulate matters are listed below [18-21].

1. Toxic effects by absorption of the toxic heavy metals such as lead. cadmium and zinc into the blood .
2. Allergic or hypersensitivity effects from particles generated form some woods, flour grains, chemicals.
3. Bacterial and fungal infections from live organism.
4. Fibrosis from asbestos, quartz particles.
5. Cancer from carcinogenic matters such as asbestos, chromates.
6. Irritation of mucous membranes from acids and alkalis.
7. Increased respiratory symptoms, aggravation of asthma and premature death. The risks are highest for sensitive groups such as the elderly and children.

In addition, scientists are evaluating new studies that suggest that exposure to high particle levels may also associated with low birth weight in infants, pre-terms deliveries and possibly fetal and infant death [12].

The factors that may influence the health effects of exposure to particles are [18]:

1. The chemical composition and physical properties of the particles.
2. The mass concentration of the airborne particles.
3. The size of the particles.
4. The duration of exposure.

Environmental effects

The effects of particulate matter can be felt over long distance as wind blown particles settle on land and water bodies far from the emitting sources [13]. When particles settle on lakes and streams, it can make these water bodies acidic and may change the nutrient balance in costal water and large river basins [22]. Vegetation exposed to wet and dry deposition of particulates may be injured when particulates are combined with other pollutants. Coarse particles, such as dust, directly deposited on leaf surfaces can reduce gas exchange and photosynthesis. leading to reduced plant growth. Heavy metals that may be present in ambient particles, when deposited on soil, inhibit the process in soil that makes nutrients available to plants. This, combined with the effects of particulates on leaves, may contribute to reduction of plant growth and yields [21]. In addition, particles contribute to the soiling and erosion of buildings, materials. and paint, leading to increased cleaning and maintenance costs and to loss of utility. The haze caused by fine particles can impair visibility and diminish crop yields by reducing sunlight [22].

2.2.4 Sources of particulate air pollutants

Sources of particulate matters can be divided into two broad groups namely natural sources and anthropogenic or man-made sources. A brief description of different sources of particulate air pollutants is given below.

Natural sources

Natural sources of primary particulate matters are wind blown soil and mineral particles, volcanic dust, sea salt spray, biological material such as pollen, spores and bacteria, and debris from forest fires [20]. By and large, coarse particles are generated from natural sources. However, fine particles can be released from high temperature natural sources such as wildfires. Secondary particle can be formed through reactions involving natural sources of the precursor gases. For instance, volatile organic carbons (VOCs) are released from trees and nitrogen oxides are released from soils [20].

Anthropogenic sources

Both primary and secondary particles of various sizes (coarse and fine) can be produced from anthropogenic sources. Anthropogenic sources can produce both primary and secondary particles, and both coarse and fine particles. Windblown agricultural soil, and dust from roads, construction sites and quarrying operations are some significant primary sources of coarse particles. Very fine and chemically complex particles can be generated from various industrial processes and fossil fuel combustion (electrical power plants. gasoline and diesel vehicles, industrial boilers, residential heating etc.) [20]. The vehicles are believed to constitute the dominant source of air pollution in Dhaka city [2]. Moreover, other effective sources of particulate air pollutants at Dhaka city are road and building construction works, industrial discharges and brickfield emissions [4]. Significant sources of ambient particulate matters are presented in Table 2.1 below.

Table 2.1. Significant sources of ambient particulate matters [17]

Sources	Examples
Combustion	Fuel burning (coal, wood, fuel oil), Incineration (house and municipal garbage), Others (open fires, forest fires, tobacco smoking)
Materials handling and processing	Loading and unloading (sand, gravel, coal, ores, lime, cement), Crushing and grinding (ores, stone, cement, rocks, chemicals), Mixing and packaging (chemicals, fertilizers) Food processing (flour, corn starch, grains). Cutting and forming (saw mills, wall board, plastics), Metallurgical (foundries, smelters), Industrial (paper, textiles manufacture)
Earth-moving operations	Construction (road, buildings, dams. site clearance), Mining (blasting) Agriculture (soil filling. land preparation). Winds
Miscellaneous	House cleaning. Mud road cleaning, Crop spraying. Poultry feeding, Engine exhaust

2.2.5 Air quality standards for particulate matters

The National Ambient Air Quality Standard adopted in 1997 for Bangladesh was updated in July 2005 based on the proposal of the World Bank-funded air quality management project, which reviewed the old standards [23]. Bangladesh is the only country in South Asia that set guideline values for $PM_{2.5}$ in its National Ambient Air Quality Standards (NAAQS) [23]. Ambient air quality standards for particulate air pollutants set by deferent authorities are given in Table 2.2 below.

Table 2.2. Ambient air quality standards ($\mu g/m^3$) for particulate matters [23]

Particulate air pollutants	Averaging period	Bangladesh Standards	WHO Standards	US EPA Standards
PM_{10}	1 year	50	20	Revoked
	24 hour	150	50	150
$PM_{2.5}$	1 year	15	10	15
	24 hour	65	25	35
Lead (Pb)	1 year	0.5	0.5	----

2.2.6 Elemental concentrations of particulate matters

Characterization of $PM_{2.5}$ and PM_{10} were made by Rahman, M. in 2005. In that study both $PM_{2.5}$ and PM_{10} were collected at Mohakhali and Farmgate in Dhaka city and elemental concentrations were determined. The concentration profiles of ambient particulate matters disclosed that levels of some heavy metals such as arsenic, copper, manganese and zinc were above the guideline values assigned by some different developed nations. The elemental concentrations of particulate matters can be used in source apportionment study to determine the contribution from various sources [4]. Elemental concentrations of PM_{10} and $PM_{2.5}$ collected from Mohakhali and Farmgate at Dhaka city are shown in Table 2.3 below.

Table 2.3. Average concentrations (ng/std.m^3) of trace elements and ions present in $PM_{2.5}$ and PM_{10} at Mohakhali and Farmgate [7]

Parameter	Mohakhali		Farmgate	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Al	1,105	15,597.3	163.27	2,518.80
As	10.7	12.9	10.35	13.60
Cd	2.7	2.6	2.91	4.30
Cr	57.4	63.2	24.82	23.80
Co	2.9	1.5	3.57	2.80
Cu	669.0	919.3	973.70	989.40
Fe	609.2	10,419.4	237.19	1,167.50
Mn	29.6	215.0	3.69	47.30
Ni	6.6	25.0	14.53	5.00
Pb	463.0	500.4	350.46	561.30
Ti	912.4	1,340.1	786.82	224.70
V	1.0	16.0	1.65	13.10
Zn	2,164.3	2,964.7	1,336.31	2,412.70
Ca^{+2}	1,160	7,720	840	2,650
Cl^-	750	2,240	530	1,320
F^-	80	330	60	60
K^+	260	800	550	310
Na^+	140	320	200	1,580

2.2.7 Source apportionment of particulate matters

The contribution of particulate air pollutants by various sources in any given area can be evaluated in two ways namely top-down or receptor-based methods (e.g. receptor modeling) and bottom-up or source-based methods (e.g. dispersion modeling) [24, 25].

Dispersion models use detailed emission inventory of air pollution sources and local wind fields to estimate the impact of those sources on pollutant concentration to any desired location in the impact zone. Dispersion models are prospective in the sense that they are extremely useful for estimating projected impacts of new air pollution sources [24, 25].

Receptor models use monitored pollutant concentration and some information (signature) about chemical composition of local air pollution sources to estimate the relative influence of these sources on pollutant concentrations at any single monitoring location. Receptor models are retrospective in the sense that they can only assess the impact of air pollution source categories on pollutant concentrations that have already been monitored [24, 25]. Receptor–based source apportionment of particulate matter was made for Dhaka city during 1993-1994 by The Bangladesh Atomic Energy Commission [5]. The results of that source apportionment study are given in Table 2.4 below.

Table 2.4. Average mass contributions (%) of various sources to ambient PM of Dhaka city during 1993-1994 [5].

Source type	**Percentage contribution to APM**	
	Coarse (PM_{10})	**Fine ($PM_{2.5}$)**
Re-suspended Soil	54 7	8 88
2-stroke engine	6.07	2.03
Construction works	7.09	-----
Motor vehicles	31.2	29.1
Sea salt	0.22	4.11
Refuse burning	0.74	------
Natural gas/diesel burning	------	45.7
Metal Smelting	------	10.2

The Atomic Energy Commission also performed source apportionment of ambient $PM_{2.2}$ and $PM_{2.2-10}$ collected from Farmgate hot spot area and semi residential area at Atomic Energy Commission, Dhaka during July 2001 and March 2002 using Positive Matrix Factorization (PMF) receptor modeling technique. In that study seven to eight sources were identified such as motor vehicles, soil dust (from construction, road and earth crust), sea salt, brick kiln, fugitive lead, and two-stroke engines. It was found from the study that vehicles contributed approximately 38-45 % of the total $PM_{2.2}$ mass and soil dust contributed 43-48.7 % of total $PM_{2.2-10}$ mass at these areas in Dhaka city [6].

2.3 Tracking trace heavy metals in air pollutants sources

There is a scarcity of data on trace heavy metal levels in particulate air pollutants sources in Dhaka city as well as in Bangladesh because of limited number of research works were performed regarding this issue. The significant research works that have been found relating to heavy metal status in sources of particulate air pollutants are described in the subsequent subsections.

2.3.1 Heavy metals in contaminated soil

Contamination of soil environment can be identified with the elevated levels of trace heavy metal concentrations. Trace heavy metal contamination is a threat to human life and the environment because of their toxic effects [10].A study was conducted to investigate the heavy metal pollution of soil in the vicinity of industries around Dhaka city [26]. Concentrations of some toxic heavy metals obtained from the investigation are presented in Table 2.5 below.

Table 2.5. Average concentrations (mg/kg) of heavy metal in soils collected from different industrial areas around Dhaka city [26]

Heavy metals	Industrial areas			
	Tannery (n =12)	Ceramic (n =13)	Textile dying (n=15)	Sulphuric acid (n=13)
Cadmium (Cd)	1.26	0.33	0.48	0.53
Copper (Cu)	115.5	38.4	163.7	63.5
Manganese (Mn)	425.2	216.9	382.4	277
Nickel (Ni)	89.8	50.1	51.1	88.2
Lead (Pb)	68.1	28.6	56.4	36.9
Zinc (Zn)	290.1	286.5	206.5	125.9

n = number of soil samples.

It can be observed in Table 2.5 that the average levels of cadmium, manganese, nickel, lead and zinc in soil samples collected from tannery industrial area were the highest. The elevated levels of these heavy metals in tannery area soil might be due to liquid and solid waste discharges from different tanning process [26]. The second highest average level of lead was observed in the samples collected from textile dying industrial areas with highest content of copper, which was due to effluents, and solid waste of dying industry [26].

2.3.2 Heavy metals in road dust

Study of road soils can provide more information of air pollution of an area, as atmospheric pollution is one of the major sources of heavy metal contamination in soils and roadside dusts in urban areas [9]. Accumulations of heavy metals including copper, lead and zinc on urban surfaces arise from various sources such as vehicular exhausts, industrial discharges, lubricating oils, automobile parts, corrosion of building materials, and atmospheric deposition [10]. A study was performed to determine the heavy metal levels in road dusts collected from industrial, commercial and residential areas areund Dhaka city [9, 10].

Concentrations of some significant trace heavy metals found in Dhaka city road dusts are given in Table 2.6 below.

Table 2.6. Concentrations (mg/kg) of some trace metals in road dust of Dhaka city [9]

Sampling area	No. of samples	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Vanadium (V)	Zinc (Zn)
Industrial	7	136	105	35	54	72	169
Commercial	23	105	46	26	74	68	154
Residential	33	99	22	23	35	64	97

It is observed in Table 2.6 that the highest average levels of chromium, copper, nickel, vanadium and zinc found in road dust samples collected form industrial area. However, the highest average lead concentration was found in the commercial area. Average levels of these heavy metals are lowest in the samples collected form residential area due to low level of pollution from various sources.

2.3.3 Heavy metals in coal

There are approximately 4000 brickfields around Dhaka city and about twenty lakh metric ton coal is burnt every year in these brickfields [27]. These brick kilns are one of the major sources of air pollution in the city. Realizing coal as a potential source of toxic heavy metals, coal samples were collected from the different depths of bore hole GDH-38, GDH-39 of Barapukuria and GDH-45, GDH-46 of Khalaspir coals in Northwestern Bangladesh and nineteen trace elements were quantified using Proton Induced X-ray (PIXE) spectroscopy [28]. Concentrations of some heavy metals found in the coal samples are given in Table 2.7 below.

Table 2.7. Concentrations (mg/kg) of some trace heavy metals found in Barapukuria and Khalaspir coal samples [28]

Elements	Barapukuria coal		Khalaspir coal	
	GDH-38	GDH-39	GDH-45	GDH-46
Chromium (Cr)	23.10	20.88	18.93	23.78
Copper (Cu)	29.74	17.15	22.41	31.34
Manganese (Mn)	211.63	-----	14.42	183.11
Nickel (Ni)	8.03	5.03	40.24	22.72
Lead (Pb)	25.31	34.30	15.93	------
Zinc (Zn)	23.51	13.29	45.45	26 49

It is observed in Table 2.7 that coal of Barapukuria and Khalaspir is enriched with some toxic heavy metals which can be released in the atmosphere from coal combustion and consequently increased the toxicity of ambient particulate matters.

2.4 Sources of trace heavy metals in soil

Soil can be enriched with trace heavy metals from various natural and man made sources. Some significant sources of trace heavy metals in soil are discussed below.

Soil parent rock material

Soil can be enriched with trace heavy metals by weathering of natural rock. This process depends on reactions such as hydrolysis, ion exchange, oxidation, reduction and others reactions to form soil. Trace element enrichment from weathering process of rock is decreased with the increasing age of the soil [29].

Agricultural activities

Soil can be enriched with heavy metals form various agricultural activities such as fertilization, irrigation, using of pesticides. Fertilizers may contain heavy metal such as cadmium, chromium, lead, molybdenum, vanadium and zinc and sewage sludge used for fertilization and irrigation may have elevated levels of various toxic heavy metals. Moreover, manures from intensive animal firming may have copper, arsenic and zinc and pesticides used to control pests may have heavy metals such as copper, arsenic, mercury, lead, manganese and zinc. In addition, corrosion of metal objects used in cultivation also can increase trace heavy metal levels in soil [29].

Mining and metallurgical processes

Soil may be contaminated with heavy metal from mining processes. Extraction of minerals from lower grade ore bodies leaves high level of waste product in the form of tailings. The tailing particles can be transported through wind and water. Moreover, overflowing of tailing dams may cause pollution incidents. In the metal processing industries heavy metals in soil may be generated from aerosols and dust particles, polluted effluent and metals leaching into soil form corroded dumps [29].

Sewage sludge and municipal wastes

Industrial effluents and municipal waste may have elevated levels of toxic heavy metals. Significant heavy metals found in these contamination sources are arsenic, cadmium, chromium, copper, iron, mercury, manganese, nickel, lead and zinc [26]. Moreover, municipal wastes may also have various toxic heavy metals [30].

Chemical industries

Various trace heavy metals are released from deferent types of chemical industries. Soil may be contaminated with heavy metals from use of various chemical products, land disposal of chemical waste from various manufacturing industries. Various trace heavy metal from different chemical industries are given in Table 2.8 below.

Table 2.8. Trace heavy metals from various chemical industries [29, 30]

Name of the sources	**Trace heavy metals**
Chlorine manufacturing	Hg
Battery industries	Cd. Cu, Hg, Ni, Pb, Sb , Zn
Crude oil processing	As, Cr. Pb, Zn
Fuel additives and lubricants	Li, Pb, Mo, Se
Paints and coatings	As, Ba, Cd, Cr, Co. Cu, Hg, Pb, Mo, Sb, Se, Zn
Medical uses	Ag, As, Ba, Cu, Hg, Pt, Sb, Se, Sn, Zn
Iron and steel production	As, Cd. Cr, Cu, Pb, Hg, Sb and Zn
Plastic industries	Cd, Cr, Pb, Zn
Plant protection	As, Cr, Hg, Pb, Zn

Combustion of fossil fuels

Various trace heavy metal can be generated from combustion of fossil fuels. Coal combustion is an important source of trace metals in the environment. Coal and petroleum deposits are enriched with various trace metals at the time of their formation [29].

Vehicular emissions

Trace heavy metal can be released from different kinds vehicles. Numerous studies indicate that lead concentrations in soils near highways are high and decline exponentially as a function of distance from the highways. Fortunately, lead from vehicular exhaust has been significantly reduced due to use of unleaded fuel in vehicles since 1980s. Other modes of transportation such as trains and aircraft also contribute heavy metals such as cadmium, nickel, lead, vanadium, platinum and zinc in the environment .However, the extent of contamination from these sources has not been clearly assessed [30].

2.5 Sources of trace heavy metals in road dust

Many research works have been done around the world to know the elemental profiles of road dust with special emphasis on some toxic heavy metals such as arsenic. cadmium, cobalt, chromium, copper, lead, manganese, mercury, nickel, zinc and vanadium [31-36].

The sources of trace heavy metals in road dust have been investigated by various researchers by applying various techniques. Sources of trace metals in road dust can be identified using two methods. The first method is trend analysis of levels of individual elements with respect to some sources and the second method is multi-element data analysis using various statistical techniques. Four major types of sources have been identified from the studies of trends in concentrations of individual elements in road dust. They are road traffic, industrial, weathered materials and specific occasional events [32].

Petrol-driven automobile is a major source of various trace heavy metals. Elements originated form the automobiles are Pb, Cd, Cu, Zn, Fe, Cr and Ni etc. Lead in road dust may come from leaded gasoline and cadmium and zinc may come from tire wire [32].

Industrial sources of trace metals are varied and elements such as Pb, Cd, Cu, Zn, Fe, Cr and Ni have been identified with specific industries. Investigation of some local hot spots identified newspaper-printing works as a significant source of lead in road dust. Elevated level of cadmium, zinc and lead in street dust may come from electroplating, galvanizing and battery manufacturing industries respectively [32].

The elements Pb, Cu, Zn and Cd have been identified as coming from weathering materials. The deterioration of lead paint is a localized source of lead in road dust [32].

A number of circumstances can periodically raise the trace metal concentrations in street dust. However, this may not significantly affect in the long term. Use of lead based paint for the redecoration of houses is a significant source of lead in road dust [32].

2.6 Characteristics of trace heavy metals

Knowledge on characteristics of trace heavy metals is helpful to understand this project. Characteristics of some selected environmentally significant trace heavy metals are discussed in the subsequent subsections.

2.6.1 Cadmium (Cd)

General properties

Pure cadmium is a soft silver-white electropositive metal. It is most often present in nature as complex oxides, sulfides, and carbonates in zinc, lead, and copper ores. It is element 48 and a member of Group IIB in the periodic table. It has atomic weight 112.41 and density 8.6 g/cm^3 (at 20^{0}C).The melting of cadmium is 320.9^{0}C and the boiling point is 765^{0}C. The most common oxidation state of cadmium is + II. CdS is the most commonly found cadmium compound [29, 37].

Sources and uses

The major natural emission sources of cadmium in the air are volcanoes, airborne soil particles, sea spray, biogenic materials and forest fires. On the other the largest anthropogenic source of cadmium in the atmosphere is metal production. Other significant sources of cadmium are production of nickel-cadmium batteries, fossil fuel combustion and dust from cement industries. Water may be contaminated with cadmium form mines process water from smelters, phosphate mining and related fertilizer production and electroplating wastes. Soil may be polluted with cadmium from smelters, iron and steel plants, electroplating wastes and battery production [21].

Cadmium is mainly used to manufacture low melting point alloys. It is also used in electroplating industries and in the production in nickel-cadmium batteries. Cadmium sulfides are commonly used as a pigment in the production of paints and plastics and cadmium stearate is used as a stabilizer in plastics [21, 29, 37].

Health effects

Cadmium has both acute and chronic health effects. Breathing air with very high levels of cadmium can severely damage the lungs and may cause death. Eating food or drinking water with very high levels severely irritates the stomach, leading to vomiting and diarrhea. The chronic effects of cadmium exposures are kidney and liver damage, anemia, hypertension and negative effects on bone formation. Moreover, cadmium is also regarded as carcinogenic (cancer forming agent), teratogenic (substance effecting fetuses) and mutagenic (inducing chromosomal abnormalities) [29, 37].

2.6.2 Chromium (Cr)

General properties

Chromium is a steel-gray, lustrous, hard metal. It is element 24 and is a member of Group VIB in the periodic table. It has atomic weight 51.996 and density 7.19 g/cm^3 (at 20^{0}C) .The melting point of chromium is 1857^{0}C and the boiling point is 2672^{0}C. The most common oxidation states of chromium are +II, +III and +VI [29, 37].

Sources and uses

Chromium can be entered in the environment mostly Cr (III) and Cr (VI) forms by natural processes and human activities. Level of Cr (III) can be increased in the air by emissions from coal and oil burning and steel production industries. Concentration of Cr (VI) can be increased in the air from the wielding of stainless steel, manufacturing of chemicals and use of compounds containing Cr (VI). Moreover, Cr (VI) can be liberated from electroplating waste streams. Both Cr (III) and Cr (VI) are released in the waterways from leather tanning, textile, and pigments and dyes industries. Soil can be enriched with Cr from disposal of commercial products containing Cr. chromium waste from industries and coal ash from electric utilities [38].

The metallurgical, refractory and chemical industries are the main users of Cr. In the metallurgical industries, Cr is used to produce stainless steel, nonferrous alloys and other miscellaneous materials. In the refractory industries, Cr is a used to build linings for high temperature industrial furnaces. In the chemical industries, Cr is mainly used in pigments, metal finishing, leather tanning and wood preservatives. Cr compounds are also used in drilling muds, rust and corrosion inhibitors, textiles and toner for copying machines [38].

Health effects

Cr (VI) is much more toxic than Cr (III) and is easily absorbed via lungs and gastrointestinal tract. Cr (III) is an essential nutrient that helps the body to use sugar, protein, and fat. Breathing high levels (greater than 2 μg/m^3) of Cr (VI) can cause irritation to the lining of the nose, nose ulcers, runny nose and breathing problems such as asthma, cough, shortness of breath or wheezing. Moreover, Cr (VI) has carcinogenic, mutagenic and teratogenic properties [29, 38].

2.6.3 Cobalt (Co)

General characteristics

Cobalt is a hard, silvery gray metal. It is element 27 and is a member of Group VIII in the periodic table. It has atomic weight 58.9 and density 8.9 g/cm^3 (at 20^{0}C). The melting point of cobalt is 1495^{0}C and the boiling point is 2870^{0}C. Cobalt commonly occurs in the 0, +II, and +III valance states. There is only one stable isotope of cobalt which has atomic number of 59. The compounds generally found are cobalt oxide, cobalt tetra oxide, cobalt chloride, cobalt sulfide and cobalt sulfate [29, 39].

Sources and uses

Significant natural sources of cobalt are windblown soil, seawater spray, volcanic eruptions and forest fires. Primary anthropogenic sources include fossil fuel and waste combustion, vehicular and aircraft exhausts. processing of cobalt and cobalt containing alloy, copper and nickel smelting and refining and the manufacture and use of cobalt chemicals and fertilizers derived from phosphate rocks. Radioactive forms of cobalt may be released to the environment from nuclear research and development activities, nuclear accidents, operation of nuclear power plants, and radioactive waste dumping in the sea or in radioactive waste landfills [39].

Cobalt is used to produce alloys which are used in the manufacture of aircraft engines, magnets, grinding and cutting tools, artificial hip and knee joints. Moreover, Cobalt compounds are used as pigments in glass, ceramics, and paints; as catalysts in the petroleum industry; as paint driers; and as trace element additives in agriculture and medicine. Radioactive cobalt such as ^{60}Co is used for sterilizing medical equipment and consumer products, radiation therapy for treating cancer patients, manufacturing plastics, and irradiating food. ^{57}Co is used in medical and scientific research. [29, 39].

Health effects

Exposure to high levels of cobalt may cause lung and heart effects and dermatitis. Liver and kidney effects have also been observed in animals exposed to high level of cobalt. Exposure to high level of radiation from radioactive cobalt can damage cells in human body . Moreover, cobalt is also a mutagen, teratogen and carcinogen [29, 39].

2.6.4 Copper (Cu)

General properties

Copper is radish-brown, ductile and malleable metal. It is element 29 and is a member of Group IB in the periodic table. It has atomic weight 63.54 and density 8.96 g/cm^3 (at 20^{0}C).The melting point of copper is 1083^{0}C. Copper usually occurs in +I and +II oxidation states in nature [29, 40].

Sources and uses

Copper can be released in the environment from the mining of copper and other metals, and from factories that make or use copper or copper compounds. Copper can also be entered in the environment from waste dumps, domestic waste water, combustion of fossil fuels and wastes, wood production, phosphate fertilizer production and natural sources such as volcanoes, windblown dusts, the weathering of soil, decaying vegetation, and forest fires [40].

Copper is widely used to make alloys such as brass, bronze, gun metal, and monel metal. Copper and copper compounds are used to make electrical and electronics products, in building construction (water pipes, roof coverings), equipment and heating and chemical and pharmaceutical manufacturing. They are also used in pigments and dyes, electroplated protective coatings and undercoating, cooking utensils, insulation for liquid fuels, coins, cement, food and drugs, metallurgy, nylons, insecticides, herbicides and fungicides, pollution control devices, printing and photocopying, photo graphics, pyrotechnics and wood preservatives and timber treatments. Moreover, they are also used to manufacture anti-fouling paints, electrolysis and electroplating processes, fabrics and textiles, flame proofing materials, glass and ceramics [40. 41].

Health effects

Everyone must absorb small amounts of copper every day because copper is essential for good health. However, High levels of copper can be harmful. Breathing high levels of copper can cause irritation of human nose and throat. Ingesting high levels of copper can cause nausea, vomiting, and diarrhea. Moreover, very-high doses of copper can cause damage to human liver and kidneys, and can even cause death [40].

2.6.5 Manganese (Mn)

General properties

Manganese is a transition metal and is element 25 and a member of Group VIIB in the periodic table. It has atomic weight 54.94 and density between 7.21-7.44 g/cm^3 (at 20^{0}C).The melting point of manganese is 1244^{0}C and the boiling point is 1962 ^{0}C.Pure manganese is a silver-colored but, does not occur naturally. The most common oxidation states of manganese are +II, +III, +IV, +VI and +VII [29, 42].

Sources and uses

The main sources of manganese into the air are industrial emissions, combustion of fossil fuels and re-entrainment of manganese-containing soils. The leading sources of industrial emissions are ferroalloy production and iron and steel foundries, and the dominant sources of combustion emissions are power plants and coke ovens. It can be released into air by combustion of unleaded gasoline that contains MMT (methylcyclopentadienyl manganese tricarbonyl) as an antiknock ingredient. The main source of manganese in soil is land disposal of manganese-containing wastes. The environment may be enriched with manganese from manganese containing pesticides namely Maneb and Mancozeb when they are applied to crops or released to the environment from packaging factories [42].

Metallic manganese (ferromanganese) is used mainly in steel production to improve hardness, stiffness, and strength. The metal and its compounds are also widely used in alkaline batteries, glass, pigments and driers in paint, disinfectants and animal food additives. Organic carbonyl compounds of manganese are used as smoke inhibitors and anti-knock additives in petrol [29, 42].

Health effects

Manganese is an essential for biological processes as part of enzyme structures. However, too much manganese may also cause illness. Manganese miners or steel workers exposed to high levels of manganese dust in air may have mental and emotional disturbances, and their body movements may become slow and clumsy. This combination of symptoms when sufficiently severe is referred to as "manganism". Nervous system and reproductive effects have been observed in animals after high oral doses of manganese [29, 42].

2.6.6 Nickel (Ni)

General properties

Nickel is a hard, silvery white, malleable metal with good electrical conductivity. It is element 28 and is a member of Group VIII in the periodic table. It has atomic weight 58.71 and density 8.9 g/cm^3 (at $20^{0}C$) and melting point $1455^{0}C$. It generally occurs in 0, +I, +II, +III and +IV oxidation states. The most common and important oxidation states of nickel found are the 0 and II states and these are also the most stable of the nickel compounds. It is soluble in dilute nitric acid and to a small extent in sulphuric and hydrochloric acids. However, it is not soluble in NH_4OH [29, 43].

Sources and uses

Nickel can be released from natural sources such as volcanoes, windblown dusts, the weathering of rocks, forest fires and decaying vegetation . Nickel can be released into the atmosphere during nickel mining and by industries that make or use nickel, nickel alloys, or nickel compounds. These industries also can discharge nickel in waste water. Nickel is also released into the atmosphere by oil-burning power plants, coal-burning power plants, and trash incinerators [43, 44].

Production of stainless steels is the single largest use of nickel. It is also used in the production of alloys with other metals such as iron, copper, chromium and zinc Other major uses are in electroplating , nickel-cadmium batteries, electronic components, fuel cells, specialty ceramics, magnets, specialty chemicals, filters for gases, hydrogenation of fats, petroleum products, preparation of colored pigments and for color stabilization of color copy paper [43, 44].

Health effects

Nickel is toxic to animals, humans and plants. The most common harmful health effect of nickel in humans is an allergic reaction. Approximately 10-20 % of the population is sensitive to nickel. Workers exposed to high levels of nickel while working in nickel refineries or nickel processing plants can be victim to chronic bronchitis, and cancer of the lung and nasal sinus. Nickel has carcinogenic and teratogenic properties and contact with it must be avoided [29, 43].

2.6.7 Lead (Pb)

General properties

Pure lead is a silvery-white metal that oxidizes and turns bluish-gray when exposed to air. Lead is element 82 and is a member of Group IVA in the periodic table. It has atomic weight 207.19 and density 11.35 g/cm^3 (at 20^{0}C). The melting point of lead is 327.5^{0}C and the boiling point is 1740^{0}C. It also has poor electric conductivity. It generally occurs in the +II or +IV oxidation states and is slowly soluble in acids [29, 45].

Sources and uses

Lead occurs naturally in the environment. However, lead is dispersed throughout the environment primarily from man made sources such as coal-fired power plants, cement production, ceramic industries, mining, ore processing, smelting of lead ores, refining, the production and use of lead alloys and compounds, recycling, combustion processes, industrial processes and lead waste disposal. Many of the anthropogenic sources of lead have been eliminated or phased out due to its toxicity. For instance, lead has been phased out from gasoline, paint, and pesticides, and ammunition and sinkers [45. 46].

Lead is used to make storage batteries, metal products (solder. pipes, fishing weights, electronics and alloys with other metals) and devices to shield x-rays. Lead compounds are used to manufacture electronic parts, plastics, rubbers .metals, matches, ammunition, fireworks. explosives. pottery glazes, ceramics, brake shoes, flame retardants for plastics and as catalysts for industrial production and epoxy curing agents. Lead is also used in pigments, dyes. paints and coatings [45, 47].

Health effects

Lead can affect almost every organ and system in the human body. Lead toxicity mostly affects the nervous system. Exposure to lead may cause paralysis in fingers, wrists or ankles. Lead exposure can also cause small increases in blood pressure and may cause anaemia, malnutrition, abdominal pain and colic. High level of lead can severely damage the brain and kidneys. In pregnant women, high levels of exposure to lead may cause miscarriage. The carcinogenic, teratogenic and genetic effects of lead are also widely published in the literature [29, 45, 47].

2.6.8 Vanadium (V)

General properties

Vanadium is a soft white metal. Vanadium is element 23 and is a member of Group VB in the periodic table. It has atomic weight 50.94 and density 6.11 g/cm^3 (at 20^{0}C) .The melting point of vanadium is 1890^{0}C. Vanadium forms numerous and complicated compounds because it has many valence states which may range from +II to +V, with +V being the principle oxidation state. In the environment it is usually combined with other elements such as oxygen, sodium, sulfur, or chloride [29, 48].

Sources and uses

Vanadium can be entered in the environment from natural sources such as continental dust, marine aerosols, and volcanic emissions. Major anthropogenic sources of environmental contamination of vanadium result from the combustion of fossil fuels, the burning of coal wastes, the disposal of coal waste and fly ash, and releases from metallurgical works and smelters. The natural release of vanadium to water and soils occurs primarily as a result of weathering of rocks and soil erosion. Other anthropogenic sources of vanadium in the environment are leachates from mining tailings, vanadium-enriched slag heaps, municipal sewage sludge and certain fertilizers [48, 49].

Vanadium is mostly used to make rust resistant and high speed tools steels. These steels are used to build automobile parts, springs, and ball bearings. It is a major component of titanium alloys. Vanadium compounds are used as catalysts in the production of various chemicals such as phthalic anhydride and sulfuric acid. Moreover, Smaller amounts of vanadium compounds are used as color modifiers in mercury-vapor lamps, driers in paints and varnishes, corrosion inhibitors in flue-gas scrubbers and as components in photographic developers [29, 48].

Health effects

Exposure to high levels of vanadium can cause harmful health effects. The major effects from breathing high levels of vanadium are on the lungs, throat, and eyes. Workers who breathed it for short and long periods sometimes had lung irritation, coughing, wheezing, chest pain, runny nose, and a sore throat [48].

CHAPTER 3

OBJECTIVES OF THE STUDY

The main purpose of this thesis was to track particulate air pollutants sources within and around Dhaka city. More specific aims were :

1. to characterize particulate air pollutants sources in terms of concentrations of some major elements and some significant toxic heavy metals.
2. to correlate contributions of some important sources of particulate air pollutants to air pollution at Dhaka city.
3. to compare concentrations of trace heavy metals among the source samples to realize significance of sources based on levels of toxic heavy metals.
4. to compare concentrations of trace heavy metals in air pollutants source samples with the background and guideline values to know the status of heavy metal contamination from various sources.

To accomplish these objectives samples were collected from various sources of particulate air pollutants within and around Dhaka city and preserved for elemental analysis. Major elements were identified from spectrum generated by energy dispersive x-ray spectrometer. Concentrations of some major elements and trace heavy metals were determined using inductively coupled plasma mass spectrometer (ICP-MS), atomic absorption spectrophotometer (AAS) and flame photometer. Elemental concentrations in the sources samples and ambient particulate matters at Dhaka city were observed to realize contributions from these sources. Moreover, concentrations of toxic trace heavy metals in the source samples were studied comparatively to realize relative importance of the sources based on levels of some important toxic heavy metals. In addition, status of heavy metals contamination in the sources (soil and road dust) were determined by comparing the trace heavy metals levels in the source samples with the background and standard values and possible sources of heavy metal contamination in the air pollutants sources were also identified .

CHAPTER 4

MATERIALS AND METHODS

4.1 Introduction

In this study particulate air pollutants sources were tracked by investigating the elemental compositions of the collected samples with the help of sophisticated equipments namely scanning electron microscope (SEM) coupled with energy dispersive x-ray (EDX) analyzer, inductively coupled plasma mass spectrometer (ICP-MS), atomic absorption spectrophotometer (AAS) and flame-photometer. Descriptions of sampling, sample preparation, analytic technique and quality control are given in the subsequent sections.

4.2 Sampling

Five types of particulate air pollutants sources were selected and eleven samples were collected from these sources. Types, locations and sampling dates of collected samples are summarized in Table 4.1 and sampling locations are shown in Figure 4.1.

Table 4.1. Types, locations and sampling dates of collected samples

No	Type	Location	Sampling date
1	Soil	Joynabari, Hemayetpur	July 2007
2	Soil	Basta, Keraniganj	July 2007
3	Coal	HMB Brickfield, Aminbazar	22/03/2007
4	Coal	HNB Brickfield, Aminbazar	27/06/2006
5	Road dust	Gulistan	24/06/2006
6	Road dust	Farmgate	27/06/2006
7	Road dust	Mohakhali	27/06/2006
8	Road dust	Jatrabari	24/06/2006
9	Road dust	Rayerbagh	24/06/2006
10	Rock dust	Kachpur	24/06/2006
11	Cement	Scan Cement, Rupganj	July 2007

About 500 gm road dust samples were collected from the pavement edges and stored in small plastic jar. The road dust samples were screened through ASTM NO 35 sieve (500 µ) to remove extraneous matter such as small pieces of brick, paving stone, and other debris. Moreover, the road samples were further screened through ASTM NO 100 sieve (150 µ) and preserved in small self-sealed plastic bags for subsequent sample preparation and analysis. The soil samples were dried and ground into fine powder by mortar and pestle. The crushed soil dust was screened and preserved according to road dust sampling procedures. The rock dust was also preserved in the same procedure.

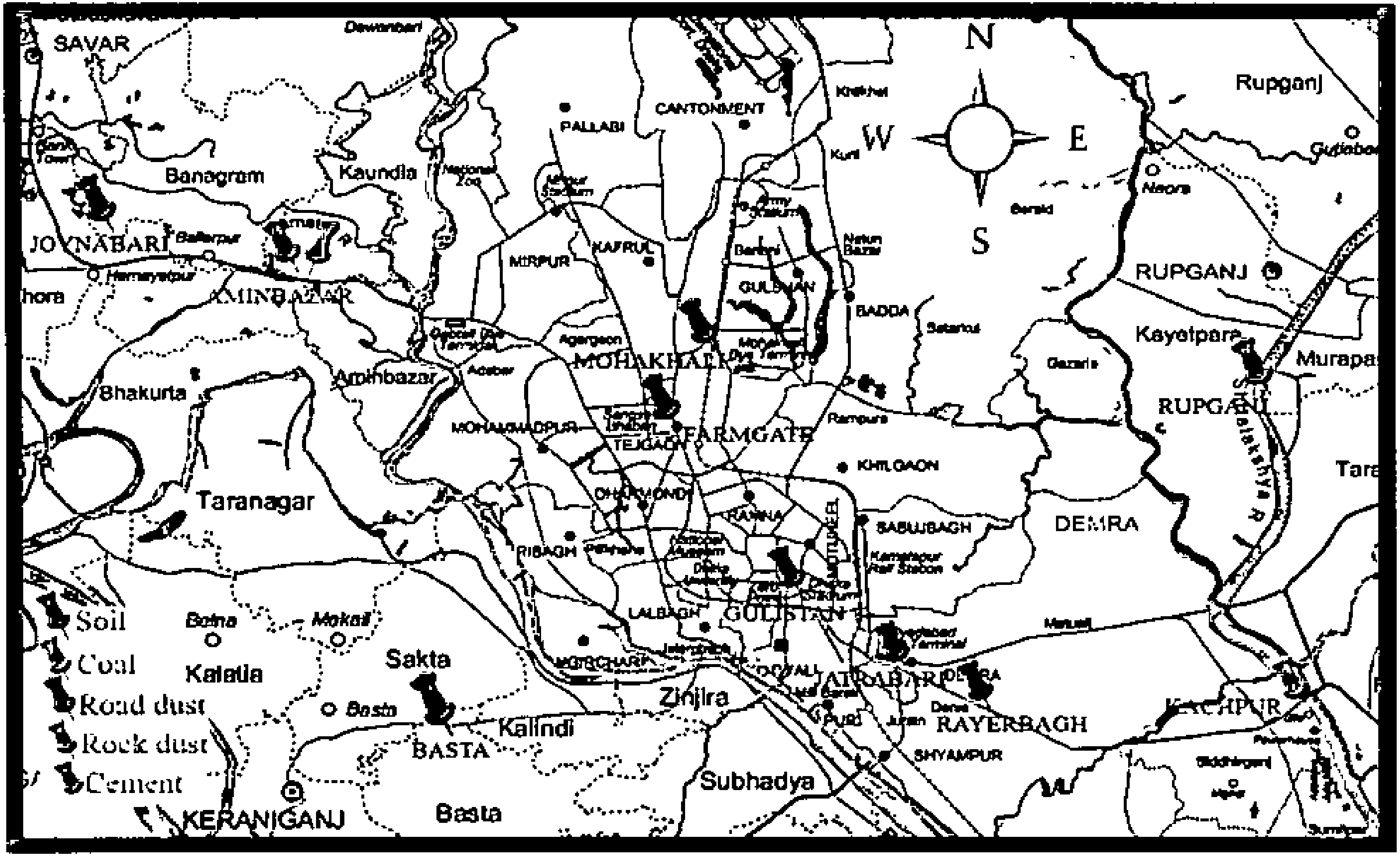

Figure 4.1. Sampling sites within and around Dhaka city

4.3 Sample preparation

The preserved samples were treated to make them suitable for analyzing in different equipments. For EDX analysis soil, road dust, cement and rock dust samples were shaped to small disc (diameter 12 mm and thickness 2 mm) with the help of special disc making dye. In the disc making process sodium silicate was used as a binding material among the dust particles and CO_2 was used for drying up. Moreover, gold coating was applied on the soil, road dust, rock dust and cement disc shaped samples using Agar Auto Sputter Coater prior to EDX analysis so that they would have conducting properties Approximately 0.25g of each sample was digested using Anton Paar Microwave 3000 acid digester. The digested samples were filtered and transferred to volumetric flask and diluted to 100 ml for ICP-MS, AAS and Flame-Photometric analysis. HNO_3, HCl and HF acids were used in different proportion for different types of samples as recommended in the digester's programmed library. Table 4.2 shows acid digestion recipe recommended for different types of samples.

Table 4.2. Amount of acid (ml) to digest 0.25 gm of sample

Sample type	Nitric acid (HNO_3)	Hydrochloric acid	Hydrofluoric acid
Soil	1.5	1.5	3.0
Road dust	1.5	1.5	3.0
Coal	5.5	0.5	---
Rock Dust	5.5	---	0.5
Cement	5.0	---	2.5

4.4 Analytical techniques

To identify major elements in the collected samples SEM-EDX analysis was performed. Some identified major elements and some toxic trace elements that are predominantly found in ambient air were quantified using ICP-MS, AAS and Flame-photometer Working principles of different types of analytical equipment used in this study are given in the in the following subsections.

Scanning electron microscopy and energy dispersive x-ray spectroscopy

The SEM operates by scanning an energetic, finely focused electron beam over an individual feature or a field of features. This primary electron beam interacts with the specimen producing a variety of secondary signals that can be monitored with appropriate detectors. These signals can be collected in synchronization with the position of the scanned electron beam to generate high-resolution images providing detailed spatial and acomposition information [50]. Interaction of the primary electron beam with atoms in the sample causes inner electron shell transitions, which result in the emission of X-rays. Two types of X-rays are generated:(1) Bremsstrahlung or continuous X-rays, which generate a broad and slowly-varying background over the entire X-ray spectrum. and (2) characteristic X-rays, which are narrow, discrete peaks in the spectrum whose energies are characteristic of specific elements present in the sample [50]. In this study Philips XL-30 SEM/EDX analyzer, made in Netherlands, was used.

Atomic absorption spectroscopy

The basic principles of atomic absorption spectroscopy can be expressed as by the following three statements.

1. All atoms can absorb light.
2. The wavelength at which light is absorbed is specific for a particular element.
3. The amount of light absorbed is proportional to the concentration of absorbing atoms [51].

The atomic absorption spectrophotometer is simply an instrument in which these basic principles are used. Schematic diagram of typical atomic absorption spectrophotometer (AAS) is shown in Figure 4.2 below.

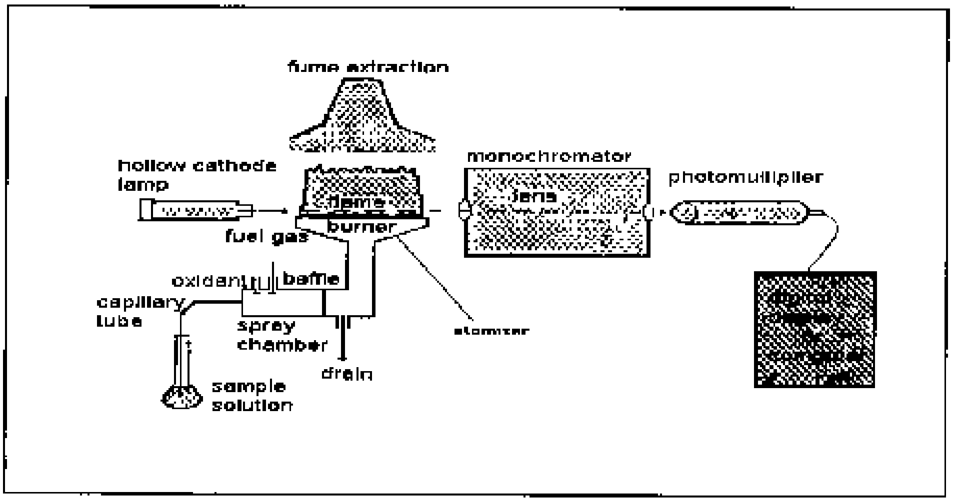

Figure 4.2. Typical arrangement of atomic absorption spectrophotometer

The instrument consists of:

1. A light source to generate light at the characteristic wavelength.
2. An atomizer to create a population of analyte atoms.
3. A monochromator to separate light at the characteristic wavelength.

4. An optical system to direct light from the source through the atom population and into the monochromator.
5. A light-sensitive detector.
6. Suitable electronic devices, which measure the response of the detector and translate this response into useful analytical measurements.

In this study atomic absorption spectrophotometer (FS 220, VARIAN, Australia) was used to determine Ca, Fe and Mg in the digested samples.

Inductively coupled plasma-mass spectroscopy

The digested sample was nebulized and the resulting aerosol transported by argon gas into the plasma torch of ICP-MS. The ions produced are entrained in the plasma gas and introduced into a mass spectrometer by means of an interface. The ions produced in the plasma are sorted according to their mass-charge ratios and quantified with a channel electron multiplier [7]. Schematic diagram of typical Inductively Coupled Plasma Mass Spectrometer is displayed in Figure 4.3 below.

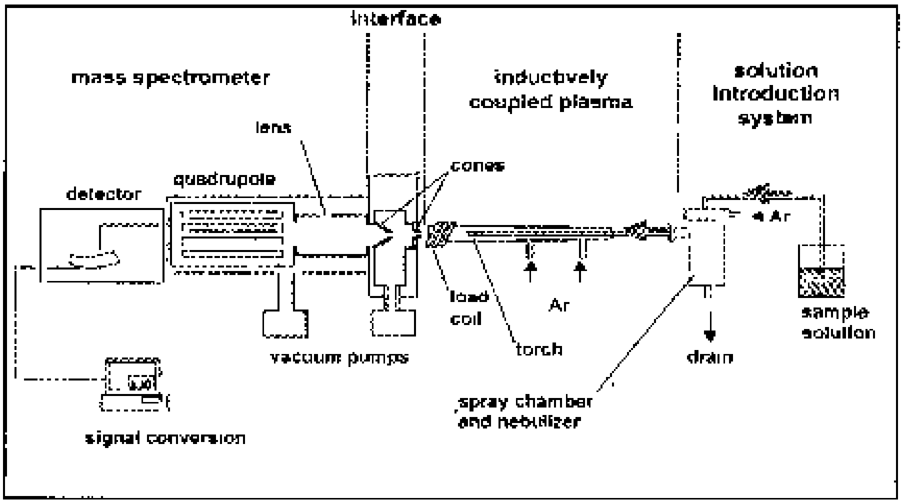

Figure 4.3. Schematic diagram of typical ICP-MS

In this study ICP-MS (VARIAN. USA) was used to determine concentration of Cd, Cr, Co, Cu, Mn, Ni, V and Zn in the digested samples.

Flame photometry

A Photoelectric Flame Photometer is a device used in inorganic chemical analysis to determine the concentration of certain metal ions, among them sodium, potassium, lithium, and calcium.

In principle, it is a controlled flame test with the intensity of the flame colour quantified by photoelectric circuitry. The sample is introduced to the flame at a constant rate. Filters select which colours the photometer detects and exclude the influence of other ions. Before use, the device requires calibration with a series of standard solutions of the ion to be tested (wikipedia.org). Flame photometry is crude but cheap compared to flame emission spectroscopy, where the emitted light is analysed with a monochromator. Flame photometer (PFP7, Jenway) was used to quantity potassium (K) in the samples.

4.5 Quality Control

In this study proper laboratory quality control procedure were followed for the reliability of the analytical results. Duplicate and spiked samples were made and analyzed to check the accuracy of the concentration data. Reagent without sample was also run besides the actual sample to know the contaminants in the reagent. Moreover, equipments were celebrated with standard solution prior to analysis and in the middle of the analysis for monitoring the equipment consistency.

CHAPTER 5

RESULTS

5.1 Introduction

Five types of air pollutants sources were studied for inorganic elements as well as some toxic heavy metals. Major elements were identified from the energy despersive x-ray spectroscopic analysis and some major and trace elements concentrations in the samples were determined with the help of analytical equipments such as inductively couple plasma mass-spectrometer, atomic absorption spectrophotometer and flame photometer. The samples analytical results are given in the following sections.

5.2 Major elements

Major elements that present in the samples were identified from the EDX spectrum. It should be mentioned that peak corresponding to gold was observed in the spectrums of soil, road dust, rock dust and cement samples due to applying gold coating on the samples prior to analysis for conductivity purpose. Moreover, height of characteristic peak of sodium and silicon could be increased due to addition of sodium silicate in the soil, road dust, rock dust and cement samples as a binding material. EDX spectrums of soil sample collected from Basta Keraniganj is given in Figure 5.1 (a)

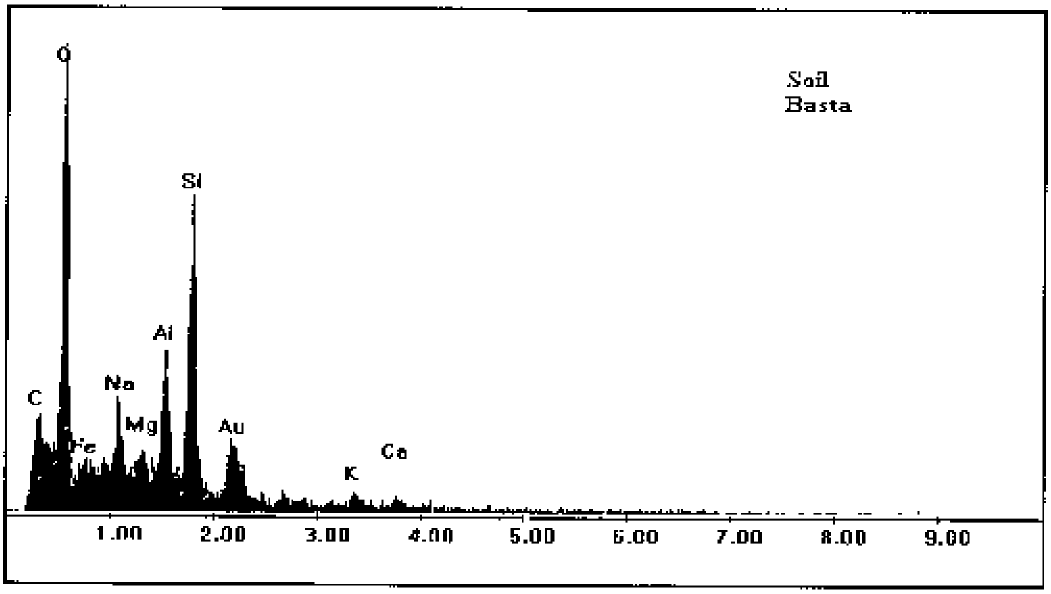

Figure 5.1 (a). EDX spectrum of soil sample collected from Basta, Keraniganj

Major elements observed in the EDX spectrum of the soil sample collected from Basta, Keraniganj were C, O, Fe Na, Mg, Al, Si, K and Ca.

EDX spectrum of soil sample collected from Joynabari, Hemayetpur is given in Figure 5.1 (b) below.

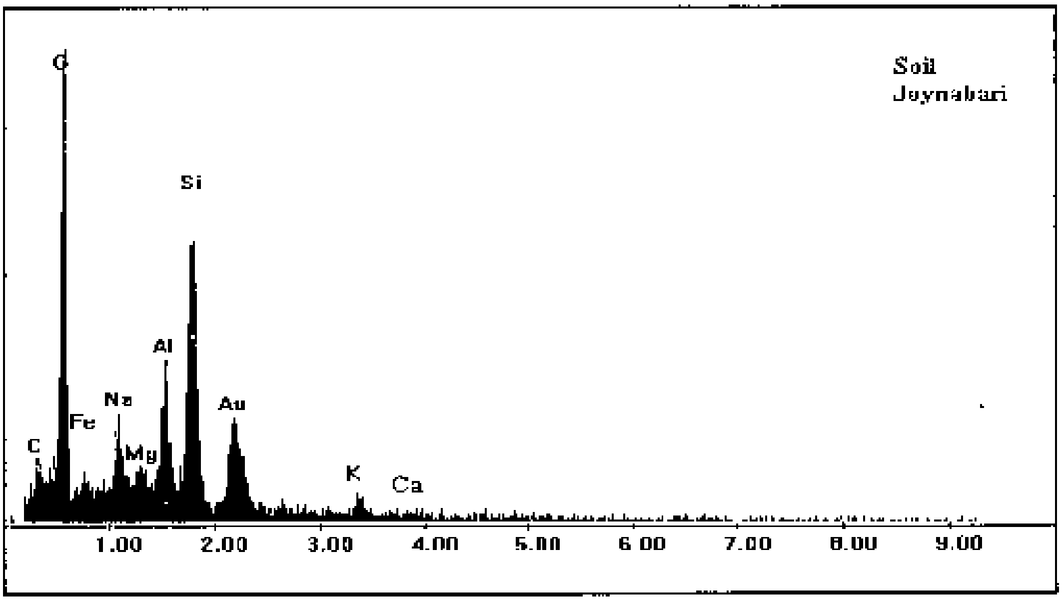

Figure 5.1 (b). EDX spectrum of soil sample collected from Joynabari, Hemayetpur

Major elements observed in the EDX spectrum of the soil sample collected from Joynabari were the same that found in Basta soil sample. EDX spectrum of coal sample collected from HMB Brickfield, Aminbazar is given in Figure 5.2 (a) below.

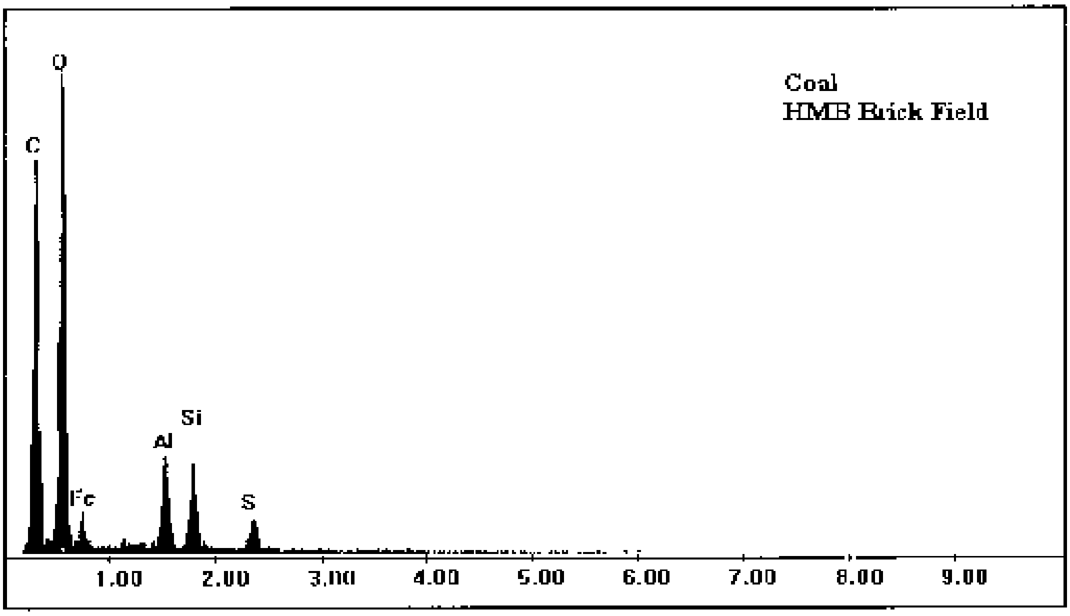

Figure 5.2 (a). EDX spectrum of coal sample collected from HMB Brickfield, Aminbazar

Only six major elements were found in coal sample collected from HMB brickfield, Aminbazar. The elements were C, O, Fe, Al, Si and S.

EDX spectrum of coal sample collected from HNB Brickfield, Aminbazar is given in Figure 5.2 (b) below.

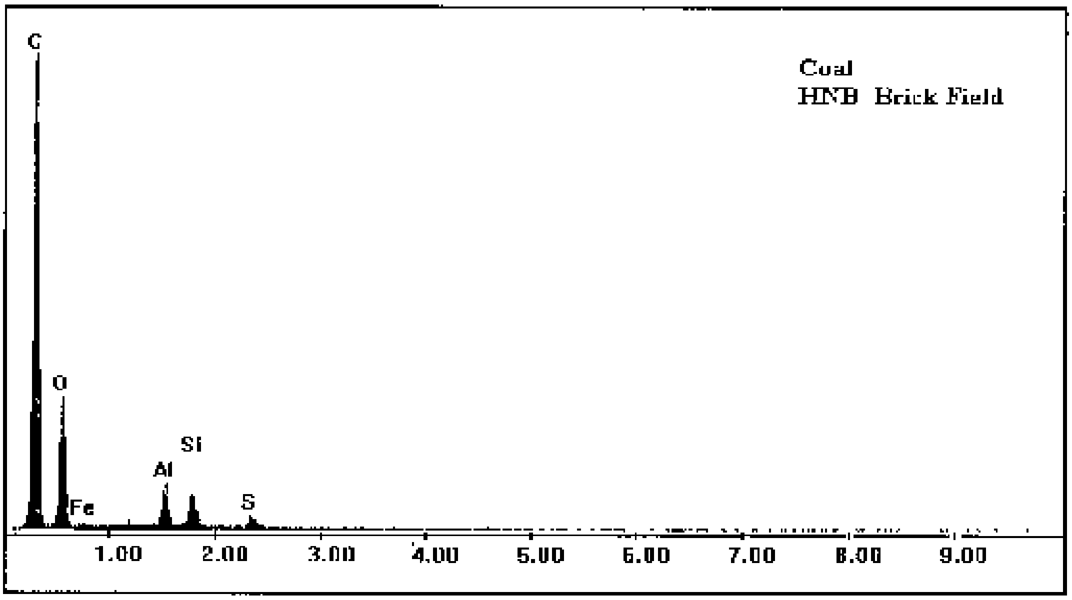

Figure 5.2 (b). EDX spectrum of coal sample collected from HNB Brickfield, Aminbazar

Major elements found in coal sample collected from HNB Brickfield were same as that of coal sample collected from HMB brickfield. EDX spectrum of road dust sample collected from Mohakhali, Dhaka is given in Figure 5.3 (a) below.

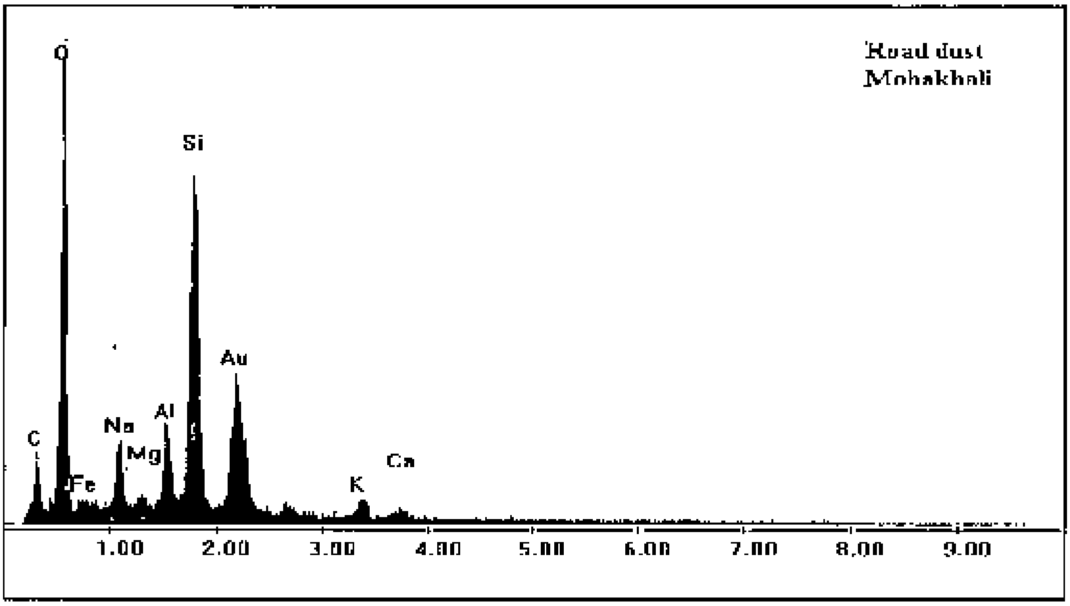

Figure 5.3 (a). EDX spectrum of road dust sample collected from Mohakhali, Dhaka

Major elements found in road dust sample collected from Mohakhali were C, O, Fe, Na, Mg, Al, Si, K and Ca.

EDX spectrum of road dust sample collected from Farmgate. Dhaka is given in Figure 5.3 (b) below.

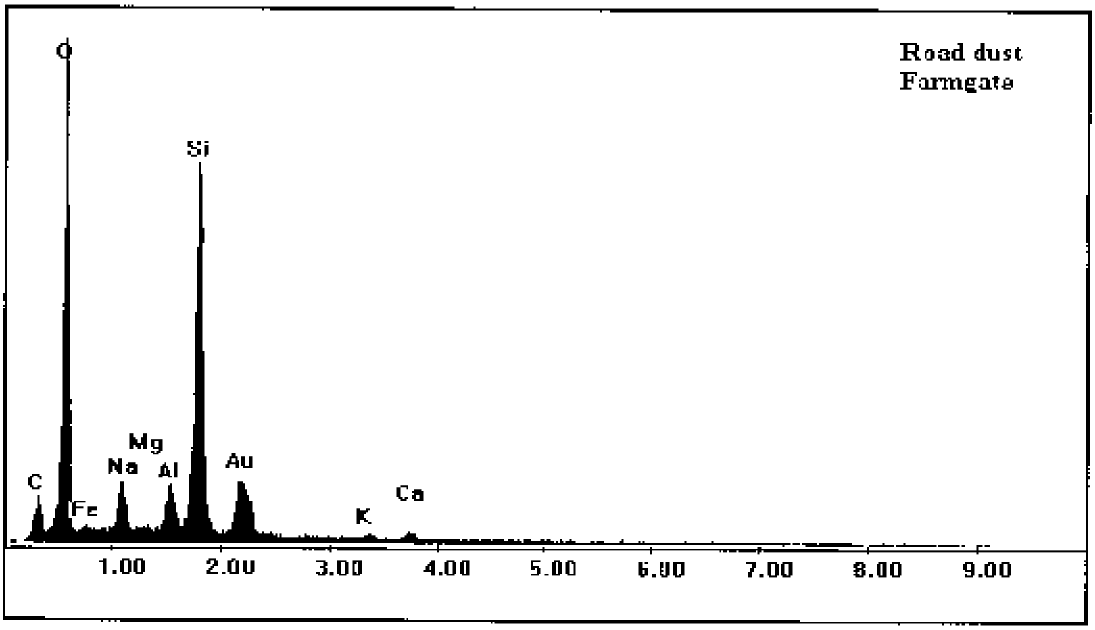

Figure 5.3 (b). EDX spectrum of road dust sample collected from Farmgate, Dhaka

Major elements found in road dust sample collected from Farmgate were same as that of Mohakhali road dust sample. EDX spectrum of road dust sample collected from Gulistan, Dhaka is given in Figure 5.3 (c) below.

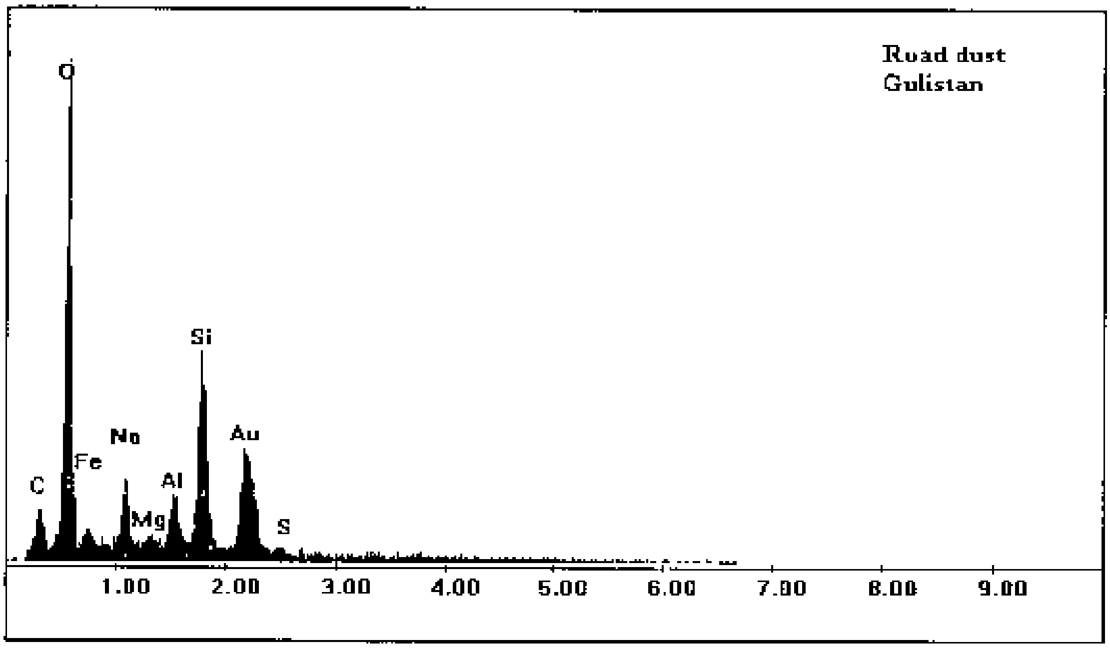

Figure 5.3 (c). EDX spectrum of road dust sample collected from Gulistan, Dhaka

Major elements found in road dust sample collected from Gulistan were C, O, Fe, Na, Mg, Al, Si and S.

EDX spectrum of road dust sample collected from Jatrabari, Dhaka is given in Figure 5.3 (d) below.

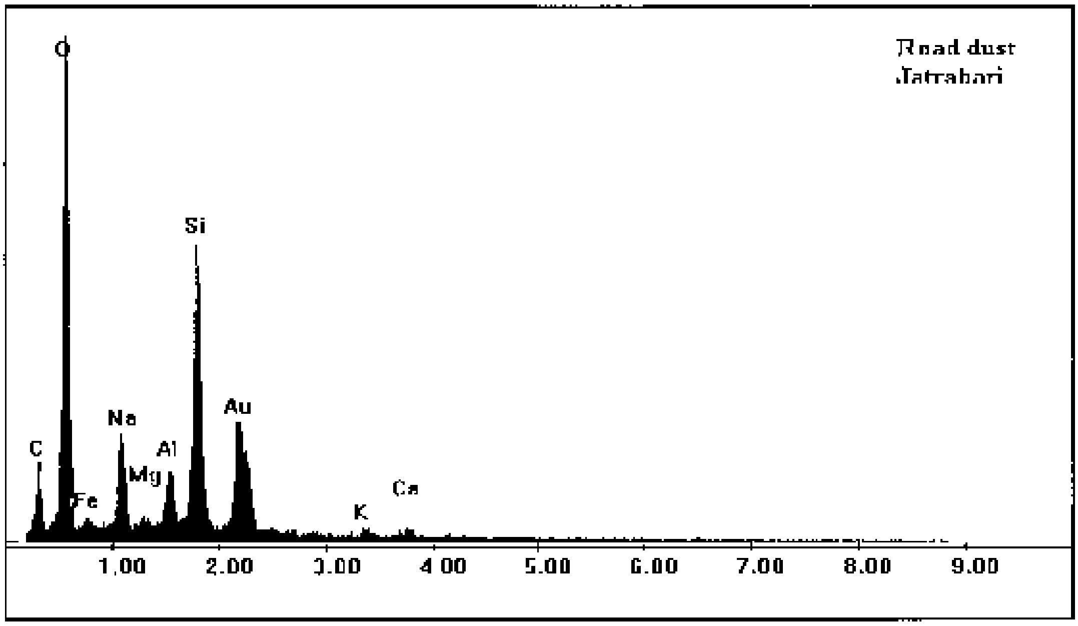

Figure 5.3 (d). EDX spectrum of road dust sample collected from Jatrabari, Dhaka

Major elements observed in the EDX spectrum of road dust sample collected from Jatrabari were same as that of Gulistan and Farmgate road dust sample. EDX spectrum of road dust sample collected from Rayerbagh, Dhaka is given in Figure 5.3 (e) below.

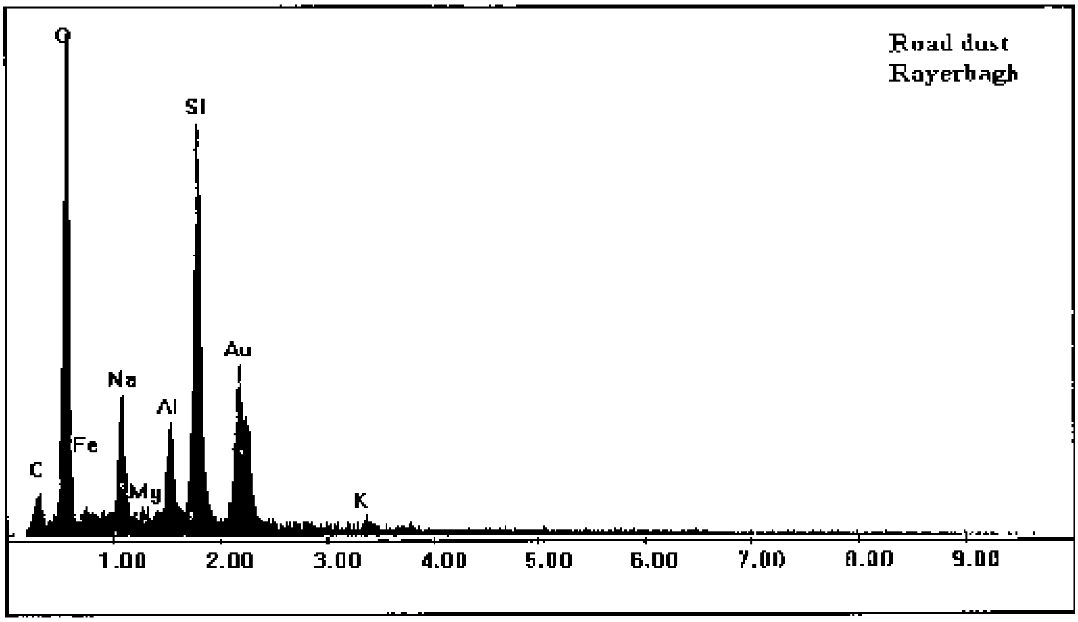

Figure 5.3 (e). EDX spectrum of road dust sample collected from Rayerbagh, Dhaka

Major elements observed in the EDX spectrum of road dust sample collected from Rayerbagh were C, O, Fe, Na, Mg, Al, Si and K.

EDX spectrum of rock dust sample collected near Kachpur Bridge, Narayanganj is given in Figure 5.4 below.

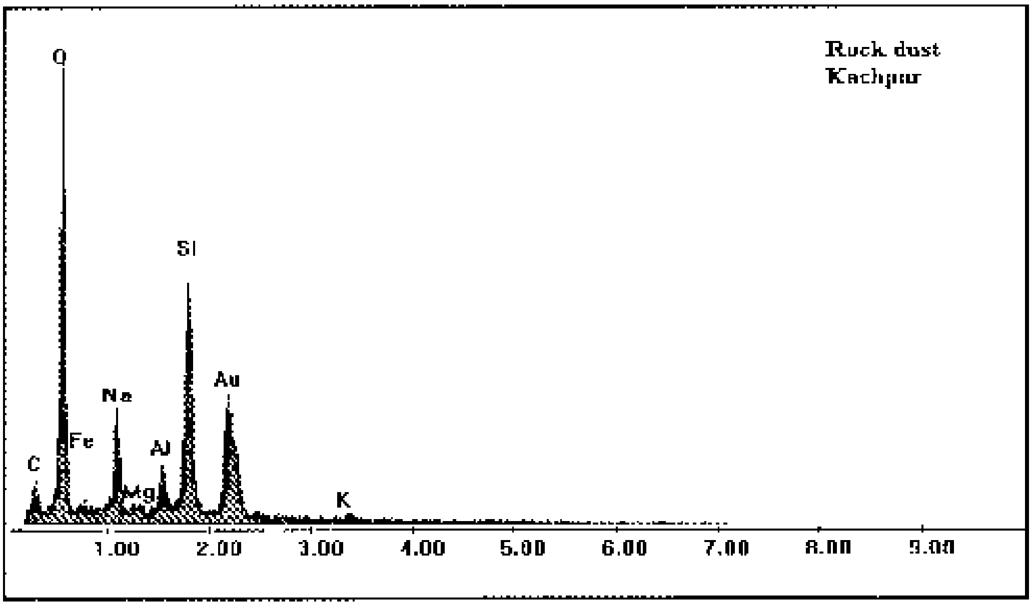

Figure 5.4. EDX spectrum of rock dust sample collected near Kachpur Bridge

Major elements identified from EDX spectrum of rock dust sample collected near Kachpur Bridge were C, O, Fe, Na, Mg, Al and K.EDX spectrum of cement sample collected from Scan Cement, Rupganj is displayed in Figure 5.5 below.

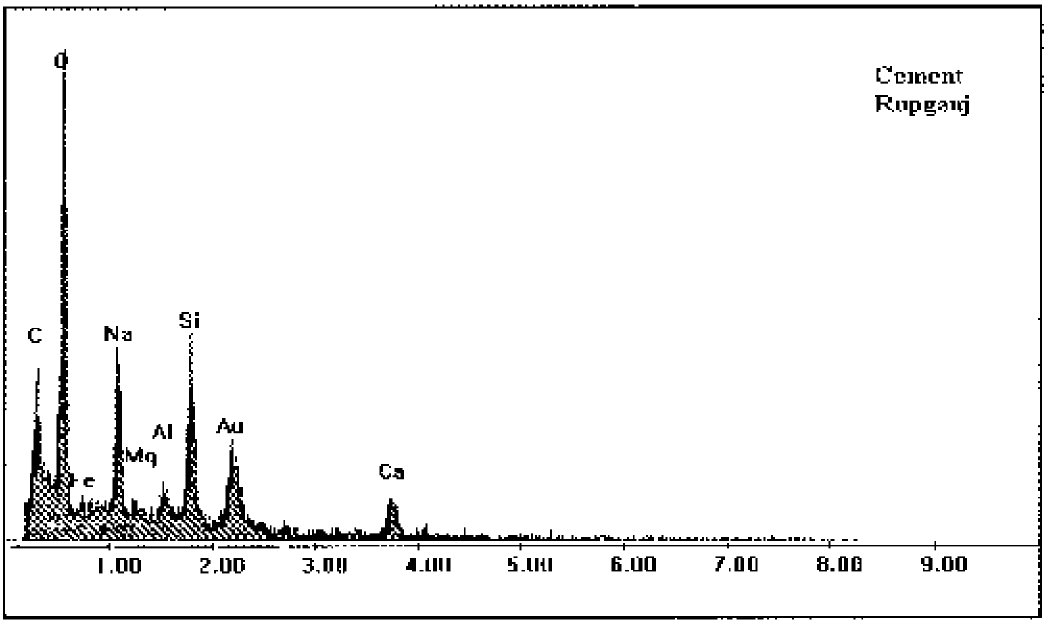

Figure 5.5. EDX spectrum of cement sample collected from Scan Cement, Rupganj

Major elements observed in the spectrum of cement sample were C, O, Fe, Na, Mg, Al, Si and Ca. Trace elements in the samples were not identified with the EDX analyzer due to the limitation of the operating range of the apparatus.

5.3 Elemental concentrations

Concentrations of some major and trace elements were determined via ICP-MS, AAS and Flame-photometer. Elemental concentrations of soil, coal, rock dust and cement samples are shown in Table 5.1 below.

Table 5.1. Concentrations (mg/kg) of some major and trace elements in soil, coal, rock dust and cement samples

Element	Soil Joynabari	Soil Basta	Coal, HMB Brickfield	Coal, HNB Brickfield	Rock dust Kachpur	Cement Rupganj
Ca	7773	5172	3237	3917	4717	166547
Cd	4.15	ND	ND	ND	ND	4.66
Cr	113	133	49.8	36.6	62.1	267.4
Co	19.9	21.2	2.65	3.12	16.3	36.4
Cu	86.6	90.1	48.8	33.7	69.4	165.1
Fe	38500	40467	14747	14209	17034	14429
K	15700	13960	ND	ND	8058	18200
Mg	12376	3842	ND	ND	1396	2189
Mn	812	698	19.4	45.5	675	684.4
Ni	54.5	73	43.6	16.2	25.2	165.1
Pb	174	50.5	14.2	14.3	50.5	140.7
V	125	155.7	46.3	44.8	109	93.3
Zn	------	------	36.1	18.2	------	-------

Elemental concentrations of road dust samples are given in Table 5.2 below.

Table 5.2. Concentrations (mg/kg) of some major and trace elements in road dust samples

Element	Road dust Mohakhali	Road dust Farmgate	Road dust Gulistan	Road dust Jatrabari	Road dust Rayerbagh	Average
Ca	46300	12200	18000	89233	101983	53543.2
Cd	3.14	8 28	1.20	4.48	5 42	4.5
Cr	60.5	45 5	40.6	98.4	121	73.2
Co	10.8	8 17	7.06	12.5	18 3	11.4
Cu	68.5	122	111	216	103	124.1
Fe	28300	23700	29700	45900	53540	36228
K	23400	12700	15128	30889	57600	27943.4
Mg	4200	2669	527	7000	6279	4135
Mn	652.6	619	472.8	1046	1338	825.7
Ni	21.5	24.8	24.5	33.5	42.4	29.3
Pb	144	108	83.6	164	238	147.5
V	72.9	70.5	62.8	87.1	102	79.1

It should be mentioned that due to some technical problems concentrations of environmentally significant major element aluminum and trace elements such as arsenic, zinc (except for coal samples) and mercury were not determined in this study.

CHAPTER 6

DISCUSSION

6.1 Major elements in the sources

Preliminary elemental tracking in the collected air pollutants sources were performed using Energy Dispersive X-ray Analyzer and major elements were identified. Major elements that observed in the EDX spectrums of the samples are presented in Table 6.1 below.

Table 6.1. Major elements in the samples identified by EDX analysis

Type	Location	Major elements
Soil	Joynabari, Hemayetpur	C, O, Fe. Na. Mg, Al. Si, Ca. K
Soil	Basta, Keraniganj	C, O, Fe. Na, Mg, Al. Si, Ca, K
Coal	HMB Brick Field, Aminbazar	C, O, Fe. Al, Si. S
Coal	HNB Brick Field. Aminbazar	C, O, Fe. Al, Si. S
Road dust	Mohakhali	C, O, Fe. Na. Mg, Al, Si, Ca K
Road dust	Farmgate	C, O, Fe. Na. Mg. Al, Si, Ca K
Road dust	Gulistan	C. O. Fe, Na, Mg, Al. S
Road dust	Jatrabari	C, O, Fe. Na. Mg. Al, Si, Ca. K
Road dust	Rayerbagh	C, O, Fe. Na. Mg. Al, Si, K
Rock dust	Kachpur	C, O, Fe. Na. Mg. Al, Si, K
Cement	Rupganj	C, O, Fe. Na. Mg, Al, Si, Ca

It is observed in Table 6.1 that C, O, Fe, Al and Si were most commonly found in all source samples. Ambient particulates may be enriched with metals such as iron and aluminum from these sources. Moreover sulfur (S) was identified in both coal samples. This sulfur can be converted to sulfur oxides while coal is burned and sulfur oxide is a significant air pollutant, which can harm human health as well as the environment.

6.2 Distribution of elements in the sources

Concentrations of some major and trace elements in the collected samples were determined and elemental distributions were observed graphically. Analyzing the elemental distribution graphs many significant information were found. Descriptions of the selected particulate air pollutants sources in terms of the elemental concentrations are given in the subsequent subsections.

6.2.1 Soil

Many literatures mentioned soil as one of the main sources of particulate air pollutants as well as toxic heavy metals. Distribution of elements in soil sample collected from Joynabari, Hemayetpur is shown in Figure 6.1 below.

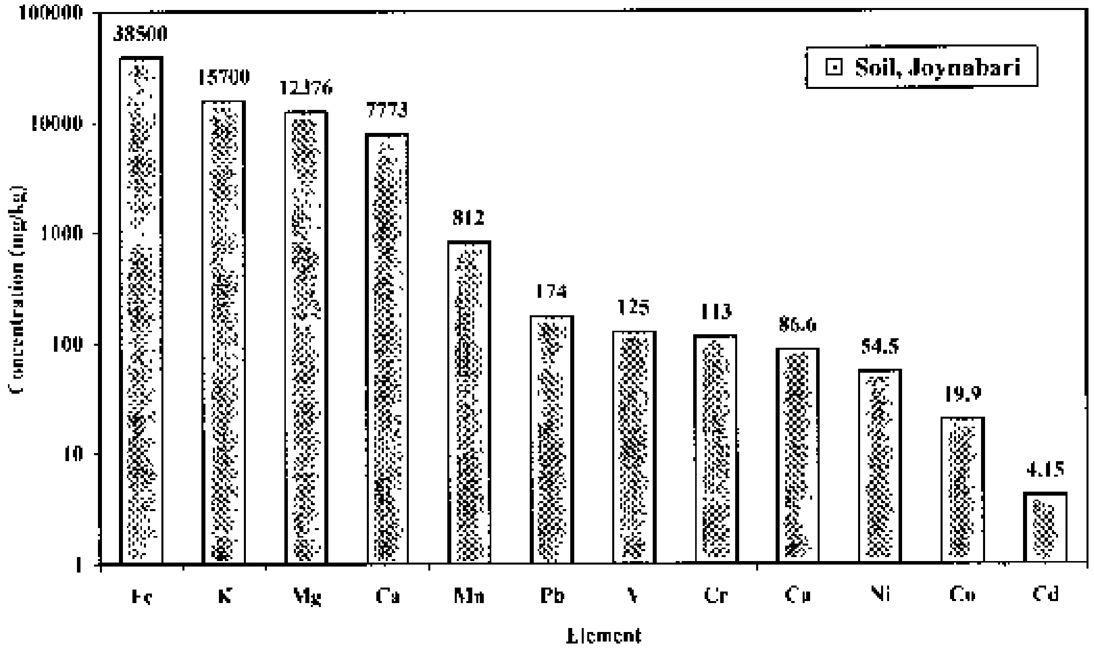

Figure 6.1. Distribution of elements in soil sample collected from Joynabari, Hemayetpur

Concentrations of Fe. K, Mg and Ca in Joynabari soil samples were much higher than other elements levels. Trace metals can be arranged in decreasing order with respect to concentration for Joynabari soil as: Mn > Pb > V > Cr > Cu > Ni > Co > Cd. Guideline values of lead. chromium, copper, nickel and cadmium for common soil are 100, 100, 50, 50 and 3 mg/kg [9, 26]. It was found that levels of lead, chromium. copper, nickel and cadmium in Joynabari soil sample exceeded the maximum tolerable limits for common soil. On the other hand no cadmium was detected in soil sample collected from Basta, Keraniganj and lead level was lower than lead level in Joynabari soil sample. Concentrations of copper, chromium and nickel in Basta soil sample found higher than standard levels. Arrangement of trace metals in decreasing order with respect to concentration for Basta soil is: Mn > V > Cr > Cu > Ni > Pb > Co > Cd. In Basta soil concentrations of Fe, K, Mg and Ca were also found high. Distribution of elements in soil sample collected from Basta, Keraniganj is shown by Figure A.1 in Appendix-A.

6.2.2 Coal

Concentrations of the trace elements in the coal are essential for the assessment of possible environmental impact from coal-fired power stations, brick-kiln, as coal combustion has been regarded as an important global source of emission of many trace elements to the environment [28]. Levels of different elements in coal sample collected form HMB brickfield. Aminbazar is graphically shown in Figure 6.2 below.

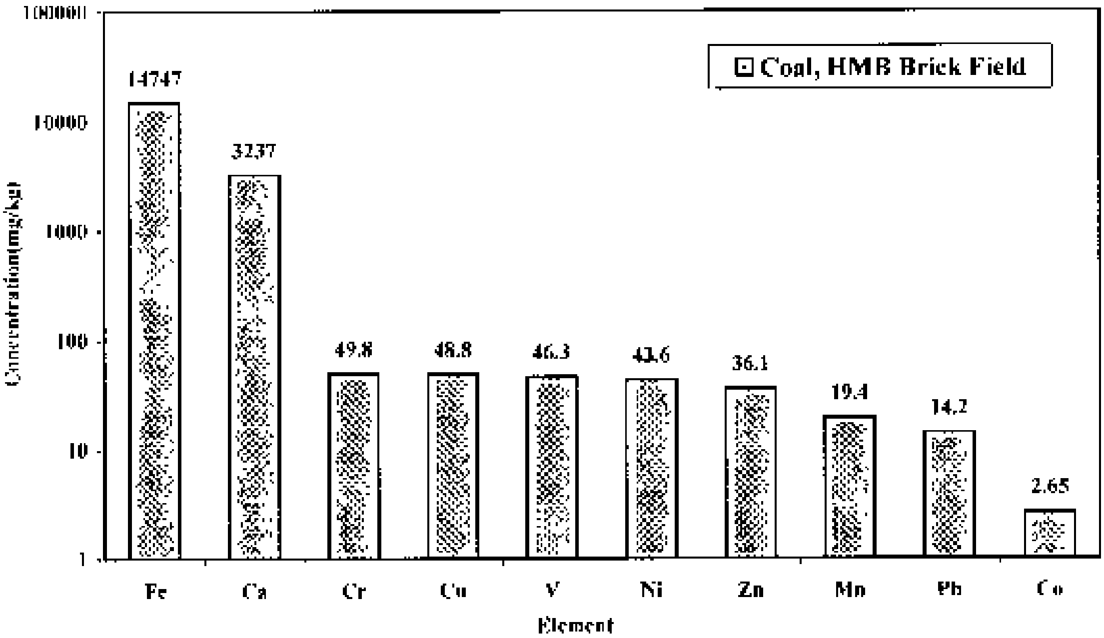

Figure 6.2. Distribution of elements in coal sample collected from of HMB Brickfield, Aminbazar

Levels of Fe and Ca in coal samples were found much higher than other elements. Trace metals in coal sample collected from HMB brickfield can be sorted in descending order with respect to concentrations as: Cr > Cu > V > Ni > Zn > Mn > Pb > Co. Very small difference in concentrations of elements such as cobalt, lead and vanadium were observed between the two coal samples. Nickel level in coal sample collected form HMB brickfield is much higher than HNB brickfield coal sample. Significant level of zinc found in both coal samples. Concentration of manganese in HNB brickfield coal found much higher than HMB brickfield coal. Descending order of trace metals based on concentrations for coal sample collected from HMB brickfield is: Mn > V > Cr > Cu > Zn > Ni > Pb > Co. Elemental distributions of coal sample collected form HNB brickfield is shown by Figure A.2 in Appendix-A. The toxic heavy metals that found in coal samples may contribute to air pollution when they release in the atmosphere with fly ash after coal combustion and this fly ash may settle or precipitate on the surface environment and enrich toxic trace metal concentration of soil and road dust.

6.2.3 Road dust

The elemental concentrations of road dust reflect the characteristics of the activities going on in a specific area [34]. Distribution of elements in road dust sample collected from Mohakhali is presented in Figure 6.3 below.

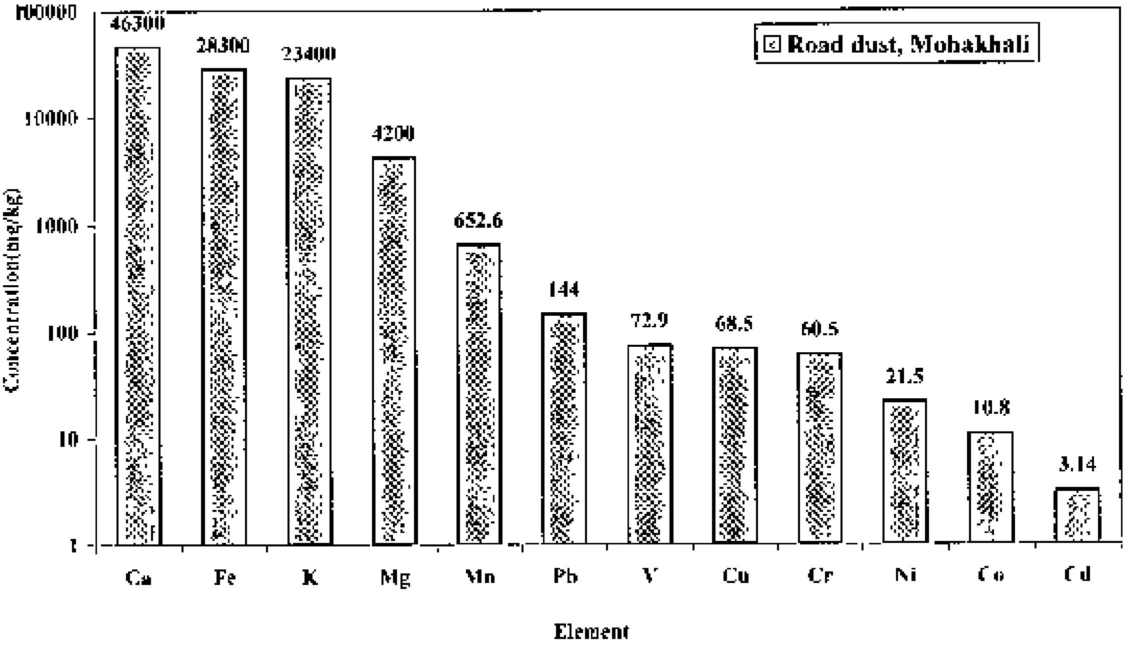

Figure 6.3. Distribution of elements in road dust sample collected from Mohakhali, Dhaka

The concentrations of Fe, Ca and K were found much higher than the concentrations of other elements in all road dust samples. Levels of magnesium in road dust samples also found high. Arrangements of trace metals in road dust samples in descending order with respect to concentrations are given in Table 6.2 below.

Table 6.2. Arrangements of trace metals in road dust samples in descending order with respect to concentrations

Road location	Order of trace elements
Mohakhali	Mn > Pb > V > Cu > Cr > Ni > Co > Cd
Farmgate	Mn > Cu > Pb > V > Cr > Ni > Cd > Co
Gulistan	Mn > Cu > Pb > V > Cr > Ni > Co > Cd
Jatrabari	Mn > Cu > Pb > Cr > V > Ni > Co > Cd
Rayerbagh	Mn > Pb > Cr > Cu > V > Ni > Co > Cd

It is observed in Table 6.2 that the orders of the trace element based on concentration declining do not follow the same pattern. For any two of these concentration series at least one metal varied in position. This variation in distribution of trace heavy metals in road dust may be due to contribution from various specific heavy metal pollutants sources.

Concentrations of lead, copper and cadmium in Mohakhali, Farmgate, Jatrabari and Rayerbagh road dust were found higher than the acceptable levels for common soil. Moreover, level of copper in Gulistan, and level of chromium in Rayerbagh road dust also exceeded the corresponding maximum allowable limits for common soil. Distribution of major and trace elements in road dust samples collected from Farmgate, Gulistan, Jatrabari and Rayerbagh are shown by Figure A.3, A.4, A.5 and A.6 respectively in Appendix-A.

6.2.4 Rock dust

There are many stone crushing zones around Dhaka city where stones are frequently crushed without thinking of environmental impact of particulate matters generated from rock dust. Rock dust may become air borne while crushing in crusher or piled besides roads or construction areas. Distribution of elements in rock dust sample collected near Kachpur Bridge is displayed in Figure 6.4 below.

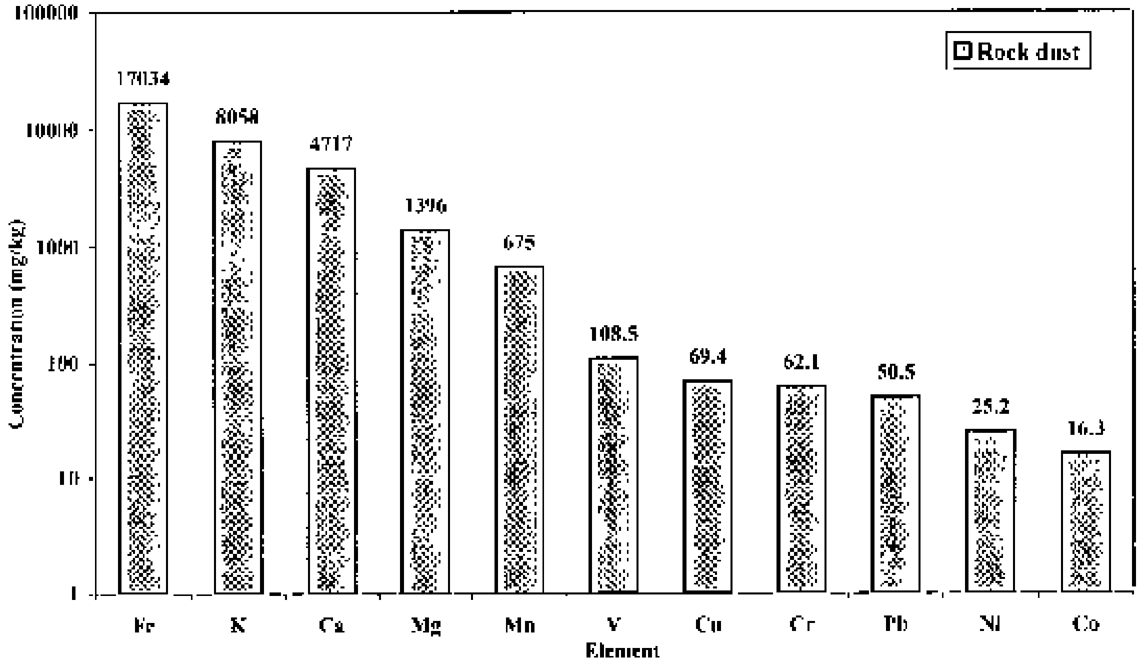

Figure 6.4. Distribution of elements in rock dust sample collected near Kachpur Bridge

Higher level of Fe, K, Ca and Mg were found in rock dust sample. No cadmium was found in rock dust sample. The arrangement of trace metals in decreasing order with respect to concentration for rock dust sample is: Mn > V > Cu > Cr > Pb > Ni > Co. Rock dust may significantly contribute to particulate air pollution in Dhaka city.

6.2.5 Cement

Cement is one of the main construction materials. In Dhaka city cement is used for construction of buildings, bridges, footpaths etc. Cement particle may be air borne at the time of mixing with other construction materials and emitting from cement industries. Distribution of elements in cement sample collected from Scan Cement produced at Rupganj is shown in Figure 6.5 below.

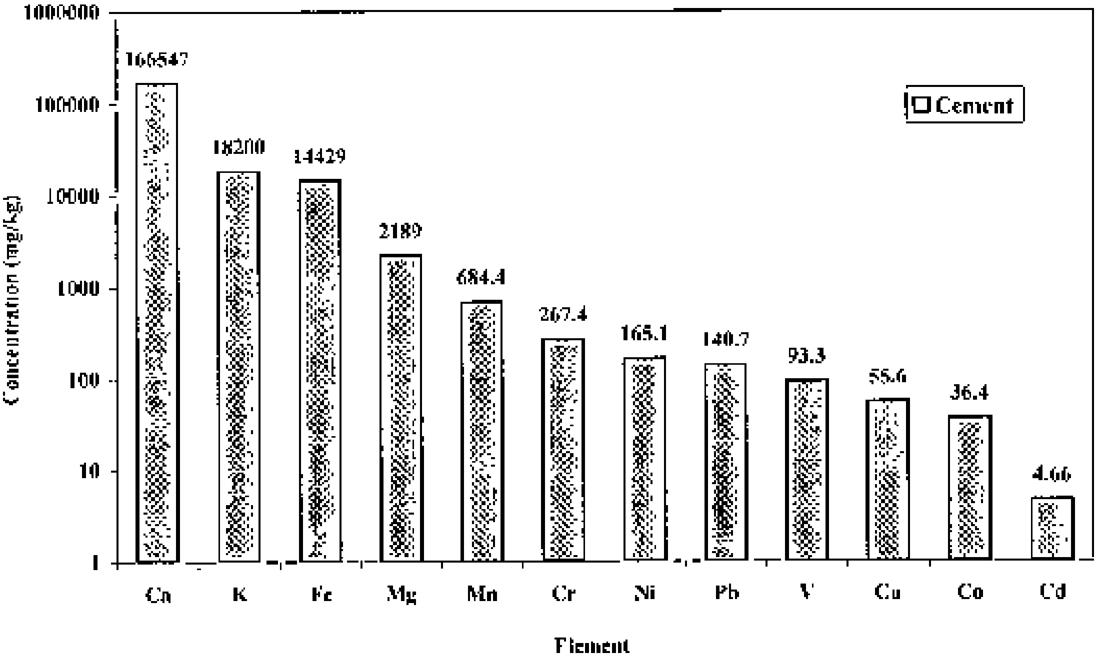

Figure 6.5. Distribution of elements in cement sample collected from Scan Cement produced at Rupganj

Major elements in cement sample were Ca, K, Fe, and Mg in comparison to other elements. Concentrations of toxic trace metals such as Cr, Ni, Pb, Cu, Co and Cd were found higher than maximum permissible levels of corresponding metals for common soil. Trace heavy metals in cement sample can be rearrange in decreasing order with respect to concentration as: Mn > Cr > Ni > Pb > V > Cu > Co > Cd. Air may be enriched with heavy metal from cement particles. Various heavy metals can be accumulated in soil and road dust from erosion of building materials and deposition of air borne cement particles.

6.3 Distribution of toxic trace metals among the sources

In this study eight environmentally significant toxic trace metals were commonly searched among the samples. They were cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), manganese Mn), nickel (Ni), lead (Pb) and vanadium (V). Distributions of these heavy metals in ambient particulate matters and the air pollutants source samples are discussed in the subsequent subsections.

6.3.1 Cadmium (Cd)

Concentrations of cadmium in $PM_{2.5}$ and PM_{10} collected from Mohakhali were found 2.7 and 2.5 ng/std.m^3 respectively. Concentrations of cadmium in $PM_{2.5}$ and PM_{10} at Farmgate were detected 2.91 and 4.3 ng/std.m^3 respectively [7]. Concentrations of cadmium in different types of particulate air pollutant sources are presented in Figure 6.6 below.

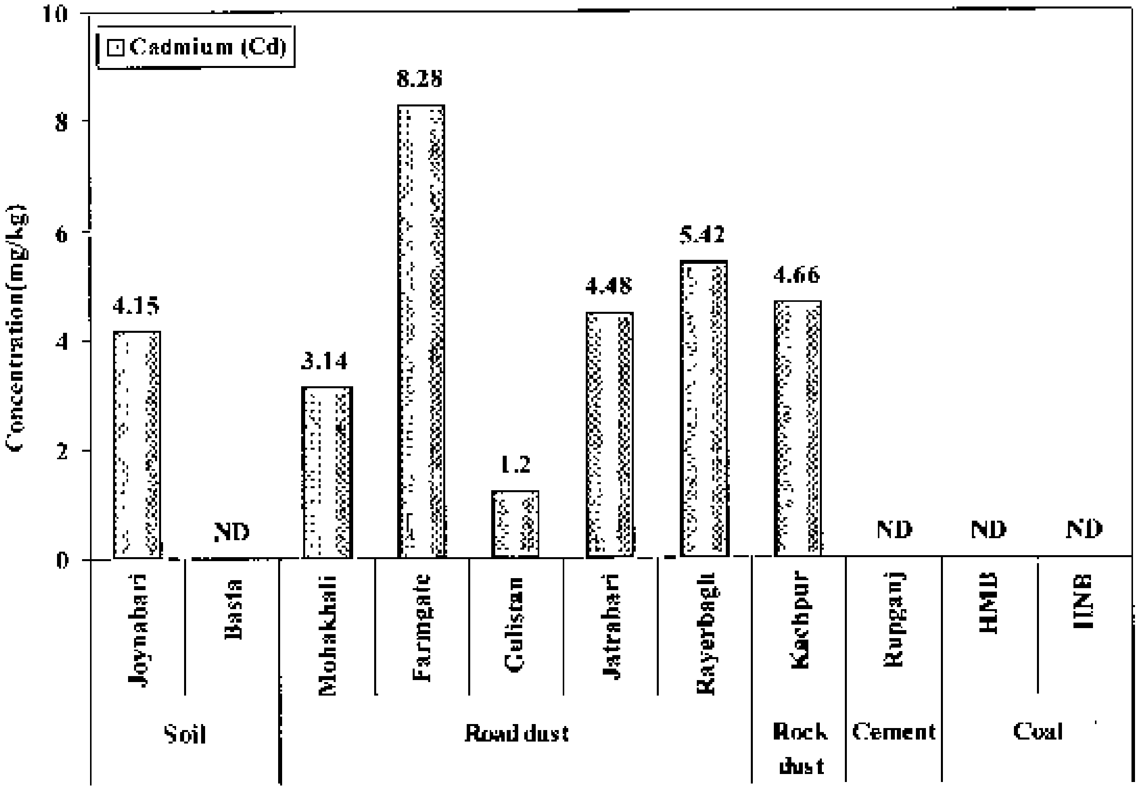

Figure 6.6. Levels of cadmium in different types of source samples collected from various locations within and around Dhaka city

Cadmium found below detectable limit in Basta soil, cement and coal samples. Maximum tolerable limit of cadmium in soil is 3.0 mg/kg [26]. Levels of cadmium in Joynabari soil and Mohakhali, Farmgate, Jatrabari and Rayerbagh road dust samples exceeded the acceptable limit for common soil. The highest level of cadmium was found at Farmgate road dust. Elevated level of Cd at Farmgate road dust may be due to high traffic load, tire rubber wear. However, Joynabari soil sample may be enriched with cadmium from application of phosphate fertilizers during cultivation. Significant amount of cadmium found in rock dust sample. Cadmium accumulates in body and persists for a long time. Cadmium poisoning may lead to kidney disease, lung damage, fragile bones, abdominal pain and even chocking [7].

6.3.2 Chromium (Cr)

Concentrations of chromium in air borne $PM_{2.5}$ and PM_{10} collected from Mohakhali were reported 57.4 and 63.2 ng/std.m^3 respectively and those from Farmgate were 24.82 and 23.80 ng/std.m^3 respectively [7]. Levels of chromium in different types of particulate air pollutant sources are presented in Figure 6.7 below.

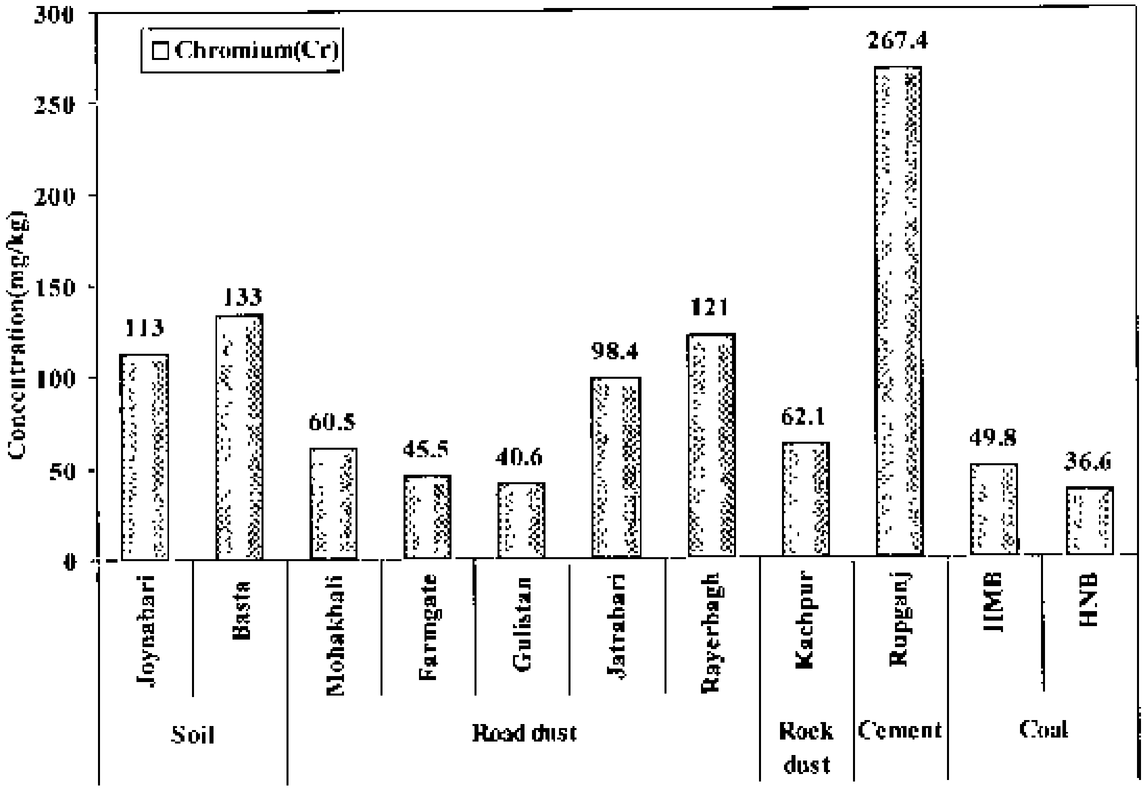

Figure 6.7. Levels of chromium in different types of samples collected from various locations within and around Dhaka city

Average level of chromium in soil of Bangladesh is 95.90 mg/kg and acceptable level of chromium in common soil is 100 mg/kg [9, 26]. Concentrations of chromium in Joynabari and Basta soil exceeded the maximum allowable value for common soil. Moreover, chromium level was also high in Rayerbagh road dust. However, Cr in Mohakhali, Farmgate, Gulistan and Jatrabari were within the acceptable limit. Ahmed et al (2006) reported levels of Cr in road dust of Dhaka city as 136, 105, 99 mg/kg for industrial, commercial and residential areas respectively. Elevated level of chromium in Basta soil may come from effluents of tanning industries. Moreover, soil may be contaminated with chromium from metallurgical industries, fly ash, dyes and pigments, chrome plating and wood preserving, fertilizer. The highest level of chromium detected in cement sample. Availability of chromium in coal and rock dust indicates them as potential sources of chromium in the ambient air.

6.3.3 Cobalt (Co)

Levels of cobalt found in $PM_{2.5}$ and PM_{10} at Mohakhali were 2.9 and 1.5 ng/std.m^3 respectively and those at Farmgate were 3.57 and 2.8 ng/std.m^3 respectively [7]. Levels of cobalt in different types of particulate air pollutant sources are shown in Figure 6.8 below.

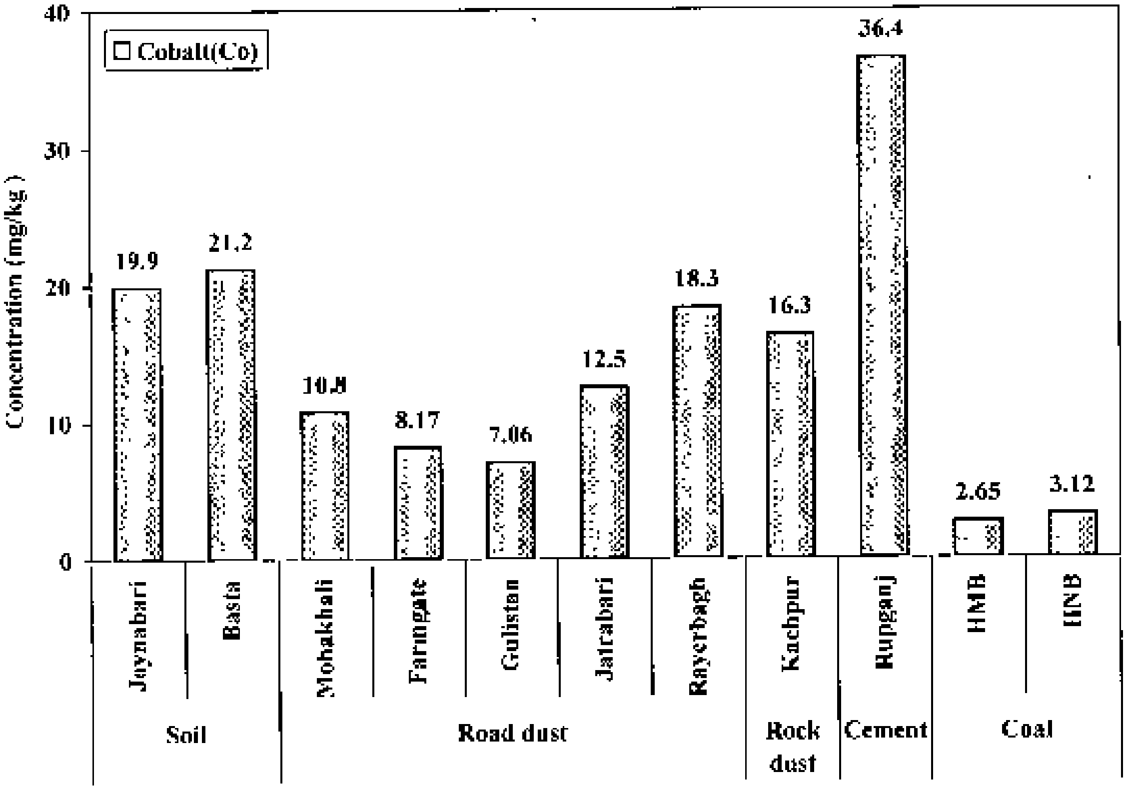

Figure 6.8. Levels of cobalt in different types of samples collected from various locations within and around Dhaka city

Average concentration of cobalt in the earth's crust is 20-25 mg/kg [39]. Among the particulate air pollutants source samples the highest level of cobalt was found in cement sample. Elevated level of cobalt in cement sample may come from its raw materials. Cobalt level in soil and road dust may be increased due to anthropogenic activities. Among the road dust samples the highest level of cobalt found in Rayerbagh road dust sample and average cobalt level in road dust samples was 11.4 mg/kg. Cobalt level in soil samples also found higher. Elevated levels of cobalt in soil may result from anthropogenic activities such as the application of cobalt-containing sludge or phosphate fertilizers to soil, the disposal of cobalt-containing wastes, and atmospheric deposition from activities such as the burning of fossil fuels and smelting and refining of metals [39]. Significant amount of cobalt found in rock dust sample. Small amount of cobalt found in coal sample.

6.3.4 Copper (Cu)

Concentrations of copper in $PM_{2.5}$ and PM_{10} collected from Mohakhali were 669 and 919.3 ng/std.m^3 respectively and those from Farmgate were 973.70 and 989.40 ng/std.m^3 respectively [7]. Concentrations of copper in different types of particulate air pollutant sources are presented in Figure 6.9 below.

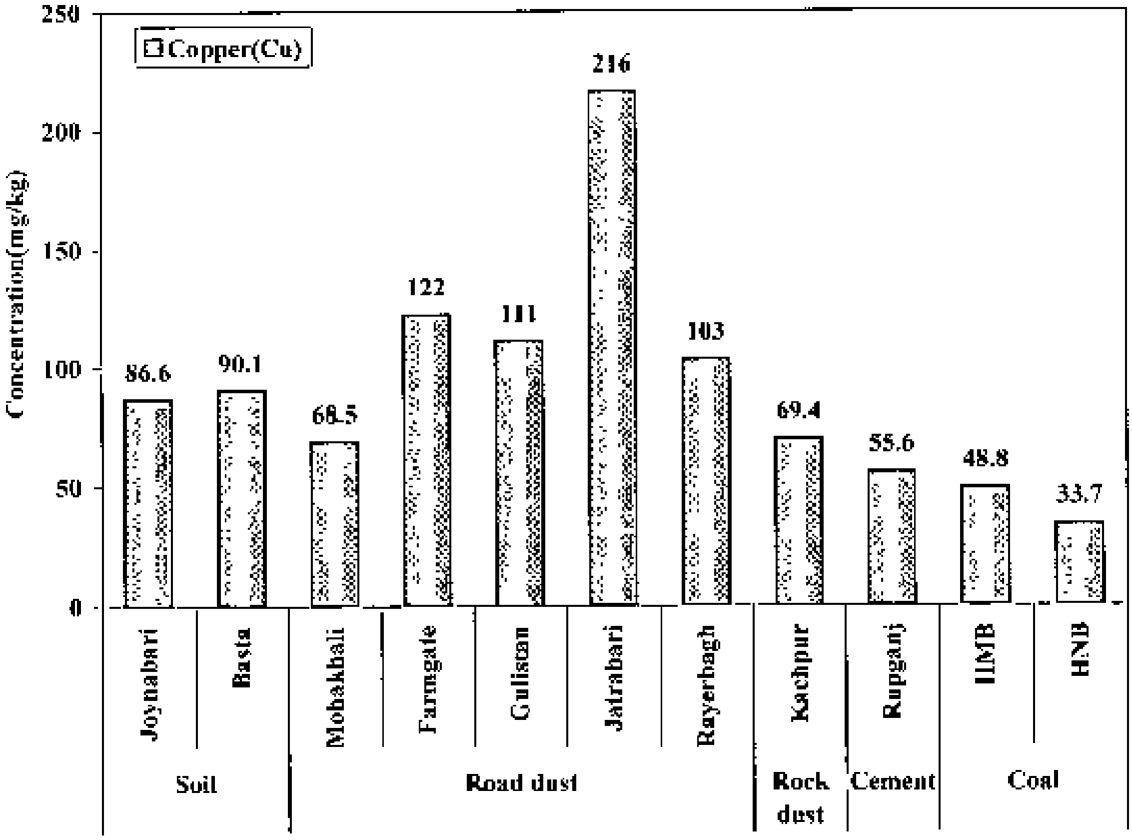

Figure 6.9. Levels of copper in different types of samples collected from various locations within and around Dhaka city

Average level of copper in soil of Bangladesh is 27 mg/kg and maximum permissible limit for common soil is 50 mg/kg [9]. Copper concentrations in soil and road dust samples exceeded the standard level for common soil. The Highest level of copper found in Jatrabari road dust sample. Ahmed et al (2006) reported copper levels in road dust of Dhaka city as 105, 46, 22 mg/kg for industrial, commercial and residential areas respectively. Soil and road dust may enriched with copper from decaying vegetation and sea spray, anthropogenic emissions such as smelters, iron foundries, power stations, incineration of municipal waste, application of bactericide, fungicides, algaecides, and antifouling paints, electroplating and textile-dyeing industries. Significant amount of copper also found in rock dust, cement and coal samples.

6.3.5 Manganese (Mn)

Levels of manganese in $PM_{2.5}$ and PM_{10} at Mohakhali were 30 and 215 ng/std.m^3 respectively and those at Farmgate were 3.7 and 47 ng/std.m^3 respectively [7]. Concentrations of manganese in different types of particulate air pollutant sources are presented in Figure 6.10 below.

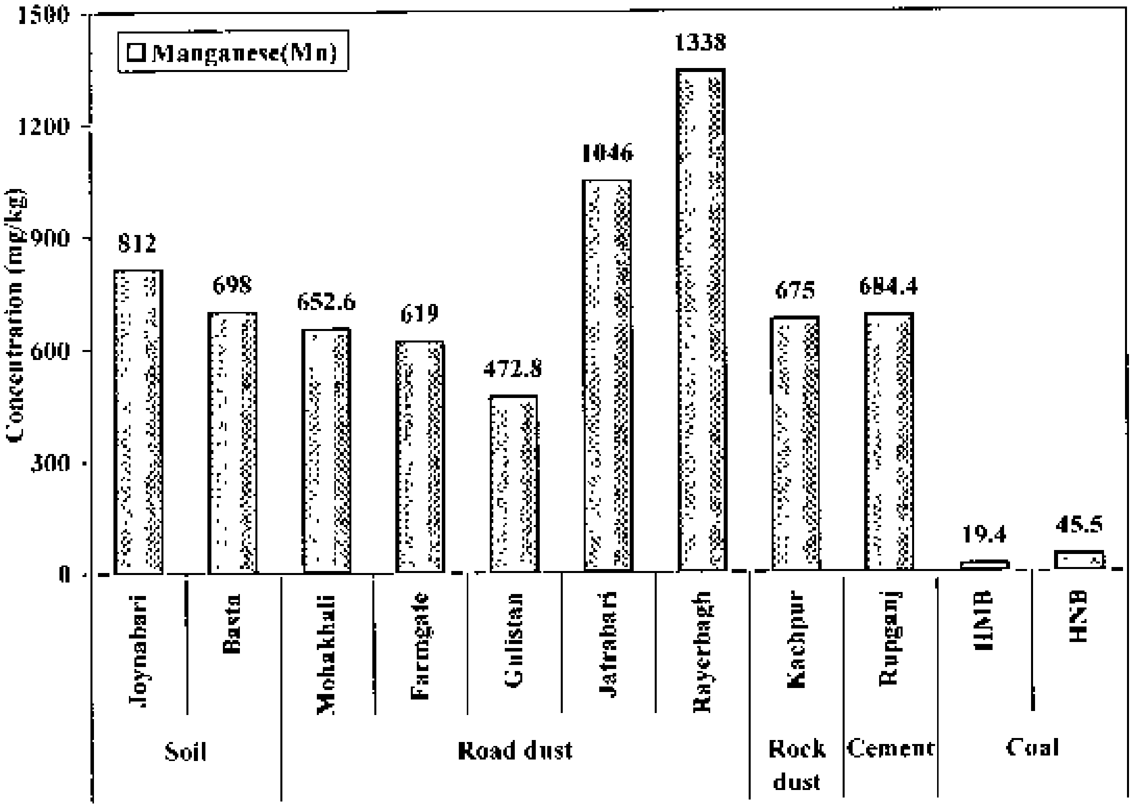

Figure 6.10. Levels of manganese in different types of samples collected from various locations within and around Dhaka city

Average natural (background) levels of manganese in soils vary from around 40 to 900 mg/kg and the mean background concentration is 330 mg/kg [42]. The highest level of manganese found in Rayerbagh road dust. Concentration of manganese found in Jatrabari road dust was the second highest among the samples. Road dust may be enriched with manganese from vehicular emissions if gasoline contains MMT (mehylcyclopentadienyl manganese tricarbonyl) as an anti-knocking agent [42]. Significant amount of manganese was found in rock dust and cement samples. Manganese was also found in coal samples and this Mn can be released in the environment from coal combustion. Land disposal of manganese-containing wastes is the principal source of manganese releases to soil. However, soil may be contaminated by manganese from industrial and smelting processes, agriculture and combustion of fossil fuel (mainly coal).

6.3.6 Nickel (Ni)

Levels of nickel in $PM_{2.5}$ and PM_{10} collected from Mohakhali were 6.5 and 25 ng/std.m^3 respectively and those from Farmgate were 14.5 and 5 ng/std.m^3 respectively [7]. Levels of nickel in different types of samples are displayed in Figure 6.11 below.

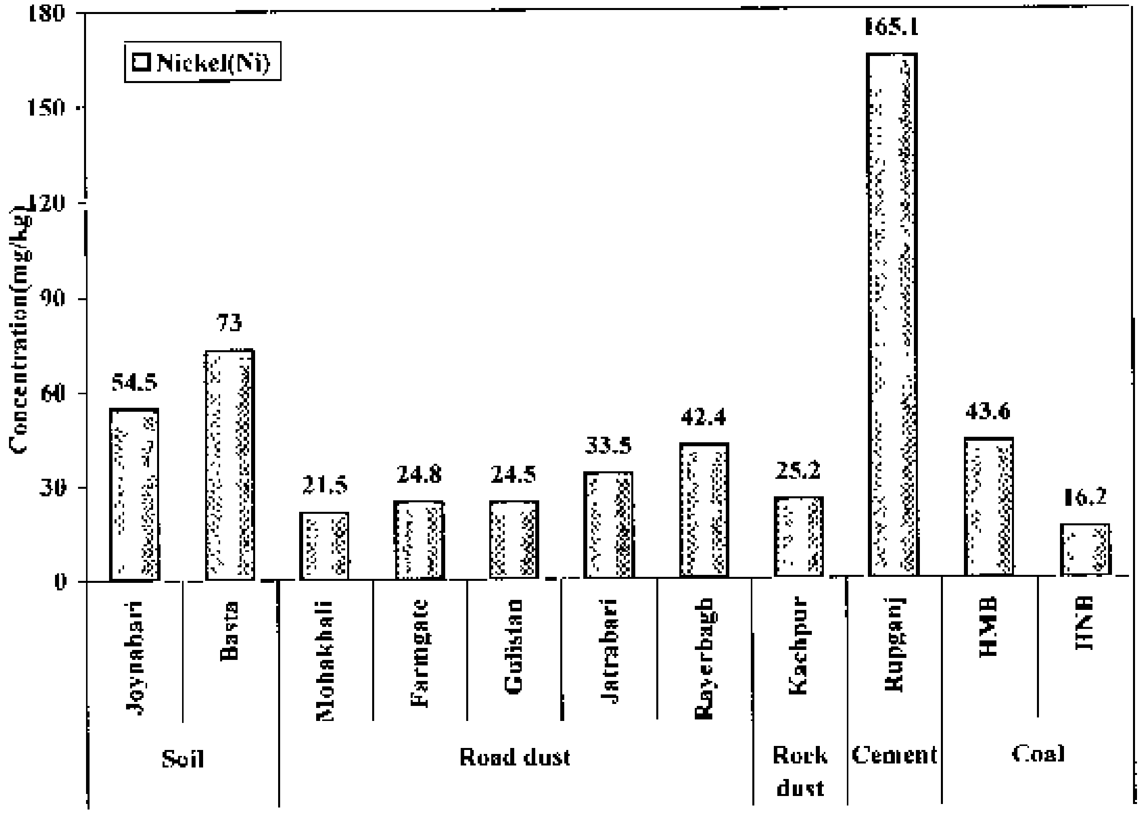

Figure 6.11. Levels of nickel in different types of samples collected from various locations within and around Dhaka city

Average nickel level in soil of Bangladesh is 22 mg/kg and acceptable level of nickel for common soil is 50 mg/kg [9]. Concentrations of nickel in both soil samples exceeded the maximum permissible levels for common soil. Moreover, levels of nickel in Jatrabari and Rayerbagh road dust samples are much greater than average value of Bangladeshi soil but within the maximum allowable limit for common soil. Ahmed et al (2006) reported nickel levels in road dust of Dhaka city, as 35. 26 and 23 mg/kg for industrial, commercial and residential areas respectively. Some important sources of nickel contamination to soil are coal fly ash and bottom ash, waste from metal manufacturing, commercial waste, atmospheric fallout, urban refuse, and sewage sludge [43]. The highest nickel level was detected in cement sample. Significant amount of nickel were also found in rock dust and coal samples.

6.3.7 Lead (Pb)

Concentrations of lead in air borne $PM_{2.5}$ and PM_{10} at Mohakhali were 463 and 500 ng/std.m^3 respectively and those at Farmgate were 350.46 and 561.30 ng/std.m^3 respectively [7]. Levels of lead in different types of collected source samples are presented in Figure 6.12 below.

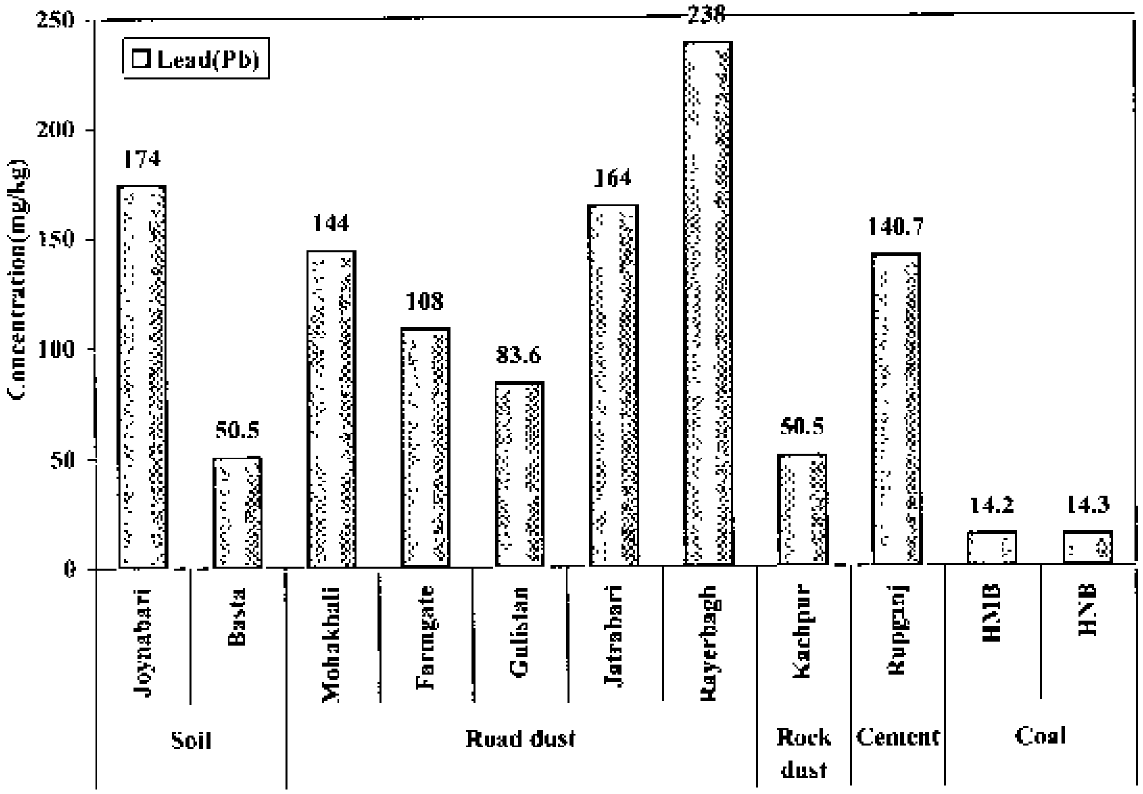

Figure 6.12. Levels of lead in different types of samples collected from various locations within and around Dhaka city

Average lead level in soil of Bangladesh is 23.50 mg/kg and acceptable level of lead for common soil is 100 mg/kg [9]. Levels of lead in Joynabari soil and Mohakhali, Farmgate, Jatrabari and Rayerbagh road dust samples crossed the guideline value for common soil. The highest level of lead was found in Rayerbagh road dust sample. Ahmed et al (2006) reported lead levels in road dust of Dhaka city as 54, 74 and 33 mg/kg for industrial, commercial and residential areas respectively. Significant amount of lead was found in cement sample. Levels of lead in coal samples indicate that lead can be liberated in the air from coal burning. Remarkable amount of lead was also discovered in rock dust sample. Increasing levels of lead in soil and road dust may be originated from various sources such as coal burning, lead-battery manufacturing, recycling industries, soldering, ceramics and plastics industries and vehicular emissions.

6.3.8 Vanadium (V)

Levels of vanadium in $PM_{2.5}$ and PM_{10} at Mohakhali were 1 and 16 ng/std.m^3 respectively and those at Farmgate were 1.65 and 13 ng/std.m^3 respectively [7]. Concentrations of vanadium in different types of samples are presented in Figure 6.13 below.

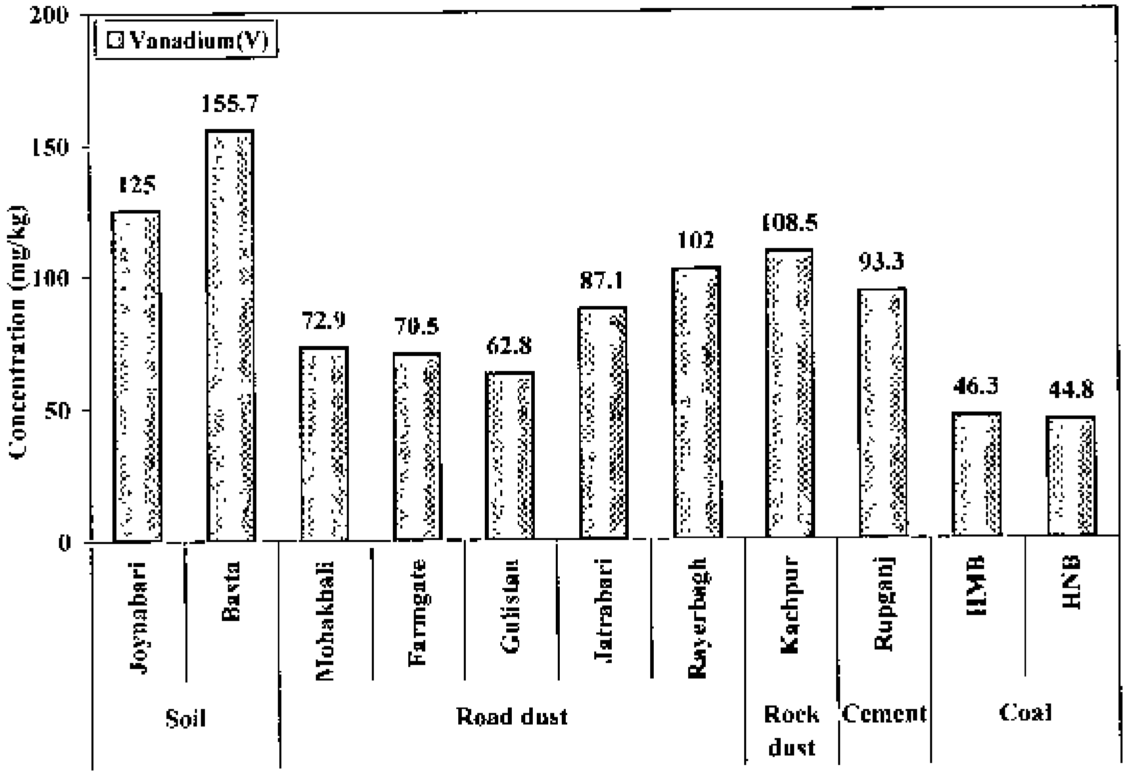

Figure 6.13. Levels of vanadium in different types of samples collected from various locations within and around Dhaka city

The average concentration of vanadium in the earth's crust is 150 mg/kg [48]. The highest level of vanadium was found in Basta soil sample. Moreover, average vanadium concentrations in road dust and soil samples were 79.1 and 140.4 mg/kg respectively. Ahmed et al (2006) reported vanadium levels in road dust of Dhaka city as 72, 68 and 64 mg/kg for industrial, commercial and residential areas respectively. Significant amounts of vanadium were located in rock dust and cement samples. Concentrations of vanadium in coal samples specify them as potential sources of vanadium in the atmosphere when coals are burned. Soil may be enriched with vanadium from natural sources such as weathering of rock, deposition of vanadium particles from the atmosphere, deposition of suspended particles from water, and plant and animal wastes. Some remarkable anthropogenic contamination sources of vanadium in the soil are use of fertilizers such as rock phosphate, super phosphate and basic slag as well as disposal of industrial waste [48].

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Ambition of this thesis work was to track some significant particulate air pollutants sources to know their elemental composition along with some trace heavy metals that found predominantly in Dhaka city ambient air. The existences of some toxic heavy metals among the source samples justify them as effective sources of heavy metals in the ambient air. Moreover, the following realization has been made from the analysis of the collected particulate air pollutants source samples.

1. Soil samples were contaminated with heavy metals such as cadmium, chromium, copper, lead and nickel. The polluting sources were most likely agricultural and industrial activities.

2. Concentration profiles achieved from coal samples analysis revealed that coal might be a source of heavy metals in the atmosphere when it burns in brickfields.

3. Road dust samples were polluted by heavy metals like cadmium, chromium, copper, lead, nickel and manganese. The major contamination sources were most probably construction works, vehicular emissions and industrial discharges.

4. Rock dust sample was enriched with toxic trace heavy metals such as cobalt, chromium, copper, manganese, nickel, lead and vanadium.

5. Cement sample had high levels of cadmium, chromium, cobalt, copper, nickel and lead. The sources of heavy metals in cement were raw materials.

All these five types of sources should be taken into account when source apportionment studies will be carried out for ambient particulate matters in Dhaka city. Regular monitoring of heavy metals in various particulate air pollutants sources will help to control atmospheric pollution from these sources.

7.2 Recommendations for future works

This thesis work had some limitations. However, these limitations open some new windows for future research works. In this study concentrations of some environmentally significant trace heavy metals such as arsenic (As), mercury (Hg) and zinc (Zn) in the particulate air pollutants source samples were not determined due to some technical problems. Moreover, chemical speciation of heavy metals in the soil and road dust samples was not performed. Chemical speciation of heavy metals in soil and sediment samples helps to understand the mobility, bioavailability, and fate of contaminant metals in environmental systems, to assess health risks posed by them, and to develop methods to improve metal contaminated sites. Considering the limitations of this study as well as some knowledge gap on the environmental aspects of Dhaka city the following research works can be recommended to perform in future.

1. Levels and chemical speciation of heavy metals in road dust of Dhaka city.
2. Source apportionment of ambient particulate matters in Dhaka city.
3. Air pollutants source tracking for arsenic, mercury and zinc in Dhaka city.

CHAPTER 8

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APPENDIX-A

Graphical presentation of elemental concentrations of different samples.

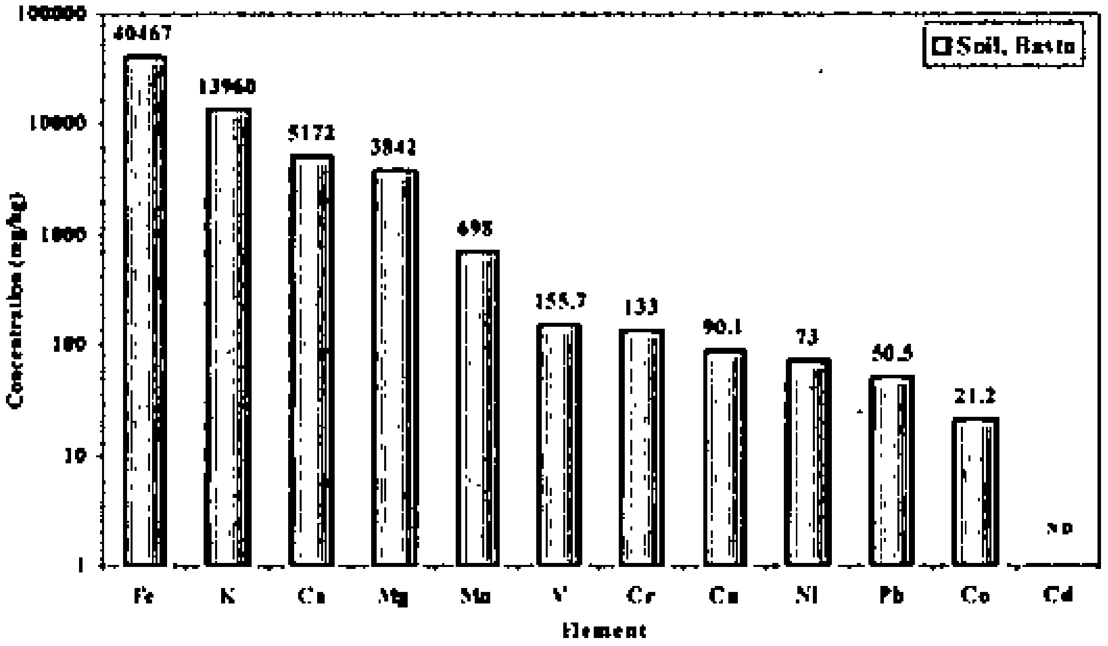

Figure A.1. Distribution of elements in soil sample collected from Basta, Keraniganj

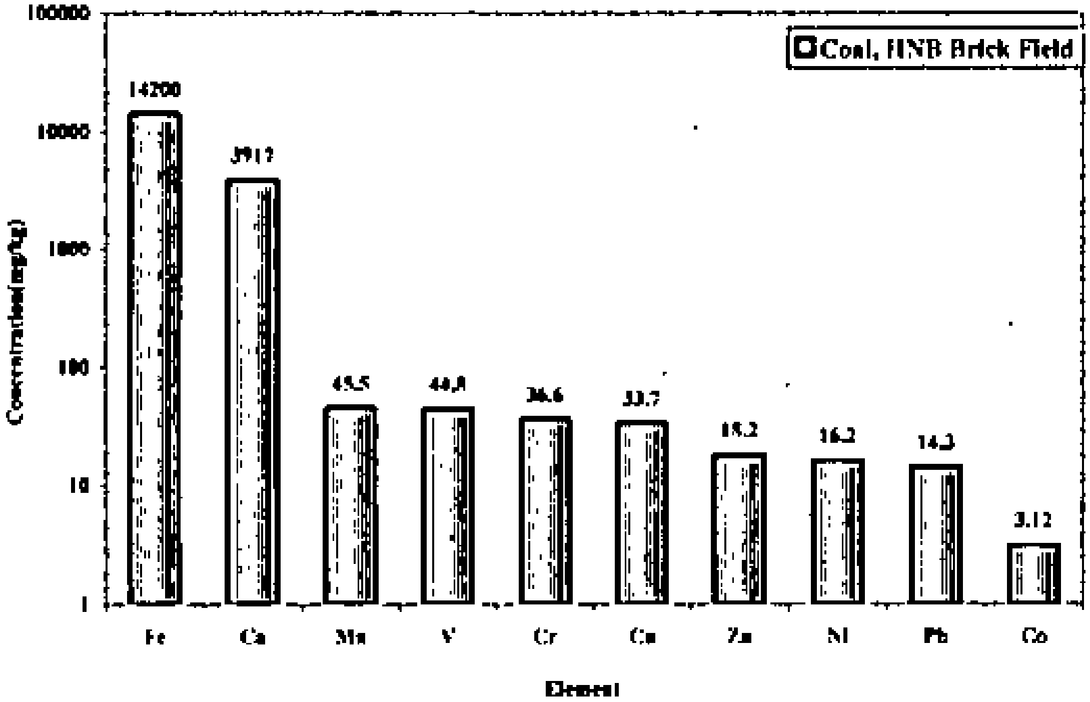

Figure A.2. Distribution of elements in coal sample collected form HNB Brickfield, Aminbazar

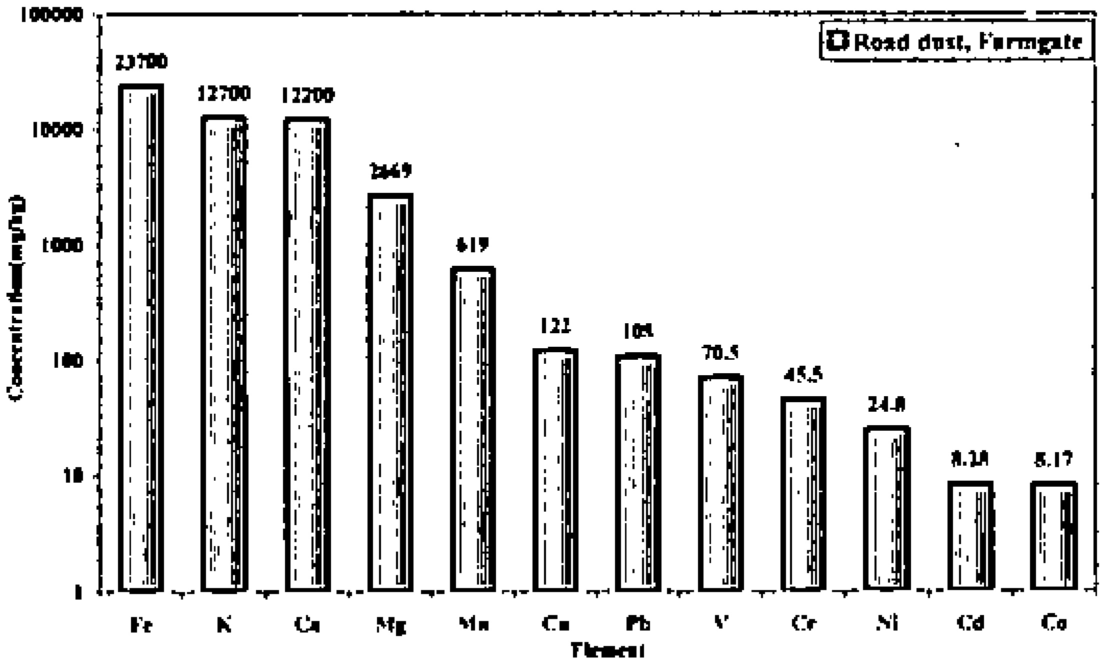

Figure A.3. Distribution of elements in road dust sample collected form Farmgate, Dhaka

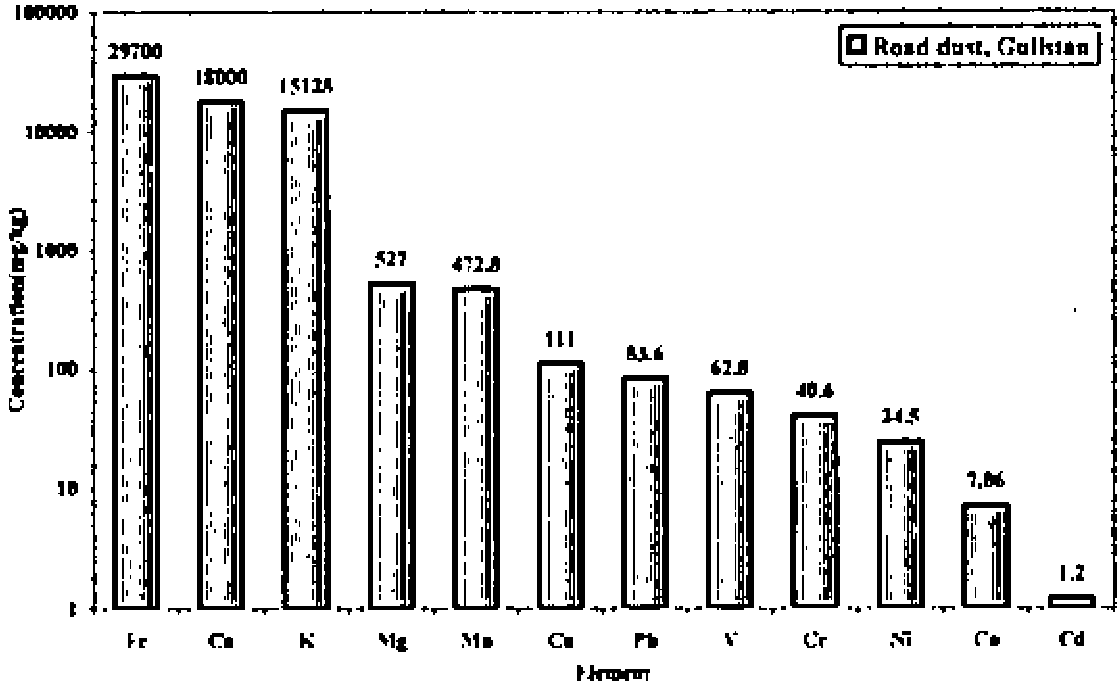

Figure A.4. Distribution of elements in road dust sample collected from Gulistan, Dhaka

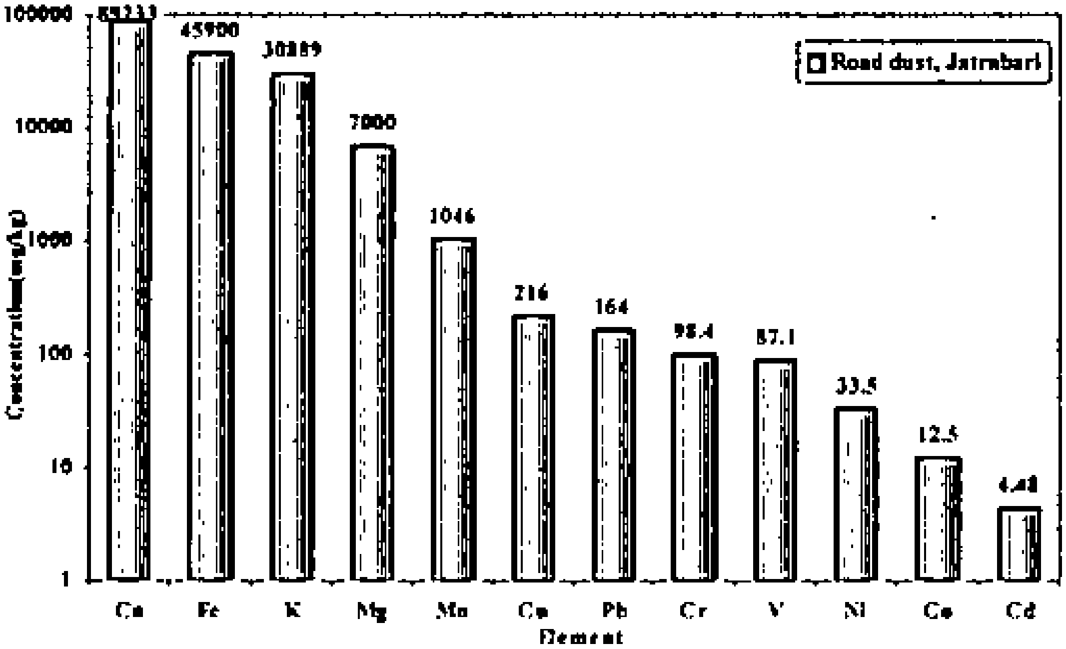

Figure A.5. Distribution of elements in road dust sample collected from Jatrabari, Dhaka

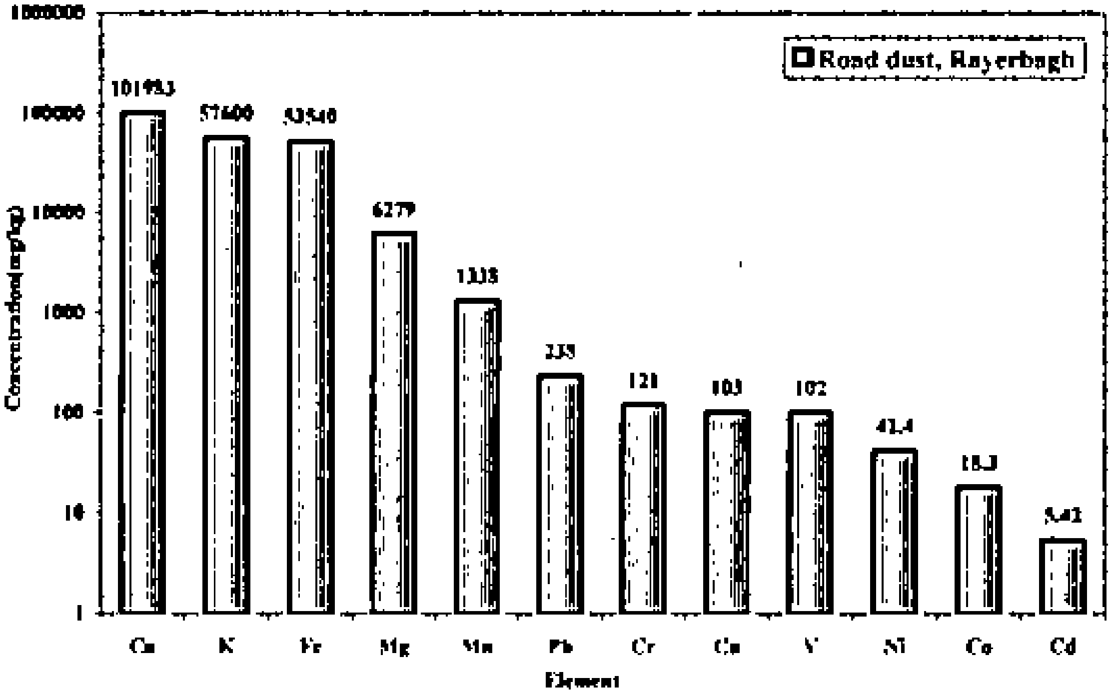

Figure A.6. Distribution of elements in road dust sample collected from Rayerbagh, Dhaka

APPENDIX-B

Air pollution glossary

Acid deposition : A comprehensive term for the ways that acidic compounds deposit from the atmosphere to the earth's surface. It can include: 1) wet deposition by means of acid rain, fog, and snow; and 2) dry deposition of acidic particles (aerosols).

Acid rain : Rain which is especially acidic ($pH < 5.2$). Principal components of acid rain typically include nitric and sulfuric acid. These may be formed by the combination of nitrogen and sulfur oxides with water vapor in the atmosphere

Aerosol : Particles of solid or liquid matter that can remain suspended in air for long periods of time because of extremely small size and light weight.

Air : So called "pure" air is a mixture of gases containing about 78 percent nitrogen; 21 percent oxygen; less than 1 percent of carbon dioxide, argon, and other gases; and varying amounts of water vapor. See also ambient air.

Air pollutants : Amounts of foreign and/or natural substances occurring in the atmosphere that may result in adverse effects on humans, animals, vegetation. and/or materials.

Air pollution : Degradation of air quality resulting from unwanted chemicals or other materials occurring in the air.

Air pollution episode : A period of abnormally high concentration of air pollutants, often due to low winds and temperature inversion, that can cause illness and death.

Air quality simulation model : A mathematical relationship between emissions and air quality which simulates the transport, dispersion, and transformation of compounds emitted into the air (also referred to as a Air Pollutant Dispersion Model).

Airshed : A subset of air basin, the term denotes a geographical area that shares the same air because of topography, meteorology, and climate.

Air quality index (AQI) : A numerical index used for reporting severity of air pollution levels to the public

Air toxics : A generic term referring to a harmful chemical or group of chemicals in the air. Substances that are especially harmful to health, such as those considered under U.S. EPA's hazardous air pollutant program are considered to be air toxics. Technically, any compound that is in the air and has the potential to produce adverse health effects is an air toxic.

Ambient air : The air occurring at a particular time and place outside of structures, particularly accessible to the public. Often used interchangeably with outdoor air.

Ambient air quality standards (AAQS) : Health and welfare-based standards for outdoor air which identify the maximum acceptable average concentrations of air pollutants during a specified period of time.

Area sources : Those sources for which a methodology is used to estimate emissions. This can include area-wide, mobile and natural sources, and also groups of stationary sources (such as dry cleaners and gas stations).

Area-wide sources : Sources of pollution where the emissions are spread over a wide area, such as consumer products, fireplaces, road dust and farming operations. Area-wide sources do not include mobile sources or stationary sources.

Atmosphere : The gaseous mass or envelope of air surrounding the Earth. From ground-level up, the atmosphere is further subdivided into the troposphere, stratosphere, mesosphere, and the thermosphere

Attainment area : A geographical area identified to have air quality as good as, or better than, the national ambient air quality standards (NAAQS). An area may be an attainment area for one pollutant and a non-attainment area for others.

Baghouse : An air pollution control device that traps particulates by forcing gas streams through large permeable bags usually made of glass fibers.

Biogenic source : Biological sources such as plants and animals that emit air pollutants such as volatile organic compounds. Examples of biogenic sources include animal management operations, and oak and pine tree forests.

Burn day : A day officially determined by meteorologists and air pollution specialists to have favorable weather conditions for good dispersal of smoke from the burning of agricultural and wild lands refuse.

Cancer : A group of diseases characterized by uncontrolled growth of body cells leading to the formation of malignant tumors that tend to grow rapidly and spread (metastasize).

Carbon dioxide (CO_2) : A colorless, odorless gas that occurs naturally in the Earth's atmosphere. Significant quantities are also emitted into the air by fossil fuel combustion.

Carcinogen : Any substance that can cause or contribute to the production of cancer.

Carbon monoxide (CO) : A colorless, odorless gas resulting from the incomplete combustion of fossil fuels. Over 80% of the CO emitted in urban areas is contributed by motor vehicles (mobile sources). CO interferes with the blood's ability to carry oxygen to the body's tissues and results in numerous adverse health effects. CO is a criteria air pollutant.

Catalytic converter : A motor vehicle pollution control device designed to reduce emissions such as oxides of nitrogen, hydrocarbons, and carbon monoxide.

CFCs (Chlorofluorocarbons) : A wide variety of chemical compounds consisting of chlorine. fluorine, and carbon. CFCs are used for refrigeration and air conditioning, foam packaging, solvents, and propellants. They are proven to cause depletion of the atmosphere's (stratospheric) ozone layer.

Clean Air Act : The original Clean Air Act was passed in 1963, but our national air pollution control program is actually based on the 1970 version of the law. The 1990 Clean Air Act Amendments are the most far-reaching revisions of the 1970 law. In this summary, we refer to the 1990 amendments as the 1990 Clean Air Act.

Criteria air pollutant : An air pollutant for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set. Examples include: ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and PM_{10} and $PM_{2.5}$.

Diesel engine : A type of internal combustion engine that uses low-volatility petroleum fuel and fuel injectors and initiates combustion using compression ignition (as opposed to spark ignition that is used with gasoline engines).

Dose : The amount of a pollutant that is absorbed. A level of exposure which is a function of a pollutant's concentration, the length of time a subject is exposed, and the amount of the pollutant that is absorbed. The concentration of the pollutant and the length of time that the subject is exposed to that pollutant determine dose.

Dose-response : The relationship between the dose of a pollutant and the response (or effect) it produces on a biological system.

Electrostatic Precipitator (ESP) : An air pollution control device that removes particulate matter from an air stream by imparting an electrical charge to the particles for mechanical collection at an electrode.

Elemental carbon (EC) : Also known as "black carbon" or "soot", is formed by incomplete combustion of hydrocarbons. Its major sources are biomass and fossil fuel burning. It is a good indicator of primary anthropogenic emission sources as it is relatively inert.

Emission factor : For stationary sources, the relationship between the amount of pollution produced and the amount of raw material processed or burned. For mobile sources, the relationship between the amount of pollution produced and the number of vehicle miles traveled. By using the emission factor of a pollutant and specific data regarding quantities of materials used by a given source, it is possible to compute emissions for the source. This approach is used in preparing an emissions inventory.

Emission inventory : An estimate of the amount of pollutants emitted into the atmosphere from major mobile, stationary, area-wide, and natural source categories over a specific period of time such as a day or a year.

Emission standard : The maximum amount of a pollutant that is allowed to be discharged from a polluting source such as an automobile or smoke stack.

Environment : the combination of all external conditions and influences relating to the life, development, and survival of all living things.

Environmental assessment (EA) : A process whose breadth, depth, and type of analysis depend on the proposed project. EA evaluates a project's potential environmental risks and impacts in its area of influence and identifies ways of improving project design and implementation by preventing, minimizing, mitigating, or compensating for adverse environmental impacts and by enhancing positive impacts.

Evaporative emissions : Emissions from evaporating gasoline, which can occur during vehicle refueling, vehicle operation, and even when the vehicle is parked. Evaporative emissions can account for two-thirds of the hydrocarbon emissions from gasoline-fueled vehicles on hot summer days.

Exposure : The concentration of the pollutant in the air multiplied by the population exposed to that concentration over a specified time period.

Fly ash : Air-borne solid particles that result from the burning of coal and other solid fuel.

Fossil fuels : Fuels such as coal, oil, and natural gas; so-called because they are the remains of ancient plant and animal life.

Fugitive dust : Dust particles which are introduced into the air through certain activities such as soil cultivation, off-road vehicles, or any vehicles operating on open fields or dirt roadways.

Fugitive emissions : Emissions not caught by a capture system which are often due to equipment leaks, evaporative processes, and windblown disturbances

Greenhouse effect : The warming effect by the earth's atmosphere on the earth's surface. Light energy from the sun which passes through the earth's atmosphere is absorbed by the earth's surface and re-radiated into the atmosphere as heat energy. The heat energy is then trapped by the atmosphere, creating a situation similar to that which occurs in a greenhouse or a car with its windows rolled up. Many scientists believe that the emission of CO2 and other gases into the atmosphere may increase the greenhouse effect and contribute to global warming.

Greenhouse gases : Atmospheric gases such as carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, ozone, and water vapor that slow the passage of re-radiated heat through the Earth's atmosphere.

Hazardous air pollutant (HAP) : An air pollutant considered by EPA to be particularly hazardous to human health. Emission sources of hazardous air pollutants are identified by EPA, and emission standards are set accordingly.

Heavy metals : Metallic elements with atomic number greater than 20, such as mercury and lead. They can damage living things at low concentrations and tend to accumulate in the food chain.

Indoor air pollution : Air pollutants that occur within buildings or other enclosed spaces, as opposed to those occurring in outdoor, or ambient air. Some examples of indoor air pollutants are tobacco smoke, asbestos, formaldehyde, and radon.

Inversion : An atmospheric condition that occurs when a layer of warm air prevents the rise of cooling air trapped beneath it. This in turn prevents the rise of pollutants that might otherwise be dispersed and can cause an air pollution episode.

Incineration : A treatment technology involving destruction of waste by controlled burning at high temperatures; e.g., burning sludge to remove the water and reduce the remaining residues to a safe, non-burnable ash that can be disposed of safely on land, in some waters, or in underground locations.

Mobile sources : Motor vehicles and other moving objects that release pollution; mobile sources include cars, trucks, buses, planes, trains, motorcycles, and gasoline-powered lawn mowers. Mobile sources are divided into two groups: road vehicles, which include cars, trucks, and buses, and non-road vehicles, which includes trains, planes, and lawn mowers.

Mutagen : Any substance that can cause a change in genetic material.

Natural sources : Non-manmade emission sources, including biological and geological sources, wildfires, and windblown dust.

Nitrogen oxides (Oxides of Nitrogen, NOx) : A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes, and are major contributors to smog formation and acid deposition. NO_2 is a criteria air pollutant, and may result in numerous adverse health effects.

Ozone : A strong smelling, pale blue, reactive toxic chemical gas consisting of three oxygen atoms. It is a product of the photochemical process involving the sun's energy. Ozone exists in the upper atmosphere (stratosphere) as well as at the earth's surface. Ozone at the earth's surface causes numerous adverse health effects and is a criteria air pollutant. It is a major component of smog.

Ozone depletion : The reduction in the stratospheric ozone layer. Stratospheric ozone shields the Earth from ultraviolet radiation. The breakdown of certain chlorine and/or bromine-containing compounds that catalytically destroy ozone molecules in the stratosphere can cause a reduction in the ozone layer.

Particulate Matter (PM) : Any material, except pure water, that exists in the solid or liquid state in the atmosphere. The size of particulate matter can vary from coarse, wind-blown dust particles to fine particle combustion products.

$PM_{2.5}$: Includes tiny particles with an aerodynamic diameter less than or equal to a nominal 2.5 microns. This fraction of particulate matter penetrates most deeply into the lungs.

PM_{10} : A criteria air pollutant consisting of small particles with an aerodynamic diameter less than or equal to a nominal 10 microns (about 1/7 the diameter of a single human hair). Their small size allows them to make their way to the air sacs deep within the lungs where they may be deposited and result in adverse health effects. PM_{10} also causes visibility reduction.

Primary particle : The fraction of PM_{10} and $PM_{2.5}$ that is directly emitted from combustion and fugitive dust sources.

Primary pollutant : The emissions discharged from a source that either retain their form or are transformed into secondary pollutants.

Primary standard : a pollution limit based on health effects. Primary standards are set for criteria air pollutants.

Quality assurance (QA) : a set of external tasks to provide reasonable certainty that the quality control system is satisfactory. These tasks include independent performance audits, on-site system audits, inter-laboratory comparisons, and periodic evaluations of internal quality control data.

Quality control (QC) : Quality control; a set of internal tasks performed to provide accurate and precisely measured ambient air quality data. These tasks address sample collection, handling, analysis, and reporting (e.g., periodic calibrations, routine service checks, instrument-specific monthly quality control maintenance checks, and duplicate analyses on split and spiked samples).

Radon : A colorless, naturally occurring, radioactive, inert gaseous element formed by radioactive decay of radium atoms in soil or rocks

Receptor model : Statistics-based software tools that equate empirical relationships between ambient data for emissions collected at a receptor (in the community) and the sources of those emissions.

Scrubber : An air pollution control device that uses a high energy liquid spray to remove aerosol and gaseous pollutants from an air stream. The gases are removed either by absorption or chemical reaction.

Secondary standard : a pollution limit based on environmental effects such as damage to property, plants, visibility, etc. Secondary standards are set for criteria air pollutants.

Smog : A combination of smoke and other particulates, ozone, hydrocarbons, nitrogen oxides, and other chemically reactive compounds which, under certain conditions of weather and sunlight, may result in a murky brown haze that causes adverse health effects.

Soot : Very fine carbon particles that have a black appearance when emitted into the air.

Source : Any place or object from which air pollutants are released. Sources that are fixed in space are stationary sources and sources that move are mobile sources.

Source apportionment : Process of determining the types and amounts of ambient pollutants that came from emissions sources.

Stationary sources : Non-mobile sources such as power plants, refineries, and manufacturing facilities which emit air pollutants.

Sulfur dioxide (SO_2) : A strong smelling, colorless gas that is formed by the combustion of fossil fuels. Power plants, which may use coal or oil high in sulfur content, can be major sources of SO_2. SO_2 and other sulfur oxides contribute to the problem of acid deposition. SO_2 is a criteria air pollutant.

Sulfur oxides : Pungent, colorless gases (sulfates are solids) formed primarily by the combustion of sulfur-containing fossil fuels, especially coal and oil. Considered major air pollutants, sulfur oxides may impact human health and damage vegetation.

Teratogen : Substance that causes malformation or serious deviation from normal development of embryos and fetuses.

Toxicity : The degree of danger posed by a substance to animal or plant life.

VOCs (Volatile Organic Compounds) : Hydrocarbon compounds which exist in the ambient air. VOCs contribute to the formation of smog, and may themselves be air toxics. VOCs often have an odor, and some examples include gasoline, alcohol, and the solvents used in paints.

Zero emission vehicle (ZEV) : Vehicles which produce no emissions from the on-board source of power (e.g., an electric vehicle).