ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

QUANTIFYING AIR POLLUTION OF ROAD TRANSPORT IN ADDIS ABABA CITY

A Thesis submitted to

School of Civil and Environmental Engineering

In partial fulfillment of the requirements for degree of

Masters of Science in Civil Engineering

(Road & Transport Engineering)

By

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Advisor

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MSc. Thesis on

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DECLARATION

I declare that the work entitled **"QUANTIFYING AIR POLLUTION OF ROAD TRANSPORT IN ADDIS ABABA CITY"** was carried out by me in the stream of Road and Transport Engineering in the school of Civil and Environmental Engineering under the supervision of my research advisor Dr. Getu Segni. The information derived from other literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree in any institution.

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Abstract

Transport is one of the key necessities for the development of a country. In the contrary, transport sectors contribute in air pollution by exhausting harmful gaseous. Quantifying and determining the road transport emission of vehicles is an essential step in pollution control and management. Therefore, the aim of this paper is to assess emission levels and identify possible alternatives of environmentally friendly public transports vehicles in Addis Ababa city.

The data was collected with electronic instruments; Smoke Opacity Meter and FGA 4000XDS Gas Analyzer on the site through tail pipe. It employs a descriptive research with quantitative approaches considering vehicle model year, category, model names and kilometer driven. These data were analyzed through quantitative (descriptive and statistical analysis) methods.

From the total of 358 tested diesel fueled vehicles, 243 (67.9%) vehicles failed the standard cut points with smoke opacity values greater than or equal to 41%. Of these vehicles 45 (19%) registered 100% smoke opacity value. Only 115 (32.1%) vehicles passed the standard limit. The results of this study show that (Taxi vehicles) is the dominant air pollutant with an average emission of 86.36% smoke opacity which is above the U.S. EPA Standard and only 7.4% passed the standard guidelines. Vehicles in this category were those with the oldest model year of 1960-1999 with an average age of 33 years.

From 62 tested gasoline vehicles 29(46.8%), 21(33.87%) scored between 2000-3903ppm, 21-1541ppm HC respectively and 57(92%) failed Californian BAR-90 standards. Again, 53(85.5%), 9(14.5%) recorded between 3.14-5.87% and 0.03-0.49% CO respectively and 53(85.5%) failed Californian BAR-90 standards.

This study found that, Travelling by old and new Anbessa bus can decrease air pollution by 32 and 176 as much as using minibus taxis respectively. Also, travelling by Sheger Bus can reduce air pollution by 34 times as much as minibus taxi. Overall, the study found that Taxi vehicles both diesels and gasoline fueled were termed as supper emitter together with Higer Bus.

Key words: Quantifying, Road transportation, FGA 4000XDS four and Five Gas Exhaust Analyzer, Smoke Opacity, Air pollution

Acronyms and Abbreviations

AA -------Addis Ababa

AACGA--Addis Ababa City Government Administration

AAEPA--Addis Ababa Environmental Protection Authority

AATA---Addis Ababa Transport Authority

BAR-90 ------Bureau of Automotive Repair

CARB----California Air Resources Based

CO--------Carbon monoxide

EC--------European Community (now EU)

EEC-------European Economic Communities (now EU)

EEPA-----Ethiopian Environmental Protection Authority

EMFAC---Emission Factors

GHG------Green House Gas

HC--------Hydrocarbons: Harmful tailpipe emissions made up of unburned fuel. Key element in forming photochemical Smog

IPCC-----Intergovernmental Panel on Climate Change

LRT------Light Rail Transport

NO_x------Nitrogen oxides

NO_2------Nitrogen dioxide

NSW EPA—New South Wales Environmental Protection Authority

OECD-------- Organization for Economic Co-Operation and Development

ORAAMP----Office for the Revision of Addis Ababa Master Plan

Ppm------Parts per million

PM_{10}-----Particulate Matter of 10 micron

$PM_{2.5}$----Particulate Matter of 2.5 micron

SO_2------Sulphur dioxide

US EPA--Unite States Environmental Protection Agency

VOCs-------Volatile organic compounds

WBCSD---- World Business Council for Sustainable Development World

WHO-------World Health Organization

Table of contents

List of Figure

List of Table

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Transport is the engine of social and economic activities. The provision of competent and efficient transportation system is of paramount importance for the cities especially in the modern era of globalization and information age where cities are the centers of urbanization and propellers of national and global economies. Addis Ababa, the capital city of Ethiopia, is the heart of social, political and economic activities of the country and is the 4th largest diplomatic center in the world as the city is a seat of UN Economic Commission for Africa (UNECA) and African Union (AU).

Addis Ababa is seeing a fast paced urbanization which imposes intense pressure on the urban infrastructures, particularly on transport. Urbanization is a challenge which when joined with congestion and automobile oriented-development practices intensifies the magnitude and dimension of urban problems across cities of the world, particularly in developing cities like Addis Abba. Addis is already in peak pressure of providing competent transportation infrastructure and service that can absorb the pressing demand of the ever growing population (Demdime, 2012). Thus urban transport, transport infrastructure, and traffic management should involve the optimal integration of the means and ways of mobility to make maximum ease and comfort maintaining the socioeconomic and physical integration of the city (Eshete, 2015). Additionally, transportation is the basic sectors supporting people's daily activities because without any movement it is impossible for them to fulfill their needs. People conduct activities in different places due to biological needs, social obligations, and personal desires (Eriksson, 2009). Therefore, urbanization process increases substantially the demand for urban transport for the transformation of society and facilities modernization at large. Moreover, Road transportation has an essential economic and social role. However, mobility is also associated with a variety of negative impacts: - Congestion, Pollution, Greenhouse gas emissions, Disruption of neighborhoods, Noise, Crashes, etc. (WBCSD, 2001).

Road transport contributes significant amount of air pollutants in urban areas. This is mainly due to increase in population and consequent need for travel to participate in activities at different locations. In addition, increasing of vehicle ownership, decreasing of patronage public transport, and inadequate maintenance of vehicles pose serious challenges to policy makers and government agencies which are responsible for maintaining air quality (Colvile et al., 2001; Pison and Menut, 2004).

The main pollutants emitted by vehicles include carbon monoxide, oxides of nitrogen and sulphur, hydrocarbon, lead, ozone and suspended particulate matter. These pollutants have harmful effects on human health and ecology. Poor air quality increases respiratory disorders like asthma and bronchitis and increases the risk of life-threatening diseases like cancer (Choudhary and Gupta, 2016). This situation is alarming and is predicated on the poor economic disposition of developing countries. Poor vehicle maintenance culture and importation of old vehicles which culminate to an automobile fleet dominated by a class of vehicles known as “super emitters’’ with high emission of harmful pollutants, has raised high this figure of emission concentration. Furthermore, in developing countries the super emitters contribute about 50% of harmful emissions to the entire average emission (Brunekreef, 2005). Specially, transportation sources were responsible for 77% of CO emissions, 45% of NO_X, 36% of volatile organic compounds, and 22% of particulates (USEPA, 1993). To a great extent, about 20% of CO_2 emissions in the US come from motor vehicles.

Mishra and Dhingra (2016) found that, the concentration level of CO pollutants in Navi Mumbai, India at some intersection is within the prescribed limit of the Central Pollution Control Board (CPCB) whereas at some of the intersections, it is exceeding the prescribed limit of CPCB. Moreover, it was found that emissions from both types of vehicles like CO, NO_x, HC, PM and CO_2 levels are well above worldwide standards for human and environmental health.

Vehicle emission rate is influenced by some factors. It largely depends on vehicle type, characteristics of traffic and type of road intersections. Specially, Vehicle age, fuel economy, mileage, engine characteristics, weight, make, general maintenance, and time of year are found to be strong determinants of emissions and test failure rates. Furthermore, the failure probability increases with the number of miles driven, because of increased engine and emissions equipment deterioration (Beydoun, 2004). Due to improper functioning and maintenance of vehicles highest level of NO_X at 3.44 g/km, HC at 6.53 g/km, CO at 13.9 g/km, $PM_{2.5}$ at 1.3 g/km and 35.96 g/km of CO_2 emissions were observed in Adama city (Neway et al., 2016).

Dallmann and Façanha, (2016) pointed out in their report on diesel passenger car emissions in Brazil, increasing number of diesel cars would significantly increase NO_X and $PM_{2.5}$ emissions, and estimated 150,000 premature deaths between 2015 and 2050. Additionally, Schwela (2012) in his study suggested that urban air pollution in sub-Saharan Africa is on the rise, due to rapid economic and population growth and an increase in motorization. As a result of this, he estimates roughly 49,000 deaths per year in the region. This is because of the use of fossil fuels in transport, combined with a lack of emission controls on vehicles, and poor monitoring and enforcement systems. As he studied, vehicles have a wide range of direct and indirect effects on ecosystems, agriculture and materials. Thus, there is an urgent need to better monitor and manage urban air quality and identify the most effective measures to reduce pollution. Recent report of (UNEP, 2016) mentioned that only 12 out of 49 countries have motor vehicle import restrictions based on the age while the rest have either no restriction or impose heavier import tax penalties for vehicles beyond specified ages. From the literatures above, it is observed that African countries are looking vehicle emission from the back and many of the nations' are suffering from it.

Ethiopia is one of Sub-Saharan African country. So, we are also suffering from this situation as the study revealed that, the status of air pollution and ambient air pollution has not been studied sufficiently (Kumie, 2009). Therefore, this paper is planned in Addis to generate empirical data as contribution to the limited information on vehicular emissions: Carbon monoxide (CO), Carbon dioxide (CO_2), Hydrocarbon (HC), and smoke opacity in the city. There are now strong evidences, which show that the vehicular emission is the main source of air pollution in urban mainly in developing countries as a result of the increasing vehicle population and no enforcing law on vehicular emission level.

1.2 Statement of the problem

Road transportation has an essential economic and social role. However, mobility is also associated with a variety of negative impacts: - Congestion, Pollution, Greenhouse gas emissions, Disruption of neighborhoods, Noise, Accidents, etc. (WCSD, 2001). Pollution is a staple problem of today's world. Rich or poor, planed or market oriented, democratic or autocratic, modern or traditional nation all over are steeped in pollution. While the facets of pollution changes from country to country or region to region, it is undeniable that we cannot live without it. It is the price of the riches that the science and technology bestowed upon us. Among them, the rise in automobile ownership is one. Moreover, it is at the origin of various other externalities, such as congestion, incidents, and noise pollution. Air quality, fuel consumption, and the production of greenhouse gases are major topics of national and local regulations and of international agreements.

In most developing countries of the world vehicular growth has not been checked properly by environmental regulating authorities leading to increase levels of pollution. Traffic emissions contribute about 50-80% of NO_2 and CO concentration in developing countries (Fu et al., 2001 ; Goyal et al., 2006). This situation is alarming and is predicated on the poor economic disposition of developing countries. Poor vehicle maintenance culture and importation of old vehicles which culminate to an automobile fleet dominated by a class of vehicles known as "super emitters'' with high emission of harmful pollutants, has raised high this figure of emission concentration (Ibrahim, 2009). Furthermore, in developing countries the super emitters contribute about 50% of harmful emissions to the entire average emission (Brunekreef, 2005). In Mexico City for example these supper emitters is reported to be responsible for 90% of hydrocarbon and CO emissions and 80% of NO_X emission accounting for 60% of the kilometers travelled in the country (OECD, 1988). Vehicle emissions have two negative effects on the environment: one is global climate change and the other is air pollution and its negative health repercussions.

Mainly, developing cities in Asia and Africa are at high risk to exposure of this traffic-related pollution. Research conducted in Ethiopia, Mozambique, Kenya and Republic of Benin, show that there is a high level of DNA damage in urban residents and higher prevalence of asthma in urban school children exposed to traffic pollution compared to rural children (Ayi et al., 2006). The African continent may be highly heated if priority is not given in understanding the scale of this problem and its control. Moreover, in Ethiopia, the assessment of CO on the road-sides and on-road lines was explorative in nature. Although the overall averaged concentrations of CO in both sampling periods were within US-EPA and WHO limits, there is a reasonable indication that these guidelines might be exceeded in the long run (Kume et al., 2010).

Moreover, other finding well explained that Addis Ababa's taxis fleet is less than 15% of its vehicle population; but, it contributes almost one-half of the fleet's hydrocarbon emissions and more than 27% of the fleet's carbon monoxide emissions. The study confirms that exhaust gases from vehicles pollute Addis Ababa's air, and this is mainly due to improperly maintained vehicles (Benjaminson et al., 2012). According to the research of Mekelle city, the average emission level of private automobiles in Mekelle city is 209.93grams of CO_2/km. This is much higher than the automobile emission standards of Europe, which is 203grams of CO_2/km for 2007 and 181.4grams of CO_2/km for 2010 (European Commission, 2013) and that of United States, which is 131.73grams of CO_2/km for 2017 which is bad on the life of human and other living things (Gebre, 2018).

The research work in Tirana has investigated that opacity value was extremely high for the vehicles produced before 2002. Vehicles with ages more than fourteen years have very high opacity level and the most problematic groups that cause high pollution level come from the produced years 1980 up to 2002 (Malka and Bidaj, 2015). Additionally, newer model-year vehicles are associated with lower emissions, due to improved vehicle technology and lesser engine and emission control equipment deterioration. Higher vehicle kilometer travelled is associated with higher emissions, as increased vehicle use results in more wear-and-tear in the mechanicals and emission control equipment. However, the mileage elasticity varies across makes, pollutants, and type of vehicle (Beydoun and Guldmann, 2006).

It is evident that vehicle emissions are problematic to the global environment. A logical way to reduce these negative impacts would be to decrease vehicle emissions; to catch the problem before it worsens. This can be achieved through letting down the number of vehicles on the road. So, the increasing trend for private vehicle ownership can be replaced by increased reliance on public transportation (Laffel, 2006). Although public transport is not defined as a "zero-pollutant" travel mode, its average emissions per passenger are far lower than that from cars.

Furthermore, cleaner and more fuel efficient public transport is becoming more common in many countries, supporting a further reduction of GHG emissions and air pollution (Xia, 2015).

Yigzaw of Federal Transport Authority (2017) reported that number of cars in Ethiopia last year was 708,410; however, it has now reached 831,265. Most of these are imported, having more likelihood of causing pollution, and cost a lot of money to import spare parts. Of these, 524,444 cars, which accounts for 63 percent of the registered vehicles are found in Addis Ababa City. In light of the issues raised above, this research work is aspired to inquire the level of emissions generated from diesel and gasoline engine user vehicles considering their vehicle makes, model year/Age, vehicle kilometer travelled, and vehicle types.

1.3 Research Questions

Table 1. 1 The research questions.

No.	Research Questions	Research objectives
1.	Did Ethiopia reduce road transport related air pollution by implementing public transport?	To analyze the impact of providing one bus transport in reduction of traffic air pollution.
2.	Which types of vehicles are the main players in the road transport related air pollution in Addis Ababa?	To identify the major vehicle types that contributes to road transport related air pollution.
3.	Is there quality control standard on the age limit for cars (both imported new and used)?	To identify the reason why it is not applied and to discuss the necessity of quality control standard.
	The regional framework on air pollution in Eastern Africa (Nairobi Agreement 2008) brings together 11 countries to develop actionable targets to address air pollution in the areas of Transport sector and others. Is it the agreement is going on as it is said in Ethiopia?	To look at actionable targets taken by Ethiopian Government to address air pollution in the transport sector.

1.4 Objective of the study

General objective

The main objective of the study is to assess vehicle emission and to find possible strategies and approaches to improve the public transportation system to play a major role in creating clean and safe air of Addis Ababa.

Specific objectives

The specific objectives of the study are to:

- To know emission generated from both diesel and gasoline fueled vehicle types by using Digital Smoke Meter and FGA4000XDS Five Gas Analyzers.
- To compare emission level with U.S. EPA (U.S.A EPA, 1998) and California BAR-90 Smog Check program for idle and 2500rpm standard guidelines, since there is no vehicle emission standard in Ethiopia.
- To know any impacts of each vehicle types and compare the emission reduction of city bus if it replaced other modes; taxi/minibus and some others.

1.5 Scope of the Research study

As a result of high dense traffic, availability of different vehicle categories, of these are oldest Taxis and Minibuses occurring in Addis Ababa leads researcher's target to focus on the city as study area. Due to budget and time constraints statistical sampling method needed to apply. An appropriate sampling method for this type of population is stratified random sampling since the sample is composed of different categories of vehicles. As a result, the researcher collects data especially around Bus stops, taxi stations in the city. Measure smoke opacity from a representative sample of Addis Ababa's diesel and gasoline fueled vehicle fleet.

1.6 Significance of the study

This study is an applied research as it employed the use of instruments to measure/test vehicle emissions. The results from this work will therefore provide an essential insight into conditions of motor vehicles entering in to Ethiopia. This insight may be a basis for future efforts by policy makers to establish the national guidelines regarding transport air pollution levels from motor vehicles. Therefore, the study is very useful to investigate the current status of transport related air pollution in Addis and to find underlying mechanism of reducing the pollution from traffic for better understanding and management of the problem.

1.7 Structure of the thesis

In this section the structure of the thesis is suggested. It is proposed a layout composed of six chapters:

Chapter one, Informs about vehicular air pollution, an area in which the research conducted, set the problem statement, state the objectives and will explain the contribution of the research.

Chapter Two, Discusses the literature reviews regarding with the research subjects. In this section different literatures are reviewed on how about the vehicle emissions, the factor for the increasing of vehicular emission, the way to minimize vehicular emission. Entirely, it provides a critical assessment of previous research efforts and its relationship with the present work.

Chapter Three, describe study area, general required data, sample size determination, the methods of data collection and analysis.

Chapter Four, dedicated to the description of vehicle emissions based on their characteristics; vehicle model year, types, kilometer travelled and vehicle make. It covers all the descriptive analysis and discussion of the relation of vehicle emission with their physical characteristics in this thesis. Describe all about statistical difference results and discussion to strengthen the results of descriptive statistical Analysis. This discusses the mean difference on the vehicle emission considering Model year, Vehicle types, Vehicle kilometer travelled and Vehicle makes. This provides the significance obtained between vehicle emission level and characteristics.

Chapter Five, will give conclusion and recommendation for the study. It will a summary of the contributions and will point out future directions of research. Finally, at the end there are lists of references used.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Definition of air pollution

The dictionary definition of environmental pollution is the introduction of contaminants in to the natural environment that causes adverse change. Air pollution occurs when gases, dust particles, fumes (or smoke) or odor are introduced into the atmosphere in a way that makes it harmful to humans, animals and plant. Air pollution threatens the health of humans and other living beings in our planet. It creates smog and acid rain, causes cancer and respiratory diseases, reduces the ozone layer atmosphere and contributes to global warming (Choudhary and Garg, 2015). Additionally, it is the release of chemicals and particulates into the atmosphere. Common gaseous pollutants include: hydrocarbons, carbon monoxide, sulfur dioxide, chlorofluorocarbons, nitrogen oxides and Particulate matter (Pure Earth et al., 2015).

The four main sources of air pollution are:-

1) Stationary sources such as power plants, oil refineries, industrial facilities, and factories,

2) Area sources such as agricultural areas and wood burning fireplaces,

3) Natural sources such as wind-blown dust, wildfires, and volcanoes and

4) Mobile sources which includes any air pollution emitted by motor vehicles, airplanes, locomotives, and other engines and equipment that can be moved from one location to another (US EPA, 2015). Air pollution in Sub Saharan cities appears to be on the rise with respect to many key pollutants. In some cities where monitoring has been performed levels of air pollution exceed World Health Organization recommended guidelines (WHO, 2006). The main cause of urban air pollution is the use of fossil fuels in transport, power generation, industry and domestic sectors.

2.2 Road transport and vehicular emission

Road transport is an important source of greenhouse gas emissions (United Nations, 2004). The combustion of fossil fuels in vehicles for the reason of transportation is the single largest source of human made greenhouse gases (EPA, 2013). Emissions from fossil fuels can be from gasoline fuels or diesel fuels. Black smoke belching out of diesel buses and trucks has come to shape the public image of air pollution in many cities in the world (WHO, 2002).

U.S EPA (1993) reported that, transportation sources were responsible for 77% of CO emissions, 45% of NO_x , 36% of volatile organic compounds, and 22% of particulates in the US. It is estimated that approximately 50% of these effects are caused by CO_2. More importantly, about 20% of CO_2 emissions in the US come from motor vehicles. In the developing countries too, increasing modernization has led to an increased presence of motor vehicles which means a large percentage of CO_2 emissions in these countries comes from motor vehicles as well (Harrington and Mcconnell, 2010). In addition to CO_2 emissions and the resulting climate change, other vehicle emissions contribute to air pollution.

Vehicles account for most of the carbon monoxide (CO) and a large share of the Hydrocarbons (HC), Nitrogen oxides (NO_x), and particulates found in the atmosphere in major urban areas. Nitrogen oxide (NO_x) results when nitrogen in the fuel or in the combustion of air heats to temperatures above 1,200 degrees Fahrenheit in the presence of oxygen. This reaction occurs in most car engines today. Nitric oxide (NO) is the initial product and oxidizes to nitrogen dioxide (NO_2). Nitrogen oxides also combine with water leading to a component of atmospheric acidification, specifically nitric acid (HNO_3). In turn, this leads to “acid” rain. The general term “NO_x” is used to describe this family of emissions (Cunningham et al., 2006).

Vehicle emissions are responsible for about two third of air pollution in urban areas. The main pollutants emitted by vehicles include carbon monoxide, oxides of nitrogen and sulphur, hydrocarbon, lead, ozone and suspended particulate matter. These pollutants have harmful effects on human health and ecology. Poor air quality increases respiratory disorders like asthma and bronchitis and increases the risk of life-threatening diseases like cancer (Choudhary and Gupta, 2016). Moreover, vehicle emissions constitute the greatest individual source of nitrogen oxides in industrialized courtiers (Suess, 1993). Table 2.2 below shows the contribution of vehicle emissions to pollution in the atmosphere and their resultant effects.

Table 2. 1 Amount of Air Pollution from Motor Vehicles in US

Air Pollutant	Proportion from On-Road Motor Vehicles in US	Effects
Hydrocarbons	48%	Antecedent to ground-level
Oxides of Nitrogen (NO_x)	43%	Antecedent to ground-level ozone (smog)
Carbon Monoxide (CO)	66%	Contributes to smog production, poisonous in high concentrations
Particulate Matter (PM_{10})	10%	Health problems when passing through the throat, nose, and entering lungs

Source: Federal Highway Administration, 2002; Harrington and McConnell, 2003

Road transport sector accounts for approximately 16 percent of the global annual mean anthropogenic radioactive forcing of black carbon, the vast majority of which is from diesel-fueled vehicles (WHO, 2014; Koch et al., 2007). The exhaust of a typical diesel engine contains elemental carbon (soot or smoke), semi-volatile organic hydrocarbons, sulfates (primarily sulfuric acid), and water vapor (Lubrizol Corporation, 2013). It contributes a major share to environmental pollution (around 70%) and of these pollutants; CO is the major pollutant coming from the transport sector, contributing 90% of total emission. Hydrocarbons are next to CO. It is indeed interesting to observe that the contribution of transport sector to the particulate pollution is as less as 3-5%, most of the SPM (Suspended Particulate Matter) are generated due to re-suspension of dust out of which PM_{10} is the most prominent air pollutant. NO_x is another important air quality indicator. All these situations indicate that air pollution becoming a major problem in Indian context and there is an essential need to build up healthy environment and increase level of research around the world (Shrivastava, Neeta and Geeta, 2013).

Motor vehicles in the road transport systems are the most vital means of movement through which both passenger and good transportations are ensured. On the other hand, road transportation is becoming the victim of its own success and faces considerable challenges and is one of the most polluting modes of transportation (European Union, 2012). The effects of vehicular emissions have global implications whilst its health impact varies across continents.

Zhang and Batterman (2013) identified four factors contributing to increased vehicular emissions. They are culture, poor maintenance of vehicles, importation of over used cars and automobile overdependence. They further argued that because all the factors stated above are highly representative to developing countries, the harmful effects of vehicular emissions are likely to have huge implications on the region coupled with the fact that developing countries are confronted with a paucity of standards and guidelines for most of the pollutants present in the air. M. O. W. a. T. Uganda, "National Transport Database," (2006) and Boulter, McCrae and Barlow (2007) observed that, vehicle emission levels were dependent upon many parameters including vehicle-related factors such as model, size, fuel type, technology level and mileage, and operation factors such as speed, acceleration, gear selection, road gradient and ambient temperature. They further stated that the power to move a car comes from burning fuel in an engine and that pollution from cars came from byproducts of this combustion process (exhaust) and from evaporation of the fuel itself.

Moreover, Bluett et al., (2008) stated that emissions of all pollutants increase with increasing age of petrol vehicles. Emissions of NO_x do not appear to vary significantly with the age of diesel vehicles. Anna Alberini, et al., (1994) stated that, old vehicles tend to emit pollutants at much higher level, on average, than newer vehicles. Because, old vehicles often do not have effective emission control equipment; even it has a system for emission control, it sometimes no longer functions properly. They also stated that a potentially effective way to reduce hydrocarbon, Carbon monoxides, and nitrogen oxides emissions in urban areas is to take older, highly polluting cars off the road. Older or larger vehicles emit more hydrocarbons, carbon monoxide, and oxides of nitrogen per mile. Thus, alternative policies can approximate the effects of emissions taxes by explicitly or implicitly taxing miles, taxing engine size, or subsidizing vehicle newness (West, 2002).

Vehicle types also had an effect on emission levels. The results of annual emission from different vehicles show that, the total pollution load on the city per year for CO is 4,534.33 tones/year, for HC is 2,428.45 tones/year and for NO_x is 167.02 tones/year. CO and HC emissions due to two-wheelers were enormously high, that is 2,204.41 tones/year and 1,559.04 tones/year respectively. NO_x emission due to four- wheelers/diesel vehicles is 67.83 tones/year, which is low as compared to the CO and HC emissions. Therefore two-wheelers contribute maximum amount of emission of CO (49%) and HC (65%), among all the vehicles, thus revealing a high pollution load on the city (Shergill and Thukral, 2009).

In Ethiopia, the assessment of CO on the road-sides and on-road lines was explorative in nature. Although the overall averaged concentrations of CO in both sampling periods were within US-EPA and WHO limits, there is a reasonable indication that these guidelines might be exceeded in the long run (Kume et al., 2010). According to (Neway et al., 2016) analysis of emissions did on three wheelers and public minibuses taxi vehicles which amount to 80% of the automobile population in Adama city. It was found that emissions from both types of vehicles like CO, NO_x, HC, PM and CO_2 levels are well above worldwide standards for human and environmental health. Additionally, the research in Mekelle city pointed out the average emission level of private automobiles in Mekelle city is 209.93grams of CO_2 /km. Again the study approved as it is much higher than the automobile emission standards of Europe, which is 203grams of CO_2 /km for 2007 and 181.4grams of CO_2 /km for 2010 (European Commission, 2013) and that of United States, which is 131.73grams of CO_2 /km for 2017 which is bad on the life of human and other living things (Gebre, 2018).

Kebede and Gebresenbet (2017) estimated the amount of pollutants released by Freight Transport Vehicles considering the case in two scenarios in Addis Ababa City. In the first scenario, the study estimated the amount of CO_2 released to the air as 36.84 tons per day and 100 Kilogram per day of CO pollutant. The exhaust emission has share of 12% for Night movement and 88% for the Day time movement. These higher differences on exhaust emission percentage share showed most of the movements of Freight Vehicles were takes place at the Day time. For the Second scenario, it estimated amount of CO_2 as 29.18 tons per day and that of CO as 90 Kilogram per day. The exhaust emission has reduced 7.66 tons of CO_2 and 10 Kilogram CO per day compared to Scenario-1. These higher differences on exhaust emission percentage share showed most of the movements of Freight Vehicles were takes place at the day time. This is due to the absence and poor implementation of the concept of optimized freight delivery and coordinated logistics system of the city. Also the Age of vehicles have direct effect on the exhaust emission, as the Age of Vehicle goes higher, then the amount of gases released from the vehicle increase. The study believed that this might be the result of the lack of policies on vehicles replacement and lack of encouragement from the Government on the use of newer Freight Vehicles. In Addition Benjaminson et al., (2012) did vehicular exhaust tests on 782 passenger vehicles, and tests on ambient air quality, to investigate the level of air pollution from gasoline passenger vehicles. They measured tail pipe exhausts using Vehicle Gas Analyzers. From their research, they concluded that both ambient and vehicular HC, CO and PM levels are well above worldwide standards for human and environmental health. This study has also found that improperly functioning motor vehicles are major contributors to Addis Ababa's air pollution. The situation is serious enough that urgent regulatory actions are strongly needed.

2.3 Effects of air pollution

2.3.1 Local Effects

Regionally, the main effects of vehicles air-pollution are photochemical smog and ground level ozone caused by HC and NO_x in the presence of strong sunlight, in addition to the health effects of NO_2. Locally, the main effects of vehicles air-pollution are the immediate localized health effects of CO emissions; CO disperses rapidly into the atmosphere (NSW EPA, 1996). Researchers have indicated that traffic-related exposures cause stroke; cancers, including childhood leukemia, lower IQ levels in children (Suglia et al., 2008) and adverse reproductive outcomes, low birth weight and premature birth.

U.S. Environmental Protection Agency (U.S. EPA) has identified several key health effects of human exposure to present levels of ozone (U.S. EPA, 1996a, 1996c). When inhaled, ozone can cause acute respiratory problems, including asthma attacks, significant temporary decreases in lung function of 15 to over 20 percent in some healthy adults, and inflammation of lung tissue, leading to increased hospital admissions and emergency room visits. Inhaling ozone also may impair the body's immune system defenses, making people more susceptible to respiratory illnesses. Children and outdoor workers are likely to be exposed to elevated ambient levels of ozone during exercise and therefore are at greater risk of experiencing adverse health effects.

In developing nations, it is envisaged that with rising income and the rapidly rising mobility that accompanies it, the increase in automobile emissions will be even greater than the developed nations. Steady growth in vehicular populations has put environmental stress on urban centers in various forms particularly causing poor air quality. There is growing evidence that links vehicle pollutants to human ill health. Motor vehicles are major emission sources for several air pollutants, including NO_x, CO, PM, and HCs (Weyn Chris and R. Klaus Meier., Air care I/M Program, Radian Corporation, 1994). Additionally they stated that vehicle emissions cause both short and long term problems associated with health effects. For example, HCs and NO_x are the precursors of ozone gas, which has effects ranging from short term consequences such as chest pain, decreased lung function, and increased susceptibility to respiratory infection, to possible long-term consequences, such as premature lung aging and chronic respiratory illnesses.

Haq and Schwela (2012) in their study stated that, urban air pollution in sub-Saharan Africa is on the increase, due to rapid economic and population growth and raise in motorization. It is now estimated to cause roughly 49,000 deaths per year in the region. One main cause of this pollution is the use of fossil fuels in transport, combined with a lack of emission controls on vehicles, and poor monitoring and enforcement systems. In addition to its effects on human health, ozone is known to adversely affect the environment in many ways. These effects include reduced yields for commodity crops, fruits and vegetables, and commercial forests; deleterious effects on the ecosystem and vegetation in areas such as national parks; damage to urban grass, flowers, shrubs, and trees; reduced yields for tree seedlings and noncommercial forests; increased susceptibility of plants to pests; materials damage; and decreased visibility. In these studies, Transport related emission is shown as the main outdoor air polluting in urban areas. So it should have studied and monitored regularly, as the number of vehicle population will increase with the development of the city. Moreover, it was found that the effect of vehicular emission on human health in Lagos show that, on the average, 28.3%, 16.6%, 23.3%, 18.3%, 13.3% were respectively affected by sleeplessness, running nose, heavy eyes, asthmatic attack, and headache respectively (Adeyanju and Manohar, 2017).

It was pointed out that, very little amount of CO is due to natural events almost all is as a result of man-made events. Approximately 90% of man caused CO is from automobiles. Even if, some carbon monoxide comes from natural events such as marsh gas, coal gas mines, seed germination, injured vegetation, forest etc., and found as odor-less and color less gas. From health point of view CO is dangerous because it has a strong affinity for combining with the hemoglobin of the blood. Hence the hemoglobin available to carry the oxygen to body tissues is reduced (Subramani, 2012).

Subramani, Arutselvan and Ganesan (2014) identified that; Nitrogen oxides are formed during high temperature combustion processes from the oxidation of nitrogen in the air or fuel. The principal source of nitrogen oxides - nitric oxide (NO) and nitrogen dioxide NO_2 collectively known as NO_x is road traffic. NO and NO_2 concentrations are therefore greatest in urban areas where traffic is heaviest. Other important sources are power stations, heating plants and industrial processes. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infections such as influenza. It is continued or frequent exposure to concentrations that are typically much higher than those normally found in the ambient air may cause increased incidence of acute respiratory illness in children. Sulphur dioxide is a colorless gas with a characteristic, sharp, pungent odor. It is an acidic gas which combines with water vapor in the atmosphere to produce acid rain. These gases are formed when fossil fuels containing Sulphur are burned. Even moderate concentrations may result in a fall in lung function in asthmatics. Tightness in the chest and coughing occur at high levels, and lung function of asthmatics may be impaired to the extent that medical help is required. Sulphur dioxide pollution is considered more harmful when particulate and other pollution concentrations are high.

2.3.2 Global Effects of Air Pollution

Globally, the main effects of vehicles air-pollution are climate change caused by enhanced greenhouse gases, and depletion of ozone layer in the upper atmosphere (NSW, 1996). Climate change is a result of increasing carbon dioxide (CO_2) emissions. The climate change of concern is increasing global temperatures that are attributed to the “greenhouse” effect. The greenhouse effect resulted from carbon dioxide, the most important of the greenhouse gases, which acts like a blanket around the earth, keeping surface temperatures at warm levels. Increasing the CO_2 concentration in the earth’s atmosphere effectively adds another blanket which warms the Earth’s surface even more (Hare, 1997). As a result of this warming, world temperatures have risen by about 0.5 degrees Celsius in the past century. Furthermore, if the trend of increasing

CO_2 emissions continues, scientists project that the global temperature will increase by 3 degrees Celsius in the next century (some US agencies assume an even higher increase of 4-5 degrees Celsius. The results of this temperature increase would also mean a global average increase in sea-level of 0.66 m due to melting of the polar icecaps, causing a loss of some coastal areas. There may also be desertification – the conversion of formerly productive land to desert- in some areas which would contribute to poverty, famine, and food insecurity (Cunningham et al., 2006; Suess, 1993). Recently, scientific evidence has proven that global warming has occurred at a rate of 0.2°C per decade, leading to observable changes such as varying rainfall patterns, sea level rise, ice and snow melt, and increase in intensity and frequency of extreme weather events (IPCC, 2007).

Subramani, Arutselvan and Ganesan (2014) stated in their study that vehicle emission can affect the global life in terms of acid rain, distraction of vegetation from acid rain and air pollution damage to property. They stated that pollutants from road vehicles have an adverse impact on air pollution. The rain can injure plants if it is sufficiently acidic. Mortification, green color to the skin, shedding of flowers and leaves, downward curvature of leaves, suppressed growth etc. are the effects on plants due to pollutants. Additionally, there are lots of negative impacts on aquatic systems due to Acid rains. The destruction by acid rains is not confined only to plants, lakes and forests. It corrodes building, monuments and metals. It causes serious effects on human health since it contaminates the drinking water. Air pollution damage to property is a very important economic aspect of pollution. Damage to property covers a wide range-corrosion of metals, soiling and eroding of building surfaces, fading of dyed materials, rubber cracking, spoiling or destruction of vegetation, effects on animals, as well as interference with production and services in most urban communities.

In the last century, the level of CO_2 in the atmosphere has increased by more than 30% as a result of human activities. The effects of climate change are becoming more pronounced and they include droughts, floods, heat waves and changes in the weather patterns. Global temperatures have increased by almost 0.8°C over the past 150 years. Without any global action, it is expected that temperatures will increase further by 1.8 - 4 °C by 2100 (IPCC, USA, 1996).

2.4 Determination of Vehicular Emissions

The power to move a car comes from burning fuel in an engine. Pollution from cars comes from by-products of this combustion process (exhaust) and from evaporation of the fuel itself (S. E. Institute, 2018). Road transport is the major source of air pollution in urban areas. It is necessary to quantify emission levels as accurately as possible, with appropriate spatial and temporal resolutions. Pollutant emission levels from in-service vehicles vary depending on vehicle characteristics, operating conditions, level of maintenance, fuel characteristics, and ambient conditions such as temperature, humidity, and altitude (Mayer, 1999). The transportation emission measurement technology is the cornerstone of emissions research. The widely used measurement technologies include the dynamometer and driving cycle testing, vehicle inspection and maintenance (I/M) programs, remote sensing devices (RSDs), the Portable Emission Monitoring System (PEMS), etc.

There are different types of vehicular emission tests:

1. On-Board Diagnostics (OBD) Check
2. Tailpipe Tests
3. Gas Cap Test
4. Visual Anti-Tampering Check

2.4.1 On-Board Diagnostics (OBD) Check

OBD is an on-board system comprised of a computer with diagnostic software and sensors. The OBD system monitors the performance of the ignition, fuel metering and emissions systems, including the sensors and the computer itself, while the vehicle is being driven to insure they are working “as designed.” The on-board computer has the ability to identify a problem well before the driver may recognize symptoms (Drive Clean Pennsylvania, 2003).

2.4.2 Tailpipe Test

A Tailpipe test uses a tailpipe probe to collect a sample of the exhaust and an emissions analyzer to measure pollutants while the engine is idling. The Tailpipe test can be performed on many diesel and gasoline-powered passenger vehicles, vans and light-duty trucks. First, a certified technician will verify that the vehicle’s engine is running at operating temperature. Then, the technician will insert a probe into the tailpipe to capture a sample of the engine’s exhaust. After approximately 30-45 seconds, the analyzer will determine whether or not the vehicle is emitting excess pollutants based on the vehicle's model year. For this paper such type of tests will be employed by using FGA4000XDS for gasoline engine vehicle and Opacity meter for diesel engine.

2.4.3 Gas Cap Test

A Gas Cap test is a functional check that tests whether harmful evaporative emissions (fumes) are escaping from a vehicle's gas tank into the atmosphere. A certified technician will remove the gas cap and insert it into a device that will then apply pressure to the gas cap. The testing unit will verify that the gas cap holds pressure for a period of approximately 45 seconds and a determination will be made as to whether or not fumes are escaping.

2.4.4 Visual Anti-Tampering Check

The Visual Anti-Tampering Check is a visual inspection for the presence of emission control components that were installed on a vehicle by the manufacturer. A certified technician will look for the presence of the following emission control devices:

- Catalytic converter,
- Exhaust gas recirculation (EGR) valve,
- Positive crankcase ventilation (PCV) valve,
- Fuel inlet restrictor,
- Air pump, and
- Evaporative control system components such as vapor canisters and lines.

The certified technician will also determine if these devices are properly connected and if they are the correct type for the vehicle being inspected.

2.5 Emission mitigation

Quantifying emissions from transport sector is crucial for deciding the remedial measures to be taken to improve air quality. From the review, the following measures are recommended by different researchers for controlling the emissions from the transport sector.

There are several ways to make transportation more environmentally sustainable. One strategy implemented by car manufacturers in the US involves increasing fuel efficiency through the corporate average fuel economy (CAFE). CAFE standards set an average gas mileage requirement for a car manufacturer's fleet, rather than for individual cars. The fuel economy of all the cars sold by a manufacturer in any given year must average 27.5 miles/gallon and the fuel economy of all light trucks sold must average 20.7 miles/gallon. However, many opponents to this approach offer that in the absence of higher gasoline prices, improved fuel economy encourages people to drive an extra 10-20% more miles than they otherwise would, thus potentially negating the positive impact of the increased fuel efficiency (Holzman, 2005).

Vehicular CO_2 emissions cause climate change and contribute to air pollution that leads to human health effects. The two problems are exacerbated by the increasing trend for private vehicles. The trend calls for more vehicles on the road which means more vehicle emissions and thus more deleterious environmental effects. If public transportation is used more frequently, this can serve as a way to reduce the number of vehicles on the road and subsequently reduce emissions (Uhl and Anderson, 2001). Furthermore, policy of modal shift to public transport not only leads to reduced space consumption in urban areas and regained public spaces for the citizens but also to reduced emissions. Switching from cars to buses, local trains and trams with occupancy rates of 20-25% - halves CO_2 emissions. Carbon monoxide emissions are reduced by a factor of 10 to 50, volatile organic compounds by a factor of 5 to 15, or even reduced to zero. The reduction of NO_2 and particulate matter (PM) depends on the use of diesel engines and particulate filters (Clean Air, 2015). The reduction effect of every car ride substituted by emission-free public transport, is approximately 140g CO_2, 0.9g carbon monoxide, 0.17g VOC, 0.3g NO_2 and 0.008g PM per km (Germany Environmental Protection Agency, 2011).

Other study explained more the positive outcome of public transports that, a trip by sedans or motorcycles emit 97 times and a trip by taxi emits 63 times as air pollutants as a trip by public buses. Therefore, raising public awareness about emissions of criteria air pollutants by vehicles for one trip or traverse of one kilometer in the city, and also encouraging them to manage their trips and make optimal use of private and public vehicles play important roles in reducing Tehran's air pollution (Jafari, Ehsanifar and Arfaeinia, 2016).

According to the study on over-aged car legislation as an environmental policy law aimed at reducing air pollution (CO_2 and (PM_{10}) emissions) in Ghana, it was intended to suppress demand for used cars, and consequently reduce air pollution (Sulemana, 2012). Retirement of old, high emission vehicles in metropolitan areas is practiced in Japan and it has been singled out as a unique example of a country in the World that has overcome the severe air pollution of nitrogen oxides (NO_x) and particulate matter (PM). However, it is not clear which policy instruments have been effective in mitigating the air pollution from automobiles (Iwata, Arimura and Shimane, 2014) because of the use of several policy instruments and measures in her efforts to minimize emissions.

Vehicle technology is also the factor increasing of vehicular emission. It was pointed out that two stroke emits more than four stroke. Motorcycles and auto-rickshaws having two-stroke engines vehicles emit relatively higher amount of pollutants than four-stroke engines. Phasing out these engines would lead to drastic reductions in emissions and noise (Nagpure et al., 2016). Passenger rail systems powered by electricity can contribute to the reduction of GHG emissions of the transport system and make it more sustainable. Research's in Rio de Janeiro on Metro Line shows an annual net reduction of 55.45 thousand tons of NO_2 and 949 million MJ, with 91% of this energy corresponding to non-renewable energy (de Andrade and De Agosto, 2016)

Sustainable transportation will that lead to less environmental damage before it occurs rather than as a reaction to the damage that results from vehicle emissions (Skinner and Fergusson, 1999). Smarter traffic management -Intersections are areas where higher concentrations of pollutants are observed due to stop-and-go movement of traffic. This interrupted flow can be improved by using actuated signals and variable speed limits. Use of coordinated signals along major corridors would lead to lesser dispersion of platoon and hence smoother flow of traffic. Reduction in emissions of the order of 10%-40% was found due to coordinated traffic lights (De Coensel et al., 2012).

Walk able and complete streets improve the quality and vibrancy of urban environments by attracting social events and economic activities and hence give life to the place where we work, play and live. Approaching transport planning and designing work from the perspective of place making helps to integrate transport and land use activities (Toth, 2011). In light of this, Gary

Toth stated the principle of playmaking as: "*If you plan cities for cars and traffic, you get cars and traffic. If you plan for people and places, you get people and places*". Moreover, a vehicle emission regulation or standard guideline is also the main controlling methods of the effect of this emission. European Union emission regulations for new light duty vehicles (passenger car and light commercial vehicles <3.5 tons) are specified in the Directive 70/220/EEC.

Table 2. 2 European emission standards for passenger cars, g/km

Tier	**Date**	**CO**	**THC**	**NMHC**	**NO_X**	**$HC+NO_X$**	**PM**
Diesel							
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	0.14 (0.18)
Euro 2	January 1996	1.0	-	-	-	0.7	0.08
Euro 3	January 2000	0.64	-	-	0.50	0.56	0.05
Euro 4	January 2005	0.50	-	-	0.25	0.30	0.025
Euro 5	September 2009	0.500	-	-	0.180	0.230	0.005
Euro 6 (future)	September 2014	0.500	-	-	0.080	0.170	0.005
Petrol (Gasoline)							
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	-
Euro 2	January 1996	2.2	-	-	-	0.5	-
Euro 3	January 2000	2.3	0.20	-	0.15	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-
Euro 5	September 2009	1.000	0.100	0.068	0.060	-	0.005**
Euro 6 (future)	September 2014	1.000	0.100	0.068	0.060	-	0.005**

* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicles N_1-I

** Applies only to vehicles with direct injection engines

*** A number standard is to be defined as soon as possible and at the latest upon entry into force of Euro 6

Source: Zhu, S. (2014) *Development of vehicle emissions models for Australian conditions*

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Study Area

Addis Ababa is the capital of Ethiopia, which has been one of the world's fastest-growing economies over the past decade and has bold plans to become a major regional manufacturing and energy hub. The economy remains heavily dependent on the agricultural sector, which accounts for 43% of economic output; this makes the economy particularly vulnerable to adverse weather conditions like the recent droughts which have exposed weaknesses such as elevated domestic food prices (Addis Ababa City Report, 2016).

The city is divided into 10 boroughs, called sub-cities and 99 kebele. The 10 sub-cities are: Addis Ketema, Akaky Kaliti, Arada, Bole, Gullele, Kirkos, Kolfe Keranio, Lideta, Nifas Silk-Lafto and Yeka sub-cities. The rapid urbanization of Addis Ababa is necessitating growth in the need of transportation in the city. Birhanu (2003), in his study defined the transportation system of the city as the most complex in the country due to the rapid rate of urbanization initiated movements in the city. Vehicle ownership is low in Addis Ababa (below 100 vehicles per 1000 of population), though rapidly increasing mainly due to economic growth and the introduction of low cost private cars into the local market (Haregewoin, 2010). There are about 403,711 vehicles where most of them are old more than 15 years of age with an annual average growth rate of 10% (Tsehaynesh, 2010). Even there is no enough road infrastructure until the mid of 2015, all passenger and freight mobility in the city was ensured through roads. It was only recently that a Light Rail Transport (LRT) for passenger transport began construction in 2011 and was opened for public use on November 2015.

Surprisingly, there is no standard guideline on the limit of vehicle age (both imported new and used) and for the number of years a vehicle can serve in the country as a whole. Used cars from around the world are imported and operate throughout the country and continue to serve for unlimited number of years. There is no quality control standard in place to check how long vehicles (used or new ones) should serve, if they are prone to accidents, if their carbon dioxide

(CO_2) emission level is acceptable and when they should completely stop giving service (removed). Definitely, these over served cars have the lion's share on the road traffic accidents and environmental pollution (IBIS Transport Consultants Ltd., 2005).

According to Yigzaw of Federal Transport Authority (2017), the number of cars in Ethiopia last year was 708,410, however, it has now reached 831,265. From the entire number of cars, 524,444 cars, which accounts for 63 percent of the registered vehicles are found in Addis Ababa city.

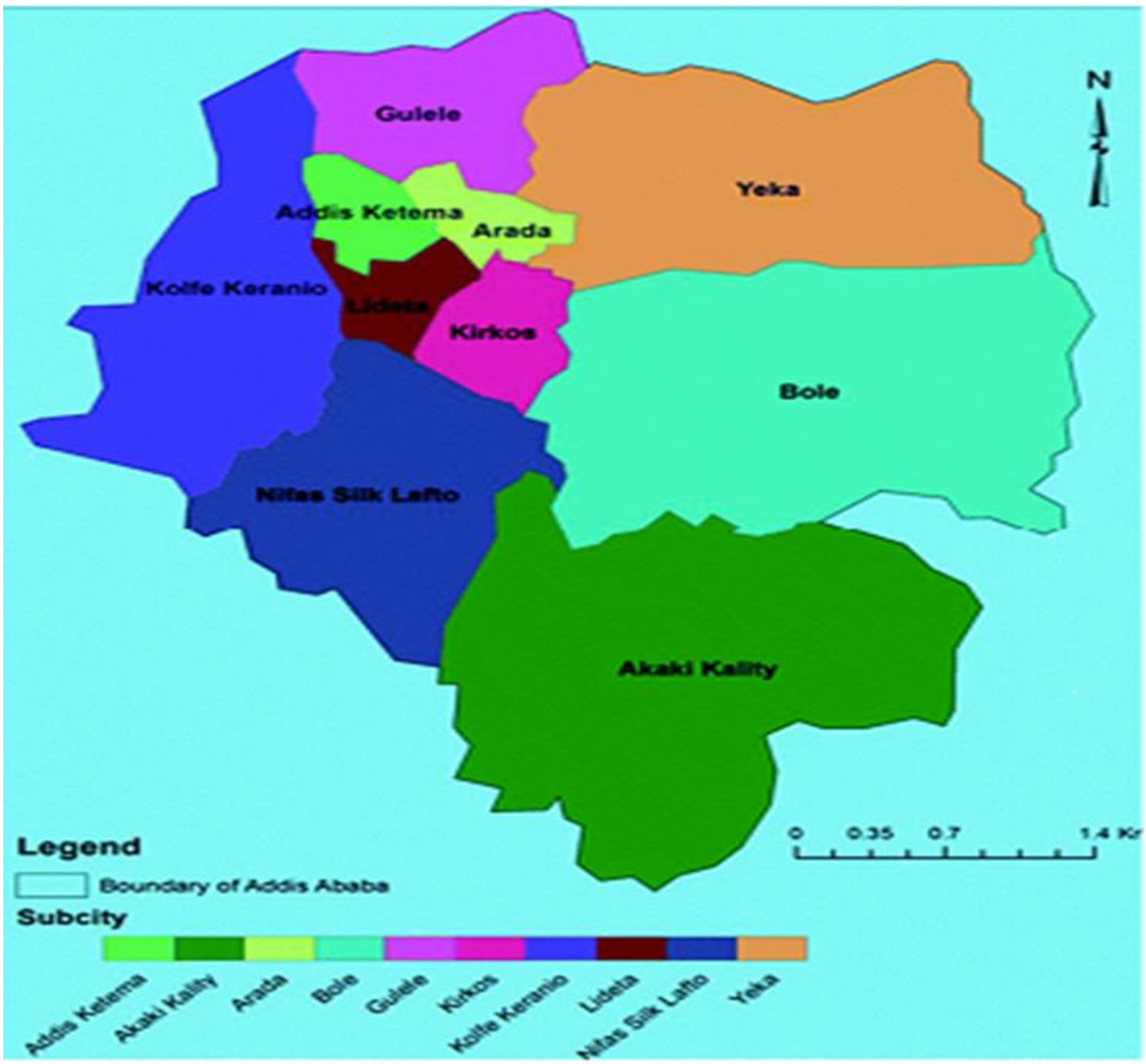


Figure 3. 1 City Map of Addis Ababa (Source: ORAAMP)

3.2 General Required Data

The following are very relevant data to the study:

I. Gasoline fueled vehicle emission data considering specific air pollutants as HC, CO and CO_2 and vehicle characteristics.

II. Diesel fueled vehicle emission (smoke opacity values) considering specific vehicle characteristics. Parameters measured are opacity value in percentage.

III. Information related to vehicle characteristics as model year, vehicle kilometer travelled, vehicle types and vehicle makes of public transport vehicles will be collected.

IV. Key information from various Federal Offices such as the Ministry of Environment, Forest and Climate change, the Ministry of Environment, Forest and Climate change research center, etc., were used to determine pressing issues and current needs.

3.3 Methods

Transport sector contributes significant amount of emissions in urban areas leading to deterioration in air quality. Quantifying emissions from transport sector is a challenging task due to presence of different modes and their varying characteristics in terms of distance travelled, fuel used, and emissions produced (Kühlwein & Friedrich, 2000). Many researchers have used different approaches based on the mode of transport, scale of estimation, fuel used and type of pollutants. This study starts with gathering of emission levels data from public transport vehicles in the city by using Digital Opacity Meter instrument, which is used to collect smoke opacity of diesel fueled vehicles and FGA 4000XDS four and five gas analyzer, which is used to collect HC, CO and CO_2 of gasoline fueled vehicles**.**

Digital Opacity Meter instrument: - Allows us the measurement of percentage of smoke exhaust of diesel fueled vehicles through tail pipe.

FGA 4000XDS four and five gas analyzer: - Allows us the measurement of volume concentrations of HC (as N-hexane), CO (carbon monoxide), CO_2 (carbon dioxide), O_2 (oxygen), and optionally NO_x (nitric oxide). But, in this study the researcher measures only HC

(Hydrocarbon), CO (carbon monoxide) and CO_2 (Carbon dioxide) since the available instrument at Addis Ababa Environmental Protection Authority is calibrated only to measure them. Both instruments are fully portable and have the ability to store data.

3.3.1 Sample Size Determination

According to the current data until the end of June, 2018 there are about 561,490 vehicle population in the city (Addis Ababa Transport Bureau, 2018/19). About 401,756 (71.55%) vehicles have "*Code* **A** *Plate Number* **AA**" means Addis Ababa plate number and 159,734 (28.45) have "*Code Plate Number* **ET**". From this figures 31,740 (7.9%) Taxi, 200,724 (49.96%) private, 146,983 (36.59%) Commercial and around 22,309 (5.55%) are other vehicles.

There are also many "Code Plate Number **OR**" vehicles operating in the city. But, Addis Ababa Transport Authority did not record the amount of these vehicles and did not include in the above figures. This is the weakness of data handling on the side of the authority and should be included in the data for the future. Therefore, for this study only the two codes "*Code* **A** *Plate Number* **AA**" and "*Code Plate Number* **ET**" were considered to collect data from on road vehicle emission specifically for vehicles serving as Public transportation [Taxi (code-1) and Commercial (code-3) vehicles] excluding freight vehicles.

To simplify the complexity and minimize the cost of data collection a sampling method from the given population was recommended. The representative sampled data should have the power to explain the behavior of all population. The two category (Taxi and commercial) vehicles operating in Addis Ababa city are 290,211 vehicle populations (AARTA report, 2018/2019). The number of vehicle included in the test was calculated by the sample size determination of Cochran's formula.

Table 3. 1 Composition of Vehicles Operating in Addis Ababa City up to June, 2018 G.C

Major Code	Code Name	Total number of AA License Plate vehicle	ET License plate Vehicles
1	Taxi	31,740	-
2	Private	200,724	-
3	Commercial	146,983	111,488
4	Government	4,925	22,202
5	Mass organization	2,306	1,933
6	Reserved	3	-
7	Diplomatic	32	3,073
8	United Nation	49	2,782
9	O.A.U	5	698
10	AID Org.	1,195	13,975
14	Police	445	656
15	Special	1,543	104
21	3 Tasebi		-
22	2 Special Tesabi	6	1
23	3 Liyu Tesabi	1	1
24	AID Code	-	123
25	O.A.U Code	-	201
26	United Nation Code	-	76
35	35 AID Org.	319	1,496
90	Daily	3	2
91	Transferable	11,477	923
Subtotal AA and ET Code		**401,756**	**159,734**
Total vehicle Operate in Addis Ababa		**561,490**	

Source: Addis Ababa Transport Authority since June, 2018/19 G.C

It was assumed that the common and traditional confidence level, 95%, +/-5% (e) standard error for precision, and (p=0.5, assumed standard deviation) and hence q=1-p=0.5. A 95 % confidence level gives us Z values of 1.96.

So, the formula used for these calculations was:

$$n_o = \frac{z^2pq}{e^2} \qquad n_o = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 384.16, \text{ where}$$

$$n = \frac{n_o}{1+\frac{(n_o-1)}{N}} \qquad n = \frac{384}{1+\frac{(384-1)}{290{,}211}} = 383.65 \approx 384$$

The study needs a minimum of 384 vehicles to explain the behavior of population from the two categories. Accordingly, random sampling method was used to sample 420 vehicles more than calculated sample size to give the confidence levels needed. This large sample size also helps as safety factor to include vehicles of “OR” plates, Oromia plate vehicles operating in Addis Ababa City which are not recorded by Addis Ababa city transport authority.

3.3.2 Diesel Fueled Vehicles air pollution Assessment

3.3.2.1 Study design

The research involved in an experimental design with public transportation-based air pollution that involves quantitative study to measure tail pipe exhaust smoke from on road vehicle at idle condition by pulling off them on shoulder, around Bus stop and Taxi station for the period of March 20 to April 20, 2019 G.C in 10 Sub cities of Addis Ababa City Administration. Back ground data were collected simultaneously during the test by researchers data collector teams.

From the total sample size more than half of the test includes diesel vehicles. Because many Public transport such as taxi, different type of buses use diesel engine to operate. In consistent with study design, only public transportation vehicles operating on road during the study period were included, while freight transportation vehicles operating on the road were excluded from this study. Because, the research targets to explore the effect of public transport on air pollution and the way how to improve them. In this manner, smoke opacity values and vehicle characteristics such as kilometer traveled, Model year, vehicle types vehicle make data were collected.

3.3.2.2 Study subjects

The study subjects were public transportation vehicles with diesel fueled. Traffic police helped us to enforce driver with refusals. Due to old age of operating vehicles on road it was not easy to get full data such as kilometer driven and model year of them. To make this easy sometimes driver was interviewed to get the data. But, in case of refusal drivers the data were estimated by technician's researchers based on their model.

3.3.2.3 Test Location

Figure below shows twenty-four locations that were selected from 10 sub-cities of Addis Ababa. In some sub cities the test location may be more than others. This was done depending on the size of sub cities.

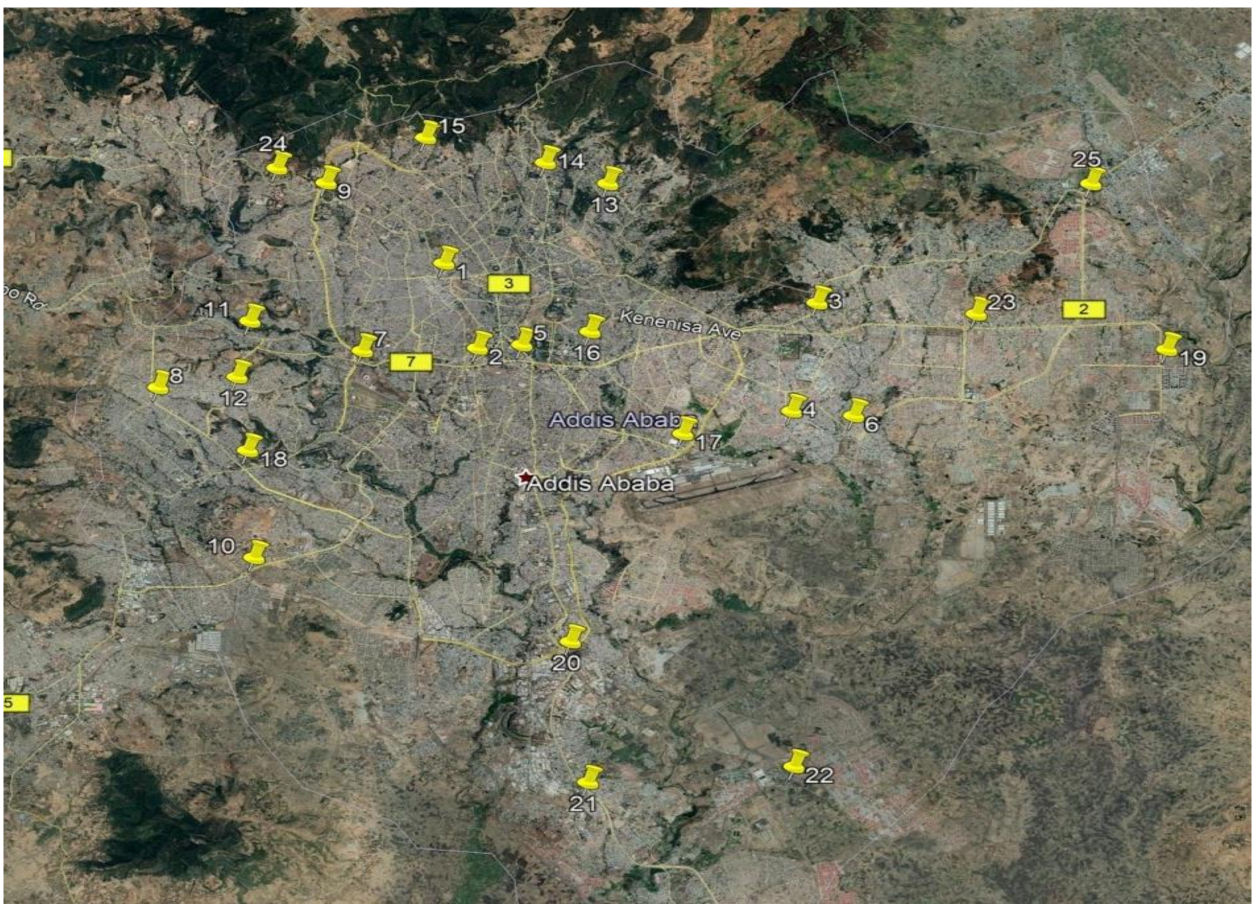


Figure 3. 2 Test locations Maps

Table 3. 2 Test Location name and their site Code given

Site Name	Site Number	Site Name	Site Number
Gojam Berenda	1	Shiro Meda	14
Mexico at Shebelle	2	Tsihon Hotel Addisu Gebeya	15
Lamberat Meneharia	3	Kezanchis	16
Roba Bread	4	Bole Milinium Hall	17
Stadium taxi Bay	5	Ayertena	18
Yerer Goro	6	Ayat Mekedonia	19
Torhailoch Taxi	7	Kality Meseltegna	20
Alem Bank	8	Kality Menharia	21
Winget	9	Koye Fache	22
Jemo-2	10	CMC Area	23
Yeshi Debele	11	Asko	24
Bethel	12	Tafo Round About	25
Ferensay	13		

3.3.2.4 Sample size for Diesel Fuel Vehicles

The consideration of involving all diesel user public transport vehicle in the experiment/ test was too difficult and expensive. Therefore statistical data sampling was applied for the whole vehicle sample size population first. Percentage of diesel fueled public transport vehicles were more than that of gasoline fueled [Lada and Meter Taxi] vehicles. Therefore from the total sample size, 358 vehicles were selected to be tasted under diesel fueled vehicles since many public transport are diesel fuel users. The method of vehicle selection during data collection is by stratified random sampling.

3.3.2.5 Diesel engine user vehicle testing and equipment

The Wager 6500 Digital Opacity Smoke Meter was used to measure the concentrations of emitted gases from the diesel fueled vehicles sampled.

This equipment should also be checked for proper operation and calibration.

- Warm-up smoke meter: - prior to any zero and/or full-scale checks or adjustments, the smoke meter shall be warmed up and stabilized. If the smoke meter is equipped with a purge air system to prevent sooting of the meter optics, this system should also be activated.

- Smoke meter zero: - with the smoke meter in the Opacity readout mode, and with no blockage of the smoke meter light beam, adjust the readout to display 0.0% ± 1.0% opacity.
- Smoke meter full scale: - with the smoke meter in the Opacity readout mode, and all light prevented from reaching the detector, adjust the readout of the smoke meter to display 100.0% ± 1.0% opacity. Note that smoke density (K) is a calculation based upon opacity and EOPL. The opacity scale offers two truly definable calibration points, namely 0% opacity and 100% opacity. The upper end of the smoke density scale is infinite, which makes this point on the K scale undefined. Because of this, the preferred method to set the zero and full scale of the meter when measuring in either smoke density (K) or opacity (N) units is to set the meter to the opacity readout mode and make the zero and full- scale adjustments.
- Smoke meter zero: - with the smoke meter in the Smoke Density (K) readout mode, and with no blockage of the smoke meter light beam, adjust the readout to display 0.00 m-1 ± 0.10 m-1.
- Note that neutral density calibration filters are precision devices and can easily be damaged during use. Handling should be minimized and, when required, should be done with care to avoid scratching or dirtying

Figure 3. 3 Digital Smoke Opacity Meter for Diesel Engine vehicle

3.3.2.6 Smoke Opacity testing Procedure

The roadside inspectors performed the following procedure while collecting data for the study:

- All vehicles under this study were idled condition;
- Directed vehicles to the roadside shoulder;
- Informed vehicle owners about the study;
- The opacity meter is turned on;
- The opacity meter is plugged on the tail pipes of vehicles;
- Repeated the exhaust smoke opacity measurements three times per test to complete the snap acceleration cycles and the three results of opacity values are then averaged to give one final accurate result;
- Recorded and stored test data; and
- Finally, informed test results to the drivers and released vehicles to merge to the flowing traffic.
- Generally it consumed 15-20 minutes per test.

3.3.3 Smoke Density Calculation ($K=m^{-1}$)

The Beer-Lambert Law is the relationship between Transmittance, Smoke Density, and Effective Optical Path Length (Malka and Bidaj, 2015)

$$\boldsymbol{T = e^{-KL}} \quad \text{…………………………………………………....…………Eq (1)}$$

Where:

T = Transmittance

K= Smoke density (meter $^{-1}$)

L= Effective optical path length (EOPL), L=0.430m Constant for

Transmittance (%) = $\mathbf{100}\% - \boldsymbol{Opacity}$ (%) **…………………………………...………**Eq (2)

From Eq (1) above solving for K; **K=$\mathbf{-1/}\boldsymbol{L}$ (lnT)…………………………………………..** Eq (3)

Opacity (N):- The percentage (%) of light transmitted from a source which is prevented from reaching a light detector. It is the extent to which black exhaust, as measured by a smoke meter and expressed as a percentage, blocks the transmission of light (e.g., smoke that completely blocks out all light has 100% opacity). Opacity % = 100∗ (1-Transmittance). In the execution of the test, beam of light is transmitted from the light source. Part of the light reaches the light detector and part of it is blocked by the smoke accumulated in the tail pipe. Opacity is expressed by (Raj Kumar and Deesh, 2017) as it is a measure of light reduction/loss over a smoke column path usually expressed as a percentage.

Transmittance (T):-The fraction of light transmitted from a source which reaches a light detector. It measures the percentage of light reaching a light detector in percentage.

Effective Optical Path Length (EOPL):- is the length of smoke obscured optical path between the smoke meter light source and detector. Portions of the total light source to detector path length which are not smoke obscured do not contribute to the effective optical path length.

Smoke Density K (m^{-1}):- (also known as “light extinction coefficient” and “light absorption coefficient”) is a fundamental means of quantifying the ability of a smoke plume or smoke containing gas sample to obscure light. By convention, smoke density is expressed on a per meter basis (meter $^{-1}$). The smoke density is a function of the number of smoke particles per unit gas volume, the size distribution of the smoke particles, and the light absorption and scattering properties of the particles.

Light Source - The light source is a lamp with a color temperature in the range of 2800 to 3250 °K, or a green light emitting diode.

Light Detector - The light detector is a photocell or a photodiode which detects the light scattered by the light source. A photodiode is a semiconductor device that converts light into current. The current is generated when photons are absorbed in the photodiode.

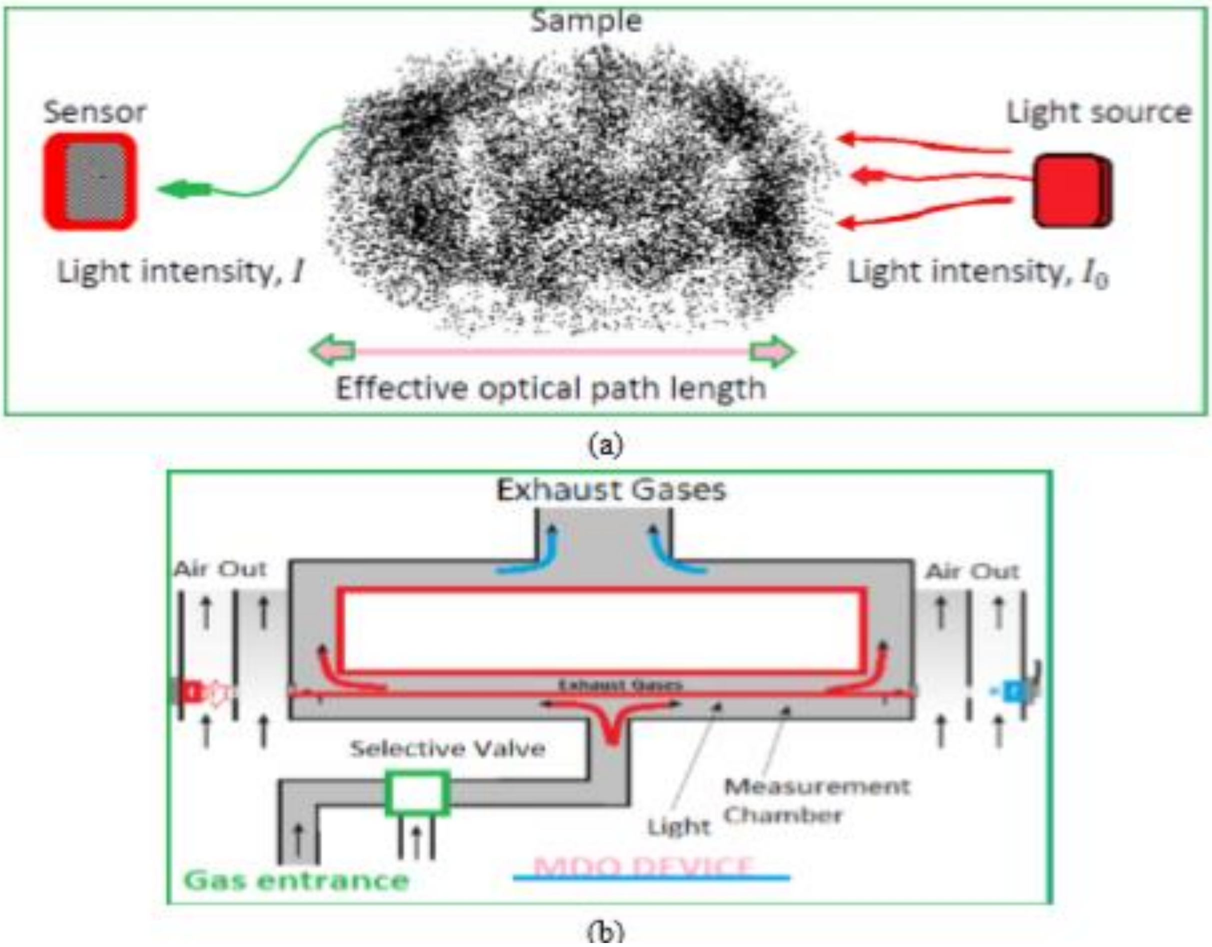


Figure 3. 4 (a) Basic principle and (b) measurement principle of MDO2 opacimeter

3.3.4 Pass/Fail Limits

The Pass/Fail limit is the emission point above which a vehicle is held to fail an emission inspection. The Pass/Fail limit utilized for this study was referenced from the US EPA, 1998 National Vehicle and Fuel Emissions Laboratory recommended guidance for in-use diesel-fueled vehicles compliance test using the SAEJ1667 procedure (U.S.EPA, November 1998). The limit for 1991 and newer diesel-fueled vehicles is less than or equal to 40% (≤40%) and for 1990 and older diesel-fueled vehicles is less than or equal to 50% (≤50%).

Figure 3. 5 A, B, C, E and F; Old Anbessa Bus, New Anbessa Bus, Sheger Bus, Smoke opacity of fig. B, Minibus and Lada Taxi, Commercial Minibus under test respectively

3.3.5 Data Analysis Method

Data were analyzed using IBM SPSS Statistics (version 22.0; SPSS Inc., Chicago, IL, USA). Mean values and 95% CI of Smoke opacity were calculated to compare with relevant data.
Analysis of variance (one way ANOVA) was employed for the detection of any difference and change in smoke opacity in the presence of vehicle characteristics such as vehicle kilometer traveled, make, model year and types. Descriptive statistics, tables, and charts were used to present major findings.

3.3.6 Ethical Considerations

Addis Ababa police commission Department was formally wrote a letter to every concerning legal body facilitate/soften the communication between me and those while I was conducted the test. Additionally, it wrote a letter to all sub cities police and specially traffic police to help me in pulling any vehicles to test locations. The Department had communication with branch traffic offices about the study after securing permission. Preliminary work was communicating with the Traffic Police Department in September 2019.

3.3.7 Gasoline Vehicles air pollution Assessment

3.3.7.1 Study design

Gasoline fueled vehicles are emitting differently from diesel fueled vehicles because of the chemical contents of the fuel used. Therefore, an experimental design that involves quantitative study to measure tail pipe exhaust emission of these vehicles are HC (Hydrocarbon), CO (Carbon Monoxide), and CO_2 (Carbon Dioxide). Under Taxi (code-1) vehicles category there are both diesel and gasoline fuel users. From this minibus taxi vehicles of diesel fuel user are tested under diesel fueled and Lada taxis of gasoline fuel user are selected to be tested under gasoline fuel as they are using gasoline fuel. The test was conducted by pulling off them on shoulder for appropriate test location for the period of April 15 to April 20, 2019 G.C.

3.3.7.2 Study subjects

The study subjects were public transportation vehicles with gasoline user. Traffic police helped us to enforce driver with refusals. The same to diesel engine vehicle due to old age of operating vehicles on road it was not easy to get full data such as kilometer driven and model year of them.

To make this easy sometimes driver was interviewed to get the data. But, in case of refusal drivers the data were estimated by technicians and researchers based on their model.

3.3.7.3 Sample size

The consideration of involving all gasoline fuel user public transport vehicles in the experiment/ test was too difficult and expensive. In this case from a total sample size, out of 420 around 62 vehicles were Lada and meter taxi vehicles. Gasoline fueled public transport vehicles are few in quantity as compared to diesel fuel users in Addis Ababa city.

3.3.7.4 Gasoline fuel user vehicle testing and equipment

FGA 4000XDS Gas Analyzer was used to measure the concentrations of emitted gases from the gasoline vehicles sampled.

Figure 3. 6 FGA 4000XDS four and Five Gas Exhaust Analyzer for Diesel Engine vehicle

3.3.7.5 Instrument Calibration and Testing Procedure

Field calibration of the following should be done on the basis of data collection

- To calibrate the analyzer press the Mode button repeatedly until you see FIELD CAL appear on the screen.
- Press the Up arrow button once to select YES and then press MODE. The CAL indicator will be on and the analyzer will enter a purge and zero sequence. Please wait until you see ENTR TAGS GO.

- Press the MODE button and begin entering the Tag values zero in each of the windows. Use the UP or DOWN arrow keys to increment or decrement each digit and Left or Right arrows to move to individual digits. It is recommended always entering all zeros in the O_2 window.
- During measurement highly emitter vehicles smoke closed the head of hose filter. In case of this the head of measuring hose should be shaking up by hand or cleaning with clean clothes until the window shows zero gas measuring.

The roadside inspectors performed the following procedure while collecting data for the study:

- Instrument should be calibrated first before starting measurement;
- Directed vehicles to the roadside shoulder;
- Informed vehicle owners about the study;
- The analyzer is turned on;
- The probe is inserted into the vehicle tailpipe, ensuring that the probe is fully inserted;
- Waited until the analyzer indicates that it is in the STANDBY mode.
- Engine speed maintained at about 2500 RPM for 30 seconds;
- Set on STANDBY mode for 30 minutes;
- Probe inserted fully into the vehicle tailpipe;
- START key Pressed;
- Displayed exhaust gas values read;
- Recorded, stored and printed out test data;
- Finally, informed test results to the drivers and released vehicles to merge to the flowing traffic;
- Generally it consumed 15-20 minutes per test.

3.3.7.6 Pass/Fail Limits

The Pass/Fail limit is the emission point above which a vehicle is deemed to fail an emission inspection.

3.3.8 Data Analysis Method

Data analysis methods for this case were also the same as in the case the first part.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Descriptive Analysis of Diesel and Gasoline Fueled Vehicles Emission

4.1.1 Descriptive Analysis of Diesel Fueled Vehicle Emission by Vehicle Characteristics

The study focused on Taxi and Commercial vehicles as study subject. The reason was clear that transport authority would made them out of market by providing competitive public transportation system easily when they failed to meet air pollution standard limit.

Based on the calculated sample size, three hundred fifty (358) unique diesel vehicles were selected by stratified random sampling and tested at different roadside test locations in Addis Ababa. The sample distribution covered vehicle model-years from 1960 to 2017 of Taxi vehicles and commercial vehicles (public transport).

Descriptive data analyses were made to:

- ✓ Compare average emissions generated by the two categories of vehicles at idle condition,
- ✓ Compare average emissions level with presence of dependent variable (vehicle model year/age, make, types and kilometer travelled),
- ✓ Determine impacts of each category and identify super emitter categories.

Descriptive analyses were made on the relationship between the data recorded about model year (vehicle Age), vehicle kilometer travelled, and vehicle categories Taxi vehicles, Commercial vehicles (code-3) with smoke opacity and density. The vehicle parameters were grouped in categories and sub categories as stated above, so that emission patterns are seen according to each category and sub category.

4.1.1.1 Description of vehicle emission by vehicle category

Table 4.1 Group of vehicles by AATA Category

Group No.	Vehicle Categories
1	Taxi Vehicles (Code-1)
2	Commercial Vehicles (Code-3)

4.1.1.2 Description of Commercial vehicles emission by vehicle types

According to Ethiopian transport authority all vehicles having code-3 are categorized as commercial vehicles. Among those the study focused on vehicles of code-3 which served for public transportation. This category was sub grouped as Code-3; Minibus, Anbessa City Bus, Sheger Bus, Higer Bus, and Isuzu NPR Bus in the study.

Table 4. 2 Group of vehicle by vehicle types

Category No.	Local model name/ Vehicle types
1	Minibus Taxi (Code-1)
2	Commercial Minibus (Code-3)
3	Anbessa Bus (Code-3)
4	Higer Bus (Code-3)
5	Sheger Bus (Code-3)
6	Isuzu NPR Bus (Code-3)

4.1.1.3 Description of vehicle emission by Model Year

Vehicle Model year/Age highly impacts the exhaust emissions from vehicles. Latest model vehicles were less emitter than the older as vehicle technology modernized.

Table 4. 3 Category for model year of vehicles

Category No.	Model name/ Vehicle types	**Model Year**
1	Minibus Taxi (Code-1)	1960 - 1990
		1991 - 1999
2	Commercial Minibus (Code-3)	2000 - 2009
		2010 - 2018
3	Anbessa Bus (Code-3)	1980 - 1991
		1991 - 2018
4	Higer Bus (Code-3)	2007
5	Sheger Bus (Code-3)	2008-2015
		2016-2018
6	Isuzu NPR Bus (Code-3)	1975-1990
		1991-1999
		2000-2009
		2010-2018

4.1.1.4 Description of vehicle emission by vehicle kilometer travelled

Vehicle kilometer travelled also has impacts on the emission level. So, the data were also classified by length of vehicle kilometer travelled in each vehicle sub category. This data are based on odometer reading from production to data collection year represented as service year.

Table 4. 4 Group of Vehicle by Cumulative Kilometer Travelled in thousands

Model name/ vehicle Types	Cumulative Vehicle Kilometer Travelled (CVKT) in (‘000s)	Model name/ vehicle Types	Cumulative Vehicle Kilometer Travelled (CVKT) in (‘000s)
Taxi (code-1) Minibus	500 - 550	Anbessa City Bus (code-3)	10-66
	550 - 600		66-790
	650 - 700		790-998
	700 - 750	Sheger Bus (code-3)	45-100
	750- 800		300-350
	800 - 850	Higer Bus (code-3)	377-427
	850 - 900		427-477
	900 - 950		477-527
	950 - 1000	Isuzu NPR Bus (code-3)	33-233
Commercial (code-3) Minibus	37- 112		233-433
	112- 187		433-633
	187 - 262		633-933
	262 - 337		
	262 - 337		
	337 - 412		
	412-487		
	487-562		
	562-637		

- As discussed on the above sections, the overall analysis was based on vehicle classification as Model name, Model year and kilometer travelled with the respective opacity and calculated smoke density values. The impacts of all this characteristics are discussed below.

4.1.1.5 Smoke Opacity and Density results by vehicle Category

The total sampled vehicles under diesels fueled are three hundred fifty eight 358 vehicles. From 358 vehicles 229 (66%) were commercial vehicles (Anbessa, Sheger, Higer, Isuzu NPR bus and minibus) and 129 (34%) were minibus taxi. As the data analysis showed, it was seen that the average of opacity values of Taxi vehicles and commercial vehicles were 86.36% and 43.31% respectively. Again, the level of smoke density of Taxi vehicles and code-3 commercial vehicles were 6.47 and 2.48 respectively.

Under this category it was not appropriate to compare with US EPA smoke opacity and smoke density standards since the category included all vehicles of different model years. This showed us, the emission level of Taxi vehicles was much higher than that of commercial vehicles. Taxis are mainly characterized by old age, poor maintenance and high vehicle kilometer traveled. This might be the main factor for high emission rate. This is related with the findings of (Malka and Bidaj, 2015) new cars have more opportunity to keep the results “pass” compare to the older cars. Figure 4.1 was presented the discussion.

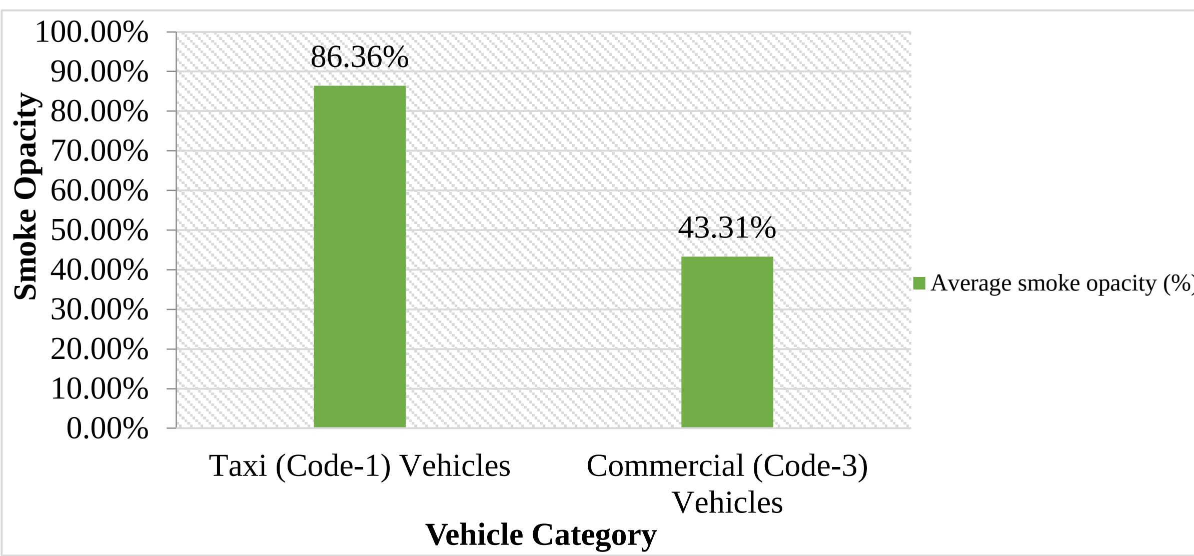


Figure 4. 1 vehicle category versus Smoke Density

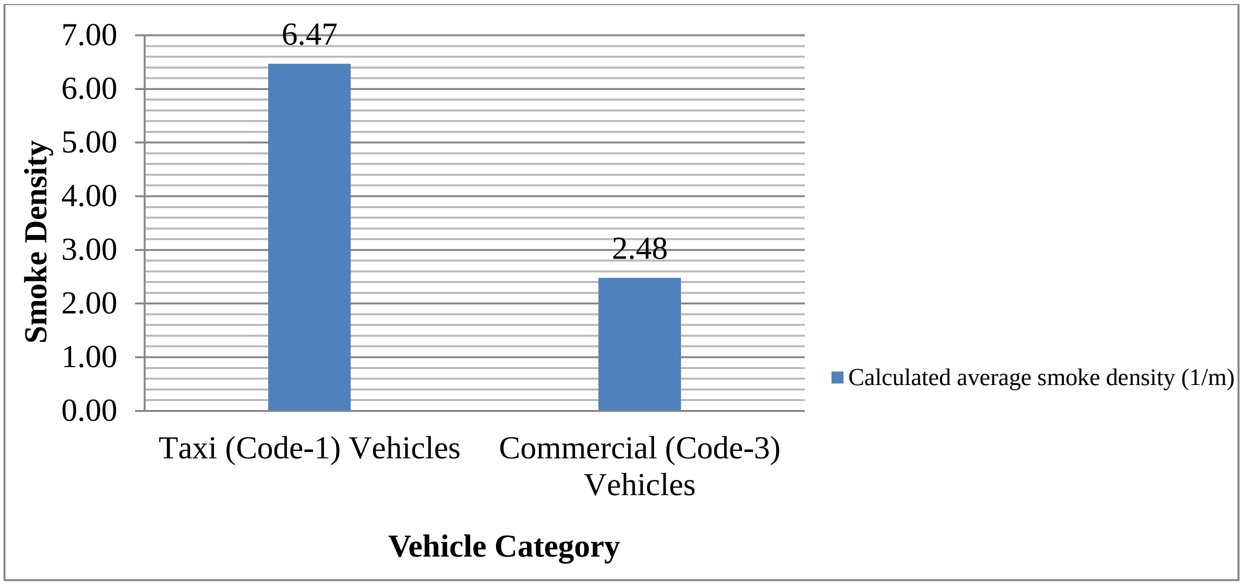


Figure 4. 2 Vehicle Category and Smoke Density

4.1.1.6 Smoke Opacity and Smoke Density results by Model Name/Vehicle Type

Overall 358 diesel fueled vehicles were tested smoke opacity values. From this figures 122 minibus taxi, 129 commercial minibus, 32 Anbessa City Bus, 30 Higer Bus, 30 Isuzu NPR busses, and 15 sheger Busses. According to the results obtained from the test 9 (7.4%) minibus taxi, 41 (31.8%) commercial minibus, 32 (100%) Anbessa City Bus, 6 (20%) Higer Bus, 12 (40%) Modified Isuzu NPR Bus, 15 (100%) Sheger Bus Passed both (40% and 50% USA EPA Smoke Opacity Standard Limit of ≤1990 and ≥1991 diesel fueled vehicles). In contrary, 113 (92.56%) minibus taxi, 88 (68.22%) commercial minibus, 24 (80%) Higer Bus, 18 (60%) Isuzu NPR Bus failed both (40% and 50% USA EPA Smoke Opacity Standard Limit of ≤1990 and ≥1991 diesel fueled vehicles). Again, the results showed us 27 (24%) minibus taxis, 9 (10%) commercial minibus, 5 (21%) Higer Bus, 4 (22%) Modified Isuzu NPR Bus registered 100% smoke opacity values.

From the sampled data both Anbessa City Bus and Sheger Bus registered smoke opacity value totally far below the standards. Taxis were the most smoke emitter/polluter of the city. In this case it is difficult to have single column for the standard cut point since it depends on the vehicle production year not vehicle types. So, in the table below each vehicle types compared as if they were emitting smoke opacity below or above 40% for model year of ≤1990, and 50% for model year ≥1991 standard guidelines. This study agrees with the study of (Rouf et al., 2008) who reported that Opacity of 18 Volvo double decker buses (out of total 142 double decker buses) was tested. All the Volvo buses were found smoke opacity less than 50 %. Volvo buses were the best among all the buses plying in the roads of Dhaka City. Average smoke opacity of Volvo and Ashoke Leyland buses were 34 and 45% respectively. Opacity of Volvo buses were much less than Ashoke Leyland buses. Volvo buses were considered as the most environments friendly.

Table 4. 5 Illustrates the pass and fail rate for the sample distribution

Vehicle Types	No. vehicle under test	*Passed Standard		**Failed Standard		Vehicle registered 100% smoke opacity	
		No.	%	No.	%	No.	%
Taxi minibus	122	9	7.4%	113	92.6%	36	31.86%
Commercial minibus	129	41	31.8%	88	68.2%	9	10%
Anbessa Bus	32	32	100.0%	0	0.0%	0	0.0%
Higer Bus	30	6	20.0%	24	80.0%	5	21%
Isuzu NPR Bus	30	12	40.0%	18	60.0%	4	22%
Sheger Bus	15	15	100.0%	0	0.0%	0	0.0%
Total	358	115	32.1%	243	67.9%	45	19%

* Vehicles Passed USA EPA 1998 Standard Guidelines 40% for model year of ≤1990, and 50% for model year ≥1991.

** Vehicles Failed USA EPA 1998 Standard Guidelines 40% for model year of ≤1990, and 50% for model year ≥1991.

4.1.1.7 Smoke Opacity and Density results by Model Year/Age

Under this sub groups different vehicle model year of different vehicle types were compared. Smoke opacity and Smoke density of [Minibus Taxi, Commercial Minibus, Anbessa City Bus], [Minibus Taxi, Commercial Minibus, Higer Bus], [Minibus Taxi, Commercial Minibus, Sheger], [Minibus Taxi, Commercial Minibus, Isuzu NPR Bus] and [Anbessa Bus, Higer Bus, sheger Bus, Isuzu NPR Bus] were compered.

4.1.1.7.1 Smoke Opacity and Density of Minibus Taxi, Commercial Minibus and Anbessa Bus

The analysis from Smoke Opacity test showed that, average smoke opacity of Minibus taxi vehicles was 87.82%. Only 6 (8.57%) out of 70 vehicles were passed the US A EPA standard of 50% smoke opacity value for model year 1990 and older. The others 64 (91.43%) failed to meet the standards. Out of 70 vehicles 24 (34.28%) vehicles were registered 100% smoke opacity values. Regarding model year of (1991-1999) out of 52 vehicles only 3 (5.88%) was passed U.S.A EPA standard of 40% for model year of 1991 and newer. 48 (94.12%) vehicles failed to meet the standards/registered smoke opacity greater than the standards and 12 (24%) vehicles were with opacity of 100%.

From the tested vehicles, model year of commercial minibus was 2000-2018 G.C. It was divided into two ranges of 2000-2009 and 2010-2018 G.C to simplify for comparison with other models. From 2000-2009 model year were about 96 vehicle tested. Of those vehicles 20 (20.83%) were passed the standards, means registered smoke opacity 40% or less and 76 (79.17%) vehicles were failed to meet the standard. Out of 96 vehicles 9 (9.4%) vehicles were registered smoke opacity values of 100%. Regarding with model year of 2010-2018 G.C. from 30 tested vehicle 9 (30%) registered above 40% limit and 21 vehicles were recorded (12%-39%) below 40% standard limit. Anbessa Bus, in both model year (1980-1990) and (1991-2018) recorded below the standards. Model (1980-1990) recorded 11-30% smoke opacity but, the new model (2017) of Anbessa City Bus registered (0-5%) smoke opacity value which was too far down from 40% standard limit. Other finding of previous study (Shankute, 2015) which also stated that 14 (58%) out of 24 Anbessa city busses recorded smoke opacity of 40% or less. Seven vehicles (29%) registered smoke opacity values between 41% and 99%, and 3 (12.5%) registered 100%. In his study he founded a failure rate of 10 (42%) Anbessa city as he sampled the oldest model of Anbessa city busses such as ‘DAF’. Currently, ‘DAF’ models are forcing off the road and rarely ridden on the road. The city authority rehabilitated it for a road side commercial activity that is why it is was excluded for this study.

As the figure 4.3 below shows, smoke opacity decreases with decreasing of vehicle age. Vehicle age have impact on smoke opacity level highly, as smoke opacity decreasing from 1960 to 2018 model years. But, Smoke opacity of minibus taxi in the range of (1960-1990) model year was 4 folds of Anbessa City Bus of (1980-1990) model year and minibus Taxi in the range of (1991-

1999) was 4 folds of (1980-1990) model year Anbessa City Bus. Again, it was seen that model year (2010-2018) commercial minibus smoked out 22 folds of (1991-2018) model year Anbessa City Bus. According to the calculated smoke density values from smoke opacity only Anbessa City Bus of Model year (1991-2018) passed. Minibus taxi of (1960-1991) models were highly spew denser smoke (7.62 per meter) to the environment or 14 times the limit of USA EPA 1998 standard (0.5 per meter). It was also spew out 13 folds denser smoke than Anbessa city Bus of model year (1980-1990). This was very high as compared to the USA EPA standards. The average opacity value and Average smoke density of minibus taxi, commercial Minibus and Anbessa City Bus were summarized well in histogram shown in figure 4.1 and 4.2, respectively.

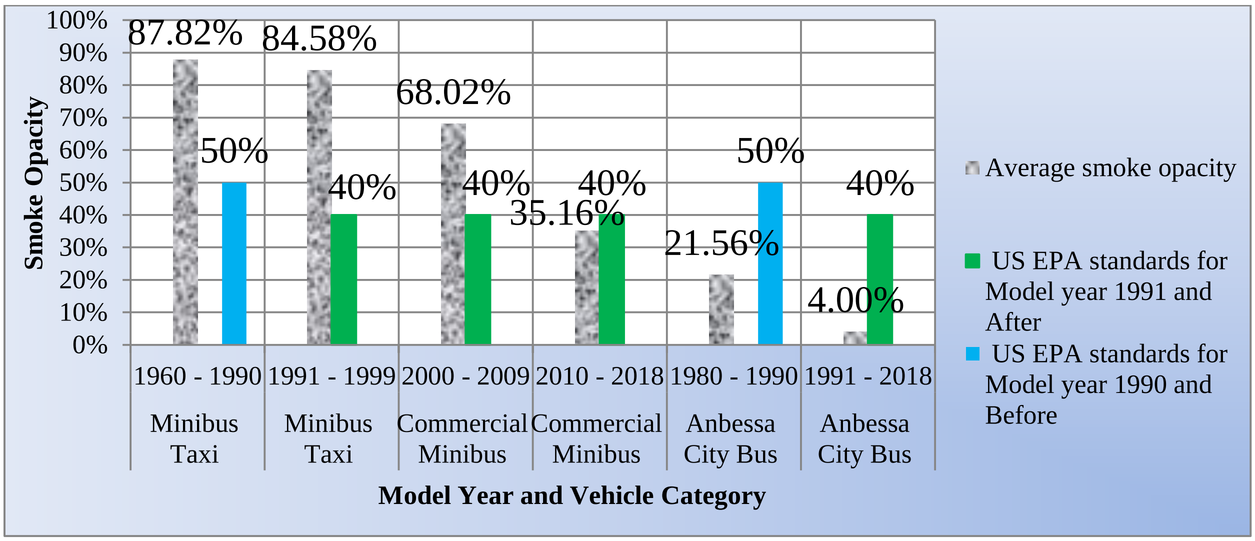


Figure 4. 3 Smoke opacity of Minibus Taxi, Commercial Minibus and Anbessa City Bus

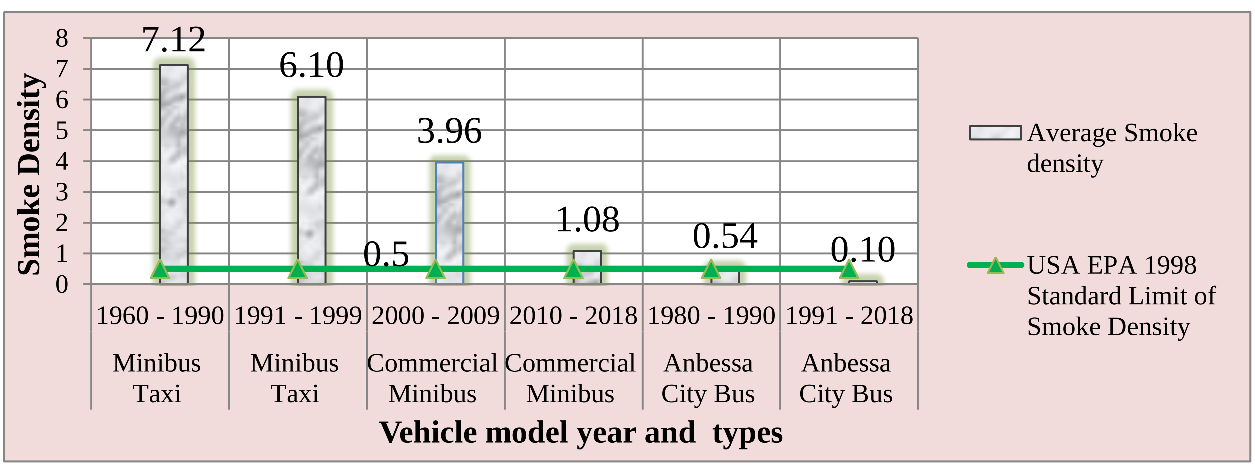


Figure 4. 4 Smoke density of Minibus Taxi, Commercial Minibus and Anbessa City Bus

4.1.1.7.2 Smoke Opacity Density of Minibus Taxi, Commercial Minibus and Higer Bus

The analysis from Smoke Opacity test results showed that, the average smoke opacity of Higer Bus was 75.03%. Only 6 (20%) out of 30 vehicles were passed the USA EPA standard of 40% smoke opacity for model year of 1991 and newer. The others 24 (80%) failed to meet the standards. Out of 30 vehicles 3 (10%) Higer Bus was registered 100% smoke opacity values. The results of minibus taxi and commercial minibus were discussed in subgroup topics of (4.1.1.7.1) above. As a whole, it was found that Higer Bus of model year (2007) had high average smoke opacity value which was not expected from Public Bus model groups. The average value of smoke opacity showed that Higer Bus Model year of (2007) was emitted 1.1 times than that of the same model year ranges (2000-2009) Code-3 Minibus. Comparing Higer and Code-3 Minibus (2010-2018), Higer Bus was smoked out twice of Code-3 Minibus (2010-2018) model year. To compare smoke opacity value of Higer Bus in different Model year with its family models there was only one model (2007) available in the city. In contrary, as it was seen Higer Bus of 2007 model year emits higher smoke opacity than the same range of Minibus means, there was a another technical problems or impacted by the number of kilometer travelled from Higer Bus. Comparing Higer and Code-3 Minibus (2010-2018), Higer Bus was smoked out twice of Code-3 Minibus (2010-2018) model year.

In the case of smoke density value all categories stated here were failed to meet the standards. Figure 4.5 and 4.6 shows that the variation in smoke opacity and smoke density value of Higer, Code-1 Taxi and code-3 Minibus with different model year respectively. The finding of this study is contrary to that of (Shankute, 2015) as his finding showed 0% of Higer busses recorded opacity of 40% or less. But, in this finding 6 (20%) out of 30 vehicles were registered less than 41% and passed the USA EPA standard cut point for model year of 1991 and newer. This study again corroborates the study of (Aduagba et al., 2013; Malka and Bidaj, 2015) observed smoke opacity coefficient among the production years of the different cars. From the result he found that the new cars have more opportunity to keep the results “pass” compare to the older cars and this implies opacity value is a strong function of vehicle age and their type. In this finding the results of minibus taxi and commercial minibuses with different production year from the oldest model to the later shows decreasing in emission, this was strengthening the study of Malka and

Bidaj. In the case of Higer Bus it is difficult to observe the effect of age on emission level of it because only 2007 model year are operating in the city.

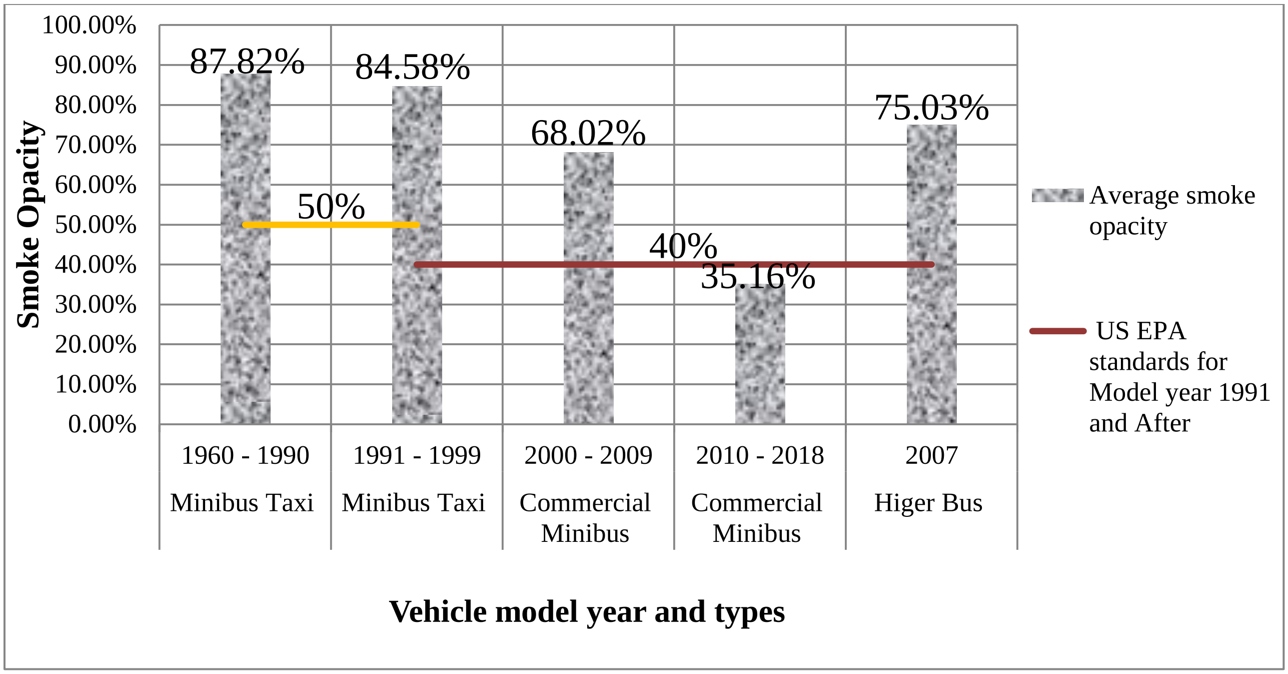


Figure 4. 5 Smoke opacity comparison of Minibus Taxi, Commercial Minibus and Higer Bus

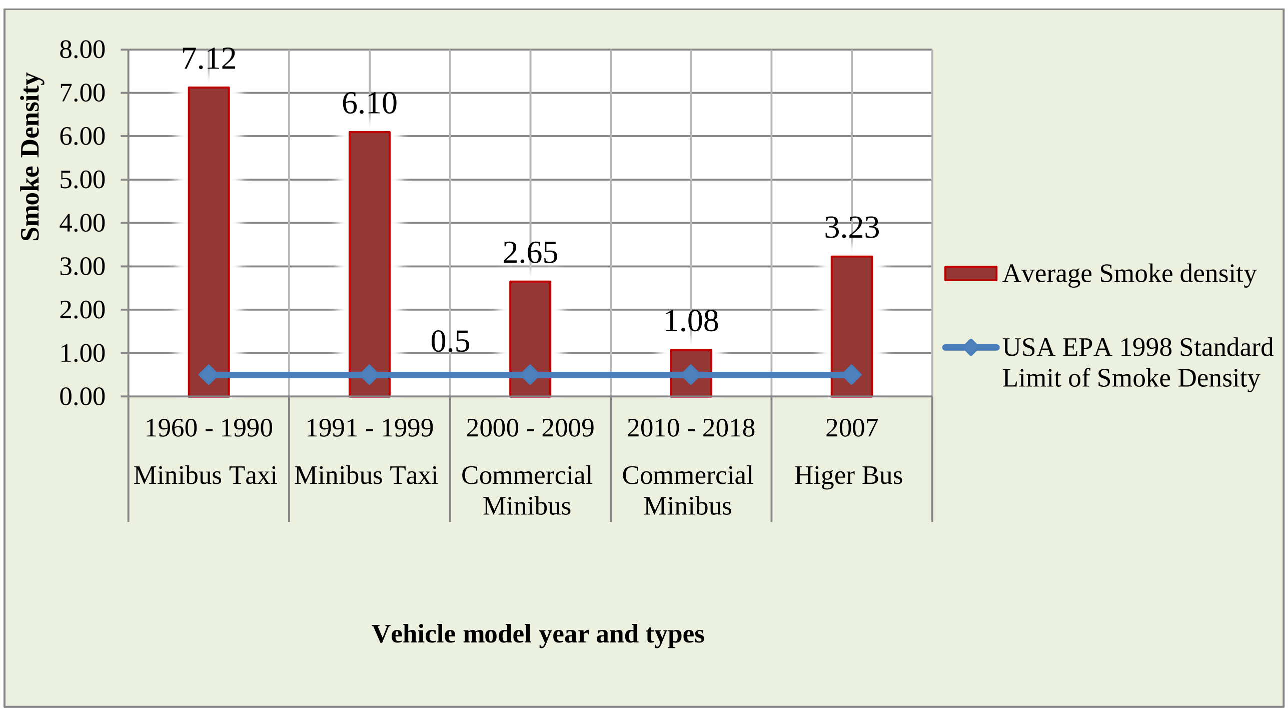


Figure 4. 6 Smoke density comparison of Minibus Taxi, Commercial Minibus and Higer Bus

4.1.1.7.3 Smoke Opacity and Density of Minibus Taxi, Commercial Minibus and Sheger Bus

Sheger Bus had a family model year (2008-2016). As Smoke Opacity test results from Sheger Bus Express showed Smoke opacity values of it was appears far down below the USA EPA Smoke Opacity Standards of model year 1991 and newer. The average registered smoke opacity values of Sheger Bus were 13.69% for (2008-2015) and 9.92% for (2015-2019) model year. Two model years were included in the test since only two models available. Model year (2008) which was registered Opacity value of (10%-25) and another 2016 model with (4%-10%) smoke opacity values. It was seen in the test, Code-3 minibus of (2010-2018) latest model than sheger (2008) model year registered smoke opacity value of more than 2.5 times. The study implied that sheger Bus Transport was termed under green transportation since the registered smoke opacity values were far away from the standard. Also the study found that, there was a variation of smoke opacity values as the age of sheger Bus getting older as of model year (2008) registered 13.69% and (2016) registered 9.92% smoke opacity values.

In the case of smoke density value in this category only Sheger Bus of (2008-2015) was passed the settled standards by USA EPA. Figure 4.7 and 4.8 displays the variation in smoke opacity and smoke density value Sheger, Code-1 Taxi and code-3 Minibus with different model year. This result is similar to the findings of (Rouf et al., 2008) who reported that average smoke opacity of all Volvo and Ashoke Leyland buses were below the standards and the opacity of Volvo buses were much less than Ashoke Leyland buses. Again in his finding Volvo buses were believed as the most environments friendly. Sheger busses were also shows the characteristic of Volvo busses and were similarly taken as environments friendly.

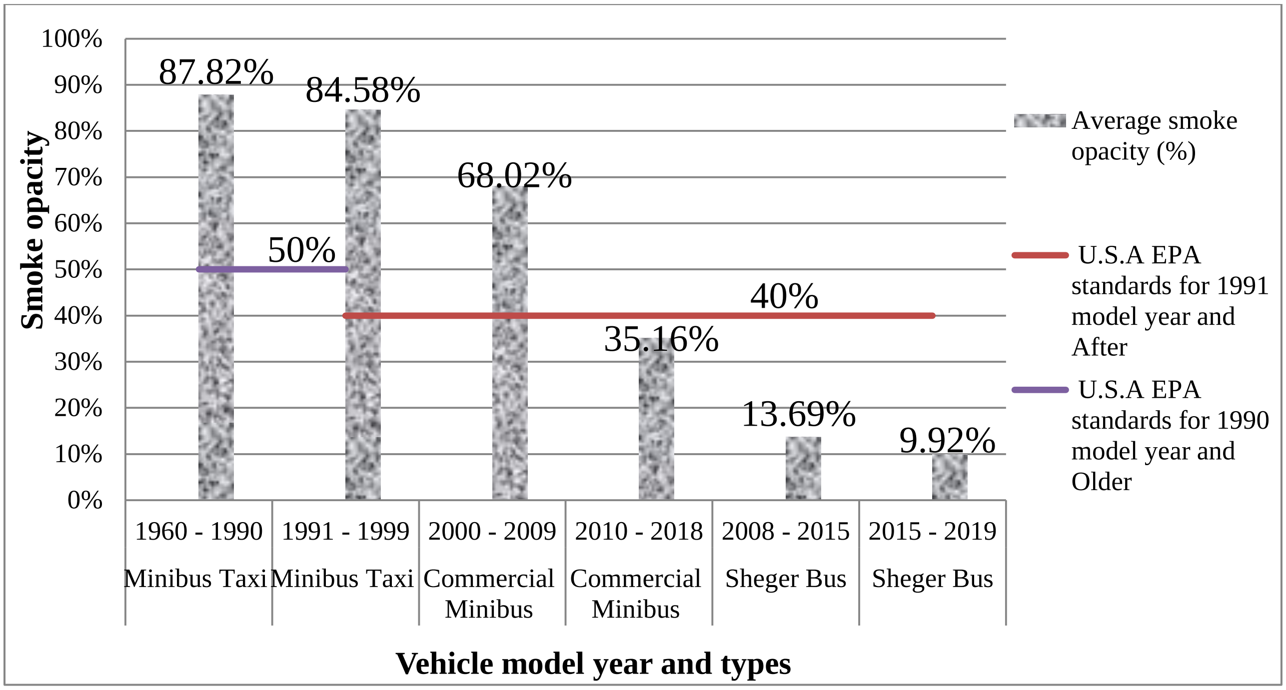


Figure 4. 7 Smoke opacity comparison for Minibus Taxi, Commercial Minibus and Sheger Bus

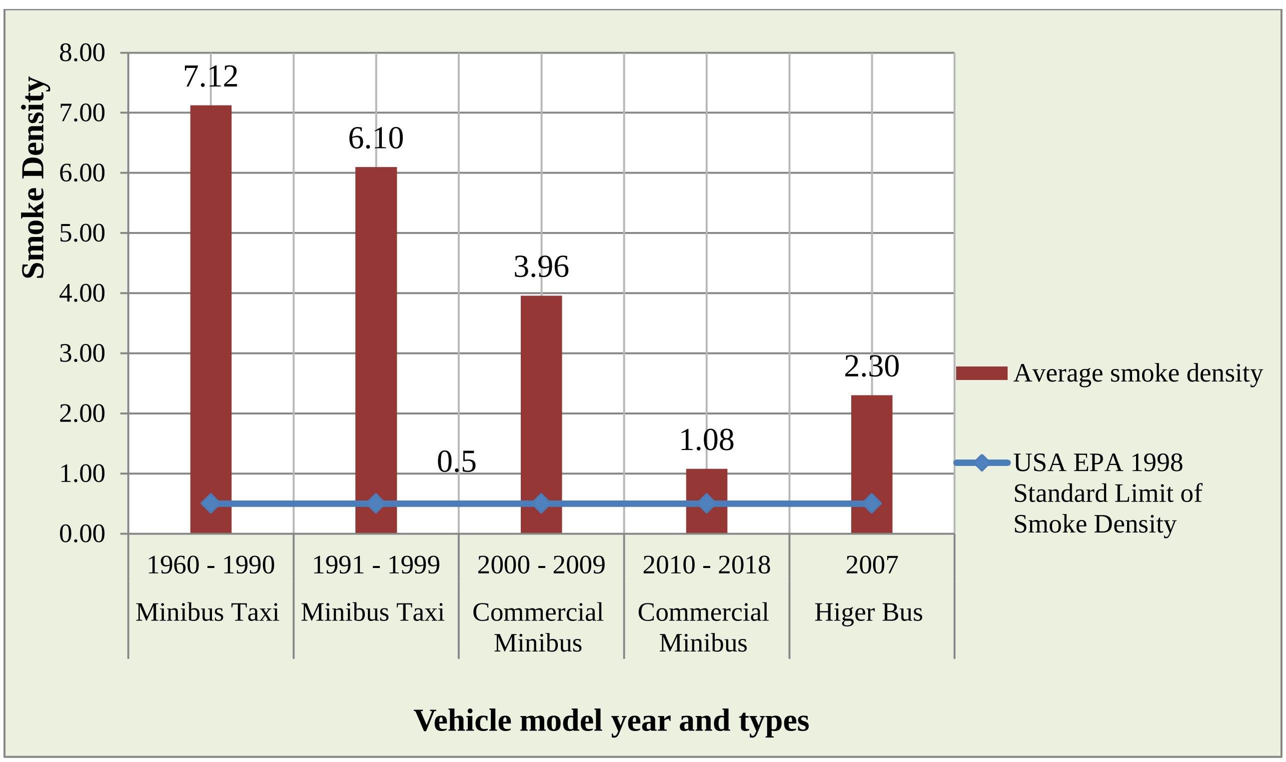


Figure 4. 8 Smoke density comparison of Minibus Taxi, Commercial Minibus and Sheger Bus

4.1.1.7.4 Smoke Opacity and Density of Minibus Taxi, Commercial Minibus and Isuzu NPR Bus

Isuzu NPR Bus had a family model year (1975-1990), (1991-1999), (2000-2009) and (2010-2018). According to the registered smoke opacity value from Isuzu models, Model (1975-1990) had an average smoke opacity value of 80.16% which was less than that of code-1 Taxi (1960-1990) by 7.66%. As per to the data described on histogram below Modified Isuzu NPR Buses smoke opacity value were decreased as the model increased. But, their smoke opacity values were relatively compared with both Code-1 Taxi and Code-3 Minibus up to model year (2010-2018). Regarding with (2010-2018) Isuzu NPR Bus had less smoke opacity level than code-3 minibus by half or code-3 minibus registered of Isuzu NPR Bus. Generally, the aggregate opacity values of Isuzu Bus were less than that of Taxi and code-3 Minibus and the result showed that vehicle age had an impact on emission level. In case of smoke density value all were failed to meet the USA EPA standards. Especially the oldest model of Isuzu and Taxi smoked out very denser smoke/means they were highly polluting the environment. Figure 4.9 and 4.10 shows the variation in average smoke opacity and density respectively. The finding of this study strongly agreed with that of (Beydoun and Guldmann, 2006) older vehicles are more likely to fail their overall emissions test.

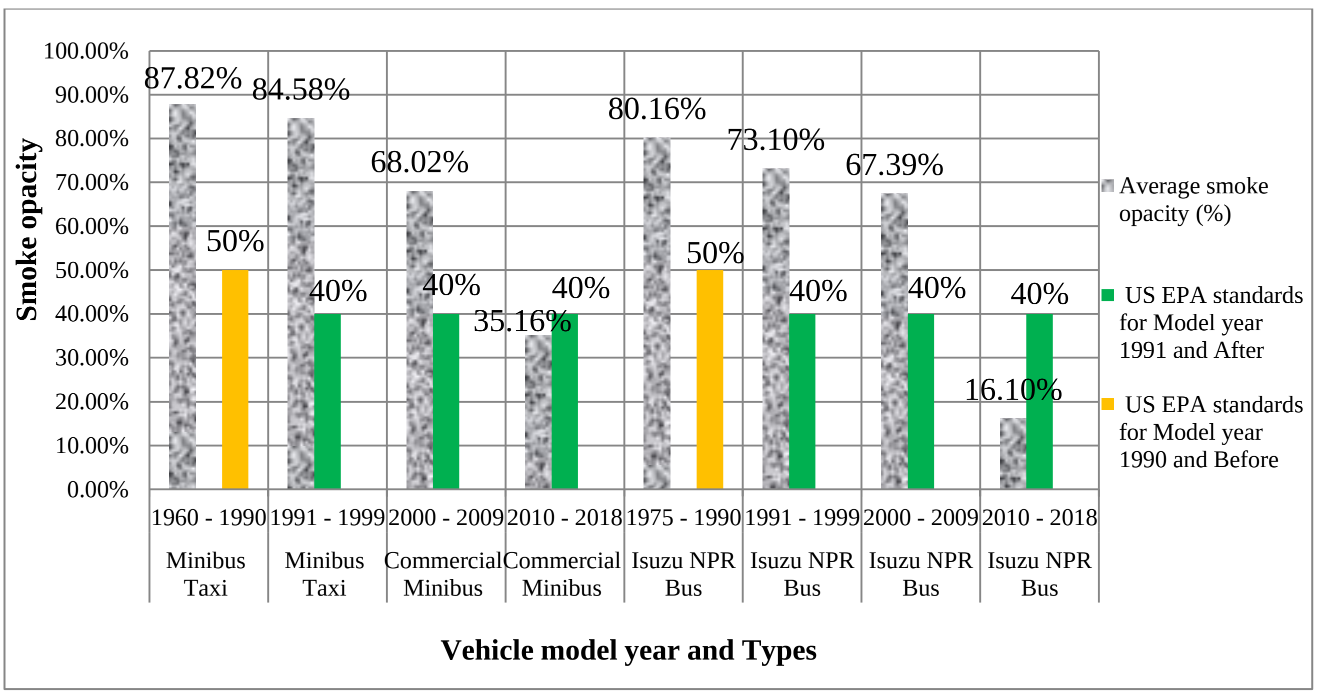


Figure 4. 9 Smoke opacity comparison of Isuzu NPR Bus, Minibus Taxi and Commercial Minibus with different model year

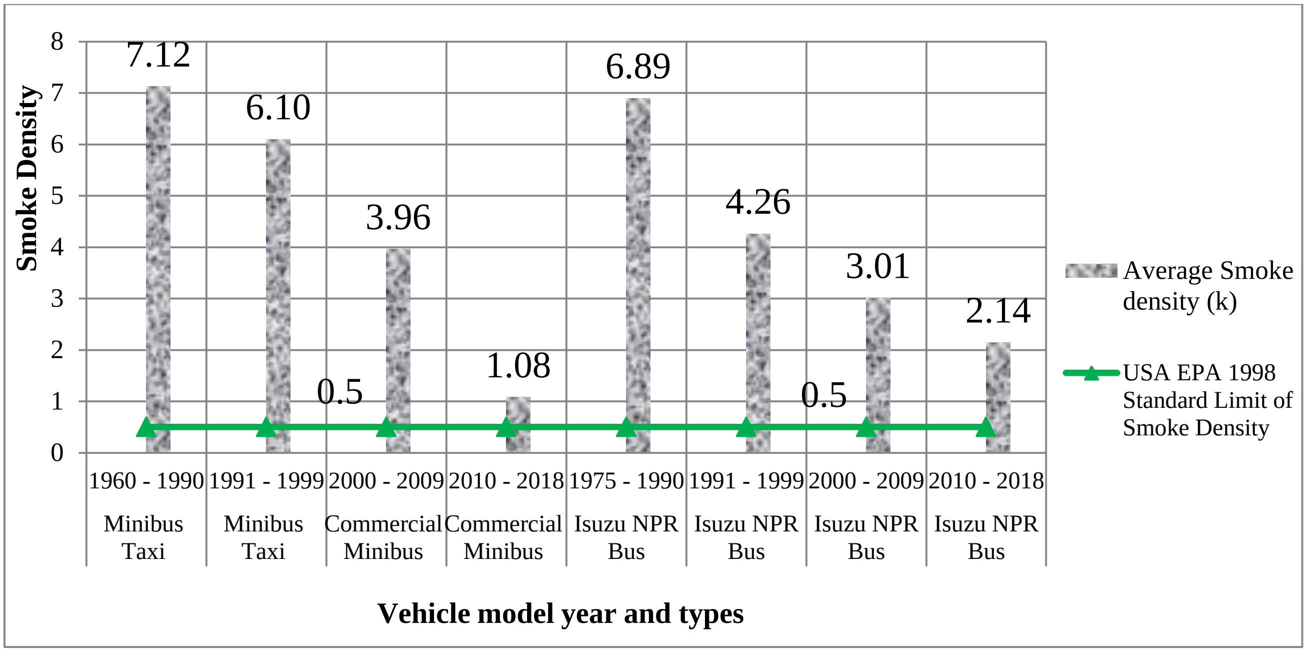


Figure 4. 10 Smoke Density comparison of Isuzu NPR Bus, Minibus Taxi and Commercial Minibus

4.1.1.7.5 Smoke Opacity and Density of Anbessa Bus, Higer Bus, sheger Bus and Isuzu NPR Bus

The results of overall Bus family showed, Anbessa city Bus was registered an average opacity value of 21.56% and 4% for the model year of (1980-1990) and (1991-2018) respectively. The first model (1980-1990) was less by more than half (28.44%) from the standard limit setted for the model year (50%) and (1991-2018) model were also less by more than half (36%) from the standard limit Settled for the model year (40%).

In case of Higer Bus as the value obtained from the test result showed, the average value of smoke opacity was higher (40%) than the settled standard limit (40%). Regarding with Sheger Express Bus model year of (2008-2015) registered with 13.69% was less by more than half (26.31%) and that of model year (2015-2018) registered with 9.92% was far away by (30.08%) from the standard limit (40%).

The result of Isuzu NPR Bus showed that, it was highly emitted smoke at idling condition from model year (1975-2009) above the standard limit. Only the newest models were emitting below the standards. When they are compared each other Anbessa City Bus were minimized emission from black smoke by (71.03%) opacity value than Higer bus with the same model year range.

This means Higer Bus was emitting 19 times Anbessa City Bus and 5.5 times Sheger Bus at idle conditions. Isuzu NPR Bus was emitting 3.7 times Anbessa City Bus in the same model year range of (1980-1990) and 4 times than Anbessa city Bus for model year of (2010-2018). Also Isuzu bus was emitting 1.6 times sheger Bus of model year (2010-2018). This study confirms the findings of (Beydoun, 2004; Beydoun and Guldmann, 2006; Aduagba et al., 2013; Gebre, 2018) that stated older vehicles have significantly higher emissions than newer ones. The reason for this may be as a vehicle gets older, the effects of age and equipment deterioration become more evident and thus older vehicles, on average, emit much more than newer ones and newer model-year vehicles are associated with lower emissions, due to improved vehicle technology and lesser engine and emission control equipment deterioration. It was displayed in figure below.

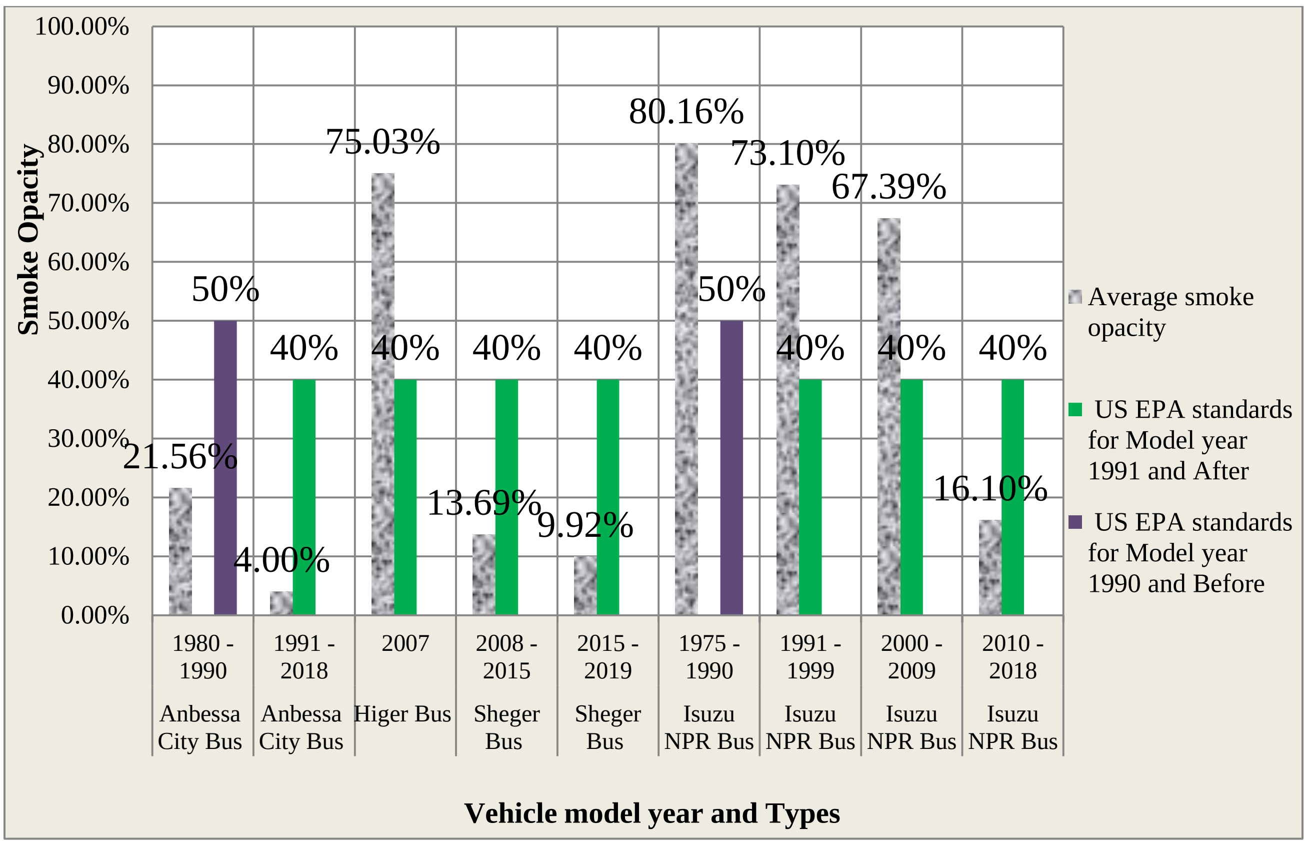


Figure 4. 11 Smoke opacity comparison of Bus family with different model year

4.1.1.8 Description of vehicle emission by vehicle Cumulative Kilometer Travelled

Under this subtopics vehicle kilometer travelled of all models were discussed as if there was an impact on smoke opacity value of vehicles. Therefore, the impacts were discussed for code-1

Taxi, Commercial minibus, Anbessa City Bus, Higer Bus, Isuzu NPR Bus, and Sheger Bus. But, data under this category were not obtained for all vehicles since some of them had malfunctioned odometer reading. The analysis was made only for available data.

4.1.1.8.1 Smoke opacity of minibus taxi by Cumulative Kilometer travelled

From the data description it was seen that opacity values Taxi vehicles getting high with kilometer travelled up to (700-800) km range and started to be stagnant after. They emit almost at the same level beyond (700-800) km. This implies that, the impacts of kilometer travelled on emission level were less for vehicles as the age did. Figure 4.12 illustrates the trends of emission level of Taxi with kilometer travelled. This show that minibus taxi travelled 500-550 thousands of km reduced emission by 1.09 and 1.24 as much as 550-600 and 700-750 thousands of km travelled respectively. Beyond 750 there was small variation. This implies the vehicles emission control technology and other spare parts totally deteriorated.

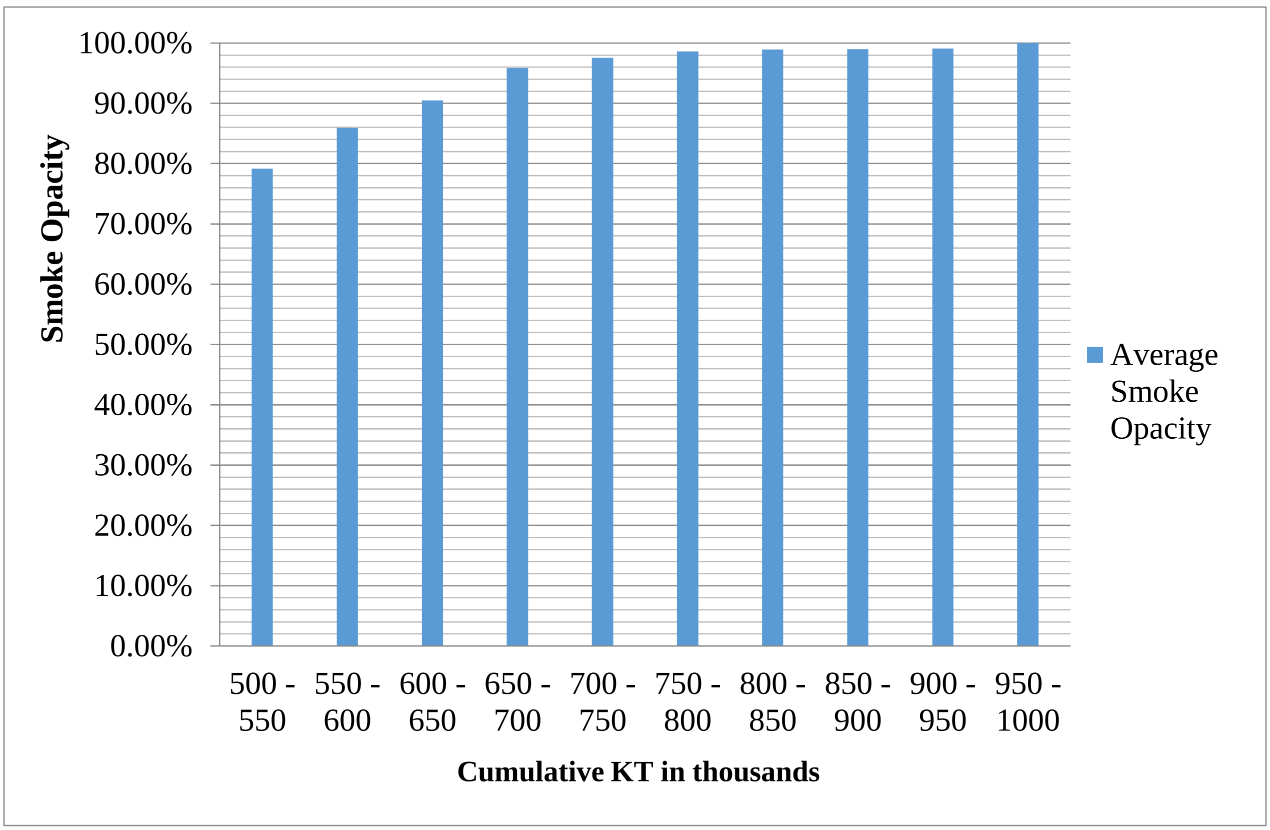


Figure 4. 12 Trends of kilometer travelled with Smoke opacity levels of Minibus Taxi

4.1.1.8.2 Smoke opacity of Commercial Minibus by Cumulative Kilometer Travelled

Regarding with code-3 minibus the trend of opacity level increase with kilometer travelled increasing by different rate between the ranges. Looking for (37-112) km range to (337-412) increasing with significant manner. But, from (337-412) km range to (562-637) km almost increasing with less sloped than the first case. From this and in the case of Taxi vehicles above it was observed that for the range of large kilometer driven above 500 thousand kilometer the value of smoke opacity was more than 80% and increasing with small rate and nearly equal. It was seen that minibus 37-112 thousands of km, there was a reduction in air pollution by 1.94, 4.92 and 5.40 as much as 112-187, 487-562 and 562-637 thousands of km travelled in respectively.

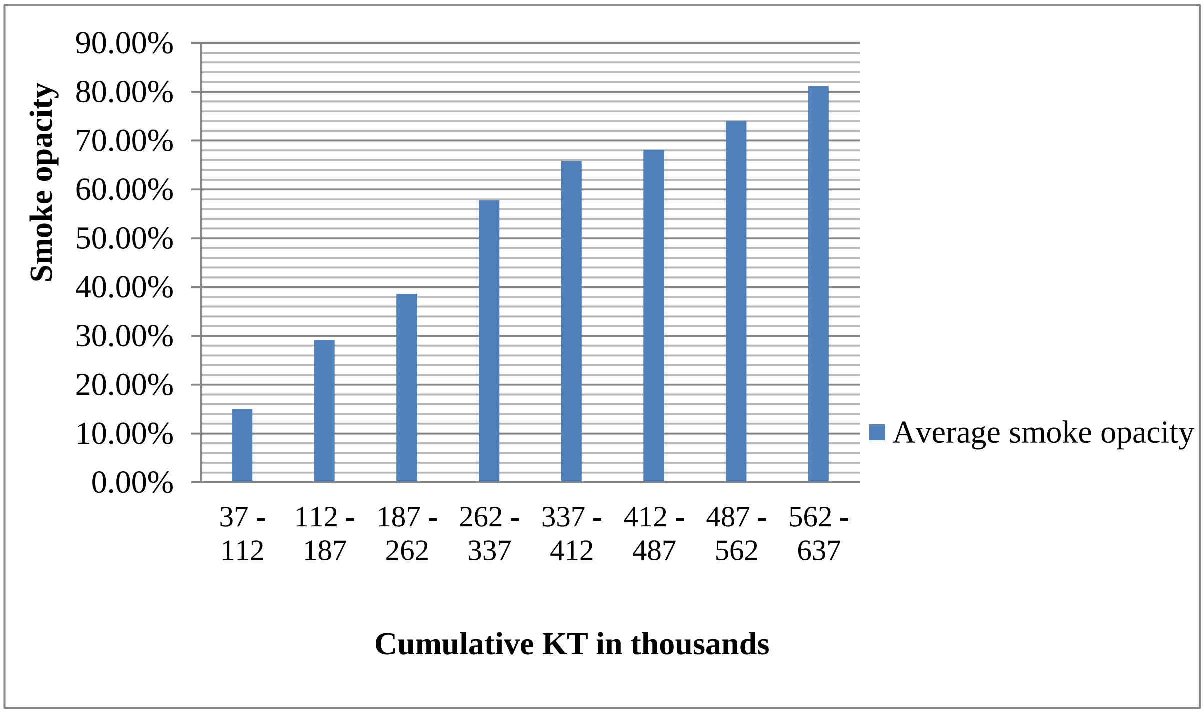


Figure 4. 13 Trends of kilometer travelled with Smoke opacity levels of Commercial Minibus

4.1.1.8.3 Smoke opacity of Anbessa City by Cumulative Kilometer travelled

In the case of Anbessa city Bus the trends of smoke opacity value were increased as the number of kilometer travelled increased. The average smoke opacity value of Anbessa City Bus was 21.56% even at 998 thousand kilometer driven. But, the emission level of Commercial Minibus between the (262-337) thousand km range and Taxi vehicles were more than both 40% and 50% USA EPA standard guidelines. Anbessa City Bus was the green transportation system that which had low emission level for whatever kilometer travelled. But, their emission levels were increased as kilometer travelled increased. Thus Anbessa bus travelled 10-66km by 6.53 and 10.37 as much as 66-790 and 790-998 km in thousand emissions in the order given.

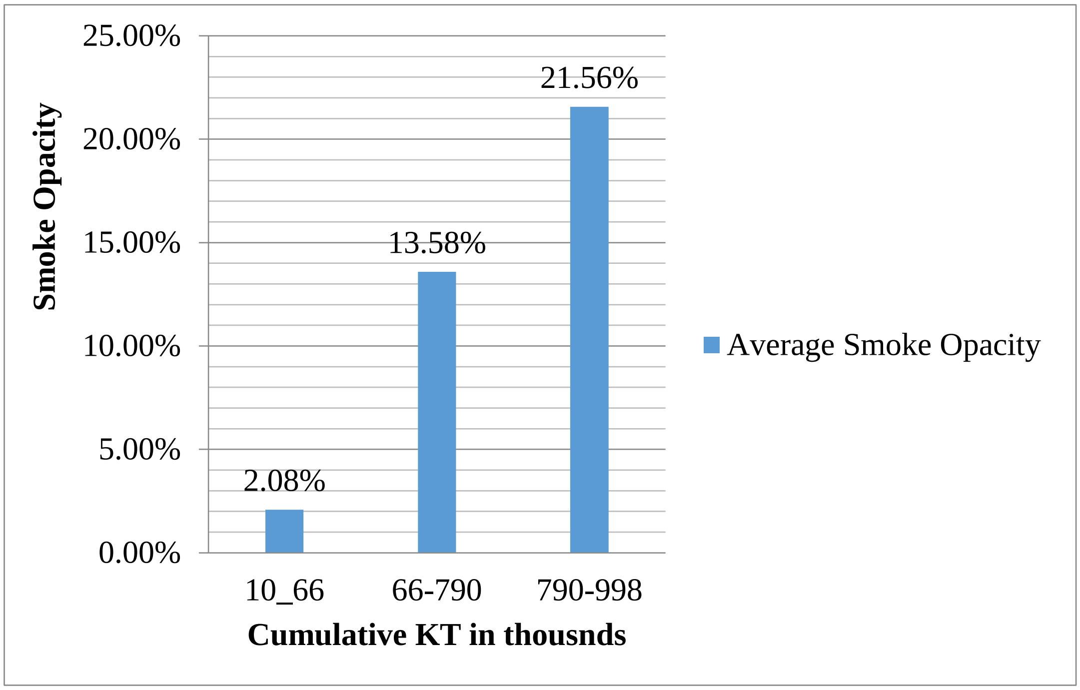
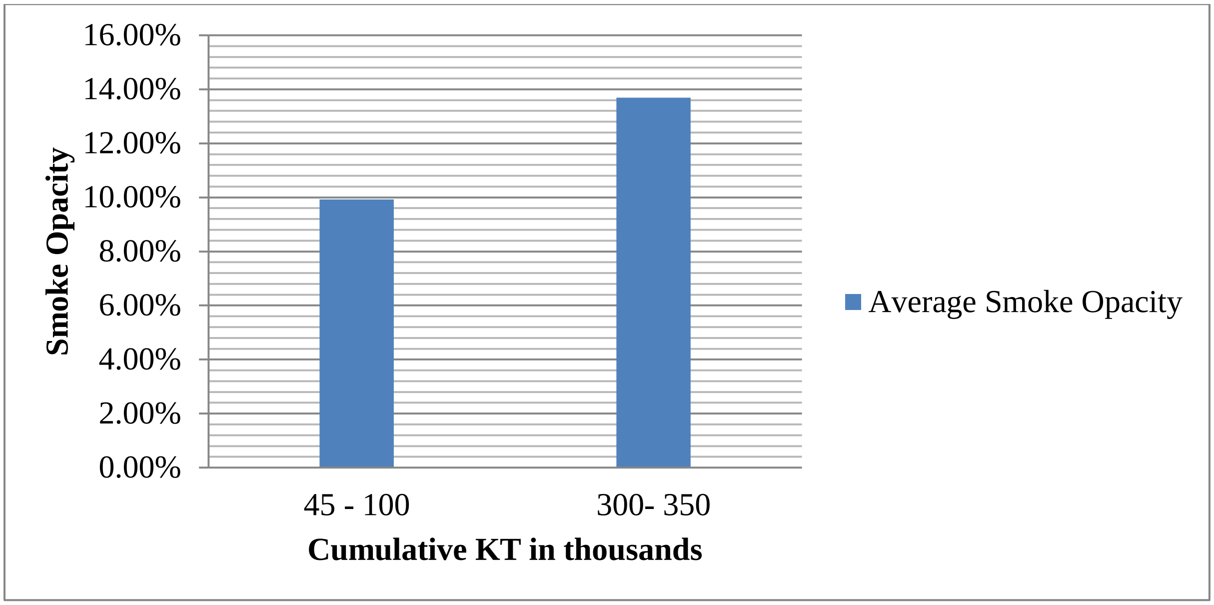


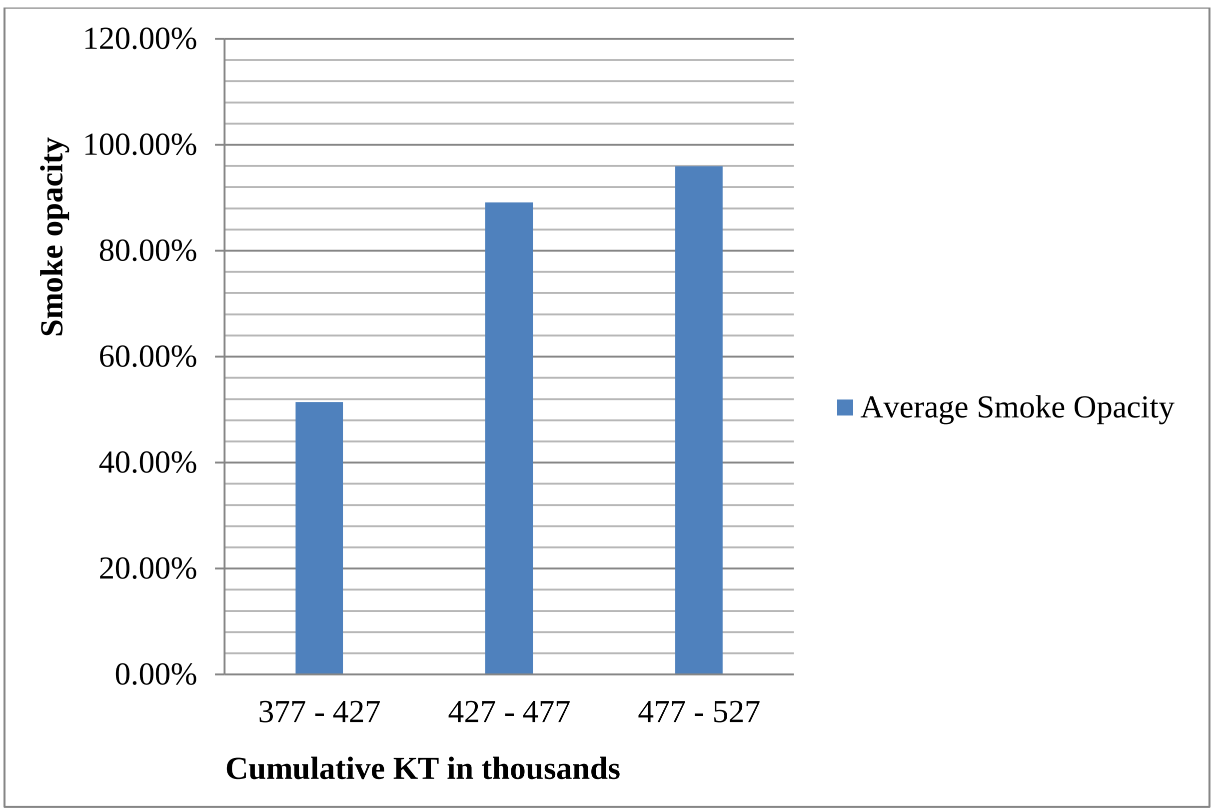
Figure 4. 14 Trends of kilometer travelled with Smoke opacity levels of Anbessa City Bus

4.1.1.8.4 Smoke opacity of Sheger and Higer Bus's by Kilometer travelled

In case of Higer Bus fig (b) below, there was a relationship of increasing smoke opacity value as the number of kilometer travelled increased. But, similar to commercial Minibus and Taxi vehicles there was found a rapid increase between (377-427) km and (427-477) km range. From (427-477) to (477-527) km there was a decrease in smoke opacity value difference between Higer Buses. Sheger bus with 45-100km travelled recorded a reduction of air pollution 1.38 as much as with 300-350km travelled in thousand. Higer bus recorded with 377-427km in thousand registered reduction of 1.73 and 1.87 as much as 427-477 and 477-527 km in thousand. Higer bus emits more than other vehicle types of the same kilometer travelled range. It may have technical problem on emission control technology during manufacturing. Figure 4.15 (a) and (b) illustrates the impact of kilometer travelled on Sheger and Higer Bus.



(a)



(b)

Figure 4. 15 (a) Trends of kilometer travelled and Smoke Opacity of Sheger Bus and (b) Trends of kilometer travelled and Smoke opacity of Higer Bus

4.1.1.8.5 Smoke opacity of Isuzu NPR Bus by Cumulative Kilometer travelled

Figure below shows the trends of smoke opacity value were increased as the number of kilometer travelled increased. Especially, higher increasing rate of average smoke opacity was observed for the Buses of (633-933) km travelled. The average smoke opacity value of (233-433) and (433-633) were closer to each other. Because, from randomly sampled data most Isuzu NPR Bus in the 433-633) km range were close to 433 in kilometer travelled length. That is why the rate of difference in smoke opacity values (233-433) and (433-633) km range became small. Isuzu NPR Bus with 500km travelled in thousands and above most of them failed to pass the standard guidelines and emit almost at the same level. This agrees with the finding of (Beydoun, 2004) that showed as the number of miles that a vehicle is driven increases, the probability of it failing its emissions test also increases. As with model-year, this is probably attributable to the effects of engine and emissions equipment deterioration associated with increased vehicle use. The finding of this study confirms to the study of (Beydoun and Guldmann, 2006) which found increasing vehicle mileage is associated with higher emissions, as increased vehicle use results in more wear-and-tear in the mechanicals and emission control equipment.

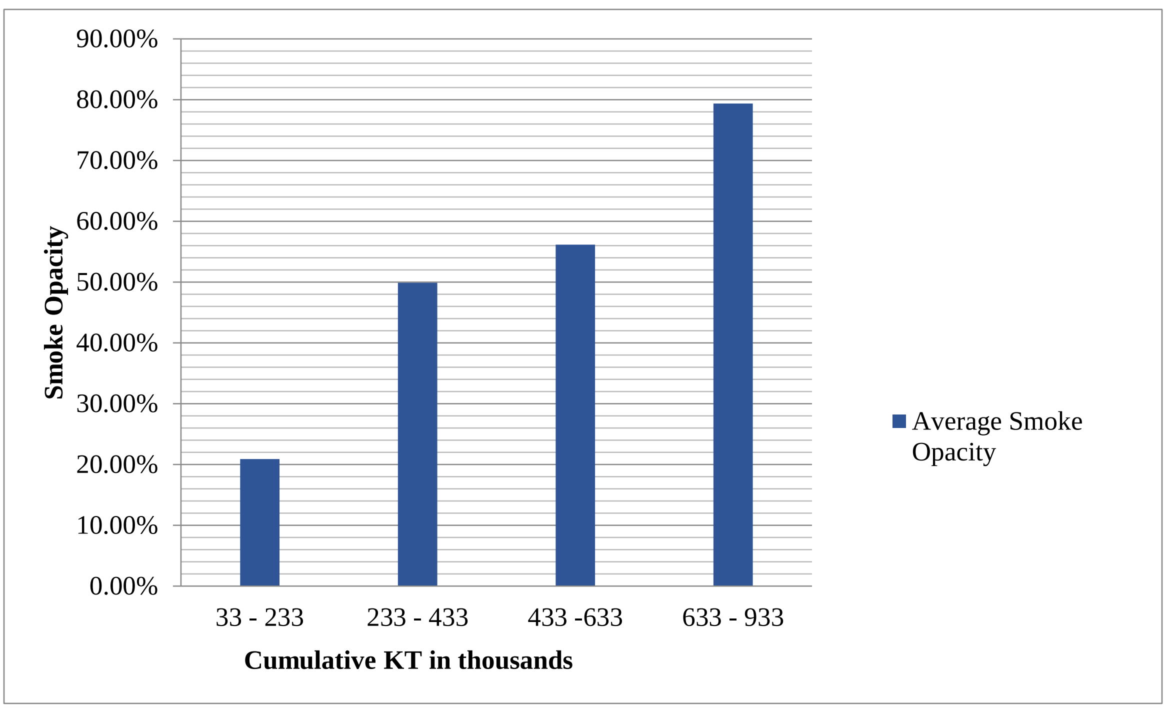


Figure 4. 16 Trends of kilometer travelled and Smoke opacity value of Isuzu NPR Bus

4.1.2 Descriptive Analysis of Gasoline Fueled Vehicle Emission by Vehicle Characteristics

As discussed above the study focused emission from public transportation, specifically on (Taxi and other Commercial) vehicles were taken as study subject. Lada Taxi was categorized under Code-1 and used gasoline fuel. Therefore, the researcher intended to study all family of Taxi vehicles that includes Minibus Taxi, Lada Taxi and Meter Taxi. From the total calculated sample size (62) unique gasoline fuel user Lada and Meter Taxi were tested. Vehicles were randomly selected and tested at different roadside shoulder in Addis Ababa. The sample distribution covered vehicle model-years from 1966 to 2016 of Lada Taxi and Meter Taxi vehicles.

Descriptive data analyses were made to:

- ✓ Compare average emissions Hydrocarbon(HC), Carbon Monoxide (CO), Carbon dioxide (CO_2) generated from Lada and Meter Taxi both at idle and operating condition 2500rpm condition,
- ✓ Compare average emissions level with presence of independent variables (model year/age, of different types of vehicles Lada vehicles and Meter Taxi.
- ✓ Determine impacts of each category and identify super emitter categories.

4.1.2.1 Hydrocarbon (HC) Emission by Model year and vehicle Type

The overall test results show that, the highest level was observed for Fiat Lada 2738.33ppm Hydrocarbon at idle condition and 2456.10ppm at free acceleration of 2500rpm operating condition. This value was too much higher than the Californian smoke check BAR-90 which was 4 times the standards. The least value from observed 62 samples was 21ppm. From observed data only 3(4.84%) passed the standards both at idle and 2500rpm operating conditions.

In the case of idling condition 5(8%) and 3(4.84%) at 2500rpm was passed the standard cut points. From 62 tested vehicles 29(46.8%) scored between 2000-3903ppm hydrocarbon concentration, 21(33.87%) scored between 21-1541ppm and 57(92%) failed in both case to meet the standards. From figure 4.16, it was observed that Toyota DX and Lifan (meter taxi) of 2016 model year were scored under the standards both at idling and accelerating condition. It was seen that the latest vehicle model year recorded lower emission level of Hydrocarbon than the oldest group even though most of the sample were recorded above the standard limits. Also, the emission values at idling vehicle operating condition were higher than in the case of accelerating condition of 2500rpm. This shows us vehicles are polluting the ambient air more when they are operating under idling condition specially, at Traffic light, Taxi or Bus station. This study again in line with (Al-Momani, 2006) that indicated the pass results of emission tests of the tested vehicles were the highest in the new vehicles and lowest for older ones. Moreover, in his study he indicated that the most important factors affecting vehicular emission levels for German gasoline vehicles are manufacturing year, gasoline type (regular, super, and unleaded), and engine fuel supply system (injection or carburetor). However, the result of his study showed that that 79.9%, 69.7%, 87.0%, and 78.9% of the whole sample pass the Jordanian standard emission limits of CO, CO_2 and HC, respectively which is the reverse of the results of this study.

Table 4. 6 Average HC level at Idle, at 2500rpm and with their respective standard limit

Model Name	Model Year	No of Counts	Average HC @ Idle	Bar-90 Standard at Idle	Average HC @ 2500rpm	Bar-90 Standard at 2500rpm
Fiat 124	1966-1967	3	2738.33	700.00	2456.10	600.00
Fiat 124	1968-1970	4	2350.00	650.00	2140.00	600.00
Fiat 124	1975-1980	3	2107.00	220.00	2015.60	180.00
Fiat 124	1981-1983	8	1966.00	120.00	1891.50	150.00
Fiat Leda	1984-1986	5	2235.67	120.00	1755.67	150.00
Fiat Leda	1987-1992	4	1009.50	120.00	1029.50	140.00
Toyota 3K	1984-1986	3	2323.20	120.00	2244.00	150.00
Toyota 3K	1987-1992	4	2672.83	120.00	2546.45	140.00
Toyota DX	1981-1983	8	2432.00	120.00	2631.33	150.00
Toyota DX	1984-1986	9	2308.67	120.00	2189.00	150.00
Toyota DX	1987-1992	6	1570.26	120.00	1389.88	140.00
Toyota DX	2016	2	92.00	100.00	123.00	130.00
Lifan Meter Tax	2016	3	64.67	100.00	37.50	130.00

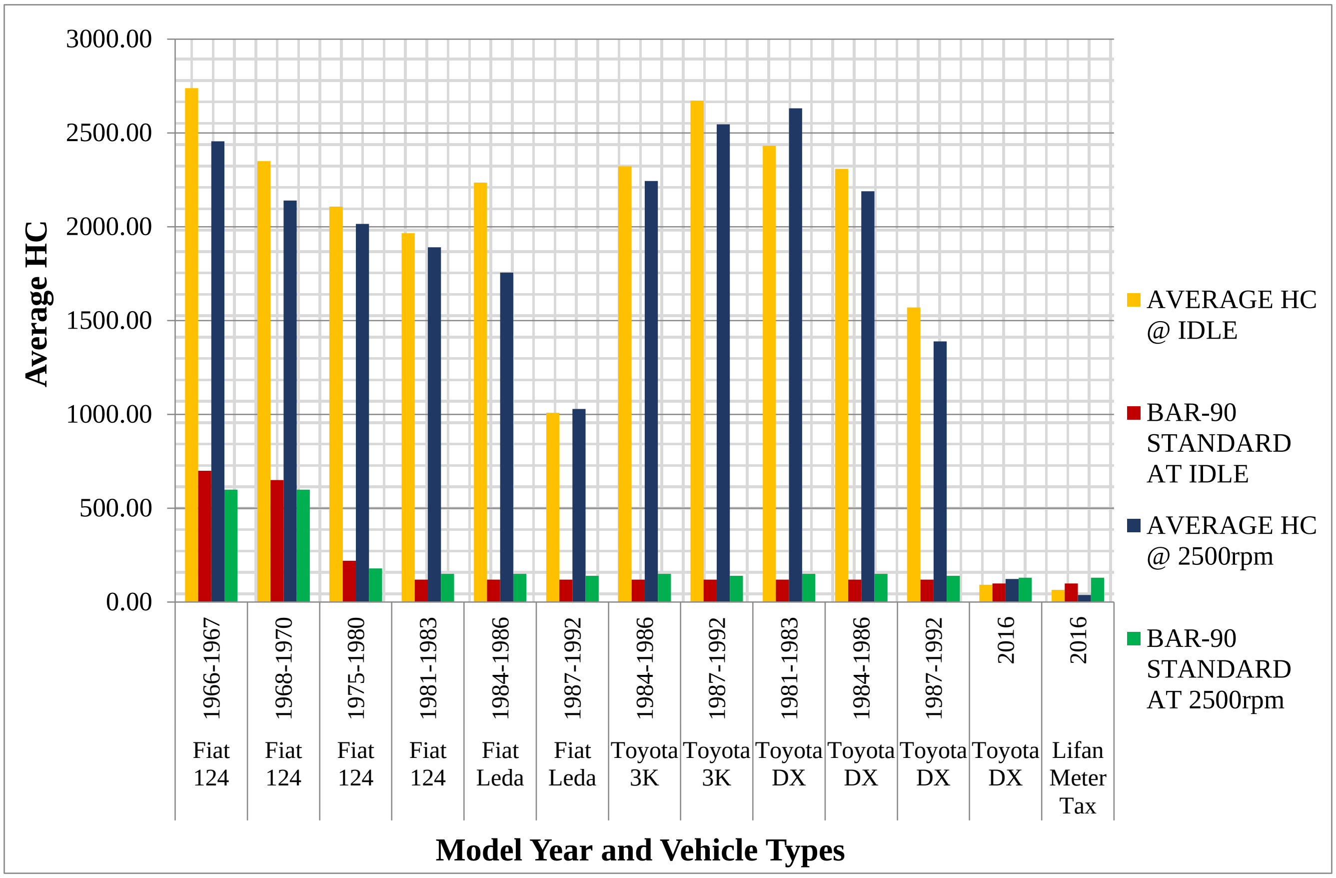


Figure 4. 17 Average HC at Idle, at 2500rpm and their respective standards

4.1.2.2 Carbon Monoxide Emission by Model year and Vehicle Type

According to the test results the highest average level of Carbon Monoxide was observed for Fiat 124 (1968-1970) with 5.87% Carbon monoxide at idle condition and followed by Toyota 3k (1987-1992) with a value of 5.42% that was above the standard 5.5% and 1% respectively. But, at free acceleration the values were decreased to 4.71% and 5.16% respectively. This shows carbon monoxide at acceleration mode was converted to carbon dioxide and water as the combustion process increased. Overall, from the registered data of test results only 9(14.5%) passed the standards in both at idling and accelerating (2500rpm) operating conditions. Others or 85.5% failed the cut points both case. But, the emission level of Carbon Monoxide also lower in an accelerating condition than idling case.

The study shows that idling of cars on road increase air pollution level of carbon monoxide which was very harmful to the health of city inhabitants. Generally, the oldest Fiat 124 (1966-1967) emitted slightly above the standard whereas Toyota 3k (1987-1992) recorded an average of 5.42 times the standard cut point. This study concorded with (Nasir et al., 2016) indicates that higher percentage of the fuel went through complete combustion and the percentage with incomplete combustion produced the CO. Figure 4.18, illustrates variation of CO with model year and vehicle types

Table 4. 7 Average CO level at Idle, at 2500rpm and with their respective standard limit

Model Name	Model Year	No of Counts	Average CO @ Idle	Bar-90 Standard at Idle	Average CO@ 2500rpm	Bar-90 Standard at 2500rpm
Fiat 124	1966-1967	3	5.87	5.50	4.71	4.50
Fiat 124	1968-1970	4	4.20	5.50	3.97	4.50
Fiat 124	1975-1980	3	4.46	2.00	3.97	1.70
Fiat 124	1981-1983	8	3.23	1.50	3.09	1.50
Fiat Leda	1984-1986	5	3.14	1.00	4.45	1.20
Fiat Leda	1987-1992	4	0.49	1.00	0.48	1.00
Toyota 3K	1984-1986	3	5.06	1.00	4.67	1.20
Toyota 3K	1987-1992	4	5.42	1.00	5.16	1.00
Toyota DX	1981-1983	8	5.03	1.50	4.75	1.50
Toyota DX	1984-1986	9	5.10	1.00	5.42	1.20
Toyota DX	1987-1992	6	4.36	1.00	4.27	1.00
Toyota DX	2016 (1993+)	2	0.03	1.00	0.03	1.00
Lifan Meter Tax	2016 (1993+)	3	0.16	1.00	0.04	1.00

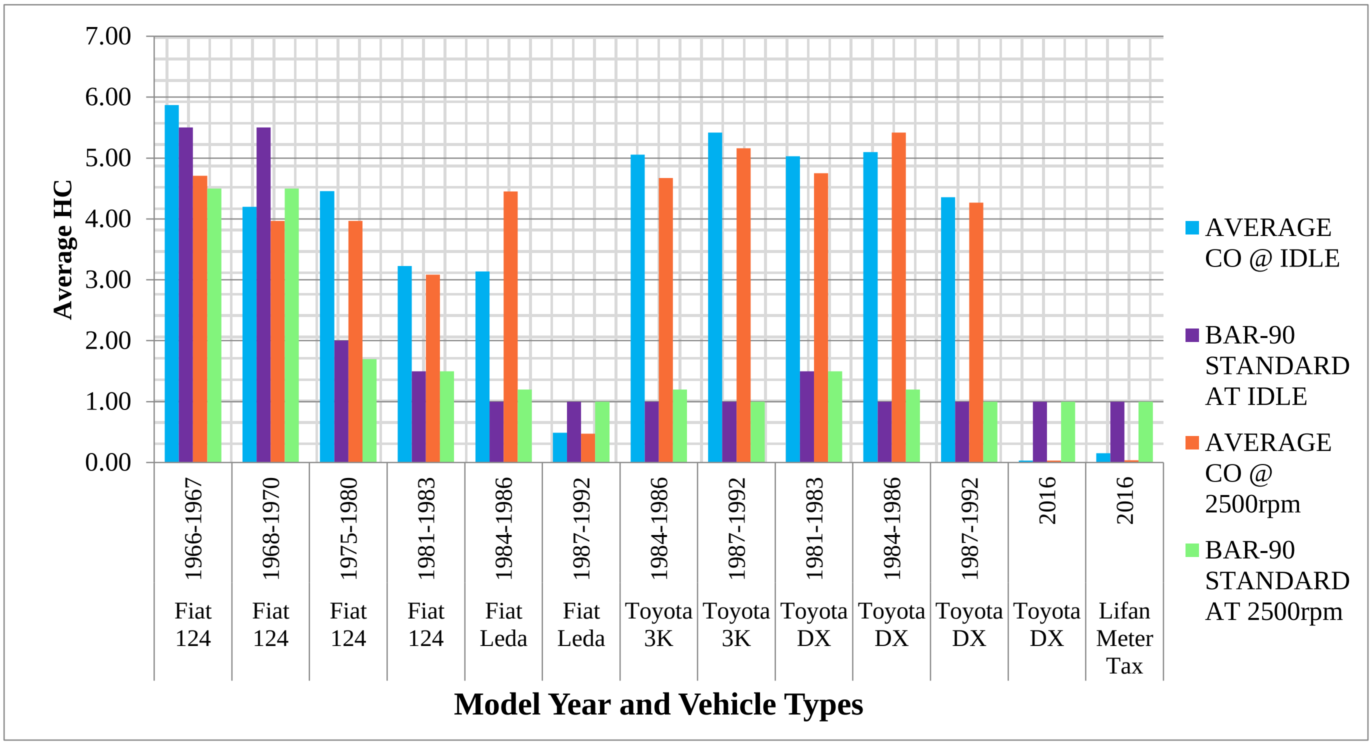


Figure 4. 18 variation of CO with model year and vehicle types

4.1.2.3 Carbon Dioxide Emission by Model year and Vehicle Type

According to the test results the highest level of Carbon Dioxide was observed for Lifan Meter Taxi (2016) model year with 12.50% Carbon Dioxide in accelerate mode case which was above the standard and 11.96 below the standard in idle mode case. Other vehicles were below standard cut points as they emit high concentration of Hydrocarbons that could be converted to water vapor and carbon dioxide during combustion process. Carbon dioxide has less effect on human health and environment. The study shows the impact of vehicle age on air pollution was highest than every factors for vehicle exhaust emission. Figure 4.18 illustrates variation of CO_2 with model year and vehicle types.

Table 4. 8 Average CO_2 level at Idle and 2500rpm with standard limit

Name	Model Year	Count	CO_2 @Idle	CO_2 @2500rpm	New Jersey Smoke Check Standard
Fiat 124	1960-1970	4	5.13%	6%	12%
Fiat 124	1971-1980	5	5.26%	5.57%	12%
Fiat 124	1981-1990	3	5.89%	5.3%	12%
Fiat Leda	1980-1990	5	7.51%	7.77%	12%
Toyota 3K	1980-1990	11	5.41%	5.43%	12%
Toyota DX	1980-1990	27	6.94%	7.32%	12%
Toyota DX	1991-2000	2	9.11%	9.35%	12%
Lifan Meter Tax	2016	6	11.96%	12.50%	12%

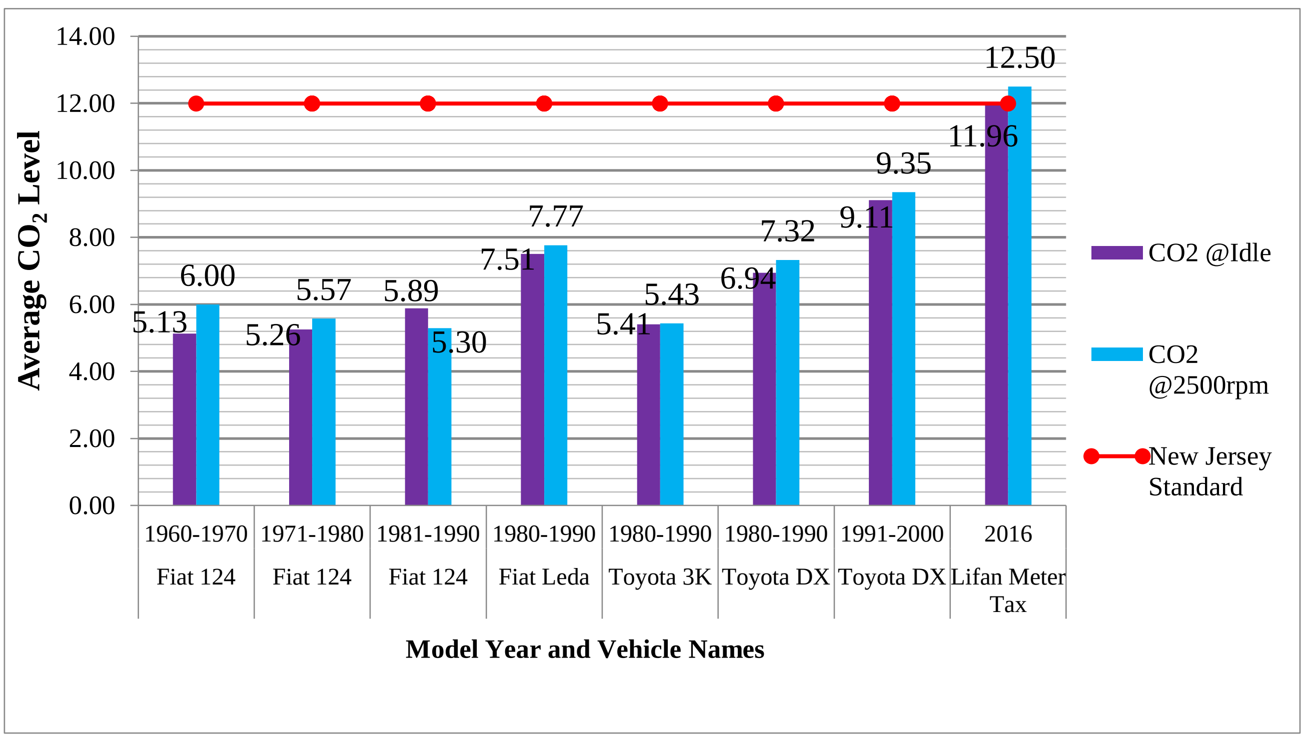


Figure 4. 19 Variation of CO_2 with model year and vehicle types

4.2 Statistical Tests for Mean Differences of Emission by Vehicle Characteristics

Vehicle emission levels were affected by different characteristics. Under this study the following were observed and tested as if they had an impact on the emission level.

4.2.1 Emission Differences by Vehicle Category

Null Hypothesis (H_o): There is no statistically significant difference in emission level between different Vehicle categories.

Alternative Hypothesis (H_1): There is statistically significant difference in emission level between different vehicle categories

To check significance difference of opacity level between the groups of Vehicle category, ANOVA test of T-statistics have been used and the outputs are shown in table. Table 4.9 below shows the mean of smoke opacity value for Taxi and Commercial Vehicles for emission level of the two. The t-values were found for each category of vehicle emission level is presented in table-1 along with their statistical meaning at 5% error. Comparing taxi and Commercial vehicles, Taxi vehicles registered higher smoke level than commercial (p-value=0.0006<0.05). Therefore, the hypothesis said "There is no statistically significant difference in emission level between different Vehicle categories" was rejected.

Table 4. 9 ANOVA Test results of smoke opacity between within Vehicle Category

Smoke Opacity	Taxi Vehicles (Mean)	Commercial Vehicle (Mean)	Df	P-Value
Vehicle Category	87.87	52.23	356	0.0006

4.2.2 Emission Differences by Vehicle Makes

Null Hypothesis (H_o): There is no statistically significant difference in emission level between different Vehicle making countries.

Alternative Hypothesis (H_1): There is statistically significant difference in emission level between different vehicle making countries

F-statistic test was used to use to check whether there was a statistically significant difference available between the groups when the independent groups were 3 or greater than it. Table 4.10 below shows the statistical difference in emission of smoke opacity among different vehicle making country of the sampled data. Regarding with the test value shown in Table 4.10 F-statistics-calculated (60.472) is much higher than the F- critical (2.4) which implies that there was a statistically significant difference in smoke opacity between each group of vehicle makes country. From post hoc one way ANOVA test there was a statistically significant difference in smoke opacity between pairwise group of Toyota (Japan) – Huanghai (China); Toyota (Japan) – Yu-Tong (China); Isuzu (Japan) – Huanghai (China); Isuzu (Japan) – Yu-Tong(China)); Higer Bus (China) – Huanghai (China); Higer Bus (China)- Yu-Tong (China). This implies that Toyota (Japan), Isuzu (Japan), and Higer Bus were emitting the air more than other country in this study.

According to the value of F- Statistics test, there was no statistically significant difference in smoke opacity level between the groups of Toyota (Japan) – Isuzu (Japan); Toyota (Japan) - Higer Bus (China); Huanghai (China) –Yu-Tong (China). This shows that Toyota Japan and Higer Bus (China) participated in air pollution almost at the same levels, means that they were considered as super emitter. In case of Huanghai (China) and Yu-Tong (China) they were also participated almost at the same level on Addis Ababa air pollution, means that they were considered as green transportation with minimum air pollution.

Therefore, the hypothesis said “There is no statistically significant difference in emission level between different Vehicle Making Countries” was rejected. The finding of this study concided with (Beydoun, 2004) vehicle make is significant in determining the probability of a vehicle failing its emissions test. In his study he found out; BMW, Honda, and Toyota vehicles are less likely to fail than other makes. Conversely, Chrysler, GM, Hyundai, Mitsubishi, and Volkswagen vehicles are more likely to fail. Some vehicle manufacturers obviously build “cleaner” vehicles than others. That factor by itself certainly accounts for a significant portion of the variations between makes. Moreover, a vehicle’s make, whether it be a car or truck, influences its emissions.

Table 4. 10 Mean differences of vehicles by make

Vehicle Make		Mean Difference	F-Value	P-Value
Toyota (Japan)	Isuzu (Japan)	6.909	0.62	.649
	China, Higer Bus Company	-4.496	0.26	.901
	China, Yu-Tong	66.510*	7.4	.000
	China, Huanghai	53.694*	7.4	.000
Isuzu (Japan)	Toyota (Japan)	-6.909	0.62	.649
	China, Higer Bus Company	-11.405	0.94	.442
	China, Yu-Tong	59.601*	7.4	.000
	China, Huanghai	46.785*	7.4	.000
China, Higer Bus Company	Toyota (Japan)	4.496	0.26	.901
	Isuzu (Japan)	11.405	0.94	.442
	China, Yu-Tong	71.006*	7.4	.000
	China, Huanghai	58.190*	7.4	.000
China, Yu-Tong	Toyota (Japan)	-66.510*	7.4	.000
	Isuzu (Japan)	-59.601*	7.4	.000
	China, Higer Bus Company	-71.006*	7.4	.000
	China, Huanghai	-12.816	0.71	.586
China, Huanghai	Toyota (Japan)	-53.694*	7.4	.000
	Isuzu (Japan)	-46.785*	7.4	.000
	China, Higer Bus Company	-58.190*	7.4	.000
	China, Yu-Tong	12.816	0.71	.586

*. The mean difference is significant at the 0.05 level.

4.2.3 Emission Differences by Vehicle Model Years

Null Hypothesis (H_o): There is no statistically significant difference in emission level between different Vehicle Model years.

Alternative Hypothesis (H_1): There is statistically significant difference in emission level between different vehicle Model Years.

Table 4.11 below shows that there was a statistically significant difference between different vehicle years. Mean difference and F-values were calculated for each P-Value. From the statistical test, there was a significant difference between the model year group of 1960-1975 and 1976-1990 (p-value =0.024<0.05), 2000-2005 (P-value = 0.000<0.05), 2006-2010 (P-value = 0.000<0.05), 2011-2018(P-value = 0.000<0.05). This may be related with vehicle ages. As vehicle technology increased the reduction in emission increases and this can be referred with an installation of vehicle emission Catalytic converters in the new model groups. Looking for model year groups of 1976-1990 and 2006-2010 (p-value =0.025<0.05), 2011-2018 (p-value =0.000<0.05) shows again the significant difference in mean. In case of model year 1991-1999 and 2006-2010 (p-value =0.006<0.05), 2011-2018 (P-value = 0.000<0.05). But, in the case of model year groups of 1960-1975, 1976-1990 and 2000-2005 there was not statistically significant difference in mean of the groups. Mean that, their emission levels had differed from each other with small smoke opacity value.

Again looking at the last rows of the first column there was a statically significant difference in the mean of all the older model of (2011-2018) model year. Between Model year group of 2011-2018 and 1960-1975 (p-value =0.000<0.05), 1976-1990 (P-value = 0.000<0.05), 1991-1999 (P-value = 0.000<0.05), 2000-2005 (P-value = 0.000<0.05), 2006-2010(P-value = 0.000<0.05). This implies that vehicle age was highly impacted the emission level of vehicle in road transport. But, the impacts were not much for the model year of 2000-2005 and before, because the difference in mean of smoke opacity values was small. Almost most of the vehicles before 2000 model years were emit the same level that was difficult to differentiate the effects of model year between them. Therefore, the hypothesis said “There is no statistically significant difference in emission level between different Vehicle Model years” was rejected.

Table 4. 11 Differences in Smoke opacity of different vehicle Model year

Model year		Mean Difference	F-Value	P-Value
1960-1975	1976-1990	17.561*	2.62	.024
	1991-1999	15.586	2.075	.068
	2000-2005	26.391*	5.43	.000
	2006-2010	30.370*	6.42	.000
	2011-2018	78.451*	8.93	.000
1976-1990	1991-1999	-1.974	0.056	.998
	2000-2005	8.831	1.05	.389
	2006-2010	12.809*	2.60	.025
	2011-2018	60.891*	7.54	.000
1991-1999	2000-2005	10.805	1.52	.182
	2006-2010	14.783*	3.33	.006
	2011-2018	62.865*	7.14	.000
2000-2005	2006-2010	3.978	0.26	.937
	2011-2018	52.060*	6.42	.000
2006-2010	2011-2018	48.082*	6.42	.000

*. The mean difference is significant at the 0.05 level.

4.2.4 Emission Differences by Vehicle Model Types

Null Hypothesis (H_o): There is no statistically significant difference in emission level between different Vehicle Model names.

Alternative Hypothesis (H_1): There is statistically significant difference in emission level between different vehicle Model Names.

Referring to the table 4.12 below shows that, there was a statistically significant mean difference between different vehicle model names and F-values were calculated for each P-Value. According to the statistical test in the table below, there was a significant difference between Taxi vehicles and Minibus vehicles (p-value =0.000<0.05), New Anbessa Bus (P-value = 0.000<0.05), Sheger Bus (P-value = 0.000<0.05), Old Anbessa Bus (P-value = 0.000<0.05) and Isuzu NPR Bus (P-value = 0.000<0.05). Specially, the mean difference between Taxi minibus, New Anbessa Bus, Sheger bus and old Anbessa bus were high, mean that Taxi Vehicles were highly emitted than the following transport mode and relatively the same emission level with Higer Bus. In the case of Commercial Minibus there was a statistically significant difference in opacity value between New Anbessa Bus (p-value =0.000<0.05), Sheger Bus (P-value = 0.000<0.05), Old Anbessa Bus (P-value = 0.000<0.05) and Higer Bus (P-value = 0.003<0.05). But, there was no significant mean difference between Isuzu NPR Bus (P-value = 0.789>0.05). Looking at New Anbess Bus, There was statistically significant difference in mean Higer Bus (P-value = 0.000<0.05), Isuzu NPR Bus (P-value = 0.000<0.05) and as discussed above with Minibus Taxi. But, there was no statistically significant difference between New Anbessa Bus, sheger bus, and Old Anbessa Bus as their emission level was closely related to each other. Mean that these three buses were emitting below the standards. Therefore, the hypothesis said "There is no statistically significant difference in emission level between different Vehicle Model Names" was rejected.

Table 4. 12 Differences in Emission between different vehicle model types

Vehicle Model types		Mean Difference	F-value	P-Value
Minibus (Code-1)	Minibus (Commercial)	28.084*	5.75	.000
	New Anbessa Bus	84.950*	5.75	.000
	Sheger Bus	75.602*	5.75	.000
	Higer Bus	9.937	1.10	.362
	Isuzu NPR Bus	21.343*	4.54	.000
	Old Anbessa Bus	68.128*	5.75	.000
Minibus (Code-3)	New Anbessa Bus	56.866*	5.75	.000
	Sheger Bus	47.518*	5.75	.000
	Higer Bus	-18.146*	3.40	.003
	Isuzu NPR Bus	-6.741	0.53	.789
	Old Anbessa Bus	40.044*	5.75	.000
New Anbessa Bus (Code-3)	Sheger Bus	-9.348	0.36	.904
	Higer Bus	-75.012*	5.75	.000
	Isuzu NPR Bus	-63.607*	5.75	.000
	Old Anbessa Bus	-16.822	0.99	.434
Sheger Bus (Code-3)	Higer Bus	-65.665*	5.75	.000
	Isuzu NPR Bus	-54.259*	5.75	.000
	Old Anbessa Bus	-7.475	0.36	.982
Higer Bus (Code-3)	Isuzu NPR Bus	11.405	0.91	.487
	Old Anbessa Bus	58.190*	5.75	.000
Isuzu NPR Bus (Code-3)	Old Anbessa Bus	46.785*	5.75	.000

4.2.5 Emission Differences by Vehicle Kilometer Travelled

Null Hypothesis (H_0): There is no statistically significant difference in emission level between different Vehicle kilometers travelled.

Alternative Hypothesis (H_1): There is statistically significant difference in emission level between different vehicle kilometers travelled.

Table 4.13 below shows statistical mean difference between different vehicle model names and the F-values were calculated for each P-Value. According to the statistical test result from SPSS in the table below, there was a significant mean difference between 1-100km travelled vehicles and 301-400km, 401-500km, 5001-600km, 6001-700km, 7001-800km and 8001-999km travelled groups as the (P-value=0.000<0.05). But, there were no statistically differences in mean between 101-200km and 201-300km travelled as (P-Value=0.985 and 0.074>0.05). This implies that the influence of kilometer travelled on vehicle emission level was minimum in this range, means almost they had emit almost equally and difficult to differentiate emitter vehicle based on kilometer travel in this range.

When the mean of 101-200km travelled vehicle compared with 301-400km, 4001-500km, 5001-600km, 6001-700km, 7001-800km and 8001-999km travelled groups as the (P-value=0.000<0.05) there was a statistically significant difference in means of vehicle smoke opacity. In case of comparing the mean difference between 201-300km and 401-500km, 501-600km, 601-700km, 801-900km, and 901-999km travelled, it was found that there was a statically difference in mean of the groups. Mean that there was an impact of vehicle kilometer travelled on smoke opacity level of vehicles. But, between 201-300km and 701-800km travelled it was found an insignificant difference as (P-Value = 0.718>0.05). In this kilometer range there was smoke opacity of Anbessa Bus which was lower. This was affects the mean difference of vehicle kilometer travelled with smoke opacity.

Regarding with 301-400km, there was a statistical significant difference in means of 4001-500km, 5001km-600km, and 601-700km travelled vehicles as the value of (P= 0.004, 0.030, 0.007<0.05). But, for the range of 701 to 999km the mean difference was found to be insignificant as the values of (P= >0.05). Beyond 701km to 999km the mean difference was minimum/ insignificant/, means that difficult to conclude the effect of kilometer travelled on vehicle emission level even if it had an effect. Therefore the hypothesis said "There is no statistically significant difference in emission level between different Vehicle kilometers travelled" was rejected. This result is in line with (Beydoun, 2004) as the number of miles that a vehicle is driven increases, the probability of it failing its emissions test also increases. As with model-year, this is probably attributable to the effects of engine and emissions equipment deterioration associated with increased vehicle use.

Table 4. 13 Differences in Emission between different vehicles by kilometer travelled

Kilometer Travelled in thousands		Mean Difference	F-Value	P-Value	Kilometer Travelled in thousands		Mean Difference	F-Value	P-Value
1-100	101-200	-10.227	0.256	.985	301-400	401-500	-21.504*	2.782	.004
	201-300	-29.837	1.769	.074		501-600	-20.215*	2.101	.030
	301-400	-45.767*	4.663	.000		601-700	-29.361*	2.598	.007
	401-500	-67.271*	4.663	.000		701-800	-3.108	0.042	1.000
	501-600	-65.982*	4.663	.000		801-900	-30.155	1.247	.267
	601-700	-75.127*	4.663	.000		901-999	-17.579	1.503	.147
	701-800	-48.875*	3.511	.000	401-500	501-600	1.289	0.042	1.000
	801-900	-75.922*	4.663	.000		601-700	-7.856	0.216	.992
	901-999	-63.346*	4.663	.000		701-800	18.396	0.851	.570
101-200	201-300	-19.610	0.982	.455		801-900	-8.651	0.126	.999
	301-400	-35.540*	4.325	.000		901-999	3.925	0.042	1.000
	401-500	-57.044*	4.663	.000	501-600	601-700	-9.145	0.262	.984
	501-600	-55.755*	4.663	.000		701-800	17.107	0.692	.716
	601-700	-64.900*	4.663	.000		801-900	-9.940	0.150	.998
	701-800	-38.648*	2.650	.006		901-999	2.636	0.042	1.000
	801-900	-65.695*	4.450	.000	601-700	701-800	26.253	1.226	.279
	901-999	-53.119*	4.663	.000		801-900	-.795	0.042	1.000
201-300	301-400	-15.930	0.902	.524		901-999	11.781	0.408	.930
	401-500	-37.434*	3.984	.000	701-800	801-900	-27.048	0.768	.646
	501-600	-36.145*	3.436	.001		901-999	-14.472	0.484	.885
	601-700	-45.290*	3.895	.000	801-900	901-999	12.576	0.216	.992
	701-800	-19.038	0.690	.718					
	801-900	-46.085*	2.242	.020					
	901-999	-33.509*	2.876	.003					

* The mean difference is significant at the 0.05 level.

4.2.6 Statistical Differences of HC, CO, CO_2 emission by different Vehicle Making country

Null Hypothesis (H_o): There is no statistically significant difference in emission level between different Vehicle making countries.

Alternative Hypothesis (H_1): There is statistically significant difference in emission level between different vehicle making countries.

According to the table 4.14 of F-statistic test below there was significant difference in emission level of Hydrocarbon, Carbon Monoxide, and Carbon Dioxide both at an Idle and snap acceleration of 2500rpm in comparing China making vehicles with Italy and Japan vehicles (P-Value=0.00<0.05). This mean that, China making vehicles was less emitting than both Italy and Japan since the difference in mean were negative in the first case. This was the reality that observed during the test. China vehicles tested under this were the new Meter Taxi vehicle of 2016 models with minimum emission level. In this case the null hypothesis said “There is no statically difference in emission level between different vehicles making country” was rejected as there was a difference. This finding accorded with (Beydoun, 2004); The strong connection between fuel efficiency and emissions was also found in all vehicle makes. When controlling for model-year and vehicle type, fuel efficiency was found to be significant for the whole vehicle fleet, cars and trucks, and all makes.

Table 4. 14 Differences in Emission between different vehicles by makes

Dependent Variable			Mean Difference	F-Value	P-Value	Dependent Variable			Mean Difference	F-Value	P-Value
HC@Idle	China	Italy	-2192.677*	8.309	.000	HC@2500 Rpm	China	Italy	-2104.878*	7.881	.000
		Japan	-1998.163*	8.508	.000			Japan	-1900.876*	7.940	.000
		Russia	-1425.850	2.224	.095			Russia	-1749.500*	3.424	.023
	Italy	Japan	194.514	0.187	.905		Italy	Japan	204.001	0.212	.887
		Russia	766.827	0.897	.448			Russia	355.378	0.201	.895
	Japan	Russia	572.313	0.598	.619		Japan	Russia	151.376	0.043	.988
CO@Idle	China	Italy	-4.459*	7.469	.000	CO@2500 Rpm	China	Italy	-4.034*	7.881	.000
		Japan	-4.564*	9.620	.000			Japan	-4.730*	10.77	.000
		Russia	-1.601	0.621	.604			Russia	-2.967	2.698	.054
	Italy	Japan	-.104	0.013	.998		Italy	Japan	-.696	0.669	.574
		Russia	2.858	2.668	.056			Russia	1.067	0.492	.689
	Japan	Russia	2.963*	3.385	.024		Japan	Russia	1.763	1.579	.204
CO_2@Idle	China	Italy	6.507*	10.77	.000	CO_2@2500 Rpm	China	Italy	4.784*	7.212	.000
		Japan	5.157*	8.403	.000			Japan	3.961*	6.199	.001
		Russia	3.396	1.880	.143			Russia	3.750*	2.797	.048
	Italy	Japan	-1.350	1.322	.276		Italy	Japan	-.823	0.607	.613
		Russia	-3.112	2.164	.102			Russia	-1.034	0.300	.825
	Japan	Russia	-1.762	0.837	.479		Japan	Russia	-.211	0.017	.997

*. The mean difference is significant at the 0.05 level.

4.2.7 Gasoline Fueled Vehicle Emission Differences by Vehicle Model Name

Null Hypothesis (H_0): There is no statistically significant difference in emission between different Vehicle model names.

Alternative Hypothesis (H_1): There is statistically significant difference between in emission between different model names.

According to the table 4.15 of F-statistic test below there was significant difference in emission as there was seen an increase in HC emission of (Fiat 124 Leda than Lifan meter taxi) and (Fiat Leda than Lifan meter Taxi). This shows there was higher fuel combustion in Lifan Meter taxi than Fiat124 and Fiat Leda. Fiat Leda and Fiat 124 Leda was used fuel excessively and spray out droplet of fuel during the inspection time. The same things were observed for HC under snap acceleration also, but there was a decrease in emission level than Idling condition.

Comparing in the case of carbon monoxide (CO), it was seen an increase of Fiat 124 emission of CO than Lifan Meter Taxi and Fiat Leda (P=Value<0.05). Again there was seen a decrease in emission level of Lifan and Fiat Leda as compared with Toyota 3k and Toyota DX (P=Value<0.05). Increase in CO implies there were less combustion of fuel in the engine and High emission rate of HC. In the case for snap acceleration the significant difference was found only for Lifan with other groups. As the reality of combustion process there was decrease in Co as the cars operate under acceleration but, in this case the decrease was only obtained for Lifan Meter Taxi (P=Value<0.05) between other groups there was not found significant difference.

Looking at CO_2 (Carbon dioxide) it was seen, that there was an increase in both at Idling and Snap acceleration for Lifan Meter Taxi. Mean that, good fuel combustion was processed in the case of Lifan Meter Taxi. The above discussion and the result of ANOVA test shows fail to accept there was no statically difference in mean of vehicle emission for the null hypothesis.

Table 4. 15 Differences in Emission between different vehicles by Types

Dependent Variable			Mean Difference	F-Value	P-Value	Dependent Variable			Mean Difference	F-Value	P-Value
HC@Idle Rpm	Fiat 124	Fiat Leda	843.833	1.324	.275	HC@2500 Rpm	Fiat 124	Fiat Leda	489.968	0.397	.755
		Lifan (Meter Taxi)	2261.500*	10.773	.000			Lifan (Meter Taxi)	2166.034*	10.773	.000
		Toyota 3K	-435.712	0.508	.678			Toyota 3K	-467.455	0.632	.598
		Toyota Dx	464.887	0.917	.438			Toyota Dx	484.010	1.06	.373
	Fiat Leda	Lifan (Meter Taxi)	1417.667*	3.089	.034		Fiat Leda	Lifan (Meter Taxi)	1676.067*	4.584	.006
		Toyota 3K	-1279.545*	3.167	.031			Toyota 3K	-957.423	1.785	.160
		Toyota Dx	-378.946	0.253	.859			Toyota Dx	-5.957	0.00037	.990
	Lifan (Meter Taxi)	Toyota 3K	-2697.212*	10.773	.000		Lifan (Meter Taxi)	Toyota 3K	-2633.489*	10.773	.000
		Toyota Dx	-1796.613*	9.325	.000			Toyota Dx	-1682.024*	8.508	.000
	Toyota 3K	Toyota Dx	900.599*	3.631	.018		Toyota 3K	Toyota Dx	951.466*	4.266	.009
CO@Idle Rpm	Fiat 124	Fiat Leda	2.738*	2.846	.045	CO@2500 Rpm	Fiat 124	Fiat Leda	1.172	0.58	.631
		Lifan (Meter Taxi)	4.599*	9.621	.000			Lifan (Meter Taxi)	4.128*	10.041	.000
		Toyota 3K	-.745	.254	.858			Toyota 3K	-.920	0.581	.630
		Toyota Dx	.168	.008	.999			Toyota Dx	-.647	0.396	.756
	Fiat Leda	Lifan (Meter Taxi)	1.861	0.917	.438		Fiat Leda	Lifan (Meter Taxi)	2.956*	3.388	.024
		Toyota 3K	-3.483*	4.585	.006			Toyota 3K	-2.091	2.075	.113
		Toyota Dx	-2.570*	3.017	.037			Toyota Dx	-1.819	1.926	.135
	Lifan (Meter Taxi)	Toyota 3K	-5.344*	10.773	.000		Lifan (Meter Taxi)	Toyota 3K	-5.047*	10.773	.000
		Toyota Dx	-4.432*	10.773	.000			Toyota Dx	-4.774*	10.733	.000
	Toyota 3K	Toyota Dx	.913	.604	.615		Toyota 3K	Toyota Dx	.273	0.042	.988
CO2@Idle Rpm	Fiat 124	Fiat Leda	-2.611	1.759	.165	CO2@2500 Rpm	Fiat 124	Fiat Leda	-1.814	1.086	.362
		Lifan (Meter Taxi)	-6.382*	10.773	.000			Lifan (Meter Taxi)	-5.060*	10.774	.000
		Toyota 3K	.337	.020	.996			Toyota 3K	.539	.106	.956
		Toyota Dx	-1.913	2.298	.087			Toyota Dx	-1.623	2.215	.096
	Fiat Leda	Lifan (Meter Taxi)	-3.771*	2.931	.041		Fiat Leda	Lifan (Meter Taxi)	-3.246*	2.926	.041
		Toyota 3K	2.948	2.223	.095			Toyota 3K	2.353	1.880	.143
		Toyota Dx	.698	0.096	.962			Toyota Dx	.191	0.038	.990
	Lifan (Meter Taxi)	Toyota 3K	6.718*	10.773	.000		Lifan (Meter Taxi)	Toyota 3K	5.599*	10.773	.000
		Toyota Dx	4.468*	7.723	.000			Toyota Dx	3.437*	6.103	.001
	Toyota 3K	Toyota Dx	-2.250*	3.041	.036		Toyota 3K	Toyota Dx	-2.162*	3.787	.015

*. The mean difference is significant at the 0.05 level.

4.2.8 Gasoline Fueled Vehicle Emission Differences by Vehicle Model Year

Null Hypothesis (Ho): There is no statistically significant difference in emission level between different Vehicle model years.

Alternative Hypothesis (H_1): There is statistically significant difference between in emission level between different model years.

Table 4.16 below shows there was found a statistically significant difference only between vehicles of model year (1891-1990) and older ranges with Model year 2016. Between other groups there was a statistically insignificant difference available. This shows that it was difficult to identify vehicle emission level of those with 1990 and older. Because, the emission level of vehicles older than model year of 1990 or vehicles with age of 29 or more could emit highly and had almost equal emission level. In this case, vehicle model year of 2016 was emitting too less than the others as the (P-Values<0.05) for both at Idling and snap acceleration the Null hypothesis that said "There is no statically significant difference in an emission level between different vehicle model years" was rejected.

Table 4. 16 Mean differences in vehicle emission of HC, CO, CO_2 by model year

Dependent Variable			Mean Difference	F-Value	P-Value	Dependent Variable			Mean Difference	F-Value	P-Value
HC@Idle Rpm	1960-1970	1971-1980	534.250	0.296	.880	HC@2500 Rpm	1960-1970	1971-1980	440.503	0.211	.931
		1981-1990	526.506	0.473	.756			1981-1990	430.435	0.332	.855
		1991-2000	1647.250	1.637	.177			1991-2000	1524.603	1.477	.221
		2016	2568.917*	6.806	.000			2016	2411.769*	6.29	.000
	1971-1980	1981-1990	-7.744	6.807	.999		1971-1980	1981-1990	-10.068	6.807	.999
		1991-2000	1113.000	0.814	.521			1991-2000	1084.100	0.811	.523
		2016	2034.667*	4.896	.002			2016	1971.267*	4.896	.002
	1981-1990	1991-2000	1120.744	1.1	.365		1981-1990	1991-2000	1094.168	1.101	.365
		2016	2042.411*	9.04	.000			2016	1981.334*	9.042	.000
	1991-2000	2016	921.667	0.590	.671		1991-2000	2016	887.167	0.574	.683
CO@Idle Rpm	1960-1970	1971-1980	.994	0.189	.943	CO@2500 Rpm	1960-1970	1971-1980	.740	0.147	.964
		1981-1990	1.073	0.364	.833			1981-1990	.081	0.003	.990
		1991-2000	-.073	0.022	.999			1991-2000	.313	0.003	.990
		2016	5.366*	5.343	.001			2016	4.669*	5.826	.001
	1971-1980	1981-1990	.079	.022	.999		1971-1980	1981-1990	-.658	0.235	.917
		1991-2000	-1.067	0.141	.966			1991-2000	-.427	0.032	.998
		2016	4.371*	4.203	.005			2016	3.930*	4.896	.002
	1981-1990	1991-2000	-1.146	0.217	.928		1981-1990	1991-2000	.231	0.003	.990
		2016	4.293*	7.69	.000			2016	4.588*	9.042	.000
	1991-2000	2016	5.438*	3.602	.011		1991-2000	2016	4.357*	3.249	.018
CO2@Idle Rpm	1960-1970	1971-1980	-.131	0.003	.990	CO2@2500 Rpm	1960-1970	1971-1980	.424	0.003	.990
		1981-1990	-1.477	0.481	.749			1981-1990	-.584	0.099	.982
		1991-2000	-1.545	0.193	.941			1991-2000	-1.033	0.113	.977
		2016	-6.512*	5.683	.001			2016	-4.661*	3.872	.008
	1971-1980	1981-1990	-1.346	0.489	.743		1971-1980	1981-1990	-1.008	.360	.836
		1991-2000	-1.414	0.173	.951			1991-2000	-1.456	0.239	.915
		2016	-6.381*	6.190	.000			2016	-5.084*	5.173	.001
	1981-1990	1991-2000	-.068	0.022	.999		1981-1990	1991-2000	-.448	0.002	.998
		2016	-5.035*	7.417	.000			2016	-4.077*	6.406	.000
	1991-2000	2016	-4.967	2.149	.086		1991-2000	2016	-3.628	1.518	.209

*. The mean difference is significant at the 0.05 level.

4.3 Discussion

This study on quantifying air pollution related to road transportation found that, road transportation vehicles were one of the major air pollutants in Addis Ababa City. From the total 358 tested diesel fueled vehicles, 243 (67.9%) vehicles failed to meet the standard cut points with the recorded smoke opacity values greater than or equal to 41%. Of these vehicles 45 (19%) registered 100% smoke opacity value. Only 115 (32.1%) vehicles passed the standard limit.

The test results show that Code-1(Minibus Taxi) was the dominant air pollutant with an average smoke opacity value of 86.36% and only 8.57% passed the standard limit. Most of Vehicles in this category were those with the oldest model year of 1995 and older. In the contrary, code-3 (commercial vehicles) were recorded with an average smoke opacity value of 43.31% which was less than that of Minibus Taxi by half but, greater than the standard cut points. This group includes different newest model of Minibus, Anbessa City Bus, Sheger Bus, those with lowest smoke opacity value. That is why the total average smoke opacity of Code-3 vehicles runs down toward the standard limit.

Regarding with Anbessa City bus, both model years before and after 1990 registered smoke opacity value less than the standard limit. Those with model year 1980-1990 recorded an average 21.56% and the newest models (2017) an average smoke opacity value of (4%). This result shows us each Code-1 Minibus Taxi spew out smoke to the environment 4 (four folds) of the oldest model of Anbessa Bus and around 22 (twenty two) folds of the newest Model year. In Average using one bus can travel 90 passengers for a single trip but, in case of using one taxi an average of 12 passengers can travelled. This means each bus can take off (90/12=8) Taxi Minibus from road and Minimize the air pollution by (4x8) =32 times emission level of Taxis. Similarly, the newest model of Anbessa City Bus can travel 90 passengers for a single trip but, in case of using one minibus taxi an average of 12 passengers can travelled. This means each bus can take off (90/12=8) Taxi Minibus from road and Minimize the air pollution by (22x8) =176 times emission level of Taxis. In my knowledge, when it was compared with Higer and Isuzu NPR Bus, Anbessa City Bus was reduced emission level by 19 times Higer Bus and 4 times Isuzu NPR Bus. When we compared depending on passenger carrying capacity, in trip a single

Anbessa Bus can take off two two Higer or two Isuzu Bus from roads, Mean that a single Anbessa Bus can minimize 38 times an emission of Higer or 8 times emission of Isuzu NPR Bus for per trip.

Sheger Express Bus Was the second green transport next to anbessa bus. Comparing Sheger Bus with Higer and Isuzu NPR Bus shows that, in using Sheger Bus can reduce air pollution level 10.1 times Higer Bus and 3.2 times Isuzu NPR Bus per trip.

The Findings of this study shows that gasoline code-1(Leda Taxi) gasoline vehicles were polluting the environment as similar with code-1(Minibus) taxi. Especially the oldest model of Leda Taxi named Fiat 124 Leda as of the test result showed emit about 2641.25ppm Hydrocarbon (HC) at idle condition and 2456.10ppm at free acceleration of 2500rpm followed by Toyota 3K. Those vehicles were highest in Carbon monoxide emission and lowest in carbon dioxide emission. But, the newest model of meter Taxi and Toyota DX emit under the guidelines. This implied that model year had an impact on vehicle emission level.

As visual observation during the test handled, most of the Leda Taxi was spray out unburned gasoline. This was not only affecting human healthy but also degraded the economy of the country. Because, almost imported gasoline would sprayed without perform combustion processes in engine. This implies the use of fuel gallon per kilometer would be increase.

Different literatures found out that the chemical components of the smoke or soot have been linked to acute short-term symptoms such as headache, dizziness, light-headedness, nausea, coughing, difficult or labored breathing, tightness of chest, and irritation of the eyes, nose and throat (Onursal and Gautam, 1997). Additionally, (Ogur and Kariuki, 2015) found in his study eye irritations, throw-ups, and odor are the immediate effects of the exhaust gas pollutants on humans from vehicles. They stated that high number peoples seem to be ailing from Asthma, Cancer and other exhaust gas related diseases.

Furthermore, air pollution causes eye irritation, affects the respiratory system (cough, bronchitis, etc), kidneys, nervous and immune system, cardiovascular, reproductive and developmental systems, leading to neurological dysfunction, heart disease and high blood pressure, birth defects, cancer and sometimes death (Choudhary and Garg, 2015).

If any research will be conducted regarding with the health effects of vehicular air pollution in Addis Ababa city based on the data of peoples admitted in hospital regarding with the illness stated above from the literatures many of them may be due to vehicular air pollution as the emission level from it were too much above the worldwide standard guidelines.

Lastly, the study covered factors that can aggravate smoke opacity level such as vehicle age, Kilometer driven, and vehicle model types. From these, vehicle age mostly a role player for all factors. Of course, Anbessa Bus was less affected by age and taken as the best Transport System the city have expand more widely for the city residents.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

To summarize the results of the study:-

- The data collection and analysis of emissions was done on Minibus taxi, Commercial minibuses, and different Buses which amount to 51.7% of the vehicle population with an average age of 23 years.
- This study reveals that from 358 sampled diesels fueled vehicles, 243 (67.9%) vehicles failed (recorded smoke opacity greater than or equal to 41%) and 115 (32.1%) vehicles passed (U.S.A EPA, November 1998) standard limit.
- The results of this study show that taxi vehicles both diesel and gasoline are the dominant air pollutant in the city.
- Minibus tax registered 86.36% and 6.47m^{-1} average smoke opacity density which is above the USA EPA Standard Guidelines and only 8.57% passed the standard limit. Most of Vehicles in this category were those with the oldest model year of 1999 and before with an average age of 33 years. This is the reason to fail the standard cut point.
- Commercial vehicles were recorded with an average smoke opacity value of 43.31% which was less than that of Taxi vehicles by half but, greater than the standard cut points.
- The findings of the study revealed that as production year increase 1960 to 2018 vehicle smoke opacity and density decreased. This implies that increasing number and percentage of passed vehicles as the production year increase implies the higher impact of vehicle age on emission level.
- It was found that Higer Bus only one model year (2007) had high average smoke opacity value which was not expected from Public Bus. The average smoke opacity of it was 1.1 times than that of the same model year ranges (2000-2009) commercial Minibus.
- There was an increasing on smoke opacity/emission level as the number of vehicle mileage increasing.

- Using old and new Anbessa bus can minimize the air pollution 32 and 176 times as much as emission of minibus Taxis per passenger. Also, it can reduce 19 and 4 times the emission level of Higer and Kikit Bus respectively in Addis. Therefore, Anbessa city bus and Sheger bus are considered as environmentally-friendly transport alternative in Addis Ababa city.
- Many of gasoline user vehicles under test were recorded the highest values between 2000-2738.33ppm HC at idle and free acceleration of 2500rpm which was 4 times BAR-90 standards.
- The same is true both for CO and CO_2 emissions level. The Findings of this study shows that oldest model of Leda Taxi gasoline vehicles was polluting the environment to Minibus taxi.
- Those vehicles were emitting higher when they are operating under idle condition both for CO and HC.
- Generally, Most of vehicles serving in Addis Ababa are polluting the environment highly. This is mainly due to their old model year, high in kilometer travelled, vehicle type and poor maintenance. This indicates that vehicles transport had the lion share of air pollution in Addis Ababa city.

RECOMMENDATIONS

Depending on the results of this study, the researcher recommended the following points;

The study distinguished factors which increase on road vehicular emission in Addis Ababa city. Therefore the government should work on the mitigation to vehicle emission problem. Several mitigation methods can be recommended below for implementation at policy level to ensure a sustainable transport sector.

- Transport Authority should set up standard guidelines for on road vehicle emission. This is found as a problem in our country even to examine the differences of research findings with standard guidelines. After the set-up of the standard guidelines following up every vehicles moving on the road that all vehicles must comply with standards. This will assist in the implementation of the set vehicle emission standards through an inspection and monitoring.

- It is highly recommended that action should be taken by the government especially on the importation of vehicles. The government should restrict the age of imported vehicles. Not only age restriction of second hand, the newer vehicles should be undergo inspection to check technical problem of manufacturer such as emission control technology and should be comply with the established standards.
- Installation of vehicle emission inventory on some places of road side.
- Government should provide maximum support and attention to green transport, including support such as cycling, LRT, electric buses and bus rapid transit. Introduction of buses that would carry more passengers at a time compared to the minibuses again reduces congestion and remove vehicle emission coming from idling. This can be lowering the number of minibus taxi on the road and increased reliance on public transportation
- Planting of trees along the road side is one that will reduce the emission by photosynthesizing.
- Introduction of fast and easily controllable taxi such as meter taxis in order to integrate with Buses and Train to push out the old cars and taxis outside of the city

LIMITATIONS OF THE STUDY

The limitation for this research was the problem unavailable vehicle characteristic data. Since minibus taxi and some other vehicles were very old, their odometer reading was not working to get the number of vehicle kilometer driven. Similarly, it was too difficult to know their model years. In case of this problem, such data was collected by questionnaire from the driver. This may not be showing the true characteristics of vehicles. The researcher tried to collect data from custom and revenue authority and transport authority but, there is no recorded data there. This is one of our country problems. Research data is collected by electronic machine which is available only at Addis Ababa city Environmental Authority. It is only one brand and single in number. Some vehicles emit at higher levels and close a hose. Sometimes the data quality may be disturbed.

FUTURE WORK

This work is very expensive and needs hard work for data collection. However, it has attempted to fill in some of the gaps as concerns vehicle emission studies in Addis Ababa city. The biggest achievement has been the characterization and quantification of both commercial and taxi vehicles emissions in Addis Ababa city. However, there are many areas that were not addressed and they are discussed below.

- The analysis did not examine the effect of road geometry on real world vehicle emission and implementing mitigation methods. This would relate vehicle emission with vehicle characteristics, road geometry, and vehicle speed and air condition. It provides good information for the road designer to set the road alignment early that complies with safe vehicle pollution. To work for this paper, the instrument for collecting data is not available for a time being. It is applied mostly in western country such as USA.
- Motor vehicle emission simulator (MOVES) –A state of the science emission modeling system that estimates emission for mobile sources at national, county and project level for criteria air pollutants, greenhouse gas and air toxic. It needs some calibration and best for estimation on road vehicle emission. Someone can advance his or her knowledge on this.

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APPENDICES

Appendix-A Smoke opacity and density of minibus taxi

No	Vehicle Make	Model Name	Manufactured Y	Vehicle Age	Kilometer Travelled	Remark	Opacity Value	Calculated Transmittance	Calculated Smoke Density
1	Toyota (Japan)	Minibus Taxi	1986	33		Odometer Not Working	44%	0.56	1.35
2	Toyota (Japan)	Minibus Taxi	1986	33		Odometer Not Working	49.32%	0.51	1.58
3	Toyota (Japan)	Minibus Taxi	1988	31		Odometer Not Working	45.50%	0.55	1.41
4	Toyota (Japan)	Minibus Taxi	1989	30		Odometer Not Working	49%	0.51	1.58
5	Toyota (Japan)	Minibus Taxi	1990	29		Odometer Not Working	48%	0.52	1.52
6	Toyota (Japan)	Minibus Taxi	1990	29	807,485.00		42%	0.58	1.27
7	Toyota (Japan)	Minibus Taxi	1992	27	751,797.00		83.50%	0.17	4.19
8	Toyota (Japan)	Minibus Taxi	1993	26	723,952.00		96.20%	0.04	7.61
9	Toyota (Japan)	Minibus Taxi	1998	21	584,731.00		74.40%	0.26	3.17
10	Toyota (Japan)	Minibus Taxi	1960	59		Odometer Not Working	100.00%	0.00	10.00
11	Toyota (Japan)	Minibus Taxi	1960	59		Odometer Not Working	99.60%	0.00	12.84
12	Toyota (Japan)	Minibus Taxi	1960	59		Odometer Not Working	100.00%	0.00	10.00
13	Toyota (Japan)	Minibus Taxi	1960	59		Odometer Not Working	100.00%	0.00	10.00
14	Toyota (Japan)	Minibus Taxi	1960	59		Odometer Not Working	100.00%	0.00	10.00
15	Toyota (Japan)	Minibus Taxi	1960	59		Odometer Not Working	100.00%	0.00	10.00
16	Toyota (Japan)	Minibus Taxi	1960	59		Odometer Not Working	100.00%	0.00	10.00
17	Toyota (Japan)	Minibus Taxi	1962	57	999,635.00		100.00%	0.00	10.00
18	Toyota (Japan)	Minibus Taxi	1963	56		Odometer Not Working	91.40%	0.09	5.71
19	Toyota (Japan)	Minibus Taxi	1963	56		Odometer Not Working	89.00%	0.11	5.13
20	Toyota (Japan)	Minibus Taxi	1963	56	954,538.00		100.00%	0.00	10.00
21	Toyota (Japan)	Minibus Taxi	1964	55		Odometer Not Working	100.00%	0.00	10.00
22	Toyota (Japan)	Minibus Taxi	1964	55		Odometer Not Working	63.00%	0.37	2.31
23	Toyota (Japan)	Minibus Taxi	1964	55	946,321.00		97%	0.03	7.88
24	Toyota (Japan)	Minibus Taxi	1965	54		Odometer Not Working	99.60%	0.00	12.84
25	Toyota (Japan)	Minibus Taxi	1965	54	936,410.00		100%	0.00	10.00
26	Toyota (Japan)	Minibus Taxi	1966	53		Odometer Not Working	96.22%	0.04	7.62
27	Toyota (Japan)	Minibus Taxi	1967	52		Odometer Not Working	85.90%	0.14	4.56
28	Toyota (Japan)	Minibus Taxi	1968	51	923,006.00		99.00%	0.01	10.71
29	Toyota (Japan)	Minibus Taxi	1969	50		Odometer Not Working	99.20%	0.01	11.23
30	Toyota (Japan)	Minibus Taxi	1969	50		Odometer Not Working	85%	0.15	4.35
31	Toyota (Japan)	Minibus Taxi	1969	50		Odometer Not Working	95.50%	0.05	7.21
32	Toyota (Japan)	Minibus Taxi	1970	49		Odometer Not Working	90%	0.10	5.41
33	Toyota (Japan)	Minibus Taxi	1970	49		Odometer Not Working	98%	0.02	9.10
34	Toyota (Japan)	Minibus Taxi	1971	48		Odometer Not Working	69.75%	0.30	2.78
35	Toyota (Japan)	Minibus Taxi	1972	47	921,200.00		100%	0.00	10.00
36	Toyota (Japan)	Minibus Taxi	1972	47		Odometer Not Working	85%	0.15	4.41
37	Toyota (Japan)	Minibus Taxi	1972	47		Odometer Not Working	100.00%	0.00	10.00
38	Toyota (Japan)	Minibus Taxi	1974	45	919,900.00		94%	0.06	6.70
39	Toyota (Japan)	Minibus Taxi	1977	42		Odometer Not Working	99%	0.01	10.10
40	Toyota (Japan)	Minibus Taxi	1977	42		Odometer Not Working	100%	0.00	10.00
41	Toyota (Japan)	Minibus Taxi	1978	41	900,103.00		98.20%	0.02	9.34
42	Toyota (Japan)	Minibus Taxi	1981	38		Odometer Not Working	79.51%	0.20	3.69
43	Toyota (Japan)	Minibus Taxi	1982	37		Odometer Not Working	98%	0.02	9.52
44	Toyota (Japan)	Minibus Taxi	1983	36		Odometer Not Working	89.24%	0.11	5.18
45	Toyota (Japan)	Minibus Taxi	1983	36		Odometer Not Working	64.28%	0.36	2.39
46	Toyota (Japan)	Minibus Taxi	1983	36		Odometer Not Working	97%	0.03	8.15
47	Toyota (Japan)	Minibus Taxi	1984	35		Odometer Not Working	46.19%	0.54	1.44
48	Toyota (Japan)	Minibus Taxi	1984	35		Odometer Not Working	100.00%	0.00	10.00
49	Toyota (Japan)	Minibus Taxi	1985	34		Odometer Not Working	69.42%	0.31	2.76
50	Toyota (Japan)	Minibus Taxi	1985	34		Odometer Not Working	100%	0.00	10.00
51	Toyota (Japan)	Minibus Taxi	1985	34	916,730.00		99.00%	0.01	10.71
52	Toyota (Japan)	Minibus Taxi	1986	33		Odometer Not Working	85%	0.15	4.37
53	Toyota (Japan)	Minibus Taxi	1986	33		Odometer Not Working	86%	0.14	4.57
54	Toyota (Japan)	Minibus Taxi	1986	33		Odometer Not Working	100%	0.00	10.00
55	Toyota (Japan)	Minibus Taxi	1986	33		Odometer Not Working	100.00%	0.00	10.00
56	Toyota (Japan)	Minibus Taxi	1986	33	913,000.00		100%	0.00	10.00
57	Toyota (Japan)	Minibus Taxi	1986	33	900,580.00		89%	0.11	5.22
58	Toyota (Japan)	Minibus Taxi	1987	32		Odometer Not Working	98.30%	0.02	9.48
59	Toyota (Japan)	Minibus Taxi	1987	32		Odometer Not Working	96.33%	0.04	7.69
60	Toyota (Japan)	Minibus Taxi	1987	32		Odometer Not Working	98.90%	0.01	10.49
61	Toyota (Japan)	Minibus Taxi	1987	32		Odometer Not Working	100.00%	0.00	10.00

62	Toyota (Japan)	Minibus Taxi	1987	32		Odometer Not Working	97%	0.03	8.08
63	Toyota (Japan)	Minibus Taxi	1988	31		Odometer Not Working	88%	0.12	5.00
64	Toyota (Japan)	Minibus Taxi	1988	31		Odometer Not Working	100%	0.00	10.00
65	Toyota (Japan)	Minibus Taxi	1988	31		Odometer Not Working	69%	0.32	2.69
66	Toyota (Japan)	Minibus Taxi	1989	30		Odometer Not Working	99%	0.01	11.54
67	Toyota (Japan)	Minibus Taxi	1989	30		Odometer Not Working	62%	0.38	2.27
68	Toyota (Japan)	Minibus Taxi	1989	30	885,350.00		100.00%	0.00	10.00
69	Toyota (Japan)	Minibus Taxi	1989	30	857,020.00		100.00%	0.00	10.00
70	Toyota (Japan)	Minibus Taxi	1990	29	848,486.00		75%	0.26	3.18
71	Toyota (Japan)	Minibus Taxi	1990	29		Odometer Not Working	89%	0.11	5.13
72	Toyota (Japan)	Minibus Taxi	1990	29	837,605.00		96.70%	0.03	7.93
73	Toyota (Japan)	Minibus Taxi	1990	29	846,370.00		100.00%	0.00	10.00
74	Toyota (Japan)	Minibus Taxi	1991	28		Odometer Not Working	97%	0.03	8.15
75	Toyota (Japan)	Minibus Taxi	1992	27	799,563.00		94.80%	0.05	6.88
76	Toyota (Japan)	Minibus Taxi	1992	27	750,478.00		74.70%	0.25	3.20
77	Toyota (Japan)	Minibus Taxi	1992	27	780,490.00		90.30%	0.10	5.43
78	Toyota (Japan)	Minibus Taxi	1992	27		Odometer Not Working	100.00%	0.00	10.00
79	Toyota (Japan)	Minibus Taxi	1993	26	723,953.00		100%	0.00	10.00
80	Toyota (Japan)	Minibus Taxi	1993	26	739,650.00		94.00%	0.06	6.54
81	Toyota (Japan)	Minibus Taxi	1993	26		Odometer Not Working	76.90%	0.23	3.41
82	Toyota (Japan)	Minibus Taxi	1994	25	696,108.00		90.80%	0.09	5.55
83	Toyota (Japan)	Minibus Taxi	1994	25	749,038.00		100%	0.00	10.00
84	Toyota (Japan)	Minibus Taxi	1994	25		Odometer Not Working	84.90%	0.15	4.40
85	Toyota (Japan)	Minibus Taxi	1995	24	688,264.00		95.20%	0.05	7.06
86	Toyota (Japan)	Minibus Taxi	1995	24		Odometer Not Working	100%	0.00	10.00
87	Toyota (Japan)	Minibus Taxi	1995	24	676,900.00		87.90%	0.12	4.91
88	Toyota (Japan)	Minibus Taxi	1995	24	699,908.00		100.00%	0.00	10.00
89	Toyota (Japan)	Minibus Taxi	1996	23	647,940.00		73.90%	0.26	3.12
90	Toyota (Japan)	Minibus Taxi	1996	23	639,820.00		86%	0.14	4.57
91	Toyota (Japan)	Minibus Taxi	1996	23		Odometer Not Working	65.30%	0.35	2.46
92	Toyota (Japan)	Minibus Taxi	1996	23	659,740.00		100.00%	0.00	10.00
93	Toyota (Japan)	Minibus Taxi	1996	23	614,780.00		48.65%	0.51	1.55
94	Toyota (Japan)	Minibus Taxi	1997	22	612,576.00		88.54%	0.11	5.04
95	Toyota (Japan)	Minibus Taxi	1997	22	637,450.00		94.70%	0.05	6.83
96	Toyota (Japan)	Minibus Taxi	1997	22	638,693.00		97.60%	0.02	8.67
97	Toyota (Japan)	Minibus Taxi	1997	22	639,890.00		99.10%	0.01	10.95
98	Toyota (Japan)	Minibus Taxi	1997	22	699,940.00		100%	0.00	10.00
99	Toyota (Japan)	Minibus Taxi	1997	22		Odometer Not Working	70.20%	0.30	2.82
100	Toyota (Japan)	Minibus Taxi	1997	22		Odometer Not Working	100%	0.00	10.00
101	Toyota (Japan)	Minibus Taxi	1997	22	612,590.00		84.13%	0.16	4.28
102	Toyota (Japan)	Minibus Taxi	1997	22	666,790.00		97%	0.03	8.15
103	Toyota (Japan)	Minibus Taxi	1998	21	598,050.00		95.80%	0.04	7.37
104	Toyota (Japan)	Minibus Taxi	1998	21	599,067.00		100%	0.00	10.00
105	Toyota (Japan)	Minibus Taxi	1998	21	549,030.00		76.99%	0.23	3.42
106	Toyota (Japan)	Minibus Taxi	1998	21	537,890.00		94.00%	0.06	6.54
107	Toyota (Japan)	Minibus Taxi	1998	21	599,680.00		100%	0.00	10.00
108	Toyota (Japan)	Minibus Taxi	1998	21	535,000.00		93%	0.08	6.02
109	Toyota (Japan)	Minibus Taxi	1998	21		Odometer Not Working	81.6%	0.18	3.94
110	Toyota (Japan)	Minibus Taxi	1998	21	500,540.00		45.61%	0.54	1.42
111	Toyota (Japan)	Minibus Taxi	1998	21	583,090.00		96.20%	0.04	7.61
112	Toyota (Japan)	Minibus Taxi	1998	21	599,012.00		100%	0.00	10.00
113	Toyota (Japan)	Minibus Taxi	1999	20	556,887.00		43.80%	0.56	1.34
114	Toyota (Japan)	Minibus Taxi	1999	20	579,040.00		100%	0.00	10.00
115	Toyota (Japan)	Minibus Taxi	1999	20	569,045.00		91.30%	0.09	5.68
116	Toyota (Japan)	Minibus Taxi	1999	20	534,000.00		71.50%	0.29	2.92
117	Toyota (Japan)	Minibus Taxi	1999	20	548,930.00		94.40%	0.06	6.70
118	Toyota (Japan)	Minibus Taxi	1999	20		Odometer Not Working	46.60%	0.53	1.46
119	Toyota (Japan)	Minibus Taxi	1999	20	564,039.00		89%	0.11	5.20
120	Toyota (Japan)	Minibus Taxi	1999	20		Odometer Not Working	91.2%	0.09	5.65
121	Toyota (Japan)	Minibus Taxi	1999	20	585,000.00		96.10%	0.04	7.54
122	Toyota (Japan)	Minibus Taxi	1999	20	568,910.00		95.80%	0.04	7.37
Average Age of Minibus Taxi				**33**					

Appendix-B Smoke opacity and density of Commercial Minibus

	Vehicle Make	Model Name	Manufactured Year	Vehicle Age	Kilometer Travelled	Remark	Opacity Value	Calculated Smoke Density
1	Toyota (Japan)	Commercial Minibus	2001	18	501,198.00		38%	1.12
2	Toyota (Japan)	Commercial Minibus	2000	19	529,042.00		74.10%	3.14
3	Toyota (Japan)	Commercial Minibus	2000	19	587,403.00		82.30%	4.03
4	Toyota (Japan)	Commercial Minibus	2000	19	537,480.00		76.80%	3.40
5	Toyota (Japan)	Commercial Minibus	2000	19	597,200.00		99.40%	11.90
6	Toyota (Japan)	Commercial Minibus	2000	19		Odometer Not Working	53.00%	1.76
7	Toyota (Japan)	Commercial Minibus	2000	19		Odometer Not Working	42.00%	1.27
8	Toyota (Japan)	Commercial Minibus	2000	19	586,503.00		84.60%	4.35
9	Toyota (Japan)	Commercial Minibus	2000	19	573,820.00		73.60%	3.10
10	Toyota (Japan)	Commercial Minibus	2000	19		Odometer Not Working	93.60%	6.39
11	Toyota (Japan)	Commercial Minibus	2000	19	592,451.00		90%	5.35
12	Toyota (Japan)	Commercial Minibus	2000	19	599,270.00		100.00%	10.00
13	Toyota (Japan)	Commercial Minibus	2001	18	563,200.00		97.66%	8.73
14	Toyota (Japan)	Commercial Minibus	2001	18	543,800.00		50.50%	1.64
15	Toyota (Japan)	Commercial Minibus	2001	18	571,400.00		97.20%	8.32
16	Toyota (Japan)	Commercial Minibus	2001	18	523,710.00		62.30%	2.27
17	Toyota (Japan)	Commercial Minibus	2002	17	473,354.00		35.3%	1.01
18	Toyota (Japan)	Commercial Minibus	2002	17		Odometer Not Working	29.00%	0.80
19	Toyota (Japan)	Commercial Minibus	2002	17	483,354.00		94%	6.58
20	Toyota (Japan)	Commercial Minibus	2002	17	473,490.00		84%	4.26
21	Toyota (Japan)	Commercial Minibus	2002	17	484,500.00		93.10%	6.22
22	Toyota (Japan)	Commercial Minibus	2002	17	482,040.00		86.60%	4.67
23	Toyota (Japan)	Commercial Minibus	2002	17	435,000.00		51.4%	1.68
24	Toyota (Japan)	Commercial Minibus	2002	17	499,612.00		100%	10.00
25	Toyota (Japan)	Commercial Minibus	2003	16		Odometer Not Working	33.00%	0.93
26	Toyota (Japan)	Commercial Minibus	2003	16		Odometer Not Working	26.6%	0.72
27	Toyota (Japan)	Commercial Minibus	2003	16	445,509.00		46.1%	1.44
28	Toyota (Japan)	Commercial Minibus	2003	16	461,008.00		63.80%	2.36
29	Toyota (Japan)	Commercial Minibus	2003	16	453,009.00		55.10%	1.86
30	Toyota (Japan)	Commercial Minibus	2004	15		Odometer Not Working	17.0%	0.43
31	Toyota (Japan)	Commercial Minibus	2004	15	417,665.00		38.2%	1.12
32	Toyota (Japan)	Commercial Minibus	2004	15		Odometer Not Working	22.45%	0.59
33	Toyota (Japan)	Commercial Minibus	2004	15	446,265.00		100%	10.00
34	Toyota (Japan)	Commercial Minibus	2004	15	424,790.00		72.50%	3.00
35	Toyota (Japan)	Commercial Minibus	2004	15	418,900.00		67%	2.58
36	Toyota (Japan)	Commercial Minibus	2004	15	460,665.00		91.00%	5.60
37	Toyota (Japan)	Commercial Minibus	2004	15	457,801.00		80.00%	3.74
38	Toyota (Japan)	Commercial Minibus	2004	15		Odometer Not Working	72.9%	3.04
39	Toyota (Japan)	Commercial Minibus	2004	15	459,706.00		61.8%	2.24
40	Toyota (Japan)	Commercial Minibus	2004	15	446,290.00		60.90%	2.18
41	Toyota (Japan)	Commercial Minibus	2004	15	417,845.00		54.80%	1.85
42	Toyota (Japan)	Commercial Minibus	2005	14		Odometer Not Working	19.9%	0.52
43	Toyota (Japan)	Commercial Minibus	2005	14		Odometer Not Working	16.8%	0.43
44	Toyota (Japan)	Commercial Minibus	2005	14		Odometer Not Working	16.8%	0.43
45	Toyota (Japan)	Commercial Minibus	2005	14	389,821.00		89.60%	5.26
46	Toyota (Japan)	Commercial Minibus	2005	14		Odometer Not Working	97.60%	8.67
47	Toyota (Japan)	Commercial Minibus	2005	14	396,410.00		90%	5.35
48	Toyota (Japan)	Commercial Minibus	2005	14	385,732.00		88.90%	5.11
49	Toyota (Japan)	Commercial Minibus	2005	14	400,540.00		90%	5.35
50	Toyota (Japan)	Commercial Minibus	2005	14	413,780.00		100%	10.00
51	Toyota (Japan)	Commercial Minibus	2005	14		Odometer Not Working	80.33%	3.78
52	Toyota (Japan)	Commercial Minibus	2005	14	397,200.00		74.90%	3.21
53	Toyota (Japan)	Commercial Minibus	2005	14	385,809.00		71.40%	2.91
54	Toyota (Japan)	Commercial Minibus	2005	14	394,300.00		89.7%	5.29
55	Toyota (Japan)	Commercial Minibus	2005	14		Odometer Not Working	70.5%	2.84
56	Toyota (Japan)	Commercial Minibus	2006	13	361,976.00		18%	0.46
57	Toyota (Japan)	Commercial Minibus	2006	13	389,400.00		28.80%	0.79
58	Toyota (Japan)	Commercial Minibus	2006	13	398,554.00		40.0%	1.19
59	Toyota (Japan)	Commercial Minibus	2006	13	375,902.00		33.70%	0.96
60	Toyota (Japan)	Commercial Minibus	2006	13	398,021.00		39%	1.16
61	Toyota (Japan)	Commercial Minibus	2006	13		Odometer Not Working	32.3%	0.91
62	Toyota (Japan)	Commercial Minibus	2006	13	371,976.00		100%	10.00
63	Isuzu (Japan)	Commercial Minibus	2006	13	365,930.00		47.00%	1.48
64	Toyota (Japan)	Commercial Minibus	2006	13	376,300.00		100.0%	10.00
65	Toyota (Japan)	Commercial Minibus	2006	13		Odometer Not Working	86.4%	4.64

66	Toyota (Japan)	Commercial Minibus	2006	13	379,999.00		100%	10.00
67	Toyota (Japan)	Commercial Minibus	2006	13	376,627.00		96.50%	7.80
68	Toyota (Japan)	Commercial Minibus	2006	13		Odometer Not Working	41.87%	1.26
69	Toyota (Japan)	Commercial Minibus	2006	13	364,800.00		53.40%	1.78
70	Toyota (Japan)	Commercial Minibus	2006	13	384,000.00		65.30%	2.46
71	Toyota (Japan)	Commercial Minibus	2006	13	398,700.00		94.9%	6.92
72	Toyota (Japan)	Commercial Minibus	2006	13	376,403.00		79.40%	3.67
73	Toyota (Japan)	Commercial Minibus	2006	13	384,190.00		89.7%	5.29
74	Toyota (Japan)	Commercial Minibus	2007	12	389,237.00		69.80%	2.78
75	Toyota (Japan)	Commercial Minibus	2007	12	404,900.00		95.1%	7.01
76	Toyota (Japan)	Commercial Minibus	2007	12	398,730.00		66.7%	2.56
77	Toyota (Japan)	Commercial Minibus	2007	12	342,700.00		76.00%	3.32
78	Toyota (Japan)	Commercial Minibus	2007	12	367,650.00		97%	8.15
79	Toyota (Japan)	Commercial Minibus	2007	12	359,800.00		96.00%	7.49
80	Toyota (Japan)	Commercial Minibus	2007	12	369,000.00		100%	10.00
81	Toyota (Japan)	Commercial Minibus	2007	12	357,200.00		77.5%	3.47
82	Toyota (Japan)	Commercial Minibus	2008	11	306,288.00		20.20%	0.52
83	Toyota (Japan)	Commercial Minibus	2008	11	327,650.00		34.56%	0.99
84	Toyota (Japan)	Commercial Minibus	2008	11	334,132.00		71.40%	2.91
85	Isuzu (Japan)	Commercial Minibus	2008	11	345,720.00		87%	4.78
86	Toyota (Japan)	Commercial Minibus	2008	11	335,370.00		96.8%	8.00
87	Toyota (Japan)	Commercial Minibus	2008	11	306,288.00		43.22%	1.32
88	Toyota (Japan)	Commercial Minibus	2008	11	314,200.00		49.30%	1.58
89	Toyota (Japan)	Commercial Minibus	2008	11	326,402.00		65.6%	2.48
90	Toyota (Japan)	Commercial Minibus	2008	11	338,400.00		66.30%	2.53
91	Toyota (Japan)	Commercial Minibus	2008	11	341,225.00		82.30%	4.03
92	Toyota (Japan)	Commercial Minibus	2008	11	309,945.00		50.12%	1.62
93	Toyota (Japan)	Commercial Minibus	2008	11	346,850.00		90.54%	5.48
94	Toyota (Japan)	Commercial Minibus	2008	11		Odometer Not Working	100.00%	10.00
95	Toyota (Japan)	Commercial Minibus	2009	10		Odometer Not Working	34.67%	0.99
96	Toyota (Japan)	Commercial Minibus	2009	10	288,443.00		65%	2.44
97	Toyota (Japan)	Commercial Minibus	2010	9		Odometer Not Working	23.6%	0.63
98	Isuzu (Japan)	Commercial Minibus	2010	9	250,599.00		19.10%	0.49
99	Toyota (Japan)	Commercial Minibus	2010	9	276,577.00		35.3%	1.01
100	Toyota (Japan)	Commercial Minibus	2010	9	264,890.00		27.60%	0.75
101	Toyota (Japan)	Commercial Minibus	2010	9	274,632.00		29.20%	0.80
102	Toyota (Japan)	Commercial Minibus	2010	9	251,743.00		43%	1.32
103	Toyota (Japan)	Commercial Minibus	2010	9	261,110.00		58.46%	2.04
104	Toyota (Japan)	Commercial Minibus	2010	9	245,770.00		43.11%	1.31
105	Toyota (Japan)	Commercial Minibus	2010	9		Odometer Not Working	45.76%	1.42
106	Toyota (Japan)	Commercial Minibus	2010	9	234,901.00		44%	1.34
107	Toyota (Japan)	Commercial Minibus	2011	8	222,755.00		12.60%	0.31
108	Toyota (Japan)	Commercial Minibus	2011	8	239,087.00		28.90%	0.79
109	Toyota (Japan)	Commercial Minibus	2011	8	245,483.00		34.50%	0.98
110	Toyota (Japan)	Commercial Minibus	2011	8	248,659.00		37.6%	1.10
111	Toyota (Japan)	Commercial Minibus	2011	8	223,755.00		51.3%	1.67
112	Toyota (Japan)	Commercial Minibus	2012	7	200,058.00		35%	1.00
113	Toyota (Japan)	Commercial Minibus	2012	7	198,910.00		25.10%	0.67
114	Toyota (Japan)	Commercial Minibus	2012	7		Odometer Not Working	30.23%	0.84
115	Toyota (Japan)	Commercial Minibus	2012	7	191,650.00		15.40%	0.39
116	Toyota (Japan)	Commercial Minibus	2012	7	210,340.00		38.10%	1.12
117	Toyota (Japan)	Commercial Minibus	2012	7		Odometer Not Working	12.5%	0.31
118	Toyota (Japan)	Commercial Minibus	2012	7	192,170.00		26.90%	0.73
119	Toyota (Japan)	Commercial Minibus	2012	7	193,000.00		49%	1.57
120	Toyota (Japan)	Commercial Minibus	2012	7	194,332.00		49.7%	1.60
121	Toyota (Japan)	Commercial Minibus	2012	7	195,500.00		54%	1.82
122	Toyota (Japan)	Commercial Minibus	2012	7	195,733.00		57.80%	2.01
123	Toyota (Japan)	Commercial Minibus	2013	6	176,066.00		24%	0.64
124	Toyota (Japan)	Commercial Minibus	2014	5	154,730.00		21.4%	0.56
125	Toyota (Japan)	Commercial Minibus	2014	5	152,900.00		17.1%	0.44
126	Toyota (Japan)	Commercial Minibus	2014	5	157,300.00		29.20%	0.80
127	Toyota (Japan)	Commercial Minibus	2014	5	139,128.00		29.20%	0.80
128	Toyota (Japan)	Commercial Minibus	2017	2	37,000.00		13.00%	0.32
129	Toyota (Japan)	Commercial Minibus	2017	2	57,274.00		13.00%	0.32
				13				

Appendix-C Smoke opacity and density of Anbessa and Sheger Bus

1	China, Huanghai	Old Anbessa Bus	1983	36	975,396.00		17.1%	0.44
2	China, Huanghai	Old Anbessa Bus	1983	36	997,560.00		29.28%	0.81
3	China, Huanghai	Old Anbessa Bus	1983	36	990,200.00		27.89%	0.76
4	China, Huanghai	Old Anbessa Bus	1983	36	977,270.00		15.10%	0.38
5	China, Huanghai	Old Anbessa Bus	1983	36	988,607.00		26.00%	0.70
6	China, Huanghai	Old Anbessa Bus	1983	36	979,450.00		23.26%	0.62
7	China, Huanghai	Old Anbessa Bus	1983	36	975,477.00		20.22%	0.53
8	China, Huanghai	Old Anbessa Bus	1984	35	964,551.00		13.65%	0.34
9	China, Huanghai	Old Anbessa Bus	1992	27	751,894.00		11.9%	0.29
10	China, Huanghai	Old Anbessa Bus	1992	27	777,910.00		14.6%	0.37
11	China, Huanghai	Old Anbessa Bus	1992	27	776,064.00		12.45%	0.31
12	China, Huanghai	Old Anbessa Bus	1992	27	780,388.00		15.38%	0.39
13	China, Yu-tong	New Anbessa Bus	2017	2	17,063.00		2.00%	0.05
14	China, Yu-tong	New Anbessa Bus	2017	2	21,110.00		4.60%	0.11
15	China, Yu-tong	New Anbessa Bus	2017	2	15,780.00		0.05%	0.00
16	China, Yu-tong	New Anbessa Bus	2017	2	38,920.00		2.10%	0.05
17	China, Yu-tong	New Anbessa Bus	2017	2	27,021.00		0.15%	0.00
18	China, Yu-tong	New Anbessa Bus	2017	2	55,984.00		2.30%	0.05
19	China, Yu-tong	New Anbessa Bus	2017	2	54,688.00		4.10%	0.10
20	China, Yu-tong	New Anbessa Bus	2017	2	37,249.00		1.52%	0.04
21	China, Yu-tong	New Anbessa Bus	2017	2	23,264.00		0.86%	0.02
22	China, Yu-tong	New Anbessa Bus	2017	2	10,230.00		0.85%	0.02
23	China, Yu-tong	New Anbessa Bus	2017	2	49,456.00		0.72%	0.02
24	China, Yu-tong	New Anbessa Bus	2017	2	55,310.00		3.12%	0.07
25	China, Yu-tong	New Anbessa Bus	2017	2	36,720.00		2.60%	0.06
26	China, Yu-tong	New Anbessa Bus	2017	2	65,868.00		1.45%	0.03
27	China, Yu-tong	New Anbessa Bus	2017	2	34,990.00		0.50%	0.01
28	China Yu-tong	New Anbessa Bus	2017	2	30,593.00		5.00%	0.12
29	China, Yu-tong	New Anbessa Bus	2017	2	14,073.00		3.40%	0.08
30	China, Yu-tong	New Anbessa Bus	2017	2	25,079.00		2.90%	0.07
31	China, Yu-tong	New Anbessa Bus	2017	2	29,054.00		1.86%	0.04
32	China Yu-tong	New Anbessa Bus	2017	2	38,476.00		1.53%	0.04
Average Age of Anbessa Bus				**14**				
1	China, Yu-tong	Sheger Bus	2008	11	318,022		11.1%	0.27
2	China, Yu-tong	Sheger Bus	2008	11	348,302		24.3%	0.65
3	China, Yu-tong	Sheger Bus	2008	11	325,480		12.6%	0.31
4	China, Yu-tong	Sheger Bus	2008	11	333,670		15.5%	0.39
5	China, Yu-tong	Sheger Bus	2008	11	309,390		8.2%	0.20
6	China, Yu-tong	Sheger Bus	2008	11	316,250		10.4%	0.26
7	China, Yu-tong	Sheger Bus	2016	3	90,064		34.3%	0.98
8	China, Yu-tong	Sheger Bus	2016	3	86,206		9.5%	0.23
9	China, Yu-tong	Sheger Bus	2016	3	84,679		5.5%	0.13
10	China, Yu-tong	Sheger Bus	2016	3	69,390		4.92%	0.12
11	China, Yu-tong	Sheger Bus	2016	3	45,200		7.40%	0.18
12	China, Yu-tong	Sheger Bus	2016	3	75,015		7.9%	0.19
13	China, Yu-tong	Sheger Bus	2016	3	76,064		9.3%	0.23
14	China, Yu-tong	Sheger Bus	2016	3	87,000		5.0%	0.12
15	China, Yu-tong	Sheger Bus	2016	3	91,800		5.5%	0.13
Average Age of Sheger Bus				**6**				

Appendix-D Smoke opacity and density of Higer and Isuzu NPR Bus

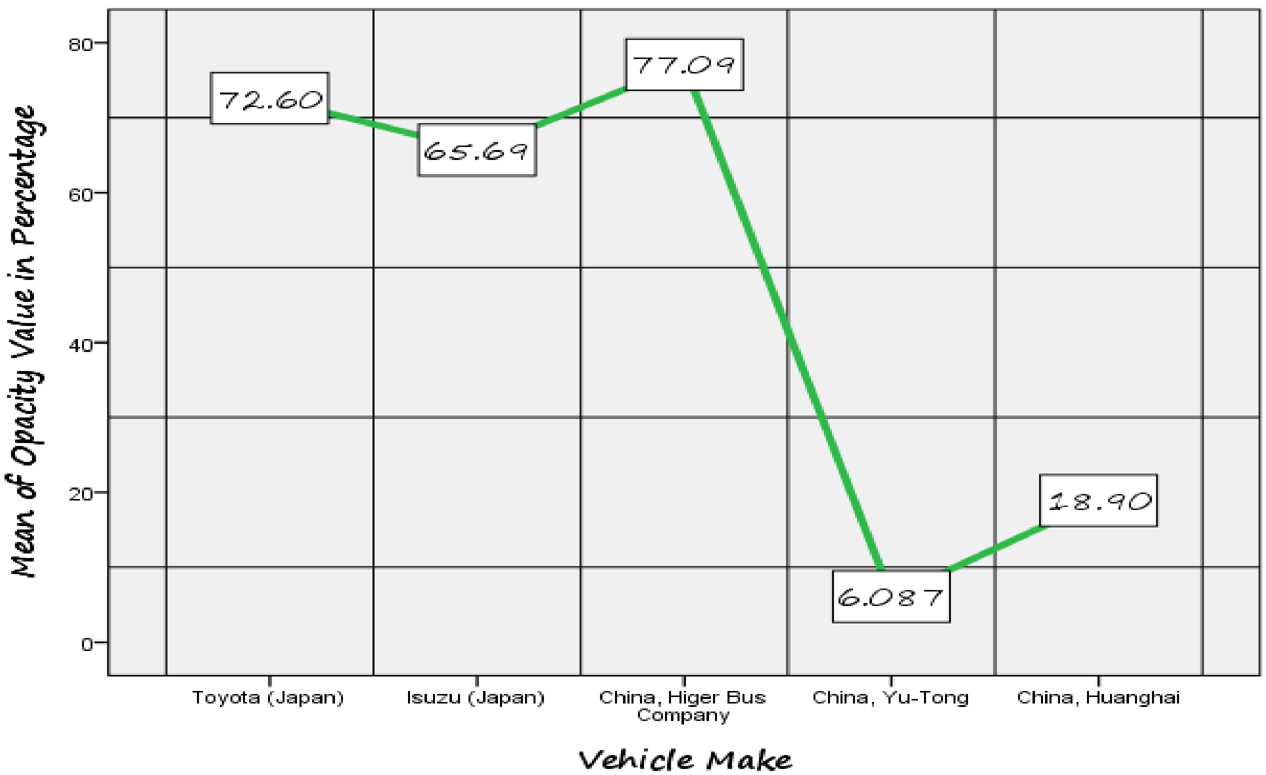
1	China, Higer Bus Company	Higer Bus	2007	12	408,356.00		87.50%	4.84
2	China, Higer Bus Company	Higer Bus	2007	12	427,093.00		91.6%	5.76
3	China, Higer Bus Company	Higer Bus	2007	12	416,742.00		87.0%	4.74
4	China, Higer Bus Company	Higer Bus	2007	12	454,030.00		79.0%	3.63
5	China, Higer Bus Company	Higer Bus	2007	12	489,022.00		100.0%	10.00
6	China, Higer Bus Company	Higer Bus	2007	12	377,053.00		41.0%	1.23
7	China, Higer Bus Company	Higer Bus	2007	12	492,044.00		100.0%	10.00
8	China, Higer Bus Company	Higer Bus	2007	12	488,642.00		100.0%	10.00
9	China, Higer Bus Company	Higer Bus	2007	12	398,025.00		44.0%	1.35
10	China, Higer Bus Company	Higer Bus	2007	12	457,079.94		67.72%	6.30
11	China, Higer Bus Company	Higer Bus	2007	12	460,695.78		65.0%	6.42
12	China, Higer Bus Company	Higer Bus	2007	12	464,311.61		62.4%	6.53
13	China, Higer Bus Company	Higer Bus	2007	12	467,927.44		59.7%	6.64
14	China, Higer Bus Company	Higer Bus	2007	12	471,543.28		57.0%	6.76
15	China, Higer Bus Company	Higer bus	2007	12	478,742.00		85.20%	4.44
16	China, Higer Bus Company	Higer bus	2007	12	483,657.00		98.10%	9.22
17	China, Higer Bus Company	Higer bus	2007	12	400,050.00		34.30%	0.98
18	China, Higer Bus Company	Higer bus	2007	12	480,060.00		100.00%	10.00
19	China, Higer Bus Company	Higer bus	2007	12	433,750.00		85.90%	4.56
20	China, Higer Bus Company	Higer bus	2007	12	460,635.00		95.00%	6.97
21	China, Higer Bus Company	Higer bus	2007	12	494,002.00		97.80%	8.88
22	China, Higer Bus Company	Higer bus	2007	12	499,000.00		100.00%	10.00
23	China, Higer Bus Company	Higer bus	2007	12	415,639.00		39.00%	1.15
24	China, Higer bus company	Higer Bus	2007	12	468,926.00		100.00%	10.00
25	China, Higer Bus Company	Higer Bus	2007	12	477,560.00		90.70%	5.52
26	China, Higer Bus Company	Higer Bus	2007	12	484,890.00		95.30%	7.11
27	China, Higer Bus Company	Higer Bus	2007	12	393,000.00		35.90%	1.03
28	China, Higer Bus Company	Higer Bus	2007	12	411,064.00		52.7%	1.74
29	China, Higer Bus Company	Higer Bus	2007	12	493,089.00		98.20%	9.34
30	China, Higer Bus Company	Higer Bus	2007	12	401,673.00		37.10%	1.08
Average Age of Higer Bus				**12**				
1	Isuzu (Japan)	Isuzu NPR Bus	2017	2	36,400.00		4.50%	0.11
2	Isuzu (Japan)	Isuzu NPR Bus	2017	2	49,000.00		12.30%	0.31
3	Isuzu (Japan)	Isuzu NPR Bus	2017	2	45,350.00		11.50%	0.28
4	Isuzu (Japan)	Isuzu NPR Bus	2014	5	133,936.00		22.80%	0.60
5	Isuzu (Japan)	Isuzu NPR Bus	2012	7	207,417.00		34.80%	0.99
6	Isuzu (Japan)	Isuzu NPR Bus	2010	9	274,732.00		74.00%	3.13
7	Isuzu (Japan)	Isuzu NPR Bus	2008	11	342,560.00		72.50%	3.00
8	Isuzu (Japan)	Isuzu NPR Bus	2000	19	539,200.00		84.8%	4.38
9	Isuzu (Japan)	Isuzu NPR Bus	1976	22	628,000.00		97.00%	8.15
10	Isuzu (Japan)	Isuzu NPR Bus	1982	37	946,580.00		42.52%	1.29
11	Isuzu (Japan)	Isuzu NPR Bus	1983	36	975,430.00		96%	7.69
12	Isuzu (Japan)	Isuzu NPR Bus	1978	38	980,435.00		99%	10.71
13	Isuzu (Japan)	Isuzu NPR Bus	1983	36	953,000.00		97%	8.15
14	Isuzu (Japan)	Isuzu NPR Bus	1975	36	972,000.00		100%	10.00
15	Isuzu (Japan)	Isuzu NPR Bus	1982	37	987,200.00		99%	10.71
16	Isuzu (Japan)	Isuzu NPR Bus	1984	35	965,000.00		78%	3.52
17	Isuzu (Japan)	Isuzu NPR Bus	1984	35	976,000.00		99.7%	13.29
18	Isuzu (Japan)	Isuzu NPR Bus	1975	36	994,500.00		100%	10.00
19	Isuzu (Japan)	Isuzu NPR Bus	1983	36	951,223.00		89.30%	5.20
20	Isuzu (Japan)	Isuzu NPR Bus	1981	38	977,680.00		42.00%	1.27
21	Isuzu (Japan)	Isuzu NPR Bus	1980	36		Odometer Not Working	100.00%	10.00
22	Isusu (Japan)	Isuzu NPR Bus	1988	31		Odometer Not Working	48.20%	1.53
23	Isuzu (Japan)	Isuzu NPR Bus	1993	26		Odometer Not Working	89.50%	5.24
24	Isuzu (Japan)	Isuzu NPR Bus	1993	26		Odometer Not Working	78.40%	3.56
25	Isuzu (Japan)	Isuzu NPR Bus	1994	25		Odometer Not Working	100.00%	10.00
26	Isuzu (Japan)	Isuzu NPR Bus	1994	25		Odometer Not Working	33.70%	0.96
27	Isuzu (Japan)	Isuzu NPR Bus	1998	21		Odometer Not Working	50%	1.61
28	Isuzu (Japan)	Isuzu NPR Bus	2017	2	33,090.00		1.8%	0.04
29	Isuzu (Japan)	Isuzu NPR Bus	2003	16		Odometer Not Working	42.80%	1.30
30	Isuzu (Japan)	Isuzu NPR Bus	2008	11		Odometer Not Working	69.5%	2.76
Average Age of Isuzu NPR Bus				**23**				
Total Average Of diesel Vehicles Under Test				**23.0**				

Appendix-E Gasoline vehicle emission

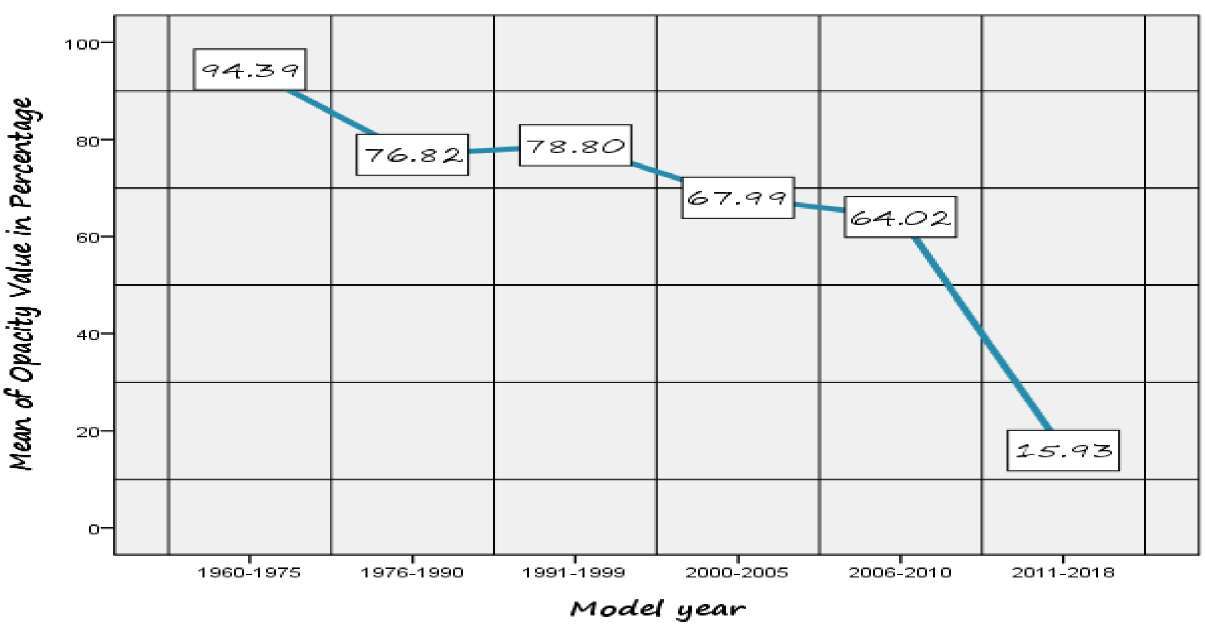
TEST RESULTS FROM 5-GAS ANALYZER LEDA AND METER TAXI EMISSIONS TEST

No. of Data	Vehicle Make	Vehicle Model	Model year	Vehicle Age (2019-Model year)	Fuel Type	HC (ppm) at Idle	CO (%) at Idle	CO2 (%) at Idle	HC (%) at 2500rpm	CO (%) at 2500rpm	CO2 (%) at 2500 rpm
1	Russia	Fiat Leda	1987	32	Gasoil	1160.00	0.17	8.52	1052.00	0.83	6.74
2	Japan	Toyota DX	1986	33	Gasoil	2352.00	0.78	11.28	2280.00	5.26	8.55
3	Japan	Toyota DX	1987	32	Gasoil	855.00	6.24	9.63	349.00	6.63	10.01
4	Japan	Toyota DX	1986	33	Gasoil	2402.00	4.72	5.86	2329.00	5.04	7.54
5	Japan	Toyota 3K	1986	33	Gasoil	3105.00	4.21	4.69	2977.00	4.09	4.76
6	Japan	Toyota DX	1996	23	Gasoil	952.00	6.82	5.68	861.00	4.78	6.24
7	Japan	Toyota DX	1987	32	Gasoil	579.00	5.18	8.32	885.00	6.30	6.67
8	Italian	Fiat 124	1981	38	Gasoil	1942.00	3.36	5.99	1922.00	3.38	5.60
9	China	Lifan meter taxi	2016	3	Gasoil	85.00	0.35	10.26	46.00	0.05	9.63
10	Italian	Fiat 124	1979	40	Gasoil	3120.00	5.10	3.20	2993.00	4.30	4.53
11	Russia	Fiat Leda	1989	30	Gasoil	859.00	0.15	9.30	1007.00	0.78	7.67
12	Russia	Fiat Leda	1986	33	Gasoil	1004.00	0.78	11.28	2280.00	5.26	8.55
13	Japan	Toyota DX	1981	38	Gasoil	1902.00	3.54	6.31	1871.00	3.35	6.10
14	Japan	Toyota DX	1987	32	Gasoil	1351.00	0.95	7.50	1169.00	0.67	8.23
15	Japan	Toyota 3K	1988	31	Gasoil	3215.00	3.41	3.68	2997.67	3.19	3.96
16	Japan	Toyota 3K	1983	36	Gasoil	3912.00	8.90	2.80	3880.38	8.30	3.27
17	China	Lifan meter taxi	2016	3	Gasoil	67.00	0.05	10.83	41.00	0.04	10.59
18	Japan	Toyota DX	1981	38	Gasoil	2962.00	3.56	4.99	2932.00	3.41	4.63
19	Italian	Fiat 124	1966	53	Gasoil	3214.00	6.90	4.23	3002.00	5.23	7.57
20	China	Lifan meter taxi	2016	3	Gasoil	62.00	0.04	11.43	33.00	0.08	10.29
21	Italian	Fiat 124	1986	33	Gasoil	2974.00	5.68	4.51	2839.00	5.15	4.73
22	Japan	Toyota DX	1987	32	Gasoil	668.00	2.97	9.93	357.00	3.47	11.14
23	Japan	Toyota DX	1987	32	Gasoil	855.00	6.24	9.63	349.00	6.63	10.01
24	Japan	Toyota DX	1988	31	Gasoil	2402.00	4.72	5.86	2329.00	5.04	7.54
25	Italian	Fiat Leda	1981	38	Gasoil	1894.00	3.11	6.00	1862.00	3.00	5.80
26	Italian	Fiat Leda	1981	38	Gasoil	2533.00	5.53	4.23	2401.00	5.10	8.30
27	Japan	Toyota DX	1987	32	Gasoil	1967.00	3.56	5.92	1945.00	3.87	5.60
28	Japan	Toyota DX	1986	33	Gasoil	1743.00	3.20	4.97	1659.00	3.30	4.22
29	Japan	Toyota DX	1987	32	Gasoil	1977.00	3.60	5.98	1935.00	3.90	5.72
30	Japan	Toyota DX	1992	27	Gasoil	1036.00	4.23	7.66	1002.00	4.01	7.82
31	Japan	Toyota DX	1989	30	Gasoil	2105.00	5.01	4.38	1943.00	4.75	5.02
32	Japan	Toyota DX	1984	35	Gasoil	3584.00	7.99	3.56	3091.00	7.49	3.96
33	Japan	Toyota DX	1986	33	Gasoil	1584.00	0.83	12.44	1791.00	4.35	9.47
34	Japan	Toyota DX	1985	34	Gasoil	2504.00	4.38	5.11	2293.00	4.92	4.17
35	Japan	Toyota DX	1987	32	Gasoil	2919.00	3.15	4.41	2617.00	4.03	4.52
36	Japan	Toyota DX	1986	33	Gasoil	2402.00	4.72	5.86	2329.00	5.04	7.54
37	Japan	Toyota DX	1987	32	Gasoil	645.00	7.06	10.59	579.00	6.91	10.77
38	Japan	Toyota DX	1986	33	Gasoil	503.00	7.42	9.63	439.00	7.73	10.01
39	Japan	Toyota 3K	1987	32	Gasoil	2740.00	5.55	6.03	2580.00	5.10	6.84
40	Italian	Fiat 124	1979	40	Gasoil	2013.00	5.02	4.56	1948.00	4.91	4.80
41	Japan	Toyota 3K	1988	31	Gasoil	3004.00	4.77	3.65	2986.00	4.50	3.97
42	Italian	Fiat 124	1982	37	Gasoil	1990.00	3.09	5.78	1861.00	2.79	4.99
43	Japan	Toyota 3K	1987	32	Gasoil	3430.00	8.12	3.47	3301.00	7.93	3.96
44	Japan	Toyota 3K	1986	33	Gasoil	3903.00	8.32	2.97	3861.00	8.11	3.45
45	Italian	Fiat 124	1966	53	Gasoil	2890.00	5.32	4.44	2702.00	5.05	4.88
46	Italian	Fiat 124	1964	55	Gasoil	2111.00	5.39	6.46	1980.41	4.65	5.74
47	Japan	Toyota DX	1985	34	Gasoil	3704.00	8.30	2.11	3490.00	7.70	2.90
48	Japan	Toyota DX	1987	32	Gasoil	2795.50	5.49	7.55	2500.00	5.01	6.43
49	Japan	Toyota DX	1987	32	Gasoil	2000.00	4.50	8.55	1737.00	4.11	9.00
50	Japan	Toyota DX	1987	32	Gasoil	1993.00	4.08	6.59	1756.00	3.99	7.06
51	Japan	Toyota DX	1987	32	Gasoil	1589.00	3.27	10.41	1521.00	3.06	11.33
52	Italian	Fiat 124	1970	49	Gasoil	2350.00	4.20	5.37	2140.00	3.90	5.80
53	Italian	Fiat 124	1975	44	Gasoil	2060.00	4.86	5.10	1900.00	3.85	6.00
54	Italian	Fiat 124	1975	44	Gasoil	1642.00	3.36	7.55	1587.00	3.38	6.22
55	Italian	Fiat 124	1975	44	Gasoil	1700.00	3.95	5.87	1650.00	3.40	6.32
56	Japan	Toyota 3K	1984	35	Gasoil	1541.00	3.94	7.36	1472.00	3.40	6.30
57	Japan	Toyota 3K	1985	34	Gasoil	1067.00	2.98	8.54	963.00	2.31	7.79
58	Japan	Toyota 3K	1987	32	Gasoil	2548.00	5.00	5.30	2491.00	4.80	6.05
59	China	Lifan meter taxi	2016	3	Gasoil	76.00	0.03	12.11	45.00	0.02	10.27
60	China	Lifan meter taxi	2016	3	Gasoil	80.00	0.04	11.49	58.00	0.03	10.62
61	China	Lifan meter taxi	2016	3	Gasoil	64.00	0.01	13.70	43.00	0.01	12.55
62	Japan	Toyota 3K	1986	33	Gasoil	2000.00	4.54	5.61	1947.00	4.21	5.30
AVERAGE VEHICLES AGE				32							

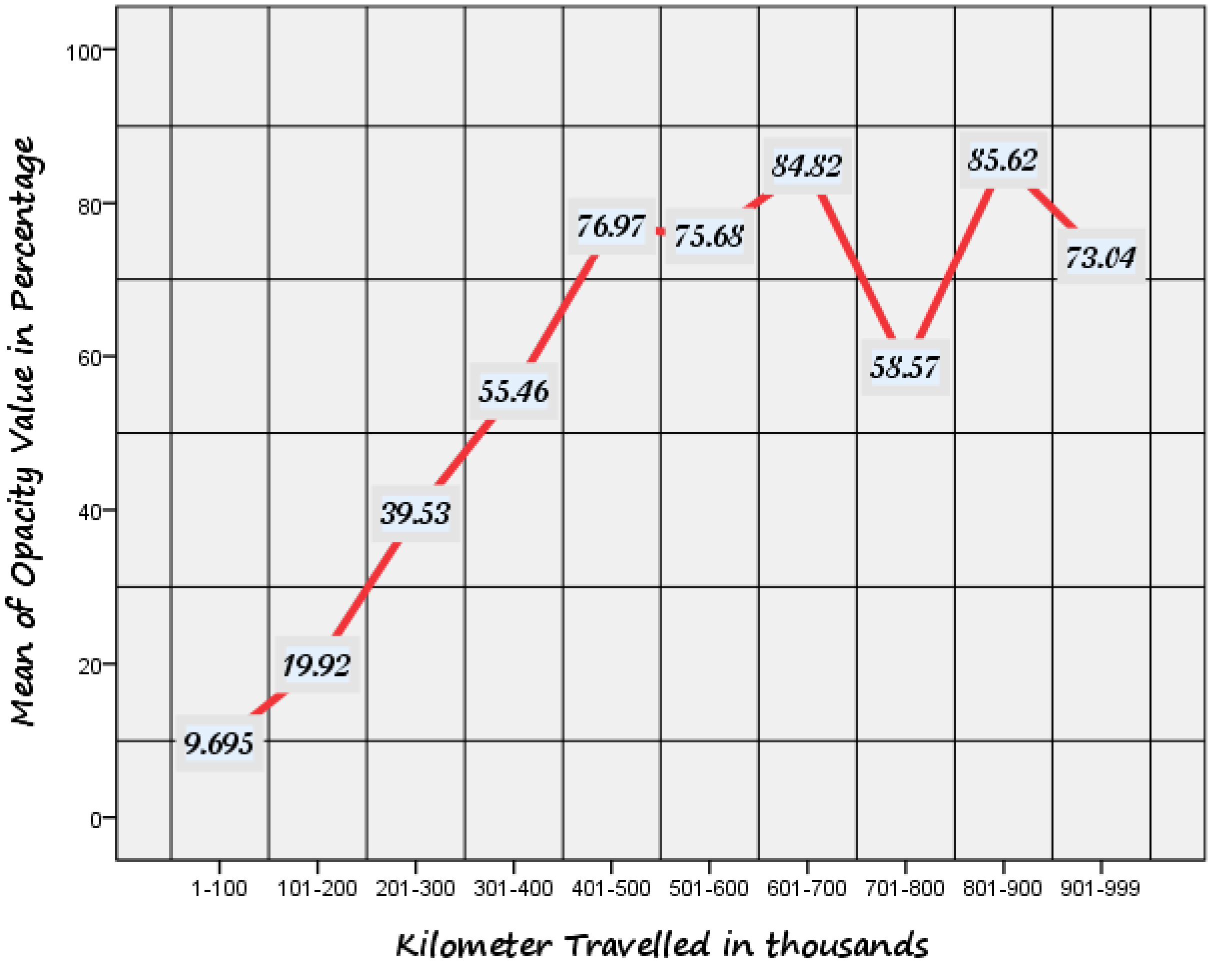
Appendix-F Mean Plots of vehicle make versus smoke opacity



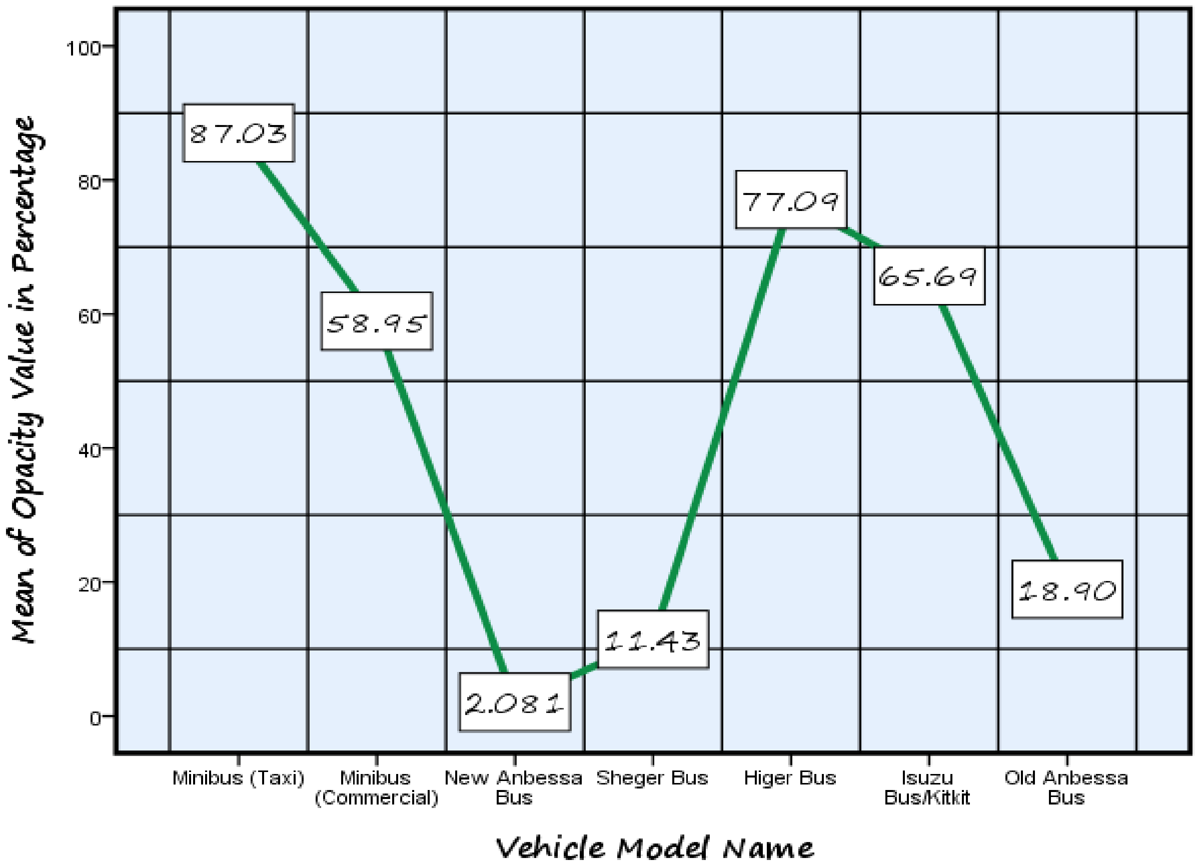
Appendix-G Mean Plots of Model year versus Smoke opacity



Appendix-H Mean Plots of Kilometer travelled and smoke opacity



Appendix-I Mean Plots of Vehicle types/model name and smoke opacity



Appendix-J Descriptive Analysis of Vehicle Make

Smoke Opacity	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Toyota (Japan)	251	72.60	27.388	1.729	69.19	76.00	13	100
Isuzu (Japan)	30	65.69	33.477	6.112	53.19	78.19	2	100
China, Higer Bus Company	30	77.09	25.915	4.731	67.42	86.77	30	100
China, Yu-Tong	35	6.09	7.065	1.194	3.66	8.51		34
China, Huanghai	12	18.90	6.226	1.797	14.95	22.86	12	29
Total	358	64.09	33.773	1.785	60.58	67.60		100

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
HC@Idle Rpm	China	5	73.40	10.040	4.490	60.93	85.87	62	85
	Italy	13	2266.08	520.855	144.459	1951.33	2580.83	1642	3214
	Japan	40	2071.56	1019.526	161.201	1745.50	2397.62	67	3912
	Russia	4	1499.25	990.820	495.410	-77.37	3075.87	859	2974
	Total	62	1914.28	1047.797	133.070	1648.19	2180.37	62	3912
CO@Idle Rpm	China	5	.09	.144	.064	-.08	.27		
	Italy	13	4.55	1.152	.319	3.86	5.25	3	7
	Japan	40	4.66	2.132	.337	3.98	5.34		9
	Russia	4	1.70	2.673	1.336	-2.56	5.95		6
	Total	62	4.08	2.337	.297	3.48	4.67		9
CO2@Idle Rpm	China	5	11.80	1.256	.562	10.24	13.36	10	14
	Italy	13	5.29	1.153	.320	4.59	5.99	3	8
	Japan	40	6.64	2.622	.415	5.80	7.48	2	12
	Russia	4	8.40	2.843	1.422	3.88	12.93	5	11
	Total	62	6.89	2.805	.356	6.18	7.60	2	14
HC@2500 Rpm	China	5	45.00	8.916	3.987	33.93	56.07	33	58
	Italy	13	2149.88	476.256	132.090	1862.08	2437.68	1587	3002
	Japan	40	1945.88	1013.332	160.222	1621.80	2269.96	41	3880
	Russia	4	1794.50	912.534	456.267	342.46	3246.54	1007	2839
	Total	62	1825.59	1016.820	129.136	1567.36	2083.81	33	3880
CO@2500 Rpm	China	5	.04	.028	.012	.00	.07		
	Italy	13	4.07	.853	.236	3.56	4.59	3	5
	Japan	40	4.77	1.880	.297	4.17	5.37		8
	Russia	4	3.01	2.541	1.270	-1.04	7.05	1	5
	Total	62	4.13	2.108	.268	3.59	4.66		8
CO2@2500 Rpm	China	5	10.67	1.109	.496	9.29	12.05	10	13
	Italy	13	5.89	1.077	.299	5.24	6.54	5	8
	Japan	40	6.71	2.425	.383	5.94	7.49	3	11
	Russia	4	6.92	1.638	.819	4.32	9.53	5	9
	Total	62	6.87	2.368	.301	6.27	7.47	3	13

Appendix-K Descriptive Analysis of Vehicle Model year

Opacity Value in Percentage	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1960-1975	29	94.39	9.256	1.719	90.86	97.91	63	100
1976-1990	63	76.82	28.682	3.614	69.60	84.05	14	100
1991-1999	61	78.80	25.503	3.265	72.27	85.33	12	100
2000-2005	57	67.99	25.895	3.430	61.12	74.86	17	100
2006-2010	90	64.02	29.362	3.095	57.87	70.17	8	100
2011-2018	58	15.93	16.267	2.136	11.66	20.21		58
Total	358	64.09	33.773	1.785	60.58	67.60		100

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
HC@Idle Rpm	1960-1970	4	2641.25	501.966	250.983	1842.51	3439.99	2111	3214
	1971-1980	5	2107.00	595.627	266.373	1367.43	2846.57	1642	3120
	1981-1990	45	2114.74	937.031	139.684	1833.23	2396.26	503	3912
	1991-2000	2	994.00	59.397	42.000	460.34	1527.66	952	1036
	2016	6	72.33	9.352	3.818	62.52	82.15	62	85
	Total	62	1914.28	1047.797	133.070	1648.19	2180.37	62	3912
CO@Idle Rpm	1960-1970	4	5.45	1.108	.554	3.69	7.22	4	7
	1971-1980	5	4.46	.767	.343	3.51	5.41	3	5
	1981-1990	45	4.38	2.192	.327	3.72	5.04		9
	1991-2000	2	5.53	1.831	1.295	-10.93	21.98	4	7
	2016	6	.09	.130	.053	-.05	.22		
	Total	62	4.08	2.337	.297	3.48	4.67		9
CO2@Idle Rpm	1960-1970	4	5.13	1.019	.509	3.50	6.75	4	6
	1971-1980	5	5.26	1.611	.720	3.26	7.26	3	8
	1981-1990	45	6.60	2.579	.384	5.83	7.38	2	12
	1991-2000	2	6.67	1.400	.990	-5.91	19.25	6	8
	2016	6	11.64	1.191	.486	10.39	12.89	10	14
	Total	62	6.89	2.805	.356	6.18	7.60	2	14
HC@2500 Rpm	1960-1970	4	2456.10	477.729	238.864	1695.93	3216.28	1980	3002
	1971-1980	5	2015.60	568.024	254.028	1310.31	2720.89	1587	2993
	1981-1990	45	2025.67	915.469	136.470	1750.63	2300.71	349	3880
	1991-2000	2	931.50	99.702	70.500	35.71	1827.29	861	1002
	2016	6	44.33	8.140	3.323	35.79	52.88	33	58
	Total	62	1825.59	1016.820	129.136	1567.36	2083.81	33	3880
CO@2500 Rpm	1960-1970	4	4.71	.590	.295	3.77	5.65	4	5
	1971-1980	5	3.97	.648	.290	3.16	4.77	3	5
	1981-1990	45	4.63	1.876	.280	4.06	5.19	1	8
	1991-2000	2	4.40	.544	.385	-.50	9.29	4	5
	2016	6	.04	.025	.010	.01	.06		
	Total	62	4.13	2.108	.268	3.59	4.66		8
CO2@2500 Rpm	1960-1970	4	6.00	1.129	.565	4.20	7.79	5	8
	1971-1980	5	5.57	.843	.377	4.53	6.62	5	6
	1981-1990	45	6.58	2.276	.339	5.90	7.27	3	11
	1991-2000	2	7.03	1.117	.790	-3.01	17.07	6	8
	2016	6	10.66	.993	.405	9.62	11.70	10	13
	Total	62	6.87	2.368	.301	6.27	7.47	3	13

Appendix-L Californian BAR-90 emission Standard

(1)	MODEL YEAR GROUP	VEHICLE TYPE (by GVWR) [lb]					PASS/FAIL STANDARDS [2]				GROSS POLLUTER STANDARDS [3]				(4)	
		Pass Car	TRUCK (includes motor-home, mini-van & sport utility)													
		≤6000	≤6000	6001 to 8500	8501 to 14 000	≥14 001	IDLE HC	IDLE CO	2500 HC	2500 CO	IDLE HC	IDLE CO	2500 HC	2500 CO	MIN $CO+CO_2$	MAX IDLE RPM
1	1966-1967	X	X				700	5.5	600	4.5	950	8.0	850	7.0	8.0	1100
2	1968-1970	X	X				650	5.5	600	4.5	900	8.0	850	7.0	8.0	1100
3	1971-1974	X	X				550	5.0	400	4.0	800	7.5	650	6.5	8.0	1100
4	1975-1980	X					220	2.0	180	1.7	470	4.5	430	4.2	8.0	1100
5	1981-1983	X					120	1.5	150	1.5	270	3.0	300	3.0	8.0	1100
6	1984-1986	X					120	1.0	150	1.2	270	2.5	300	2.7	7.0	1100
7	1987-1992	X					120	1.0	140	1.0	270	2.5	290	2.5	7.0	1100
8	1993+	X					100	1.0	130	1.0	250	2.5	280	2.5	8.0	1100
9	1975-1978		X				250	2.5	200	3.0	500	5.0	450	5.5	7.0	1100
10	1979-1983		X	X			250	2.0	200	2.0	400	3.5	350	3.5	8.0	1100
11	1984-1987		X	X			150	1.2	180	1.2	300	2.7	330	2.7	7.0	1100
12	1988-1992		X	X			120	1.0	180	1.0	270	2.5	330	2.5	8.0	1100
13	1993+		X				100	1.0	170	1.0	250	2.5	320	2.5	7.0	1100
14	1993+			X			100	1.0	180	1.1	250	2.5	330	2.6	7.0	1200
15	1966-1969			X	X	X	700	5.5	750	5.0	950	8.0	1000	7.5	7.0	1200
16	1970-1973			X	X	X	550	5.0	600	4.5	800	7.5	850	7.0	8.0	1200
17	1974-1978			X	X	X	300	3.0	350	3.5	550	5.5	600	6.0	7.0	1200
18	1979-1983				X	X	250	2.2	250	3.0	400	3.7	400	4.5	7.0	1200
19	1984-1986				X	X	250	1.5	200	1.6	400	3.0	350	3.1	7.0	1200
20	1987-1990				X		220	1.5	200	1.6	370	3.0	350	3.1	7.0	1100
21	1991+				X		150	1.2	150	1.5	300	2.7	300	3.0	7.0	1100
22	1987-1990					X	250	2.5	200	1.6	400	4.0	350	3.1	7.0	1100
23	1991+					X	150	1.5	150	1.5	300	3.0	300	3.0	7.0	1100

Source: Dartoy, J. *et al.* (2005) *Motor vehicle emission regulations and fuel specifications appendix to part 1 2004 / 2005 update*