DETERMINATION OF CONCENTRATION OF TOTAL SUSPENDED PARTICULATE MATTER AND SOME GASEOUS AIR POLLUTANTS IN ATHI RIVER URBAN AREA, IN KENYA

By

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DECLARATION

This is my original work and has not been submitted for award of a degree in this or any other University.

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DEDICATION

This thesis is dedicated to my wife (Milkah), daughters (Rebecca and Marble), sons (Darwin and Derrick), parents (Yusabiah and Henry), sisters, brothers and to all those who contributed towards the success of this work

ABSTRACT

A study for the assessment of air quality with respect to total suspended particulate matter, heavy metals (Zn, Cd, Pb, Cu, Mn, Fe) analysis together with SO_2, H_2S, and NH_3 gases emitted in Athi-River town was carried out. Concentrations of the daily samples collected at various sites during the whole sampling period were determined using gravimetric and Atomic / Molecular spectrophotometric instrumental methods. The data so obtained were analysed using the cumulative frequency distribution method on log – probability graph paper. The use of log – probability cumulative frequency distribution curves in determining the number of times when hourly total suspended particulate matter or half – hourly sulphur dioxide, hydrogen sulphide and ammonia concentrations equalled or exceeded or were in the range of indicated levels at selected sites, was discussed. The correlation between diurnal concentration cycles and meteorological variables (temperature and relative humidity) was presented.

Variation of the pollutants concentrations with time showed diurnal high values for hydrogen sulphide and ammonia at industrial area during 1200 – 1400 hours, and 1000 – 1130hours & 1400 – 1700hours respectively. This was partly attributed to increased microbial activity on wastewaters from Barbar, Bawazir and Fishmeal factories which resulted into increased hydrogen sulphide and ammonia generation during midday or close to midday temperature. Industrial emissions as a result of thermal breakdown of animal and plant protein products at fishmeal and Athi Thread Factories respectively were also implicated as contributory sources to increased ammonia pollutant levels.

High concentration levels for total suspended particulate matter and sulphur dioxide pollutants at urban commercial area during 1000-1200hours and 1300 – 1700hours were associated with increased traffic volume during morning, midday and evening hours. This was in addition to long-range transport of the pollutants from Industrial heating processes and power generation at the beginning of industrial operations.

Diurnal concentration values were also noted to be high at low humidity and high temperatures.

Variation of daily average total suspended particulate matter, sulphur dioxide, hydrogen sulphide, cadmium, and lead concentrations showed high values of 621, 109, 75.50, 3.6, 9.7 μg/m^3 respectively at industrial area and low values of 160, 49, 15.30, 2.8, 1.5 μg/m^3 respectively at the residential area. Ammonia and copper mean concentration values were highest of 50.0 and 4.3 μg/m^3 respectively at urban commercial area and lowest of 39.5, 3.9 μg/m^3 respectively at industrial zone. On the contrary, the mean concentration values of manganese and iron of 6.7 and 129 μg/m^3 respectively were noted to be highest at industrial area and lowest of 3.1 and 56.5 μg/m^3 respectively at urban commercial centre.

Zinc metal concentrations were noted to be varying differently with the highest of 213 μg/m^3 observed at urban commercial centre and lowest of 156 μg/m^3 at residential area.

In general, above average concentrations of 666.93, 125.12, 77.65, 52.86, 290.30, 147.56, and 7.96 μg/m^3 for total suspended particulate matter, sulphur dioxide, hydrogen sulphide, ammonia, zinc, iron and manganese respectively at industrial area were observed during June – October dry season and below average of 544.75, 61.70, 14.21, 25.71, 213.58, 112.69 and 3.93 μg/m^3 respectively during the relatively wet months of May and November. The concentrations of Cadmium, Lead and Copper trace metals were practically not affected by seasonal changes. This was partly attributed to their existence in probably small particle sizes for which rainfall washout had minimal or no effect.

The prevailing low wind speeds did not favour the dispersion of the pollutants while the characteristic concentration patterns were linked to the production mechanisms, the dominant wind direction (South-easterly), and the prevailing temperature and relative humidity meteorological conditions.

The measured mean concentration values for total suspended particulate matter, sulphur dioxide, Lead and Cadmium were above the long term WHO standard limits of 60 – 90 μg/m^3, 40 – 60 μg/m^3, 0.5 – 1.0 μg/m^3 and 0.01 – 0.02 μg/m^3 respectively.

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TABLE OF CONTENTS

Page

Declaration..ii
Dedication..iii
Abstract..iv
Acknowledgement..vi
Table of contents viii
List of abbreviations.. xi
List of figures..xii
List of tables.. xiv

CHAPTER ONE

1.0 **INTRODUCTION**..1
1.1. Air pollution..1
1.2. Sources of air pollution.. 2
1.3. Classes of air pollution..2
1.4 Statement of the problem.. 4
1.5 Objectives..7

CHAPTER TWO

LITERATURE REVIEW.. 8
2.1. The significance of Air pollution..8
2.1.1. Total suspended particulate matter.. 9
2.1.2. Sulphur dioxide..11
2.1.3. Hydrogen sulphide..13
2.1.4. Ammonia..15
2.1.5. Cadmium..15
2.1.6. Lead..16
2.1.7.Other metals: The essential elements..18
2.2 Air pollution scenario in Kenya.. 22

CHAPTER THREE

THEORETICAL ASPECTS OF INSTRUMENTAL METHODS COMMONLY USED IN AIR POLLUTION STUDIES.. 25

3.1 Analytical Techniques...25

3.2 Atomic Absorption Spectrophotometry...25

3.2.1 Principle.. 25

3.2.2 Instrumentation 27

3.2.3. Practical Considerations... 30

3.3 Molecular Absorption Spectrophometry..................................... 30

3.3.1 Principle.. 30

3.3.2. Instrumentation 32

CHAPTER FOUR

EXPERIMENTAL METHODS AND MATERIALS.. ..35

4.1 Field sampling sites and their description.................................... 35

4.1.1 Athi-River town...35

4.2 Field sampling requirements...37

4.2.1 Apparatus... 37

4.2.2 Field working solutions and materials... 37

4.2.3 Sampling procedure...38

4.3Physical and chemical analysis procedures.................................. .41

4.3.1 Gravimetric determination of total suspended particulate matter..................41

4.3.2 Atomic absorption spectrophotometric determination of metallic elements in total suspended particulate matter..42

4.3.3 Molecular absorption spectrophotometric determination of sulphur dioxide....44

4.3.4 Molecular absorption spectrophotometric determination of hydrogen sulphide..48

4.3.5 Molecular absorption spectrophotometric determination of Ammonia 51

CHAPTER FIVE

RESULTS, DISCUSSIONS AND CONCLUSIONS. 54

5.1 Total suspended particulate matter (TSP) 54

5.2 Sulphur Dioxide (SO_2)..67

5.3 Metallic elements... 72

5.3.1 Lead (Pb)... 72

5.3.2 Cadmium (Cd)...74

5.3.3 Zinc (Zn)..75

5.3.4 Manganese (Mn).. 76

5.3.5 Iron (Fe) 77

5.3.6 Copper (Cu) 78

5.4 Hydrogen sulphide..79

5.5 Ammonia (NH_3) 88

CHAPTER SIX

RECOMMENDATIONS.. 95

REFERENCES..96

APPENDICES..109

List of Abbreviation

ISO	International Organization for Standardization
WHO	World Health Organization
UNEP	United Nations Environment Programme
UV	Ultra-Violet
ACGIH	American Conference of Governmental Industrial Hygienists
USEPA	United States Environmental Protection Agency
SGD	Standard Geometric Deviation
TSP	Total Suspended Particulates
R.H	Relative humidity
GEMS	Global Environment Monitoring System
APHA	American Public Health Association.

LIST OF FIGURES

Figure 3.1 Absorption/Emission Transitions in Atomic Spectrometry............ 26

Figure 3.2 Schematic diagram of Atomic Absorption Spectrophotometry........ 27

Figure 3.3` Absorption transitions involving molecular orbitals in electronic spectroscopy...31

Figure 4.1 Sampling sites and their description 36

Figure 4.2 A set-up of the sampling apparatus... 39

Figure 4.3 A typical calibration graph for sulphur dioxide...........................47

Figure 4.4 A typical calibration graph for Hydrogen sulphide......................50

Figure 4.5 A typical calibration graph for Ammonia................................53

Figure 5.1 Variation of total suspended particulate matter and sulphur dioxide pollutants with meteorological variables (Athi-River urban commercial centre).. 56

Figure 5.2 Cumulative frequency distribution of concentrations of suspended particulate matter in the three area categories of Athi-river town..... 60

Figure 5.3 Cumulative frequency distributions of total suspended particulate matter and sulphur dioxide observations in Athi-River Industrial zone 61

Figure 5.4 Cumulative frequency distribution of total suspended particulate matter and sulphur dioxide observations in Athi-River urban commercial centre.. 63

Figure 5.5 Cumulative frequency distribution of total suspended particulate matter and sulphur dioxide observations in Athi-River residential urban area.. 65

Figure 5.6 Cumulative frequency distribution of concentrations of sulphur dioxide in the three area categories of Athi-Rver town... 70

Figure 5.7 Half-hourly variation of hydrogen sulphide mean concentration and meteorological variables (Athi-River Industrial commercial area.. 82

Figure 5.8 Cumulative frequency distributions of diurnal hydrogen sulphide concentrations in the Athi-River industrial zone, urban commercial centre and residential urban area.................................... ...86

Figure 5.9 Half-hourly variation of ammonia mean concentrations with meteorological variable (Athi-River industrial commercial area) 90

Figure 5.10 Cumulative frequency distributions of diurnal ammonia concentrations in Athi-River industrial zone, urban commercial centre and residential urban area.......................................94

List of tables

Table 4.1 Trapping solutions and filter medium for various pollutants..................38

Table 4.2 Number of samples taken from each sampling site in the three areas 41

Table 4.3 Standard stock solutions for some selected metal ions in atomic absorption Spectrophotometry..44

Table 5.1 Diurnal mean concentration cycles of total suspended particulate matter and Sulphur Dioxide with temperature & relative humidity changes in Athi – River urban commercial center..55

Table 5.2 Mean concentration (± SGD $\mu g/m^3$) of total suspended particulate matter in the three areas of Athi – River town...57

Table 5.3 Cumulative frequency distribution of total suspended particulate matter and sulphur dioxide observations in Athi – River Industrial zone..................59

Table 5.4 Cumulative frequency distribution of total suspended particulate matter and sulphur dioxide observations in Athi – River urban commercial center......62

Table 5.5 Cumulative frequency distribution of total suspended particulate matter and sulphur dioxide observations in Athi – River residential urban area..........64

Table 5.6 Mean concentration (±SGD $\mu g/m^3$) of sulphur dioxide pollutants in the three area categories of Athi – River town.......................................69

Table 5.7 Mean (Geometric mean) concentration (+SGD $\mu g/m^3$) values of metallic elements in air borne particulate matter sampled in the three area categories of Athi – River town..72

Table 5.8 Diurnal half-hourly variations of hydrogen sulphide concentration (+SGD $\mu g/m^3$) with temperature and relative humidity changes in Athi - River industrial zone..80

Table 5.9 Mean concentration (+SGD $\mu g/m^3$) of hydrogen sulphide pollutant in the three area categories of Athi – River town..83

Table 5.10 Cumulative frequency distribution of hydrogen sulphide concentration in Athi-River Industrial Zone, Urban Commercial Centre and residential urban area...85

Table 5.11 Diurnal half – hourly variations of ammonia concentration ($\pm$SGD $\mu g/m^3$) with temperature and relative humidity changes in Athi-River industrial zone...89

Table 5.12 Mean concentration ($\pm$SGD $\mu g/m^3$) of ammonia pollutant in the three area categories of Athi-River town..91

Table 5.13 Cumulative frequency distribution of ammonia concentrations in Athi-River Industrial Zone, urban commercial centre and residential urban area 93

CHAPTER ONE

1.0 INTRODUTION

1.1 Air Pollution

Air pollution is classified as a component of Environmental pollution characteristic of the air layer surrounding the earth, i.e. the atmosphere (colls, 1997). The quality and composition of clean air of the atmosphere in respect to solids, liquids and gases is well defined (Fenger, 1979). Air is considered polluted when any material introduced into the atmosphere causes detrimental effects on human, animals, plants, materials, and property (Tyagi Mehra, 1990; UNEP, 1992).

Air pollution is one of the greatest environmental pollution threat on global scale primarily due to its insidious nature. The rapidity at which it occurs is facilitated by the huge capacity and spatial mobility properties of the atmosphere. It was and continues to be aggravated by the unplanned urbanization, rapid growth in industrialization and population, increased public mobility, and other technological advances. Considerable public awareness can be drawn from one of the severe air pollution episodes, which occurred in Belgium in 1930's. The Meuse Valley Smog accumulation was favored by the topography in connection with the pronounced inversion layers. It resulted to more than 600 people being taken ill and 63 died. The worst affected victims were the old (above 70 years) and individuals with pre-existing pulmonary and cardiac problems (Douglas and Stewart, 1953).

The disaster led to the enactment by the British Government, of the 1956 "Clean air Act" which other countries and Belgium have started to practice a model making Legislation Laws. Similar disastrous occurrences in other parts of the world indicate that air pollution poses a significant Public Health and Welfare problem mainly in urban areas. This recognition has been realized by more attention being focussed on air quality control measures (UNEP, 1991).

1.2 Sources of Air Pollution

Air pollutants are emitted as a result of both natural processes and /man-made activities. Natural causes include wind-blown dust, volcanic activity, esters and terpenes from vegetation, pollen and other aeroallergens, natural decomposition of animal and plant material, and radioactivity (Grey and Jensen, 1972). The level of pollution from these sources constitutes a minor portion of the total global air pollution. Little environmental effect on population can be attributed to these natural sources because they are widely distributed all over the world and are liable to dilution.

Man made sources cover a wide spectrum of chemical and physical activities, and are the major contributors to urban air pollution. The incineration of domestic and industrial refuse, vehicular emissions and industrial processes produce significant quantities of air pollutants (Robinson & Robbins, 1968) . Vehicular emissions involve pollutants emanating from the exhaust system, engine crank-case blowby, carburettor, and fuel tank in an uncontrolled gasoline-powered vehicles. The exhaust emissions consist of all the products of fuel combustion whereas those for crank-case, carburetor and fuel tank are evaporative hydrocarbon emissions.

The burning of fossil fuel for heating and for the generation of power has been one of the major causes of pollution in urban environments. Various industrial activities such as petroleum processing, smelter operations and wood pulping are some of the heating operations where significant emissions are produced in form of gases, aerosols and/or solid particles.

1.3 Classes of Air Pollution

Air pollutants are generally classified according to their source characteristics, and there are five major types: particulates, carbon monoxide, sulphur oxides, nitrogen oxides, and hydrocarbons. The minor pollutants include volatile organic compounds, photochemical oxidants, inorganic pollutants such as ammonia, hydrogen sulphide, hydrogen chloride, radioactive substances and thermal energy (Miller, 1992).

The major pollutants are mainly released into the environmental atmosphere by the burning of fuels of various kinds. In urban areas, most of the sulphur dioxide and total suspended particulate matter in the air originate from the combustion of fuels and incinerators. The type of fuel, the combustion efficiency, and the flue velocity influence the quantity and quality of emissions. In cold and temperate weather conditions, the burning of coal for domestic heating purposes can be a major contributor of both the sulphur oxides and suspended particulate matter contents in urban air. This is particularly true of the situation in the United Kingdom prior to the implementation of the Clean Air Act (Committee on Air Pollution, 1954). The Domestic heating emissions are liable to have disproportionate effect on concentrations in the immediate vicinity, because of the low level of the chimneys and low emission velocity.

Industrial and domestic chimneys pollutant emissions of sulphur dioxide suspended particulate matter and nitrogen oxides are relatively high compared with those of motor vehicles. But the motor vehicle emissions occur close to the ground and within the breathing zone. They influence the total suspended particulate matter concentration in air on points close to mixed traffic (Waller, 1965).

Seasonal and time variations of pollution strength is affected by the prevailing meteorological conditions. In winter emissions of sulphur dioxide and suspended particulate matter from heating are usually much higher than in summer during calm wind conditions.

1.4 Statement of the Problem

Virtually there is no available information related to air pollution in Athi River urban Area. The recent surveys done in Mombasa (Ngugi, 1983) and Nairobi (Murakaru, 1991) indicates an upward trend in Air quality deterioration, which has been solely attributed to industrial growth and the increasing traffic volume flow within the urban area.

Athi River is a fast growing industrial urban area characterized by many industries and business establishments. The existing industries include:

East African Portland Cement and Bamburi cement Factories

The Industrial operations involve manufacture of cement by crushing, clinkering, grinding, and drying of limestone and gypsum. The release of dust particulates in addition to smokestacks gaseous emissions such as sulphur dioxide, and metal dust are inevitable.

Chloride Metal Limited, a smelter factory for Battery Manufacturing

Operations of this factory involve smelting lead for the production of automotive batteries. It belches thick blackish and grey rolling smoke into the atmosphere. Effluents from smoke stacks and other gaseous emissions from smelting processes distribute very significant quantities of sulphur dioxide and trace heavy metals such as lead, arsenic, cadmium and zinc as well as particulates into vapour, mist or dust to the air of the surrounding area.

Auto Springs factory

This factory manufactures automotive suspension springs by pyrolysis processes, which involves high consumption of fuel energy. Exposure to pyrolysis by-products such as metal dust and fumes together with sulphur dioxide emissions from the stacks is inevitable.

Athi Threads Factory

Production of silk materials involves wet processing of highly proteinous raw materials. The release of Ammonia and Hydrogen sulphide from the drying process in addition to sulphur dioxide from fuel combustion is possible. Fibre particulates and polymer fumes are also likely to be experienced as air pollutants.

Nova Chemicals Limited

This Factory is purposely for storage, packaging and marketing of pesticides. Evaporative emissions containing trace metals such as copper, arsenic, mercury and lead are inevitable. Inhalation of pesticides is very harmful due to their cumulative effect and carcinogenicity in the human body.

Steel Industries:

Foundry operations for the manufacture of iron and steel structural materials are performed in these industries. Flue emissions may contain trace heavy metals such arsenic, lead, and zinc in addition to sulphur dioxide from fuel combustion. Iron metal dust and fumes are also inevitable.

Werrot Company Limited and Athi-River Mining Limited

The operations of these factories involve crushing and grinding of limestone and chalk for the manufacture of marble slabs. Heavy dust particulates and flue sulphur dioxide emissions are inevitable.

Fishmeal Factory

Drying and crushing operations of highly proteinous materials like fish and cereal products are the main industrial processes. From the residents outcry it is evident that the raw discharge of the partially solid waste is done in the open. Through the biodegradation process of the waste, high levels of hydrogen sulphide in addition to ammonia are the possible gaseous pollutants.

Barbar/Bawazir Tanneries:

The factory processes involve thermal degradation of highly proteineous animal hides and skins. Additions of chromium salt and sulphuric acid are also required during the dehairing stage. Hydrogen sulphide, ammonia and sulphur dioxide are emitted together with chromium fumes as pollutants.

From the above-mentioned operational characteristics, it is evident that a disproportionate number of these factories use high sulphur-containing fuels. The furnace processes emit particulates and gases into the immediate environment. These emissions impacts negatively on the general community and the factory workers.

The residents voiced complaints of obnoxious and choking gaseous pollutants accompanied by excessive particulate emissions, through the media. Eye and respiratory irritations, coughing and chest congestion, fatigue, and abdominal pains were the common health problems among the factory workers and the area residents.

Buildings were covered with extensive soiling which degraded the decorative aspect of the building. This resulted in peeling off of paints from the structural walls and wearing out of the galvanised iron sheets. Plants in the vicinity of these industrial agglomerates also exhibited general suppressed growth. The leaves appeared brown, dark and flaccid which ultimately dropped from the plants. There was also a remarkable chlorosis, the yellowing or bleaching of leaves.

Evidently no Pollution Impact Assessment was done prior to the setting up of these industries. This coupled with the non-existence of available air quality data in this area, warrants a monitoring and assessment survey to be established to determine the severity of the exposure to the pollutants.

1.5 Objectives

(i) To determine the levels and distribution of total suspended particulates (TSP); sulphur dioxide (SO_2); Hydrogen sulphide (H_2S), Ammonia (NH_3); and the selected trace elements such as zinc, lead, cadmium, manganese, copper, and iron in ambient air, in Athi-River urban area.

(ii) To determine the extent of influence of industrial activity on pollutant concentrations in ambient air.

(iii) To determine the influence of relative humidity on the levels of pollutant concentrations.

(iv) To determine the effect of temperature on the levels of pollutant concentrations.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Significance of Air Pollution

From the recent past, there has been a trend of mass exodus of population from rural to urban centres in search of employment. The urban space has become overstrained by the increase in road traffic and rapid industrial development. These have adversely affected the environment, and constitute the major source of air pollution. The urban residents are likely to experience unfavourable health problems resulting from the contaminated airspace (UNEP / WHO, 1996).

Air pollutants cause adverse effects either directly or indirectly on human life and health, the biosphere, natural resources, and material structures. The extent of damage is dependent on the type of pollutants in the air. The possibility of considerable risk to human is also dependent on the health status of the inhabitants (WHO / UNEP, 1992).

Severe short-term exposure of air pollutants to human leads to immediate effects, whereas the chronic effects due to low, long-term exposure are experienced after a long-time interval. In both categories the worst affected subjects are the young, the elderly, and those with pre-existing health problems. Given the foregoing situation, human health effects can be grouped into four major classes:

(i) **Acute Effects:** as a result of episodic or accidental air pollution incidences associated with increased cardiovascular and respiratory morbidity and mortality (UNEP / WHO, 1996).

(ii) **Chronic Effects:** as a result of long period, low-level exposures of pollutants, Long-term exposure of low concentrations of sulphur dioxide and particulates to children causes the prevalence of respiratory diseases (Colley and Reid, 1970).

(iii) **Psychological effects:** Effects lead to those of outward symptoms or discomfort associated with for instance dust fall (Stalker and Robinson, 1967).

(iv) **Carcinogenic, fibrogenic and toxic effects:** as a result of carcinogenic and other toxic substances such as nickel oxide, sodium selenite, asbestos, and heavy metals such as lead and cadmium (UNEP/WHO, 1996).

2.1.1 TOTAL SUSPENDED PARTICULATE MATTER:

Airborne particulates and/or aerosols consist of either solid or liquid droplets ranging in aerodynamic diameter from 0.001 μm to 500 μm. The particles can be dispersed into the air from combustion processes, industrial activities, or natural sources. The composition of the particles is dependent on the type of sources and the settling velocity of the particles (Fuchs, 1964).

The inorganic phase of the suspended matter consists of mainly siliceous minerals and soot in addition to metallic particles. Asbestos constitutes one of the siliceous particulate matter that is of increasing concern in terms of human health. Considerable amount of asbestos particles (0.02-0.05 μm) in the atmosphere is emitted mainly from construction works and vehicular brake linings. (Holt and Young, 1973).

The organic phase mainly polycyclic aromatic hydrocarbons result from incomplete combustion of fossil fuels. Polycyclic aromatic hydrocarbons are present in large quantities in automobile exhausts, cigarette smoke, and industrial combustion processes. They are of great public health concern because they are absorbed or adsorbed on other particulate matter and carried deep into the respiratory system (UNEP, 1992). The notorious, 3,4-benzo-a-pyrene urban air peak concentration of 0.1 $\mu g/m^3$ has been detected (Lindsay and Sawicki, 1962).

Effects on Human/Animals

Particles smaller than 10 μm are deposited at different levels in the respiratory tract of animals (WHO, 1987). Depending on both their size and chemical composition, their effects can be physical irritation or chemical action damage of vital internal tissues (Brian and Valberg, 1974; US-Task Group on Lung Dynamics, 1966; US-Task Group on Metal Accumulation, 1973). The respirable insoluble particles usually accumulate in the lymph nodes leading to deposition of particles in the lungs whereas the soluble fraction enters the body fluids.

Respiratory effects from acute exposure to sulphuric acid aerosol (350-500 $\mu g/m^3$) are associated with increased respiratory rate, and inability to inspire deeply and/or exhale freely (US. EPA, 1982). These may lead to maldistribution of air and blood in the lungs and impairment of oxygen diffusion from air to blood in the lung capillaries. Similar studies in central Japan implicated sulphuric acid aerosol as the cause for excess respiratory morbidity (Kitagawa, 1984).

In separate studies (Camner, 1973; Toigo, 1963) on human inhabitants suffering from chronic obstructive lung cancer, it was shown that the individuals were also likely to experience an impaired mucociliary transport. Decreased respiratory function was mainly to blame for the predisposition to such effects (Ferris, 1973).

The risk of lung cancer in asbestos exposed population is far more common among cigarette smokers than non-smokers. There is no detectable excess of lung cancer among asbestos-exposed non-smokers. The occurrence of the mesothelioma, asbestos-related disease, in persons living in the vicinity of mines, mills and shipyards suffices to indicate the need for careful handling of this hazardous substance.

Pulmonary reactions to inhaled asbestos are likely to be widely experienced by urban populations than rural ones (Thomson, 1965). This can be attributed to the wear of automobile break linings, which adds asbestos fibrils to street dust (National Academy of Sciences, Washington, D.C, 1971). The clinical changes in the lungs of affected individuals are characterized by chronic endobronchitis and pulmonary emphysema (Kovnatsky, 1963),

Effects on Vegetation

Vegetation exhibits growth defects in areas where particulate pollutants release is excessive. (Stokinger and Coffin, 1976). The particulate matter carries deleterious pollutant substances to leaf surfaces and thus damages the leaves. Particles directly block the leaf stomata and prevent sunlight from reaching photosynthetic sites within the leaf. Transpiration process is hampered and this leads to suppressed plant growth and poor yields (Tyagi Mehra, 1990; UNEP, 1992).

Effects on Materials

Sticky particulates wear out structural materials through soiling, corrosion and mechanical abrasiveness. Building materials such as paints, are decolorized and eventually acquires softened finish. This leads to the weakening and destruction of structures (Tyagi Mehra, 1990).

Effects on the Atmosphere

Combustion of fossil fuels in certain high-temperature industrial processes produce large amounts of very small particles (< 10µm). These particles are less influenced by gravitational forces, and tend to stay longer in the atmosphere. They can cause haze or smog which reduces visibility in urban areas. The reduction in visibility is due to the scattering of light by the small particles suspended in the air. The scattering of light further reduces the amount of solar radiation reaching the earth, and may cause adverse local climatic changes such as photochemical smog. (Kabbe, 1976).

2.1.2 Sulphur Dioxide

Sulphur dioxide is a colourless gas that can be detected by taste by most people at concentrations in the range 1000-3000 $\mu g/m^3$ (0.35-1.05 ppm). It dissolves readily in water, and either catalytically or photo chemically reacts in the gas phase with other substances to form sulphur trioxide (SO_3), sulphuric acid (H_2SO_4), and sulphates (Freiberg, 1975; Johnstone and Coughhanour, 1958; Kellogg, 1972).

Most emissions of sulphur dioxide into the air results from energy production processes and industrial activities mainly concentrated in urban areas. Like the suspended particulate matter, sulphur dioxide is one of the most widely monitored air pollutants.

Effects on Animals/Human

Severe human health effects from high concentration exposures are brochoconstriction, chemical bronchitis, trancheitis, and bronchospasm in asthmatics (WHO, 1977). Acid aerosols, an oxidized form, cause more harm to the respiratory system. Its potentiated effect results in excess respiratory morbidity and mortality in humans (WHO, 1977). Bronchitis and Emphysema are some of the respiratory diseases associated with long-term exposures (WHO, 1987, UNEP, 1991, UNEP, 1992). Epidemiological studies done in England and Wales over a spread of time, showed a correlation between bronchitis or pneumonia death rates and sulphur oxides pollution index (Pemberton and Goldberg, 1954). Sulphur dioxide also causes eye and throat irritations (Habitat, 1989).

Absorption of sulphur dioxide on chemically inactive solid particles concentrates the sulphur dioxide and thus increases its potential for harm on human health. The particles are small enough to enable the gas to reach more vulnerable lung surface and cause damage. This may lead to the narrowing of the respiratory passages and increased resistance to the passage of air in the respiratory tract. Eventually, this results in asthma and its complications (Lowe, 1970; Warner, 1969). In animals, chronic exposures to sulphur dioxide increases the number and area of goblet cells. Guinea pigs and lambs are the most affected subjects (Mawdesley – Thomas, 1971). Studies with guinea pigs at lower concentrations have shown that a sodium chloride aerosol, administered concomitantly enhances the effects of sulphur dioxide on lungs in the form of broncho-constriction and increased airway resistance (Amdur, 1957).

Effects on Vegetation

Sulphites and sulphates forms of sulphur dioxide affects plants through weakening of the leaves. The effect is more pronounced during high relative humidity when acid aerosol concentrations are high (Tyagi Mehra, 1990). Acidification of soils and freshwater is associated with oxidized form, acid aerosol. This leads to the destruction of aquatic ecosystems and decrease in soil fertility through leaching of essential minerals (Tyagi Mehra, 1990).

Effects on Materials

Sulphur dioxide reduces the durability of building materials, corrodes the metals, makes paper fragile and brittle, and disintegrates leather and textile (Tyagi Mehra, 1990; UNEP 1992). The damage is due in part to the more toxic acid aerosol form of sulphur dioxide. Extensive studies (Committee A-5 of the American Society for Testing and Materials, 1952) of protected and unprotected iron and steel shapes showed that most rapid corrosion occurred in the most highly industrialized areas. The durability of the structural form was discovered to be proportional to the thickness of the protective coating such as paint.

2.1.3 Hydrogen Sulphide

Hydrogen sulphide is a colourless gas with a characteristic odour that is soluble in various liquids including water, solutions of amines, alkali carbonates and bicarbonates. It undergoes oxidation reactions to yield products of sulphur dioxide, sulphuric acid, and elemental sulphur.

Biological decay in oceans, land, and industrial processes where thermal breakdown of proteinaceous material is involved are some of the major sources. Petroleum refineries, sewage disposal, natural gas processing, and meat processing are some of the potential emitters (Macaluso, 1969; ILO, 1971).

The importance of hydrogen sulphide as an air pollutant is primarily due to its irritation and asphyxiation effects.

Effects on Humans

Several episodes of general population exposure to hydrogen sulphide have been reported. The effects of such exposure range from minor nuisance to serious illness and death. The catastrophic exposure episode which occurred in 1950 in Poza Rica, Mexico, a city of 22,000 people involved the release of large quantities of hydrogen sulphide into the atmosphere from malfunctioning waste gas flare (McCabe and Clayton, 1952). It caused the hospitalization of 320 people and 22 deaths.

High concentrations exposure has a direct effect on the respiratory center. Hydrogen sulphide is rapidly absorbed through the lungs, and is a potent inhibitor of cytochrome C Oxidase enzyme by interfering with lung tissue use of oxygen to the point where metabolic demands cannot be met. (Smith and Gosselin, 1979). In the central nervous system, the result may be paralysis of the respiratory centres.

Chronic poisoning results in hyperventilation hypocapnia, depression and paralysis. Finally respiratory failure and asphyxiation ensues. In all cases, people with pre-existing respiratory complaints are the most susceptible subjects. (McCabe & Clayton, 1952).

Effects on Animals

Very little information is available on the effect of low level concentrations of hydrogen sulphide gas on animals. Most of the published data emphasizes the effects of exposure to lethal or near-lethal concentrations of the gas. The effects of high doses of hydrogen sulphide and high doses of cyanide are similar (Evans, 1967; Smith and Gosselin, 1979). Both inhibit the physiological reactions of enzyme, cytochrome C oxidase.

In studies on a number of animal species including the mouse, rat, cat, dog and goat, it has been shown that the primary target of hydrogen sulphide in high doses is the nervous system. Collapse, followed by respiratory arrest and asphyxias is the common sequence of events leading to death of an animal. The asphyxia physiological conditions results from the paralyzing effects of high concentrations of hydrogen sulphide on the respiratory centers of the central nervous system.

Effects on Materials

Moisture and atmospheric pollution by acidic gases such as hydrogen sulphide, plays a major role in surface degradation of materials and structures (Moore and Potter, 1962). Hydrogen sulphide is capable of attacking a wide range of structural materials and Rubber through its ability to react with metals and form metal sulphides. The gas reduces the durability of paint by darkening, metals by tarnishing, and plastics by disintegrating, and concrete by corroding.

2.1.4 Ammonia

Ammonia is a colourless gas at atmospheric pressure, which is lighter than air and possesses a strong irritating odour. It is a widely used industrial chemical after sulphuric acid, lime and oxygen (Chemical and Engineering news, 1980). It is used in the manufacture of fertilizers, plastics, and explosives, (Chemical and Engineering News, 1980), in addition to animal feed, pulp paper, and rubber (Keyes, 1975). Ammonia and ammonium compounds are also used as cleaning agents, stabilizers, and/or food flavours.

Emissions of ammonia into the atmosphere are by agricultural, waste disposal and industrial activities. Globally municipal wastes emit less ammonia than fossil fuel combustion (US-EPA, 1981).

Ammonia causes a severe irritation in eyes, nose and throat. Respiratory distress accompanied by Lachrymation and coughing are also some of the irritant effects (Caplin, 1941). More severe respiratory effects include Laryngeal and pulmonary oedema, and bronchopneumonia (Slot, 1938, Caplin 1941; Levy, 1964, Taplin, 1976. Flury, 1983).

Acute effects of ammonia on animals are exhibited as extreme cynosis, dyspnoea, haemorrhagic lungs and pneumonia (MacEwen and Vernot, 1972; Propkopieva, 1973). Enzymatic alterations are some of the effects due to low concentrations (Zlateva,1974).

2.1.5: Cadmium

Cadmium is a soft, silver-white metal, which has a relatively high vapour pressure. In air, the vapour is rapidly oxidized to cadmium oxide, which reacts with other reactive gases to produce cadmium salts in the environment.

Cadmium and its compounds are used in steel plating, plastic and glass as pigments, and in polyvinyl chloride the compounds are used as stabilizers. The compounds are also used in nickel – cadmium batteries, and Alloys (Wilson, 1988).

Cadmium metal is commonly found in association with zinc (1:100-1:1000) in the earth's crust (Commission of the European communities, 1978). Therefore zinc-related industrial processes in addition to volcanic processes are the major sources of atmospheric emissions of cadmium (Wilson, 1988; Nriagu, 1979). Cadmium-containing fertilizers and sewage sludge application to agricultural soils also contribute to cadmium release in the air (Hutton, 1982; Davis, 1984). The increased cadmium levels in the soil which find their way in the growing plant, may sooner or later end up in incinerators whose effluents becomes airborne.

Despite its uses, cadmium is highly toxic whereby high inhalation of cadmium oxide fume and its salts results in acute pneumonitis, pulmonary oedema and gastroenteritis (MacFarland, 1979, Lucas, 1980). Similar acute-poisoning in work environments can also be experienced by the workers (Friberg, 1974). Long-term occupational exposure causes renal dysfunction and emphysema (Friberg, 1948 a, b, 1950).

An assessment of the available data from various European countries shows that average values range from 1 to 5 ng/m^3 in rural areas, 5 to 15 ng/m^3 in urban areas, and 15 to 50 ng/m^3 in industrialized areas (WHO, 1987).

Cadmium is removed from the atmosphere by gravitational fallout and by precipitation. Leaching of cadmium from soils and sediments is enhanced through the acidification of soils and lakes by sulphur and nitrogen oxides pollutants. This leads to increased cadmium levels in surface and groundwaters (WHO working Group, 1986).

Plants grown adjacent to a highway shows proportionately high levels of cadmium. The concentrations decreases with increase in distance away from the highway and a similar pattern is found in air (Williamson, 1988; Watkins, 1981).

2.1.6 Lead

Lead is a heavy, dull grey soft and ductile metal. Despite its uses, it is potentially toxic (UNEP, 1992). The uses include: automobile batteries, roof-sheathing, pipes and plastic industries, paint and printing industries, and as a gasoline additive (tetraethyl. lead) which improves the octane rating in petrol (Habitat, 1989).

Ambient air lead emissions, result mainly from natural silicate dusts, volcanic activity and automobile exhausts in addition to industrial processes involving battery manufacturing, metal-smelting and paint production (World Resources Institute, 1996-1997; UNEP, 1991). In favorably situated urban areas, the concentrations of lead in the air can be substantially higher than the levels normally encountered. Significant quantities in the air have been detected in sites close to a heavily travelled highway (Symposium on Environmental Lead Contamination, 1966. US – Public Health Service Publication, 1440).

Small quantity of lead inhaled can do far more damage to human body than a large quantity ingested. The fine particles emitted especially from automobile exhaust systems can be retained within the alveoli of the lungs and absorbed by the body with an efficiency of about 40%. Because of these circumstances, the emission of lead through exhaust pipes of internal combustion – engined automobile has become man's greatest worry in connection with lead poisoning (Calabrese and Kenyon, 1991).

The most prominent adverse effects of lead involve three organ systems in human body. These are the central nervous system, the hematopoietic system, and the kidney. The acute effects in human are stupor, then coma and eventually death.

The greatest associated danger of chronic exposure to lead poisoning is the harmful effect on the red blood cells. Haemoglobin synthensis is inhibited and this results in anaemia. Cumulative high levels in the body resulting from long-term exposure can also cause kidney dysfunction, encephalopathy, and brain damage (UNEP, 1991, De, 1994). Mental retardation and consequently slower learning capabilities have been noted in students living in areas with high lead levels in the atmosphere (Strauss and Mainwaring, 1984; UNEP, 1992). Students in areas with high lead levels in ambient air seems to learn two to four times slower than those in non-polluted areas. This has partly been attributed to the high gastrointestinal tract absorption rate of lead in children.

Lead affects various enzymatic reactions in the body by either binding to the sulfhydryl protein groups or by displacing the constituent essential metal ions (WHO, 1987). It also interferes with calcium deposition in the bones by replacing the calcium ions (Waldron, 1985; De 1994). In humans, lead and its compounds has been labeled as a likely carcinogen by Environmental Protection Agency (Calabrese and Kenyon, 1991). It is also carcinogenic to animals. Lead in its ionic form interferes with vital plant physiological processes such as photosynthesis and transpiration. Levels of 20-50 ppm cause remarkable reductions in these two processes (Bazzaz, 1974).

2.1.7 Other Metals: The Essential Elements:

(i) Zinc

Zinc, a blue-white metal, is used in making alloys and in galvanizing iron and steel (Hunter, 1978; Daintith, 1990). The metal is also used in the manufacture of batteries, and its oxide in electronic devices, cosmetics, pigments, paints, and in rubber and ointments manufacturing (Calabrese and Kenyon, 1991).

Zinc dust and fume in the ambient air is as a result of industrial activities such as galvanizing, and battery and brass manufacturing plants. Zinc metal is classified as an essential element in the human body necessary for vital physiological functions. It is a component of many important enzymes in the body. Alcohol dehydrogenate, arginase, alkaline phosphate, carbonic anhydrase, carboxypeptidase and collagenase are some of the enzymes. DNA and RNA polymerase enzymes responsible for DNA and RNA formation also contain zinc (Suttle, 1983).
Metal fume fever is due to the adverse effects of zinc oxide fumes and dust (Hunter, 1978; Waldron, 1985). Other disorders associated with zinc toxicity are lethargy, vomiting, pancreatitis, respiratory distress and pulmonary fibrosis (Braunwald, 1987). In animals, zinc toxicity causes profound weakness, salivation, diarrhoea, anorexia and parakeratosis (Underwood, 1977).

Excess amount of zinc adversely affects plants growth by retarding and/or inhibiting cell division (Strauss and Mainwaring, 1984). This results in stunted growth of plant, injured roots, chlorotic and Necrotic leaf tips.

(ii) Iron

A silvery hard metal capable of being magnetized. It is abundantly available in the earth's crust, and is used in steel making, alloying of iron and carbon (Daintith, 1990). Steel and iron are important component of household tools, machinery, vehicle parts, and many building materials such as galvanized roofing sheets, doors, windows and gates.

Iron is an important component of haemoglobin and myglobin, the oxygen carrying molecules in the blood and muscles respectively. It is also a crucial component of some enzymes necessary for cell protection purposes and protein used for storage and transport of iron in living systems in the body (Suttle, 1983).

Metal fume fever due to iron dust and fumes is rampant in industrial occupational settings (Hunter, 1978; Waldron, 1985). The associated human disorders include coughing, headache, exhaustion, fever, nausea, and pain in the limbs and thirst.

(iii) Copper

Copper, a red-brown malleable metal is a good conductor of heat and electricity. The metal's applications include electric cables, alloys such as brass and bronze; and copper sulphate used in electroplating, textile dyeing, and timber preservation. In fish and cash crop farming, copper sulphate is also used as an algicide and as a fungicide respectively. At trace levels, copper is an essential element necessary for vital physiological functions in man and animals. It is a constituent of several important enzymes in the body. The enzymes catalyze reactions involving synthesis of the hair and skin pigments, oxidative phosphorylation and collagen cross-linking.

The element is also a component of plastocyanin, a protein in the chloroplasts of leaves that acts as an electron carrier during the photosynthetic process (Bonner and Varner, 1976).

Ambient air copper contamination emanates from industrial activities involved in the manufacture of copper products. High levels of metal dust and its salts cause irritation to the eyes, and upper respiratory tract. Skin itching, ulceration and perforation of the nasal septum are some of the human disorders due to metal dust and mist.

Loss of appetite, apathy, thirst, jaundice, haemoglobinulia and death from hepatic coma are the effects associated with chronic toxic copper intakes in grazing ruminants. Acute symptoms involve abdominal pain and diarrhoea (Underwood, 1983).

Copper toxicity in plants causes darkening of leaves, depressed tillering and thickening or shortening of roots. These symptoms are most prominent in cereals, legumes, spinnach and citrus seedlings (Pendias and Pendias, 1984).

(iv) Manganese

Manganese is a steel gray, lustrous hard and brittle metal. It is superficially oxidised on exposure to air. The metal is used in the manufacture of steel; railway points and crossings; and as a constituent of several alloys such as ferromanganese, copper manganese and manganin. Manganese can also be used as an additive to fuel oil for reducing particulate emissions. It has some desirable antiknock properties as a gasoline additive as methylcyclopentadenyl manganese tricarbonyl.

Manganese is considered as an essential element for man and animals at trace levels. It is a critical component to normal biochemical and physiological functions in the body. DNA and urea formation in the body from arginase and deoxyribonuclease enzymes respectively, are some of the biological functions in which the metal plays an important role (Suttle, 1983).

Ambient air toxic levels occurs as a result of metal dust and fumes from industrial activities. The production of the metal alloys from metallurgical plant operations forms the major source of the metal emissions in addition to the automobile exhausts. Chronic adverse effects from manganese poisoning are manifested in central nervous system disorders and Parkinson's disease.

Psychological disturbances and disorders of co-ordination are some of neurological effects experienced by persons occupationally exposed. A form of lobar pneumonia was reported among inhabitants of a Norwegian Town contaminated by metal emissions from a metallurgical plant producing ferromanganese ("Committee on Biological Effects of Atmospheric Pollutants Manganese", 1973).

2.2 Air Pollution Scenario in Kenya

The limited air quality data available from studies of some selected urban areas indicates that little attention has been focused to air pollution. In Nairobi, studies on total suspended particulate matter showed high concentrations in industrial zone as compared to urban or residential and commercial centers (Ngugi, 1983). A maximum level of 252 $\mu g/m^3$ was noted, and levels decreased with increasing distance away from the industrial sites. An average concentration of 80 $\mu g/m^3$ obtained in residential areas was below the WHO acceptable limit of 230 $\mu g/m^3$ (WHO, 1987).

Seasonal variations in concentrations was also revealed with high levels in dry season than wet season. This was attributed to washout by precipitation and favourable wind changes during wet season (Nganga, 1976).

Investigations in Mombasa town revealed distinct variations from site to site characterised by the daily pattern of human and industrial activities (Kimani, 1990). Time variations of total suspended particulate matter was noted with higher values during the day than at night. Likewise seasonal variations were associated with favourable diurnal wind changes with concentrations in the range 100-260$\mu g/m^3$ of total suspended particulate matter.

In a study on total suspended particulate matter and heavy metal content of the air in Nairobi (Murakaru, 1991), the mean concentrations in industrial area varied from 282-393 $\mu g/m^3$. These values show an upward trend in air pollution with respect to total suspended particulate matter as from 1983 (Ngugi) to 1991. Average level in residential/commercial areas (84.1 $\mu g/m^3$) was comparable with that reported earlier by (Ngugi, 1983) in the same area. Lead levels (0.738-0.782 $\mu g/m^3$) were within the World Health Organization (WHO) guideline (0.5-1.0 $\mu g/m^3$), but higher than those reported in some European countries.

Research work by Thuo (1991) on elemental composition of Dust fall in the vicinity of East Africa Portland cement Factory in Athi River Town, revealed high levels of iron (7480.3-9670.7 ppm) and manganese (404-595.5 ppm). The heavy metal levels were noted to decrease with increase in distance away from the kiln/electrostatic precipitator.

Vehicular emission influence on roadside air quality in some areas of Nairobi (Oketch, 1994) revealed high Lead levels directly proportional to the traffic density. Mean concentrations decreased with increase in distance away from the road centerline, with maximum non-peak period levels in the range (21.9-35.9 μg/m^3). Assessment of the contribution of total suspended particulate matter on the air pollution load in Nairobi's suburban area, Kenya Meteorological Department, was carried out (Gatebe 1990;Gatebe and kinywa, 1994). Total Suspended particulate matter concentrations and lead levels were found to be in the ranges 30-80 μg/m^3 and 0.031-0.465 μg/m^3 respectively. Both levels were below the WHO recommended guidelines 230 μg/m^3 and (0.5-1.0 μg/m^3) respectively. Total Suspended particulate matter concentrations increased with increasing wind speed. This was due to dust resuspension in addition to the existing particulate load.

Ambient air sulphur dioxide level study was first carried out in 1977/78 under the Global Environment Monitoring Programme (GEM), an urban air assessment programme. The highest levels at the industrial zone, the city (urban) centre, suburban and residential/commercial centre were found to be 142, 25, 51 and 41μg/m^3 respectively (UNEP/WHO, 1978). Levels in the industrial area were above the WHO long-term standard 40-60μg/m^3.

Monthly average levels of sulphur dioxide study (Kollikho, 1995) in Nairobi's industrial area, varied between 57.2 and 143.2 μg/m^3. In the residential areas concentrations fluctuated between 18.2 and 64.3 μg/m^3. Seasonal variations characterized by dispersion conditions revealed lower concentrations (14.2-157.8μg/m^3) in October-November period than in June-September (15.5-175.5μg/m^3). Time variations in levels was also noted with higher values in the mornings than in the afternoon.

A preliminary survey carried out in Nderi/Kikuyu (Jumba, 1988: personal communication) revealed high levels of sulphur dioxide (3,300-8,200μg/m^3) and ammonia concentrations of 23,2000-27,200 μg/m^3. Both levels were higher than the long-term WHO recommended standards: 40-60 μg/m^3 and 500 μg/m^3 respectively.

Recent studies revealed that the mean airborne concentrations of Sulphur dioxide in Nairobi's industrial area and Nderi / Kikuyu were 82.3 and 63.7 $\mu g/m^3$ respectively (Wafula, 1999). The level at the industrial area in Nairobi was comparable with that determined by Kollikho (1995) at the same sampling site, whereas that at Nderi / Kikuyu was far much lower than the levels recorded at the same area by Jumba (1988): personal communication.

The same study by Wafula(1999) also recorded significantly low mean concentration of ammonia ranging from 50.9 – 136 $\mu g/m^3$ in Nderi / Kikuyu as compared to the levels of 23,200 – 27,200 $\mu g/m^3$ determined at the same site by Jumba (1988): personal communication. These showed a reduction in pollution level with respect to Ammonia gas at the rate of approximately 296 - 738 $\mu g/m^3$ every year since 1988, hence a clear indication of the major steps that have been taken to control this menace in this area.

To change from the traditional end – of – pipe method of control of air pollution, National Environment Management Authority (NEMA) has adopted a preventive approach aimed at minimizing waste discharges right from the source. To achieve this change, National Environment Management Authority in accordance with the provisions of National Environmental Management and Coordination Act No. 8 of 1999 insists on Environmental Impact Assessment study report as a project site requirement from prospective industrialists before setting up a factory.

Also as a precautionary measure, National Environment Management Authority routinely carries out Environmental Audits on existing industries to establish their compliance with WHO standard guidelines.

On the basis of the foregoing pollution levels in various areas, it is still evident that there is an eminent public health and welfare problem to be tackled urgently. A concerted effort from all sectors is required to assist in establishing a monitoring and assessment programme to alleviate the severity of health risks posed by the pollution menace, hence the purpose of this project.

CHAPTER THREE

THEORETICAL ASPECTS OF INSTRUMENTAL METHODS COMMONLY USED IN AIR POLLUTION STUDIES

3.1 Analytical Techniques

Quantitative determination of air pollution contaminants can successfully be carried out using accurate and reliable instrumental techniques. The most commonly used are the Atomic Absorption Spectrophotometry and UV/Visible Spectrophotometry.

3.2 Atomic Absorption Spectrophotometry

3.2.1 Principle

When a solution of a metallic salt is sprayed as a fine mist into a flame, the solvent in the droplets immediately evaporates leaving non-ionized salt particles, which vaporise. If no interference occurs, the gaseous salt partially dissociates into gaseous metal atoms. When the gaseous atoms receive sufficient energy from the flame, some will be excited to a higher energy level and on reaching the cooler part of the flame will emit this excitation energy as radiation at wavelength characteristic of the metal atoms.

The flame temperature determines the fraction of species that exist in excited states and thus influences emission intensities. The Boltzman equation permits the calculation of this fraction. (Milner and Whiteside, 1984) If the N_J and N_o are the number of atoms in an excited and ground states respectively, their ratio is given by:

$$\frac{N_j}{N_o} = \frac{P_j}{P_o} \exp. \left(\frac{-\Delta Ej}{KT} \right) \text{ .... Eq:3.1}$$

Where; K is the Boltzman constant, T is the temperature and ΔE is the energy difference between the excited state and the ground state. The quantities P_j and P_o are statistical factors that are determined by the number of states having equal energy at each quantum level.

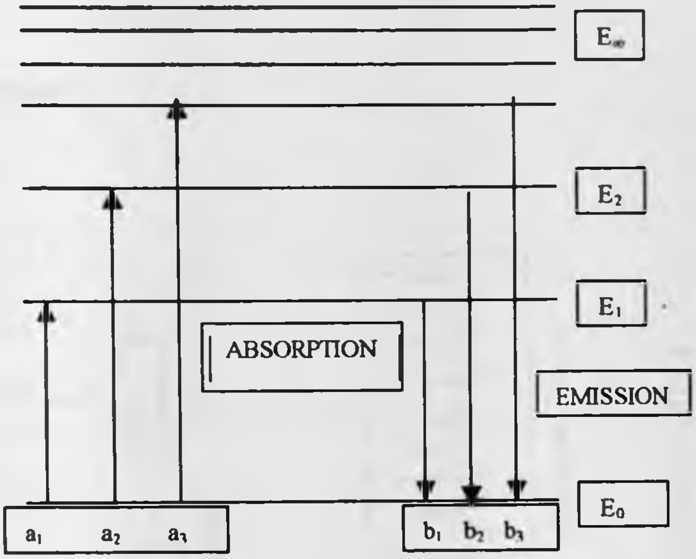


Fig. 3.1 Absorption/Emission Transitions in Atomic Spectrometry

The atoms in the ground state absorb radiation as discrete lines of narrow band-width of the same frequencies as would be emitted if the element were excited.(Milner and Whiteside, 1984). Hence the beam of light will be reduced in intensity in proportion to the number of ground state atoms in the flame.

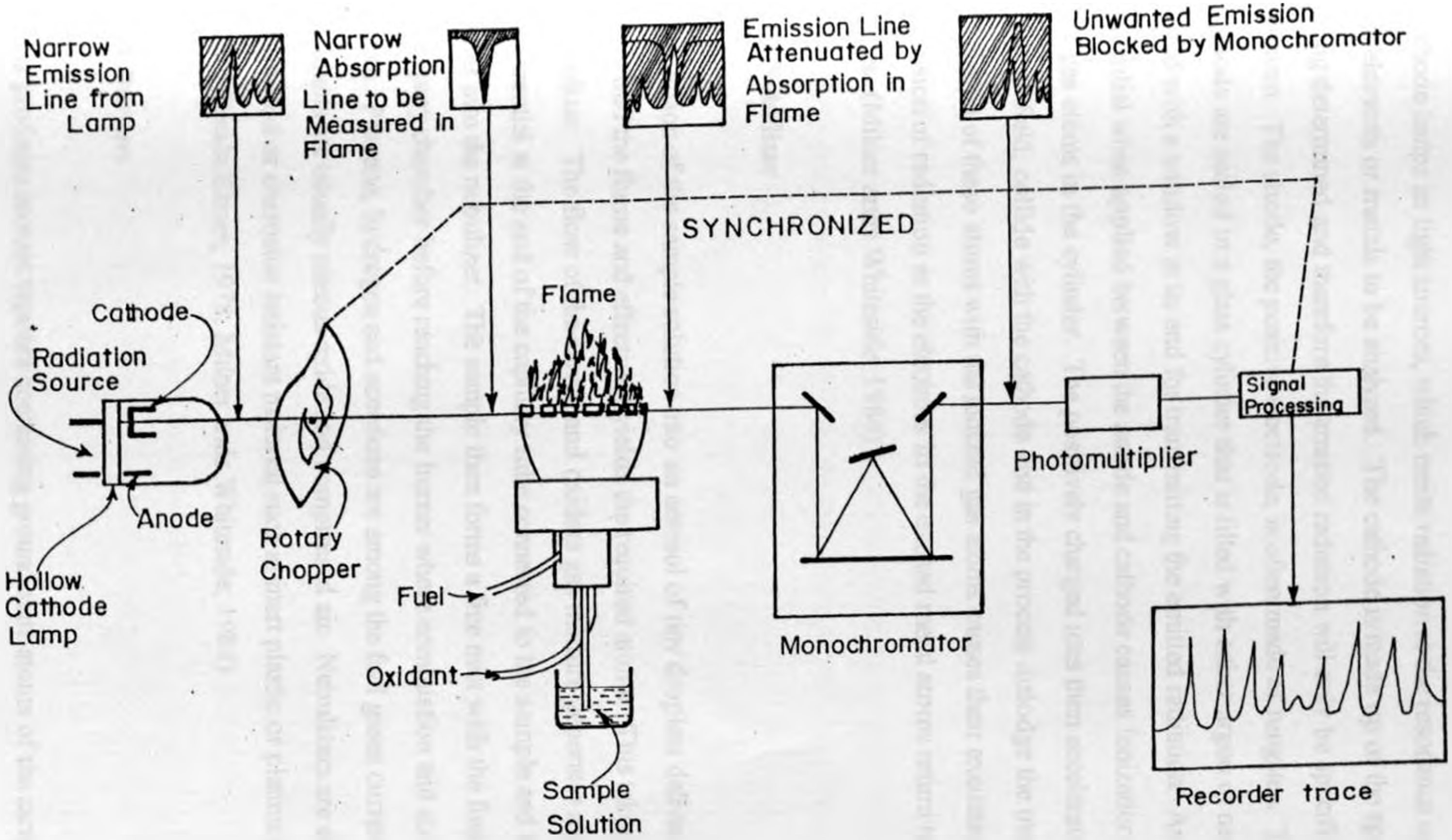


Fig. 3.2 Schematic diagram of Atomic Absorption Spectrophotometry
(SOURCE : Perkin – Elmer, 1978)

The Atomic Absorption Spectrophotometer (AAS) Comprises of:

(a) A Light Source:

Most Atomic Absorption Spectrophotometry instruments are equipped with Hollow Cathode lamps as light sources, which emits radiation at the resonance wavelengths of the elements or metals to be analyzed. The cathode is made up of the specific element being determined and therefore the emitted radiation will only be specific to that element. The anode, the positive electrode, is often made of tungsten. The anode and cathode are sealed in a glass cylinder that is filled with either argon or neon and is fitted with a window at its end for transmitting the emitted radiation. An electrical potential when applied between the anode and cathode causes ionization of some of the gas atoms in the cylinder. The positively charged ions then accelerate through the electric field, collide with the cathode and in the process dislodge the metal atoms. Collision of these atoms with the ionized gas atoms causes their excitation, leading to emission of radiation as the electrons in the excited metal atoms return to their ground states. (Milner ands Whiteside, 1984)

(b) Nebulizer

Dispersion of the sample solution into an aerosol of tiny droplets delivers a steady flow into the flame and effectively yields the required atoms. This takes place in the Nebulizer. The flow of the carrier and oxidant gas mixture generates a pressure differential at the end of the capillary tube connected to the sample and this draws the latter into the nebulizer. The sample then forms a fine mist with the fuel mixture in the spray chamber before reaching the burner where combustion and atomization take place. Propane, hydrogen and acetylene are among the fuel gases currently used. The oxidants are usually nitrous oxide and compressed air. Nebulizers are either made from steel or corrosion resistant material such as inert plastic or platinum-rhodium alloy (Perkin Elmer, 1978; Milner ands Whiteside, 1984)

(c) Burner:

This produces atomic vapours containing ground state atoms of the sample being analysed. There are essentially two types of burners that are used in the flame atomic absorption spectrophotometry: the total consumption burner and the premix chamber or laminar flow burner. In the former type, the fuel and oxidant gases are mixed and combust at the tip of the burner. The entire aspirated sample goes into the flame. The fuel and oxidant gases in the premix chamber burner are mixed in a chamber prior to entering the burner head where they burn. Only fine droplets of the sample mix with the gases and ultimately enter the flame. Large droplets usually condense and drain out of the chamber. The premix chamber burner is utilized in most commercial spectrophotometer (Christian, 1980). There are several types of flames used in atomic absorption spectrophotometry but the most widely used one is the air-acetylene flame (with a maximum burning temperature of about 2955°C), which can easily ionize gaseous atoms. It is therefore mainly used for elements, such as aluminum, which form heat stable oxides in the air-acetylene flame (Christian, 1980).

(d) Monochromator

This device separates the desired resonance line from the other lines. The resonance line is the one which corresponds to the electronic transitions from the ground state to the lowest excited state. This is often, but not always, the most strongly absorbed line. Wavelength selection enables quantitative determination of a selected element in the presence of others.(Milner ands Whiteside, 1984)

(e) The Detector, Amplifier and Readout System:

The detector converts radiant energy into an electrical signal. Photo multipliers are widely used due to their high sensitivity and wide wavelength range, from 190 to 900 nm. The photo multiplier is made up of an evacuated tube containing a photosensitive cathode (photocathode) and a series of electrodes called dynodes. When radiation strikes the photocathode it emits electrons. These electrons are accelerated in the electric field present in the photomultiplier and strike the first dynode which is maintained at a higher voltage than the photocathode. Each electron striking the first dynode causes two or more electrons to be emitted and these, after accelerating in the electric field, hit the second dynode, which is at a higher potential than the first one. More electrons are again released from the second dynode and these go on to strike the third dynode causing further release of electrons. This process continues until electrons are emitted from the last dynode. As a result, the initial electrical signal is increased by many orders of magnitude (Milner ands Whiteside, 1984 Pye Unicam, 1985)

The electrical signal from the detector is further amplified and then conveyed to the readout system which comprises the electronic circuitry and a digital display unit. The amplified signal from the detector is directly proportional to the percentage transmittance of the sample and for this relationship to be more useful, the percentage transmittance must be converted to absorbance. This conversion and further processing of the signal up to the instrument readout is effected by a microprocessor (Pye Unicam, 1985).

3.2.3: Practical Considerations:

Absorption methods are theoretically less dependent upon temperature because the measurement is based upon initially unexcited atoms rather than thermally excited ones.

An increase in temperature usually influences the efficiency of the atomization process hence the total number of atoms in the flame. Line broadening and a consequent decrease in peak height occur because of the emission of atomic particles at greater rates, which enhance the Doppler-effect. Increased concentrations of gaseous atoms at higher temperatures also cause pressure broadening of the absorption lines. Because of these indirect effects, a reasonable control of the flame temperature is required for quantitative absorption.

3.3 Molecular Absorption Spectrophotometry

3.3.1 Principle

Molecular absorption in the UV/Visible regions arises from energy transitions involving the outer orbital or valency electrons. The energy (ΔE) of photons

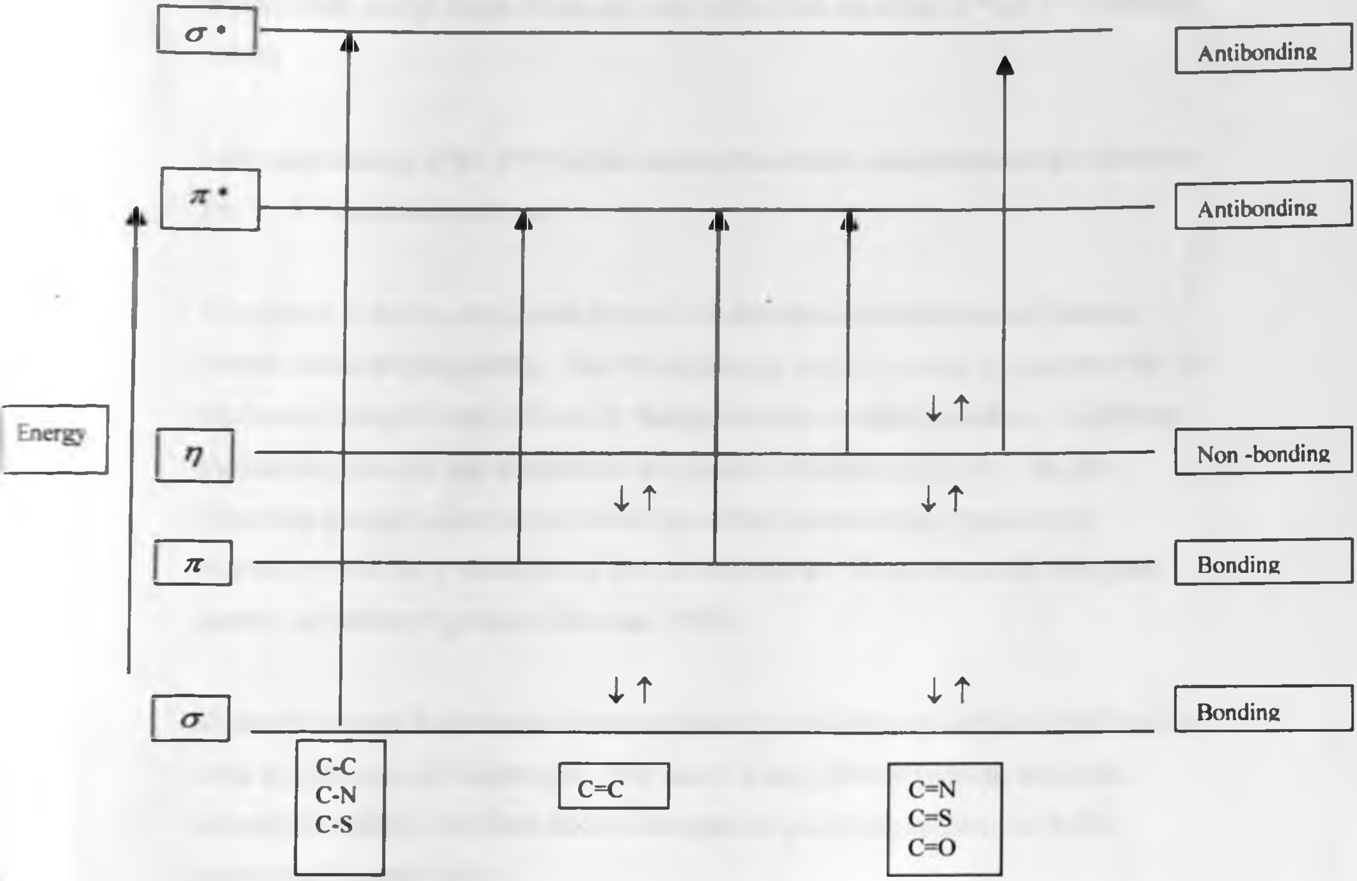


Fig. 3.3: Absorption transitions involving molecular orbitals in electronic spectroscopy .

associated with the electronic transitions is expressed in terms of the principal parameters that define electromagnetic radiation: frequency ν (Hz) ; Wavelength, λ (nm) and wave number, υ (cm^{-1}).

$$\Delta E = h\nu = \frac{hc}{\lambda} = hc\upsilon \quad \text{.. Eq.3.2:}$$

where h is Planck's constant, and c is the velocity of light.

Molecules contain closed shell electrons that do not participate in bonding, covalent single bond electrons (sigma electrons), electrons in the π Orbital (π-electrons) and paired non-bonding outer electrons (n-electrons). Closed shell and sigma electrons are close to the atomic nucleus and are therefore more strongly attracted. The comparatively less attracted non-bonding and π-electrons are easily excited by the ultraviolet and visible radiations (Christian, 1980). All molecules also possess bonding and antibonding orbitals. The former are ground state orbitals, which are occupied by electrons, and are either σ (sigma) or π. Antibonding orbitals are the excited-state energy levels which are unoccupied and are either σ^* or π^* (Christian, 1980).

Most applications of the UV/Visible spectrophotometric measurements are based on the π - π^* transitions or n - π^*.

Absorption is due to conjugated system with extensive delocalization of electron density called chromophores. The chromophores usually contain π-electrons that can be excited to higher energy levels by the unltraviolet or visible radiation. Aldehydes, anthracene, benzene and naphthalene are some of the chromophores. The non-absorbing groups auxochromes usually modifies the absorption spectrum by interacting with the π-electrons of the chromophores. Examples are the halogens, amines and hydroxyl groups (Christian, 1980).

Measurements of absorbance or transmittance by an absorbing sample system can be done as a function of wavelength. The law of absorptiometry which relates the intensity of radiation incident on the homogenous absorbing system (Io) to the transmitted intensity (I) is:

$\text{Log } I_o/I = kcb$ .... Eq. 3.3

where k is: the absorptive of the system; c is concentration of homogenous absorbing system; and b is the path-length. (Perkln Elmer, 1978) The logarithmic term is linearly related to concentration and path-length and is referred to as Absorbance (A).

$\text{Log}(I_o/I) = A = kcb$ .... Eq. 3.4

Concentrations of coloured chemical species in the samples are then determined from the Absorbance values (Perkin Elmer, 1978).

3.3.2: Instrumentation

There are two types of UV/visible spectophtometers: single beam and double beam. The single beam has only one light path, the monochromatic radiation is not split into two components as is the case for the double beam instrument. Absorbance readings for the reference and sample solutions are taken separately in the same light path. The double beam spectrophotometer has two light paths: the monochromatic beam of radiation strikes a rotating or vibrating mirror that alternately passes the beam through the reference and sample solutions. The detector also alternately detects beams from the reference and samples (Christian, 1980). The basic components of the double beam UV/Visible spectrophotometer are:

(a) A Radiant Energy Source

This emits a continuous radiation consisting of the wavelengths of interest; a tungsten filament lamp (330 – 800nm) and hydrogen or deuterium discharge lamp radiations in the ultraviolet region of the spectrum.

(b) A wavelength Selector

This selects a narrow band of wavelengths from the source spectrum. The wavelength selectors are usually filters that are made up of colored glass. A glass filter disperses the source radiation into its component wavelengths. The frame holding the filter serves as an entrance slit which confines the source radiation to where it is to be used. The exit slit, which in many cases is a simple fixed mask blocks the undesired dispersed radiation and confines the transmitted beam of radiation to the dimensions of the sample holder (Pye unicam, 1985).

(c) Cells or Cuvettes:

These are rectangular sample holders, with a length of 1.0 centimeter and are placed in the beam of the spectrophotometer. The Cells are constructed from glass quartz, silica or moulded polystryene. Glass cells are suitable for use in the 340 to 1000 nm region of the spectrum. Quartz cells serve well in the ultraviolet region. Work between 220 and 340 nm requires cells constructed of silica while a special ultraviolet grade of silica is necessary for the region between 185 and 220 nm (Pye Unicam, 1985).

(d) Detector

The device converts the radiant energy into an electrical signal, which can be processed, amplified and displayed on readout. Several types of detectors exist, including photocells; phototubes, photodiodes and photo multipliers but the most widely used are the photocells and phototubes.

A photocell consists of a metal plate that is coated with a light sensitive material such as selenium. When radiant energy strikes this material, it causes the release of electrons. A small a mount of current will flow when the front and rear ends of the photocell are connected. The wavelength range of photocells is about 400 to 750 nm. This type of detector is simple, does not require external power supply, and is comparatively less expensive. Photocells however suffer from low sensitivity, are prone to fatigue and have a slow response to changing illumination levels. They also require protection from the heat generated by the radiation source because their output is temperature dependent (Pye Unicam, 1985).

A phototube consists of an anode and a cathode, both enclosed in evacuated glass or silica. The anode is a fine wire mesh while the cathode is a metal coated with a photo-sensitive/emission alloy. Radiant energy striking or falling on the photocathode causes electrons to be ejected from the cathode. These electrons are then attracted to the anode and the resultant current is conveyed to the amplifier. The wavelength range of the cathode can either be adjusted from 190 to about 650 nm or from 600 to 1000 nm. Spectrophotometer therefore require two phototubes to cover the entire ultraviolet and visible range of the electromagnetic spectrum. Phototubes are more sensitive than photocells but are relatively more expensive. They require an external power supply to maintain the voltage between the electrodes and also an external amplifier for the signal (Pye Unicam, 1985).

(e)Readout System

This comprises the electronic circuitry and a digital display unit. The amplified signal is processed by a microprocessor and finally displayed on a digital readout meter (Pye Unicam, 1985).

CHAPTER FOUR

EXPERIMENTAL:

METHODS AND MATERIALS

4.1 Field sampling sites and their Description

The Locations of the sampling sites are shown in Fig. 4.1

4.1.1 Athi River Town

The town is about 25 Km to the southeast of Nairobi city. It covers an area of 69.3 square kilometers and its geographical location is 1°27'S and 36°58.7'E. The population of Athi River township was estimated to be 14,338 people in 1989 (Central Bureau of Statistics, 1994). It lies at an altitude of 1480-1520 metres. The climate is predominantly hot and dry almost throughout the year except for the short-rains wet seasons of April/May and November/December. A contrasting topography of gentle slope combining some depressions and flat grounds landscape exist.

Samples were taken from the three areas: industrial zone, urban commercial center and residential area. At industrial zone four sampling sites were chosen.

(i) Site IA: At a distance of 200 metres away from the Athi River Mining company Ltd.

(ii) Site IB: At about 150 metres away from the Exide Chloride, a smelter factory for battery manufacturing company.

(iii) Site IC: The East Africa Portland Cement Factory at a distance of 150 metres away from the plant kiln.

(iv) Site ID: The fishmeal factory at a distance of 200 metres away from the open treatment pools and disposal sewers.

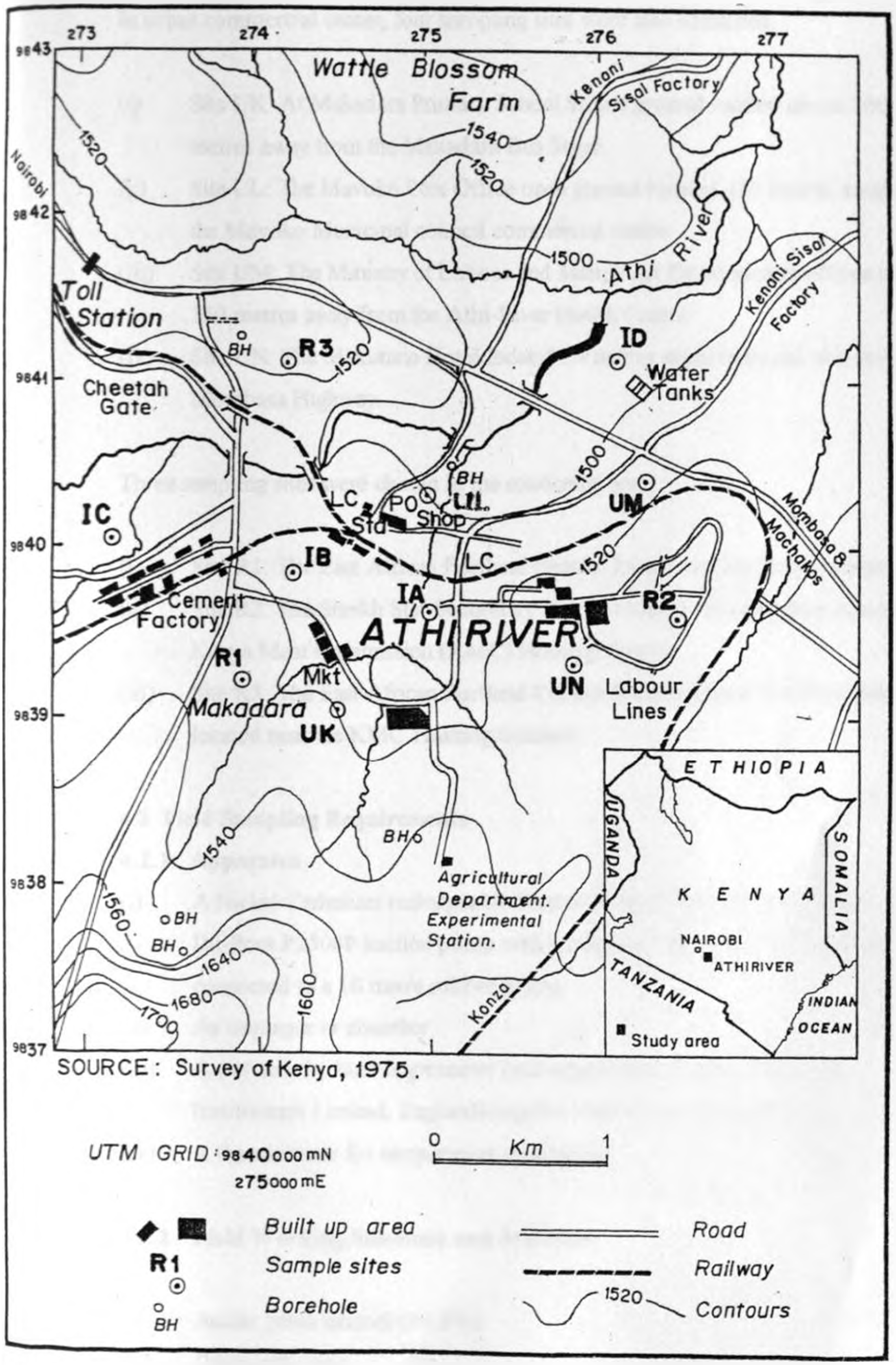


Fig. 4.1 Sampling sites and their description

In urban commercial center, four sampling sites were also identified.

(i) Site UK: At Makadara Primary School Sports ground located about 200 metres away from the Makadara Bus Stage.
(ii) Site UL: The Mavoko Post Office open ground located 150 metres away from the Mavoko Municipal council commercial centre
(iii) Site UM: The Ministry of Labour and Manpower Development offices located 150 metres away from the Athi-River Health Centre
(iv) Site UN: The Makutano Hotel located 50 metres away from the Nairobi-Mombasa Highway.

Three sampling sites were chosen in the residential area.

(i) Site R1: The East African Portland Cement Factory Junior Staff Quarters.
(ii) Site R2: The Sheikh Star Secondary School situated near slaughter house and Kenya Meat Commission (KMC) Housing Estates.
(iii) Site R3: The East African Portland Cement Factory Senior Staff Quarters located near the KMC Training Institute

4.2 Field Sampling Requirements

4.2.1: Apparatus

(i) A Nickel-Cadmium rechargeable Battery (P/No:576B) power driven portable Du-Pont P2500P suction pump with a constant flow rate of 2.0 l/min when connected to a 10 metre rubber tubing.
(ii) An impinger or absorber
(iii) A wet and dry bulb hygrometer (manufactured by Russell Scientific Instruments Limited, England) together with its conversion tables.
(iv) A thermometer for temperature monitoring.

4.2.2 Field Working Solutions and Materials:

(i) Analar grade ethanol (99.9%).
(ii) Deionized water
(iii) 0.1 M sodium tetrachloromercurate
(iv) 0.003 M sulphuric acid

(v) 0.05M cadmium hydroxide

(vi) PVC membrane Millipore filter type AA: 0.8 μm pore size and 37 mm deposit diameter.

(vii) Filter holders (filter cassettes)

4.2.3: Sampling Procedure:

The set up of the sampling Apparatus is shown in Fig. 4.2. It involved combination of the filter and impinger for simultaneous sampling of both particulates and vapour/gas.

The filters were dried at 110^{0}C and then stored in sealed containers (filter cassettes) before sampling.

The impinger was first rinsed with deionized water and then by the trapping solution for the particular pollutant to be sampled. Table 4.1 below shows the various trapping solutions and filter medium for various pollutants.

Table 4.1: Trapping solutions and filter medium for various pollutants:

Parameter:	Trapping solution or filter medium:
TSP/ heavy metals	0.8 μm Pvc membrane Millipore filter
Sulphur dioxide	0.1M sodium tetrachloromerculat.
Hydrogen sulphide:	0.05M Cadmium hydroxide suspension.
Ammonia:	0.003M Sulphuric acid.

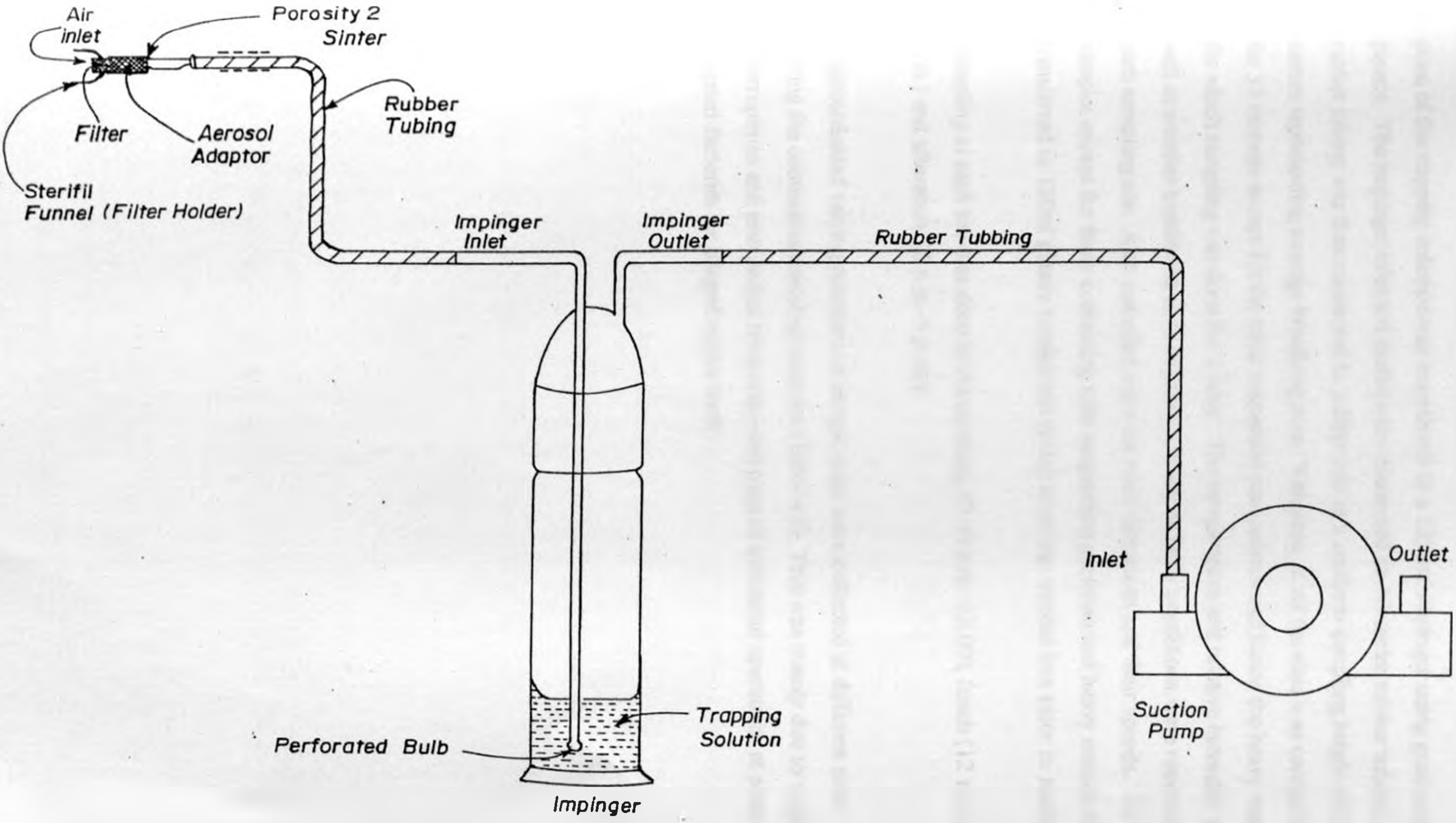


Fig. 4.2 A Set-up of the sampling apparatus.

60ml of the trapping solution was transferred to a 125 ml impinger using graduated pipette. The impinger inlet and outlet were connected to 10-metre rubber tubing. The rubber tubing was then connected to a filter unit at a uniform sampling height of 2.0 metres representing average breathing zone. Sampling at all the sites was carried out for 30 minutes except for the total suspended particulates and hence the heavy metals for which sampling was done for 1 hour. The temperature and relative humidity as well as weather conditions such as sunny, cloudy or rainy conditions were recorded at each sampling site. Also recorded were the wind directions and their speeds. All the samples except for those containing total suspending particles and heavy metals were transferred to 120ml plastic bottles and stored in an ice- cooled box prior to analysis.

Sampling at each site was done in the morning, (9.00 a.m.-12.00), lunch (12 noon-2 p.m.) and afternoon (2 p.m.-5 p.m.).

Unprecedented varying numbers of sample sizes were collected at different sites during the continuous sampling exercise (Table 4.2). This was mainly due to rainfall interruptions and unexpected temporary stoppage of industrial operations at some targeted factories for alleged repair work.

Table 4.2: Number of samples taken from each sampling site in the three areas:

Industrial	**TSP**	**Zn**	**Cd**	**Pb**	**Mn**	**Cu**	**Fe**	**SO_2**	**H_2S**	**NH_3**
IA	15	20	20	20	20	20	20	12	5	8
IB	18	18	18	18	18	18	18	13	4	4
IC	11	13	13	13	13	13	13	3	3	2
ID	13	23	23	23	23	23	23	10	7	8
Urban										
UK	12	15	15	15	15	15	15	8	3	7
UL	9	12	12	12	12	12	12	9	5	7
UM	8	9	9	9	9	9	9	13	7	5
UN	11	16	16	16	16	16	16	8	3	7
Residential										
R1	5	7	7	7	7	7	7	12	7	4
R2	4	9	9	9	9	9	9	12	9	10
R3	5	10	10	10	10	10	10	9	4	6

All the samples were analysed within 24 hours in the laboratory.

4.3: Physical and Chemical Analytical Procedures

4.3.1: Gravimetric determination of Total Suspended Particulate Matter

(a) Principle

Molecular membrane millipore filters (type AA: 0.8 µm pore size) were used for quantitative measurements. They exhibit uniformity of pore size and approach 100% efficiency for removing particles as small as 0.1µm in size (Silverman and First, 1953). They also have little tendency to absorb moisture, and are light and uniform in weight.

The particle collection is achieved by the co-operative effect of direct interception (Impaction), inertial deposition, diffusional deposition, electrical attraction and gravitational attraction. In sieving action any particle larger than the opening in the filter is blocked and held mechanically on the surface of the filter. Particles smaller than the pores penetrate the surface but may be retained within the filter as a result of greater diffusion aggregation effect. This provides a high degree of retention of particles smaller than the stated pore size. Particles of high and low velocity flow are collected by impaction and diffusional process respectively.

(b) Materials

(i) Filtration medium (type AA: 0.8µm millipore filter)
(ii) Filter holders (filter cassettes)
(iii) Plastic tweezers
(iv) Gas meter (bubblemeter)
(v) Dessicator (with magnesium perchlorate)
(vi) Microanalytical balance (Cahn model)

(c) Experimental Procedure

A measured volume of air was drawn through a humidity controlled weighed filter at a constant flow rate of 2.0 l/min for 1 hour using the suction pump. The unloaded filters were maintained at a temperature of 75°C and 50% relative humidity for at least 16 hours in a mermett incubator until constant weight was reached (US- EPA, 1974). The unloaded and loaded equilibrated filters were weighed to the nearest 0.0001mg to determine the total suspended particulate loading. The following relationship shows an example of the data work up.

$$\text{Conc. of TSP matter } (\mu g/m^3) = \frac{\text{wt.Of the equilibrated loaded filter } (\mu g) - \text{wt. Of unloaded filter } ((\mu g)}{\text{Volume of air sampled } (m^3) \text{ at } (25^\circ C \text{ and } 1 atm)}$$

(Oikawa. 1977)

4.3.2: Atomic Absorption Spectrophotometric Determination of Metallic Elements in TSP Matter

Sample configuration of the equilibrated particulate samples on the membrane millipore filters remains the same. The sample is in the same form as when it was airborne and for the recovery of metallic elements the filter was dry-ashed with the aid of fuming – HNO_3 (s.p. gravity 1.40 gm/ml and Assay: 64%) at 500°C (Kometani, 1972). The conversion of metal salts to nitrates by the addition of HNO_3 before dry-ashing ensured complete recovery of metals. The ash was then dissolved in 1% HNO_3, filtered and made up to 25 ml analytes prior to Atomic Absorption Spectrophotometric analysis. Shimadzu model AA680 Atomic Absorption/Emission Spectrophotometer with an appropriate hallow cathode lamp was used in this study. The standard working solutions, the blank (1% HNO_3 v/v solution), and the sample analytes were aspirated into the Air – acetylene flame of appropriate wavelength and the corresponding absorbance values recorded.

The apparatus was flush washed with deionized water and the aspiration of sample analytes repeated thrice. The mean of the three-absorbance readings was used to determine the concentration of the element from the calibration curve.

Table 4.3 shows the standard working concentrations; weights of metal salts dissolved in one litre 1% HNO_3 to make required standard concentration and analytical lines.

Table 4.3: Standard stock solutions for some selected metal ions in Atomic Absorption Spectrophotometry.

Metal	**Std. Working Conc. (ppm)**	**Wt. Of salt to be dissolved in 1 litre 1% HNO_3 solution**	**Analytical line λnm**
Cu	1000	3.9492gm, $CuSO_4.5H_2O$	344.8
Pb	1000	1.6065gm $Pb(NO_3)_2$	217.0
Zn	1000	4.6436gm. $Zn(NO_3)_2.6H_2O$	213.9
Mn	1000	5.9455gm. $Mn(NO_3)_2.6H_2O$	279.5
Cd	1000	2.0417 g $CdCl_2.2\frac{1}{2}H_2O$	228.8
Fe	1000	7.128 gm $(NH_4)_2(FeSO_4)_2.6H_2O$	248.3

4.3.3 Molecular Absorption Spectrophotometric determination of sulphur dioxide

(a) **Principle:** The pararosaniline method which is a modification of the West-Gaeke procedure has been widely used as a reference method for quantitative determination of atmospheric sulphur dioxide. The method is recommended by the International Organization for Standardization (ISO 6767, 1990). Concentration ranging from 0.005-5 ppm can be detected without difficulty (Tyagi Mehra, 1990; De, 1994).

Sulphur dioxide in samples reacts with sodium tetrachloromercurate (TCM) to form a dicholorosulphito mercurate complex which is resistant to oxidation in air.

$$SO_2 + HgCl^{2-}_4 + H_2O \rightarrow HgCl_2SO^{2-}_3 + 2H^+ + 2Cl^-$$

The complex then reacts with pararosaniline in the presence of formaldehyde at pH 1.6 to form the intensely red-purple pararosaniline methyl sulphuric acid. The absorbance of the solution is measured spectrophotometrically at 560 nm (ISO 6767, 1990; UNEP and WHO, 1994).

(b) Reagents

(i) 0.1 molar a mixture of sodium tetrachloromercurate (TCM) solution was prepared by dissolving 27.80 gms of 98% mercuric chloride ($HgCl_2$) and 11.70 gm of 99.9% sodium chloride (NaCl) salts in distilled water and diluting to one litre.

(ii) 0.04% pararosaniline was prepared by dissolving 0.04 gm of pararosaniline in 6ml of concentrated hydrochloric acid (HCl). The solution was then shaken with 50 ml distilled water, filtered and diluted to 100 ml with distilled water.

(iii) 0.6% sulphamic acid (H_2NSO_3H) solution which reduces the interfering oxides of nitrogen to nitrogen gas, was prepared by dissolving 0.60 gm of Sulphamic acid in 100 ml. distilled water.

(iv) 0.2% formaldehyde (HCHO) solution was prepared by diluting 5.3 ml of 38% formalin to one litre with distilled water.

(c) Standard Solutions

1000 ppm stock solution of sulphur dioxide was prepared by dissolving 0.1562 gm of 95% sodium metabisulphite ($Na_2S_2O_5$) in distilled water and making it to 100ml.
A working stock solution of 50 ppm was then prepared from the stock solution by diluting a given volume of 1000ppm of stock solution . Calibration solutions in the range of 0.005 – 0.6ppm SO_2 were prepared from 50ppm working solution by serial dilution.

(d) Experimental Procedure for determination of Sulphur Dioxide

2ml of 0.6% sulphamic acid was added to 10 ml.of each sample contained in a 50 ml volumetric flask. After 10 minutes, 4 ml of 0.04% pararosaniline reagent and 4 ml of 0.2% formaldehyde solution were added. The contents were made to the mark with sodium tetrachloromercurate (TCM) trapping solution. Reference blank solutions containing only 0.1M TCM and standards were treated in the same way as the samples. The absorbance was then measured spectrophotometrically at 560 nm after 20 minutes using a pye unicam SP6-550 UV-VIS spectrophotometer. A typical calibration curve (fig 4.3) had a slope of 0.1348 and an intercept of 0.01.

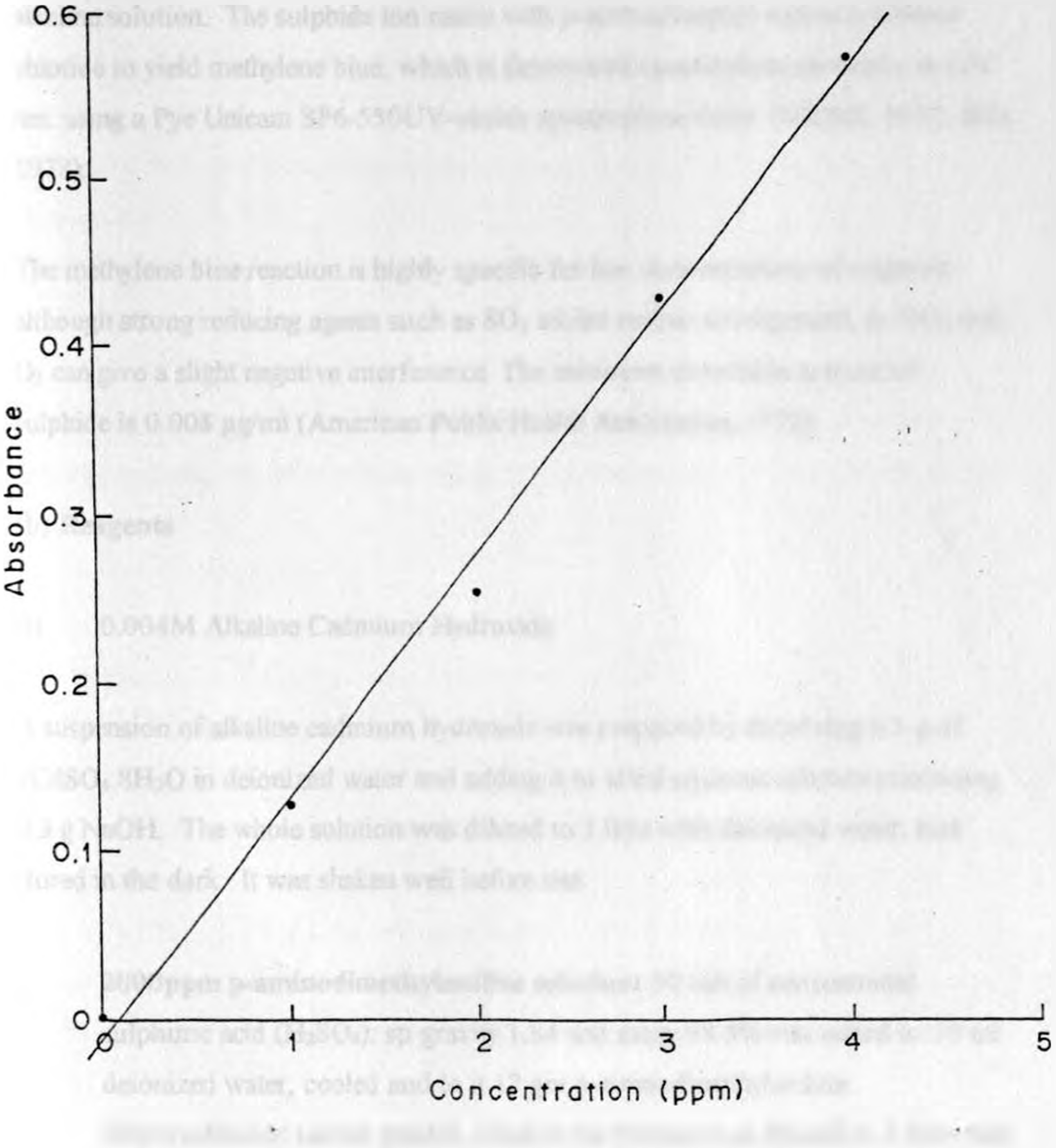


Fig. 4.3: **A typical calibration graph for sulphur dioxide**

4.3.4 Molecular Absorption Spectrophotometric Determination of Hydrogen Sulphide (H_2S)

(a) Principle

The method involves the absorption of hydrogen sulphide in an alkaline suspension of cadmium hydroxide (Cd $(OH)_2$). The sulphide is precipitated as cadmium sulphide (CdS) to prevent air oxidation of the sulphide which occurs rapidly in aqueous alkaline solution. The sulphide ion reacts with p-aminodimethyl aniline and ferric chloride to yield methylene blue, which is determined spectrophotometrically at 670 nm. using a Pye Unicam SP6-550UV-visible spectrophotometer. (NIOSH, 1977; ISO, 1978).

The methylene blue reaction is highly specific for low concentrations of sulphide although strong reducing agents such as SO_2 inhibit colour development, as NO_2 and O_3 can give a slight negative interference. The minimum detectable amount of sulphide is 0.008 µg/ml (American Public Health Association, 1972).

(b) Reagents

(i) 0.004M Alkaline Cadmium Hydroxide

A suspension of alkaline cadmium hydroxide was prepared by dissolving 4.3 g of $3CdSO_4.8H_2O$ in deionized water and adding it to 10ml aqueous solution containing 0.3 g NaOH. The whole solution was diluted to 1 litre with deionized water, and stored in the dark. It was shaken well before use.

(ii) **2000ppm p-aminodimethylaniline solution:** 50 mls of concentrated sulphuric acid (H_2SO_4): sp gravity 1.84 and assay 98.4% was added to 30 ml deionized water, cooled and to it 12 gm p-aminodimethylaniline dihydrochloride (analar grade). 25ml of the mixture was diluted to 1 litre with 50% H_2SO_4.

(iii) 1% of ferric chloride solution was prepared by dissolving 10gm ferric chloride hexahydrate ($FeCl_3.6H_2O$) in deionized water and made up to 1litre solution.

(iv) 40% Ammonium phosphate solution was prepared by dissolving 400 gm of 97%diammonium phosphate $(NH_4)_2HPO_4$) in deionized water and diluted to 1 litre.

(c) Standard Solutions

A 400 ppm standard stock solution Sulphide ion was prepared by dissolving 0.4 gm. of 32-38% $Na_2S.9H_2O$ in 1 litre of 0.1 M NaOH. Sodium sulphide nanohydrate ($Na_2S.9H_2O$) was weighed after washing with distilled water and drying quickly on filter paper. Diluted working standard sulphide solution (4ppm) was prepared by diluting 10 ml. of the freshly standardized stock solution to 1 litre with boiled distilled water.

(d) Experimental Procedure

A measured volume of air was aspirated through 10 mls of absorbing solution (alkaline cadmium hydroxide suspension) in an impinger at 1.5l/min for a period of 30 minutes. Excessive foaming was controlled by the addition of 5 ml. of 95% ethanol just prior to sampling.

For analysis, 1.5 ml of the p-aminodimethylaniline working solution was added to the absorbing solution in the impinger. A drop of 1% $FeCl_3.6H_2O$ solution was added and the solution transferred to a 25 ml volumetric flask. Further 1 drop or more of ammonium phosphate solution was added to discharge the yellow colour of the ferric ion and made up to volume with distilled water. It was allowed to stand for 30 minutes for the colour to develop. The colour of the methylene blue was measured at 670 nm against a reagent blank prepared with unexposed absorbing solution. A typical calibration curve (fig.4.4) had a slope of 0.1059 and an intercept of 0.04 (x – axis).

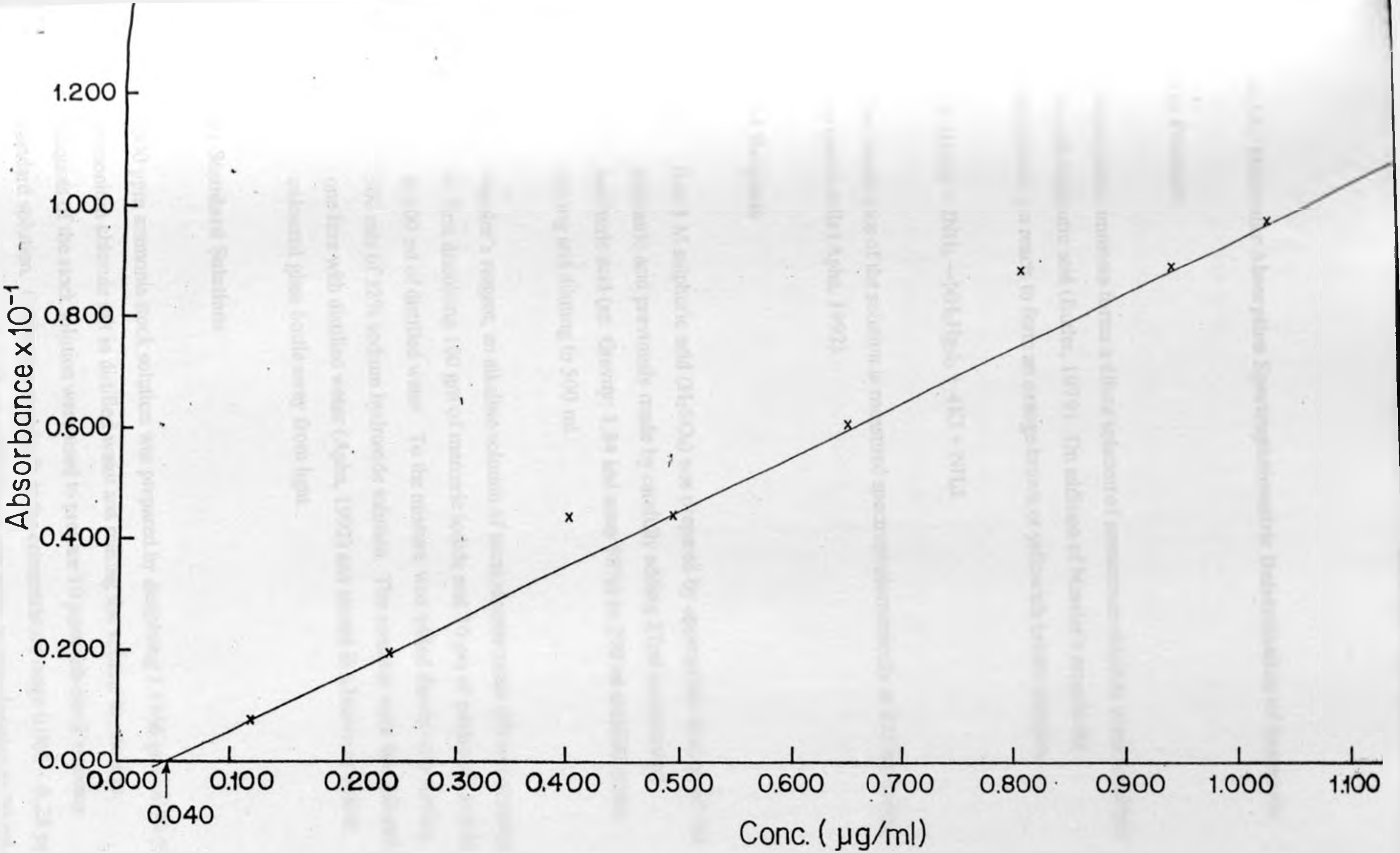


Fig. 4.4 A typical calibration graph for hydrogen sulphide.

4.3.5: Molecular Absorption Spectrophotometric Determination of Ammonia

(a) Principle

Atmospheric ammonia forms a dilute solution of ammonium sulphate when scrubbed through sulphuric acid (Butler, 1979). On addition of Nessler's reagent the ammonium ion reacts to form an orange brown or yellowish brown complex.

$2K_2[HgI_4] + 2NH_3 \rightarrow NH_2Hg_2I_3 + 4KI + NH_4I$

The absorbance of the solution is measured spectrophotometrically at 425 nm using 1 cm quartz cells (Apha, 1992).

(b) Reagents

(i) 0.003 M sulphuric acid (H_2SO_4) was prepared by appropriate dilution of 1M sulphuric acid previously made by carefully adding 27ml concentrated sulphuric acid (sp. Gravity: 1.84 and assay 98%) to 250 ml distilled water, mixing and diluting to 500 ml.

(ii) Nessler's reagent, an alkaline solution of tetraiodomercurate (II) was prepared by first dissolving 100 gm of mercuric iodide and 70 gm of potassium iodide in 400 ml of distilled water. To the mixture, was added slowly with stirring 500 mls of 32% sodium hydroxide solution. The contents were then diluted to one litre with distilled water (Apha, 1992) and stored in a brown or amber coloured glass bottle away from light.

(c) Standard Solutions

1000 ppm ammonia stock solution was prepared by dissolving 3.1566 gms of 99.5% ammonium chloride salt in distilled water and making the volume to one litre. Aliquots of the stock solution were used to prepare 10 ppm sub-stock working standard solution. Calibrating standards in the concentration range 0.005 – 0.25 ppm ammonia were prepared in 25 ml of distilled water prior to complexation in 50 ml of volumetric flasks.

(d) Experimental Procedure

To 10 ml of each sample contained in a 50 ml volumetric flask was added 25 ml distilled water and 1 ml. Nessler's reagent. The mixture was shaken and made to the mark with distilled water. Reference blank solutions containing only 0.003 M sulphuric acid (H_2SO_4) and standards were treated in the same way as the samples (Apha 1992).

The absorbance was then measured spectrophotometrically after 15 minutes using a pye unicam SP6-550 UV/VIS spectrophotometer. A typical calibration curve had a slope of 0.1722 and an intercept of 0.01 (Fig. 4.5).

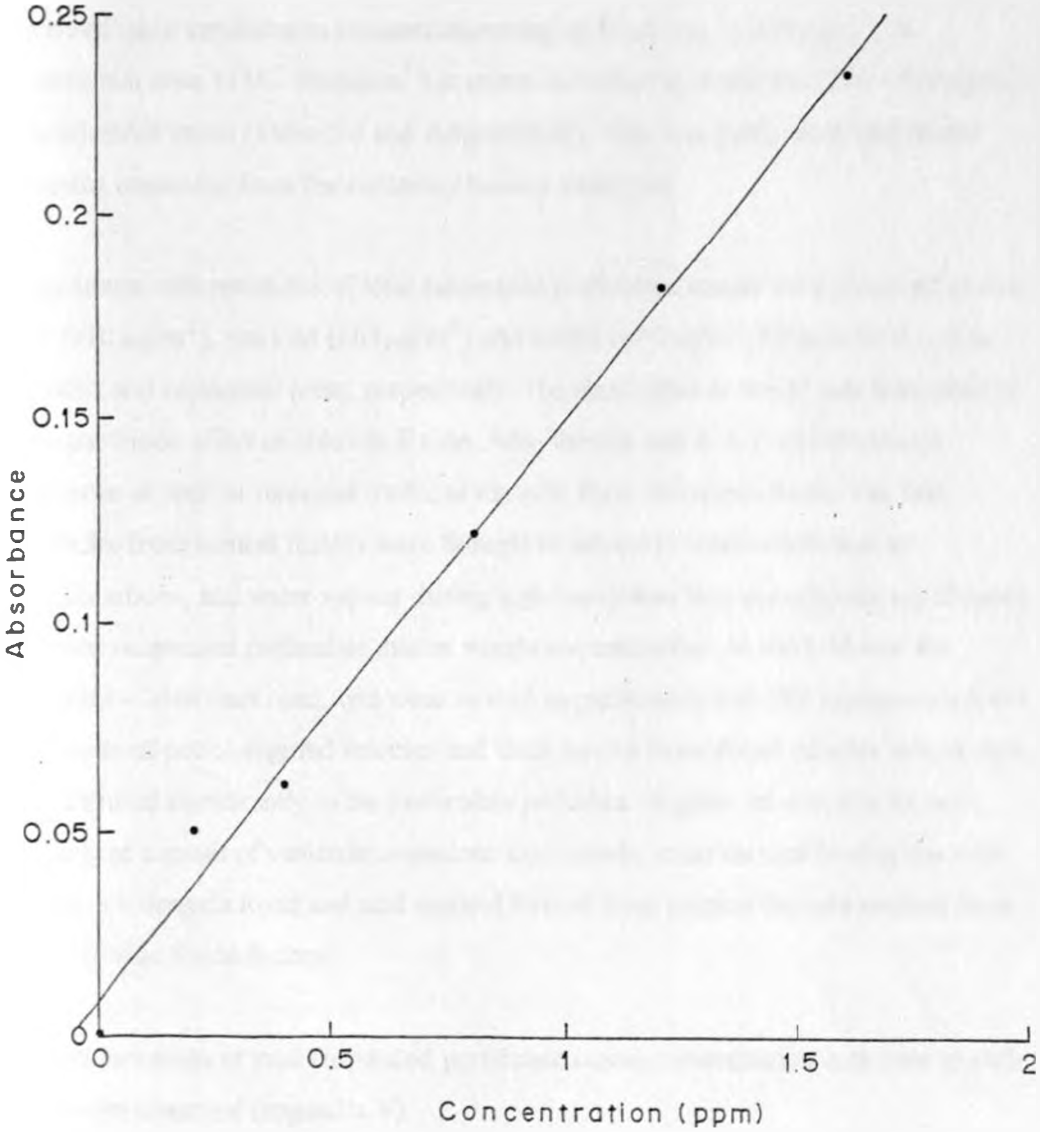


Fig. 4.5: **A typical calibration graph for ammonia.**

CHAPTER FIVE:

RESULTS, DISCUSSIONS AND CONCLUSIONS.

5.1: Total suspended particulate matter (TSP)

Levels of total suspended particulate matter measured at Athi-River area of study, showed wide variations in concentration ranging from (46.7 - 456µg/m^3) at residential area, (116 - 663µg/m^3) at urban commercial center and (244 - 910µg/m^3) at industrial zones (Table 5.2 and Appendix III). This was partly attributed to the varying emissions from the randomly located industries.

Maximum concentrations of total suspended particulate matter were observed at site IC (910 µg/m^3), site UM (663µg/m^3) and siteR1 (456ug/m^3) for industrial, urban centers and residential areas, respectively. The peak value at site IC was attributed to the combined effect of chloride Exide, Athi- threads and E.A Portland cement factories as well as vehicular traffic at the Athi River-Kitengela Road. The fine particles from cement factory were thought to adhere to other substances as hydrocarbons, and water vapour during high humidities thus contributing significantly to total suspended particulate matter weight concentration. At site UM near the Nairobi – Mombasa road, tyre wear as well as particulate lead (Pb) compounds from exhausts of petrol-engined vehicles and black smoke from diesel vehicles would have contributed significantly to the particulate pollution. Highest value at site R1 was mainly as a result of vehicular emissions from nearby murram road joining the Athi-River – Kitengela Road and acid aerosol formed from sulphur dioxide emitted from the chloride Exide factory.

Large variations in total suspended particulate matter concentration with time at each site were observed (appendix V).
Table 5.1 shows the diurnal pattern of the mean concentration determined over the whole sampling period.

Table 5:1 Diurnal mean concentration ($\pm$ SGD $\mu g/m^3$) cycles of total suspended particulate matter (TSP) and sulphur dioxide (SO_2) with temperature and relative humidity changes in Athi- River urban commercial center.

Time	Sampling height (m)	TSP conc. ±2.37 ($\mu g/m^3$)	SO_2 conc. ±1.81 ($\mu g/m^3$)	R.H. (%)	Temp(^0C)
Morning	2	111	23.33	38	24.5 – 28
(0900hr-1200hr	2	132	85.45	65	24 – 26
	2	189	93.34	64	18.5 – 21
	2	244	133.33	<36	27 – 29
	2	300	183.33	34	24 – 25.5
	2	497	143.00	-	26.5
Lunch	2	46.7	65.14	47	25.5 – 27
(1201hr – 1400hr)	2	93.0	43.20	33	26 – 28
	2	116	77	62	19 – 20.5
	2	222	38.89	36	25 – 26
	2	393	52.20	37	30.0
	2	348	166.67	41	25.5 – 28
	2	883	586	48	26.0
Afternoon	2	133	81.00	44	28.5
(1401 – 1700hr	2	178	92.37	42	24.0
	2	277	116.67	34	25-27
	2	592	154.00	59	20.5 – 22
	2	781	186.00	57	19.0

The total suspended particulate matter concentration roughly increased with increase in temperature but decreased with decrease in relative humidity (Fig.5.1).

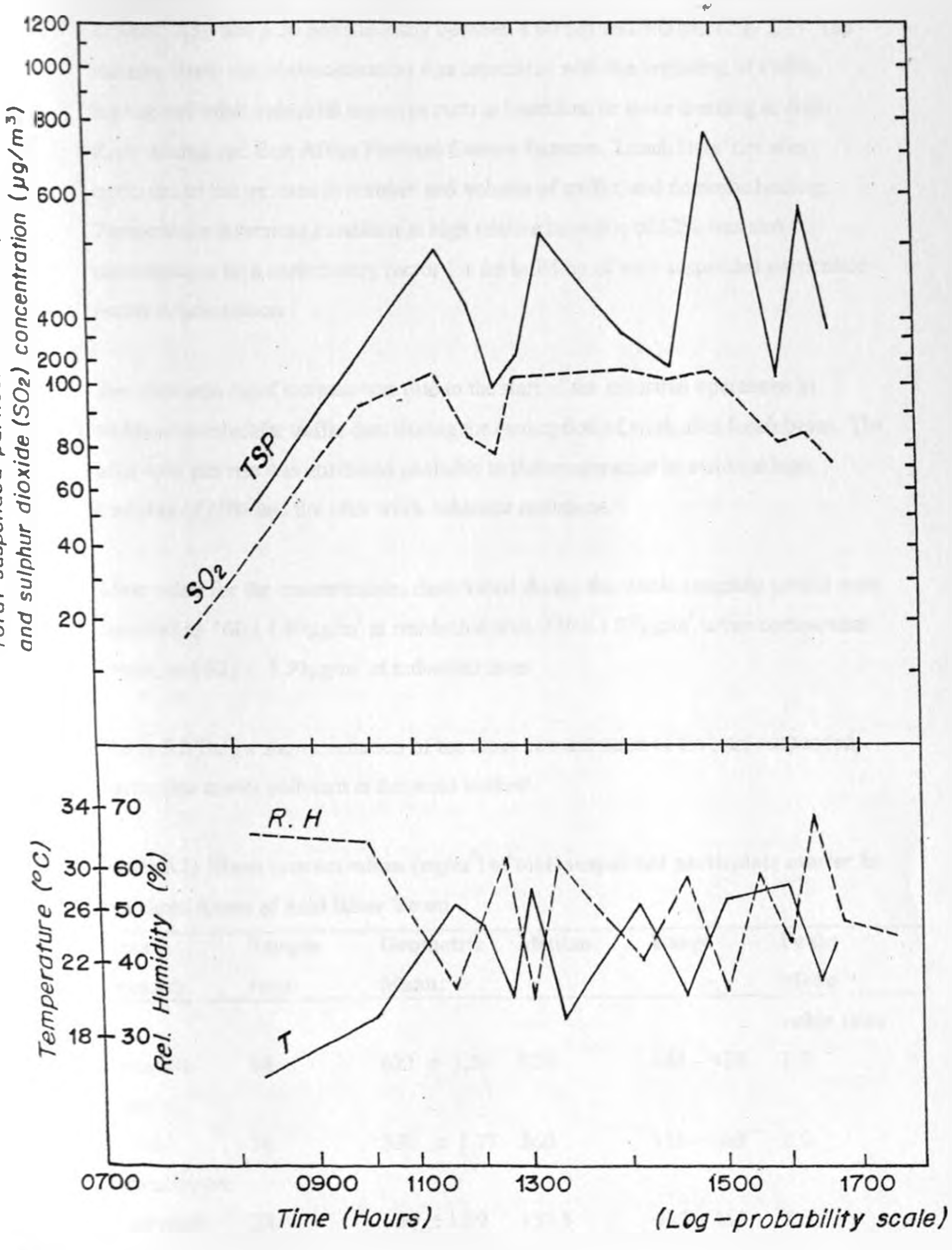


Fig. 5.1 Variation of total suspended particulate matter (TSP) and Sulphur dioxide (SO$_2$ pollutants with meteorological variables (Athi-River urban commercial centre)

Concentrations rose quite abruptly between 9.00 am and 12 noon, 1.00 pm and 2.00pm; 2.30 and 3.30 pm and lastly between 4.00 pm and 5.00pm (Fig. 5.1). The morning sharp rise in concentration was associated with the beginning of traffic, heating and other industrial activities such as limestone or stone crushing at Athi-River mining and East Africa Portland Cement factories. Lunch Hour rise was attributed to the increase in number and volume of traffic, and domestic heating. Temperature inversions condition at high relative humidity of 62% was also considered to be a contributory factor for the build up of total suspended particulate matter concentration.

The afternoon rapid increase was due to the start of the industrial operations in addition to vehicular traffic dust during the resumption of work after lunch break. The after 4.00 pm rise was attributed probably to the temperature inversion at high humidity of 69% and the after work vehicular emissions.

Mean value for the concentrations determined during the whole sampling period were recorded as 160± 1.89$\mu g/m^3$ at residential area, 330± 1.77$\mu g/m^3$ urban commercial center, and 621± 1.30$\mu g/m^3$ at industrial zone.

Table 5.2 Below shows variation of the mean concentration of the total suspended particulate matter pollutant in the areas studied.

Table 5.2: Mean concentration (ug/m^3) of total suspended particulate matter in the three Areas of Athi River Town

Area category	Sample runs:	Geometric Mean:	Median	Range	Peak: Mean value ratio
Industrial Zone	34	621 ± 1.30	620	244 – 910	1.5
Urban comm..center	36	330 ± 1.77	360	116 – 663	2.0
Residential area	28	160 ± 1.89	159.5	46.7 - 456	2.9

The geometric mean value increased by factors of 2.06 – 3.88 with increase in distance away from the residential area, an indication of industrial zone being a potential source of total suspended particulates (table 5.2).
The ratios: peak values to mean concentration were found to be 2.9, 2.0, and 1.5 for residential, urban commercial center and industrial area respectively. These ratio values correlated well with increase in range of sample concentration distribution and averaging time (Montgomery and Coleman, 1975). The residential area showed the highest peak: mean value ratio as compared to urban and industrial centers (Table 5.2; appendix III). This was attributed to the large fluctuations in total suspended particulates concentration as it was influenced by the locations of the pollution sources and the prevailing wind directions. Site R3 was favorably located in the southeasterly upwind direction whereas sites R1 and R2 were in the northwesterly downwind direction in the relation to E.A Portland cement, Chloride Exide and Athi-river Mining factories. Consequently sites in downwind direction were prone to be affected more by the pollutant than those in the upwind position.

The frequency distribution of the total suspended particulate matter concentration showed that 50% of the sample concentrations measured in each area category corresponded to the geometric mean (Fig: 5.2). The steepest portion of the frequency distribution curve was noted to correspond to concentration interval within which falls high percentage of the total data values of the daily hourly average total suspended particulate matter concentration. It is the concentration interval within which also falls the mean of the data values, and a slope of the line at 50% value (mean) gives the standard geometric deviation as an indication of the distribution of the levels of total suspended particulate matter pollutant.
Similar relationship was noted with the 50th percentiles of the analyzed data (Fig. 5.3 – 5.4). The 50th percentile signifies that half of the data values of\ the daily hourly average total suspended particulate matter concentrations measured at Industrial zone, Urban Commercial Center and residential area were lower than 621, 330 and 160μg/m^3 respectively and half more. The slope of the line gives standard geometric deviation. Representation of the data in this form as log- probability curves can conveniently be used for assessing the need for process control in the implicated factories for total suspended particulate matter pollution reduction. Tables 5.3, 5.4 and 5.5 summarize the frequency distribution of total suspended particulate matter concentrations in Athi-River town.

Table 5.3 Cumulative frequency distribution[a] of total suspended particulate matter (TSP) and Sulphur dioxide (SO_2) observations in Athi-river industrial zone.

	Date	Sample Run No.	Specified concentration (μg/m3)	No. of sample concentrations less than or equal to the specified concentration	Cumulative frequency (%).
TSP	09/05/95	TSP001	446	6	17.65
(n=30)*:	04/05/95	TSP004	615	11	41.20
	25/07/95	TSP058	756	16	64.70
	25/07/95	TSP066	842	18	82.40
	11/09/95	TSP057	883	25	94.10
	25/07/95	TSP060	910	30	99.99
SO2	23/05/95	SD014	61	3	7.7
(n=39)*:	11/09/95	SD075	68.16	7	17.9
	08/06/95	SD041	78.00	13	33.3
	30/05/95	SD030	108.00	18	46.2
	19/05/95	SD010	115.00	20	51.3
	30/05/95	SD027	143.00	26	66.7
	25/07/95	SD067	186.00	34	87.2
	19/05/95	SD012	223.00	39	99.99

SD – Sulphur dioxide

*- Number in parenthesis indicates the number of samples from all the dates shown.

[a] the cumulative frequency distribution plots as a straight line on log – probability axes (fig 5.3) as the concentrations of the total suspended particulate matter and sulphur Dioxide pollutants show log-normal frequency distribution, i.e. the logarithms of the concentrations are distributed normally (Pollack, 1975). Similar relationship applies to observations in Table 5.4 (fig .5.4) and table 5.5 (fig.5.5)

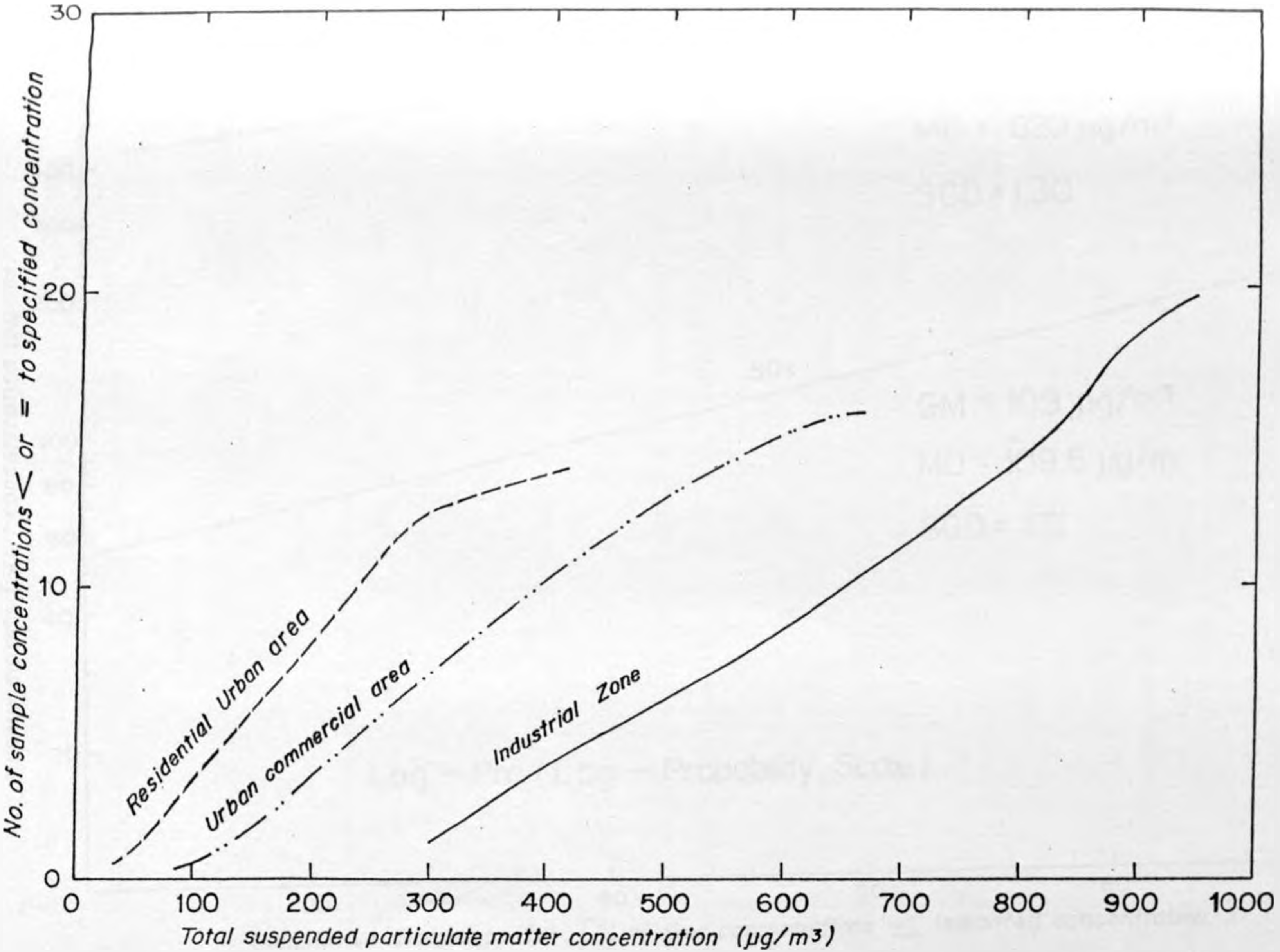


Fig. 5.2 Cumulative frequency distribution of concentrations of suspended particulate matter in the three (3) area categories of Athi-River town

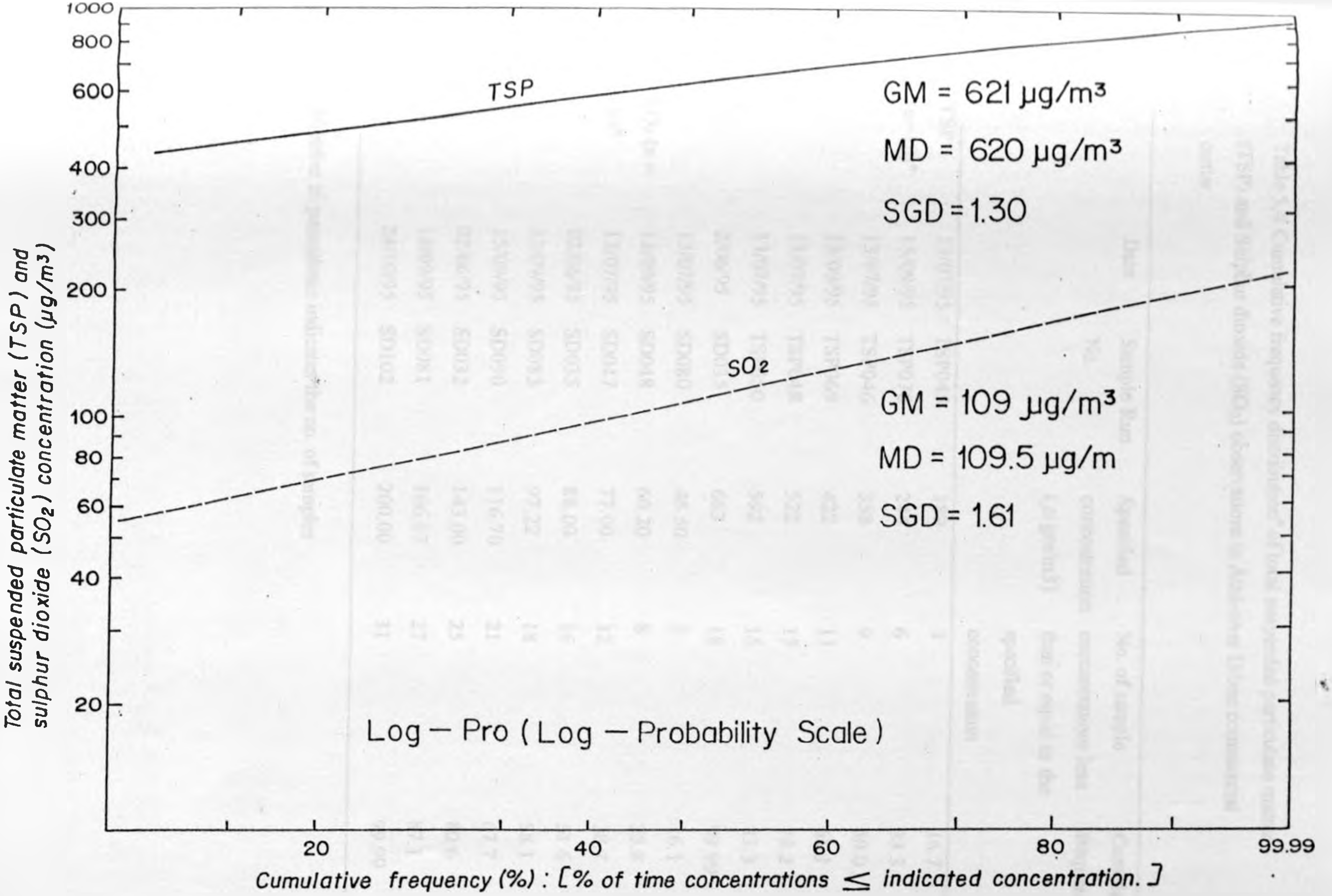


Fig. 5.3 Cumulative frequency distributions of total suspended particulate matter (TSP) and sulphur dioxide (SO_2) observations in Athi–River industrial zone.

Table 5.4 Cumulative frequency distribution[a] of total suspended particulate matter (TSP) and Sulphur dioxide (SO_2) observations in Athi-river Urban commercial center.

	Date	Sample Run No.	Specified concentration (μ gm/m3)	No. of sample concentrations less than or equal to the specified concentration	Cumulative frequency (%)
TSP (n=18)*:	13/07/95	TSP045	189	3	16.7
	15/09/95	TSP078	244	6	33.3
	13/07/95	TSP046	358	9	50.0
	13/09/95	TSP069	422	11	61.1
	13/07/95	TSP048	522	13	72.2
	13/07/95	TSP050	592	15	83.3
	2/06/95	SD035	663	18	99.99
	13/07/95	SD080	46.50	5	16.1
SO_2 (n = 39)*:	13/09/95	SD048	60.20	8	25.8
	13/07/95	SD047	77.00	12	38.7
	02/06/95	SD035	88.00	16	51.6
	13/09/95	SD083	97.22	18	58.1
	15/09/95	SD090	116.70	21	67.7
	02/06/95	SD032	143.00	25	80.6
	13/09/95	SD081	166.67	27	87.1
	24/10/95	SD102	200.00	31	99.99

* Number in parenthesis indicates the no. of samples

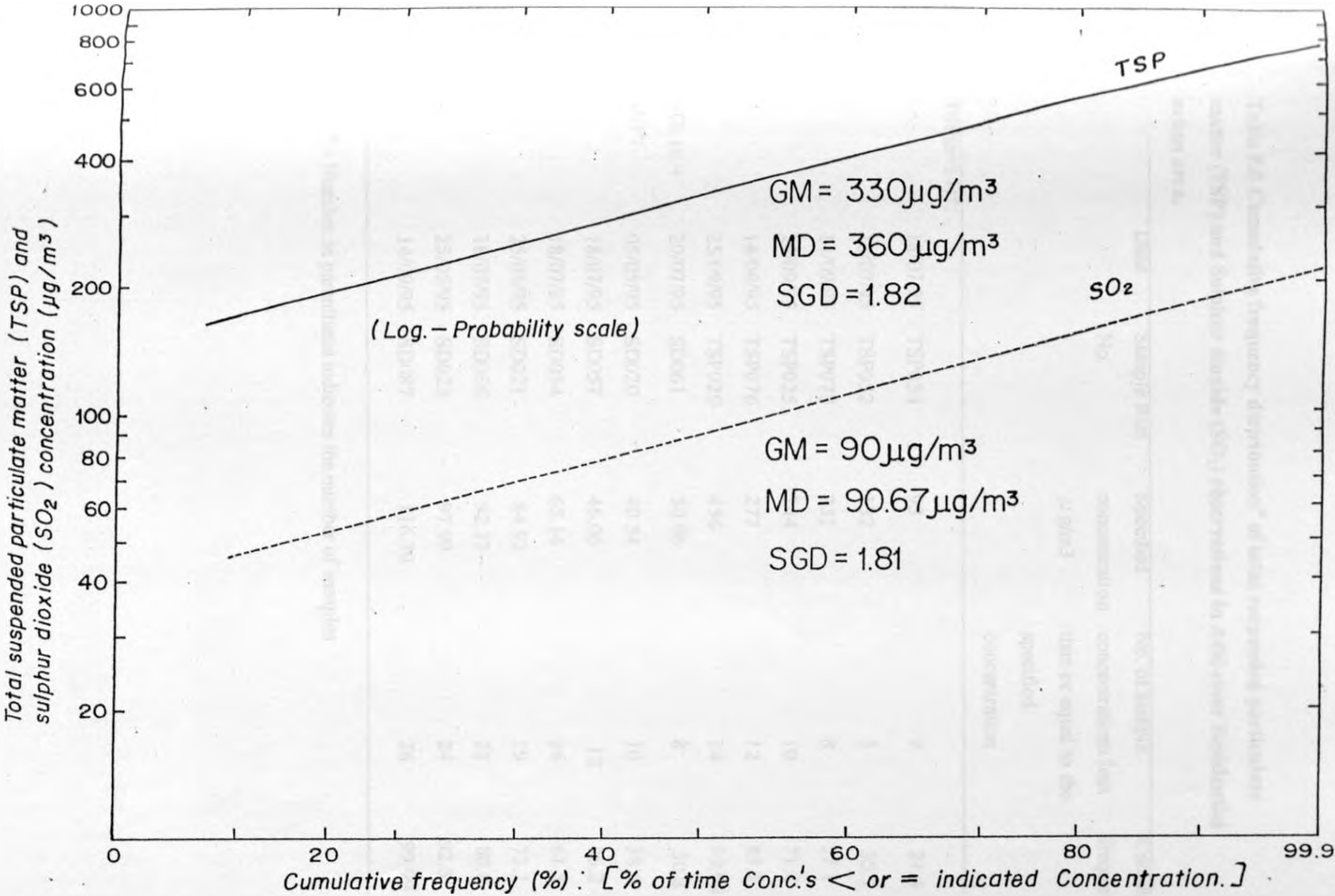


Fig. 5.4 Cumulative frequency distributions of total suspended particulate matter (TSP) and sulphur dioxide [illegible] observations in Athi-River urban commercial area.

Table 5.5 Cumulative frequency distribution^a of total suspended particulate matter (TSP) and Sulphur dioxide (SO_2) observations in Athi-river Residential urban area.

	Date	Sample Run No.	Specified concentration μg/m3	No. of sample concentrations less than or equal to the specified concentration	Cumulative frequency (%)
TSP(n=14)*:					
	18/07/95	TSP054	93	3	21.4
	18/07/95	TSP052	132	5	35.7
	14/09/95	TSP073	231	8	57.1
	25/09/95	TSP025	244	10	71.4
	14/09/95	TSP076	277	12	85.7
	25/09/95	TSP020	456	14	99.99
SO_2 (n = 26)*:	20/07/95	SD061	30.96	8	30.8
	05/05/95	SD020	40.34	10	38.5
	18/07/95	SD057	46.06	12	46.2
	18/07/95	SD054	65.14	16	61.5
	25/05/95	SD021	84.92	19	73.1
	18/07/95	SD056	92.37	21	80.8
	25/05/95	SD023	97.99	24	92.3
	14/09/95	SD087	116.70	26	99.99

* - Number in parenthesis indicates the number of samples

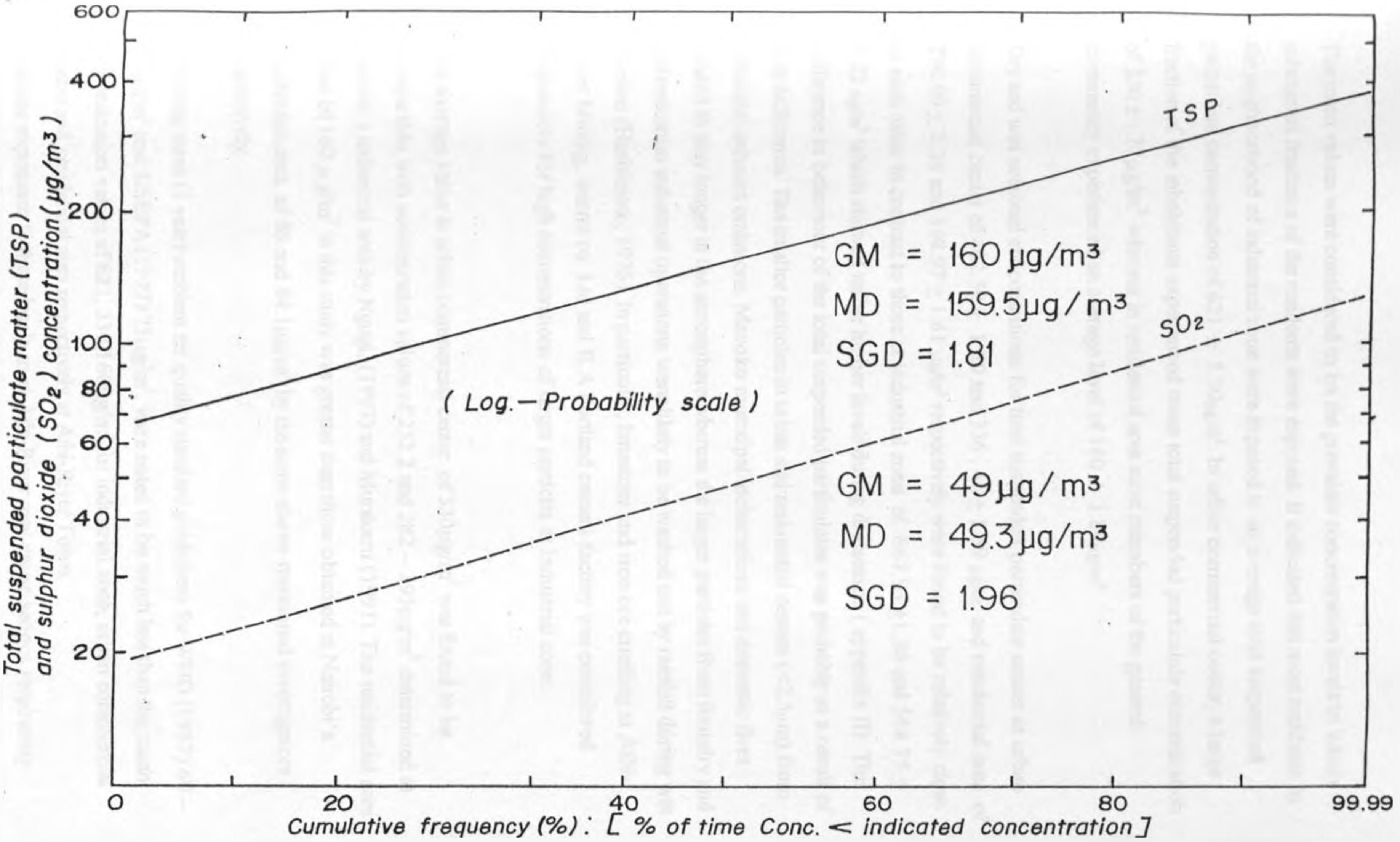


Fig. 5.5 Cumulative frequency distributions of Total suspended particulate matter (TSP) and sulphur dioxide (SO_2) observations in Athi–River residential urban area.

The mean values were considered to be the prevalent concentration levels to which substantial fractions of the residents were exposed. It indicated that most residents in the neighborhood of industrial zone were exposed to an average total suspended particulate concentration of 621 ± 1.30$\mu g/m^3$. In urban commercial center, a large fraction of the inhabitants experienced mean total suspended particulate concentration of 330 ± 1.77$\mu g/m^3$ whereas in residential area most members of the general community experienced an average level of 160 ± 1.89$\mu g/m^3$.

Dry and wet seasonal concentrations for total suspended particulate matter at urban commercial center of 402.50 $\pm$ 1.39 and 336 . 46 $\pm$ 1.69 $\mu g/m^3$ and residential area of 290.00 $\pm$ 2.36 and 198.97 $\pm$ 1.81 $\mu g/m^3$ respectively were found to be relatively close to each other in contrast to those at industrial zone of 667.93 $\pm$1.30 and 544.75 $\pm$ 1.22 $\mu g/m^3$ which showed rather higher levels during dry season (appendix II). This difference in behaviour of the total suspended particulates was probably as a result of size difference. The smaller particles in urban and residential centers ($<2.5\mu m$) from vehicular exhaust emissions, Mavoko municipal incinerations and domestic fires tended to stay longer in the atmosphere whereas the larger particles from foundry and pulverization industrial operations were likely to be washed out by rainfall during wet seasons (Hashimoto, 1976). In particular, limestone and iron ore crushing at Athi-River Mining, werrot co. Ltd and E.A Portland cement factory was considered responsible for high concentrations of larger particles at industrial zone.

The average value at urban commercial center of 330$\mu g/m^3$ was found to be comparable with concentration values of 252.2 and 282 – 393$\mu g/m^3$ determined at Nairobi's industrial area by Ngugi, (1993) and Murakaru (1991). The residential area value of 160 $\mu g/m^3$ in this study was greater than those obtained at Nairobi's residential area of 80 and 84.1$\mu g/m^3$ by the same above-mentioned investigators respectively.

The long term (1 year) ambient air quality standard guidelines for WHO (1987) 60 – 90$\mu g/m^3$ and USEPA (1977) 75$\mu g/m^3$, were noted to be much less than the mean concentration values of 621, 330,160$\mu g/m^3$ for industrial zone, urban commercial centre and residential area respectively at Athi-River Town.
Chronic exposures to these levels as at Athi-River may cause serious respiratory problems to industrial workers and the general community. Similar exposure to

vegetation may lead to the impairment of photosynthesis and transpiration physiological processes and consequently damage or kill the plant. The concentration of the total suspended particulate matter found in industrial and urban centers were also high enough to pose short-term health problems to the workers.

5.2 Sulphur dioxide (SO_2)

Levels of sulphur dioxide showed great variations between sites with concentrations of 12.0 – 116$\mu g/m^3$ at residential area, 38.22 – 200$\mu g/m^3$ at urban commercial center and 60 – 223$\mu g/m^3$ at industrial zone (table 5.6). Highest values were recorded at sites favorably located close to and in downwind direction in relation to point sources such as the Chloride Exide, Bawazir/Barbar tanneries and the Fishmeal factories. In particular, the exceptionally high industrial concentration of 571, 787, 910, 586$\mu g/m^3$ at site IB correlated with the close proximity of the Exide Chloride metal smelter battery-manufacturing factory (appendix VI). These concentrations were found to be highly localized and intermittent hence not representative of the whole industrial environment.

The daily diurnal variations in concentration with time of Sulphur dioxide pollutant followed the same trend as the total suspended particulate matter (Fig 5.1). Concentration variations were noted to correlate with temperature and relative humidity. Peak values were observed in the morning, at lunchtime and in the afternoon. This similarity in behaviour between total suspended particulates and sulphur dioxide was attributed to the same mechanism of production, most probably of anthrogenic origin. Table 5.1 shows the diurnal pattern of sulphur dioxide concentration during the period of study.

Concentration rose gradually between 9.00am and 11.30am reaching a maximum of 116.67$\mu g/m^3$. The concentration increase was associated with the following meteorological conditions: variable low wind speeds, increasing temperatures (max: 28^0c) and decreasing relative humidity which reached a minimum of 37% (Fig 5.1). Between 1.00pm and 2.30pm the concentration remained fairly constant. This was attributed to the period of less activity during lunch break when most industrial operations close temporarily. During this time interval, the temperature and relative humidity conditions were ideal for the catalytic oxidation of sulphur dioxide to form sulphur trioxide (SO_3) which in turn forms the acid aerosol particulates.

A slight increase in concentration (120 – 160μg/m^3) between 2.30 pm and 3.00pm was associated with the start of industrial operations after lunch break (figure 5.1). The concentration then dropped rather rapidly to 80μg/m^3 at around the time of closing down some industrial operations in the evening, an indication of minimal industrial activity at night.

The averages of Sulphur dioxide concentrations for the dry and wet seasons were 125.12 ± 1.74 and 61.70 ± 1.63 μg/m^3 for industrial zone, 123.94 ± 1.58 and 90. 40 ± 1.35 μg/m^3 for urban commercial center, and 72.62 ± 1.50 and 69.03 ± 1.42 μg/m^3 for residential area respectively (Appendix II). Greater reductions in sulphur dioxide concentration were observed at industrial zone from 125.12 – 61.70μg/m^3 and urban center from 123.94 – 90.40μg/m^3 as compared with residential area. This was attributed to the high concentrations of trace metal particulates (Mn, Fe, Cu, and Pb) in industrial zone and urban commercial center (Table 5.7) which catalytically accelerated the oxidation of sulphur dioxide to sulphur trioxide, which in turn formed the potential corrosive acid aerosol in the presence of high humidities or rainfall. Under these high humidity conditions, an increased corrosive effect on corrugated iron sheets especially at E.A Portland cement junior staff quarters was noticed as compared with dry season.

Complaints of persistent coughing, eye and throat irritations among the residents during morning, evening and night time hours were probably associated with high relative humidity contribution in the formation of acid aerosol.

The industrial and urban centers seasonal concentration distributions were found to be comparable with those observed by Kollikho (1995) at Nairobi's industrial area of 14.2 – 157.8μg/m^3 for October-November wet season, and 15.5-175.5μg/m^3 for June – September dry season.

Levels of sulphur dioxide pollutant determined at Athi-river area of study showed geometric mean concentration values of 109.00, 90.00,49.00μg/m^3 for industrial zone, urban commercial center and residential areas respectively (table 5.6).

Table 5.6 Mean concentration (± SGDμg/m^3) of sulphur dioxide pollutant in the three area categories of Athi-River Town.

Area category	Sample runs	Geometric mean ± SGD	Median	Range	Peak: Mean value ratio
Industrial zone	48	109.0 ± 1.61	109.50	60 – 223	2.0
Urban commercial centre	31	90.00 ± 1.81	90.67	38.22 – 200	2.2
Residential area	25	49.00 ± 1.96	49.30	12 - 116	2.4

SGD: Standard Geometric Deviation

The mean values were noted to be high at industrial area as compared to urban commercial centre or residential area. This indicated that industrial operations were significant sources of sulphur dioxide pollutant as compared with vehicular emissions common at urban commercial centre.

The average concentration value in each area category was found to correspond to 50% of the sample concentrations measured (Fig 5.6) or 50th percentile of the data represented in a frequency distribution curve (Figs 5.3 – 5.5). The 50th percentile signifies that half of the data values of the daily half-hourly average Sulphur dioxide concentration were lower than geometric mean and half more. 84th percentile signifies that 84% of the data values were lower than 175, 165 and 96 μg/m^3 of sulphur dioxide measured at Industrial area, urban commercial centre and residential area respectively (fig.5.3 – 5.5). Representation of results in this form as log – normal frequency distribution curves, can conveniently be used for assessing the need for process control at the implicated factories for sulphur dioxide pollution reduction. The 50% values or 50th percentile levels were presumed to be the prevalent concentrations which most of the residents were vulnerable to be exposed to.

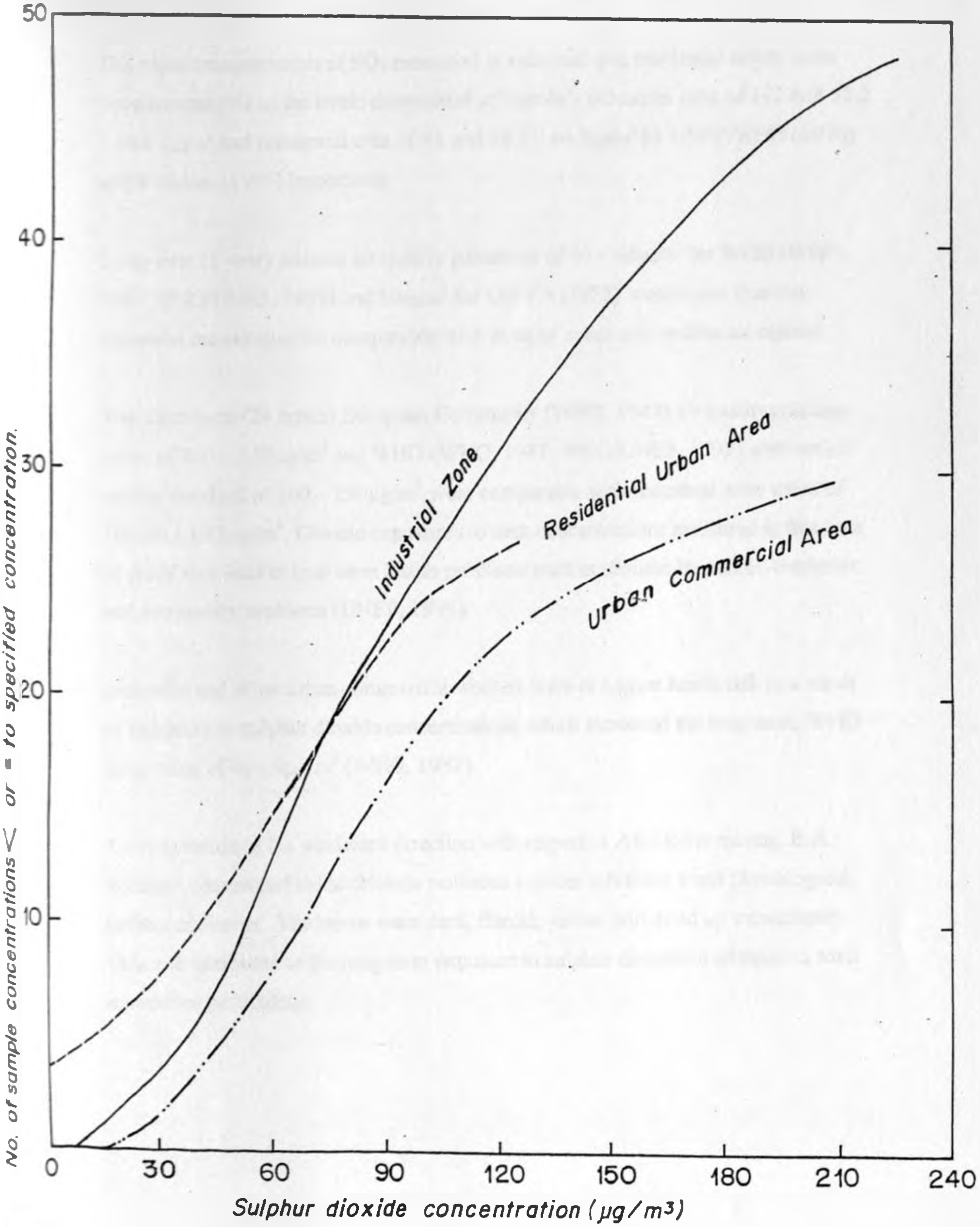


Fig. 5.6 Cumulative frequency distribution of concentrations of sulphur dioxide (SO_2) in the three (3) area categories of Athi-River town.

The mean concentrations of SO_2 measured at industrial and residential urban areas were comparable to the levels determined at Nairobi's industrial zone of 142 and 57.2 – 143.2μg/m^3 and residential area of 41 and 18.2 – 64.3μg/m^3 by UNEP/WHO (1978) and Kollikho (1995) respectively.

Long-term (1 year) ambient air quality guidelines of 40 – 60μg/m^3 for WHO (WHO, 1987;WHO/UNEP, 1992) and 80μg/m^3 for USEPA (1977) were lower than the industrial mean value but comparable with those of urban and residential centers.

The short-term (24 hours) European Community (WHO, 1987) air quality guideline value of 100 – 150μg/m^3 and WHO (WHO, 1987; WHO/UNEP, 1992) ambient air quality standard of 100 – 150μg/m^3 were comparable with industrial zone value of 109.00± 1.61 μg/m^3. Chronic exposures to such concentrations measured in this area of study may lead to long-term health problems such as chronic bronchitis, tracheitis and respiratory problems (UNEP, 1991).

Industrial and other urban commercial workers were at a great health risk as a result of exposure to sulphur dioxide concentrations, which exceeded the long-term, WHO limit value of 40-60μg/m^3 (WHO, 1987).

The vegetation in the windward direction with respect to Athi-River mining, E.A Portland cement and exide chloride pollution sources exhibited some physiological defects on leaves. The leaves were dark, flaccid, yellow and dried up immediately. This was attributed to the long-term exposure to sulphur dioxide in addition to total suspended particulates.

5.3 Metallic Elements

Levels of selected metallic elements were measured in Athi River Town during the whole period of study. Table 5.7 below shows the mean concentration distribution of the various metals considered.

Table 5.7 Mean (geometric mean) Concentration (± SGDμg/m^3) values of metallic elements in airborne particulate matter sampled in the three areas of Athi-River Town.

Area category	Sample runs	Zn	Cd	Pb	Mn	Cu	Fe
Industrial comm. Center	34	220 ± 2.27	3.6 ± 2.06	9.7 ± 2.09	3.9 ± 2.91	6.7 ± 2.81	129 ± 1.79
Urban comm. Center	17	229 ± 2.12	3.4 ± 2.24	2.7 ± 2.06	4.3 ± 1.89	3.1 ± 1.58	56.5 ± 1.80
Residential urban center	15	156 ± 3.34	2.8 ± 2.00	1.5 ± 1.11	4.0 ± 2.11	4.9 ± 2.08	59.4 ± 2.48

TSP: Total Suspended Particulate matter

Zn: Zinc; Pb: Lead; Cd: cadmium; Fe: Iron; Mn: Manganese; Cu: Copper

SGD: Standard Geometric Deviation.

Variations in concentration with time were noted from site to site (Appendix V). This was attributed to the varying industrial emissions and/or the close proximity of some sites to commercial town center where traffic congestion was noted.

5.3.1 Lead (Pb)

Varying lead levels measured at different sites ranged from of 1.01 – 15.2μg/m^3 at industrial zone; of 0.50 – 12.89μg/m^3 at urban commercial center and 0.89 – 2.0μg/m^3 at residential area (Appendix V).

Peak values were recorded at site IB of 15.2µg/m^3, site UL of 12.89µg/m^3 and site RI of 2.0µg/m^3 in industrial zone, urban commercial center and residential area respectively. The industrial peak value was attributed to the close proximity of the lead smelter factory for battery manufacturing whereas that for urban center was associated with the nearby bus station and a garage at mavoko shopping center. Vehicle idling or near idling or sudden breaking was very common in this areas, consequently the likelihood of high lead content from exhaust emissions.

The high value at residential area was attributed to the location of the sampling site (RI) in the downwind direction with respect to the Chloride exide factory.

Mean concentration values for the whole sampling period were 9.7µg/m^3 for industrial zone, 2.7µg/m^3 for urban commercial center and 1.50µg/m^3 for residential area (Table 5.7). The mean values decreased with increase in distance away from industrial area towards urban and residential centers respectively. This evidently indicated that the industrial operations were contributory factors as well as vehicular emissions to increased lead (Pb) pollution at urban commercial center.

Lead levels for precipitation in urban commercial center and industrial area of Athi River Town were higher than that determined at residential area (Appendix IV). This further confirmed the higher atmospheric lead burden in these areas as compared with residential places where there was less industrial activities.

The dry season (June – October) ambient air concentration of lead was minimally reduced during the wet season (April – May) and November – December (Appendix II). This behavior of lead was attributed to its existence in small particules (<2µm) such as halogenides which were probably least reduced in quantity by rainfall washout (Hashimoto, 1976; Munn and Bolin, 1971).

The average values were higher than those determined in Nairobi at industrial area of 0.738 – 0.782µg/m^3 by Murakaru (1991) but less than the highway values of 21.9 – 355.9µg/m^3 observed by Oketch (1994) in the same urban environment.

Long term WHO standard limit of 0.5 – 1.0μg/m^3 (WHO, 1987) and European air quality guideline of 0.5 – 1.0 μg/m^3 were considerably lower than the mean values of industrial and urban regions but marginally less than the average value of the residential area. Adverse long-term health effects such as central nervous system disorders, Anaemia, Kidney and heart diseases were likely to be experienced by the occupationally exposed workers.

The general community in this area of study was also at risk as a result of exposure to Lead concentrations which exceeded the long-term WHO limit value of 0.5 – 1.0μg/m^3 (WHO, 1987)

5.3.2 Cadmium (Cd)

Cadmium was detected in few samples collected at industrial zone and residential area sites but in all samples from urban commercial center (Appendix V). The measured concentrations ranged from 0.59 – 11.11μg/m^3 at industrial zone, 0.66 –11.78μg/m^3 at urban commercial center and 0.56 – 9.78μg/m^3 at residential area. The urban commercial center showed the highest peak value of 11.78μg/m^3 at site UK, which implicated incineration of rubber tyres ans plastic containers in addition to vehicle tyres wear as significant sources.

The mean concentration values at industrial zone of 3.6μg/m^3 urban commercial center of 3.4μg/m^3 and residential area of 2.8μg/m^3 (Table 5.7) were much higher than the levels reported in member states of the European community 0.0001-0.001, 0.001-0.05 and 0.001 –0.10μg/m^3 for remote, urban and industrial areas (WHO, 1987) respectively.

The average concentrations for Cadmium at urban and industrial centers showed some uniformity in their values. This was attributed to fairly uniform production rates of the cadmium pollutant from the sources involved in the two area categories of study.

The recorded mean concentrations in the three area categories were also noted to be much higher than the WHO long-term limit of 0.01- 0.02 μg/m^3 (WHO, 1987). This was a clear indication that adverse long term human health problems such as gastroenteritis, renal dysfunction and hypertension were bound to occur among the occupationally exposed workers as well as the general community.

5.3.3 Zinc (Zn)

Zinc was detected in all samples collected from the areas of study during the whole sampling period. The levels ranged from 79.3 – 597μg/m^3 at industrial zone, 52 – 550μg/m^3 at urban commercial center, and 12 – 498μg/m^3 at residential area (Appendix V). Concentration variations between sites were much greater at the residential area, and consequently gave rise to a wide range of sample concentration distribution of 12 – 498μg/m^3.

Levels roughly increased with total suspended particulate matter and temperature but with decrease in relative humidity (Appendix V). Highest levels were recorded around midday when temperatures were high and relative humidities low (Fig. 5.1). Mean value of 220, 229 and 156μg/m^3 for industrial zone, urban commercial center and residential area respectively (Table 5.7) were noted to be higher than the Germany long-term (1 year) air quality standard limit of 50μg/m^3 but lower than the short-term (30 min) value of 500μg/m^3 (VDI-Kommission Reinhalting der Luft, 1973). These levels were also above the short term American ambient air standards for zinc oxide and zinc acetate of 4.8 and 6.0μg/m^3 respectively (Calabrese and Kenyon 1991).

Exposure to similar levels found at Athi river town may cause human health problems such as respiratory diseases, pulmonary fibrosis, vomiting and lethargy (Braunwald, 1987).

Variations in concentration with seasonal changes were observed at industrial zone as well as at urban and residential centers. Average values of 213.58 ± 1.65 and 290.31 ± 1.82 μg/m^3 for wet and dry seasons respectively in industrial zone were observed. In urban commercial center, the mean values for wet and dry seasons were 183. 50 ± 2.80 and 243.23 ± 1.88 μg/m^3 whereas for residential area were 205 ± 1.63 and 270.63 ± 2.07 μg/m^3 respectively (Appendix II).

In particular, the great quantities of large particulates released from East African Portland cement and Athi-River mining industrial operations were likely to be reduced by rainfall during the wet season (Hashimoto, 1976; Munn & Bolin, 1971).

The industrial workers as well as the general community in areas around the Athi-River mining and Werrot Company Limited, and the E.A. Portland Cement Factory, were vulnerable to experience adverse health problems such as dehydration of lungs, vomiting, lethargy and respiratory diseases as a result of high zinc concentrations which exceeded the Germany long-term (1year) air quality limit of 50μg/m^3 (VDI – Kommission Reinhalting der luft, 1973).

5.3.4 Manganese

Manganese was detected in almost all samples collected and analyzed, with concentrations ranging from 0.93 – 26μg/m^3, 1.3 – 8.67μg/m^3, and 0.5 – 10.9μg/m^3 for industrial zone, urban commercial center and residential area respectively. Peak values of 26μg/m^3 (site IB); 8.67μg/m^3 (site UK) and 10.9μg/m^3 (site R2) in industrial, urban and residential centers respectively were observed (Appendix V). The relatively higher peak levels measured at residential area (R2) than at urban center (UK) was attributed to the location of the site R2 in downwind direction (northwesterly) with respect to the nearby municipal dumping site for industrial and domestic refuse.

The solid wastes were discovered to consist of metal cans among other solids, which on incineration can emit manganese dust or fumes together with other metals (Browning, 1969).

Variations in concentration of Manganese for wet and dry seasons respectively were recorded as 3.93 ± 2.23 and 7.96 ± 2.27 μg/m^3 for industrial zone, 3.31 ± 1.69 and 4.27 ±1.64μg/m^3 for urban commercial centre, and 3.72 ±1.90 and 4.56± 2.92 μg/m^3 for residential area (Appendix II). Evidently change in weather conditions did not have significant influence on manganese concentrations in all the three areas of study.

The mean concentration values of 6.7, 3.1 and 4.9μg/m^3 (Table 5.7) for industrial, urban and residential centers were much higher than the long term (1 year) European air quality guideline value of 1.0μg/m^3. Exposure to similar levels as at Athi River town may lead to adverse long-term health effects among the occupationally exposed workers and general community. Insomnia, weakness, emotional disturbances and spastic gait are some of the initial health disorders experienced.

5.3.5 Iron (Fe)

The total suspended particulate matter to iron mean concentration ratios were found to be 4.81, 5.84 and 2.69 for industrial zone, urban commercial center and residential area respectively. Iron formed the second largest portion after zinc of all the metals analyzed in total suspended particulate matter sampled during the whole period of study.

Peak concentration values were 340μg/m^3 at site IC; 97.78μg/m^3 at site UK and 102μg/m^3 at site R1 with corresponding ranges of 31 – 340μg/m^3, 10.9 –97.78μg/m^3 and 7.4 – 102.00μg/m^3 for industrial zone, urban commercial center and residential area respectively (Appendix V). The slightly higher value detected at residential area rather than at urban commercial center was associated with the resuspension of dust on the untarmacked road network within the residential places. The location of East Africa Portland cement factory junior staff quarters in the downwind direction with respect to the nearby Makadara shopping center was also a contributory factor. Vehicular traffic road dust and smoke production by commuter vehicles were considerable in this shopping center.

Seasonal variations in concentration within each area category were not significant. The wet and dry seasons mean concentration values were 112.69 ± 3.57& 147.56±2.28μg/m^3; 53.23± 1.36 & 45.03 ± 1.87 μg/m^3, and 59.37± 4.25 &67.57± 1.84μg/m^3 for industrial zone, urban commercial center and residential area respectively (Appendix II).

The mean concentration levels were 129.00, 56.5 and 59.4μg/m^3 for industrial, urban and residential centers respectively (Table 5.7) The slightly lower mean value measured at urban commercial center compared to the residential area was attributed to the low human activities responsible for the production of iron in the urban setting. Municipal solid waste incineration was rarely done at the urban commercial center.

5.3.6 Copper (Cu)

Most concentration values were below 4.0µg/m^3 for all the samples collected during the whole sampling period. A few samples recorded concentrations between 5 and 11.2µg/m^3 (Appendix V). Copper levels of the order of 0.6%, 1.3% and 2.5% as a component of total suspended particulate matter collected at industrial zone, urban commercial centre, and residential area respectively were observed. Slight variations in concentration between sites in industrial and urban centers were noted with values which ranged from 0.33 –9.44µg/m^3 and 1.1 – 8.0µg/m^3 respectively.

In residential area, copper was detected only in samples collected at site R1 with concentration range of 1.56 –11.1 µg/m^3 (appendix V). The Athi River Threads, Auto springs limited and the Chloride Exide metal smelter Battery factories in upwind (south easterly) direction with respect to site R1 were the possible point sources responsible for the measured copper levels.

Peak values were recorded at site A1 (9.44µg/m^3) near Athi River mining and Werrot Co. Ltd.; site UK (8.0µg/m^3 at Makadara shopping center, and R1 (11.1µg/m^3) at East African Portland cement junior staff quarters. The values were noted to be less than the short term (8 hours) American Ambient Air limit of 20µg/m^3 (Calabrese and Kenyon, 1991), and therefore could not pose an acute health risk to human beings.

Mean concentration levels of 3.9µg/m^3 at industrial zone, 4.3µg/m^{3}at urban commercial centers and 4.0 µg/m^3 at residential area were recorded (Table 5.7).

Slightly higher mean values were measured at urban and residential centers contrasting each other with industrial zone (Table 5.7). These were attributed to the disproportionate contribution of copper from municipal solid waste incinerations in addition to the long- range transport of Copper dust from steel foundry industry located in the windward direction with respect to urban commercial and residential centers.

5.4 Hydrogen Sulphide (H_2S)

Hydrogen sulphide concentrations varied greatly from site to site within the area categories of study considered. Concentrations ranged from 25.89 – 200.93µg/m^3 at industrial area, 11.30 – 119.61µg/m^3 at urban commercial center, and 1.75 – 90.83µg/m^3 at residential area (Table 5.9).

Highest values were recorded at site ID of 200.93µg/m^3, site UM of 119.61µg/m^3 and site R2 of 90.83µg/m^3 for industrial, urban and residential centers respectively (Appendix VII). These peak values decreased by factors of approximately 0.45 – 0.60 with increase in distance away from the industrial area, an indication of the industrial operations forming significant sources of hydrogen sulphide pollutant.

The maximum value at site ID was associated with its close proximity to the Barbar/ Bawazir Tanneries and fishmeal factory where increased Hydrogen Sulphide generation was probably linked to bacterial action on wastewaters rich in organic matter . Site UM and R2 maximum values were attributed to their locations in the downwind direction with respect to the tannery and fishmeal factories.

Variation of hydrogen sulphide concentration with time showed some correlation with temperature and relative humidity within the period involved. (Table 5.8).

Table 5.8: Diurnal half-hourly variations of hydrogen sulphide (H_2S) concentration ($\mu g/m^3$) with temperature and relative humidity changes in Athi River industrial zone.

Time category	Sampling height (m)	$H_2S \pm 3.98$ concentration	R. Humidity(%)	Temperature (^0c)
Morning 0900 – 1200hr	1.5	38.80	55	23.0
	1.5	52.97	64	23.0
	1.5	80.00	43-45	25.0-26.0
	1.5	88.50	43	24.5-25.0
	1.5	90.56	50	23.5-27.0
	1.5	153.00	54	22.5-27.0
Lunch 1201 – 1400hr	1.5	3.49	38	27.0-28.0
	1.5	5.20	57	28.0
	1.5	6.84	33	26.5-28.0
	1.5	-	48	24.5
	1.5	25.9	<33	26.0-29.0
	1.5	100.81	50	25.0
	1.5	111.06	41	28.0-30.0
	1.5	156.90	42	25.5-27.0
	1.5	202	43	25.0-28.5
Afternoon 1401 – 1700hr	1.5	3.40	-	-
	1.5	15.50	41.0	25.5-27.5
	1.5	26.00	43-45	26.5-27.0
	1.5	37.59	34	27.5-29.5

The concentrations rose abruptly between 11.30am and 1.30pm reaching a peak of 200.93μg/m^3 a half hourly concentration variation of 33.48μg/m^3. A second peak of (156.90μg/m^3) was also observed at around 2.30pm followed by a sharp drop up to below 20μg/m^3 (Fig. 5.7).

The time interval between 11.00am and 2.30pm marked the period during which atmospheric temperature and relative humidity conditions were ideal for optimal bacterial action on waste discharges from Barbar/Bawazir Tannery and fishmeal factory. The generation of hydrogen sulphide increases with rise in temperature up to a temperature of 30^0C in the presence of anaerobic bacteria..

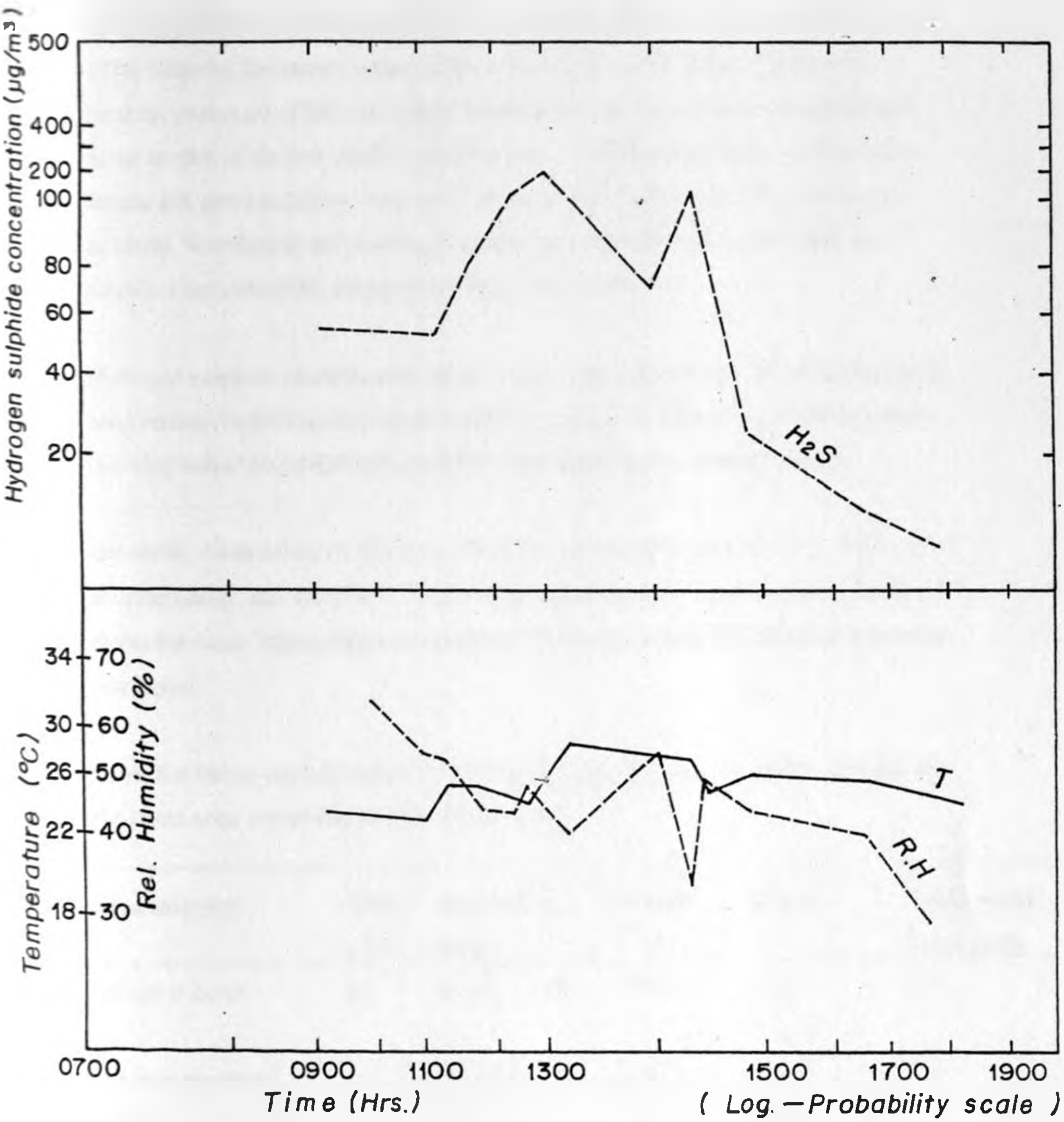


Fig. 5.7 Half Hourly variation of Hydrogen Sulphide (H_2S) mean concentration and meteorological variables (Athi-River industrial commercial area)

The obnoxious smell experienced among the residents and those in adjoining areas like Kitengela was attributed to the slow, insidious accumulation of hydrogen sulphide in the low lying area of Athi River. This was as a result of bacterial action on decaying animal and plant protein in the tannery and fishmeal wastewaters (Cooper, 1976; National Research Council, USA, 1979; ILO, 1971). Exhaust gases from smoking processes of fish products at fishmeal factory also contributed significantly to the burden of the foul smell. Loss of appetite, vomiting, headaches, stomachache, fatigue and general debility were some of the adverse health complaints among the residents. Worshiping and learning programmes in the neighboring churches and schools were sometimes disrupted by this offensive smell.

Hydrogen sulphide concentrations were noted to increase with increase in temperature and decrease with increase in relative humidity (Fig. 5.7; Table 5.8). Lowest relative humidity values coincided with peak hydrogen sulphide concentration levels.

Geometric mean values of 75.50± 1.75 $\mu g/m^3$ at industrial area, 48.30 ± 1.86$\mu g/m^3$ at urban center, and 15.53 ± 2.77$\mu g/m^3$ at residential area were measured. Table 5.9 shows the mean concentration distribution of hydrogen sulphide pollutant in the areas considered.

Table 5.9 Mean concentration (± SGD $\mu g/m^3$) of hydrogen sulphide pollutant in the three area categories of Athi-River Town.

Area category	Sample run	Geometric mean	Median	Range	Peak: mean value ratio
Industrial Zone	19	75.50 ±1.75	75.50	25.89 – 200.93	2.7
Urban commercial center	13	48.30 ±1.86	51.00	11.32 – 119.61	2.5
Residential area	14	15.53 ±2.77	15.53	1.75 – 90.83	5.9

SGD: Standard Geometric Deviation

The higher average concentration recorded at industrial area and urban center as compared with the residential area showed that the industrial operations mainly at the tanneries and fishmeal factories constituted significant point sources. The mean concentration value at industrial zone was five (5) times more than that at residential area whereas that at urban commercial center was approximately (3) times more.

The log-normal frequency distributions of the hydrogen sulphide concentrations showed that the 50th percentiles corresponded to the geometric means whereas the ratios: concentration at 84th percentile to concentration at 50th percentile correlated fairly well with the standard geometric deviations (Fig 5.8). The 50th percentile signifies that half of the data values of daily half - hourly average hydrogen sulphide concentrations were less than geometrical mean and half more. 84th percentile signifies that 84% of the data values measured at industrial area, urban commercial centre and residential area were lower than 119, 90 and 43 μg/m^3 respectively (fig.5.8). Representing the data in log – normal frequency distribution curve can conveniently be used for assessing the need for process control at the implicated factories for Hydrogen Sulphide pollution reduction. Table 5.10 summarizes the frequency distributions of hydrogen sulphide concentrations measured at the Athi-River Town.

Table 5.10 Cumulative frequency distribution[a] of hydrogen sulphide (H_2S) concentrations in Athi-River Industrial zone; urban commercial center, and residential urban area.

	Date	Sample Run No.	Specific concentration (μg/m^3)	No. of sample concentrations less than or equal to the specified concentration	Cumulative frequency (%)
Industrial zone: (n=14)*	22/09/95	HS008	38.83	3	21.4
	25/10/95	HS024	52.97	6	42.9
	20/09/95	HS005	75.50	8	57.1
	25/10/95	HS027	100.81	11	78.6
	20/09/95	HS003	120.98	13	92.9
	20/09/95	HS004	200.93	14	99.99
Urban commercial center (n=11)*:	24/10/95	HS022	22.21	3	27.3
	24/10/95	HS020	46.13	5	45.5
	27/10/95	HS029	87.14	8	72.7
	17/10/95	HS016	90.83	9	81.8
	24/10/95	HS021	97.39	10	90.9
	24/10/95	HS023	119.61	11	99.99
Residential urban area (n=14)*	31/10/95	HS031	6.84	4	28.6
	16/10/95	HS012	8.90	6	42.9
	31/10/95	HS032	15.53	8	57.1
	17/10/95	HS019	17.09	9	64.3
	22/10/95	HS014	37.59	11	78.6
	17/10/95	HS017	87.14	13	92.9
	17/10/95	HS016	90.83	14	99.99

* Number in parenthesis indicates the number of samples

[a] the cumulative frequency distribution plots as a straight line on log-probability (fig.5.8) as the concentrations of hydrogen sulphide pollutant show log-normal frequency distribution, i.e. the logarithms of the concentrations are distributed normally (Pollack, 1975)

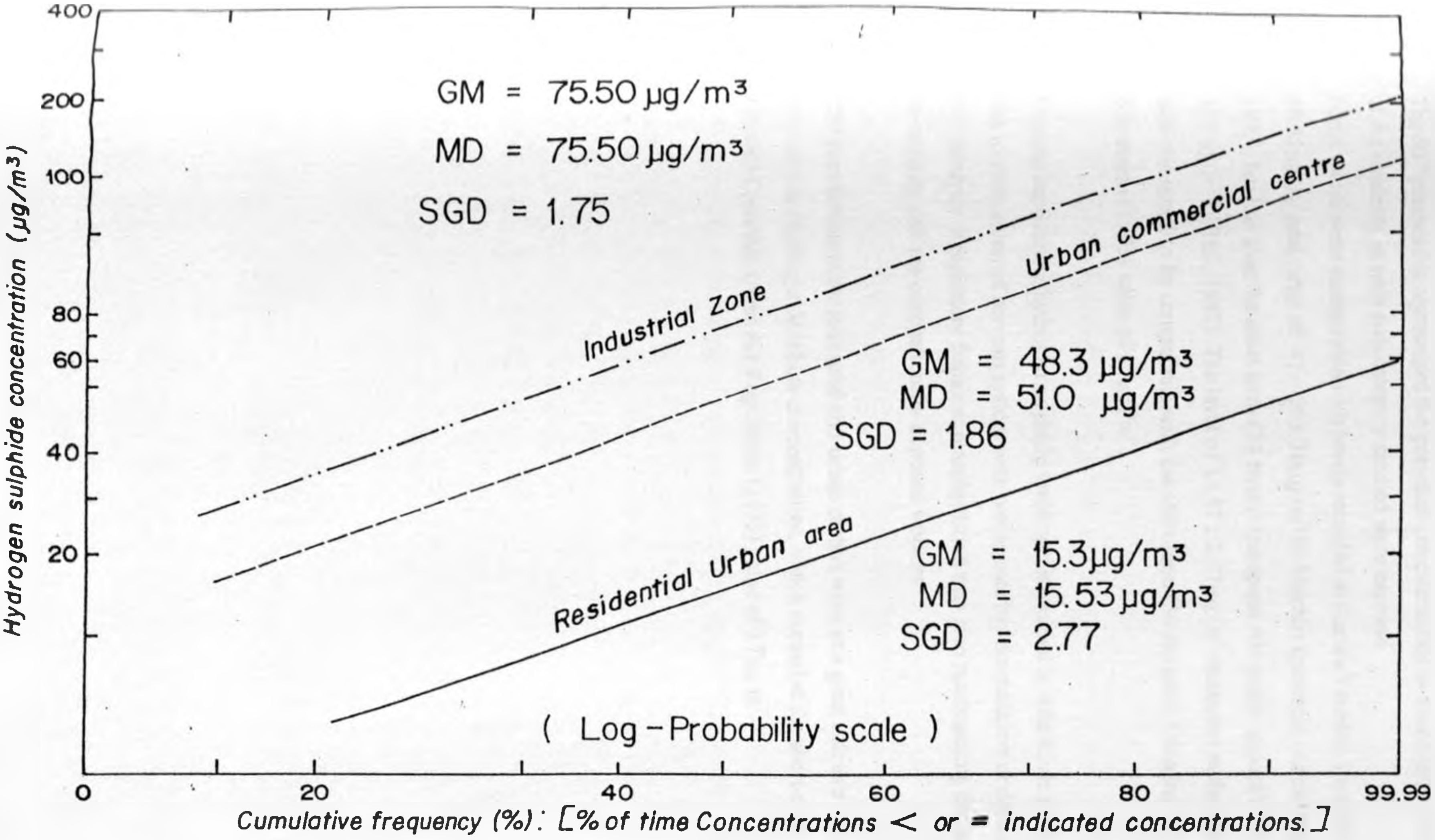


Fig. 5.8 Cumulative frequency distributions of diurnal Hydrogen Sulphide (H_2S) concentrations in the Athi-River Industrial zone, Urban commercial centre and Residential urban area.

The 50th percentiles represented the prevalent concentrations to which large fractions of the residents in each area category studied were exposed.
Mean values were comparable with levels recorded at Kamiti Tannery: mean of 88.52$\mu g/m^3$ and range of 47 – 203.30$\mu g/m^3$ by Muchiri (personal communication, 1993), but less than the short term (24 hours) European Air quality guideline of 150$\mu g/m^3$ (WHO, 1987). The level of $15.53 \pm 2.77 \mu g/m^3$ measured at the residential area was noted to be comparable with the short-term (30 minutes) Canadian Clean Air Regulation (1973) value of 17$\mu g/m^3$.

Chronic exposure to hydrogen sulphide levels as determined at Athi-River may give rise to stimulation of nervous system with consequent hyperventilation or depression and paralysis. Respiratory failure and asphyxiation may also result among the general community and the occupationally exposed workers.

The populations at the industrial and urban centers were at a great risk as a result of exposure to Hydrogen Sulphide concentrations, which exceeded the short-term (30min) Canadian Clean Air Regulation (1973) value of 17$\mu g/m^3$.

5.5 AMMONIA (NH_3)

Ammonia levels showed much greater variations between sites at each area category studied (Appendix VIII). Concentration ranged from 14.22 - 113.46μg/m^3 at industrial area, 14.22 – 137.44μg/m^3 at urban commercial center, and 17.14 – 128.00μg/m^3 at residential area (Table 5.12).

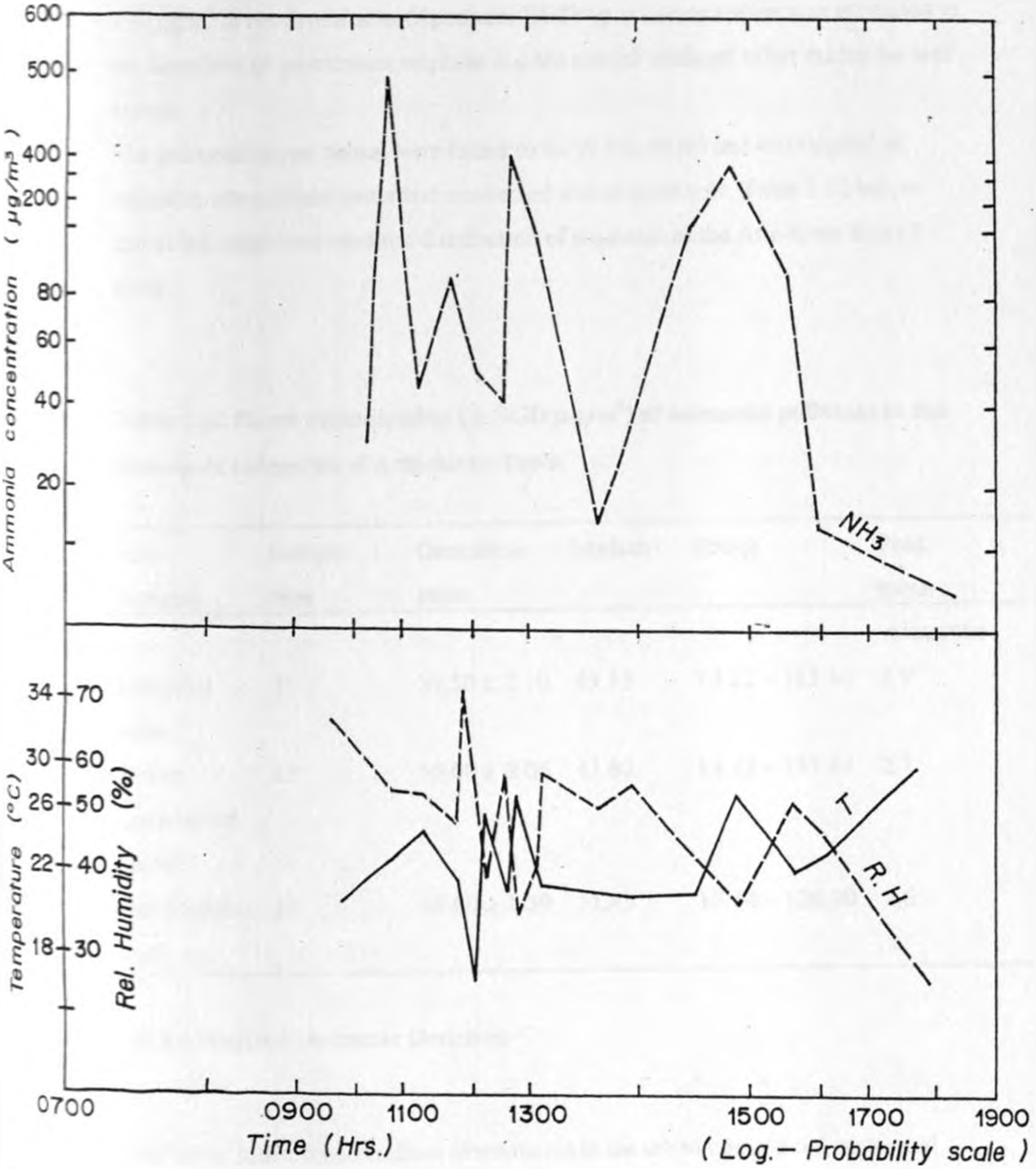
The exceptionally high industrial zone concentrations of 603, 412, 381 and 492μg/m^3 (table 5.11 and Appendix VIII) were attributed to the close proximity of site ID to potential point sources such as wastewaters from the Barbar/Bawazir Tannery and fishmeal factory. They were far above the range 14.22 – 113.6μg/m^3 of other values, and therefore could not be considered as representative of the industrial environment.

Variations of ammonia concentration with time (Fig 5.9) showed maximum values between 10.00am and 11.00 am of 492μg/m^3; 12 Noon and 1.00pm of 400μg/m^3 ; 2.00pm and 3.00pm of 381μg/m^3. These were considered as the periods during which industrial operations were at the peak. The ammonia concentrations were generally noted to increase with increase in temperature but decrease with increase in relative humidity (Fig. 5.9). Nitrogen containing organic matter in the wastewater from the factories was prone to be decomposed faster by microorganisms at midday temperature generating ammonia whereas at high relative humidity the generated ammonia was likely to be removed as ammonium sulphate, $(NH_4)_2SO_4$, in its reaction with Sulphur Dioxide (Mckay, 1971)

Table 5.11 Diurnal half-hourly variations of ammonia (NH_3) concentration ($\mu g/m^3$) with temperature and relative humidity changes in Athi-River industrial zone

Time category	Sampling Height (M)	$NH_3 \pm 1.95$ Concentration	R. Humidity (%)	Temperature (^0C)
Morning 0900 – 1200hr	2	17.14	49	25.0 –28.0
	2	34.28	61	22.5
	2	42.67	59	21.0
	2	47.62	54	22.5 –27.0
	2	51.48	55	20.5
	2	71.11	72	17.0
	2	85.71	48	21.0
	2	*492.00	55	23.0
	2	*603.00	39	25 –27
Lunch 1201 – 1400hr	2	14.22	52	21.0
	2	34.28	33	26.0 – 29.0
	2	38.23	57	19.0
	2	42.67	54 – 59	20.5–22.0
	2	63.49	43	25.0 –28.5
	2	63.50	57	28.0
	2	94.20	43	24.5
	2	102.00	60	21.0 – 21.5
	2	*412.00	36	26.0- 28.0
Afternoon 1401 – 1700hr	2	14.22	36	23.0
	2	15.87	47	26.0 – 28.5
	2	17.14	<36	27.0 – 30.0
	2	30.20	36	27.0 –30.0
	2	42.67	52	22.0 –23.0
	2	87.32	52	22.5
	2	113.46	55	21.0 –22.0
	2	*381.00	<36	28.0

* Highly localized and intermittent concentration (High-localized concentration implies the concentrations far beyond the other daily values)



ig. 5.9 Half Hourly variation of Ammonia (NH_3) mean concentrations with meteorological variables (Athi – River industrial commercial area)

Dry and wet seasonal variations of ammonia mean concentration were respectively recorded as 52.86 ± 2.04 $\mu g/m^3$ and 25.71±1.64$\mu g/m^3$ at industrial area, 86.27± 2.32 and 27.79±1.39$\mu g/m^3$ at urban commercial center and 67.92±1.89 and 53.12± 3.47$\mu g/m^3$ at residential area (Appendix II). Drop in concentration was attributed to the formation of ammonium sulphate and the rainfall washout effect during the wet season.

The geometric mean values were found to be 39.50, 50.00 and 49.00$\mu g/m^3$ at industrial zone, urban center and residential area respectively. Table 5.12 below shows the mean concentration distribution of ammonia in the Athi-River area of study.

Table 5.12 Mean concentration (± SGD $\mu g/m^3$) of ammonia pollutant in the three area categories of Athi-River Town.

Area category	Sample runs	Geometric mean	Median	Range	Peak: mean value ratio
Industrial zone	25	39.50 ± 2.10	49.55	14.22 – 113.46	2.9
Urban commercial center	15	50.00 ± 2.06	42.67	14.22 – 137.44	2.7
Residential area	13	49.00 ± 1.59	51.43	17.14 – 128.00	2.6

SGD: Standard Geometric Deviation

The higher mean concentrations of ammonia in the urban commercial center and residential area as compared with the industrial area showed that the microbiological decay processes of proteinaceous material of animal and plant refuse from Mavoko Municipal Council and residential places contributed significantly to the ammonia burden. Peak: mean value ratios of 2.9 at industrial zone, 2.7 at urban center and 2.6 at residential area correlated fairly well with standard geometric deviations of the analyzed data (Table 5.12). The ratios increased with increase in standard geometric deviations i.e. with increase in variability of the sample concentration.

The mean values were found to correspond to the 50th percentiles whereas the standard deviations to the ratios: concentration at 84th percentiles to the concentration at 50th percentiles of the frequency distribution of the data (Table 5.13 and Fig. 5.10). The 50th percentile signifies that half of the data values of the daily half-hourly average ammonia concentration measured at industrial area, urban commercial centre and residential area were lower than 39.5, 50.0 and 49.0 $\mu g/m^3$ respectively (table 5.12;fig 5.10) and half more. The 84th percentile signifies that 84% of the data values of ammonia pollutant measured at industrial area, urban commercial centre and residential area were lower than 85.3, 102.0 and 78.0$\mu g/m^3$ respectively (fig.5.10). Representation of the data in this form on log-probability axes proves the normalcy of the measured Ammonia pollutant concentrations, and can conveniently be used to assess the need for process control at the implicated sources for ammonia pollution reduction. The average concentrations were far below the levels measured at Nderi – Kikuyu of 23,200 – 27,200$\mu g/m^3$ by Jumba (personal Communication: 1988) as well as the long term (1 year) Germany air quality limit of 500$\mu g/m^3$ (VDI-Kommission Reinhalting der Luft, 1973).

Similarly the mean values were relatively below the range 63.5 – 630$\mu g/m^3$ recorded at Kamiti Tannery by Muchiri (personal Communication, 1993) for samples collected in the vicinity of mixing drums and waste water disposal pools as well as aeration ponds. The slight difference in ammonia concentration at Athi-River tannery and fishmeal factory as compared to Kamiti Tannery was attributed to the location of sampling sites at longer distances (200 –300 metres) away from the point sources. Consequently lower concentrations were likely to be recorded as a result of atmospheric dilution. Exposure to these levels as determined at Athi-River area was unlikely to pose health problems.

Table 5.13 Cumulative frequency distribution[a] of Ammonia (NH_3) concentrations in Athi-River Industrial zone; urban commercial center; and residential urban area.

	Date	Sample Run No.	Specific concentration (µg/m^3)	No. of sample concentrations less than or equal to the specified concentration	Cumulative frequency (%)
Industrial	20/09/95	NH034	15.87	3	15.8
zone:	22/09/95	NH038	21.33	6	31.6
(n=19)*	16/10/95	NH039	34.28	8	42.1
	17/08/95	NH008	42.67	10	52.6
	20/09/95	NH032	63.49	13	68.4
	25/07/95	NH005	85.71	16	84.2
	11/09/95	NH012	102.00	18	94.7
	11/09/95	NH013	113.46	19	99.99
Urban					
commercial	27/10/95	NH050	25.46	3	20.00
center (n-	13/09/95	NH019	34.28	7	46.70
15)*:	15/09/95	NH024	42.67	9	60.00
	15/09/95	NH025	99.56	10	66.67
	13/09/95	NH018	113.78	12	80.00
	13/09/95	NH016	137.00	14	93.30
Residential	14/09/95	NH023	137.14	15	99.99
urban area	18/07/95	NH004	21.33	2	20.0
(n=10)*	14/09/95	NH020	42.67	4	40.0
	14/09/95	NH020	56.89	7	70.0
	18/07/95	NH001	85.33	8	80.0
	17/10/95	NH042	85.71	9	90.0
	31/10/95	NH053	89.10	10	99.99

* Number in parenthesis indicates the number of samples.

[a] the cumulative frequency distribution plots as a straight line on log-probability axes (fig.5.10) as the concentrations of ammonia pollutant show log-normal frequency distribution, i.e. the logarithms of the concentrations are distributed normally (Pollack, 1975)

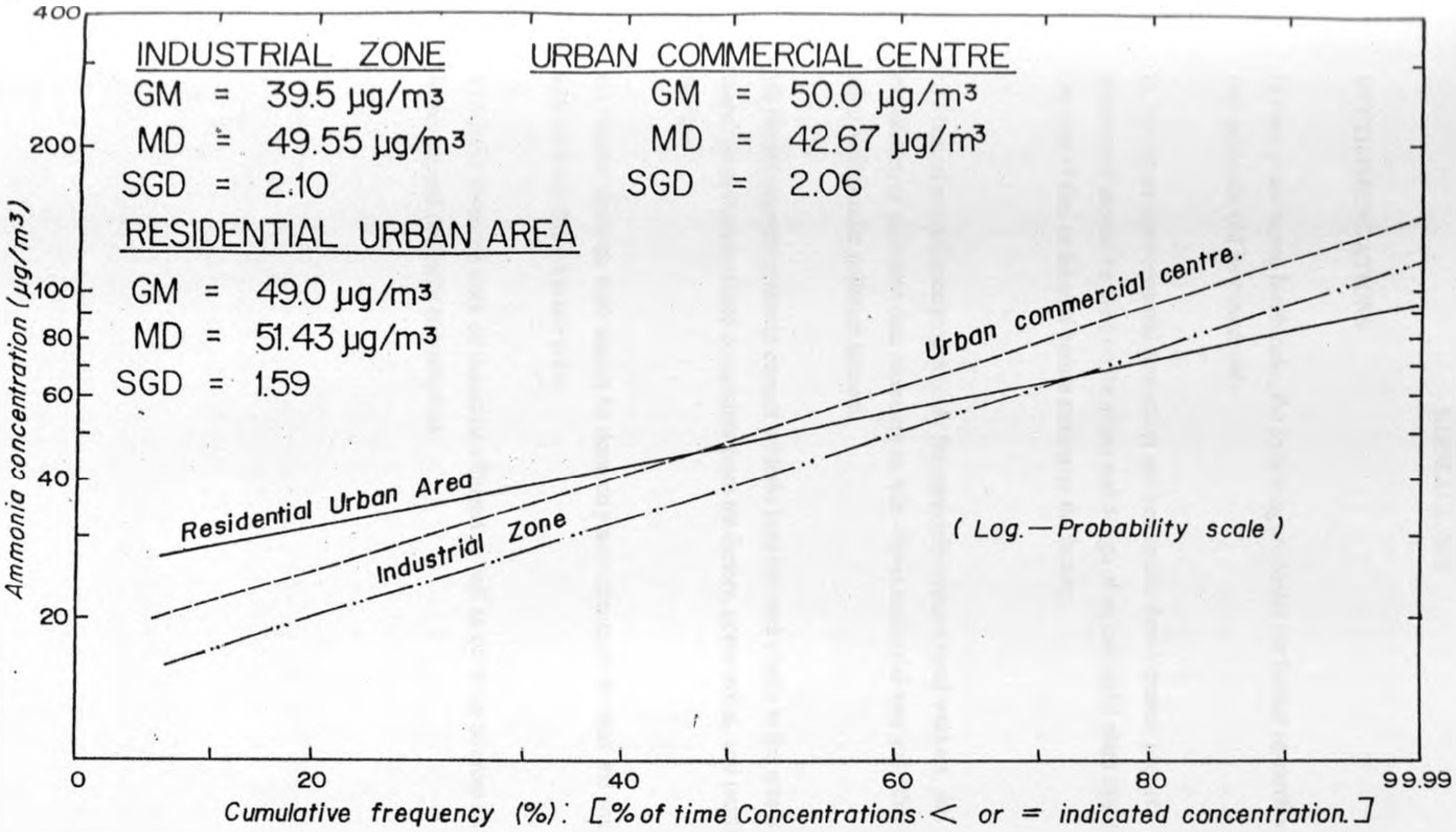


Fig. 5.10 Cumulative frequency distributions of diurnal Ammonia (NH_3) concentrations in Athi-River industrial zone, urban commercial centre and residential urban area.

CHAPTER SIX

RECOMMENDATIONS

In view of the noted health risks, the following proposals for further research work and action should be considered:-

i). For future environmental protection and sustainable development, proper assessment should be done on the siting and design of an industrial plant together with the type of fuel to be used before setting up the factory.

ii) Medical surveillance programmes for especially occupational workers, and installation of pollution data recorders in Athi –River industrial area and other urban areas with similar pollution sources.

iii) Health inspectors should consult with the hospitals and clinics in the area for major air pollution related complaints from the factory, commercial, and residential workers.

iv) Further research work should be done on plants consumed by man and animals, around the pollution prone areas.

v) Further research work on industrial effluents as well as on water sources for both industrial and domestic consumption.

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APPENDICES:

APPENDIX 1: Typical comparison of diurnal concentration cycles of total suspended particulate matter and *Meteorological variables in Athi-River Industrial Zone, Urban commercial centre and residential Area.*

	INDUSTRIAL						URBAN						RESIDENTIAL					
Sample Run	TSP 062	TSP 056	TSP 067	TSP 057	TSP 059	TSP 060	TSP 045	TSP 077	TSP 047	TSP 071	TSP 036	TSP 078	TSP 052	TSP 073	TSP 053	TSP 054	TSP 055	TSP 076
Time category	0900 – 1200hr		1201 – 1400hr		1401 -1700hr		0900 –1200hr		1201 –1400hr		1401 -1700hr		0900 – 1200hr		1201 – 1400hr		1401 - 1700hr	
Sampling Height (M)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Flow rate l/min	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Sampling time (min)	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
TSP Con. µg/m^3	244	792	587	883	781	910	189	300	116	348	133	197	132	333	46.7	93	178	277
Temperature °C	19-20	26	21	21	19	20	18-21	24-25	19-20	25-28	28.5	25-27	24-26	23-27	25-27	26-28	24	25-27
R. Humidity (%)	64	48	55	48	57	54	64	34	62	41	44	34	65	44	47	34	42	34
Wind direction	NE	SE	SE	SE	SE	SE	SE	NE	SE	SE	NE	NE	SE	SE	NE	NE	SE	SE

APPENDIX II: SEASONAL VARIATIONS OF MEAN (ARITHMETIC MEAN) CONC. (±SD $\mu g/m^3$) OF SOME OF THE POLLUTANTS MEASURED AT ATHI-RIVER TOWN.

Area category	INDUSTRIALZONE		URBAN COMMERCIAL CENTRE		RESIDENTIAL AREA	
Season	WET	DRY	WET	DRY	WET	DRY
Pollutant :TSP	544.75 ± 1.22 (737.50)	667.93 ± 1.30 (910)	336.46 ± 1.69 (663)	402.50 ± 1.39 (617)	198.97 ±1.81 (333)	290.00 ± 2.36 (456)
Zn	213.58 ±1.65 (488)	290.31 ± 1.82 (597)	183.50 ±2.80 (322)	243.23 ± 1.88 (550)	205.00 ± 1.63 (324)	270.63 ± 1.81 (498)
Fe	112.69 ± 3.57 (271)	147.56 ± 2.28 (340)	53.23 ± 1.36 (80.67)	45.03 ± 1.87 (97.78)	59.37 ± 4.25 (102.00)	67.57 ± 1.87 (148)
Mn	3.93 ± 2.23 (15.6)	7.96 ± 2.27 (17.8)	3.31 ± 1.69 (4.44)	4.27 ± 1.64 (8.67)	3.72 ± 1.90 (7.7)	4.56 ± 2.92 (8.67)
SO_2	61.70 ± 1.63 (115)	125.12 ± 1.74 (223)	90.40 ± 1.35 (143)	123.94 ± 1.58 (200)	69.03 ± 1.42 (97.99)	72.62 ± 1.50 (116.67)
H_2S	14.21 ± 3.02 (37.59)	77.65 ±1.98 (200.93)	44.45 ± 4.01 (87.14)	71.34 ± 2.22 (119.61)	7.99 ±3.09 (13.49)	67.62 ± 2.4 (87.14)
NH_3	25.7/±1.64 (34.28)	52.86 ±2.04 (113.46)	27.79 ±1.39 (34.28)	86.27 ±2.32 (137.14)	52.12 ±3.47 (89.10)	67.92 ±1.89 (128)

NB: Number in parenthesis indicates the highest (peak) value.

APPENDIX III: Statistical concentration distribution of the measured air pollutants in Athi-River town.

	INDUSTRIAL	URBAN	RESIDENTIAL
TSP (μ g/m^3)			
Arithmetic	680.06	383.94	183.98
Geometric mean	621.00	330.00	160.00
Median	620.00	360.00	159.00
98th percentile (max: 1hr)	910.00	663.00	456.00
Peak: Geo. Mean ratio.	1.47	2.01	2.85
SO_2(μ g/m^3)			
Arithmetic	121.51	101.92	54.32
Geometric mean	109.00	90.00	49.00
Median	109.50	90.67	49.30
98th percentile (max: 30min)	223.00	200..00	116.00
Peak: Geo. Mean ratio.	2.05	2.22	2.37
H_2S(μ g/m^3)			
Arithmetic	79.26	61.59	26.78
Geometric mean	*75.50*	*48.30*	*15.53*
Median	75.50	51.00	15.53
98th percentile (max: 30min)	200.93	119.61	90.83
Peak: Geo. Mean ratio.	2.65	2.50	5.9
NH_3(μ g/m^3)			
Arithmetic	49.21	65.54	52.95
Geometric mean	39.50	50.00	49.00
Median	49.60	42.67	51.53
98th percentile (max: 30 min)	113.46	137.14	128.00
Peak: Geo. Mean ratio.	2.90	2.74	2.60

APPENDIX IV: Heavy metal content of precipitation collected simultaneously in the three area categories of Athi-River town.

	Conc. ppm.						
*site	Fe	Mn	Zn	Pb	Cd	Electrical conductivity 25^{0}C mhos/cm^3	Conc. of silica Sio$_2$ (ppm).
Industrial (1A)	0.137	0.329	0.126	0.015	0.003	100	10.3
Urban (UM)	0.008	0.004	0.226	0.025	0.052	30	6.9
Residential (R2)	0.028	0.001	0.005	0.007	0.004	5	0.805

* Collection sites for precipitation:

1A – Two hundred metres away from Athi - River Mining Co. Ltd.

UM – Near Makutano stage Hotel.

R2 – Sheikh star secondary school.

NB: The rainwater collectors had lids which were automatically opened during rain and closed for the rest of the time within one week.

				TSP (μ g/m^3)		
					Zn	Cd
09.05.95	Industrial commercial centre	IA	TSP003	439	238	ND
19.05.95	-do-	-do-	TSP008	400	83	ND
	-do-	-do-	TSP009	615	298	6.50
	-do-	-do-	TSP010	737.5	472	ND
	-do-	-do-	TSP011	358.3	244	ND
23.05.95	-do-	-do-	TSP013	633	233	ND
	-do-	-do-	TSP014	401.1	327	0.80
	-do-	-do-	TSP017	528.9	257	5.60
19.08.95	-do-	-do-	TSP061	445.6	83.6	-
	-do-	-do-	TSP062	244	-	0.59
	-do-	-do-	TSP063	301	79.3	7.5

				time (hrs)		direction	
Pb	Mn	Cu	Fe				
ND	ND	1.56	138	11.00 – 12.00(1hr)	33.5(43)	SE (LOW)	SUNNY
6.50	2.22	1.33	87.30	13.56 – 14.56(1hr	25.55(55)	"	SUNNY
ND	9.05	1.10	71	13.20 – 14.20(1hr	26.55(61)	"	LIGHT CLOUD
2.33	1.11	2.17	33.50	11.00 – 12.00(1hr	28.0(51)	"	SUNNY
ND	14.3	1.43	82.70	11.00 – 12.00(1hr	26.0(55)	"	MOERATELY SUNNY
2.71	4.16	2.88	33	11.00 – 12.00(1hr	24.55(49)	"	"
ND	13.5	3.34	259	11.00 – 12.00(1hr	26.5(44)	"	SUNNY
ND	7.78	9.44	60	11.00 – 12.00(1hr	28.0(40)	"	CLEAR SKY
1.60	5.00	-	-	11.00 – 12.00(1hr	18.0(72)	"	HEAVY CLOUD
2.7	1.01	0.33	-	11.00 – 12.00(1hr	19.5(64)	Variable (Low)	MODERATELY CLOUDY
4.36	ND	0.89	71.8	11.00 – 12.00(1hr	21.5(55)		Moderately cloudy

Appendix v (continued)

14.09.95	-do-	IB	TSP092	883	417	ND
	-do-		TSP096	901	460	2.11
	-do-		TSP099	803.9	174	5.90
	-do-		TSP108	903	168	5.6
30.09.95	-do-	IB	TSP027	713	102	1.56
"	-do-		TSP028	Spoiled filter	-	-
25.07.95	-do-		TSP029	267	139.2	0.70
"	-do-		TSP030	655	93.7	1.47
"	-do-		TSP031	528	488	8.67
25.07.95	-do-	IC	TSP056	792	197	ND
04.07.95	-do-	IC	TSP058	756	597	4.44
18.05.95	-do-		TSP059	781	112	2.33
	-do-		TSP060	910	130	2.05

ND	3.78	ND	43.30	13.50-.50HR	29.5(44)	SE LOW)	SUNNY
-	14.44	1.78	76.00	16.58-17.58HR	26.0(42)	"	"
1.01	1.3	0.33	46.3	16.35-17.35HR	26.0(42)	"	"
ND	1.11	ND	172	15.55-16.55	26.0(49)	Variable (Low)	
7.56	ND	0.89	53.56	10.50-11.50(1hr)	24.0(61)		Moderately cloudy
-	-	-	-	12.00-13.00(1hr)	23.5(58)		Moderately cloudy
2.93	1.11	0.35	245	1516-16.16(1hr)	24(55)	SE (LOW)	Clear sky
7.1	ND	0.73	49.2	14.12-15.12(1hr)	24.5(55)		
3.02	3.11	ND	59.78	15.16-16.16(1hr)	24.0(55)		Moderately cloudy
15.2	26	2.33	272	10.20-11.20(1hr)	26.0(48)		Moderately cloudy
5.69	3.30	2.18	251	12.36-13.36(1hr)	20.1(50)		Moderately cloudy
7.93	ND	0.87	58.8	1342-1442 (1hr)	19.0(57)	"	Light cloudy
9.87	ND	1.01	68.5	1445-*1545(1hr)*	26.5(38)	"	"

Appendix v (continued)

	-do-		TSP001	615	152	ND	11.50
	-do-		TSP005	520	254	ND	ND
	-do-		TSP006	170	143	ND	2.83
	-do-		TSP007	459.2	246	ND	ND
08.06.95	-do-		TSP038	583.3	283	6.30	ND
	-do-		TSP039	427	392	7.00	2.44
	-do-		TSP040	482.3	394	1.01	ND
	-do-		TSP041	359.8	323	0.77	ND
	-do-		TSP042	875	283	11.11	1.56
	-do-		TSP043	604	369	4.50	ND
	-do-		TSP044	604.2	295	6.80	1.3
	-do-		TSP021	544	152	7.78	10.0
			TSP022	615	340	7.83	ND
18.06.95	-do-	IC	TSP002	660.8	327	1.10	ND
19.08.95	-do-		TSP015	666.7	319	7.20	ND
09.05.95	-do-	ID	TSP004	446	274	3.30	ND
11.09.95	-do-		TSP064	607.8	368	ND	13.5
	-do-		TSP066	842	119	1.90	9.1
	-do-		TSP067	587	463	3.40	4.4
	-do-		TSP068	Spoilt filter	-	-	-

2.00	1.78	340	1254-1354(1hr)	27.0(45)	"	Moderately Cloudy
17.8	4.22	327	1135-1235(1hr)	22.7(67)	:	Clear sky
4.33	3.00	34.4	1245-1345hr	24.0(57)	Variable(high)	Moderately cloudy
15.6	1.53	243	1350-1450hr	22.5(61)	Variable (low)	"
8.7	1.04	187	1044-1144hr	24(47)	"	Sunny
2,53	ND	48.3	1148-1248hr	25(48)	"	Moderately cloudy
17.1	4.13	31	1252-1352hr	26.5(40)	SE low)	Light cloud
13.1	3.28	248	1356-1456hr	27.5(33)	"	Clear sky
6.22	1.78	43.56	1459-1559hr	30.0(<47)		
17	7.98	77	16.1-1701(1hr)	26.0(35)		
9.2	1.07	69	1701-1801hr	24.50(37)		
8.89	1.56	53.56	1154-1254hr	27.0(49)		
2.00	1.78	201	1256-1356hr	26.5(47)	'	Moderately cloudy
17.8	4.22	34.4	1254-1354 (1hr)	25(48)	SE(low)	Clear sky
9.47	1.19	77	1245-1345(1hr)	28.0(62)		Light sunny
12.2	5.89	271	1630-1730(1hr)	30(36)	Variable (moderate)	Sunny
6.59	6.7	71.8	1401-1501hr	20(54)	SE(LOW)	Heavy cloud
0.93	1.33	63.4	1233-1333hr	20.5(54)		Moderately cloudy
2.56	1.69	191	1340-1440hr	21.0(55)		
-	-	-	1447-1547hr	21.5(52)	-	-

Appendix v (continued)

13.09.95	URBAN COMMRCIAL CENTRE	UK	TSP69	422	273	8.1
	-do-		TSP070	222	119	11.78
	-do-		TSP071	348	240	2.22
	-do-		TSP072	201	173	6.67
15.09.95	-do-	UL	TSP077	300	384	4.22
	-do-		TSP078	244	550	3.11
	-do-		TSP079	Spoilt filter	-	-
13.07.95	-do-	UM	TSP045	189	127	1.07
	-do-		TSP046	358	240	2.1
	-do-		TSP047	116	78	0.66
	-do-		TSP048	522	351	2.96
	-do-		TSP049	197	132	1.12
	-do-		TSP050	592	397	3.36
	-do		TSP051	663	97.98	8.33
02.06.95	-do-	UN	TSP032	497	322	9.56
	-do-		TSP035	647	294	6.89
	-do-		TSP036	133	52	ND
	-do-		TSP037	363	66	4.0
09.05.95	RESIDENTIAL URBAN CENRE	R1	TSP005	393	160	1.1
25.05.95	-do-		TSP020	456	324	9.78
	-do-		TSP025	237	131	3.1
13.08.95	-do-		TSP054	93	498	6.0

ND	3.2	7,9	38.60	1041-1141hr	26(49)	"	"
7.56	8.0	1.24	48.89	1226-1326hr	25.5(36)	SE (LOW)	Clear sky
ND	5.11	4.89	46	1336-1436hr	26.5(41)		
3.33	8.67	8.60	67	1439-1539hr	26.0(48)		Light cloud
7.78	2.44	7.56	97.78	1125-1225hr	25.0(36)	-	Moderate cloudy
12.89	3.33	1.56	62	1228-1328hr	28.0(36)	NE moderate	Clear sky
-	-	-	-	1333-1433hr	29.0(36)		
0.80	2.04	1.8	17.8	0958-1058hr	19.5(64)		
1.51	4.0	3.4	33.6	1101-1201hr	21.0(62)	-	Moderate cloudy
0.50	1.3	1.1	10.9	1203-1303hr	20.0(62)		
2.22	5.74	5.0	49.26	13.05-1405hr	19.0(61)		
0.80	2.2	1.9	18.5	1408-1508hr	27.0(34)	NE(LOW)	Heavy cloudy
2.40	6.0	ND	54	1510-1610hr	21.0(59)	SE(low)	
2.18	3.52	3.33	41	1612-1712hr	21.0(69)		Moderate cloudy
ND	3.78	1.33	45.56	1115-1215hr	26.5(45)		
2.07	4.44	5.78	44.89	1428-1528hr	27.0(45)		
1.38	1.7	1.3	80.67	1521-1621hr	28.5(51)	NE (moderate)	Clear cloud
8.22	ND	6.89	41.78	1634-1734hr	25.5(48)	SE (LOW)	
ND	2.22	2.67	67.8	1310-1410hr	30.0(37)		Light cloud
1.56	4.44	11.1	102	1050-1150hr	25.5(51)		Clear sky
ND	7.7	6.86	8.3	1605-1705hr	23.5(47)	-	Moderate cloudy
2.0	8.67	1.73	49.78	1353-1453hr	27.0(34)	NE (high)	

Appendix v (continued)

	-do-		TSP055	178	109	1.33
14.09.95	-do-		TSP074	111	498	9.78
	-do-		TSP075	Spoilt filter	-	-
14 09.95	-do-	R2	TSP073	333	487	210
	-do-		TSP076	277	147	1.78
17.08.95	-do-		TSP086	246	36.2	0.89
	-do-		TSP088	267	39.2	ND
	-do-		TSP089	168	127	ND
	-do-		TSP090	231	119	0.56
25.05.95	-do-	R3	TSP026	74	12	ND
	-do-	R3	TSP052	132	180	ND
13.08.95	-do-		TSP053	46.7	25	ND

*: Number parenthesis represents the relative humidity (%)

a: Term in parenthesis indicates the wind speed .

1.78	7.56	1.56	82.89	1500-1600hr	24.0 (22)	SE (LOW)	Clear sky
0.89	7.56	7.11	60.44	1221-1321hr	26.0(38)		
-	-	-	-	1330-1430hr	27.0(34)		
ND	ND	ND	7.4	1045-1145hr	25.0(44)		
ND	10.9	ND	148	1438-1538hr	26.0(34)		
3.1	0.5	ND	-	1035-1153hr	24.25(27)		
ND	1.01	ND	20	1415-1515hr	24.0(58)		Heavy cloud
ND	1.3	1.1	12.8	1141-1241hr	24.5(47)		Light cloud
ND	2.06	ND	33.33	1322-1422hr	28.0(38)		Cloudy cover clear sky
ND	0.5	ND	-	1711-1811hr	21.5(67)		Moderate cloudy
ND	1.29	ND	31	1138-1238hr	25.0(65)		Light cloud
ND	1.5	ND	21.3	1245-1345hr	26.0(47)	NE (HIGH)	

APPENDIX VI: Sulphur dioxide (SO_2) content in airborne gaseous pollutants (Athi-River town)

Date	Area Category		Sample Run No.	Conc. ($\mu g/m^3$) SO_2	Averaging Time	Temp./°C	Relative Humidity (%)	Wind Speed	Wind Direction	Time Category
09/05/95	INDUSTRIAL COMM. CENTRE	1A	SD003	54.10	1hr.	33.5	43	LOW	SE	morning
23/05/95	-do-	-do-	SD010	115.00	30 min	28.5	51	-do-	-do-	lunch
-do-	-do-	-do-	SD013	76.43	-do-	24.5	49	-do-	-do-	morning
-do-	-do-	-do-	SD014	61.57	-do-	26.5	44	-do-	-do-	-do-
-do-	-do-	-do-	SD015	76.43	-do-	28.0	62	-do-	-do-	lunch
-do-	-do-	-do-	SD016	67.94	-do-	29.5	44	-do-	-do-	-do-
-do-	-do-	-do-	SD017	38.22	-do-	28.0	40	-do-	-do-	afternoon
-do-	-do-	-do-	SD018	21.23	-do-	27.5	39	-do-	-do-	-do-
17/08/95	-do-	-do-	SD019	29.72	-do-	26.0	42	-do-	-do-	-do-
-do-	-do-	-do-	SD069	60.00	-do-	18.0	72	-do-	-do-	morning
-do-	-do-	-do-	SD070	19.44	-do-	19.5	64	-do-	-do-	-do-
-do-	-do-	-do-	SD071	131.00	-do-	21.5	55	-do-	-do-	lunch
16/10/95	-do-	-do-	SD072	146.00	-do-	20.0	54	-do-	-do-	-do-
-do-	-do-	-do-	SD095	133.30	-do-	29.5	34	-do-	-do-	morning
-do-	-do-		SD027	143.00	-do-	24.0	61	-do-	-do-	-do-
16/10/95	INDUSTRIAL COMM. CENTRE	1A	SD096	150.00	-do-	27.5	35	-do-	-do-	morning
-do-	-do-	-do-	SD097	133.30	-do-	27.5	33	-do-	-do-	Lunch
-do-	-do-	-do-	SD098	166.64	-do-	28.0	36	-do-	-do-	afternoon
-do-	-do-	-do-	SD028	187.00	15 min	24.5	58	-do-	-do-	lunch

Appendix vi (continued)

Date	Area Category		Sample Run No.	Conc. ($\mu g/m^3$) SO_2
30/05/95	-do-	1B	SD028	81.00
-do-	-do-	-do-	SD030	108.00
25/07/95	-do-	-do-	SD064	571.00
-do-	-do-	-do-	SD065	787.00
-do-	-do-	-do-	SD066	910.00
-do-	-do-	-do-	SD067	186.00
-do-	-do-	-do-	SD068	586.00
11/09/95	-do-	-do-	SD110	-
-do-	-do-	-do-	SD111	133.33
-do-	-do-	-do-	SD112	150.00
-do-	-do-	-do-	SD113	200
-do-	-do-	-do-	SD114	166.67
04.05.95	-do-	1C	SD001	53.90
18.05.95	-do-	-do-	SD005	-
-do-	-do-	-do-	SD006	63.69
-do-	-do-	-do-	SD007	31.85
08.06.95	-do-	-do-	SD038	41.80
-do-	-do-	-do-	SD039	76.00
-do-	-do-	-do-	SD040	60.00
-do-	-do-	-do-	SD041	78.00
-do-	-do-	-do-	SD042	66.00
-do-	-do-	-do-	SD043	107.00
-do-	-do-	-do-	Sdo44	72.00
-do-	-do-	-do-	SD008	204.00
09.05.95	-do-	ID	SD004	46.50
17.08.95	-do-	-do-	SD073	107.00
11.09.95	-do-	-do-	SD074	111.00

Averaging Time	Temp./°C	Relative Humidity (%)	Wind Speed	Wind Direction	Time Category
30 min	23.5	58	-do-	-do-	-do-
-do-	24.5	55	-do-	-do-	afternoon
-do-	23.0	47	-do-	-do-	lunch
-do-	19.0	33	-do-	-do-	afternoon
-do-	19.00	57	-do-	-do-	-do-
-do-	19.5	57	-do-	-do-	-do-
-do-	21.5	33	-do-	-do-	lunch
-do-	27.5	47	-do-	-do-	-do-
-do-	28.5	38	-do-	-do-	afternoon
-do-	28.0	38	-do-	-do-	-do-
-do-	28.5	36	-do-	-do-	-do-
-do-	28.5	37	-do-	-do-	-do-
1hr	27.0	45	-do-	-do-	lunch
-do-	22.70	67	-do-	-do-	morning
30min	24.0	57	-do-	-do-	lunch
-do-	28.5	61	-do-	-do-	morning
-do-	24.0	47	-do-	-do-	-do-
-do-	25.0	48	-do-	-do-	-do-
-do-	26.5	40	-do-	-do-	lunch
-do-	27.5	33	-do-	-do-	-do-
-do-	30.0	36	-do-	-do-	afternoon
-do-	26.0	35	-do-	-do-	-do-
-do-	24.5	37	-do-	-do-	-do-
-do-	25.0	55	-do-	-do-	lunch
1hr	30.0	36	-do-	-do-	morning
30min	23.5	47	-do-	-do-	afternoon
-do-	20.5	59	-do-	-do-	morning

Appendix vi (continued)

Date	Area Category		Sample Run No.	Conc. ($\mu g/m^3$) SO_2	Averaging Time
-do-	-do-	-do-	SD075	68.36	-do-
-do-	-do-	-do-	SD076	75.95	-do-
11/09/95	-do-	ID	SD077	106.00	30 min
-do-	-do-	-do-	SD078	290.05	15 min
-do-	-do-	-do-	SD011	217.00	30 min
-do-	-do-	-do-	SD012	223.00	-do-
25/10/95	-do-	-do-	SD104	150.00	-do-
-do-	-do-	-do-	SD105	135.02	-do-
13/09/95	URBAN COMM. CENTRE	UK	SD079	83.30	-do-
-do-	-do-	-do-	SD080	38.89	-do-
-do-	-do-	-do-	SD081	166.67	-do-
-do-	-do-	-do-	SD082	106.00	-do-
-do-	-do-	-do-	SD083	97.22	-do-
15/09/95	-do-	UL	SD088	183.33	-do-
-do-	-do-	-do-	SD089	133.33	-do-
-do-	-do-	-do-	SD090	116.70	-do-
-do-	-do-	-do-	SD092	100.00	-do-
27/10/95	-do-	UL	SD106	200.00	30 min
-do-	-do-	-do-	SD107	194.00	-do-
13/07/65	-do-	UM	SD045	93.34	-do-
-do-	-do-	-do-	SD046	-	-do-
-do-	-do-	-do-	SD047	77.00	-do-
-do-	-do-	-do-	SD048	60.20	-do-
-do-	-do-	-do-	SD049	139.00	-do-
-do-	-do-	-do-	SD050	154.00	-do-
-do-	-do-	-do-	SD051	69.40	-do-

Temp./°C	Relative Humidity (%)	Wind Speed	Wind Direction	Time Category
20.5	54	-do-	-do-	lunch
21.0	55	-do-	-do-	-do-
21.5	52	-do-	-do-	afternoon
22.5	47	-do-	-do-	-do-
26.0	55	-do-	-do-	-do-
26.0	49	-do-	-do-	-do-
25.0	58	-do-	-do-	morning
27.5	47	-do-	-do-	lunch
26.5	49	-do-	-do-	morning
25.5	36	-do-	-do-	lunch
26.5	41	-do-	-do-	-do-
27.0	38	-do-	-do-	afternoon
26.0	38	-do-	-do-	-do-
25.0	36	-do-	-do-	morning
28.0	36	-do-	-do-	-do-
29.0	<36	-do-	-do-	lunch
29.5	<36	-do-	-do-	afternoon
25.0	43	-do-	-do-	morning
30.0	38	-do-	-do-	lunch
19.5	64	-do-	-do-	morning
21.0	62	-do-	-do-	-do-
20.0	62	-do-	-do-	morning
19.0	61	-do-	-do-	lunch
20.0	59	-do-	-do-	afternoon
21.5	59	-do-	-do-	-do-
21.0	69	-do-	-do-	-do-

Appendix vi (continued)

Date	Area Category		Sample Run No.	Conc. ($\mu g/m^3$) SO_2
-do-	-do-	-do-	SD053	83.30
24/10/95	-do-	-do-	SD102	200.00
-do-	-do-	-do-	SD103	133.33
02/06/95	-do-	UN	SD032	143.00
-do-	-do-	-do-	SD033	275.00
-do-	-do-	-do-	SD034	70.00
-do-	-do-	-do-	SD035	88.00
-do-	-do-	-do-	SD036	81.00
-do-	-do-	-do-	SD037	70.00
09/05/95	RESIDENTIAL UBAN CENTRE	R1	SD005	52.20
25/05/95	-do-	-do-	SD020	40.34
-do-	-do-	-do-	SD021	84.92
-do-	-do-	-do-	SD022	53.90
-do-	-do-	-do-	SD023	97.99
-do-	-do-	-do-	SD024	93.09
-do-	-do-	-do-	SD025	83.29
-do-	-do-	-do-	SD026	46.54
20/07/95	-do-	-do-	SD058	72.50
-do-	-do-	-do-	SD059	12.80
-do-	-do-	-do-	SD060	29.30
-do-	-do-	-do-	SD061	30.90
-do-	-do-	-do-	SD062	13.90
-do-	-do-	-do-	SD063	37.00

Averaging Time	Temp./^oC	Relative Humidity (%)	Wind Speed	Wind Direction	Time Category
-do-	20.5	69	-do-	-do-	-do-
-do-	23.0	-	-do-	-do-	morning
-do-	23.5	-	-do-	-do-	lunch
-do-	26.5	44	-do-	-do-	morning
15 min	28.5	40	-do-	-do-	lunch
30 min	29.5	44	-do-	-do-	-do-
-do-	27.5	47	-do-	-do-	afternoon
-do-	28.5	48	-do-	-do-	-do-
-do-	25.5	55	-do-	-do-	-do-
30 min	30.0	37	LOW	SE	lunch
-do-	25.5	51	-do-	-do-	morning
-do-	27.0	49	-do-	-do-	-do-
-do-	26.5	47	-do-	-do-	lunch
-do-	25.0	43	-do-	-do-	-do-
-do-	25.0	44	-do-	-do-	afternoon
-do-	23.5	47	-do-	-do-	-do-
-do-	21.5	67	-do-	-do-	-do-
-do-	25.0	47	-do-	-do-	morning
-do-	28.0	38	-do-	-do-	-do-
-do-	27.5	33	-do-	-do-	lunch
-do-	27.0	<33	-do-	-do-	-do-
-do-	26.0	33	-do-	-do-	afternoon
-do-	26.5	34	-do-	-do-	-do-

Appendix vi (continued)

Date	Area Category		Sample Run No.	Conc. ($\mu g/m^3$) SO_2	Averaging Time	Temp./^oC	Relative Humidity (%)	Wind Speed	Wind Directi-on	Time Category
31/10/95	RESIDENTIAL URBAN CENTRE	R1	SD108	16.67	30 min	22.0	72	-do-	-do-	morning
-do-	-do-	-do-	SD109	13.30	-do-	23.5	52	-do-	-do-	afternoon
18/07/95	-do-	R2	SD053	85.45	-do-	25.0	65	-do-	-do-	morning
-do-	-do-	-do-	SD054	65.14	-do-	26.0	47	-do-	-do-	lunch
-do-	-do-	-do-	SD055	43.20	-do-	27.0	<34	-do-	-do-	-do-
-do-	-do-	-do-	SD056	92.37	-do-	24.0	42	-do-	-do-	afternoon
-do-	-do-	-do-	SD057	46.06	10 min	25.0	37	-do-	-do-	-do-
14/09/95	-do-	-do-	SD084	95.15	30 min	25.5	44	-do-	-do-	morning
-do-	-do-	-do-	SD085	23.33	-do-	26.5	38	-do-	-do-	-do-
-do-	-do-	-do-	SD086	-	-do-	27.5	34	-do-	-do-	lunch
-do-	-do-	-do-	SD087	116.67	-do-	26.5	34	-do-	-do-	afternoon
17/10/95	-do-	R3	SD099	15.00	-do-	23.5	54	-do-	-do-	morning
-do-	-do-	-do-	SD100	15.00	-do-	25.0	47	-do-	-do-	-do-
-do-	-do-	-do-	SD101	12.00	-do-	29.0	<34	-do-	-do-	afternoon

* Highly localized and intermittent concentrations

Morning (0900 – 1200hr.)
Lunch (1201 – 1400hr)
Afternoon (1401- 1700hr.)

APPENDIX VII: Hydrogen sulphide (H_2S) content in airborne gaseous pollutants (Athi-River town)

Date	Area category	Site	Sampling run no.	H_2S(μ g/m^3)	Averaging time (min)	Temp./^{0}C	Relative humidity(%)	Wind speed (m/s)	Wind direction	Time category
16.10.95	Industrial commercial centre	1A	HS013	6.84	30	27.5	33	LOW	SE	Lunch
“	“		HS014	37.59	”	28.5	36	”	”	Aftn.
01.11.95	“		HS013	3..49	”	27.5	38	”	”	Lunch
“	“		HS033	8.90	”	25.5	33	”	”	Aftn.
20.09.95	“	1D	HS001	52.40	”	25.5	54	”	”	Morn.
“	“		HS002	80.27	”	25.5	44	”	”	Mon
“	“		HS003	120.98	”	24.5	48	”	”	Lunch
“	“		HS004	200.93	”	27.0	43	”	”	Lunch
“	“		HS005	75.50	”	28.0	57	”	”	Lunch
“	“		HS006	25.89	”	26.5	44	”	”	Aftn.
“	“		HS007	15.53	”	26.0	41	”	”	Aftn.
22.09.95	“		HS008	38.33	”	23.0	55	”	”	Morn
“	“		HS009	-	”	34.5	43	”	”	Lunch
“	“		HS010	69.40	”	26.0	42	”	”	Lunch
“	“		HS011	52.40	”	27.0	33	”	”	Aftt.

Appendix vii (continued)

25.10.95	Industrial commercial centre	ID	HS024	52.97	30	23.0
“	“		HS025	90.56	„	25.5
“	“		HS026	111.06	„	29.0
“	“		HS027	100.81	„	25
24.10.95	Urban commercial centre	UM	HS020	46.13	„	23.5
“	“		HS021	97.39	„	24.5
“	“		HS022	22.21	„	24.5
“	“		HS023	119.61	„	24.0
27.10.95	“	UL	HS028	1.75	„	24.5
“	“		HS029	87.14	„	29.5
31.10.95	Residential urban centre	R1	HS030	3.49	„	24.0
“	“		HS031	6.99	„	24.0
“	“		HS032	13.49	„	25.0
17.10.95	“	R2	HS015	55.90	„	22.0
“	“		HS016	90.83	„	24.5
“	“		HS017	87.14	„	26.0

64	LOW	SE	Morn.
50	,,	,,	Mon
41	,,	,,	Lunch
50	,,	,,	Aftn.
68	,,	,,	Morn.
59	,,	,,	Lunch
56	,,	,,	Aftn.
53	,,	,,	Aftn
61	,,	,,	Morn.
47	,,	,,	Lunch.
59	,,	,,	Lunch
53	,,	,,	Aftn.
51	,,	,,	Aftn.
57	,,	,,	Morn.
48	,,	,,	Morning.
36	,,	,,	Lunch

Appendix vii (continued)

“	“	R3	HS018	87.14	”	28.5
“	“		HS019	17.09	”	28.5

HS: Hydrogen Sulphide

Morn: Morning (0900-1200hr) Lunch (1201-1400hr)

Aftn. Afternoon (1401-1700hr)

<34	”	”	Aftn.
<34	”	”	Aftn.

APPENDIX VIII: Ammonia (NH_3) content in air borne gaseous pollutants (Athi-River Town)

Area category	Date	Site	Sampling run no.	NH_3conc. ($\mu g/m^3$)	Averaging time in (min)	Temp. ^0C	Relative humidity (%)	Wind speed (m/s)	Wind direction	Time category
Industrial commercial centre	17.08.95	IA	NH007	71.11	30	17.0	72	Low	SE	Morn.
			NH008	42.67	"	21.0	59	"	"	"
			NH009	14.22	"	21.0	52	"	"	Lunch
			NH010	14.22	"	23.0	47	"	"	Aft.
	16.10.95		NH039	34.28	"	27.0	33	"	"	Lunch
			NH040	17.14	"	28.0	36	"	"	Aft.
		IB	NH005	85.71	"	21.0	48	"	"	Morn.
	25.07.95		NH006	38.23	"	19.0	57	"	"	Lunch
		IC	NH048	34.28	"	22.5	61	"	"	Morn.
	25.10.95	IC	NH049	17.14	"	26.5	49	"	"	"
		ID	NH011	51.48	"	20.5	55	"	"	"
	11.09.95		*NH012*	*102.00*	"	*21.0*	*60*	"	"	*Lunch.*
			NH013	113.46	"	21,5	55	"	"	Aft.
			NH014	87.32	"	22.5	52	"	"	"
			NH027	*603	"	26.5	39	"	"	Morn
Industrial	18.09.95	ID	NH028	*412	30	27.0	36	LOW	SE	Lunch.

Appendix viii (continued)

commercial centre					
			NH029	*381	[illegible]
			NH030	*492	[illegible]
	20.09.95		NH031	47.62	[illegible]
			NH032	63.49	[illegible]
			NH033	63.50	[illegible]
			NH034	15.87	[illegible]
	22.09.95		NH035	49.2	[illegible]
			NH036	94.2	[illegible]
			NH037	30.2	[illegible]
			NH038	21.33	[illegible]
Urban commercial centre	13.09.95	UK	NH015	14.22	[illegible]
			NH016	113.78	[illegible]
			NH017	34.84	[illegible]
			NH018	137.00	[illegible]
			NH019	42.67	[illegible]
	15.09.95	UL	NH024	99.56	[illegible]
			NH025	137.14	[illegible]
			NH026	88.44	[illegible]
	27.10.95		NH050	34,28	[illegible]

28.0	36	,,	,,	Aft.
23.0	55	,,	,,	Morn.
25.0	54	,,	,,	Morn.
27.0	43	,,	,,	Lunch
28.0	57	,,	,,	,,
27.5	36	,,	,,	Lunch
28.0	34	,,	,,	Morn.
24.0	43	,,	,,	Lunch
29.0	33	,,	,,	Aft.
-	-	,,	,,	,,
25.5	38.5	,,	,,	Morn

28.0	36	,,	,,	Lunch
26.5	41	,,	,,	Aft
25.5	42	,,	,,	,,
26.0	36	,,	,,	,,
26.5	36	,,	,,	Morn.
27	36	,,	,,	Lunch
29.0	<36	,,	,,	Aft.
29.5	34	,,	,,	Morn.

Appendix viii (continued)

			NH051	34.28
	24.10.95	UM	NH045	25.46
			NH046	-
			Nh047	17.14
Residential Urban centre	31.10.95	R1	NH052	17.14
			NH053	89.10
	18.07.95	R2	NH001	85.33
			NH002	128.00
			NH003	128.00
			NH004	42.67
Residential urban centre	17.10.95	R2	NH041	51.43
			NH042	85.71
			NH043	51.43
			NH044	-
	14.09.95	R3	NH020	56.89
			Nho21	-
			NH022	28.44
			NH023	21.33

〃	28.0	-	〃	〃	Lunch
〃	23.5	62	〃	〃	Morn.
〃	24.0	62	〃	〃	Lunch
〃	27.5	53	〃	〃	Aft
〃	23.0	69	〃	〃	Lunch

〃	26.0	45	〃	〃	Aft
〃	25.0	65	〃	〃	Morn.
〃	26.5	47	〃	〃	Lunch
〃	27.0	<34	〃	〃	Aft.
〃	24.0	42	〃	〃	〃
〃	22.0	57	〃	〃	Morn.

〃	27.0	41	〃	〃	Lunch
〃	28.5	<34	〃	〃	Aft.
〃	28.5	<34	〃	〃	Aft.
〃	24.0	43	〃	〃	Morn
〃	27.5	36	〃	〃	Lunch
〃	28.5	<34	〃	〃	Aft.
〃	24.5	34	〃	〃	〃

Appendix viii (continued)

NH: Ammonia

Morn: Morning (0900-1200hr) Lunch (1201-1400hr)

Aft: Afternoon (1401-1700hr)

*: Highly localised and intermittent concentrations.