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SPATIAL VARIATION OF POLLUTANT GASES AND PARTICULATE MATTERIN THE AMBIENT AIR OF ADDIS ABABA

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ABSTRACT

This research work presents analysis the spatial variation of ambient air pollutants patterns in Addis Ababa city area with integration of Geographical Information System (GIS).The goal of this study is to quantify and identify the spatial distribution of the four air pollutant gases namely CO, SO_2, NO_2, VOCs, and the particulate matter (PM10) in the city by the land utilization category(industrial, transport, and residential area)because of their public health risks and also their magnitude in the cities air is not known. Fifty four sampling locations are selected for ambient air pollutant gas and twenty sampling locations are selected for particulate matter (PM10). Three common locations are selected as control area. Samples were collected during the dry season (January, 1- April 30, 2017 at a total of seventy seven sites.

The average mean concentrations of the air pollutants in cities were CO=14.10 ppm, NO_2=0.18ppm, SO_2= 0.30ppm, and VOCs=526.6 µg/m3.The average mean concentration of the pollutant gases obtained at different land use in the city is indicted as follows:

Traffic related area [CO=14.99ppm, NO_2 =0.24ppm, SO_2=0.51ppm, VOCs =563 µg/m3], Industrial area [CO=14.63ppm, NO_2 =0.27ppm, SO2=0.51ppm, VOCs=563 µg/m3], and Residential area [CO=11.67ppm, NO_2 =0.16ppm, SO_2=0.2ppm, VOCs=342 µg/m3].

The particulate matter (PM10) mass concentrations found to be with mean concentration of 326 µg/m3.

The mean value of the pollutants in the ambient air of Addis Ababa were found to be above the prescribed standards of East African Standards, WHO and others international standards.

Keywords: Particulate matter; nitrogen dioxide; sulfur dioxide, carbon dioxide, VOCs.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Air is one of the most important constituents of man's environment. It is essential for life and constitutes the immediate physical environment of living organisms. It is a mixture of various gases like nitrogen, oxygen, carbon dioxide, and other trace elements; along with water vapor perceptible as humidity and suspended solids in particulate form.

An average human being requires about 12kg of air each day, which is nearly 12 to 15 times greater than the amount of food consumed. Therefore, clean and pure air is very essential for human health and survival. Any change in the natural and normal composition of air that may adversely affects the living system; particularly the human life invariably causes air pollution ((Garg, S. K., Garg, R. and Garg, R., 2006).

The atmosphere is the gaseous envelope that surrounds the earth and constitutes the transition between its surface and the vacuum of space (Bhatia, 2009). The atmosphere is composed primarily of nitrogen (N_2) and oxygen (O_2) and is made up of many layers of air, in each one which is identified by their thermal characteristics or temperature changes, chemical composition, movement and density (Narayanan, 2009).

Life on earth is supported by the layers of air, solar energy and our planet's magnetic fields, and the quality of air is very essential to its sustenance (Oxlade, 1994; Ojo and Awokola, 2012).Air pollution is the introduction of chemicals, particulate matter or biological materials that cause harm and discomfort to humans and other living organisms (Bhatia, 2009). The most common air pollutants in the urban environment

include: sulphur dioxide (SO_2); oxides of nitrogen (NO_x), such as nitrogen oxide, (NO) and nitrogen dioxide (NO_2); carbon monoxide (CO);volatile organic compounds (VOCs); ozone (O_3); suspended particulate matter (SPM) also called particulates; and lead (Pb) (Lutgens and Edward, 2000). Air pollutant can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made (USEPA, 2006; Narayanan, 2009) Air pollution is the presence in the outdoor atmosphere of one or more contaminants such as fumes, dust, gases, mist, odor, smoke, smog or vapors in considerable quantities and duration of which is injurious to human, animal and plant life or which unreasonably interferes with the comfortable enjoyment of life and property (Anjaneyulu, 2005).

Air pollution in the urban center has increased rapidly due to high population density, increased numbers of motor vehicles, use of fuels with poor environmental performance, poorly maintained transportation systems and above all, ineffective environmental regulations and policies (Komolafe*et al*,2014).

Based on this study, an attempt was made to investigate the air pollution status of the city sources of air pollution include traffic (vehicle exhaust), industrial sectors (from brick making to oil and gas production), power plants and generating sets, cooking and heating with solid fuels (e.g. coal, wood, crop waste), forest fires and open burning of municipal waste and agricultural residues (Akanni, 2010; Komolafe*et al*., 2014).

Air pollution is a problem that is directly related to the number of people living in an area and the kinds of activities they are engaged in. In a place where the population is low and their energy usage is also low, the impact of people in creating pollution is minimal.

However where the population is high, the area urbanized and industrialized with high energy usage large quantities of pollutants are released into the environment.

It is clearly obvious that the greater the concentration of people in one area, the greater the amount of pollution and the greater the sophistication of a society the more intricate and poignant its pollution (1978, Inyang, P).

Increasing demand on transportation service and challenges of the prevailing poverty are basic problems in emerging cities of developing countries, such as Addis Ababa. More than 50% of cities with increased level of ambient urban air pollution are found in developing countries (World Bank: World development indicators 2005).

Data inventories from worldwide mega cities indicated that urban air pollution due to vehicular emissions is evident in developing countries (World Health Organization Global Update 2005). There is a limited source of evidence describing urban air pollution in Ethiopia. There is only one study that has undertaken the measurement of PM10, CO, airborne lead, ozone, and SO_2 in the ambient environment and concluded the likely of increasing these pollutants in future (Atmospheric Environment 2005).

The present study focused on the exploration of the level, temporal, spatial variations of CO ,NO2, SO2,VOCs,and PM10 ambient air pollution of the City of Addis Ababa as measured by Aeroqual portable instrument in selected air sampling sites.

1.2 STATEMENT OF THE PROBLEM

Addis Ababa faces a rapid increase in air pollution due to high rate urbanization, industrialization, motorization, growing population, and migration since the recent decades. Tiwari, Alok Urban Air Pollution (June 5, 2012)

Not many studies seem to have been carried out on outdoor ambient air pollution in Addis Ababa. Review of the few studies conducted showed that a study conducted in Addis Ababa in a dry season (January-February 2004) by V. Etyemezian et al. (2005) found that PM10 mass concentrations urban sites ranged between 35 and 97 mg/m3. CO concentrations measured with portable Instruments were comfortably within both the 1-h standard (35 ppm) and the 24-h standard (9 ppm).In another study also conducted in Addis Ababa on PM10 from February 22, 2008 to April 15, 2008 found that PM10 ranging from 17 µg/m3 (COLTI site) to 285 µg/m3 (KWWT).Another study research entitled Magnitude and variation of traffic air pollution as measured by CO in the City of Addis Ababa, Ethiopia [Ethiop. J. Health Dev. 2010; 24 (3):156-166] by Dr. Abera Kumie found that the overall mean on-road CO concentration was 5.4 ppm. Since the above studies results had been done a long time ago and didn't includes the rest of main ambient air pollutants like SO_2, NO_2, and VOCs, in this study an attempt was made to fill the following gaps:-

- To measure the spatial distribution of pollutants
- To determine trends in concentrations of various pollutants
- To ascertain compliance with air quality standards

The spatial distribution of the four major air pollutant [CO, SO2, NO_2, and VOCs] gases related to Industrial, transport, and residential area are not known in the city.

1.3. GENERAL AND SPECIFIC OBJECTIVES OF THE STUDY

1.3.1. GENERAL OBJECTIVE

The general objective of the study is to evaluate the concentration level and spatial distribution of the four air pollutant gases and particulate matter (PM10) in the ambient atmosphere of Addis Ababa

1.3.2. SPECIFIC OBJECTIVES

Specific objectives that needed to be addressed in the study are:

1. To quantify the concentration level of the four ambient air pollutant gases such as Carbon Monoxide (CO) Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), Volatile Organic Compounds (VOCs), and particulate matter (PM10) in the city.

2. To analyze the distribution and pattern of the four ambient air pollutant gases and Particulate matter (PM10) in the city at different land use type

1.4 RESEARCH QUESTIONS

To respond to the study's general and specific objectives the following essential research questions are formulated. The research questions for the study are:

1. What is the level concentration of the four air pollutant gases in the ambient air in the city?

2. How is the distribution and pattern of the air pollutant gases in the city?

3. How their concentration varies at different land use?

1.5 SIGNIFICANCE OF THE STUDY

Provision of air pollution data to the public and other concerned stakeholders in a timely manner enables to support compliance with ambient air quality standards (primary and secondary), emission strategy development, and the enhancement of air pollution studies. This is through studying the level of pollutants in the city in a way, which enables to provide timely scientific and technical information that will allow the city and lower level districts to make sound policy decisions and effectively implement air pollution control programs in the city.

Based on this, the intention of this study is to investigate the level of concentration and spatial distribution of the four air pollutant gases and particulate matter (PM_{10}) in the ambient atmosphere of the city. Through its process and outcome, this research work is expected to serve two purposes. First; the study will provide basic and useful information for different stakeholders who want to know about the air pollution status of the city.

In addition it will help researchers and organizations who want detail studies in this area.

1.5 SCOPE AND LIMITATION OF THE STUDY

The scope of the study is limited to studying the air pollution status of the ambient air pollutants of city, which has been sampled in seventy-seven selected sites according to their land type: industrial, transport, and residential (fifty four sites for pollutant gases CO_2, NO_2, SO_2, VOCs, and twenty sites for PM_{10}, and 3 for control area) sample sites. The study has used the data from the selected sampling sites in the city for the months of January, 2017 and March, 2017.

It is generally to present the case of Addis Ababa with emphasis on regarding urban ambient air pollutants and their spatial distribution at different land use. It means at industrial sites. Traffic related sites, and residential area. This will be done through a literature review and evaluating them by direct measurement on the selected sites using Aeroqual portable and air pump sampling instruments.

There is a limited source of evidence describing urban air pollution in Ethiopia.

The study has revealed worth information about the presence of major air pollutant gases and indicated the need for conducting comprehensive research on air pollution status in the city. To formulate recommendations and suggestions to help solve the problem

Its limitation was the characterization of Particulate Matter (PM_{10}) and the Volatile Organic Compounds (VOCs) were not done due to unavailability of instruments.

CHAPTER TWO

LITERATURE REVIEW

2.1 URBAN AREAS FOCUS OF RESEARCH STUDY ON AIR POLLUTION

The literature review used a set criteria to select the Peer-reviewed articles.

A pilot study was conducted at 12 sites in Addis Ababa using 21 samples in a dry season (January-February 2004). The purpose of the study was to assess ambient air quality by measuring PM10, CO, and O3. In the study, the concentrations of 40 elements in the sampled particles taken from two (one urban and one sub-urban) areas were compared.

A study conducted in Addis Ababa found that PM10 mass concentrations measured in urban areas in the dry months (January/February) were higher (<100 µg/m3) than those in sub-urban areas (40 µg/m3). (26). PM10 concentrations at urban sites ranged between 35 and 97 mg/m3.Based on analysis of the aerosol components, ~35–65% of the PM10 was of geologic origin and probably due to paved and unpaved road dust, and ~35–60% was due to OM and EC.

CO concentrations measured with portable instruments were comfortably within both the 1-h standard (35 ppm) and the 24-h standard (9 ppm).A study carried out in Addis Ababa reported a significant difference in the 15-minute concentrations of CO between the wet and the dry seasons with means of 2.1ppm (Geometric Mean, GM=1.3) and 2.8ppm (GM=2.2), respectively. The study, however, reported a similar temporal and spatial profile between the wet and the dry seasons. The mean CO concentration of all on-road collected samples was 5.4ppm (GM=5.3). Fifteen percent of the samples collected on the

roadside and all (100%) on-road samples were measured at greater than 50% of the 8-hour CO WHO guideline value.

Daily maxima of CO concentration were observed in early mornings and late afternoons during the study periods (Kumie A, Ethiop. J. Health Dev. 2010h).

Ambient air quality was monitored and analyzed to develop air quality index and its implications for livability 7 and climate change in Dire Dawa, Ethiopia. Using survey research design, 16 geo-referenced locations, representing different land uses, were randomly selected and assessed for sulfur dioxide (SO_2) nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO),Volatile Organic Compound (VOC) and meteorological parameters (temperature and relative humidity). The study found mean concentrations across all land uses for SO_2 of 0.37 ± 0.08 ppm, NO2 of 0.13 ± 0.17 ppm, CO2 of 465.65 ± 28.63 ppm, CO of 3.35 ± 2.04 ppm and VOC of 1850.67 ± 402 ppm. An air quality index indicated that ambient air quality for SO_2 was very poor, NO_2 ranged from moderate to very poor, while CO rating was moderate (Kasim, Oluwasinaayomi December 2017).

2.2 OVERVIEW OF AIR POLLUTION AND URBAN AIR QUALITY MANAGEMENT

The present-day atmosphere is quite different from the natural atmosphere that existed before the Industrial Revolution, in terms of chemical composition. If the natural atmosphere is considered to be "clean", then this means that clean air cannot be found anywhere in today's atmosphere. Defining "air pollution" is not simple. One could claim that air pollution started when humans began burning fuels. In other words, all man-made (anthropogenic) emissions into the air can be called air pollution, because they alter the chemical composition of the natural atmosphere. The increase in the global concentrations of greenhouse gases CO, CH, and NO, can be called air pollution using this approach, even though the concentrations have not found to be toxic for humans and the ecosystem.

One can refine this approach and only by considering anthropogenic emissions of harmful chemicals as air pollution (Daly and Zannetti, 2007).

However, this refined approach has some drawbacks. First, one has to define what "harmful" means. Sometimes the definition abandon for chemical that does not cause any short-term harmful effects may accumulate in the atmosphere and create a long-term harmful effect. Another drawback of this approach is that it does not consider natural emissions as air pollution even though they can be very harmful. Therefore, besides anthropogenic emissions, it is useful also to consider geogenic emissions and biogenic emissions as contributors to air pollution. Geogenic emissions are defined as emissions caused by the non-living world, such as volcanic emissions, sea-salt emissions, and

natural fires. Biogenic emissions come from the living world; such as volatile organic compound (VOC) emissions from forests and CH emissions from swamps.

So by taking all of the above into account, we can define an "air pollutant" as any substance emitted into the air from an anthropogenic, biogenic, or geogenic source, that is either not part of the natural atmosphere or is present in higher concentrations than the natural atmosphere, and may cause a short-term or long-term adverse effect (Builtjes, 2003).

Air pollution information is essential for successful Air Quality Management. For an issue specific working group on Air Quality to progress effectively through the Environmental Planning and Management process, a sufficient amount of relevant and reliable information is necessary at each stage. Information must be properly analyzed and understood so that technical dimensions of the problems are known and the feasibility of various approaches is appreciated.

The first tangible output of the EPM process in a municipality usually is the development of an Environmental Profile (EP). Key stakeholders from different sectors – private, public, and community – are involved through a consultative process in the preparation of the Environmental Profile and in identifying the environmental priority issues facing the municipal areas. The main objectives of the EP are to clarify the environment-development interactions in an urban setting. Experience with City Consultations has shown that air quality is a priority issue for many municipalities, cities, and agglomerations in developing countries. The EP provides an important information base because it serves as a common context for all groups working on air quality and other environmental issues.

By design though, the Environmental Profile is not meant to contain very detailed information on any one resource (such as air).

Working groups have generally found that more detailed information is necessary, because the issues must be further clarified before considering options and formulating strategies. Consensus is usually reached on the need to prepare an Air Quality Profile (AQP). Since the Environmental Profile (EP) covers all the city's important environmental issues, the Air Quality Profile will contain valuable information on air quality and the factors affecting it (such as activities with negative effects, conflicts of interest over air pollution, overview of the organizations and groups involved in air quality management). The EP provides the first basic source of information for any air quality working group (or other groups grappling with air quality management issues). The first task of any working group preparing an Air Quality Profile should be to thoroughly review the EP in order to extract the wealth of available information and to identify gaps where progress needs to be made. ((UNHSP, 2007).)

2.3. OVERVIEW KEY URBAN AIR POLLUTANTS AND THEIR SOURCES

Pollutants, which fulfill for the above definition (i.e. substance emitted into the air from an anthropogenic, biogenic, or geogenic sources), can be classified as primary or secondary. Primary pollutants are substances that are directly emitted into the atmosphere from sources. The main primary pollutants known to cause harm in high enough concentrations are carbon, halo genic, nitrogen and sulfur compounds and particulate matters in both solid and liquid forms. Secondary pollutants are also pollutants, which are not directly emitted from sources, but instead form in the

atmosphere from primary pollutants (also called "precursors"). The main secondary pollutants known to cause harm in high enough concentrations are: Nitrogen Dioxide, Ozone (O_3), Sulfuric acid droplets formed from SO_2, and nitric acid droplets formed from NO_2, Sulfates and nitrates aerosols (e.g., ammonium (bi) sulfate and ammonium nitrate) formed from reactions of sulfuric acid droplets and nitric acid droplets with NH3, and organic aerosols formed from VOCs in gas-to-particle reactions (UNHSP, 2007) and UNEP/WHO (1992).

Air pollution emanates from various sources, which include natural and anthropogenic sources. However, most forms of air pollution are as a result of human activities. In urban areas, combustion of fossil fuels from transportation, power generation, and other human activities produces a complex mixture of pollutants comprising literally thousands of chemical constituents (Derwent, 1999). Exposure to such mixtures is a ubiquitous feature of urban life. The precise characteristics of the mixture in a given locale depend on the relative contributions of the different sources of pollution, such as vehicular traffic and power generation, and on the effects of the local geo-climatic factors (Holman 1999).

The most common air pollutants in the urban environment which are used as measurement of urban air pollution status include Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Volatile Organic Compounds (VOCs), and Atmospheric Particulate Matter (1990)US-EPA (NAAQS).

2.3.1 Carbon Monoxide (CO)

Carbon monoxide (CO) is an odorless, colorless, and tasteless gas found in high concentrations in the urban atmosphere. No other gaseous air pollutants with such a toxic

potential exist at such high concentrations in urban environments. It is also slightly heavier than air and tends to collect in confined spaces. The written history of carbon monoxide goes back many years, as Roman records discuss deaths associated with fires in enclosed spaces. Early exposures resulted from the use of wood- burning fires and then from using coal for domestic heating. Combustion of fossil fuel associated with developing industry, explosions, fires in mines, and illumination gas prepared from coal all have been sources of exposure. The migration of agricultural populations to cities increased the proportion of exposed population, as well as the number of persons generating CO. With the emergence of automobiles propelled by internal combustion engines, CO emitted from exhaust pipes has become the major source for human exposure. Serious problems also exist due to occupational exposure to increased levels of CO. (Ming-Ho, 2005)

Carbon monoxide is usually formed through one of the following three processes: incomplete combustion of carbon-containing fuels, reactions between CO and carbon-containing materials at high temperature, and dissociation of CO at high temperatures. Human exposure to CO occurs mainly from three sources: ambient air, occupational exposure, and cigarette smoke.

2.3.2 Nitrogen Dioxide (NO_2)

Six forms of nitrogen (N) oxides occur in the atmosphere: nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen trioxide (N_2O_3), nitrogen tetroxide (N_2O_4), and nitrogen pent oxide (N_2O_5). Of these, NO_2 is the most important air pollutant because of its relatively high toxicity and its ubiquity in ambient air, while N_2O, N_2O_3, and N_2O_4

have low relative toxicity and air pollution significance. Several reactive N species, including NO, NO_2, nitric acid (HNO_3), occur in the troposphere. Among these, NO_2 is of particular environmental concern because it plays a complex and important role in the production of photochemical oxidants and acidic deposition. NO_2 is a unique air pollutant because it absorbs UV light energy and is then broken down to NO and atomic oxygen. The energetic oxygen atom reacts with molecular oxygen to form O_3. The resultant O_3 then reacts with NO to form molecular oxygen and NO_2, thus terminating the photolytic cycle of NO_2. (Ming-Ho, 2005)

Nitrogen dioxide (NO_2), which has greater health effects, is a secondary pollutant and formed directly by higher temperature combustion in power plants or indoors from gas stoves. Levels of exposure to nitrogen dioxide that should not be exceeded (WHO guideline levels) are respectively 400 μg/m3 (0.21 parts per million (ppm) for one hour and 150 μg/m3 (0.08 ppm) for 24 hours (WHO, 1987).

2.3.3 Sulfur Dioxide (SO_2)

SO_2 and sulfur trioxide (SO_3) are the two sulfur oxides (SO_x) that are important air pollutants. This paper focuses on SO_2 because it is far more important than SO_3 as an air pollutant. In fact, based on the quantities emitted into the atmosphere, SO_2 is considered the most dangerous of all gaseous pollutants. It is a serious problem in air pollution starting from the earliest days of industrialization.

SO_2 is highly soluble in water. When SO_2 is emitted into the atmosphere, it can dissolve in fog or cloud droplets, forming sulfurous acid (H_2SO_3), which is readily oxidized by molecular oxygen (O_2) to sulfuric acid ($H2SO_4$). The formation of $H_2SO_4$by this process

is greatly facilitated by some metal salts, which are also dissolved in the droplets. Any ammonia (NH3) present in the atmosphere will rapidly react with the $H2SO_3$ or H_2SO_4 droplets to form ammonium sulfate or ammonium bisulfate. (Kellogg, 1972)

SO_2 has been the major problem in reducing or acidifying air pollution during the period of rapid economic growth in many countries. Sulfate, the sulfur-containing ion present in water, remains a major constituent of air pollution capable of forming acid. Low quality coal and petroleum contain sulfur compounds, and generate sulfur dioxide when burned. During this process, the gas reacts with water and atmospheric oxygen to form sulfuric acid (H_2SO_3) and thus acid rain. It may also transported long distances in the atmosphere away from its source and result in acidification of water and soils. (Ming-Ho, 2005)

Coal burning accounts for 50% of annual global SO_2 emissions, making it the largest source, with oil burning as second at 25–30 %. Oil refineries, power houses, metallurgical operations (i.e. smelting of non–ferrous ores of copper, lead, nickel, and zinc), manufacture of sulfuric acid, conversion of wood pulp to paper, refuse incineration, sulfur elements production and domestic fuel burning are also causes for the production of this pollutant gas. Natural processes like volcanoes also produce for this pollutant gas (UNHSP, 2007).

2.3.4 Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are liquid or solid compounds which contain organic carbon and their rate of evaporation is significantly high. These compounds after particulate matters have the greatest abundance and diversity of emission and are typically caused by mobile and stationary sources such as industries, paints, surfactants,

and cooking (Broderick B, Marnane I. 2002; 36:975-86).Depending upon compositions and concentrations, VOCs lead to various impacts on health and sanitation. The ranges of impacts are included from odor nuisance to lung capacity malfunctioning and even cancer. VOC concentration levels were so high in some sites in the USA which cause cancer, birth defects, and other serious diseases (Nguyen HT, Kim KH, Kim MY2009; 161:163-74).More than 50% of emitted VOCs are caused by vehicles which gasoline engines have the majority of proportion in comparison with gasoline engines (Watson JG, Chow JC, Fujita EM2001; 35:1567-84).High rate of industrialization/urbanization process, especially in developing countries, leads to an increase in the emission of many types of air pollutants due to fossil fuel combustion. Volatile organic compounds (VOCs) are one of the most important groups of air pollutants in the urban atmosphere because they can cause significant risk to human health. Many VOCs have been reported to be toxic, carcinogenic or mutagenic (Duce et al, 1983; Edgerton et al., 1989; Sweet and Vermette, 1992; Kostiainen, 1995; Mukund et al., 1996). Ground level ozone, photochemical oxidants and smog episodes (Monod et al., 2001) and they are harmful to the ecosystem (Derwent, 1995; Kuran and Sojak, 1996; Dewulf and Van Langenhove, 1997; Atkinson, 2000). In addition, ozone and photochemical oxidants lead to an increase in the formation and fate of airborne toxic chemicals and fine particles (Finlayson-Pitts and Pitts Jr., 1997).Recently, a number of volatile organic compounds (VOCs) have been identified as important cancer risk factors in the urban environment (Hagerman et al., 1997).These compounds (VOCs) are not routinely monitored in urban air, and no ambient air quality standards have yet been established for them. In addition, through complex photochemical reactions, VOCs contribute to the formation of toxic oxidants (World

Meteorological Organization, 1985; Finlayson-Pitts and Pitts, 1986; Lioy and Daisey, 1986; Atkinson et al., 1988; Shah and Singh, 1988) such as tropospheric ozone, and peroxyacetyl nitrate (PAN), which are detrimental to health and are phytotoxic.In urban and industrial areas, many hydrocarbons, including VOCs, are emitted from anthropogenic sources, such as transportation, fossil fuel-burning power plants, chemical plants, petroleum refineries, certain construction activities, solid waste disposal and slash burning (Arya, 1999; Davis and Otson, 1996). In addition to the anthropogenic sources, many VOCs are produced naturally by vegetation. Biogenic emissions of hydrocarbons are likely to exceed anthropogenic emissions in heavily vegetated and forested regions (Winer et al., 1992; Arya, 1999).The mechanisms and products of atmospheric reactions of biogenic organics are not well understood. A few quantitative studies (Kamens et al., 1982; Atkinson, 1990; Tuazon and Atkinson, 1990), have indicated that formaldehyde is the only HAP known to result from atmospheric transformations of biogenic hydrocarbons.

2.2.5 Atmospheric Particulate Matter

Particulate Matters refers to small solid and liquid aerosols suspended in the atmosphere. The physical dimensions and chemical properties of these aerosols vary greatly. Particles may be solid or liquid and are one of the most obvious forms of pollution as they are visible in the hazes that cover a city or region. The composition of particulates varies from place to place, and includes thousands of entities that differ in size, surfaces, and toxicity.

Size is the main determinant of the behavior of atmospheric particles. The size is usually expressed in terms of the ‘aerodynamic diameter’, which refers to unit density of

spherical particles with the same aerodynamic properties, such as the falling speed. Larger particles (greater than 50 μm) usually remain in the air for a few minutes and settle near the source. Smaller particles (less than 10 μm, known as PM10) can remain in the air for several days and can be spread by winds over wide areas or long distances from the original source. Fine particles (between 0.1-2.5 μm) may remain in the atmosphere indefinitely. Fine particles are capable of scattering light, causing a reduction in visibility.

Some particles may have other pollutants attached to them, which may react with different components of the earth's surface. Windblown dusts, pollens from plants and sea salts are natural sources of particles in the atmosphere. Bushfires, agricultural and forest hazard-reduction burning release smoke particles into the air. Particles or particulate matters may be either directly emitted into the atmosphere (primary particulate) or formed in the atmosphere by chemical reactions (secondary particulate). The relative importance of primary and secondary particles depends mainly on the geographical location, with its particular mix of emissions, and on the atmospheric chemistry. For example, in areas where wood is burned as heating fuel during the wintertime, most of the particles are primary in nature, whereas during summertime photochemical episodes, a substantial fraction of the particulate matter is attributed to secondary reactions in the atmosphere (Grosjean and Friedlander, 1975).

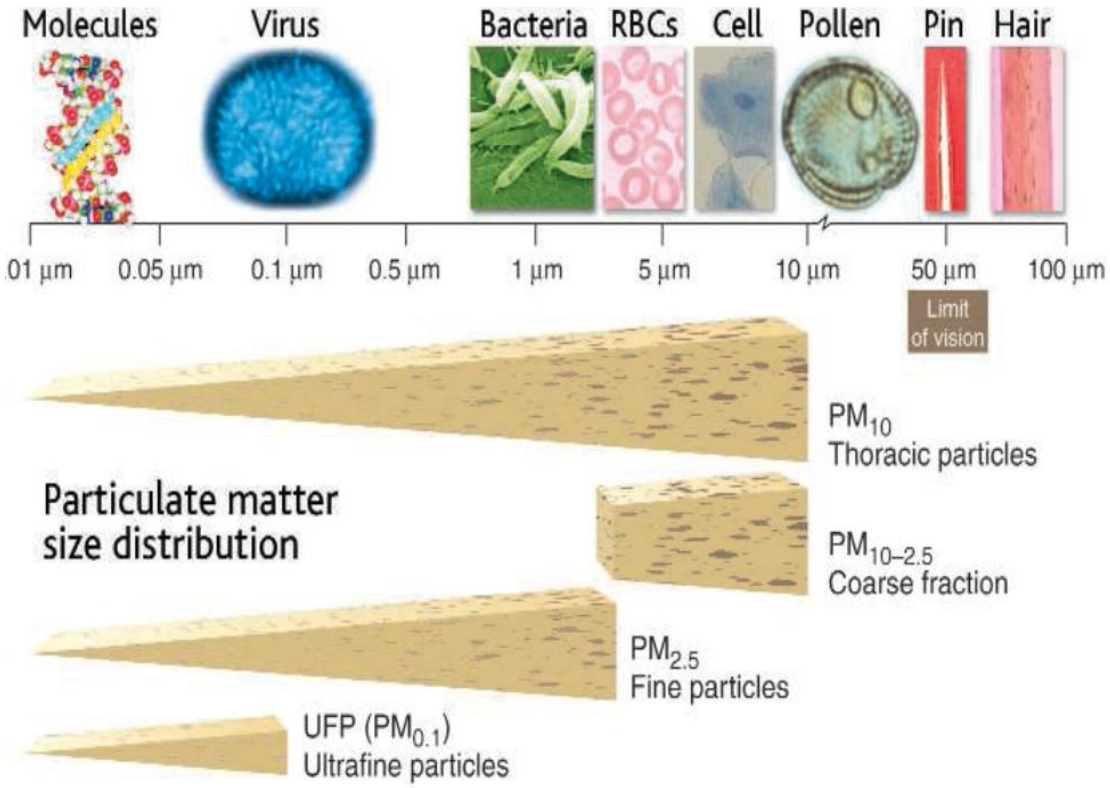


Figure1: Particulate matter size distribution (www.sciencemag.org)

These secondary reactions typically involve secondary PM precursor gases such as sulfur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3), and a wide variety of organic compounds. The resulting secondary PM compounds include sulfates, nitrates, and condensed organic compounds

PM10 are the criteria for the air quality and should be determined to estimate the air pollutants. Furthermore, PM10 is the most important ambient air polluters which harmfully affect human health (Koelemeijer, R. B. A., Homan, C. D., & Matthijesen, J. 2006).

PM10 is used as a primary indication of air pollution because it is associated with the exacerbation of respiratory and cardiovascular conditions (WHO (2006) Air Quality

Guidelines Global Update 2005) and Kappos, A. D., Bruckmann, P., Eikman, T., Englert, N., Heinrich, U., Hoppe, P. (2004).

The high concentrations PM10 leads to several health concerns. Therefore, this study focused on determination of PM10 concentrations. Therefore, the current work aimed to quantify the PM10 in ambient air of Addis city to study the air quality and their compliance to AAQG.

2.4. IMPACT OF AIR POLLUTION ON HUMAN HEALTH AND PHYSICAL ENVIRONMENT

While many of the world's people were enjoying the benefits of technological and economic expansion and higher living standards, many scientists and the public became aware that this extraordinary development was not without cost. Indeed, the impact of global air pollution problems that have accompanied development in various areas has become a growing concern. The potential for serious consequences of exposure to high levels of ambient air pollution was made clear in the mid-20th century, when cities in Europe and the United States experienced episodes of air pollution, such as the infamous London Fog of 1952 and Donora Smog of 1948, which resulted in large numbers of excess deaths and hospital admissions. ("The Great Smog of 1952", Metoffice.gov.uk Retrieved 17 August 2008).

As early as in the 1950s and 1960s, many urban dwellers and residents living in the vicinity of industrial plants began to recognize undesirable changes occurring in the environment, particularly a general deterioration of the quality of air and water. A great deal of both field and laboratory research was conducted, with the results revealing the seriousness of environmental pollution problems. Subsequently, it was widely recognized

that there was an urgent need to curb further deterioration of the environment and protect human health against the adverse effects of environmental pollution. Recent assessments suggest that the impacts on public health may be considerable.

These evidences have increasingly been used by national and international agencies to inform environmental policies, and quantification of the impact of air pollution on public health has gradually become a critical component in policy discussions as governments weigh options for the control of pollution. Quantifying the magnitude of these health impacts in cities worldwide, however, presents considerable challenges owing to the limited availability of information on both effects on health and on exposures to air pollution in many parts of the world. (Aaron J. Cohen et al, 2007)

The carbon monoxide molecule's bond to hemoglobin is 200 – 300 times stronger than is the hemoglobin- oxygen bond, so carbon monoxide is not cleared easily from the circulatory system. Exposure to short periods of high concentration of carbon monoxide is just as bad as long periods of low concentrations. Normal amounts of carbon monoxide in the blood are in the range of 1%. Smokers can have higher concentrations, and if one were to exercise at rush hour in heavy traffic (at 10-15 ppm), levels of 3 – 4% could be expected. (WHO, 1987)

It has been found that "for every 1% increase in COHb (i.e. carbon monoxide molecule attached to a hemoglobin molecule) there was a 4% decrease in time to ischemic changes" (Folinsbee, 1992). At low levels, symptoms of CO exposure include fatigue, headaches and dizziness, but higher concentrations can lead to impaired vision, disturbed coordination, nausea and eventually death.

Although, decades of studies are conducted on it, the full effects of NO_2on human health are not known. However, NO_2 leads to increase the incidence and severity of respiratory infections. It provokes bronchi-constriction and asthma in much the same way as ozone but it is less potent than ozone in causing asthmatic effects (Samet and Utell, 1990).

A study on the effects of sulfur dioxide on humans is also found that, at least in acute exposures, concentrations of up to 8 ppm caused respiratory changes that were dose dependent (Amdur et al, 1953). Later studies revealed that the main effect of sulfur dioxide is bronchi-constriction (closing of the airways causing increased resistance to breathing) which is dose dependent, rapid, and tended to peak at 10 minutes (Folinsbee, 1992).

VOCs can also cause irritation to the respiratory tract (from increased rhinitis, or runny nose, to asthma) as well as headaches and other non-specific complaints. At high concentrations, they have markedly toxic effects, some of which vary by compound, but which include neurological effects in all cases. Direct toxicity from VOCs is primarily an indoor air pollution problem and an occupational hazard, as levels indoors and in the workplace can reach many times that of outdoor levels. (UNHSP, 2007)

Studies have also demonstrated that PM_{10} (particulate matter less than 10 microns in diameter) is associated with a wide range of adverse health outcomes ranging from acute respiratory symptoms to premature mortality. Given the high correlation between pollutants PM_{10} may also serve as a surrogate measure for other pollutants including very fine particles (less than 2.5 microns) and a host of traffic-related toxins (WHO, 2002).

The grave consequences of air pollution on public health are measured not only in terms of sickness and in terms of death, but also in terms of lost productivity and missed educational and other human development opportunities. Thus, degradation of air quality not only hinders economic growth by imposing significant additional operating costs on business, industry, households, and public services – it also means that the quality of life in these affected cities is spiraling downwards. Likewise, air pollution accelerates deterioration of buildings and historic monuments. A reputation for bad air pollution certainly deters investments from the outside. Air pollution puts a strain on sustainable urban development, which includes economic growth, social inclusion, human well-being, and the environment (WHO, 2002).

Apart from having human health impacts, air pollution also adversely affects the natural environment. The atmospheric reactions of the oxides of sulfur and nitrogen lead to their corresponding acidic transformation (into sulfuric acid and nitric acid). This leads to the acidification of soil and freshwater and adverse effects on the terrestrial and aquatic ecosystems. Sulfur dioxide (SO_2) and Nitrogen Oxides (NO_x) are also the primary causes of acid rain. It occurs when these gases react in the atmosphere with water, oxygen and other chemicals to form various acidic compounds. Sunlight increases the rate of most of these reactions. The result is a mild solution of sulfuric and nitric acids. These acids fall out of the atmosphere by wet (acidic rain or fog) or dry (acidic gases or particles) deposition. Prevailing winds may blow the compounds causing both wet and dry deposition over hundreds of kilometers (Heck et al, 1998).

Table 1: the major sources of pollutants and their health effects are summarized

Pollutants	Description	Sources
Particulate Matter (PM)	diesel vehicle exhaust • power plant	increased morbidity and mortality rates at high level exposure
Carbon monoxide (CO)	•Vehicles •indoor sources, including kerosene, wood burning, natural gas, coal, or wood-burning stoves and	Prevents the uptake of oxygen by the blood. This can lead to a significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease
Nitrogen Oxides (NO_2)	• power plant • motor vehicle • fuel combustion • space heating	Long term exposure Lower resistance respiratory infections Lung development Aggravate existing chronic respiratory diseases
Sulfur dioxide (SO_2)	•combustion of sulfur-containing fossil fuels • power plant • marine vessel • motor vehicle	High level Impairment of respiratory function, Aggravateexisting respiratory and cardiac illness
Volatile Organic Carbon (VOCs)	building material Cleaning agent, Cosmetics, wax Carpet, furnishing ,laser printer / photocopier ,printing materials adhesive, sealant, paint varnish and solvent	toxicological effects on the central nervous system, liver, kidney and blood, eye irritation, respiratory problems, asthma ;headaches, dizziness tiredness, irritability

Source: The Nation's Health (February 2012)

CHAPTER THREE

STUDY DESIGN AND METHODOLOGY

3.1 DESCRIPTION OF THE STUDY AREA

This study was conducted in Addis Ababa, the capital city of Ethiopia and diplomatic center of Africa. The City of Addis Ababa, with an area of 54 thousands hectares, is located at the foot of Mountain "Entoto". The area approximates a circular shape with a diameter of about 30-40 km. The elevation varies between 2,200 and 2,800 (masl) with an average of 2, 400 (masl). The average maximum and minimum temperatures were 23.8oC and 11.1oC, respectively. The City had annual rainfall of 1175.8mm rainfall.

The population of Addis Ababa in the year 2017 as per estimated data = 6.6million (http://population of 2017.com) Accesses on 29/1/2017. Addis Ababa is divided into ten sub-cities.

The spatial organization of the sub cities shows from the past data of Addis Ababa from the year 2012-16, Lideta, Kirkos, Arada and Addis Ketema represent the central areas, whereas Akaki Kaliti, Nefas Silk Lafto, Kolfe Keraniyo, Gulele, Yeka and Bole correspond partly to the expansion areas at their peripheries. Addis Ketema is the smallest sub city in Addis Ababa with an area of 742 hectare (ha), followed by Lideta with an area of 917 ha. Bole and Akaki Kaliti are the largest sub cities with an area of 12,060 ha and 11,807 ha, respectively (CSA, 2012).

Regarding to total population of the sub cities, Kolfe Keraniyo is the most populated sub city with 428,895 inhabitants, followed by Yeka with a total population size of 346,664 inhabitants. At the contrary, Akaki Kaliti is the less populated sub city with a total

number of 181,270 people, followed by Lideta with 201,713 inhabitants. In general, the large sub cities have more dwellers than the small central sub cities. However, while considering population density, i.e. population over area, there is a converse situation. Akaki Kaliti has 15 inhabitants per ha, followed by Bole and Yeka with 26 and 40 inhabitants per ha. On the other hand, sub cities with small area coverage are densely populated. These include Addis Ketema with 344 inhabitants per ha, Lideta with 220 inhabitants per ha, and Arada with 213 inhabitants per hectare (CSA, 2012).

Rapid economic and industrial growth in the city for the past 25 years has led to the increase in the number and type of industries in the city. In Addis Ababa distribution of factories varies among sub cities. Arada and Yeka sub city have a lower number of factories (i.e. 11 and 13 factories, respectively). Alternatively, as much as 170 factories are located in Akaki Kaliti (CSA, 2012).

Condition of public transport and infrastructure in Addis Ababa city is regarded as one of the poorest in the world. Increasing demand on transportation service and challenges of the prevailing transport shortage are basic problems of the city. Although railway transport service has started in two main routes, public transport is only refers to bus and taxi services. Currently, taxis, city buses, and private cars altogether account 30 % of the modal share of which is 26 % bus, 70 % taxis and 4 % private cars (Daniel, et al, 2010). Car ownership among residents is also very low. The relative rise in automobile ownership together with the poor condition of the roads, number of main bus stations few and the poorly functioning traffic system have resulted in high level of congestion which is the cause of heavy traffic air pollution around the studied bus stations of the city particularly at peak hours.

3.2 SURVEY DESIGN

This is a cross-sectional, spatial assessment of ambient air concentrations of PM10, CO, NO_2, SO_2, and VOCs at different sites in three different land use areas (Industrial, Transport, and Residential) in Addis Ababa during the period from January, 2017 to April, 2017.

Based on this, first the areas were divided into different urban land use areas and control suburban areas. From these fifteen industrial, twenty six traffic-related, and thirteen residential urban and three control sub-urban areas were selected. The detail procedure for this selection will be discussed in the next parts.

Secondary meteorology data which helps this study like temperature and humidity and wind direction data for the city were also taken from Ethiopia Meteorology Agency office.

3.3 SITE SELECTION AND SAMPLING METHOD

3.3.1 SITE SELECTION

Air pollution studies whose objective is to determine the extent and variation of the atmospheric contaminants that requires measurement sites to be located so that the resulting data will represent the population group and spatial area, which is under this study.

In order to achieve this, the measurements have to be done in different small well-defined land use areas within the study area. (USEPA, 2007).

The sampling frame were prepared by taking data about the different parcel of lands based on their land utilization in the city. A random sampling method to select the sampling places was used.

Different areas with a contiguous geographic area were established and well defined boundaries for them were prepared as a frame. To ensure the measurements taken are representative of the city, sites prepared as a frame were categorized to represent different land use areas. The different land use categories, which were prepared as a frame to the study, were industrial, traffic-related (transport), residential and control sub-urban areas.

Figure 2 below shows the city geo-referenced land utilization as industrial, residential and traffic –related areas

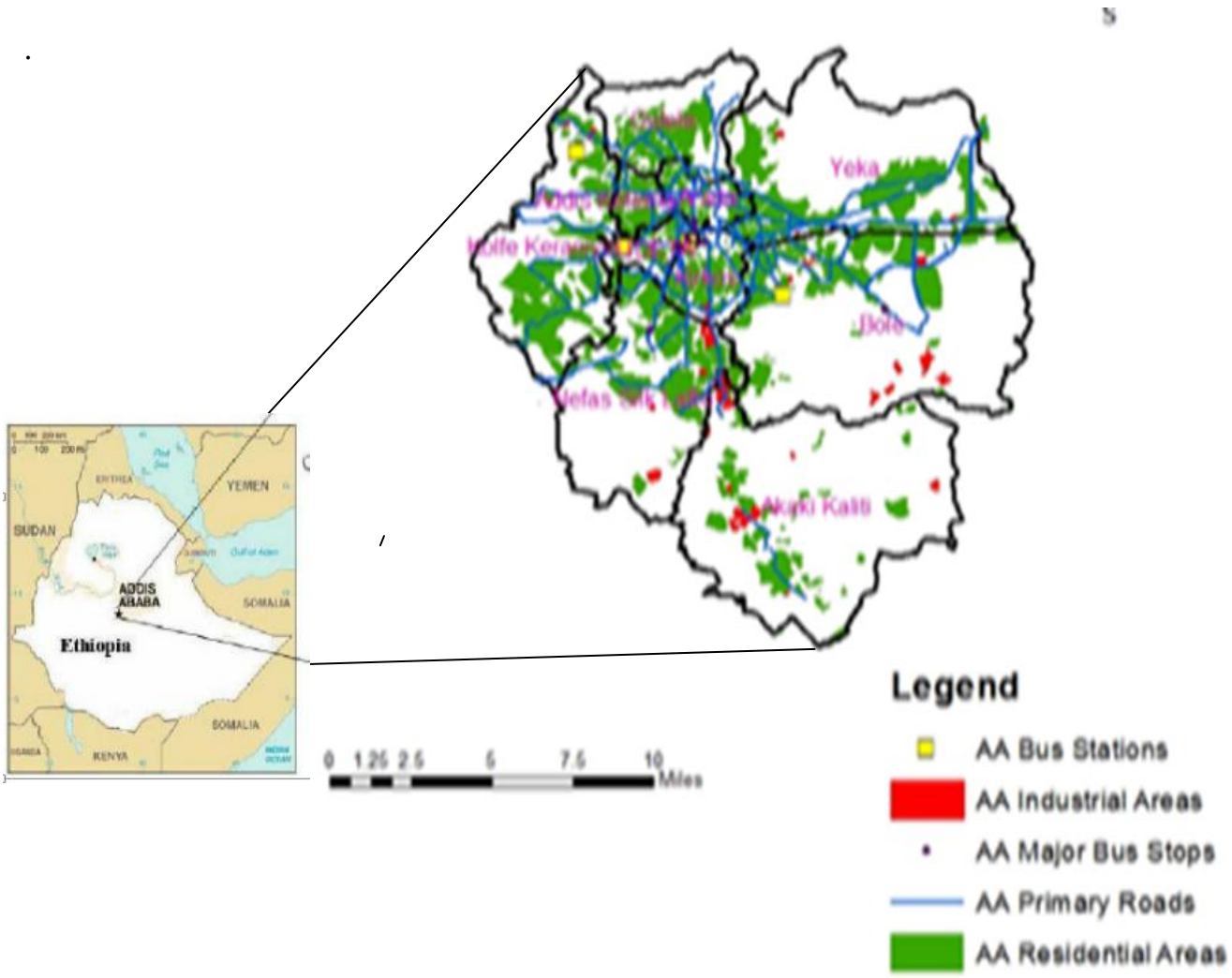


Figure 2 Map of Addis Ababa by land Utilization

3.3.2 SAMPLING METHOD

The ambient air pollutant gas measurements was done using the portable areoqual 500 series instrument by fixing it to poles for one hour around the selected locations as shown in figure 3a and sampling of particulate matter (PM10) using Portable SKC intermediate air sampling pump for twenty four hour by selection suitable position as as shown in figure 3b at two meter from the ground respectively.

Figure 3: (a) Sampling of air pollutant gas

Figure 3: (b) Sampling of particulate matter

3.3.2.1 THE POLLUTANT GASES

For evaluating of the four-pollutant gases (i.e. Sulfur Dioxide, Carbon Monoxide, Nitrogen Dioxide, and Volatile Organic Compound) Aeroqual series 500 portable gas sensor monitoring base with series sensor heads was used. The portable monitors are light and adequate to transport on hand.

The specific time-averaged (by sampling a known volume of air for the required averaging time concentration data) sampling method was used to conduct the sample measurement of the study. The pollutant gases CO, NO_2,SO_2,VOCs were sampled during the month of March and April over three times a day for one hour duration at four sampling sites being representatives of four zones viz. residential zone, industrial zone, traffic zone and control zone. The one hour duration time through day were divided into Morning (7:00-10:00 am), Noon (12:00-2:00 pm) and Afternoon (4:00-6:00 pm).

The concentration of the pollutant gases was read on the instrument display at the field. Therefore do not involve laboratory analysis except mass determination of particulate matter (PM10).

General meteorological conditions of city are also taken into account to know its influence in these criteria pollutants in the study area. Secondary meteorology data were also taken from Ethiopia of Meteorology Agency office.

The sites were divided into to three land use type transport, industrial and residential respectively. The number of selected sites and the name of the locations are shown on the map below

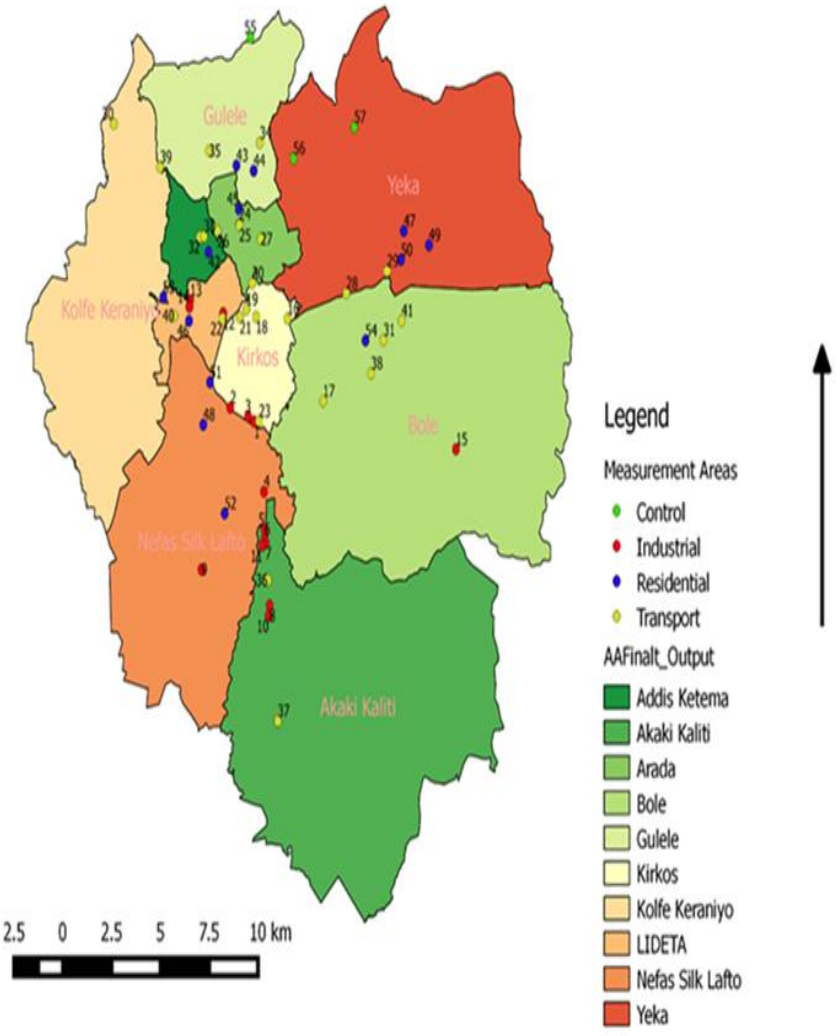


Figure 4: Spatial Location of sampling sites for the Pollutant Gases

3.3.2.2 PARTICULATE MATTER (PM10)

The measurement of particulate matter PM10 (i.e. aerodynamic diameter<10µm dust particles) was done using portable SKC intermediate air sampling pump which is in conjunction with charger operated universal air sampling pump and equipped with a vacuum pump, an internal regulator, a timer and air flow calibration unit. By putting it on suitable places of the selected sample areas, collections of samples were conducted for 24 hours for each place as shown in Figure 3: (b) Sampling of particulate matter.

During the data collection particulate matter (PM10) each site was attributed a location ID, from 1 to 23. Specific measurement sites were selected by considering to the safety of the instruments and availability of willing institutes, individual additionally by hiring a watchman for the safety of instruments during the measurement time. This method of measurement for particulate matter (PM10) was a manual (it requires the use of laboratory analysis), additional process was conducted for it.

For this, during measurement the process of filter handling throughout the process is the largest source of measurement error, particular attention to the handling of filters for particulate matter was taken. Care was taken to properly mark all samples to ensure positive, unambiguous identification throughout the sample collection, handling, and analysis procedures. Sample containers were cleaned and filters were pre-weighing and prepared in the laboratory in the morning before being used to collect samples. Precautions were also taken during transporting the sampling filters sample to the measurement sites, setting up the samplers to run, and then collecting the samples for

transport to the laboratory. Samples were delivered to the laboratory for analysis immediately after the measurement was ended.

The ambient air pollutant gases carbon dioxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2) Volatile Organic Compound (VOC) were measured at a distance to the pollution source ranging from 5 to 30 meters for of average concentrations over 1 hour and PM 10 of average concentrations over 24 hours. Installment 2~3m above the ground is preferable when one considers the effect of air pollution on the human body and the area in which people are most active (USEPA 2007. WHO,2005). WHO,2005) Figure 5: Map of the measurement sites for PM10 in the city's atmosphere

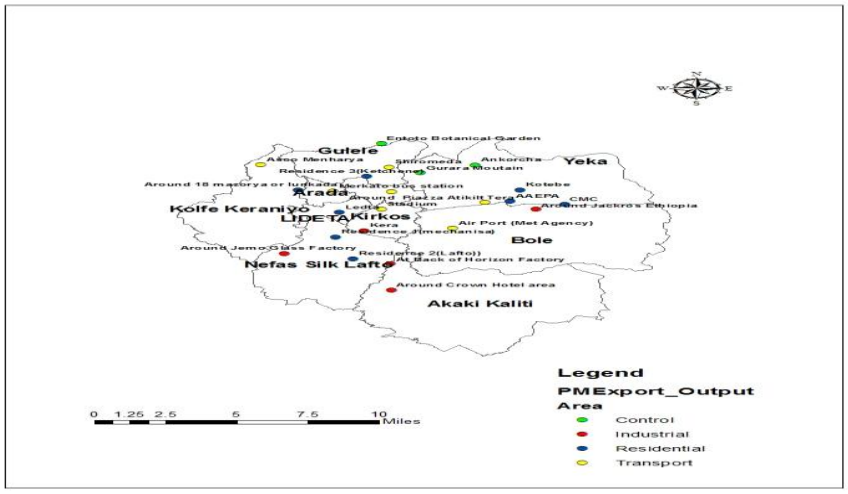


Figure 5: Map of the measurement sites for PM10 in the city's atmosphere

3.4 EXPERIMENTAL METHOD

For PM10 samples to provide useful information, laboratory analyses must meet the analytical procedures, which must be in accordance with accepted practices. Based on this the mass analysis for PM10 was done using gravimetric analysis. This analysis was used almost exclusively to obtain mass measurements of filters in a laboratory environment. Gravimetric analysis determines the net mass by weighing the filter before and after sampling with a calibrated balance. Calculation PM10 of using the volume of air sampled was done:

V= Q x t Where: V = volume of air sampled, in m^3;

Q = average flow rate, in m^3/min;

t = total sampling time, in min.

CALCULATION OF PM10 IN AMBIENT AIR

$$PM10\ (as\ \mu g/m^3) = \frac{(W2-W1)\ X\ 106)}{V}$$

PM10 = mass concentration of particulate matter less than 10micron diameter, in $\mu g/m^3$;

W1 = initial weight of filter in g

W2 = finial weight of filter in g

V=volume air sampled in m^3 and

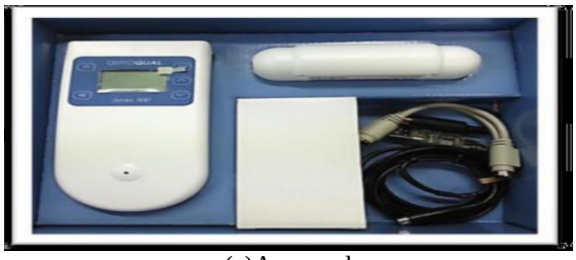
106=conversion factor g to µg

Sources :(IS 5182 (Part 4): 1999).

3.5 THE INSTRUMENTS USED FOR THIS STUDY

The following instruments were used in this study are shown in the figure below.

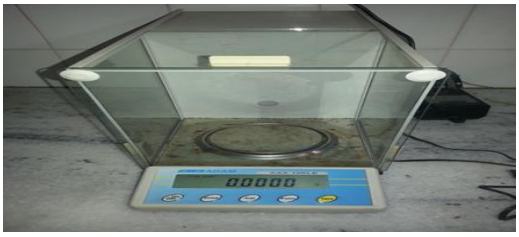
Figure 6: Instrument used in this study



(a)Aeroqual

(b) GPS Garmin

(a) Air Sampling Pump



(d)Analytical balance

Figure 6(a): Aeroqual (portable gas sensor model 500 series made in USA) is used for evaluation of air pollutant.

Figure 6(b): Portable SKC intermediate air sampling pump ((SKC 224-PCTX4 Model, SKC Ltd, UK) is used for sampling particulate matter (PM10).

Figure 6(c): Digital Analytical Balance (AAA/LE series model made in China) is used for evaluation of particulate matter (PM10)

Figure 6(d): GPS (Garmin (eTrex) made in Garman) is used for determining the location of sampling sites.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 SPATIAL VARIATION OF POLLUTANT GASES IN THE AMBIENT AIR OF ADDIS ABABA CITY

4.1.1 THE CONCENTRATION OF POLLUTANT GASES AT INDUSTRIAL AREA

Table 2: (Mean ± SD) value of the four pollutant gases at industrial sites

Name of the Area	Mean ± SD CO (ppm)	Mean ± SD NO_2 (ppm)	Mean ± SD SO_2 (ppm)	Mean ± SD VOCs($\mu g/m^3$)
Gottera A.A Cement factory	14.75 ± 0.21	0.25 ± 0.04	0.49±0.04	534 ± 13.45
Kera area	14.69 ± 0.18	0.26 ± 0.09	0.54±0.06	538 ± 16.17
Gottera Pepsi Factory	14.25 ± 0.12	0.27 ± 0.05	0.48±0.07	551 ± 18.77
Nefas Silk Paint Factory	13.6 ± 0.14	0.26 ± 0.08	0.44±0.09	557 ± 18.68
Adey Ababa yarn Factory	14.93 ± 0.41	0.31 ± 0.06	0.57±0.05	595 ± 21.59
Addis Horizon Factory	16.46 ± 0.32	0.31 ± 0.07	0.64±0.08	571 ± 23.64
ELICO Leather Factory	14.14 ± 0.13	0.31 ± 0.04	0.61±0.06	558 ± 14.50
Kadiso Paint Factory	14.72 ± 0.22	0.26 ± 0.09	0.52±0.04	586 ± 15.31
Haile Garment Factory	13.97 ± 0.26	0.24 ± 0.07	0.46±0.03	496 ± 12.12
Korki Factory area	14.96 ± 0.34	0.25 ± 0.05	0.52±0.08	580 ± 12.50
Awash Tannery area	14.84 ± 0.37	0.26 ± 0.08	0.51±0.09	589 ± 8.02
National Alcohol area	14.72 ± 0.33	0.26 ± 0.09	0.43±0.07	572 ± 8.62
Coca cola Factory area	14.38 ± 0.25	0.26 ± 0.08	0.51±0.08	537 ± 6.51
Awash wine factory area	14.74 ± 0.36	0.25 ± 0.04	0.42±0.09	584 ± 8.54
Bole Lemi Industry area	14.27 ± 0.23	0.26 ± 0.03	0.47±0.07	598 ± 9.85
Total	14.63 ± 0.26	0.27 ± 0.06	0.51±0.06	563 ± 13.89

The average mean of CO concentration at industrial area was (14.63 ± 0.26) ppm.

The maximum and minimum results were observed around Addis Horizon Factory

(16.46 ± 0.32) ppm and Nefas Silk Paint Factory (13.6 ± 0.14) ppm respectively.

This might be the presence of many of industries in these study areas like Adey Ababa yarn Factory, Addis Horizon Factory, and ELICO Leather Factory and so many other factories.

The average mean of NO_2 concentration at industrial area was (0.27 ± 0.06) ppm. Throughout the study area NO_2 concentration has similar value. But this value is a little bit higher than the East African standard which is 0.2ppm (EAC, 2010b) for one hour duration.

The average mean of SO_2 concentration at industrial area was (0.51±0.06) ppm. Throughout the study area SO_2 level is very high. The East African standard for SO_2 concentration for one hour duration is 0.175ppm (EAC, 2010b).

The maximum and minimum results were found from Addis Horizon Factory (0.64±0.08) ppm and awash wine factory area (0.420) ppm respectively.

This site is higher due to heavy vehicular traffic flow, emissions from nearby industries, emission from like rubber, shoe factories.

The average mean of VOCs concentration at industrial area was (563 ± 13.89) µg/m3. The maximum and minimum results were observed at Bole Lemi Industry area (598

µg/m3) and Haile Garment Factory (496 µg/m3) respectively.This might be due to the evaporations of different industrial activities at the selected sites.

4.1.2 THE CONCENTRATION OF POLLUTANT GASES TRANSPORT AT AREA

The concentration level of the four ambient air pollutant gases (CO, SO2, NO2, and VOCs) and their spatial variation at transport area as shown in the table 3 below.

Table 3: (Mean ± SD) value of the four pollutant gases at transport sites

Area Type	Name of the Area	Mean ± SD CO (ppm)	Mean ± SD NO_2 (ppm)	Mean ± SD SO_2 (ppm)	Mean ± SD VOCs (µg/m3)
Transport	Urael Square	15.16 ± 0.44	0.19 ± 0.09	0.24 ± 0.09	592 ± 14.34
	Bole Airport	14.27 ± 0.31	0.21 ± 0.05	0.47 ± 0.05	602 ± 17.33
	Meskel Square	14.31 ± 0.30	0.18 ± 0.07	0.26 ± 0.08	494 ± 16.25
	Stadium	13.41 ± 0.35	0.25 ± 0.04	0.39 ± 0.04	539 ± 17.22
	National theatre	13.56 ± 0.52	0.17 ± 0.05	0.23 ± 0.07	404 ±11.42
	Legar	15.09 ± 0.55	0.28 ± 0.08	0.43 ± 0.09	598 ± 16.33
	Mexico Square	15.71 ± 0.42	0.24 ± 0.06	0.37 ± 0.07	585 ± 15.44
	Gottera Exchange Road	15.04 ± 0.48	0.22 ± 0.07	0.34 ± 0.08	539 ± 13.35
	Gorgis Square	15.38 ± 0.45	0.21 ± 0.09	0.25 ± 0.09	508 ± 13.61
	Piazza	14.33 ± 0.44	0.21 ± 0.08	0.29 ± 0.07	502 ± 14.52
	Atikilt Tera	14.45 ± 0.37	0.23 ± 0.08	0.21 ± 0.06	492 ± 16.23
	Arat Kilo	13.15 ± 0.28	0.17 ± 0.07	0.13 ± 0.04	400 ± 9.82
	Megnga taxi station	14.55 ± 0.49	0.21 ± 0.09	0.24 ± 0.08	769 ± 10.63
	Lambert Menharya	15.04 ± 0.33	0.22 ± 0.05	0.42 ± 0.09	861 ± 12.25
	Asco Menharya	15.55 ± 0.41	0.36 ± 0.04	0.51 ± 0.11	853 ± 15.22
	Gergi Mebrat Haile	15.24 ± 0.51	0.21 ± 0.06	0.39 ± 0.06	632 ± 14.66
	Merkato Bus station	17.14 ± 0.28	0.29 ± 0.08	0.31 ± 0.07	812 ± 13.46
	Autobis Tera	17.16 ± 0.34	0.33 ± 0.09	0.49 ± 0.08	829 ± 14.11
	Shiromeda Bus/taxi	15.83 ± 0.38	0.28 ± 0.05	0.32 ± 0.05	714 ± 10.55
	Addisu Gebaya Bus/taxi	13.74 ± 0.43	0.26 ± 0.06	0.28 ± 0.07	645 ± 11.33
	Driver Training Center	16.09 ± 0.49	0.31 ± 0.08	0.32 ± 0.09	808 ± 17.55
	Kality Menharya	16.57 ± 0.51	0.23 ± 0.05	0.47 ± 0.13	871 ± 16.66
	Roba Bakery/Gergi	13.94 ± 0.52	0.26 ± 0.07	0.19 ± 0.12	482 ± 10.35
	Wingate	14.93 ± 0.44	0.24 ± 0.09	0.33 ± 0.06	347 ± 9.89
	Tor Hayloch	15.17 ± 0.36	0.22 ± 0.04	0.29 ± 0.08	350 ± 10.61
	Mexico taxi stat. to Lafto	15.03 ± 0.39	0.21 ± 0.08	0.22 ± 0.09	309 ± 9.77
Total		14.99 ± 0.42	0.24 ± 0.07	0.32 ± 0.09	597 ± 13.57

The average mean CO concentrations was (14.99 ± 0.42) ppm.

The maximum and minimum results were observed at Autobis Tera (17.16 ± 0.34) ppm and Arat Kilo (13.15 ± 0.28) ppm respectively.

The average mean of NO_2 concentrations at transport area was (0.24 ± 0.07) ppm. The maximum and minimum results were observed at Asco Menharya (0.33 ± 0.09) ppm and National Theatre (0.17 ± 0.05) ppm respectively.

The average mean of SO_2 concentrations at transport area was (0.32 ± 0.09) ppm.

The maximum and minimum results were observed at Asco Menharya (0.51 ± 0.11) and Arat Kilo area (0.13 ± 0.04) ppm respectively.

The average mean of VOCs value at transport area was (597 ± 13.57) $\mu g/m^3$.

The maximum and minimum results were observed at Kality Menharya site (871 ± 16.66) µg/m3 and Mexico taxi station to Lafto (309 ± 9.77) µg/m3 respectively.

This is due to the higher emission of VOCs from traffic emissions and fuel evaporations in selected areas.

The increase in traffic density will increase both exhaust and vehicle evaporative emission.

1.3 THE CONCENTRATION OF POLLUTANT GASES AT RESIDENTIAL AREA

The concentration level of the four ambient pollutant gases (CO, SO_2, NO_2, and VOCs) and their spatial variation at residential area as shown in the table 4 below.

Table 4: (Mean ± SD) value the four pollutant gases at residential sites

Area Type	Name of the Area	Mean ± SD CO (ppm)	Mean ± SD NO_2 (ppm)	Mean ± SD SO_2 (ppm)	Mean ± SD VOCs (µg/m3)
Residential	Mesalemya	13.19 ± 0.43	0.19 ± 0.07	0.23 ± 0.09	340 ± 12.34
	Kechene	11.37 ± 0.36	0.16 ± 0.06	0.22 ± 0.07	323 ± 11.55
	Gulele- woreda-1	11.31 ± 0.39	0.13 ± 0.09	0.16 ± 0.06	302 ± 13.22
	Arada-Woreda-5	12.96 ± 0.44	0.15 ± 0.04	0.12 ± 0.04	337 ± 12.54
	Ledta	13.04 ± 0.51	0.17 ± 0.05	0.23 ± 0.09	354 ± 11.85
	Kotebe(kebele02)	10.74 ± 0.29	0.16 ± 0.09	0.21 ± 0.07	356 ± 12.73
	Mekanisa	11.35 ± 0.31	0.18 ± 0.0.5	0.22 ± 0.06	396 ± 13.24
	Wosen	10.67 ± 0.38	0.15 ± 0.08	0.17 ± 0.08	342 ± 11.52
	Ethio-China College	10.62 ± 0.34	0.13 ± 0.07	0.21 ± 0.09	350 ± 13.75
	Sarbet	11.29 ± 0.41	0.16 ± 0.04	0.19 ± 0.05	330 ± 12.66
	Lafto	10.54 ± 0.26	0.18 ± 0.06	0.18 ± 0.04	332 ± 11.28
	Around Holland Embassy	12.11 ± 0.35	0.16 ± 0.05	0.21 ± 0.07	348 ± 12.76
	GergiMebrat Haile	12.47 ± 0.37	0.15 ± 0.09	0.23 ± 0.09	330 ± 13.14
Total		11.67 ± 0.37	0.16 ± 0.08	0.20 ± 0.07	302 ± 12.21

The average mean of CO value at residential area was (11.67 ± 0.37) ppm. The maximum and minimum results were observed at Mesalemya (13.19 ± 0.43) ppm and Lafto (10.54 ± 0.26) ppm respectively. The average mean of NO_2 value at residential area was (0.16 ± 0.08) ppm. The maximum and minimum results were observed at Mesalemya (0.19 ±

0.07) ppm and Gulele- woreda-1 (residential area above shromeda) and Ethio-China College (0.13 ± 0.07) ppm respectively. The average mean of SO_2 value at residential area was (0.20 ± 0.07) ppm. The maximum and minimum results were observed at Mesalemya (0.23 ± 0.09) ppm and Arada-Woreda-5 area (0.12 ± 0.04) ppm respectively.

The minimum levels were detected at residential site. The average mean of VOCs value at residential area was (302 ± 12.21) µg/m3. The maximum and minimum results were observed at Mekanisa site (396 ± 13.24) µg/m3 and Gulele- woreda-1 (302 ± 13.22) µg/m3 respectively.

Overall the mean concentration of pollutants gases at all the sampling locations were found to be higher than the control site as shown in the table 5 below.

Table 5: (Mean ± SD) concentration the four pollutant gases at control sites

Area Type	Mean ± SD CO (ppm)	Mean ± SD NO_2(ppm)	Mean ± SD SO_2(ppm)	Mean ± SD VOCs (µg/m3)
Entoto Botanical Garden	3.73 ± 0.76	0.14 ± 0.09	0.12 ± 0.03	44 ± 10.33
GuraraMoutain	3.88 ± 0.86	0.16 ± 0.06	0.13 ± 0.05	63 ± 11.61
Ankorcha	4.92 ± 1.27	0.18 ± 0.08	0.15 ± 0.07	87 ± 12.53
Total	4.18 ± 0.65	0.16 ± 0.02	0.13 ± 0.03	65 ± 21.54

4.2 VARIATION OF THE AIR POLLUTANTS GAS CONCENTRATION AT DAY TIME

The concentration ambient air pollutants varied differently according to the time of the day as shown table-7. It shows the temporal variation of air pollutant gases of the land use type of particular day. High values were obtained early in the morning (peak period) and late afternoon .Lower values were obtained at noon.

Table 6: Temporal Variation of the pollutants gas concentration during the day time

Type of the area	Time of measurement	**CO (ppm)**	**NO_2 (ppm)**	**SO_2 (ppm)**	**VOCs ($\mu g/m^3$)**
Industrial	Morning (7:00-10:00 am)	16.81	0.29	0.59	611
	Noon (12:00-1:00 pm)	13.21	0.21	0.32	496
	Afternoon (4:00-6:00 pm)	15.43	0.29	0.42	584
Transport	Morning (7:00-10:00 am)	17.63	0.26	0.43	890
	Noon (12:00-1:00 pm)	12.52	0.13	0.28	447
	Afternoon (4:00-6:00 pm)	14.84	0.19	0.34	924
Residential	Morning (7:00-8:00 am)	13.48	0.19	0.29	361
	Noon (12:00-1:00 pm)	10.67	0.11	0.17	299
	Afternoon (4:00-6:00 pm)	13.69	0.17	0.11	394

The higher levels of CO in the morning and in the afternoon period may be attributed to higher vehicular density/traffic activity and the combustion of domestic sources (combustion of coke from the domestic area surrounding the agricultural land).

Sunlight (high temperature) favors the formation of photochemical compounds such as NO_2.This suggest that increased formation of NO_2 and other compounds resulting from the reaction of NO, a vehicular exhaust gases constituent and sunlight atmosphere.

The morning peak of SO_2 may be related to other human activities such as burning of coal for cooking, refueling the coal-burning boilers for heating office buildings etc. (Ariko, J.D., B.A. Sawa. and A.A.I brahin, 20142, EEC005/0183 (COD), Brussels).

4.3 SPATIAL DISTRIBUTION OF PARTICULATE MATTER (PM10) IN THE AMBIENT AIR OF ADDIS ABABA CITY

In this study the spatial variation of the aerodynamic diameter less10µm (PM10) in the city area with map of sampling sites and the result found discussed table 7 below.

Table: 7 Concentration of PM10 (Mean ± SD) µg/m3 values of under the study

Type of the area	Name of the area	(Mean ± SD) µg/m3
Industrial area	Addis Ababa Foam & Plastic Factory	(517 ± 6.56)
	Around Jackros Ethiopia	(369 ± 15.55)
	Around Jemo Glass Factory	(401 ± 7.23)
	Around of Horizon Factory	(576 ± 8.33)
	Kera	(363 ± 10.27)
Average		(445± 9.59)
Transport area	Merkato bus station	(490 ± 17.45)
	Megenga	(327 ± 8.63)
	Shiromeda	(350 ± 11.53)
	Meterology Agency/Airport	(287 ± 9.13)
	Asco Menharya	(336 ± 13.22)
	Around Piazza AtikiltTera	(234 ± 16.44)
Average		(337 ± 12.73)
Residential area	Stadium	(130 ± 4.94)
	Around Asrasiment mazorya	(343 ± 18.35)
	Mechanisa	(329 ± 14.22)
	Ketchene	(313 ± 15.67)
	Ledta	(282 ± 8.96)
	Kotebe (Keble-02 area)	(248 ± 17.13)
	CMC area	(238 ± 8.44)
	Lafto	(217 ± 11.22)
	Ethio-China College	(187 ± 9.65)
	Total Average	(326 ± 11.64)

The average mean concentration of PM10 in the ambient air of the city was (326 ± 11.64) µg/m3.The maximum and minimum results were observed at Horizon Factory area (576 ± 8.33 µg/m3) and at Stadium (130 ± 4.94µg/m3) sites respectively.

The maximum result from transport, industrial, residential areas were observed around Horizon Factory area (576 ± 8.33) µg/m3, Merkato bus station (445 ± 9.59µg/m3), and Around Asrasiment mazorya (343 ± 18.350) µg/m3 respectively.

On the other side, the minimum result from transport, industrial, residential areas were found at Kera (363 ± 10.27) µg/m^3, Ethio-china College (187 ± 9.65) µg/m^3, and Stadium (130 ± 4.94) µg/m^3.

In measurement of PM10 next to the back Horizon Factory area (576µg/m3) at industrial area the higher value was also observed at akaki sub-city around Addis Ababa Foam & Plastic Factory (517 µg/m^3) area where a lot of industries are located. For the first PM_{10} value may be attributed to the release of aerosols from the Horizon factory and other many industry at sampling site. The latter PM_{10} concentration is due to the presence of number of industries in the study area unpaved roads, transportation, and industrial area (like sponge factories).

The minimum concentration PM_{10} measurement from industrial area was measured around Jackros Ethiopia (369 µg/m^3) and Kera (363 µg/m^3).

The number of selected sites and the name of the locations are shown on the map in Figure 6 below.

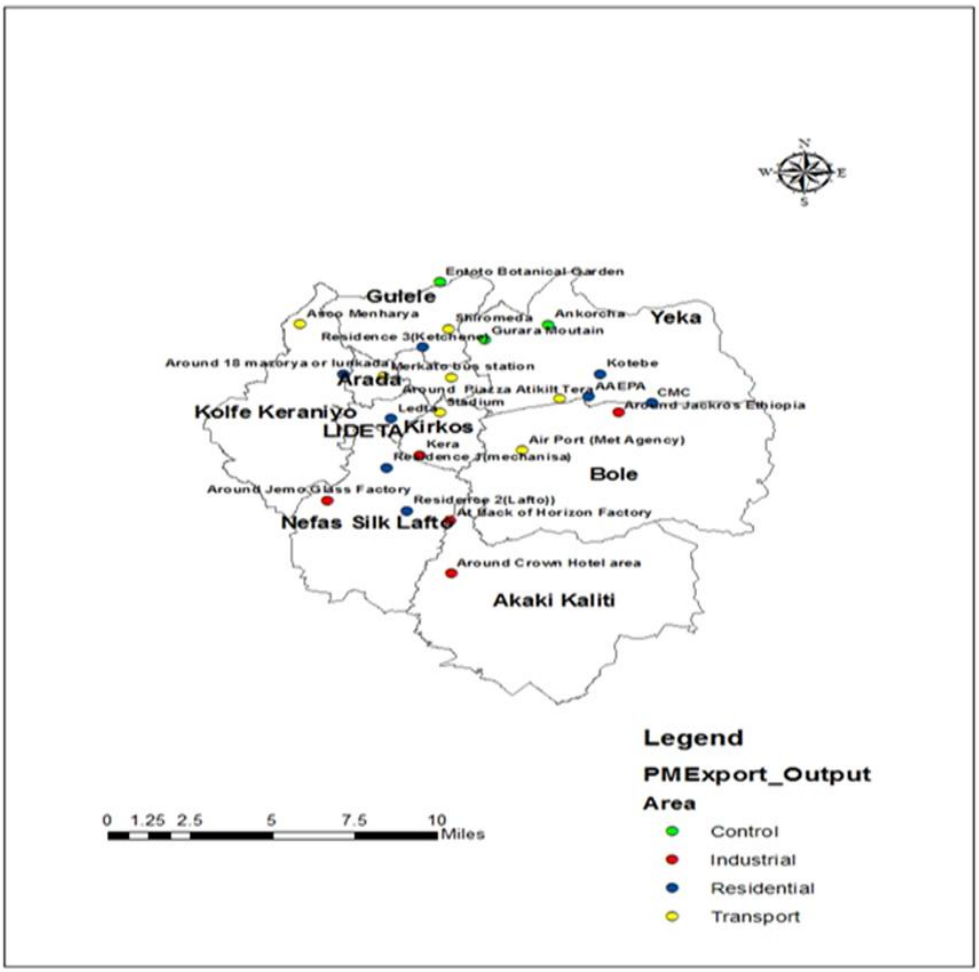


Figure 7: Sampling sites for PM10 in the city.

The measurement of PM_{10} in the transport area, the highest value was observed at Merkato bus station (590µg/m^3).Next to Merkato bus station higher value were also observed at Shiromeda (350µg/m^3) and Asco Menharya (336µg/m^3) area. This may be due to high traffic congestion.

The measurement of PM_{10} in the residential area the highest value is observed around Asrasiment mazorya (343µg/m^3). The minimum value PM_{10} measurement was measured around Ethio-China College (187µg/m3).

When compared the above results with the control area at Entoto, Gulele sub-city (63µg/m^3) which there is a significant difference between them. This indicates the ambient of the city air was polluted. Let alone the peak mean value PM_{10} (576 ± 8.33) µg/m3from the industrial area but also the mean PM_{10} value of the city (326 ± 11.64) µg/m3was above the result recorded in control area.

The overall mass concentration spatial distribution Particulate Matter (PM10) in the city's atmosphere are shown below the histogram

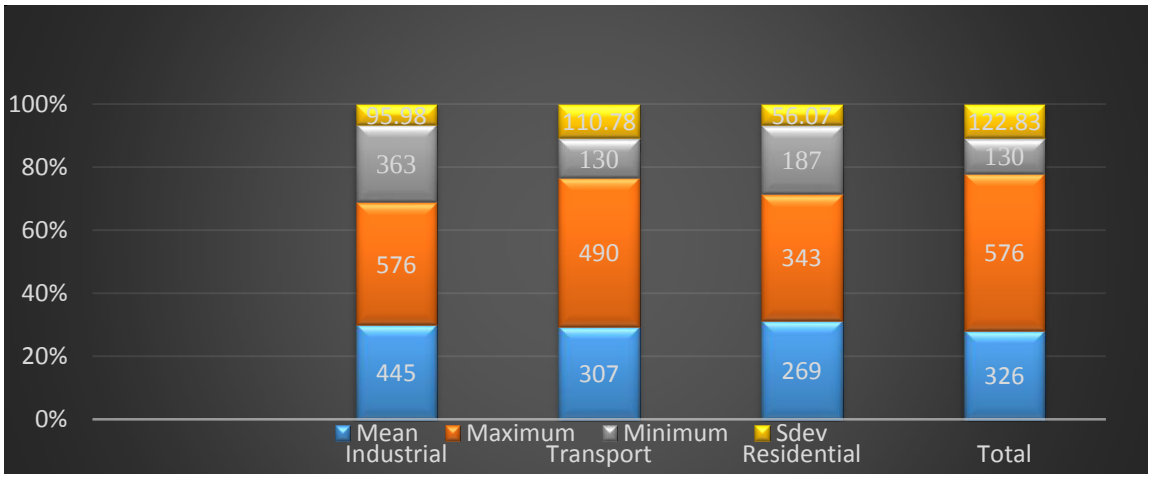


Figure 8: Spatial distribution Particulate Matter PM10 in the city's atmosphere

The weights of suspended particulate matter PM10 varied significantly between the sites. In all study area the concentration of air pollutants PM10 was found to be higher than the control sites at all the locations. The study also indicated the presence of spatial variation in PM10 concentration.

From the three selected area locations indicated in above table consistently showed relatively increased weights of PM10 (aerodynamic diameter less10µm).

Control Area < Residential area< Transport Area<Industrial Area.

There are other evidences as well that similar researches were done before10 years ago. In a pilot air pollution monitoring study carried out carried out by researchers from Desert Research Institute, Environmental Protection Authority of Ethiopia and Clark County Department of Air Quality Management in Addis Ababa during 2004 dry season found 24 hourly PM10 concentrations ranging from 35 to 97 µg/m3across 12 sampling sites around the city(Ethiopia. Atmos. Environ. 2005, 39, 7849–7860).

In another study conducted by researchers from Addis Ababa University and US based National Risk Management Research Laboratory, aerosol samples collected from February 22, 2008 to April 15, 2008 in seven urban and peri-urban areas of Addis Ababa showed concentration of total suspended particulate matter ranging from 17 (Kaliti sub-station in June 2008) to 556 (NSLP site in February 2008) a µg/m3nd PM10 ranging from 17 (COLTI site in July 2008) to 285 µg/m3 KWWT site in March 2008(G. Gebre et al, 2010).

Overall the mean concentration of PM10 at all the sampling locations were found to be higher than the control site as shown in the table 8 below.

Table: 8 the sampling sites and (Mean ± SD) µg/m^3 PM10 concentration at control area

Area type	Name of the area	(Mean ± SD) µg/m3
Control	Ankorcha	(87±19.92) µg/m3
	Gurara Mountain	(75±17.92) µg/m3
	Entoto Botanical Garden	(63 ± 19.92) µg/m3
	Total Average	(75 ± 19.14)µg/m3

4.4 GENERAL METROLOGICAL CONDITIONS

Regarding meteorological influence on ambient air pollution in the study area it can be said that wind speed and wind direction are the key factors in dispersion of pollutants. The predominant climatic condition in Addis Ababa area at the time of measurement of the ambient air pollutants could be as hot, dry, and sunny weather. The secondary metrological data obtained from Ethiopian Metrological Agency office during the study period was as described below: The mean value of the following parameters were taken: The mean wind speed value was 2.6(m/s), the mean wind direction value was 52.2(deg.), the mean temperature value was 18 ^{0}C, the mean Rel. humidity value was 52(%).The prevailing wind direction recorded throughout the study time was to north- East (NE) direction of the city. It has been observed that the meteorological parameters are less significant in explaining the variations in pollutant concentrations due to the pollutant concentration levels exceed the permissible value most of the study area location.

4.5 THE VARIATION OF GASEOUS POLLUTANT AND PM10 AT DIFFERENT LAND USE TYPE

Ambient air quality was monitored and analyzed to develop concentration level of air pollutant gases and its implications in the ambient air Addis Ababa, Ethiopia. Using survey research design, fifty seven geo-referenced locations, representing different land uses, were randomly selected and assessed for particulate matter (PM10), carbon monoxide (CO), nitrogen dioxide (NO_2),sulfur dioxide (SO_2), and Volatile Organic Compound (VOC).

The study found mean concentrations across all land uses are given table 9 below. The study results are discussed below by comparing with different land uses where the measurements were carried out and with international standard's given in table 10 below.

Table 9: (Mean ± SD) concentration of the four pollutants under the study In ambient air of Addis Ababa city.

Pollutants	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	VOCs (µg/ m3)
Industrial	(14.63 ± 0.26)	(0.27 ± 0.03)	(0.51 ± 0.06)	(563 ± 28.24)
Transport	(14.99 ± 1.05)	(0.24 ± 0.05)	(0.32 ± 0.10)	(597 ± 172.38)
Residential	(11.67 ± 0.97)	(0.16 ± 0.02)	(0.20 ± 0.03)	(342 ± 21.85)
Total Average	(14.10 ± 1.66)	(0.23 ± 0.15)	(0.34± 0.14)	(526 ± 159.93)

The average mean value of CO in the city ambient air was (14.10 ± 1.66) ppm. But below the ambient air standard of WHO limits which is 25 ppm for one hour measurement time duration. In all study area the concentration of air pollutants CO was found to be higher than the control (4.18 ± 0.65) ppm sites at all the locations in table 3.The high CO concentrations was due to the increasing traffic and congestion from automobiles and trucks, rapid urbanization and industrialization in Addis. Comparing the study results with East African Standard [for industrial (8.73 ppm), transport and residential (3.49 ppm)] CO concentration at all study areas indicates that they were above the prescribed limits. Similar study carried out by researchers obtained overall a result mean CO concentration was 5.4 ppm (Atmospheric Environment 2005).

Under the study area the maximum CO concentration observed at transport sites (14.99 ± 1.05) ppm (table 9). The minimum CO concentration observed at residential sites (11.67 ± 0.97) ppm. The mean NO_2 concentrations also determined in three different sampling area and results recoded at industrial (0.27 ± 0.03) ppm, transport (0.24 ± 0.05)ppm, and a residential (0.20 ± 0.03) ppm as shown table 8.The mean NO_2 concentrations in industrial land use areas were significantly higher than in residential land use areas ((0.27 ± 0.03) ppm vs. (0.16 ± 0.02) ppm). Among the three study area the maximum NO2 concentration observed at industrial sites of Adey Ababa yarn Factory, Addis Horizon Factory, and ELICO Leather Factory (0.31 ± 0.07) ppm. The minimum NO2 concentration observed at residential sites of Gulele-Woreda-1 (0.13 ± 0.09) ppm a few kilometer far away of above Shiromeda. NO2 concentrations recorded at transport sites (0.24 ± 0.05) ppm did not differ significantly from those of industrial one. The average mean value of NO2 in the city ambient air was (0.23 ± 0.15) ppm. The mean NO2

concentrations in the ambient air of Addis Ababa city (0.23ppm) is higher than AAQG 0.106 ppm (WHO, 2005).Similarly research done by Kasim, Oluwasinaayomi Faith entitled Analysis of air quality in Dire Dawa. The study found mean concentrations across all land uses for NO2 of 0.13 ± 0.17 ppm. The industrial and residential area values were above the prescribed standard for one hour NO2concentration (0.2ppm) in table 7.The residential areas were below the standards (Kasim et al. 2017).

Among the three study area, the maximum SO_2 result observed at industrial area (0.51 ± 0.06) ppm. From these sites highest value of SO_2 was recorded at Addis Horizon Factory (0.54±0.06) ppm. Next to this, higher similar value of SO_2result was recorded in transport area at Bole Airport and Kality Menharya station (0.47 ± 0.05) ppm. On the other side, the minimum result was recorded at residential were Gulelekef lektema Woreda-1(0.16 ± 0.06) ppm. The average mean value of SO2 in the city ambient air was (0.34± 0.14) ppm. It can be concluded that the sulfur dioxide released in the atmosphere of Addis Ababa City is high when compared to the accepted for one hour average recommended by East African Standard for some common substances found in polluted air (0.191ppm).

The finding of this study is greater than the result reported by V. Etyemezian et al (0.14ppm) (Atmospheric environment 2005).

VOCs concentration in all study area has crossed the prescribed limit in table 7 (6µg/ m3). The average mean concentration of VOCs in the city was (526 ± 159.93) µg/ m3. The maximum and minimum results were recorded at transport area of Kality Menharya (871 ± 16.66) µg/ m3and residential of Gulele- woreda-1 which is a few kilometer far away of above Shiromeda (302 ± 13.22) µg/ m3 sites respectively. This is may be due to

the higher emission of VOCs from traffic emissions and fuel evaporations in study area. The results of this study indicate that the high levels of VOCs in the city are sufficient to represent a degree of risk to the city dwellers and a more comprehensive study over a long period of time and during the four seasons of the year would be required to better quantifying the problem. In addition, it is necessary to adopt drastic measures concerning motor vehicles, either by reducing traffic or introducing emission control.

Volatile organic compounds (VOCs) monitoring was conducted in two Ethiopian cities – Jimma and Addis Ababa found higher levels. This is part of a global multi-city study done by researchers from Ghent University in which thirty four VOCs were measured at eight different urban sites across the world in Ghent (Belgium), Hanoi (Vietnam), Jimma and Addis Ababa (Ethiopia) from September 2008 to September 2010. The highest total VOC concentrations were measured in street samples with maximum values of 318 µg/m3 in Addis Ababa, 507µg/m3 in Hanoiand 54 in Ghen µg/m3, DucHoai Do et al (2013).

4.6 COMPARISON OF THE FINDING WITH OTHER URBAN AREAS, CITIES ANDTHE INTERNATIONAL STANDARD

Ethiopia has got Emissions standards only for different categories of industry (Environment Standards for Ethiopia: 2003).East African Standard gives permissible limits of some common substances found in polluted air, namely sulfur dioxide, carbon monoxides, particulate matter, oxides of nitrogen, hydrocarbons. The standard covers both the ambient air and emission sources for East African Community standard in table 10 (2010b).

For comparing the study results against International Standards such as WHO and other different International Organization Air Quality Standards are also given in table 11.

Table: 10 Ambient Air Quality Tolerance Limits in East African Community

Pollutant	Time Weighted Average	Concentration in Ambient Air		
		Industrial	Residential, Rural and other Areas	Sensitive Area
PM10	24hr.	150µg/m3	100µg/m3	50µg/m3
CO	One hour	(8.73pm	(3.49 ppm)	(1.75 ppm)
NO_2	One Hour	-	0.2ppm	-
NO_2	Instant Peak	-	0.5ppm	-
(SO2)	Instant peak	-	500 mg/m3(0.175ppm)	-
Total VOCs	$6mg/m^3$	-	-	-

Source: (EAC, 2010b)

Table 11: Other international standards

Pollutants	Average Time	WHO	US	EU
PM_{10}	24 hr.	50 mg/ m3	150 mg/ m3	50 mg/ m3
CO	1 hour	26ppm	35ppm	-
NO_2	1 hour	0.106ppm	-	0.105ppm
SO_2	1 hour	0.175ppm	-	-
VOCs	1 hour	-	-	-

Sources: WHO Air Quality Guideline adopted in 2000 and 2005

	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	VOCs (µg/m3)	PM10 (µg/m3)
STD	159.93	1.66	0.15	0.14	122.83
Average	526.37	14.10	0.23	0.31	326.85
Max	871	17.16	0.36	0.64	576
Min	302	10.54	0.13	0.12	130

From this study, the overall average mean value of ambient air pollutants results of the city is shown in table 12 below.

Table 12: Average mean value of all the ambient air pollutants concentration of the city

When we compared the finding study results with the above air quality standards, it is found that all the results are above the prescribed limit of the ambient air standards except with the who standards which is against with study results of co concentration which below the standards.

CHAPTER FIVE

CONCLUSION AND RECOMMONDATION

5.1 CONCULUSION

Air pollution has recently received wide publicity in the print and electronic media resulting in increased public awareness in Addis Ababa. The findings of this study showed that the concentration level of the four ambient air pollutant gases CO, NO2, SO2 and VOCs and particulate matter (PM10) in the ambient air of Addis Ababa are above the prescribed limits of Ambient Air Quality Tolerance Limits in East African and other international standards such as WHO. The spatial distribution ambient air pollutants at different land use showed that have high concentration level of the ambient air pollutant were observed at industrial and transport sites. To explain the finding it could be said that most stations, emissions from industries, factories and small-scale workshops (industrial) and motor vehicles (transport area) appeared to be the primary source of hydrocarbons in ambient air of the city.

The rapid urban population of the City in the last decade has resulted in unplanned urban development, industrialization, rising rate of motorization and increase in consumption; and then urban air pollution problems.

5.2 RECOMMENDATION

The city should pursue policies to control more effectively air pollution resulting from emissions of oxides of sulfur and nitrogen, hydrocarbons, and particulate matter, from stationary and mobile sources in order to achieve environmentally acceptable levels of ambient air quality and deposition of pollutants. An appropriate combination of some or all of the following means can be used to reduce the ambient air pollution of the city.

- Increased use of non-fossil energy sources, to the extent that these are compatible with other policy goals.
- The use of newer and environmentally more harmless combustion technologies.
- Pollution prevention facilities and systems.

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LIST OF ANNEXES

Annex-1 For conversions between ppm, ppb, mg/m3 and ug/m3

Molecular Weight x PPM = 24.45 x mg/m3 or

Molecular Weight x ppb = 24.45 x ug/m3

	0oC, 1 atm 25oC,1 atm	0oC, 1 atm 25oC,1 atm
Carbon Monoxide CO	1.250mg/m3	1 ppm = 1.145mg/m3 1mg/m3 = 0.873 ppm
Nitrogen Dioxide NO_2	2,050µg/m3	1 ppm = 1,880µg/m3 1 µg/m3 = 0.000532 ppm
Sulfur dioxide SO_2	2,856µg/m3	1 ppm = 2,860µg/m3 1mg/m3 = 0.35 ppm

Annex 2 Particulate matter (PM10) data collection format table

Name of the place	Type of area	Date	Time	GPS North	GPS East	Alt	PM10 Spot1 in µg/m3
	Industrial		24hr.				
	Transport						
	Residential						

Annex 3 Pollutants Gases data collection format for morning Time

Type of the Area	GIS reading	Date	Morning Time 1 (7:00-8:00 am)	CO in ppm 1	Morning Time 2 (8:00-9:00 am)	NO_2 in ppm 1	Morning Time 3 (9:00-10:00 am)	SO_2 in ppm 1	Morning Time 4 (10:00-11:00 am)	VOC in µg/m3 1

Annex 4 Pollutants Gases data collection format for noon time

Type of the Area	GIS reading	Date	Noon (11:30am-6:30 pm)	CO in ppm	Noon (11:30am-6:30 pm)	NO_2 in ppm	Noon (11:30am-6:30 pm)	SO_2 in ppm	Noon (11:30am -12:30 pm)	VOC in µg/m3

Annex 5 For Pollutants Gases data collection format for Afternoon Time

Type of the Area	GIS reading	Date	Afternoon Time 1 (1:00 pm-2:00 pm)	CO in ppm 1	Afternoon Time 2 (1:00pm-2:00 pm)	NO_2 in ppm 1	Afternoon Time 3 (2:00 pm-3:00 pm)	SO_2in ppm 1	Afternoon Time 4 (4:00 pm-5:00 pm)	VOC in µg/m3

Annex 6 Secondary Meteorological Data collection format

Location	wind speed(m/s)	wind direction (deg.)	atm. temp(0C)	Rel. humidity (%)

Annex-7 Emissions standards for different categories of industry in Ethiopia

Type of industry	Parameter	Limit value
Tanning and leather finishing	Total particulates	50 mg/Nm3
	Volatile organic carbons	75 g/m2
	Total hydrogensulphide (as S)	5 ppm v/v
	Ammonia	40 ppm v/v
	Acid vapors	30 mg/Nm3
Manufacture and finishing of textiles	Particulate matter	50 mg/Nm3
	Volatile organic carbons (as C)	50 mg/Nm3
	Formaldehyde	20 mg/Nm3
	Isocyanates (as NCO)	0.1 mg/Nm3
Production and processing of iron and steel	Particulate matter	50 mg/Nm3
	Hydrogen fluoride (as HF)	5 mg/Nm3
	Mercury (as Hg)	0.05 mg/Nm3
	Lead (as Pb)	0.5 mg/Nm3
	Zinc (as Zn)	10 mg/Nm3
	Chromium (as total Cr)	0.5 mg/Nm3
	Nickel (as Ni)	0.5 mg/Nm3
	Cadmium (as Cd)	0.05 mg/Nm3
	NOx (as NO2)	1000 mg/Nm3
	SOx (as SO2)	800 mg/Nm3
	Dioxins as International Toxicity Equivalent(I-TEQ) 1 ng/Nm3	1 ng/Nm3
Metal working plating and finishing	Particulate matter	10 mg/Nm3
	Mercury (as Hg)	0.05 mg/Nm3
	Lead (as Pb)	0.5 mg/Nm3
	Zinc (as Zn)	10 mg/Nm3
	Chromium (as total Cr)	0.5 mg/Nm3
	Nickel (as Ni)	0.5 mg/Nm3

	Cadmium (as Cd)	0.05 mg/Nm3
	NOx (as NO2)	300 mg/Nm3
	SOx (as SO2)	300 mg/Nm3
Base metal and iron ore mining	Particulate matter	50 mg/l
	Silica	15 mg/l
	SO2 (mg/Nm3)	1000 mg/l
	Nickel (as Ni)	5 mg/l
	Iron (as Fe)	10 mg/l
	Copper (as Cu)	20 mg/l
	Sulphuric acid (as H2SO4)	50 mg/l
	Nitric acid (as HNO3)	50 mg/l
	Ammonia (as NH3)	300 mg/l
	Arsine	5 mg/l
	Dioxins as International Toxicity Equivalent (I-TEQ)	1 ng/Nm3
	Particulate matter	50 mg/l
Malting, brewing, distilling, production of wines alcoholic liquors	Total Particulates	100 mg/Nm3
	Hydrogen chloride (as HCl)	30 mg/Nm3
Manufacture dairy products	Total particulates	100 mg/Nm3
	Hydrogen chloride (as HCl)	30 mg/Nm3
Fruit and vegetable processing	Total Particulates	100 mg/Nm3
	Hydrogen chloride (as HCl)	30 mg/Nm3
Manufacture of sugar	Total particulates	100 mg/Nm3
	Hydrogen chloride (as HCl)	30 mg/Nm3
Slaughtering meat processing and rendering		
a. Slaughtering and meat processing plants	Total particulates (at a mass flow of 0.5 kg/h or above) 100 mg/Nm3	100 mg/Nm3
b. Rendering plants	Total particulates	100 mg/Nm3
	Ammonia	50ppmv/v

	Amines	5ppmv/v
	Hydrogen sulphide, and mercaptans	5ppmv/v
Manufacture of fertilizers		
a. Phosphate fertilizer plant	a. Phosphate fertilizer plant	a. Phosphate fertilizer plant
fertilizer plant	Total Particulates	100 mg/Nm3
	Fluorides (as HF)	10 mg/Nm3
Sulphuric Acid plant	Sulphuric Dioxide (as SO2)	2 kg/t acid
	Sulphur Trioxide (as SO3)	0.15 kg/t acid
Phosphoric acid plant	Total Particulates	100 mg/Nm3
Fluorides (as HF)	Fluorides (as HF)	10 mg/Nm3
b. Nitrogenous fertilizers		
Ammonia production	Nitrous oxides (as NO2)	1.3 kg per tons of NH3 produced
	Sulphur oxides (as SO2)	0.1 kg per tons of NH3 produced
	Carbon dioxide (as CO2)	500 kg per tons of NH3 produced
	Carbon monoxide (as CO)	0.03 kg per tons of NH3 produced
Fertilizer plant	Total particulates	100 mg/Nm3
	Ammonia	50 mg/Nm3
	Amines	5 mg/Nm3
Pulp and paper	Total particulates	150 mg/Nm3
	Hydrogen sulphide (as H2S)	15 mg/Nm3
	Sulphur dioxide (as SO2)	800 mg/Nm3
	Total sulphur	

	Sulphite mills	2 kg/ton ADP*
	Kraft and other mills	1.5 kg/ton ADP*
	Chlorine	20 mg/Nm3
	Nitrous oxide (as NO2)	
	Natural gas	100 mg/Nm3
	Liquid fuels	150mg/Nm3
	Solid fuels	300mg/Nm3
	Volatile organic carbon compounds	20 mg/Nm3
	Smoke	2 units of Ringlemann shade
Cement manufacturing	Total particulates	150mg/Nm3
	Sulphur dioxide (as SO2)	1000mg/Nm3
Petrochemical manufacturing	Total particulates	50mg/Nm3
	manufacturing Nitrous oxides (as NO2)	500mg/Nm3
	Sulphur dioxide (as SO2)	800mg/Nm3
	Hydrogen chloride (as HCl)	20mg/Nm3
	Benzene	5mg/Nm3 0.1 ppb at plant fence
	1,2-Dichloroethane	5 mg/Nm3 1 ppb at plant fence
	6Vinyl chloride	5 mg/Nm3 0.4 ppb at plant fence

	Chlorine	20 mg/Nm3
Pesticide manufacturing	Pesticide Total particulates	10 mg/Nm3
	Volatile organic carbon compounds	50 mg/Nm3
	Hydrogen chloride (as HCl)	20mg/Nm3
	Chlorine (or chloride)	5 mg/Nm
	Pesticide Total particulates	10 mg/Nm3
Pesticide formulation	Total Particulates 10 mg/Nm3	10 mg/Nm3
	Volatile organic carbon compounds	50 mg/Nm3
	20 mg/Nm3	20 mg/Nm3
	Chlorine (or chloride)	5 mg/Nm3
	Total Particulates	10 mg/Nm3

Note:

1. In case of printing and surface coating industries, the emissions from surface coating operations come from evaporation of organic solvents in the coatings consisting primarily VOCs.

2. In case of continuous monitoring for emissions to the atmosphere, the following is to be refereed:

a) No 24 hour mean value shall exceed the emission limit value.

b) 97% of all 30 minute mean values taken continuously over an annual period shall not exceed 1.2 times the emission limit value.

c) No 30 minute mean value shall exceed twice the emission limit value.

d) For Total Organic Carbon (as C) concentration limits, no hourly average value shall exceed 1.5 times the emission limit value.

3. during non-continuous monitoring:

e) For flow, no hourly or daily mean value, calculated on the basis of appropriate spot readings, shall exceed the relevant limit value.

f) Mass flow threshold refers to a rate of discharge expressed in units of kg/h, above which concentration the emission limit value applies. Mass flow threshold rates shall be determined on the basis of a single 30 minute measurement (i.e. the concentration determined as a 30 minute average shall be multiplied by an appropriate measurement of flow and the result shall be expressed in units of kg/h).

g) Mass flow limits shall be calculated on the basis of the concentration, determined as an average over the specified period, multiplied by an appropriate measurement of flow. No value, so determined, shall exceed the mass flow limit value.

h) For all Total Organic Carbon (as C) concentration limits, the average of all readings in one monitoring exercise shall not exceed the emission limit value and no hourly average value shall exceed 1.5 times the emission limit. At least three readings shall be obtained in each monitoring exercise.

4. For all other parameters, no 30 minute mean value shall exceed the emission limit value.

The concentration and volume flow limits for emissions to the atmosphere shall be achieved without the introduction of dilution air and shall be based on gas volumes under standard conditions of :-

5. In the case of non-combustion gases, a temperature of 2730K, and a pressure of 101.3 KPa without any correction for oxygen or water content.

6. In the case of combustion gases, a temperature 2730K, and a pressure 101.3 KPa of dry gas with 3% oxygen for liquid and gas fuels, 6% oxygen for solid fuels, and 10% oxygen for thermal oxidizers.

Source: Ministry of Environment and Forests and Climate Change, Ethiopia, 2003.