ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Effects of Traffic Congestion on Ambient Air Quality on Intersections in Addis Ababa.

BY

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A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for Degree of Master of Science in Civil Engineering (Road and Transport Engineering)

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DECLARATION

I affirm that the work titled "Effects of Traffic Congestion on Ambient Air Quality on Intersections in Addis Ababa." was carried out by the author Getalem Teshager in the stream of Road and Transport Engineering in the school of Civil and Environmental Engineering under the supervision of my advisors Dr. Getu Segni and Hilina Demeke. The information derived from other literature has been accordingly 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:

Nowadays, one of the major sources of greenhouse gas emission is transportation especially road transport. There are several influential factors of transport-related air pollution like road geometry, road surface type, traffic congestion, road traffic characteristics, fuel type, and environment. This study was designed to assess the effect of traffic congestion on ambient air quality at the intersection since Traffic congestion mainly occurs at the intersection due to two or more road segments meet at a place and have high traffic flow.

The data provided in this study were quantitative and their sources were both primary and secondary. The primary data of the study collected using Aeroqual series 500 for carbon monoxide and sulfur dioxide, and laser PM2.5 for particular matter 2.5 and 10 air quality pollutant concentration at the roadside of the study area, and a video camera for traffic count survey. The secondary data was emission factors of different vehicles obtained from previous research papers. The data were analyzed using descriptive analysis and statistical test method.

This research found out the level of traffic congestion of each selected intersection has a severe congestion level. The contribution of traffic congestion on vehicular emission as a base of steady traffic flow conditions is increased by an average value of 27-37% by car, 30-39% by minibus, 49-63% by bus, and 45-70% by truck. During congested period as a base of steady period, air pollutant concentration of CO, SO2, PM2.5 and PM 10 increased on average by 19.10%, 51.61%, 33.83% and 29.07% respectively. This study develops a regression model for air quality pollutants of CO, SO2, PM2.5, and PM10 considering different factors. From the analysis, the concentration of air pollutants increases as traffic volume, percentage of heavy vehicle, green time of the approach, approach grade increases whereas the concentration of the pollutants decreases when the lane width, wind speed increase. Therefore; traffic congestion has a negative contribution to ambient air quality.

Keywords: Air quality, Emission, Traffic congestion, intersection

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ACRONOMY

AU: Africa union

CO: Carbon Monoxide

CO2: Carbon dioxide

EEA: European environment agency

ERA: Ethiopian road authority

FDRE: Federal Democratic Republic of Ethiopia

GHGs: Greenhouse gases

HC: Hydrocarbon

LDV: Light-duty vehicle

LOS: service of level

% of HV: percentage of heavy vehicle

NH3: Ammonia

NOX: Nitrogen oxides

O3: Ozone

PM: particular mater

SOx: Sulfur oxides

V/C: Volume to capacity ratio

VOCs: Volatile organic compounds

WHO: World health organization

CHAPTER ONE: INTRODUCTION

1.1. Background

Air pollution is the contamination of the atmosphere when extreme quantities of air pollutants concentrations (CO, CO2, SOx, NOx, VOC, PM, NH3, O3) are presented in the air. It shows the problem of air quality by different factors like greenhouse emission and smoke from industries, transportation, electric city production, commercial and residential, Agriculture, and land use forestry. It is the major factor of polluted-related diseases like respiratory infections, heart diseases stroke, and lung cancer(European Environment Agen cy, 2017).

Transportation is the pillar of economic development in the world. It is also the major cause of air pollution. The main concern in the world is on the way to mitigate the problem of air quality due to transportation activity. Many environmental damages that result in problems are especially delicate in the most rapidly growing economies of the developing world. The damages are costs to society that are not included in the price paid by the transport users from transportation activity, including accidents, noise, land use, and pollution of air, water, and land(Mage and Zali, 2015). According to WHO reports, the transportation sector accounts for approximately 16 percent of the global annual mean emission of black carbon. More than 40% of the emission of NOx, PM2.5 comes from road transport (European Environment Agency, 2017).

Increase traffic in urban transportation networks in recent years has led to widespread traffic congestion(European Conference Of Ministers Of Transport, 2007). Traffic congestion has now become the most visible, immediate transport problem troubling the major cities of the developing counties- daily. During congestion, vehicles spend more time on the road, idling and undergoing numerous acceleration and deceleration events and may lead to an increase in the emission of pollutants(Alessandra Cappiello, 2002). For perpendicular and parallel wind, free-flow traffic condition reduces the concentration of carbon monoxide by 73% and29-51% respectively while congested traffic condition increases the concentration of carbon monoxide by 47% for perpendicular wind direction and reduce the concentration of CO by 17-42% for parallel wind(Prashant and Sharad, 2016).

75% of the emissions in Ethiopia come from road transport (Government of FDRE, 2011). One of the worst problems in our city is traffic congestion it may be due to the day-to-day activity of all people in all parts of the city of especially during the morning and evening peak hours due to the vehicle number increase rapidly in the city(Andargie, 2017). An as different study shows traffic congestion had a great contribution to air pollution but there is not a satisfactory study conducted in our city in this area.

Reduced congestion means fewer and less extreme vehicle acceleration and deceleration events for the facility. These effects usually mean a change in the vehicle emission rates for the facility. Fewer acceleration and deceleration events will result in lower emission rates, which lead to minimizing the concentration of air pollutants due to traffic(R. Dowling, R.Ireson, A.Skabardonis, et al, 2005). So this research's main aim was to show the effect of traffic congestion on air pollutants concentration and recommend some mitigations to reduce traffic congestion by considering its impact on the environment.

1.2. Statement of the problem

About 4.2 Million premature death in the world was estimated by outdoor air pollution in 2016 and 91 % of those deaths occurred in low and middle-income countries (WHO, 2018). Outdoor air pollution would be higher in urban areas than the rural areas due to the increasing urbanization, the number of vehicles, and development of economic activity(Saeb, Malekzadeh, and Kardar, 2012). Transport, particularly road traffic is currently a major source of air pollution in most of the world.

Road transportation has an essential economic and social role. However, it is one of the major contributors to energy consumption, air pollution, and the emission of greenhouse gases (Clarke and Ainslie, 2019). Benefits on emissions and fuel consumption are generally believed to be strictly linked to a reduction in congestion. Congestion corresponds to the increase in the density of traffic as well as in the frequency of acceleration and stop and go transients, during which more emissions are generated, which might pollute the ambient air.

There are several influential factors of transport-related air pollution like road geometry (gradient, curvature), road surface type(pavement, gravel), traffic congestion, road traffic characteristics, fuel type, environment(like wind weather, etc. Traffic congestion on roads not only increases fuel consumption but also accordingly leads to an increase in carbon dioxide emissions, outdoor air pollution, and an increase in the exposure time of the passengers. Traffic congestion and traffic volume contributed more to air pollution than the impact of fluctuating terrain(Huboyo, Handayani, and Samadikun, 2017).

This research studied traffic congestion contribution for air pollution at the intersection rather than the mid-block since the intersection is one of the most places that traffic congestion occurs due to two or more road segments meet at a place, there were a high number of vehicles in the intersection than the mid-block. Besides, the researcher preferred the intersection rather than the midblock due to intersection was easier and cost-effective than the midblock to capture the required data. Traffic jam saw in intersection since traffic intersection is the main area of bottleneck and then its capacity is limited (due to weaving, merging, and diverging movements on the roadway) than the road section (Li and Cheng, 2011) and (Aderamo and Atomode, 2012).

Transportation needs in Addis Ababa have increased alongside the city's rapid population growth and economic development, a rapid increase in the number of vehicles. This may lead to a different problem in the city like traffic congestion and traffic congestion would lead to an increase in traffic-related air population. From the total greenhouse gas emission in Addis Ababa, the emission emitted from the transportation sector was about 2.273 $MtCO_2e$, which was about 47 %. On-road transportation take the major subsector of transportation greenhouse gas emission source(Addis Ababa City Administration, 2012). Most vehicles serving in Addis Ababa are polluting the environment highly due to their old model year (an average year of 23 years old), high in kilometer traveled, vehicle type, and poor maintenance. This indicates that transportation had a major contributor to air pollution in the city(Kebede, 2019).

Due to the rapid urbanization of the city, the number of vehicles increases rapidly and that tends to traffic congestion. The Transport authority takes different measurements to solve the problem of traffic congestion but emission of a vehicle has not much consideration during planning, designing, and management of road simultaneously with traffic congestion, this may consequence to transport-related air pollution. So during traffic management, considering vehicle emission that causes air pollution is essential to reduce the impact of traffic-related air pollution(Hao and Wang, 2018).

Now a time, air pollution is a serious problem in the world that consequences of climate change, health problem. One of the major sources of air pollution is transportation due to the rapid urbanization of the city especially in a congested area or place where more vehicles exist. But there was not much research conducted to solve the problem of traffic-related air pollution in Addis Ababa city, so the researcher needs to investigate the amount of air quality pollutant concentration due to congested traffic flow conditions and then recommend the mitigations for the problem.

1.3. Objective

1.3.1. General objective

The main aim of this study was to investigate the effect of traffic congestion on ambient air quality at selected intersections in Addis Ababa.

1.3.2. Specific objective

- Measure the level of traffic congestion of the selected intersections.

- Investigate the effect of traffic congestion on gaseous emission for different vehicle types using secondary data.
- Investigate ambient air quality at congested and steady flow conditions and finally show traffic congestion effect on air quality.
- Develop a regression model of ambient air pollutants to show the effect of different factors like traffic, road and metrological parameters on ambient air quality.

1.4. Research question

- What is the level of congestion of each selected intersection?
- What is the effect of traffic congestion on gaseous emission of different vehicle types?
- What is the effect of traffic congestion on air quality?
- What are the significant factors of ambient air quality pollutants in this study?

1.5. Significance of the study

The main significances of this research are:-

- ✓ The study will be useful for policymakers, transportation planners, road agencies, government, and communities for planning, identifying, and designing road networks-to minimize air pollution due to traffic from road transportation.
- ✓ Exploring the effect of traffic congestion of road transportation on air pollution has been quite limited in Ethiopia. These studies will visualize narrowing the knowledge gap in this respect and also use as a stepping-stone for further research works.

1.6. Scope of the study

The study is delimited within some selected intersections in Addis Ababa because of time and budget constraints. It is acknowledged that the study would have covered a wider scope for more generalization and reduces the gap of limitation of the study.

1.7. Limitation of the study

This study was limited by a different situation like the Airqual series 500 and Laser PM2.5 meter had not analyzed the data itself, so to record air pollutants data use a manual record(pen and paper method); approach grade and approach distance of the intersection are obtained from Google earth in this thesis but it is better to measure using measuring instruments. And also the measured data of air pollutants are a short term data.

1.8. Organization of the thesis

This thesis consists of five chapters. Chapter one deals with the background of the study, objectives to be achieved, the significance, scope, research questions, and the problem of the statement of the study. Chapter two presents the related literature reviewed in this study. Chapter three deals with an explanation of the sampling area, research approach, data collection, data analysis for the research under study. Chapter four describes the result and discussion of the analysis. And the final chapter deals with the conclusion and recommendation.

CHAPTER TWO: LITERATURE REVIEW

2.1. Air pollution from road traffic

Ambient air pollution is the contamination of surrounding air outside the home and it initiates from both natural sources and human activities. However; human activities are the major source of air pollution. Some of the human activities that lead to air pollution are fuel combustion from motor vehicles, heat and power generation, industrials facilities, municipal and agricultural waste sites (European environment agency, 2017).

Traffic-related air pollution is a type of air pollution that comes from the emissions of motor vehicles that result from fossil fuel combustion and is a major risk factor for the cardiovascular disease includes Hypertension. Traffic-related emission contributes significantly to outdoor air pollution. The pollution experienced from road vehicle emissions depends upon three general classes of factors: such as vehicle characteristics, meteorological conditions, and driving conditions. Major traffic-related air pollutants are Carbon monoxide (CO), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Particulate matter (PM 2.5, Pm10), and Ozone (O3)(Krzyzanowski and Cohen, 2008) WHO guideline). The concentration of CO, NO2, SO2, CO2, and HC in ambient air in Lagos was 29.04ppm, 0.042ppm, 0.040ppm, 370.92ppm, and 0.030ppm respectively(Adeyanju and Manohar, 2017). Carbon monoxide concentration of ambient air in Kerman measured using Kane-Mag SG91C CO single gas in 21 selected intersections, the study found out 8.3ppm highest concentration and 1.3ppm lowest concentration(Malakootian and Yaghmaeian, 2004).

Traffic air pollution in Addis Ababa City around Selected Bus Stations was investigated using the Instrumental Neutron Activation Technique. The instrument installed at 3m height and 2m distance from the fence of the bus station in Merkato bus station whereas in Megenagna bus station the instrument was placed at a height of 3 m and 10 m distance away from the station. The result showed that in Merkato bus station K, Pd, Co, Eu, Cd, Ge, Cl, Ga, and Mo with concentrations 7680.0 ± 54.0, 7640.00 ± 7.20, 4084.51 ± 17.8, 3884.00 ± 55.5, 3556.00 ±19.10, 2810.00 ± 31.62, 2510.61 ± 3.26, and 2463.50 ± 4.90, 2102.12±12.14 respectively and in Megenagna bus station area Pd, K, Sm, Eu, Mo, Co, Cd, and Ba with concentrations 6942.0±58.5, 4203.22±24.52, 3608.58±30:83, 3264.46±42.14, 2867.20 ± 16.90, 2645.32 ±12.84, 1999.00 ± 8.2 and 1792.25 ± 28.9 respectively. The researchers conclude the studied area was highly polluted due to traffic air pollution(Hailu, Chaubey, and Hibstie, 2013).

Quantifying air pollution of road transport in Addis Ababa city studied using electronic instruments which is Smoke Opacity Meter (for 358 diesel-fueled vehicles) and FGA 4000XDS Gas Analyzer (for 62 gasoline-fueled vehicles) on the site through the tailpipe. The research found out only 32.1 % of diesel-fueled vehicles passed USEPA limited standard whereas for gasoline-fueled vehicles 92% 85.5% and 0% failed Californian BAR-90 standards of HC, CO, and CO2 gaseous emission respectively. Due to the high kilometer traveled and old model year vehicles in Addis Ababa city, air pollution due to traffic is high (Kebede, 2019).

Contribution of Vehicle Exhausts Gas Emissions to the Traffic Air Pollution of Selected Areas of Addis Ababa City studied using Model HM5000 (for CO and HC) and pDR1000AN (for PM) devices The result found out on its ambient air quality inspection high amount of emission of CO, HC, and PM air pollutant parameters were recorded due to the congestion and traffic volume of heavy-duty gasoline and diesel vehicles (Fekadu, 2017).

Table 2.1. 1: Air pollutants description

air pollutants	Explanation	Its impact	The standard value with different time-weighted average		
			Time average	In Ethio($10^3 \mu g/m^3$)	In WHO(μg/ m^3)
Carbon monoxide (CO)	It is a colorless, odorless, tasteless flammable gas but highly toxic. Its sources are an incomplete composition of carbon-containing fuels when the vehicles emit smoke, burning wood, industrial process, a natural source like a forest fire	it may have a health effect if it is beyond the limited value of the standard like headaches, heart disease	15 min	100	
			30min	60	
			8 hr	10	
Nitrogen dioxide (NO_2)	It is a reddish-brown gas with a pungent, acid odor. Its source is internal combustion engines burning fossil fuels from motor vehicles.	its higher concentration causes respiratory problems, wheezing, coughing	1 hr	0.2	200
			Annual	0.4	40

Sulphur dioxide (SO_2)	It is a colorless gas with a sharp odor, it is produced from the burning of fossil fuels(coal and oil) and the smelting of minerals ores that contain sulfur	Affect the respiratory system, irritation of the eyes, it may cause deforestation.	10 min	0.5	500
			24 hr	0.13	20
Particulate matter ($Pm_{2.5}$)	It is a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. It is fine inhalable particles with a diameter of 2.5 micrometers;	The Respiratory and cardiovascular problem, creation of haze of the city	24 hr	0.65	25
			Annual	0.02	10
Particulate matter (Pm_{10})	it is inhalable particles with a diameter of 10 micrometers. it sourced from the combustion of engine, solid fuel		24 hr	0.15	50
			Annual	0.05	20
Ozone (O_3)	It is formed by the reaction with the sunlight of pollutants such as nitrogen oxides from a vehicle and industry emissions and	Its problem is breathing problems, trigger asthma, reduce lung function, and cause lung diseases.	8 hr	0.12	100
			1 hr		180

	volatile organic compounds emitted by vehicles, solvents, and industry				

Source: (Chandola, Vivek Chattopadhyaya, Anumita Roychowdhury, 2016).

2.2. Traffic congestion

Traffic congestion is a condition on transport in which the traffic demand approaches the capacity of a road which means unstable traffic flow that creates vehicular queuing, decreases speed, long trip on the roadway due to different factors(Nashua Regional Planning Commission, 2007). Traffic congestion is one of the growing problems in the world; that has a negative socio-economic impact on any nation. The three major parameters that are used to assess the influence of traffic congestion on the society, as well as the economies, are vehicle operating cost especially fuel consumption, travel time, and vehicular emission(Velmurugan and Madhu, 2011).

The cause of Traffic congestion is the capacity of the road lower than the traffic volume, traffic incident, road work, weather event, socioeconomic growth, Increase in urban population, car ownership and dependence, land uses, travel patterns, public transport operations, urban freight transport, and goods delivery, parking at the outside lane and also an imbalance between the supply of transportation and its use(Ali and Faraj, 2013).

The principal effect of traffic congestion are; increase travel time, Increase fuel consumption, Increase greenhouse gas emission, caused air pollution due to traffic, decrease productivity, impact on economic development of the country(Pratama, Arliansyah and Agustien, 2019).

To identify the level of traffic congestion, there are different congestion indicators some of them are (European Conference Of Ministers Of Transport, 2007);

i. Speed based indicators

- Average traffic speed
- Peak hour traffic speed

ii. Temporal / Delay based indicators

- Annual Hours of Delay: wasted time due to congestion
- Annual Delay per Capita: the ratio of wasted time due to congestion to area population
- Annual Delay per road user: the ratio of wasted time due to traffic congestion to several peak period road users.
- Travel time index: travel time during peak period divided by free-flow travel time; it considers both reoccurring and nonrecurring congestion delay).
- Travel time rate: travel time during peak period divided by free-flow travel time; it considers only reoccurring congestion delay.

iii. Service level/ capacity indicators

- LOS: it qualitatively measures both the operating conditions within a traffic system and how these conditions are perceived by drivers and passengers. It is related to the physical characteristics of the highway and the different operating characteristics that can occur when the highway carries different traffic volumes.
- V/C: it is the ratio of the demand volume to the capacity of the road.

iv. Reliability indicators

- Congestion Variability index: an index relating the variability of travel speeds on the network.
- Planning time index: an index that accounts for a time buffer that allows an on-time arrival for 95% of trips on a network.

Table 2.2. 1: Level of traffic congestion categorization

V/C	**Level of traffic congestion**
<0.5	Low or no congestion
0.5 – 0.74	Moderate congestion
0.75-1	Heavy congestion
>1	Sever congestion

Source: (Nashua Regional Planning Commission, 2007)

SIDRA intersection software:

SIDRA traffic analysis is used for modeling individual intersections and is not suitable for all analytical tasks requiring computer-based modeling of traffic operations.

The SIDRA software is a micro-analytical tool for the evaluation of intersection performance. Sidra intersection is a powerful software used to analyze the capacity of different intersection types that are signalized intersections, signalized and unsignalized pedestrian crossings, unsignalized roundabout, a roundabout with metering signals, fully signalized roundabouts, and different types of interchanges and also used for uninterrupted traffic flow conditions and merge analysis, it can show the fuel consumption and greenhouse gas emission (Akcelik & Associates Pty Ltd, 2018). In this study; use SIDRA intersection software to get volume to capacity ratio to identify the level of traffic congestion of the selected intersections.

Mitigation of traffic congestion:

Major traffic congestion mitigation strategies are expanding roadway capacity, expanding transit services, increasing residential densities, use of tollways and use of ramp metering, provision of adequate facilities for pedestrians and cycles, Prohibiting on-street parking of vehicles and simultaneously developing off-street parking facilities(Fesler, 2013).

There is a study map that shows the corridor of high traffic jam.

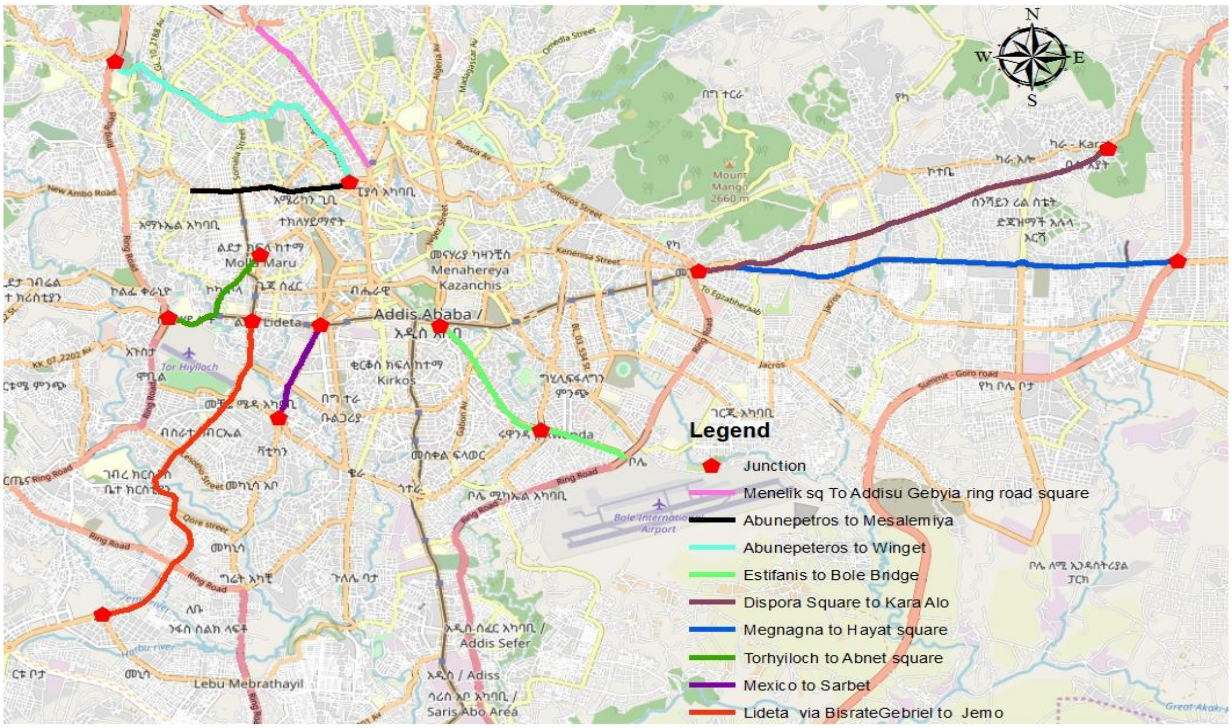


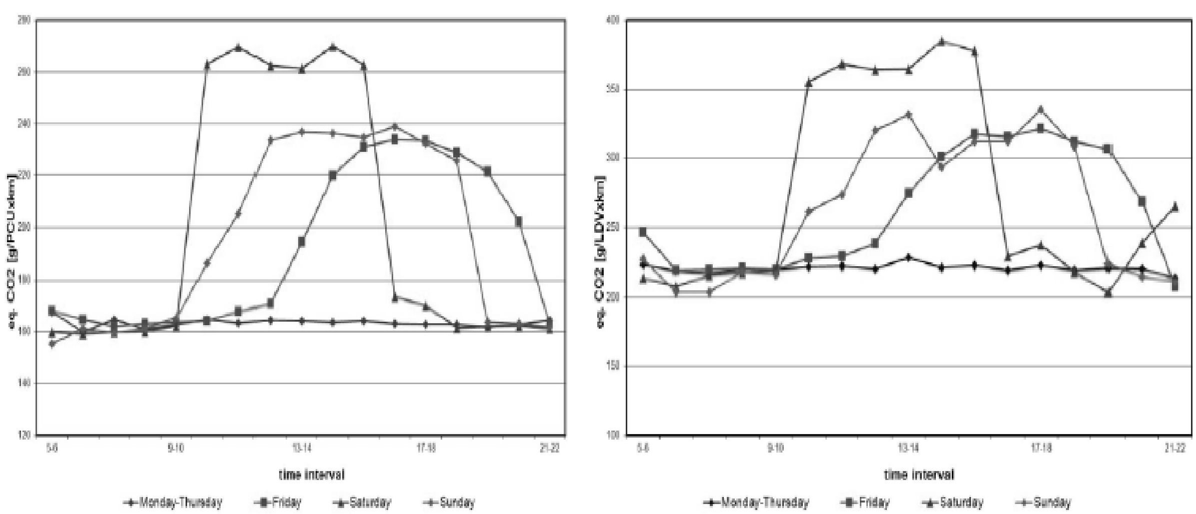
Figure 2.2. 1: Corridors of High Traffic Jam in Addis Ababa

Source: transport authority of Addis Ababa

2.3. Impact of traffic congestion on greenhouse gas emission and air pollution

Congestion corresponds to an increase in the density of traffic as well as in the frequency of acceleration and stop and go transients, during which more emissions are generated. However; improvements in congestion may not always correspond to improved total emissions. i.e. high free-flow speed generally represents favorable traffic conditions, but can generate high emissions and lower travel times may encourage vehicle drivers to make more and longer trips (Liu, Chen, and Xue, 2017). The spatial distribution of emissions can be affected negatively by a measure that improves congestion. That is, the use of traffic signals and ramp metering can prevent the formation of congestion, but their introduction leads to a higher concentration of emissions in the proximity of the signals. As a consequence, it is necessary to consider both congestion and emissions in the problem of policy development, assessment, and optimization(Alessandra Cappiello, 2002).

(Rosca, Costescu, and Rusca, 2014); assessed the impact of traffic congestion on greenhouse gas emission for different vehicle classes using the methodology of combines field recorded traffic data, computer traffic simulation using VISSIM software, and emission factors estimated through the Tier 3 approach of the EEA guidelines. They investigated, during congested periods, the average passenger car emission values increase between 40–60%. For light-duty vehicles, the eq. CO_2 average emissions overpass 200 g/LDV/km and are higher than those recorded at the European level – 170g/LDV/km (EEA, 2010). This situation reflects the aged LDV fleet in Romania. The average emissions per LDV are up to 70% greater during the congested periods of the weekends compared to the Working days.



a) Passenger car b) Light duty vehicle

Figure 2.3. 1: Average equivalent CO2 emission per vehicle type

(Bharadwaj, Ballare, and Chandel, 2017); they assess the impact of traffic congestion on greenhouse emission i.e. CO2 emission from road transport in the Mumbai metropolitan region. They used vehicle kilometer traveled and fuel consumption methods to estimate CO2 emission from vehicles and also use travel time traffic congestion measuring index to estimate the share of greenhouse gas emissions from the road transport sector that can be attributed to traffic congestion. Then, they investigate vehicles in MMR take approximately 51% more time to complete the trip under congested conditions as compared to free-flow conditions so it leads to 53% more CO2 emission during congestion. As congestion represents the situation where the combustion of fuel takes place without any significant addition in VKT, the above statement appears to be roughly correct.

(Greenwood, Dunn and Raine, 2007); Estimate the Effects of Traffic Congestion on Fuel Consumption and Vehicle Emissions Based on Acceleration Noise. The approach adopted is based on the modeling of acceleration noise, defined as the standard deviation of accelerations. During periods of high traffic congestion, there is greater variability in speed, resulting in higher acceleration noise levels. They investigate, the fuel consumed when compared to steady speed assumptions for a real-life section of motorway increased by around 13% over a 24 h period. Similarly, various vehicle emissions increased by as much as 25%.

Table 2.3. 1: predict the impact of traffic congestion on fuel consumption and GHGs emission

	Percentage increase		
Pollutant	**Minimum of 15 minute periods**	**24 hr average**	**Maximum of 15 minute periods**
Carbon monoxide, CO	+ 2%	+25%	+36%
Carbon dioxide, CO2	+1%	+12%	+17%
Hydro carbons, HC	+2%	+25%	+36%

Oxides of nitrogen, NOx	+2%	+15%	+25%
Particulate matter, PM	+1%	+12%	+17%
Fuel consumption, FC	+1%	+13%	+17%

The maximum concentration of carbon monoxide, ammonia, and nitrogen dioxide occurred during peak traffic volume and when the wind perpendicular to the road as shown in the figure below(Baldauf *et al.*, 2012).

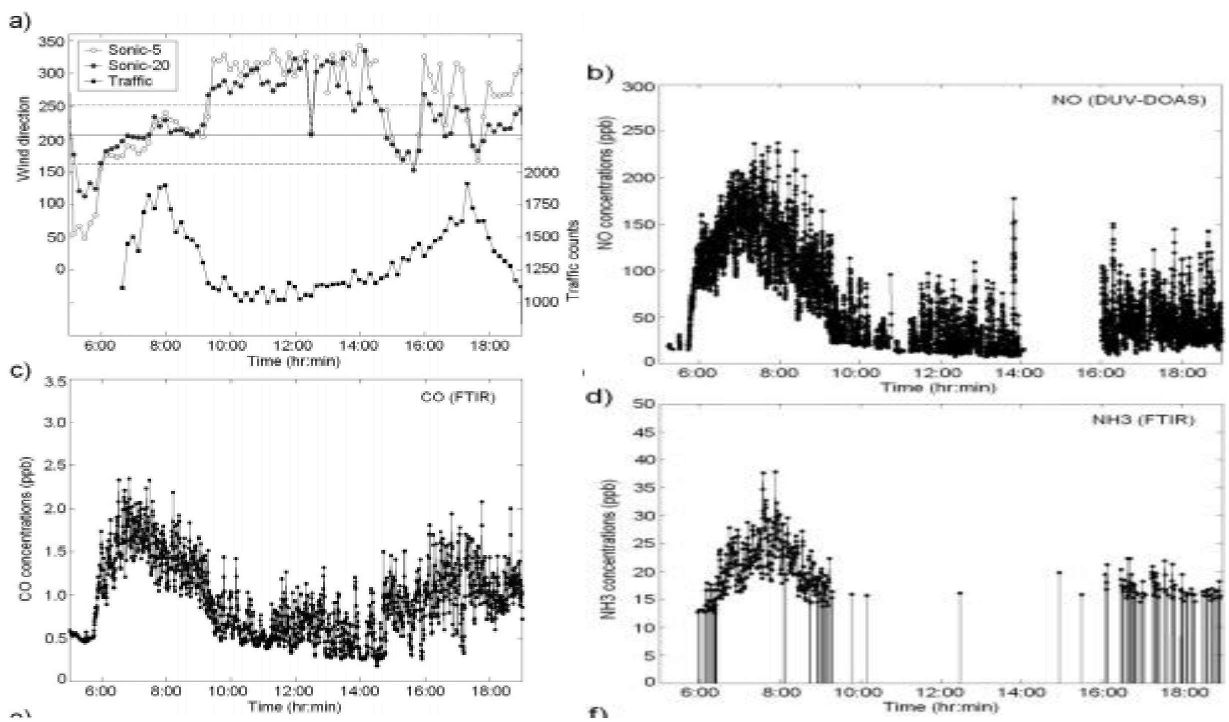


Figure 2.3. 2: Comparison of measurements from DUV-DOAs, FTIR, and Jet-REMPI for August 3, 2006, for (a) wind direction Vs traffic volume (b) NO, (c) CO, (d) NH3

(Saeb, Malekzadeh and Kardar, 2012); Investigated Air Pollution Estimation from Traffic Flows in Tehran Highways and they found out, the correlation of traffic volume with CO concentration and CO with wind speed was +0.814 and -0.655 respectively. They developed four models that could relate the traffic parameter, pollution level, geometric data, and meteorological data by using SPSS software.

1. $CO = \frac{A*Traffic}{W.Sin\alpha+B} + C * W.Sin\alpha)$

2. $CO = \frac{A*Traffic}{W.Sin\alpha+B} + C * W.Sin\alpha) + \frac{D*Traffic}{Wt}$

3. $CO = \frac{A*Traffic}{W.Sin\alpha+B} + C * W.Sin\alpha) + D * Traffic$

4. $CO = \frac{A*Traffic}{W.Sin\alpha+B} + C * W.Sin\alpha) + \frac{D*Traffic}{Wt} + E * Temp$

Where: Traffic: the rate of traffic (vehicles of hours)

$W.Sin\alpha$: wind normal speed (m/s)

Wt: total road width (m)

Temp: temperature

A, B, C, D, E : Constants

The researcher suggested; among the four models, model 1 is the best due to lower standard error of the mean and higher R^2 value than the other model.

Generally; the most studied shows emission and air pollution due to traffic were higher especially in high congested traffic flow conditions.

CHAPTER THREE: METHODOLOGY

3.1. Study area

Addis Ababa is located at the center of the country of Ethiopia and in the highland of mountain ranges at a height of 2000 to 5000m above mean sea level. Its topography ranges from rolling to a hilly area with relatively steep gradients and numerous rivers, stream valleys. Addis Ababa is a seat of the African Union and more than 100 Embassies of different countries. The Population in the city was 4 million based on the 2017 population census. One-quarter of all people in Ethiopia that live in urban areas live in the city. The city holds 527 Km^2 of an area in Ethiopia. The population density is estimated to be near 5,165 individuals per square kilometer available. Addis Ababa has 10 sub-cities and it is the quarter of the African Union.

Addis Ababa has a subtropical highland climate with precipitation varying considerably by the month. The city has a complex mix of highland climate zones, with temperature differences of up to 10 °c, depending on elevation and prevailing wind patterns. The high elevation moderates temperatures year-round, and the city's position near the equator means that temperatures are very constant from month to month.

Total numbers of a vehicle registered up to June 2011E.C (2019) in the city are 596,084Vehicles and its road surface type with length is Asphalt, Cobble, Gravel, and Earth road surface in the city have a length of 954,323.93m, 1,786,294.56m, 421,568.69m, and 262,558.69m respectively. Then the total length of the study is based on AACRA 2011e.c report is 3698.20 Km. Then, the average vehicle density of the city is the ratio of the number of the vehicle to road length which is 161.18 Veh/Km. This vehicular density implies the road infrastructure is not sufficient as compared to the vehicle population in the city which may lead to traffic congestion in the city.

The study area of this research focus at intersections since it is one of the congested area in Addis Ababa.

Sample size and sampling procedure:

The selected intersections were controlled intersections which was a congested area from the study map of the transport authority of Addis Ababa. In total controlled intersections (72 total installed signalized and 36 roundabout intersections) in the city, 7 intersections were selected using convenience sampling (non-random, non-probability) due to the researcher had limited budget or resources, time, and workforce. The selected intersections consisted of 5 (71%) signalized intersections and the remaining 2(29%) were roundabout intersections.

The selected intersection in this study were two roundabouts (Teklehaymanot roundabout and Abune Petros roundabout) and five signalized intersections (Sholla intersection, Legehar intersection, Jemo Micheal intersection, Africa union, and Imperial intersection). The selected intersection was among the congested area in the city based on the study map of high traffic jam in the transport authority of Addis Ababa as shown in chapter two figure 2.2.1 and by considering different corridors that is Sholla intersection on the north-east corridor, Jemo Michal on the south-west axis, Legehar on the east-west corridor, Africa union signalized intersection on the north-south axis, Imperial intersection on the south-east, Abune Petros roundabout and Teklehaymanot roundabout on CBD orbit; the selected area should be away from other sources of air pollution like industries, agriculture, waste; the selected area would include the center of commercial, residential, office, and transportation distribution center.

Table 3.1. 1: Description of the selected intersection of the study area:

No	Name of intersection	intersection leg number	intersection control system	Name of approach
1	Jemo Michael	4	Signalized	Ayertena
				Lideta
				Jemo1
				German roundabout
2	Africa Union	4	Signalized	Mexico
				Sarbet
				Karalo
				Bulgaria
3	Legehar	4	Signalized	Piassa
				Kirkos
				Mexico
				Meskel square
4	Sholla	4	Signalized	Kebena
				Megenagna
				Sholla Gebeya
				Begtera
5	Imperial	4	Signalized	Megenagna

				Bole
				Gerji
				Woreda 17 health center
6	Abune petros	4	Roundabout	Paster
				Piassa
				Merkato
				St. Giorgis
7	Teklehaimanot	5	Roundabout	Merkato
				Black lion hospital
				Piassa
				Abnet
				Tewodros roundabout

Figure 3.1. 1: Jemo Michael signalized intersection from Google Earth

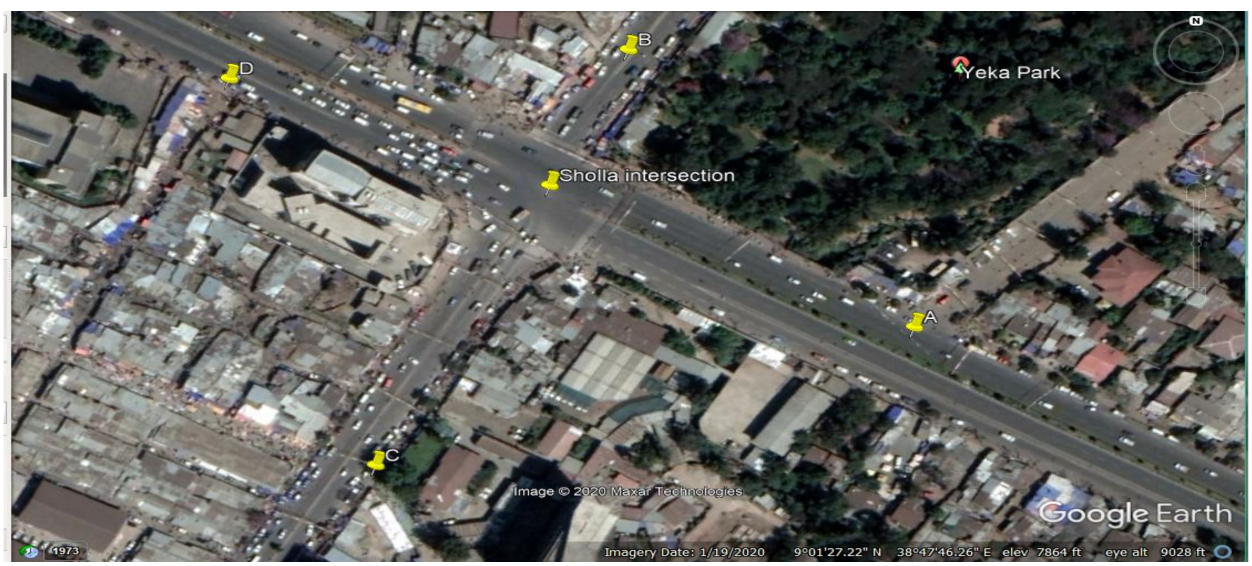


Figure 3.1. 2: Image of Sholla signalized intersection from Google Earth

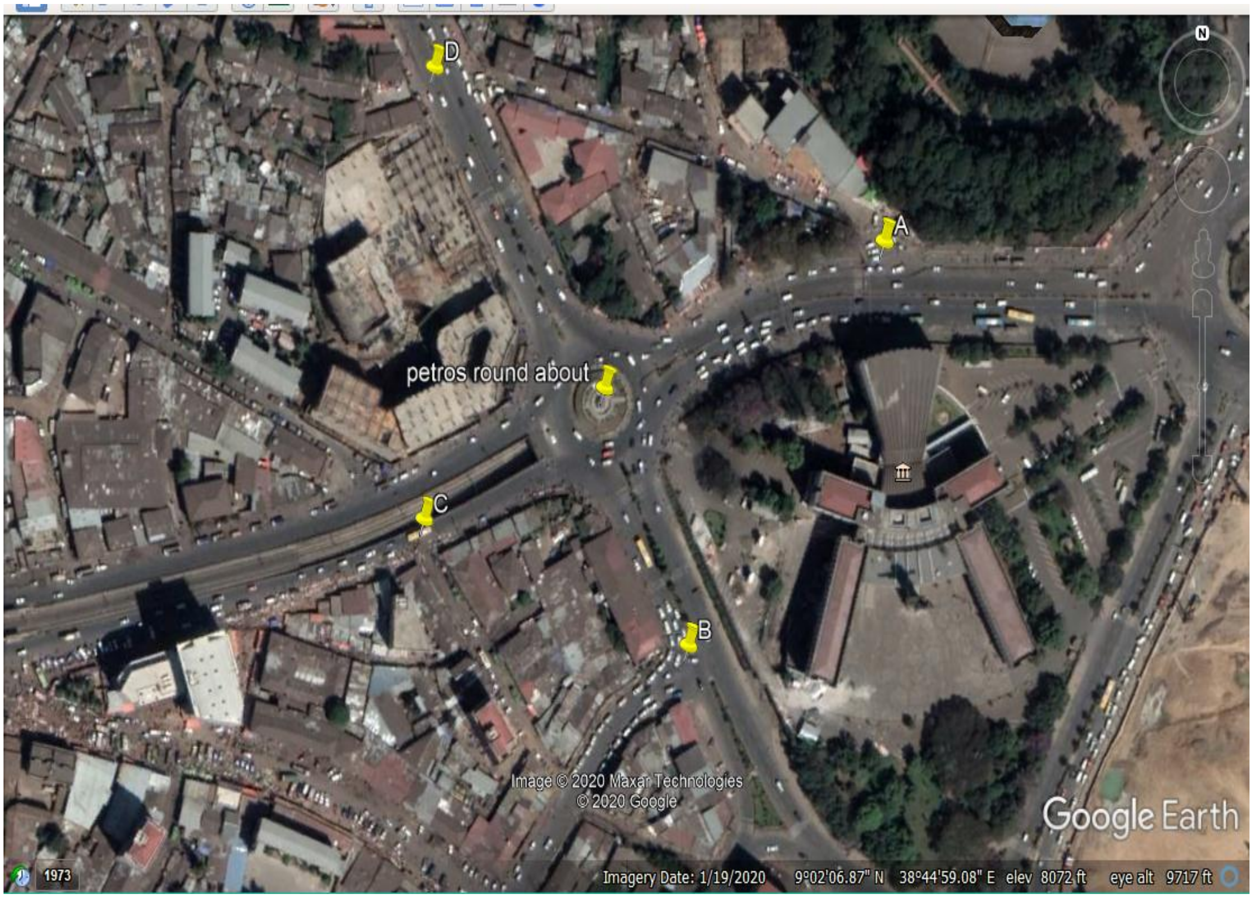


Figure 3.1. 3: Image of Abune Petros Roundabout intersection from Google Earth

3.2. Research approach

This study involves a quantitative approach to answer a research question raised in the study properly. Descriptive analysis and statistical tests were used to estimate the level of traffic congestion, pollutant concentration on the roadside, emission of different vehicle types at the selected intersections. The data sources in this study were both primary (traffic data like traffic count survey, traffic signal data; Road data like Lane width, approach grade, island diameter; ambient air quality data) and secondary (Vehicle classification, PCU, emission of different vehicle type). The data were analyzed to show the contribution of traffic congestion to air pollution.

3.3. Data collection techniques and Materials

To achieve the objective of the research; data were collected from both primary and secondary sources. Tools of primary data collection in this research were observation, field survey whereas secondary data obtained from an organization, a previous research paper. A detailed explanation of each relevant data in this study was presented in sections 3.3.1 to 3.3.4.

3.3.1. Vehicle data

Vehicle data was the essential secondary data in this thesis to convert different types of vehicles in a single unit to obtained total traffic volume in the passenger car unit (PCU).

Table 3.3.1. 1: Vehicle classification

Class	Description
1	passenger cars and taxis, pick up, minibus, land rovers, land cruisers, small bus ≤27 seats
2	Bus
3	Small and medium truck
4	Large truck
5	a class for articulate trucks that is trailers

Source:(ERA, 2013a)

PCU (Passenger car unit)

It is a standard vehicle unit to convert the other vehicle class into a single one. For the evaluation of traffic flow, the traffic volume should be converted from vehicles (Veh) to passenger car units (PCU).

The PCU value of different vehicle classes depends upon the following factors:

- Dimensions of vehicles such as width and length
- Dynamic characteristics of vehicles such as power, speed, acceleration, and braking

- Transverse and longitudinal gaps or clearance between moving vehicles
- Traffic stream characteristics
- Roadway characteristic
- Regulation and control of traffic such as speed limit

The relevance of PCU data in this research was to obtain total traffic volume in a single unit. So PCU value of motorized vehicles appropriate for Ethiopia from transport facilitation strategy for the East African community is shown in table 3.3.1.2.

Table 3.3.1. 2: Passenger car unit value of different vehicle type with the different terrain type

	PCU values for different terrain type		
Vehicle type	**Level**	**Rolling**	**Mountainous**
Bi cycle	0.5	0.5	NA
Motor cycle	0.5	1	1.5
Passenger car	1	1	1.5
Buses	2	4	6
Light good vehicles	1	1.5	3
Medium good vehicles	2.5	5	10
Heavy good vehicles	3.5	8	20

Source: (ERA, 2013b).

3.3.2. Traffic data

Traffic data such as traffic count surveys, traffic signal data that is green time, yellow, and all red time was primary data in this research. Traffic count survey conducted in each selected intersections using a video camera and then count manually from the recorded video. It is costly in the case of manpower, however; to reduce the number of manpower using a video camera at the top of the nearest building to the focused intersection and then record traffic flow of the total approach of each selected intersection.

To analysis the capacity of the intersection and to identify the peak and off-peak hours of the intersection in this research, the traffic flow of each selected intersection was collected from (7:30 am to 6:00 pm) for one day. Due to time and budget constraints this study couldn't investigate traffic data for the whole day of the week, so the data in this study were collected for the day that would have an average value of traffic i.e. on Tuesday, Wednesday and Thursday.

On Monday there was a higher traffic jam in the selected intersection during observation of the site due to it was the day that most of the work opened and then high movement that led to high jam.

3.3.3. Geometric data

The first objective of this thesis was to identify the level of traffic congestion in the selected area using Sidra software. So to know the level of traffic congestion of the intersection, the level of service or Volume to capacity ratio is the output parameters of the software. But the capacity analysis was influenced by Saturation flow rate and saturation flow rate depend on ideal saturation flow rate adjusted by different factors like the Number of the lane, Lane width, Median width, Approach grade, and so on. Then by collecting appropriate geometric data of the selected intersection and inserting them into the software to get adequate analysis.

Geometric data such as number of the lane, lane width, median width, roundabout data like island diameter, number of the circular lane, circular lane width was conducted by field measurement using a meter on Sunday (a day that has less traffic flow) for each intersection whereas altitude, approach grade, and distance of each intersection obtained from Google earth. The recorded geometric data presented in appendix B.

3.3.4. Air quality pollutant parameters data

Air quality pollutants concentration data was primary data conducted at the field to know the pollutant concentration at peak and off-peak hours and then used to investigate the effect of traffic congestion on air pollution.

In this study carbon monoxide (CO), sulfur dioxide (SO2), particular matter 2.5 and 10(PM 2.5 and PM10) are selected to conduct roadside ambient air quality to show the effect of traffic congestion on ambient air quality due to they are among the most common air pollutants from transportation, they consequence to hazard damage of society health and also the availability of the instrument for measurement of the pollutants. So using Aeroqual series 500 portable air pollutant detector-for Carbon monoxide (CO), Sulfur dioxide, and Laser PM2.5 for particular matter 2.5(PM2.5)and particular matter 10 (PM10) for three days (Tuesday, Wednesday, and Thursday) of each selected intersections of this study.

Traffic count, metrological data (wind speed, wind direction, temperature, humidity), and roadside ambient air quality survey conducted simultaneously at both peaks and off-peak hr. Field surveys for conducted traffic volume count and roadside ambient air quality were held for three days in each intersection at both congested and steady traffic flow conditions as presented in Appendix E.

Aeroqual's series 500

Aeroqual's portable air quality monitors are tools for air quality professionals and enthusiasts alike to gather real-time information on the surrounding air. They are a flexible air quality monitoring solution that can be configured with 27 different gas sensors and particle sensors for a range of uses from environmental monitoring to industrial applications.

Aeroqual's portable air quality monitors can be used to measure; Short term air quality studies, Checks on pollution "hot spots", Site air quality surveys, Personal exposure assessments, Short term fixed monitoring.

Laser PM2.5 meter

It is a high-precision air quality measurement monitor sensor to measure the PM 2.5 and PM10 air pollutant concentrations.

The instrument is a short measuring time, stable performance strong function, easy operation, low power consumption, with functions of time display, real-time measurement, very suitable for indoor and outdoor environmental monitoring, can also be used in the detection of air purification machine to air purification effect.

Figure 3.3.4. 1: instruments of air pollutant concentration measurement.

The procedure that should be taken to recorded and analyzed essential data using air pollutant concentrations would be:

- Prepare the Aeroqual and laser pm2.5 meter to record data at each selected intersection
- Gather data: Use the monitor and interchangeable sensors to take Spot measurements or log data over time and space. After that use, the paper pen method writes the recorded value.

Simultaneously to air pollutant measurement, metrological data like temperature, humidity, and wind speed, and wind direction was measured using a phone application that could show the metrological data.

Figure 3.3.4. 2: image during field measurement of air pollutant at Sholla intersection.

Date and days for data recording:

- Traffic count video recording for intersection analysis was held from sep24 to Oct 8, 2020, one day for each intersection (from 7:30 AM to 6:00 PM) to identify; traffic congestion level, peak and off peak hour and to show the effect of traffic congestion on gaseous emission of each selected intersections.
- Geometric data such as number of the lane, lane width, and median width, number of the circular lane, circular lane width, and island diameter were recorded on September 27 and October 4, 2020, on Sunday which has low traffic flow condition.
- Air pollutants parameter measurement, traffic count, and metrological data like wind speed, temperature, humidity, and wind direction were recorded from Oct 13 to Nov 26, 2020, for both congested and steady traffic flow conditions to show the effect of traffic congestion on air quality.

3.4. Method of data analysis

In this research descriptive statistical analysis, statistical tests to examine the relationships among factors, and graphical techniques using Microsoft excel were provided for an excellent method to visualize the variability and other properties of a set of data.

The data were analyzed in this study as shown below;

i. Analysis of traffic volume in the passenger car unit and determine the peak hour volume

- Manually count the recorded traffic flow in 15 min interval for each intersection approach in different movement definition (through, right turn, left turn, u-turn)
- Write the counted data on an excel sheet.
- Determine total traffic volume in PCU for each 15-minute interval to convert different class of vehicle into a single unit and then used to measure the level of traffic congestion and to show the effect of traffic congestion on ambient air quality.
- Determine hourly volume by summing up the four consecutive 15 minutes total traffic volume in PCU.
- Determine the peak hour volume, which is the maximum hourly volume.

ii. Analysis of Traffic congestion using SIDRA intersection 8 plus.

iii. Compare the concentration observed from the field from the standard adopted by the Ethiopian environment protection Authority and WHO.

iv. Emission of different vehicle type using a tier-three method (Rosca, Costescu, and Rusca, 2014) (Bharadwaj, Ballare and Chandel, 2017)

$$\text{Emission } = \text{total traffic volume} * \text{emission factor per vehicle.}$$

v. Show the effect of traffic congestion on emission and air quality using descriptive analysis using excel sheet, compute the percentage increases, ANOVA test to determine the significance of traffic flow condition on air pollution and regression analysis to identify the significant factor for the regression model.

- Analysis of the effect of traffic congestion on air quality in this research used two steps;

Step 1: Statistically test the significant difference of ambient air pollutants concentration between congested and steady traffic flow conditions by applying one way ANOVA test using Stata.

Step 2: If there is a significant difference in ambient air quality between different traffic flow conditions, and then quantify the effect of traffic congestion on air quality using percentage increase value at maximum, average and minimum value.

$$\text{Percentage increase } (\%)_{\text{(Maximum)CO, SO2, PM 10, PM2.5}} = \frac{(\text{Congested Maximum} - \text{Steady } Maximum) * 100}{\text{Steady Maximum}}$$

$$\text{Percentage increase } (\%)_{\text{(Average)CO, SO2, PM 10, PM2.5}} = \frac{(\text{Congested Average} - \text{Steady } Average) * 100}{\text{Steady Average}}$$

$$\text{Percentage increase } (\%)_{\text{(Minimum)CO, SO2, PM 10, PM2.5}} = \frac{(\text{Congested Minimum} - \text{Steady } Minimum) * 100}{\text{Steady Minimum}}$$

- Finally, develop a regression model for ambient air pollutants to show the effect of different factor on ambient air quality and also to predict a short term air pollutants concentration of CO, SO2, PM2.5 and PM10.

Assumption of multiple linear regression models (Chatterjee and S. Simonoff, 2013) are;

- There is a linear relationship between the dependent and the independent variables.
- The independent variables are not too highly correlated with each other
- Residuals should be normally distributed with a mean of 0 and variance σ

Multiple linear regressions are formulated in the form of:

$$Y = \beta o + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \cdots + \beta nXn$$

Where: Y= dependent/response variable

βo = constant coefficient

$\beta 1, \ldots, \beta n$ = slopes of explanatory variables

- The steps conducted to analyze and develop a regression model of ambient air quality pollutants are;

Step1: Identify dependent and independent variables. The dependent variables are the concentration of carbon monoxide, sulfur dioxide, particular mater 2.5 and 10 whereas the independent variables are traffic volume, percentage of heavy vehicle, green time of the selected approach, humidity, temperature, altitude, approach grade, and distance between two signalized and /or roundabout intersections that may influence the level of the focused intersection, number of lane, lane width of the selected approach, type of intersection control(signalized and roundabout categorical variable), day of week that the data collected(Tuesday, Wednesday and Thursday), time of day(morning and afternoon) and wind direction(East-North, East-South, and South-East).

Since the independent variables contain a qualitative variable, so In this case for the type of intersection coded 1 for signalized and 0 for a roundabout, for the time of day coded 1 for morning and 0 for an afternoon. For explanatory variables that have three categories, provide 2 dummy regressors. That is for a day of week, D1 coded as 1 for Tuesday and 0 for others, D2 coded as 1 for Wednesday and 0 for others and taken Thursday as baseline category, for wind direction D1 coded as 1 for east north and 0 for others, D 2 coded as 1 for east south and 0 for others and taken south-East as baseline category.

Step 2: Check the assumptions

Step 3: If the assumption is satisfied, then applied regression analysis using Stata.

Step 4: Identify the significant variable at a 95% confidence interval. If the P-value less than 0.05 then the factors are a significant variable for the regression model. And then Provide a regression model.

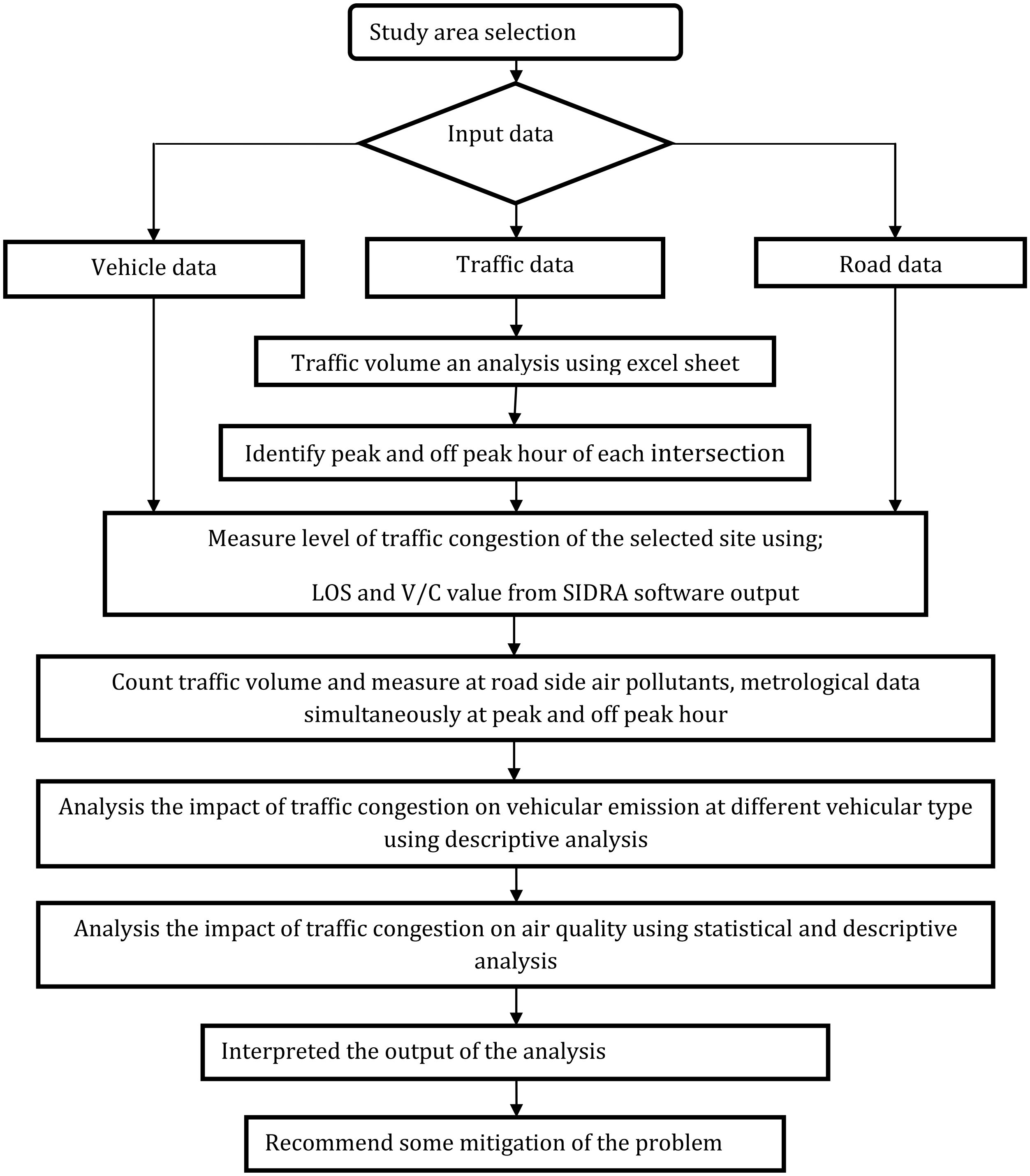


Figure 3.4: Methodology organization of this research

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Traffic congestion analysis using SIDRA software

The traffic congestion level of an intersection can be analyzed in various ways but in this research, level of service or volume to capacity ratio output from SIDRA software was used to analyze the congestion level of the selected sampling areas. Level of service and volume to capacity ratio to know the level of congestion of an intersection at peak hour traffic volume analysis using excel sheet.

As the author explained in the method of data analysis which is an analysis of traffic volume in the passenger car unit and then determine the peak hour volume. In addition to the peak hour volume; the peak hour factor and percentage of the heavy vehicle are essential input parameters to know the level of traffic congestion of an intersection. Based on the source of the ERA 2013, route selection manual, this study adopted the PCU value of level terrain since the approach grade of each intersection from google earth shows ≤ 5%. So peak hour volume (PHV), peak hour factor (PHF), and percentage of the heavy vehicle (%HV) of each intersection approaches for different movement definition computed as;

$$\text{PHV} = \max(\text{hourly volume by summing up the four consecutive 15 minutes in PCU})$$

$$\text{PHF} = \frac{\text{Peak Hour Volume}}{4 * \text{peak 15−minute volume within the peak hour}}$$

$$\%\text{HV} = \frac{\text{Total heavy vehicle volume in PCU}}{\text{Total traffic volume in PCU}} * 100\%$$

The input parameters of the software shown in the table4.1.1 and table 4.1.2 and the finding of the software are shown in table 4.1.3.

Table 4.1. 1: Geometric and traffic volume input data for SIDRA intersection software

			Geometric data			Traffic volume data		
Intersection name	Approach name	Movement	# of lane	Lane width	Median width	pcu/ hr	% of HV	PHF
Africa union	Mexico	Through	3	3.1	5	2053	13.57	0.91
		R. turn				472	13.98	0.78
	Sarbet	Through	3	3.5	1.7	2092	11.81	0.84
		R. turn				913	5.7	0.93
	Bulgaria	Through	3	3	1.15	586	25.51	0.93
		R. turn				105	2.38	0.83
		L. turn				900	5.44	0.92
		U. turn				5	0	0.92
	Karalo	Through	3	3	1	772	33.68	0.93
		R. turn				337	14.26	0.93
		L. turn				247	14.57	0.90
		U. turn				7	0	0.94
Jemo Michael	Jemo 1	Through	3	3.5	8.8	1172	18.35	0.89
		R. turn				695	14.96	0.92
		L. turn				319	26.33	0.95
		U. turn				25	20	0.9
	Lideta	Through	3	3.5	1	1064	20.39	0.96
		R. turn				119	45.99	0.86
		L. turn				326	29.91	0.87
		U. turn				48	0	0.88
	German	Through	4	3	2.5	577	47.44	0.91
		R. turn				280	28.26	0.84
		L. turn				625	14.96	0.91
		U. turn				89	19.77	0.9
	Ayertena	Through	3	3.5	2.5	673	34.18	0.94
		R. turn				144	21.53	0.83
		L. turn				235	14.29	0.89
		U. turn				58	30.43	0.93
Legehar	Mexico	Through	3	3.5	2.6	1601	10.31	0.9
		R. turn				208	18.03	0.92
		L. turn				188	3.46	0.93
		U. turn				34	7.35	0.91
	Meskel square	Through	4	3.5	4.35	1522	13.53	0.91
		R. turn				196	1.40	0.9
		L. turn				193	29.83	0.92
		U. turn				191	4.6	0.88
	Piassa	Through	3	3.5	1.92	518	11.04	0.88
		R. turn				173	0	0.87

		L. turn				210	3.14	0.89
		U. turn				33	0	0.87
	Kirkos	Through	3	3.5	14	472	10.81	0.94
		R. turn				357	14.12	0.85
		L. turn				178	25.34	0.93
		U. turn				7	0	0.84
Imperial	Bole	Through	4	3	1	1483	8.77	0.89
		R. turn				431	12.31	0.86
		L. turn				250	16	0.86
		U. turn				43	41.18	0.89
	Megenagna	Through	4	3	0.65	1481	11.04	0.89
		R. turn				136	12.18	0.87
		L. turn				271	9.78	0.87
		U. turn				9	0	0.86
	Gerji	Through	2	3.6	0	518	5.79	0.95
		R. turn				120	7.08	0.94
		L. turn				486	12.76	0.91
		U. turn				0	0	0
	Woreda 17 h.c	Through	3	3.5	1	342	8.78	0.94
		R. turn				475	19.6	0.98
		L. turn				216	8.12	0.86
		U. turn				5	0	0.63
Sholla	Kebena	Through	3	3	0.5	1699	12.63	0.97
		R. turn				476	22.82	0.91
		L. turn				20	0	0.83
		U. turn				27	9.43	0.88
	Megenagna	Through	4	3.6	4	1586	21.03	0.83
		R. turn				77	28.10	0.87
		L. turn				202	19.35	0.91
		U. turn				59	0	0.891
	Sholla	Through	3	3.5	0.90	88	2.84	0.83
		R. turn				278	14.77	0.82
		L. turn				383	2.75	0.97
		U. turn				113	2.22	0.88
	Begtera	Through	3	3	0.5	103	14.15	0.83
		R. turn				30	0	0.87
		L. turn				216	15.55	0.89
		U. turn				9	0	0.86
Teklehaymanot roundabout `Africa union	Merkato	L1. turn	3	3.2	0	851	4.18	0.86
		R1.turn				435	40.62	0.7
		L2.turn				21	12.93	0.84
		L3. turn				86	2.14	0.8
		L1. turn				30	15.28	0.91
		R1. turn				384	17.49	0.94
	Abnet	L2.turn	3	3	1	460	17.17	0.96

		L3. turn				554	19.92	0.95
	Black lion hospital	L1. turn	3	3.6	1.2	635	4.31	0.86
		R1. turn				48	4.04	0.93
		L2.turn				208	5.47	0.88
		R2. turn				167	3.7	0.86
	Piassa	L1. turn	3	3.6	1	626	4.24	0.92
		R1. turn				138	3.26	0.91
		R2.turn				236	7.41	0.91
	Tewodros roundabout	L1. turn	2	3.2	0	447	0	0.88
		R1. turn				50	6	0.79
		L2.turn				100	4	0.78
		R2. turn				100	1	0.9
Abune petros	Paster	Through	3	3.5	0.8	1345	3.39	0.86
		R. turn				379	9.59	0.87
		L. turn				315	10.67	0.78
	Merkato	Through	3	3.6	12	564	11.93	0.95
		R. turn				120	9.8	0.92
		L. turn				301	10.17	0.93
	Piassa	Through	3	3.5	1.3	649	12.65	0.84
		R. turn				290	14.06	0.92
		L. turn				267	15.85	0.94
	St. Giorgis	Through	3	3.5	0.95	465	15.09	0.79
		R. turn				168	22.62	0.75
		L. turn				12	0	0.72

Table 4.1. 2: Signalized traffic data and Roundabout data input for SIDRA software

		Phase Name							
Name of intersection		A	B	C	D	E	#of circular lane	Circular lane width(m)	Island diameter(m)
Africa union	Phase time(sec)	66	32	37	-	-			
Jemo Michael	Phase time(sec)	60	44	36	28	24			
Legehar	Phase time(sec)	25	25	45	40	45			
Imperial	Phase time(sec)	60	25	30	40	30			
Sholla	Phase time(sec)	30	20	50	50	-			
Teklehahymanot							2	10	40
Abune Petros							3	4.3	36

Based on the essential parameters that may influence the level of traffic congestion, the SIDRA software generates the level of service as well as volume to capacity ratio of each selected approach in each intersection.

Table 4.1. 3: Output analysis of SIDRA software and the level of traffic congestion

No	Name of intersection	Name of approach	LOS	v/c	Level of traffic congestion
1	Africa union	Mexico	LOS F	1.381	Severe Congestion
		Sarbet	LOS F	1.523	Severe Congestion
		Bulgaria	LOS F	1.936	Severe Congestion
		Karalo	LOS F	1.677	Severe Congestion
		Total	LOS F	1.936	Severe Congestion
2	Jemo Michael	Jemo1	LOS F	2.748	Severe Congestion
		Lideta	LOS F	1.85	Severe Congestion
		German	LOS F	1.975	Severe Congestion
		Ayertena	LOS F	2.748	Severe Congestion
		Total	LOS F	2.748	Severe Congestion
3	Legehar	Mexico	LOS F	1.88	Severe Congestion
		Meskel square	LOS F	1.394	Severe

					Congestion
		Piassa	LOS F	1.696	Severe Congestion
		Kirkos	LOS F	1.17	Severe Congestion
		Total	LOS F	1.88	Severe Congestion
4	Imperial	Bole	LOS F	1.475	Severe Congestion
		Megenagna	LOS F	1.703	Severe Congestion
		Gerji	LOS F	1.224	Severe Congestion
		Woreda 17 h.c	LOS F	1.703	Severe Congestion
		Total	LOS F	1.703	Severe Congestion
5	Sholla	Kebena	LOS F	1.584	Severe Congestion
		Megenagna	LOS F	1.523	Severe Congestion
		Sholla	LOS F	1.07	Severe Congestion
		Begtera	LOS F	1.286	Severe Congestion
		Total	LOS F	1.584	Severe Congestion
6	Teklehaymanot roundabout	Merkato	LOS F	1.581	Severe Congestion
		Abnet	LOS F	1.379	Severe Congestion

		Black lion H.	LOS E	1.079	Severe Congestion
		Piassa	LOS E	1.077	Severe Congestion
		Tewodros square	LOS D	0.814	Heavy Congestion
		Total	LOS F	1.581	Severe Congestion
7	Abune petros	Paster	LOS F	1.373	Severe Congestion
		Merkato	LOS D	0.984	Heavy Congestion
		Piassa	LOS D	0.975	Heavy Congestion
		St. Giorgis	LOS C	0.718	Moderate Congestion
		Total	LOS F	1.373	Severe Congestion

As the analysis is shown in table 4.1.3 'based on Nashua Regional Planning Commission level of traffic congestion identification', all the selected sampling areas in this study have a severe congestion level which may lead to pollution of ambient air quality due to road transportation. So the first research question answer in this study is each selected intersection has a severe congestion level since each intersection has an F level of service (LOS F) and a Volume to a capacity ratio greater than one(V/C >1).

4.2. Analysis of the effect of traffic congestion on vehicular emission

From traffic volume analysis; identify the peak and off-peak hours of each selected intersections and then compute the percentage increase of vehicular emission gases due to congestion as a base of steady traffic flow condition. So to achieve the second specific objective of this research, applied the secondary emission factor data in the previous studies and analyzed traffic volume recorded in each selected intersection approach that has higher passenger car unit volume.

Table 4.2. 1: Average value of HC, CO, CO2 (secondary data)

	The average value of HC, CO, and CO2 per vehicle		
Vehicle type	HC(PPM)	CO(PPM)	CO2(PPM)
Car(4 wheel private car their seat less than 12 like pickup, taxi, landrover, Vitz)	1670.45	3.72	7.37
Minibus	1159.33	5.83	8.86
Bus	781	5.84	11.06
Truck	1934	11.34	7.02

Source: (Kebede, 2019)

- The gaseous emission in each intersection was computed as;

Total Gaseous Emission of HC per 15 min $_i$ = 15 min total traffic volume $_i$ * average value of HC $_i$

Total Gaseous Emission of CO per 15 min $_i$ = 15 min total traffic volume $_i$ * average value of CO $_i$

Total Gaseous Emission of CO2 per 15 min $_i$ = 15 min total traffic volume $_i$ * average value of CO2 $_{i\,0}$

Where: i represent different vehicle types and

The average value of HC, CO CO2, and smoke density is in table4.2.1.

From traffic volume analysis, the congested and steady period of each selected intersection are presented in table 4.2.2.

Table 4.2. 2 : Congested and Steady time of each selected intersection

No	Name of intersection	Congested time	Steady time
1	Africa union	8:00-9:00 AM	1:30-2:30 PM
2	Jemo Michael	7:30-8:30 AM	1:00-2:00 PM
3	Legehar	8:30-9:30 AM	3:00-4:00 PM
4	Imperial	3:00-4:00 PM	10:00-11:00 AM
5	Sholla	5:00-6:00 PM	10:0-11:00 AM
6	Abune Petros	5:00-6:00 PM	8:00-9:00 AM
7	Teklehaymanot	10:00-11:00 AM	1:00-2:00 PM

I. Africa union Signalized intersection

From Africa union signalized intersection approaches, Sarbet approach has a greater number of vehicles rather than the other approach as shown in table4.1.1, so this study analyses the effect of traffic congestion on vehicular emission on Sarbet approach.

Gaseous emission of Hydrocarbon, Carbon monoxide, and Carbon dioxide and also smoke density of different vehicle types on Sarbet approach in Africa Union signalized intersection presented in appendix D. The chart that shows the vehicular gaseous emission in different vehicular types in 15 minute travel time interval presented in the figures 4.2.1 to 4.2.4.

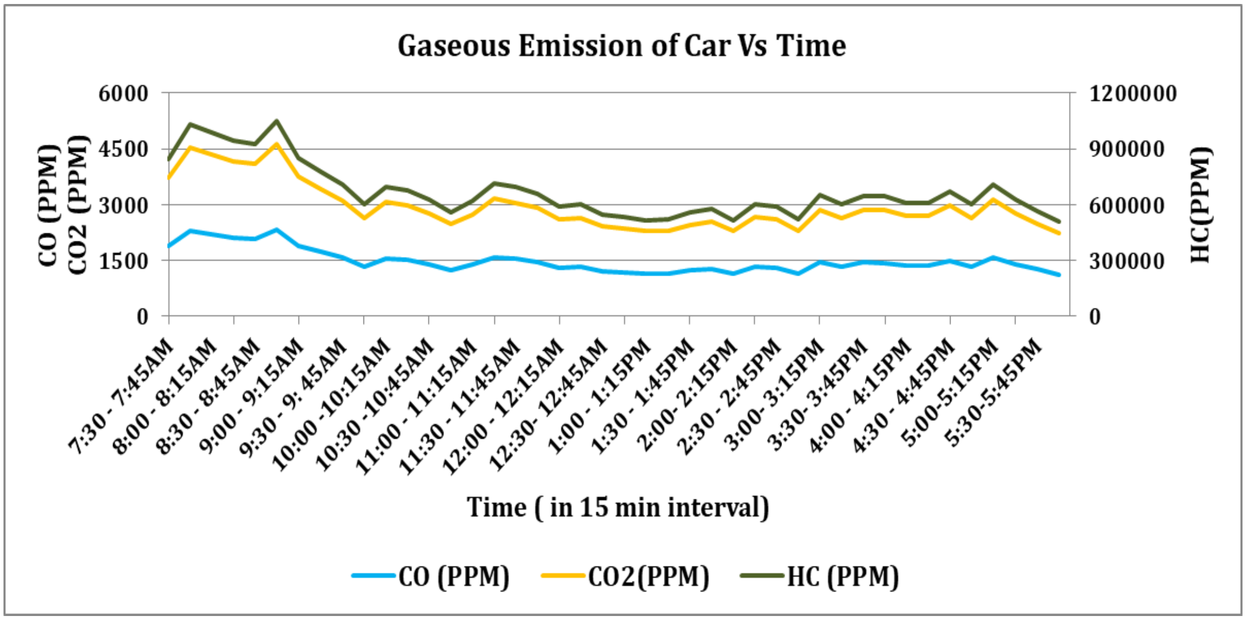


Figure 4.2. 1: Gaseous emission of Car Vs time at Africa Union signalized intersection (Sarbet approach).

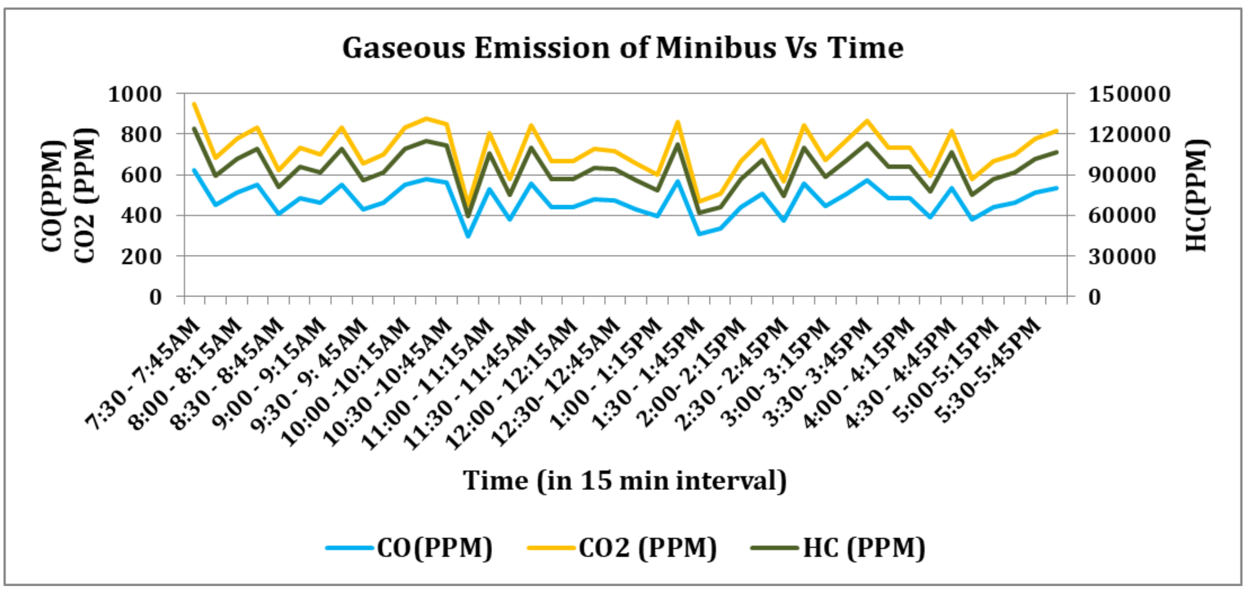


Figure 4.2. 2: Gaseous emission of Minibus Vs time at Africa Union signalized intersection (Sarbet approach).

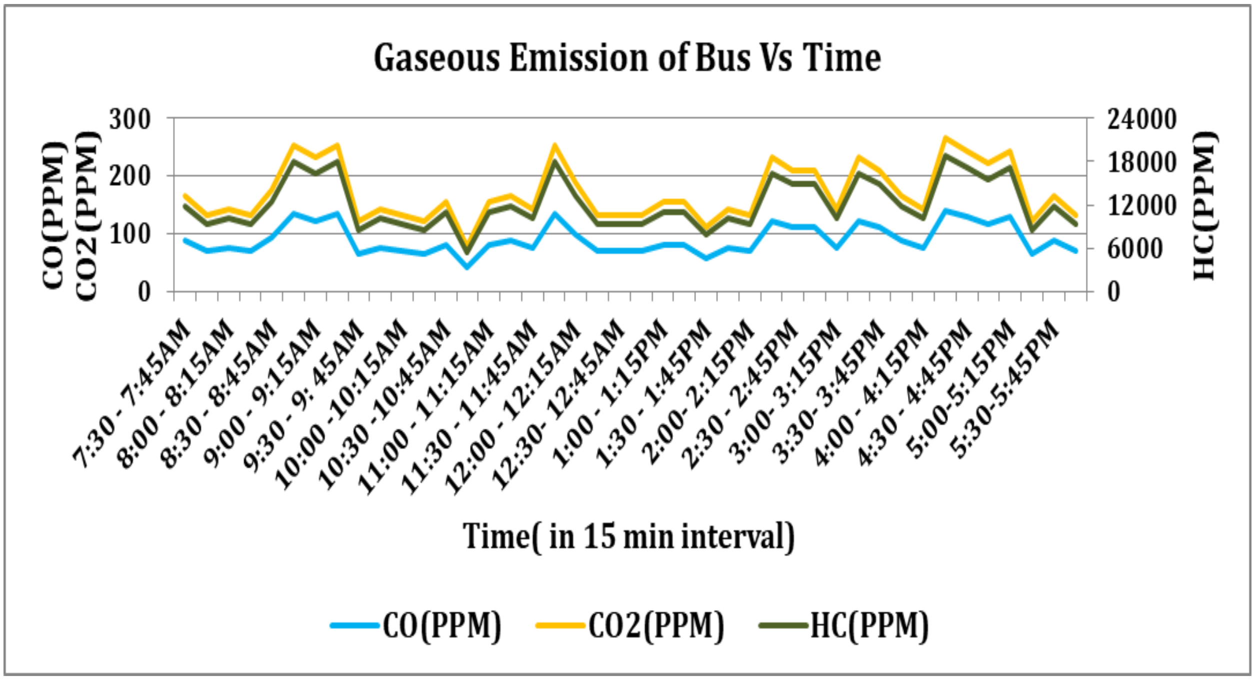


Figure 4.2. 3: Gaseous emission of Bus Vs travel at Africa Union signalized intersection (Sarbet approach).

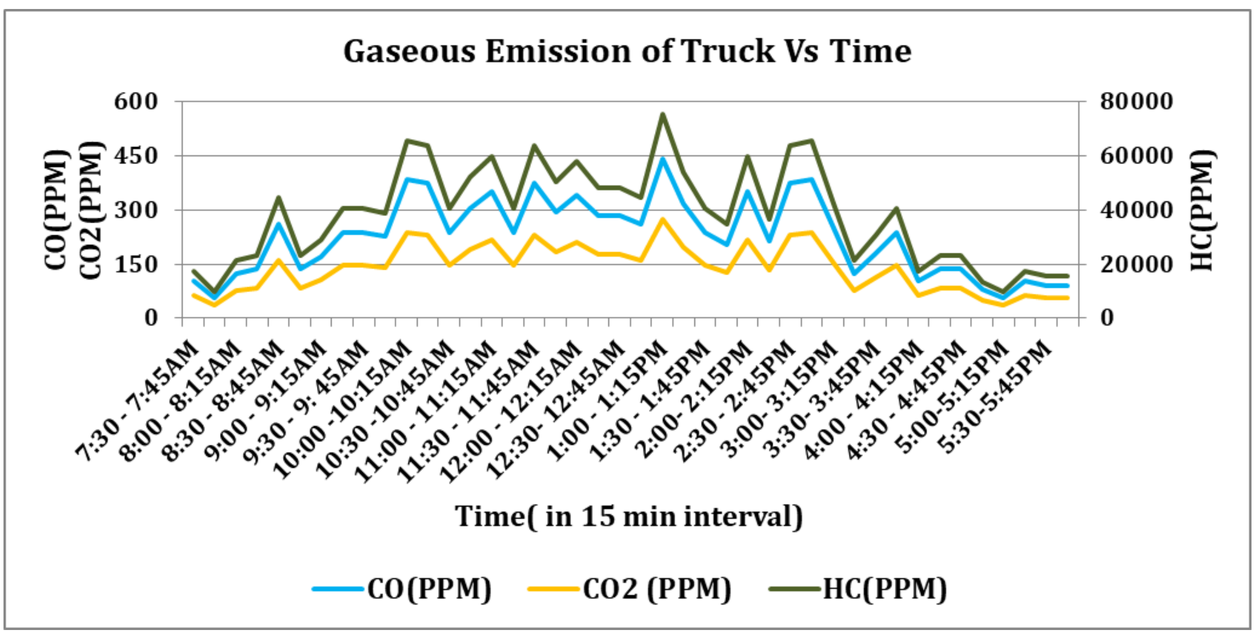


Figure 4.2. 4: Gaseous emission of Truck Vs time at Africa union signalized intersection (Sarbet approach).

During the congested period as a base of steady traffic flow conditions; the average gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide for car, minibus, bus, truck on the Sarbet approach in Africa union signalized intersection increased by 24-37 %, 24-38%, 35-55%, and 48 – 65% respectively. The result shows, on the Sarbet approach in Africa union intersection; Car and Minibus have the same percentage increase and lower than bus and truck. The truck has a higher percentage than others. This implies the number of Truck variations during congested and steady traffic flow conditions per 15-minute traffic volume analysis is higher than the car, minibus, and bus on the sarbet approach. Increase average gas emission during congested traffic conditions of Car and the Minibus are lower while the Truck is within the range that on the study done by (Rosca, Costescu and Rusca, 2014).

(Rosca, Costescu and Rusca, 2014) investigate the impact of traffic congestion on greenhouse gas emission for different vehicle classes using the methodology of combines field recorded traffic data, computer traffic simulation using VISSIM software, and emission factors estimated through the Tier 3 approach of the EEA guidelines. They investigated, during congested periods, the average passenger car emission values increase between 40–60%. And also for light duty vehicles the average emission increase up to 70%. So this study argues the Roscas investigation.

II. Jemo Michael Signalized intersection

Jemo approach has a greater number of vehicles rather than the other approach as shown in table4.1.1. So the effect of traffic congestion on vehicular emission on the Jemo approach is analyzed as shown in Figures 4.2.5 and 4.2.6.

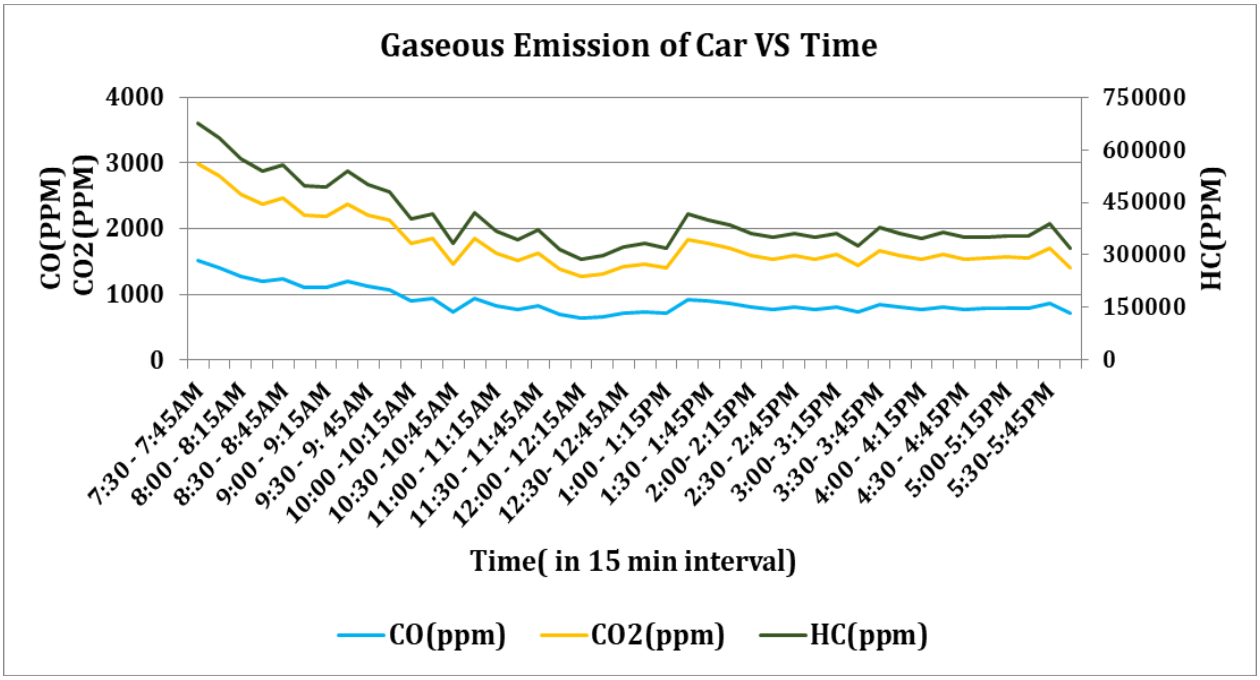


Figure 4.2. 5: Gaseous emission of Car Vs time at Jemo Michael signalized intersection (Jemo approach).

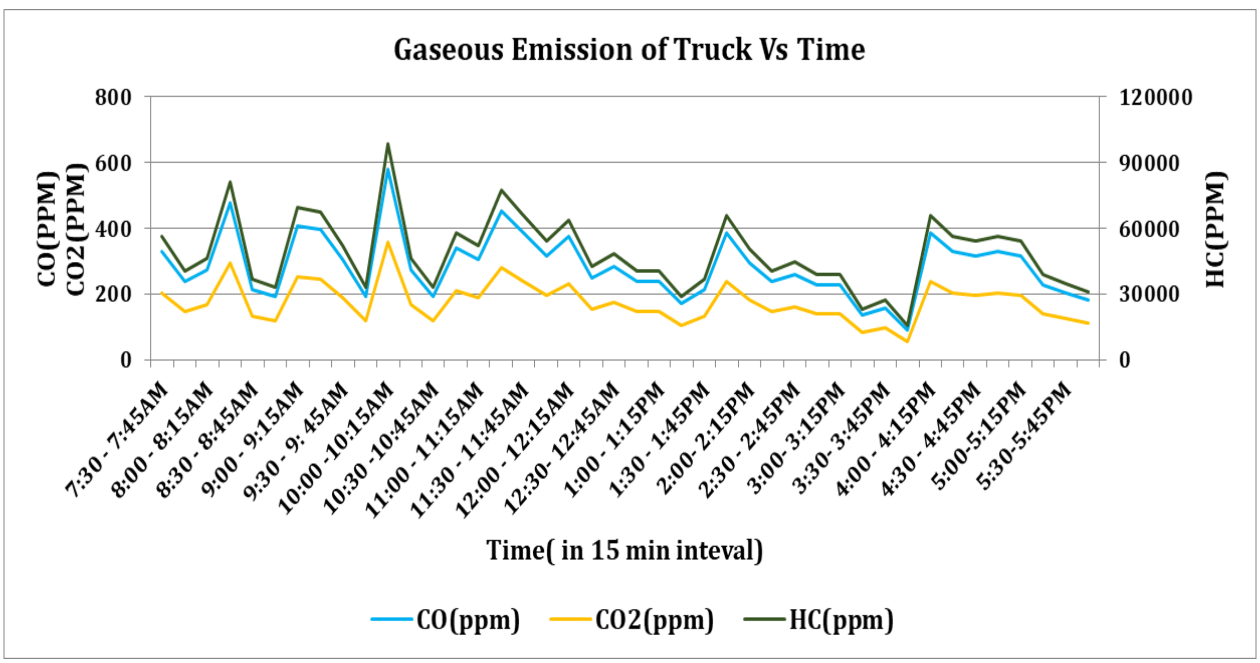


Figure 4.2. 6: Gaseous emission of Truck Vs time at Jemo Michael intersection (Jemo 1 approach).

During the congested period as a base of steady traffic flow conditions , the average gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide, and also smoke density for car, minibus, bus, truck on Jemo 1 approach in Jemo Michael signalized intersection increased by 28-41%, 23-38%, 47-56% and 50-69% respectively. As the finding shows, Minibus has a lower effect than Car, Bus and Truck whereas Truck has a higher percentage than others. This implies the number of Truck variations during congested and steady traffic flow conditions per 15-minute traffic volume analysis is higher than a car, minibus, and bus on the Jemo approach. Increase average gas emission during congested traffic flow conditions of the Car and Minibus are lower while the Truck is within the range that on the study done by (Rosca, Costescu and Rusca, 2014), it is the same as analysis on Sarbet approach.

III. Legehar signalized intersection

In Legehar signalized intersection traffic volume analysis, the Mexico approach has a greater number of vehicles rather than the other approach as shown in table4.1.1. So the effect of traffic congestion on vehicular emission on the Jemo approach was analyzed as shown in Figures 4.2.7 and 4.2.8.

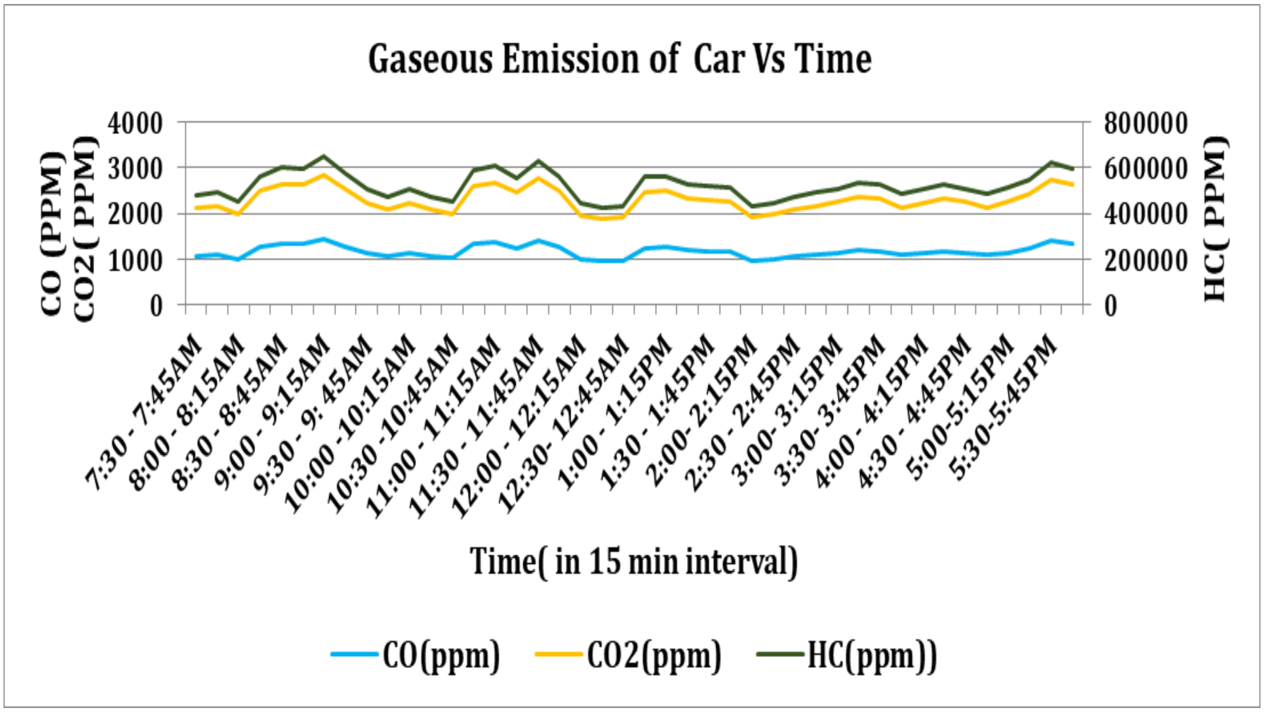


Figure 4.2. 7: Gaseous emission of Car Vs time at Legehar signalized intersection (Mexico approach).

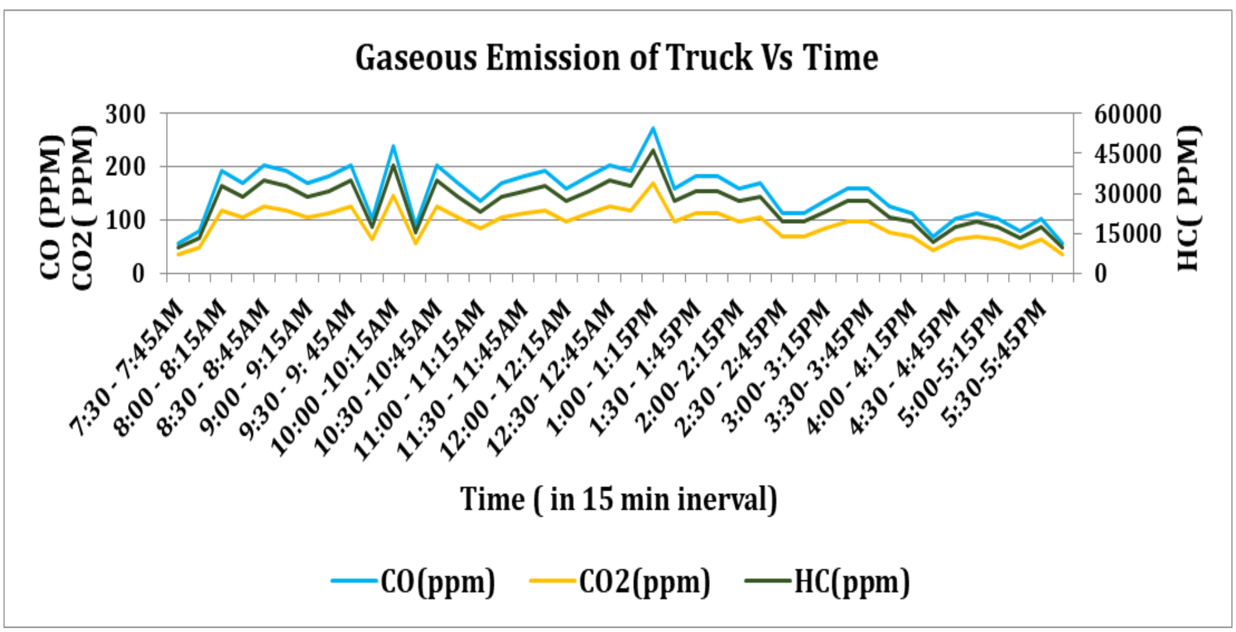


Figure4.2. 8: Gaseous emission of Truck Vs time at Legehar signalized intersection (Mexico approach).

During the congested period as a base of steady traffic flow conditions, the average gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide for car, minibus, bus, truck on Mexico approach in Legehar signalized intersection increased by 18 - 28 %, 23– 33%, 54 - 64%, and 46 – 66% respectively. The result shows, Car has a lower percentage increase and Truck has a higher percentage than others. This implies the number of Truck variations during congested and steady traffic flow conditions per 15-minute traffic volume analysis is higher than a car, minibus, and bus on Mexico approach. Increase average gas emission during congested traffic conditions of the Car and Minibus are lower while the Truck is within the range that on the study done by (Rosca, Costescu, and Rusca, 2014).

IV. Imperial signalized intersection

In Imperial signalized intersection traffic volume analysis, the Bole approach has a greater number of vehicles rather than the other approach as shown in table4.1.1. So the effect of traffic congestion on vehicular emission on the Bole approach is analyzed as shown in Figures 4.2.9 and 4.2.10.

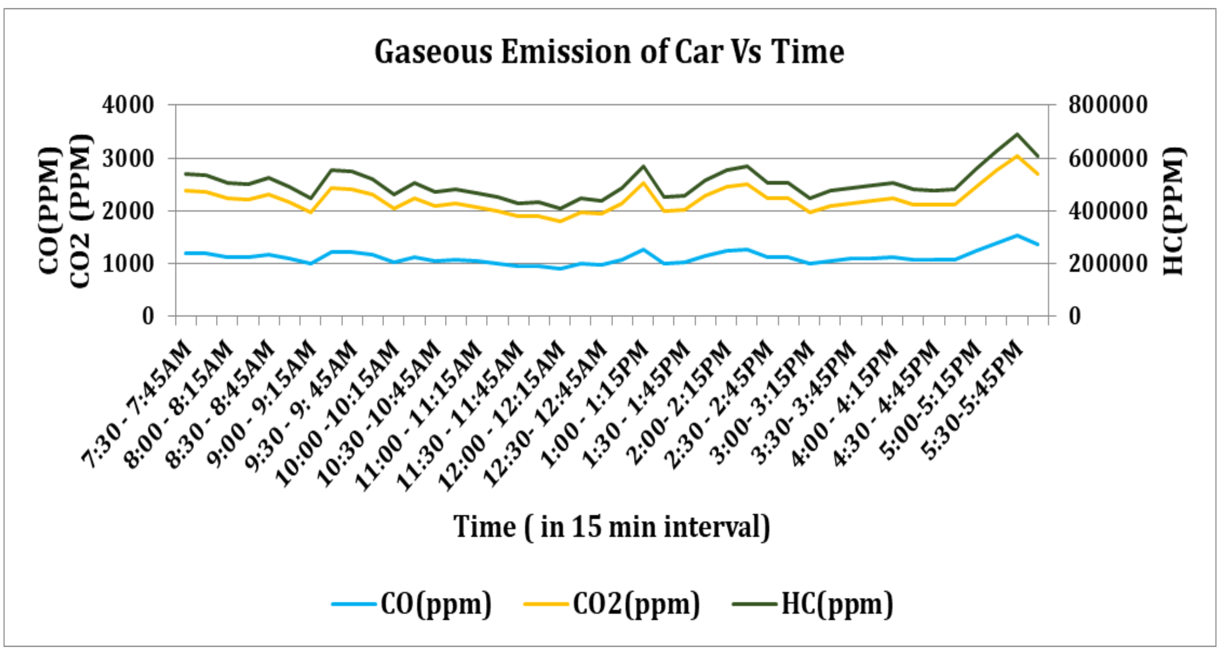


Figure 4.2. 9: Gaseous emission of Car Vs time at Imperial Signalized intersection (Bole approach).

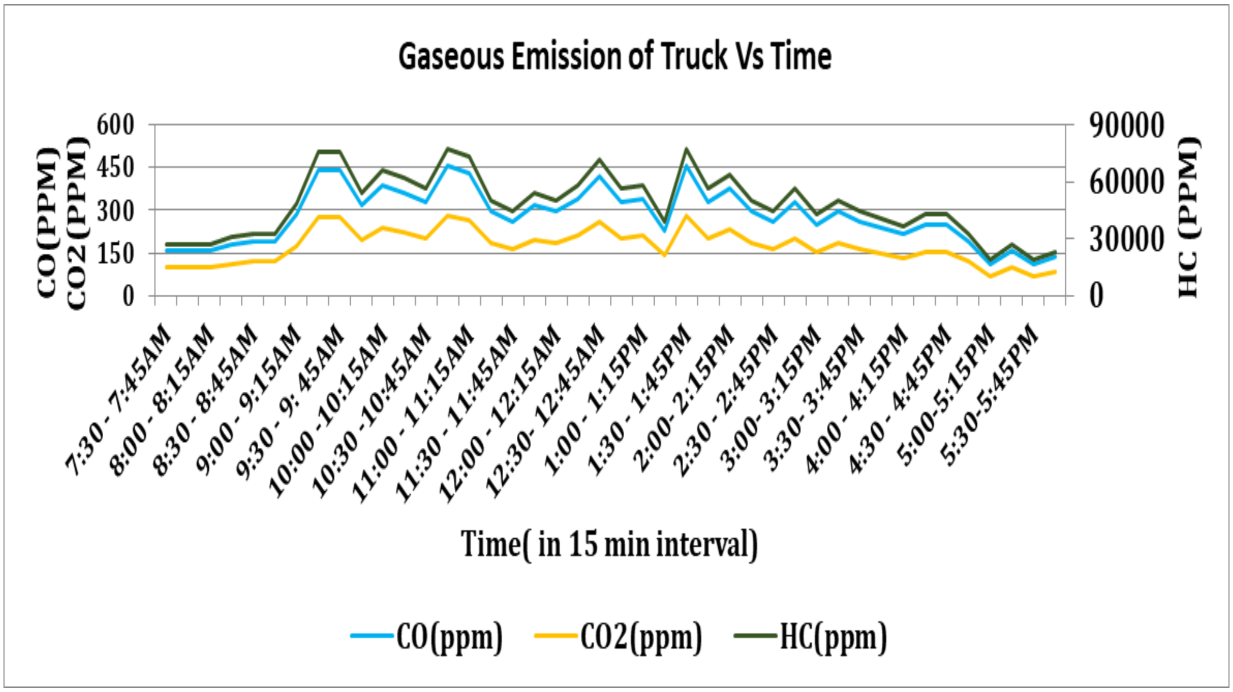


Figure 4.2. 10: Gaseous emission of Truck Vs time at Imperial signalized intersection (Bole approach).

During the congested period as a base of steady traffic flow conditions, the average gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide for car, minibus, bus, truck on Bole approach in Imperial signalized intersection increased by 18-28 %, 27– 32%, 65 -80%, and 37– 60% respectively. The result of the analysis of average gaseous emission on Bole approach in Imperial intersection shows that; Car has a lower percentage and Bus has a higher percentage than others. This implies the number of Bus variations during congested and steady traffic flow conditions per 15-minute traffic volume analysis is higher than a car, minibus, and Truck on the Bole approach. Increase average gas emission during congested traffic conditions of the Car and Minibus are lower while the Truck is within the range that on the study done by (Rosca, Costescu, and Rusca, 2014).

V. Sholla Signalized intersection

From Sholla signalized intersection traffic volume analysis, the Kebena approach has a greater number of vehicles rather than the other approach as shown in table4.1.1. So the effect of traffic congestion on vehicular emission on the Kebena approach is analyzed as shown in Figures 4.2.11 and 4.2.12.

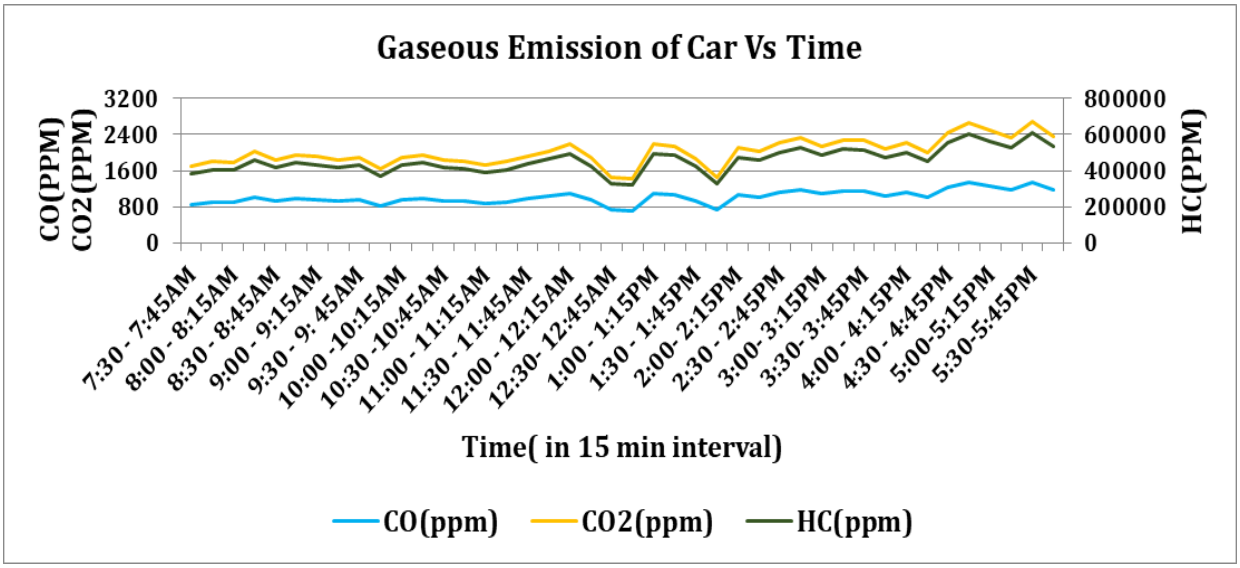


Figure 4.2. 11: Gaseous emission of Car Vs time at Sholla signalized intersection (Kebena approach).

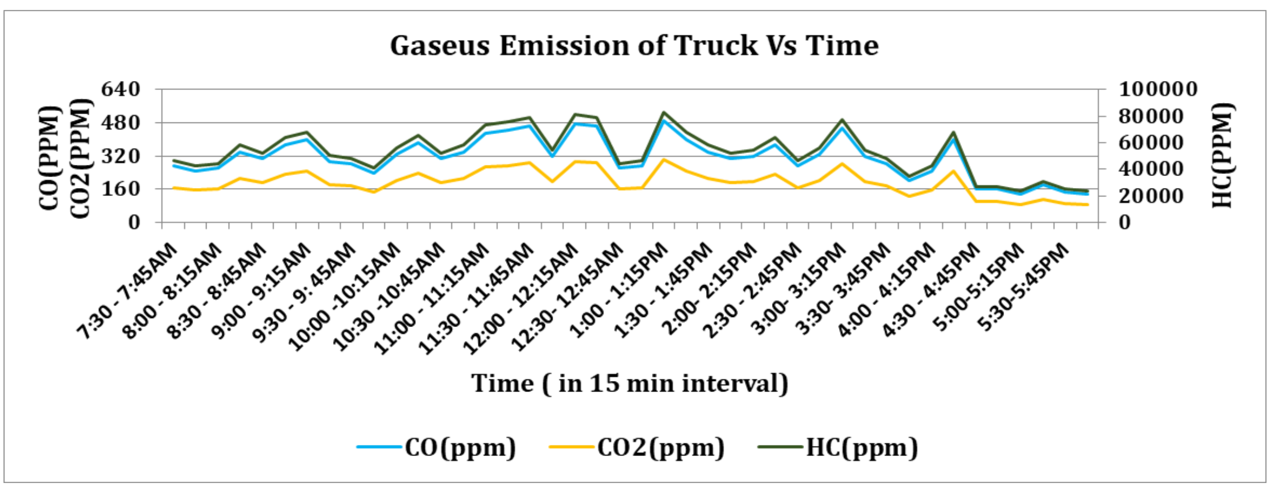


Figure 4.2. 12: Gaseous emission of Truck Vs time at Sholla signalized intersection (Kebena approach).

During the congested period as a base of steady traffic flow conditions, the average gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide for car, minibus, bus, truck on Kebena approach in Sholla signalized intersection increased by 24-29 %, 29 – 33%, 35 - 45%, and 35 – 57% respectively. As the same as Mexico approach in Legehar intersection, on Kebena approach car has lower percentage and Truck has a higher percentage than others. This implies the number of Truck variations during congested and steady traffic flow conditions per 15-minute traffic volume analysis is higher than a car, minibus, and bus on the Kebena approach. Increase average gas emission during congested traffic conditions of the Car and Minibus are lower while the Truck is within the range that on the study done by (Rosca, Costescu, and Rusca, 2014).

VI. Abune Petros signalized intersection

The Paster approach in the Abune Petros roundabout has a greater number of vehicles rather than the other approach as shown in table4.1.1. So the effect of traffic congestion on vehicular emission on the Paster approach is analyzed as shown in Figures 4.2.13 and 4.2.14.

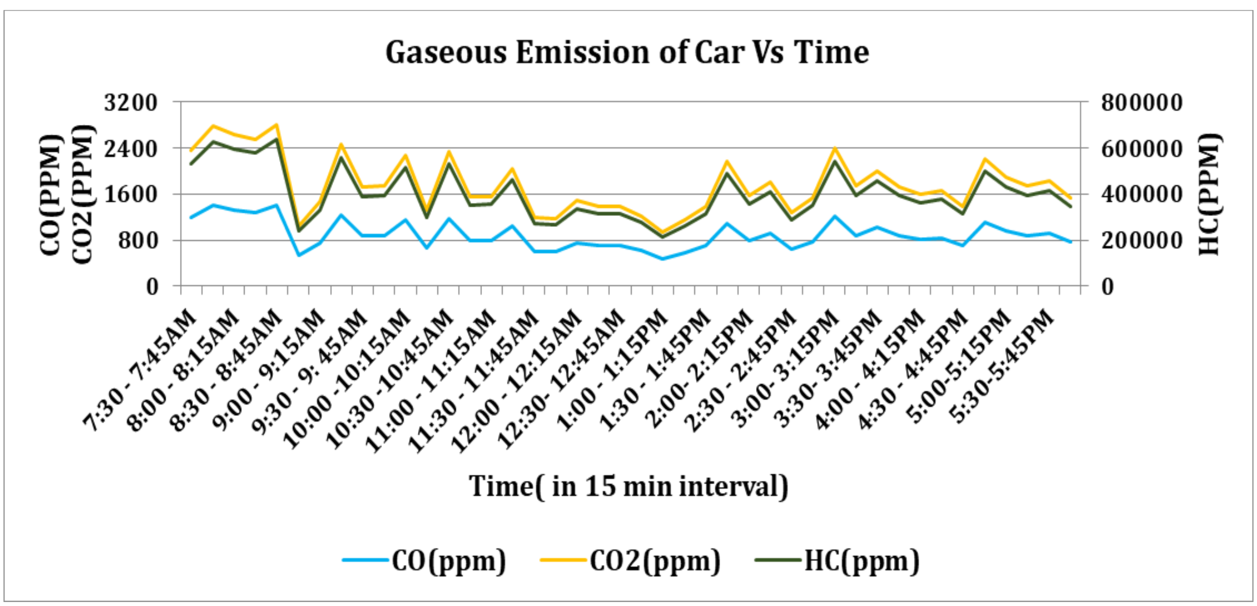


Figure 4.2. 13: Gaseous emission of Car Vs time at Abune Petros roundabout intersection (Paster approach).

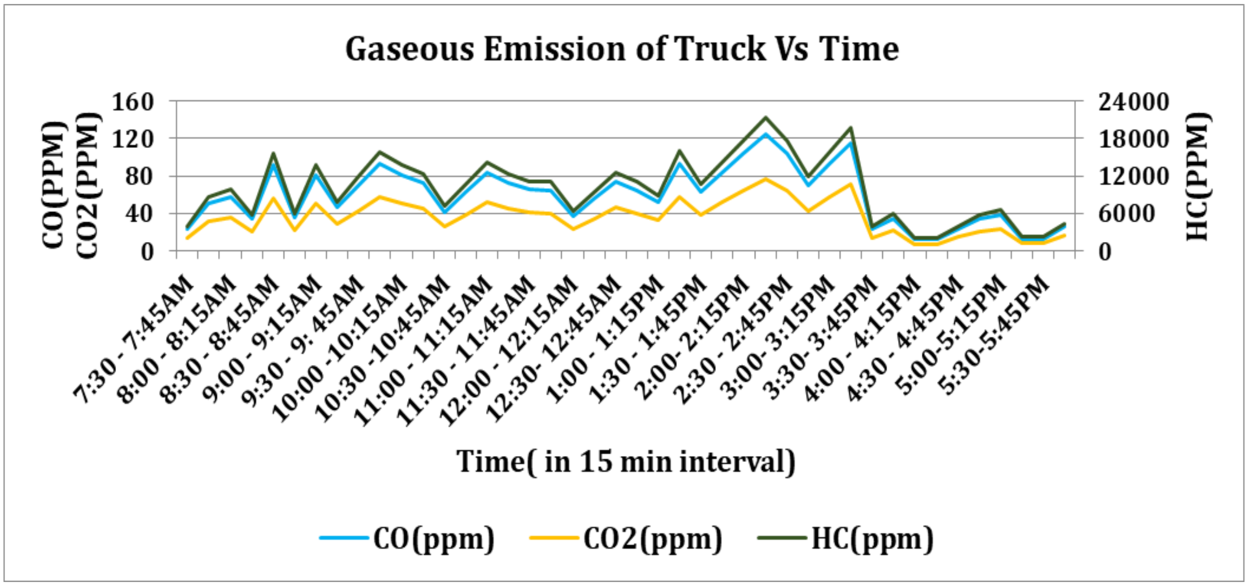


Figure 4.2. 14: Gaseous Emission of Truck Vs time at Abune Petros roundabout intersection (Paster Approach).

During the congested period as a base of steady traffic flow conditions, the average gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide for car, minibus, bus, truck on Paster approach in abune Petros roundabout intersection increased by 37-47%, 49 – 60%, 41 - 71%, and 52 – 81% respectively. The result shows, like Legehar and Shola intersection, on Petros approach Car, has a lower and Truck has a higher percentage than others. This implies the number of Truck variations during congested and steady traffic flow conditions per 15-minute traffic volume analysis is higher than a car, minibus, and bus on Paster approach of Abune Petros roundabout whereas the variation of a car in the steady and congested condition is lower than other. Increase average gas emission during congested traffic conditions Car, and Minibus are within the range while the truck is higher than on the study done by (Rosca, Costescu, and Rusca, 2014).

VII. Teklehaymanot roundabout

Based on Teklehaymanot's roundabout intersection traffic volume analysis, the Merkato approach has a greater number of vehicles rather than the other approach as shown in table4.1.1. So the effect of traffic congestion on vehicular emission on the Merkato approach is analyzed as shown in Figures 4.2.15and 4.2.16.

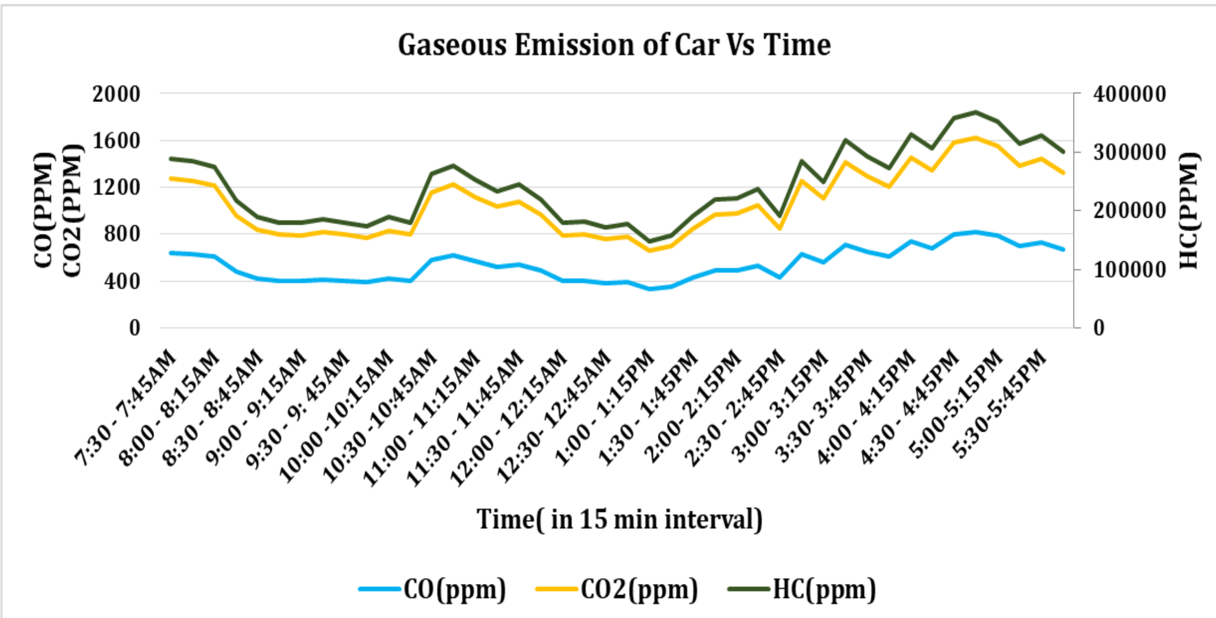


Figure 4.2. 15: Gaseous Emission of Car Vs time at Teklehaymanot roundabout intersection (Merkato approach).

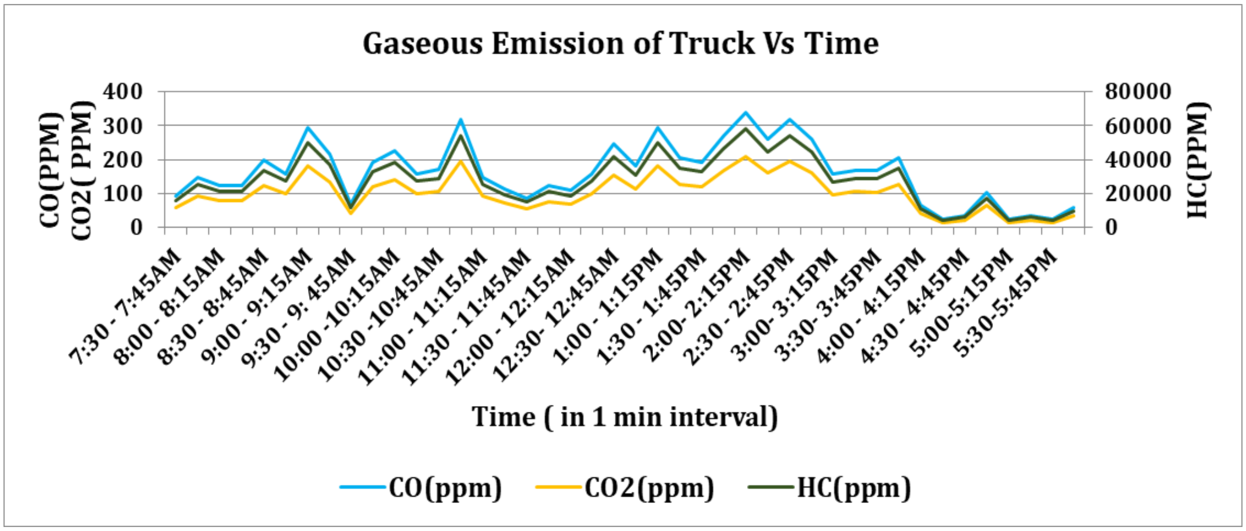


Figure 4.2. 16: Gaseous Emission of Truck Vs Time at Teklehaymanot roundabout intersection (Merkato approach).

During the congested period as a base of steady traffic flow conditions, the average gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide for car, minibus, bus, truck on Merkato approach in Teklehaymanot roundabout intersection increased by 45 - 50%, 34-38%, 68%, and 52– 86% respectively. The result shows, Minibus has a lower and Truck has a higher percentage than others. This implies the number of Truck variations during congested and steady traffic flow conditions per 15-minute traffic volume analysis is higher than a car, minibus, and bus on the Merkato approach. Increase average gas emission during congested traffic conditions of Minibus is lower and the Truck is higher while the Car is within the range that on the study done by (Rosca, Costescu and Rusca, 2014).

SO based on the analysis data using percentage increases in each selected intersection, traffic congestion has an increasing effect on vehicular gaseous emission of hydrocarbon, carbon monoxide, carbon dioxide, and smoke density as shown in the above figures on an average value of 27-37%, 30-39%,49-63%, and 45-70% by Car, Minibus, Bus, Truck respectively. It will have a greater contribution to ambient air pollution due to road traffic transportation.

4.3. Analysis of the effect of traffic congestion on air quality

Statistical hypothesis test conducted to know traffic flow condition variation that is congested and steady traffic flow condition had a statistically significant difference on ambient air pollutants concentration or not.

Null Hypothesis (H0) =There is no statistically significant difference in ambient air quality between different traffic flow conditions (congested and steady Traffic flow conditions).

Alternative Hypothesis (H1) = There is a statistically significant difference in ambient air quality between different traffic flow conditions (congested and steady Traffic flow conditions).

The traffic flow conditions (congested and steady traffic flow conditions) are dummy explanatory variables so to test the hypothesis first coded as 0 and 1. In this case, coded 1 for congested traffic flow condition while 0 for steady traffic flow condition by separating the measured air pollutants concentration with different traffic flow condition as presented in Appendix F by filtering the data as air pollutants concentration at congested and steady traffic flow condition using an excel sheet. So to conduct a hypothesis test of significant difference of ambient air pollutants concentration of carbon monoxide, sulfur dioxide, and particular matter 2.5 and 10 between different traffic flow conditions, one way ANOVA test using Stata/MP13 had used and the output are shown in table 4.3.1 to 4.3.4.

Table 4.3. 1: ANOVA test output of Carbon Monoxide between traffic flow conditions.

Source	Analysis of Variance				
	SS	Df	MS	F	Prob>F
Between groups	58840070.1	1	58840070.1	10.34	0.0016
Within groups	944411884	166	5689228.22		
Total	1.0033e+09	167	6007496.73		

Bartlett's test for equal variances: chi2 (1) =12.3763 prob>chi2 =0.000

Table 4.3. 2: ANOVA test output of Sulfur dioxide between traffic flow conditions.

Source	Analysis of Variance				
	SS	Df	MS	F	Prob>F

Between groups	160457.524	1	160457.524	11.35	0.0009
Within groups	2347495.81	166	14141.541		
Total	2507953.33	167	15017.6846		

Bartlett's test for equal variances: chi2 (1) =5.8351 prob>chi2 =0.016

Table 4.3. 3: ANOVA test output of Particular Matter 2.5 between traffic flow conditions.

Source	Analysis of Variance				
	SS	Df	MS	F	Prob>F
Between groups	38958.1071	1	38958.1071	7.39	0.0080
Within groups	432197.452	82	5270.70064		
Total	471155.56	83	5676.57301		

Bartlett's test for equal variances: chi2 (1) = 4.3038 prob>chi2 =0.038

Table 4.3. 4: ANOVA test output of Particular Matter 10 between traffic flow conditions.

Source	Analysis of Variance				
	SS	Df	MS	F	Prob>F
Between groups	55697.25	1	55697.25	8.38	0.0049
Within groups	544777.167	82	6643.62398		
Total	600474.417	83	7234.63157		

From the test at 95% confidence interval, the P-value of carbon monoxide (CO), Sulfur dioxide (SO2), Particular matter (PM2.5 and PM10) are 0.0016, 0.0009, 0.008, and 0.0049 respectively, since the P-value less than the significance value of 0.05, the null hypothesis was rejected. This means there is a significant difference in ambient air quality between congested and steady traffic flow conditions. As (Prashant and Sharad, 2016) investigated the effect of different urban traffic-flow patterns on pollutant dispersion in different winds in a real asymmetric street canyon. Free-flow traffic causes more turbulence in the canyon facilitating more dispersion and a reduction in pedestrian level concentration.

As their investigation shows, the comparison of with and without a vehicle-induced-turbulence revealed that when winds were perpendicular, the free-flow traffic reduced the concentration by 73% on the windward side with a minor increase of 17% on the leeward side, whereas for parallel winds, it reduced the concentration by 51% and 29%. The congested flow traffic increased the concentrations on the leeward side by 47% when winds were perpendicular posing a higher risk to health, whereas reduced it by 17 - 42%

for parallel winds. They investigate traffic flow had a greater factor for air pollutants. So te test done by this study argues the study done by (Khalfan, Andrews, and Li, 2017), (Prashant and Sharad, 2016).

Now quantified the percentage increase to know the effect of traffic congestion on air pollution. First, separate the measured air pollutants concentration with different traffic flow condition as presented in Appendix F by filtering the data as air pollutants concentration at congested and steady traffic flow condition using an excel sheet and then found out the maximum, average, and minimum concentration of CO, SO2, PM2.5 and PM10 for both congested and steady traffic condition. Finally, found out the percentage increase to show the effect of traffic congestion on air pollutants concentration using equation 1, 2, and 3 and the result shown in table 4.3.5.

$$\text{Percentage increase } (\%)_{(\text{Maximum})\text{CO, SO2, PM 10, PM2.5}} = \frac{(\text{Congested Maximum} - \text{Steady } Maximum) * 100}{\text{Steady Maximum}} \quad ..1)$$

$$\text{Percentage increase } (\%)_{(\text{Average})\text{CO, SO2, PM 10, PM2.5}} = \frac{(\text{Congested Average} - \text{Steady } Average) * 100}{\text{Steady Average}} \quad .....2)$$

$$\text{Percentage increase } (\%)_{(\text{Minimum})\text{CO, SO2, PM 10, PM2.5}} = \frac{(\text{Congested Minimum} - \text{Steady } Minimum) * 100}{\text{Steady Minimum}} \quad ...3)$$

Table 4.3. 5: Effect of traffic congestion on ambient air quality as a base of steady condition.

		Air pollutants concentration		
Air pollutants	Traffic flow condition with % change	Maximum (μg/m³)	Average (μg/m³)	Minimum (μg/m³)
Carbon monoxide(CO)	Congested	12,010	7,382	1,521
	Steady	9,101	6,198.38	1,007
	Percentage increase (%)	31.97	19.10	51.04
Sulfur Dioxide(SO2)	Congested	460	181.57	20
	Steady	420	119.76	16
	Percentage increase (%)	9.5	51.61	25
Particular matter	Congested	328	170.40	39

(PM2.5)	Steady	239	127.33	33
	Percentage increase (%)	37.24	33.83	18.18
Particular matter(PM10)	Congested	383	228.67	61
	Steady	311	177.17	52
	Percentage increase (%)	23.15	29.07	17.31

The percentage increase of carbon monoxide concentration at maximum, average, and minimum concentrations are (31.97, 19.10and 51.04%), sulfur dioxide concentration at maximum, average and minimum concentrations are (9.5, 51.61, and 25%), particular matter 2.5 at maximum, average and minimum concentrations are (37.24, 33.83, and 18.18%) and particular matter 10 concentration at maximum, average and minimum concentration are (23.15, 29.07 and 17.31%) respectively. When we discuss the average percentage increase, the average carbon monoxide concentration in the ambient air recorded during site measurement was 7,382 µg/m^3 at Congested traffic flow condition and 6,198.38 at steady traffic flow condition. Then the increased average CO air pollutants concentration during congested traffic flow conditions as a base of steady is 19.10%.

The average sulfur dioxide concentration in the ambient air recorded during site measurement was 181.57 µg/m^3 at Congested traffic flow condition and 119.76 at steady traffic flow condition. Then the increased average SO2 air pollutants concentration during congested traffic flow conditions as a base of the steady traffic condition is 51.61%.

The average particular matter 2.5 concentration in the ambient air recorded during site measurement was 170.40 µg/m^3 at Congested traffic flow condition and 127.33 at steady traffic flow condition. Then the increased average PM2.5 air pollutants concentration during congested traffic flow conditions as a base of steady traffic flow condition is 33.83%.

The average particular matter 10 concentration in the ambient air recorded during site measurement was 228.67 µg/m^3 at Congested traffic flow condition and 177.17 at steady traffic flow condition. Then the increased average PM10 air pollutants concentration during congested traffic flow condition as a base of steady traffic flow condition is 29.07%.

As shown in table 4.3.5 the effect of congested traffic flow is higher as a base of steady traffic flow conditions. It is due to a congested traffic flow condition there are a higher number of vehicles and they spent more time rather than the steady traffic flow condition, especially at signalized intersection higher acceleration and deceleration, which led to increasing the emission of air pollutants gaseous. Besides, most of the vehicular age are oldies that contribute to higher emission due to congested traffic flow conditions. However, the effect not only by traffic data but also by geometric and metrological factors so to know which factors are the significant or more effect on the increase of air pollutants concentration, the author provides multiple linear regression analysis as shown in section 4.4.

To support the result shown in table 4.3.5 that is the percentage increase of air pollutants concentration during congested traffic flow condition as a base of the steady traffic flow condition; the author provides figure 4.3.1 to figure 4.3.4 to illustrates a significant difference of ambient air pollutant concentrations of carbon monoxide, Sulfur dioxide, particular matter 2.5 and 10 at congested and steady traffic flow conditions.

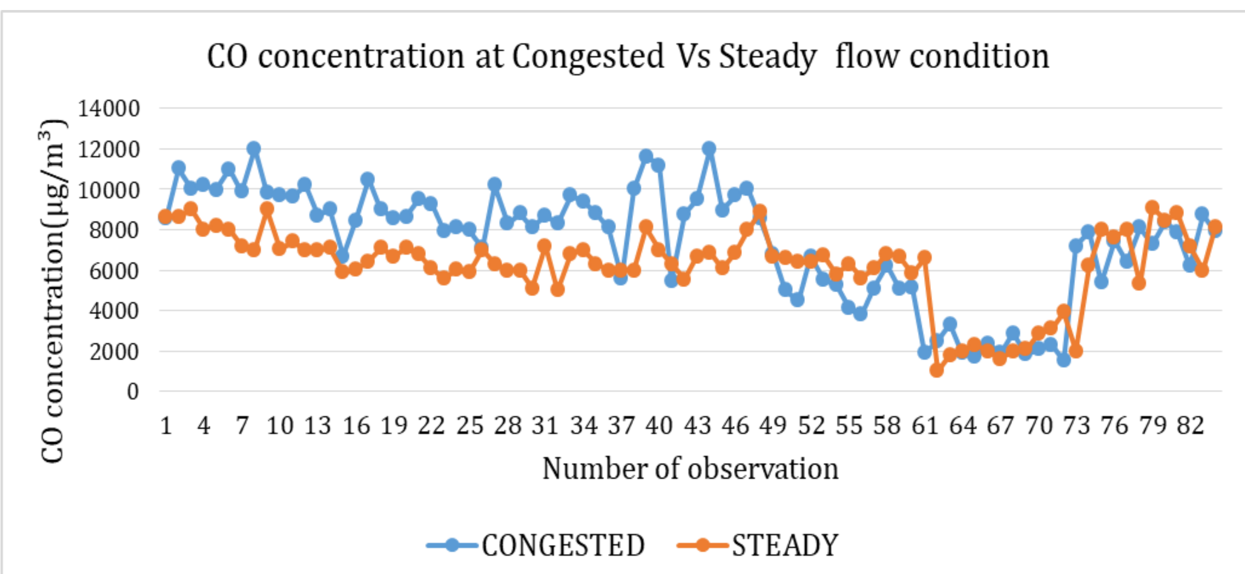


Figure 4.3. 1: CO concentration at congested Vs steady traffic flow condition.

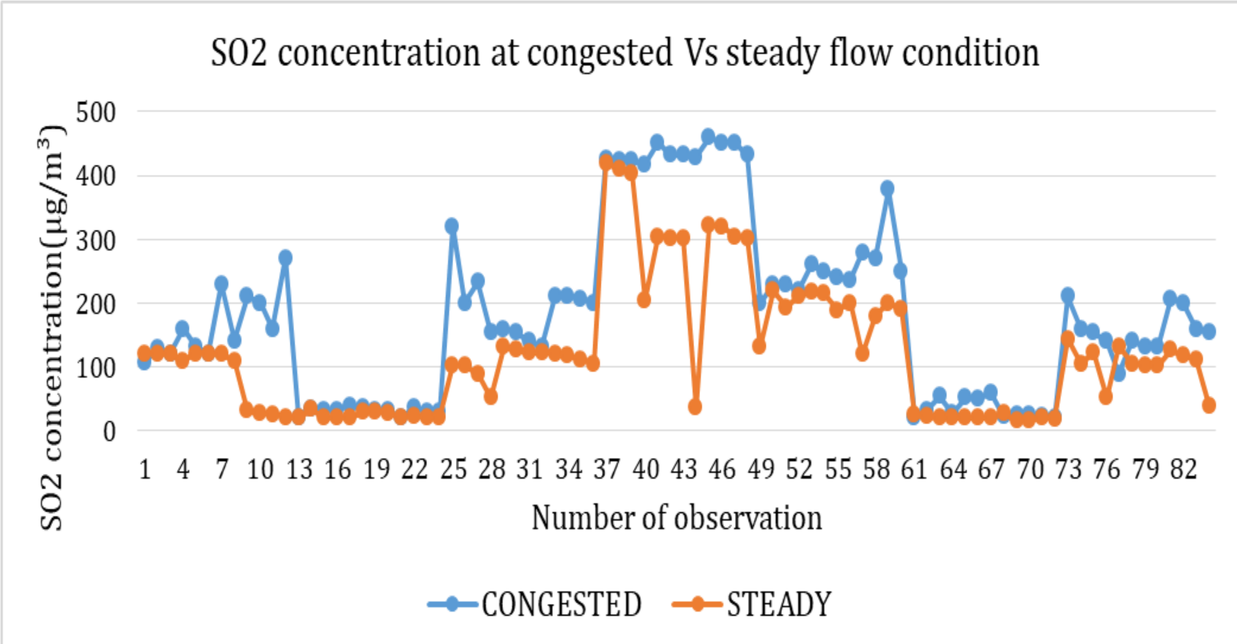


Figure 4.3. 2: SO2 concentration at congested Vs steady traffic flow condition.

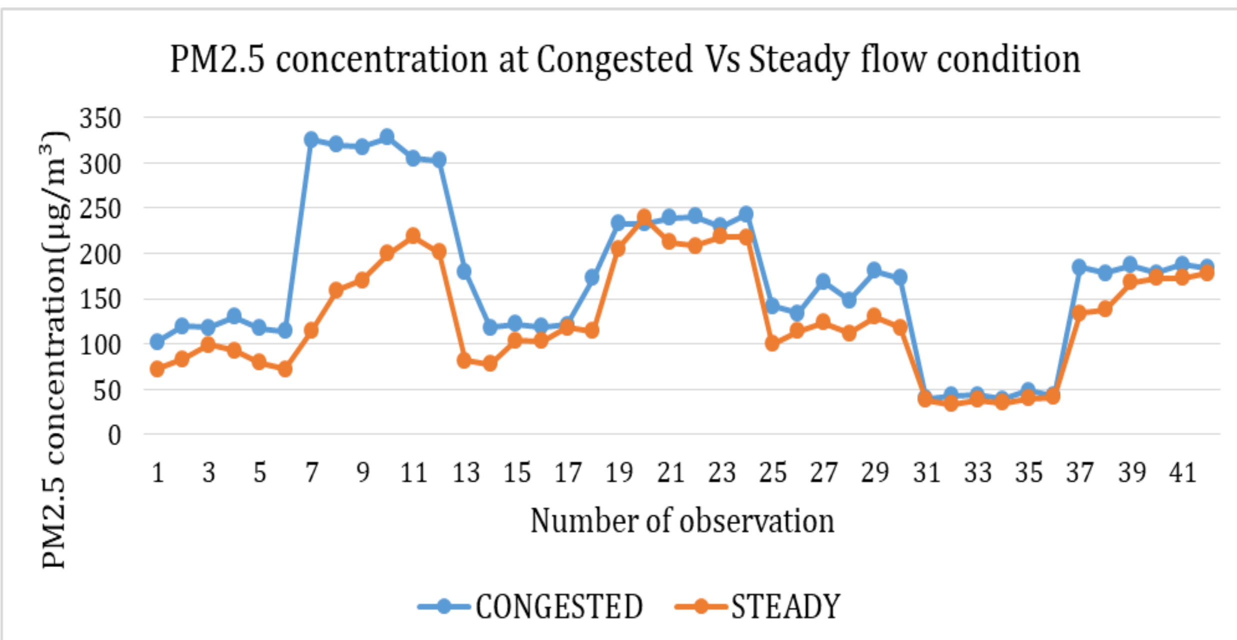


Figure 4.3. 3: PM2.5 concentration at Congested Vs Steady traffic flow condition.

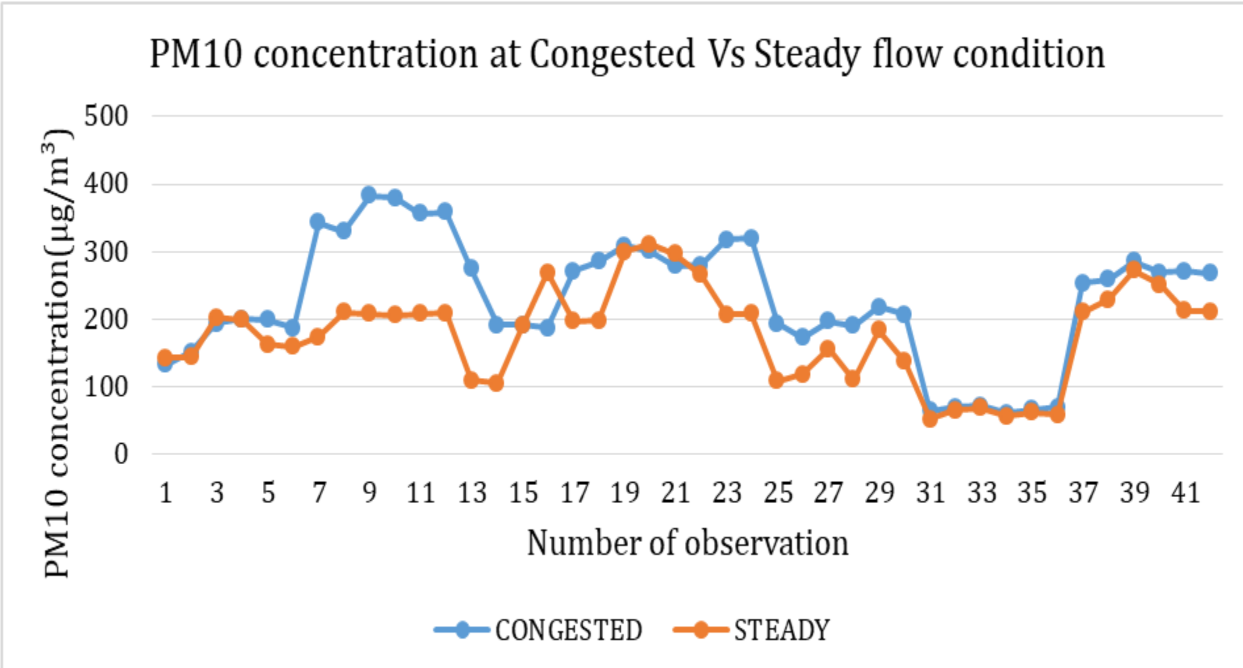


Figure 4.3. 4: PM10 concentration at Congested Vs Steady traffic flow condition.

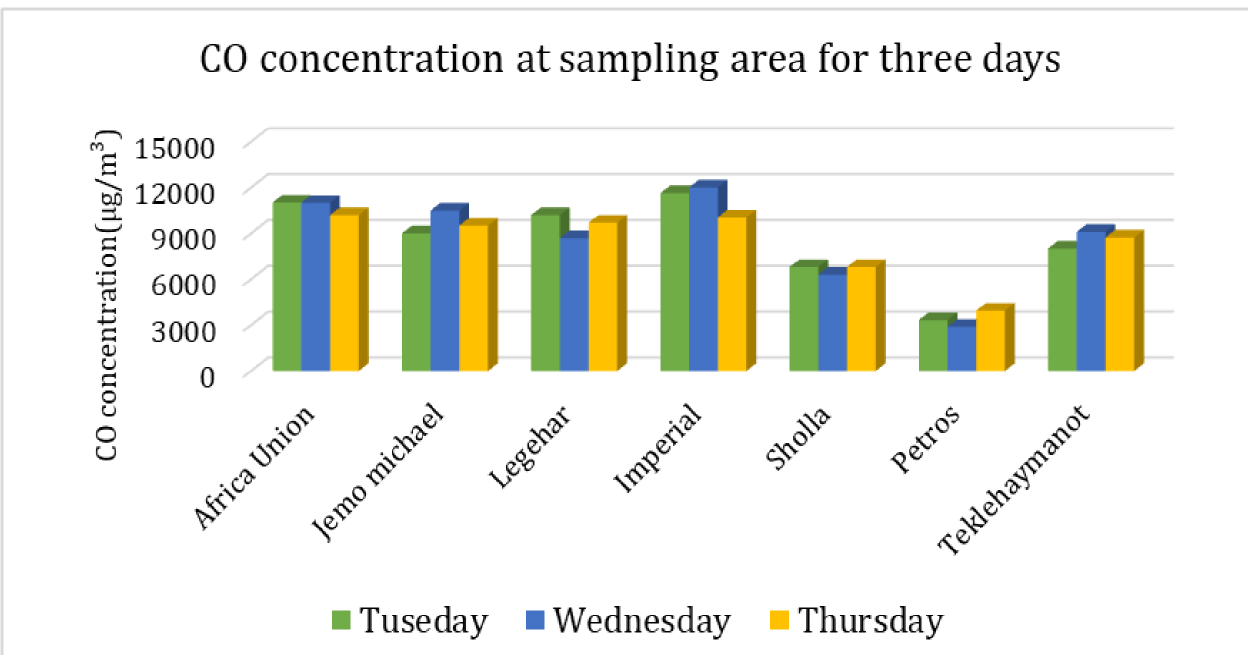


Figure 4.3. 5: CO concentration at the sampling areas for three days.

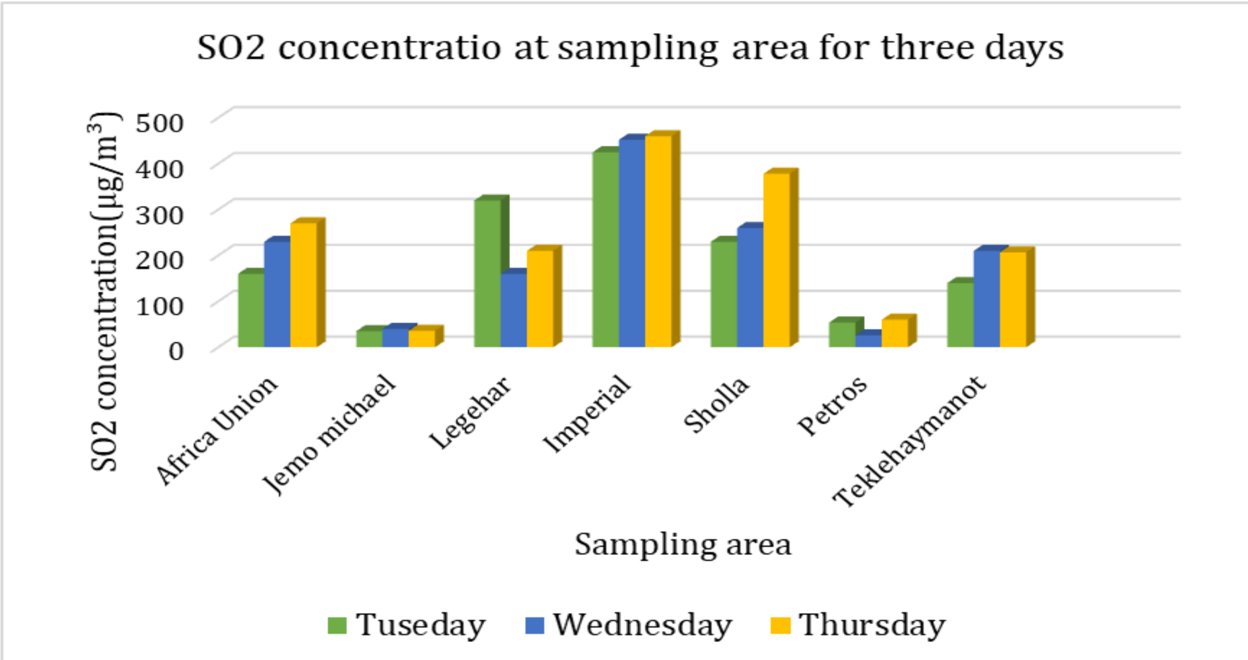


Figure 4.3. 6: SO2 concentration at the sampling areas for three days.

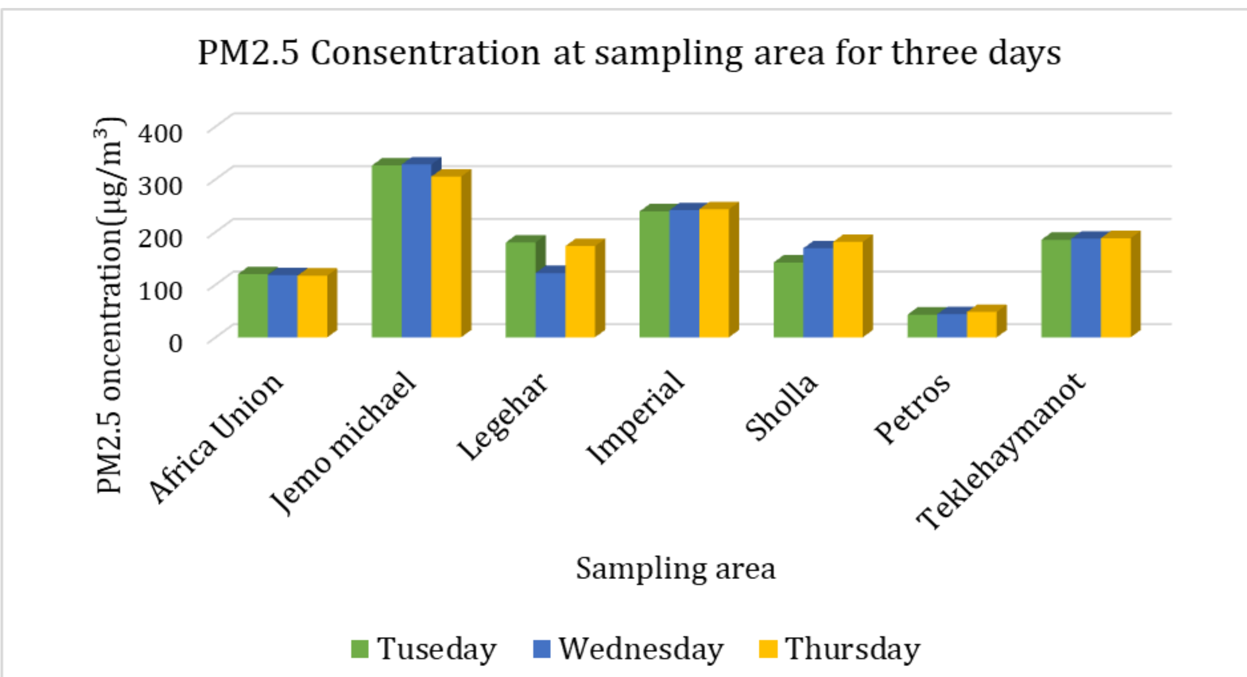


Figure 4.3. 7: PM 2.5 concentration at the sampling areas for three days.

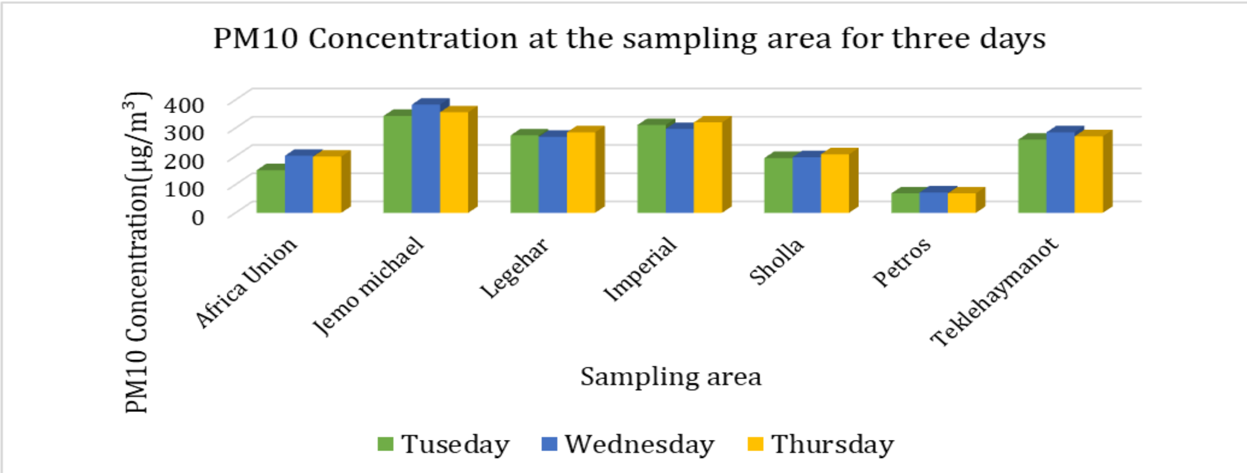


Figure 4.3. 8: PM 10 concentration at the sampling areas for three days.

Figure 4.3.5 to figure 4.3.8 illustrates that there was a little concentration variation on Tuesday, Wednesday, and Thursday due to somehow a constant traffic flow condition among the sampling areas. Carbon monoxide (CO) and sulfur dioxide (SO2) concentration recorded higher at bole approach in Imperial signalized intersection as shown in figure 4.3.5 and figure 4.3.6 respectively whereas particular matter (PM2.5 and PM10) recorded higher at Jemo1 approach in Jemo Michael signalized intersection as shown in figure 4.3.7 and figure 4.3.8 due to heavy vehicle congestion and a higher percentage of the heavy vehicle in those sampling areas and also a contribution of weathering condition to disperses vehicular emission to the atmosphere. A lower concentration of air pollutants recorded in the Abune Petros roundabout since there was a lower traffic congestion level, fewer stops, and low acceleration, the vehicles spent less time, and also the location of the sampling area more exposed to weather conditions especially wind as compared to the others sampling area.

As presented in Appendix G; the comparison of measured air pollutants concentration of carbon monoxide and Sulfur dioxide from the standard concentration value of Ethiopia and WHO, the result shows that the recorded value of Carbon Monoxide for 15 minutes and Sulfur Dioxide for 10 minutes was lower than the standard value of both Ethiopian and WHO.

4.4. Regression Analysis and Regression Model

The author tried to provide multiple linear regression analyses and then a regression model for carbon monoxide, Sulfur dioxide, particular matter 2.5, and Particular matter 10 based on the method of data analysis as presented in chapter 3, method of data analysis section. Before performing regression analysis, check the assumption were essential. The assumption of multiple linear regressions for carbon monoxide presented here and the remaining ones that are Sulfur dioxide, particular matter 2.5, and particular matter 10 were presented in Appendix H.

- Assumption 1: There is a linear relationship between the dependent and each independent variable. Check this assumption using a Scatter plot in STATA. The figure below shows a scatter plot with a linear fit plot for some independent variables and it shows there was a linear relationship between the dependent variable with each dependent variable.

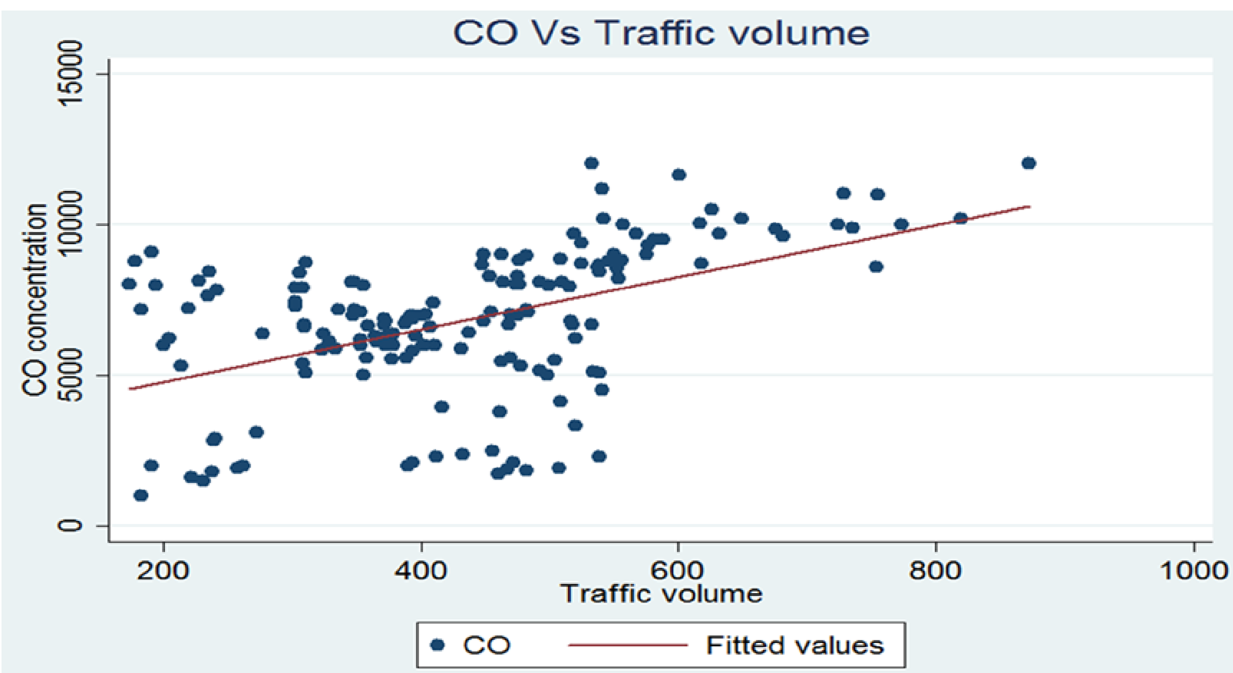


Figure 4.4. 1: Scatter plot of CO concentration with traffic volume.

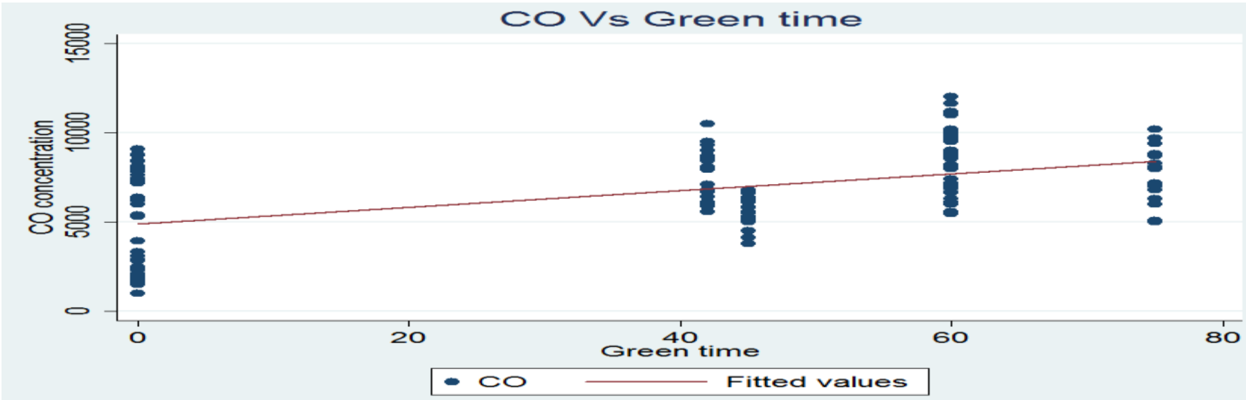


Figure 4.4. 2: Scatter plot of CO concentration with a percentage of heavy vehicle.

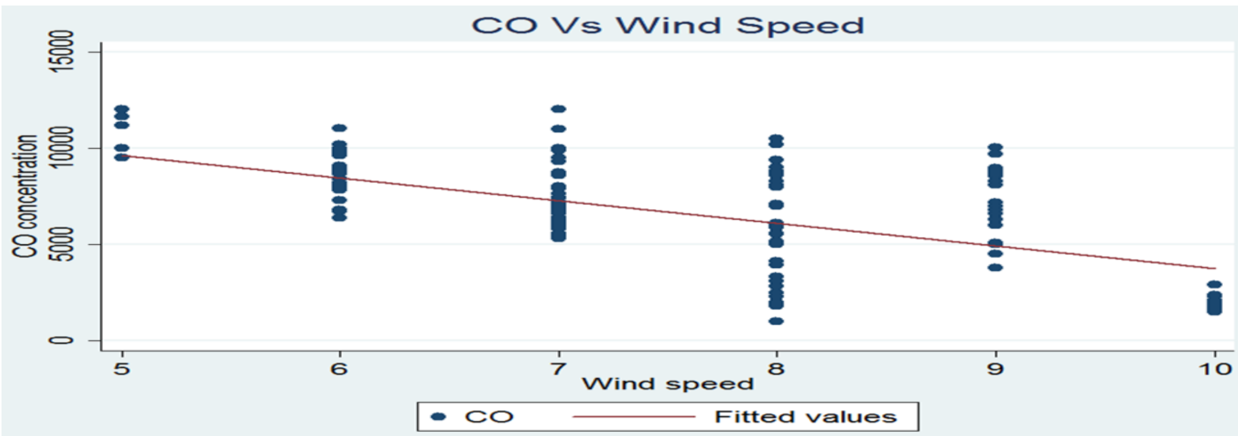


Figure 4.4. 3: Scatter plot of CO concentration with Wind Speed.

Assumption2: The independent variables are not too highly correlated with each other. It can be check using the correlation coefficient using Stata. The independent variables are Traffic data(traffic volume, percentage of heavy vehicle, green time of the selected approach), metrological parameters (humidity, temperature, wind speed, wind direction), road characteristics (altitude, approach grade, and distance between two signalized and /or roundabout intersections that may influence the level of the focused intersection, number of lane, lane width of the selected approach, type of intersection control signalized and roundabout categorical variable), day of week that the data collected(Tuesday, Wednesday and Thursday), time of day of the data recorded(morning and afternoon).

Since the independent variables contain a qualitative variable, so In this case for the type of intersection coded 1 for signalized and 0 for a roundabout, for the time of day coded 1 for morning and 0 for an afternoon. For explanatory variables that have three categories, provide 2 dummy regressors. That is for a day of week, D1 coded as 1 for Tuesday and 0 for others, D2 coded as 1 for Wednesday and 0 for others and taken Thursday as baseline category, for wind direction D1 coded as 1 for east north and 0 for others, D 2 coded as 1 for east south and 0 for others and taken south-East as baseline category.

Table 4.4. 1: Correlation coefficient among independent variables.

Independent variables	Traffic volume	% of HV	Green time	Humi.	Tem.	Winds.	Altitude	App. Grade	
Traffic volume	1								
% of HV	0.014	1							
Green time	0.532	0.11	1						
Humidity	-0.133	-0.209	0.136	1					
Temperature	-0.235	-0.109	-0.011	0.125	1				
Wind speed	-0.122	-0.225	-0.113	-0.179	-0.089	1			
Altitude	-0.52	-0.493	-0.678	0.105	-0.062	0.327	1		
Approach Grade	0.143	-0.411	-0.322	-0.009	-0.084	0.085	0.409	1	
Approach distance	0.118	0.603	0.061	-0.395	0.119	-0.105	-0.602	-0.516	
Number of lane	0.083	0.011	0.282	-0.409	0.265	-0.192	-0.222	-0.227	
Lane width	-0.056	0.112	-0.041	-0.178	-0.295	0.588	0.068	-0.13	
D1ifsignalizedD0 if roundabout	0.572	0.277	0.630	-0.053	0.072	-0.198	-0.675	-0.37	
D1if TuesdayD0 if otherwise	0.029	-0.149	0	-0.016	-0.082	-0.207	0	0	
D1if WednesdayD0if otherwise	0.004	0.152	0	0	0.021	0.135	0	0	
D1if morningD0if otherwise	0.151	0.157	0	-0.169	-0.428	-0.025	0	0	
D1if East North D0if otherwise	0.487	-0.138	0.294	0.365	-0.019	-0.306	-0.258	0.623	
D1if East South D0if otherwise	-0.195	0.358	-0.20	-0.101	-0.209	-0.372	-0.185	-0.492	
Independent variable	App. distance	N. lane	Lane width	Signal	Tuesday	Wednesday	Morning	East north	E.S
Approach distance	1								
Number of lane	0.118	1							
Lane width	0.221	-0.548	1						
D1ifsignalizedD0	0.378	0.4	-0.091	1					

if roundabout									
D1if TuesdayD0 if otherwise	0	0	0	0	1				
D1if WednesdayD0if otherwise	0	0	0	0	-0.5	1			
D1if morningD0if otherwise	0	0	0	0	0	0	1		
D1if East North D0if otherwise	-0.277	-0.258	-0.354	0.258	0	0	0	1	
D1if East South D0if otherwise	0.360	0.091	-0.167	-0.091	0	0	0	-0.354	1

If there are independent variables that have a correlation coefficient > 0.8, then it shows there is collinearity between the variables(Franke, 2010). Collinearity may lead to a missing result even if the adjusted R2 value is significant so eliminate the independent variables that had a correlation factor above 0.8. As presented in table 4.4.1 of correlation coefficient among independent variables was lower than 0.8, so not highly correlated.

Assumption 3: Residuals should be normally distributed with a mean of 0 and variance σ. Figure4.4.4 shows a bell-shaped normal distribution graph and from the normal probability plot, the points should fall approximately along a straight line, then it shows the residuals almost normally distributed.

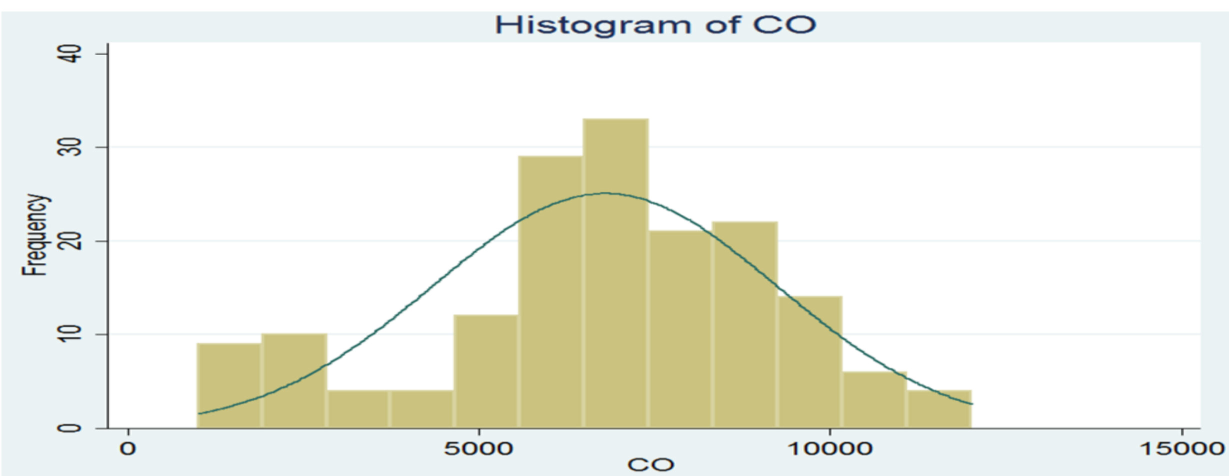


Figure 4.4. 4: Histogram of CO concentration with normal density plot.

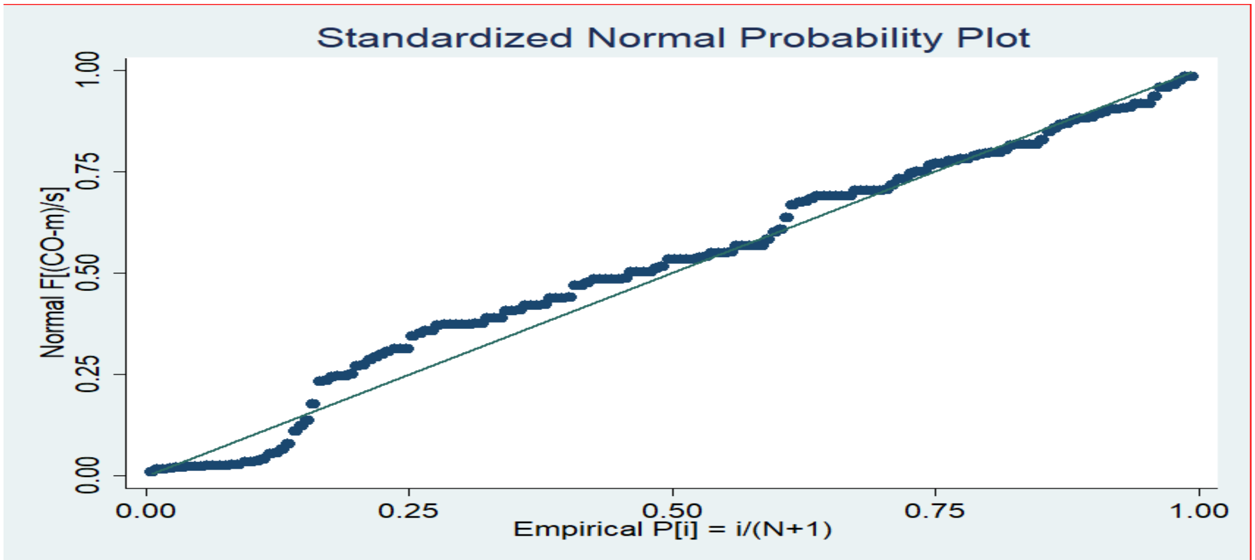


Figure 4.4. 5: Standardized normal probability plot of CO concentration.

Assumption4: Residuals should have constant variance along with fitted value (homoscedasticity). It can be checked by plotting a scatter plot of residual Vs fitted (predicted). As shown in figure 4.4.6, the standardized residuals are concentrated around zero this implies that homogeneity of variance of the residuals, then it obeys the assumption.

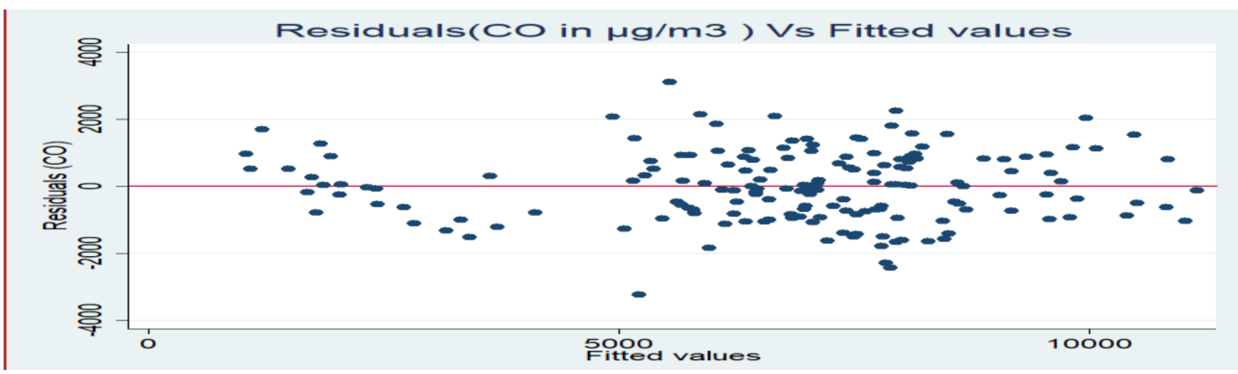


Figure 4.4. 6: Residual Vs fitted value to test homoscedasticity.

Assumption 5: Check the outliers using a Box plot. Outlier data should be excluded from the analysis because it is different from the value estimated by the regression model. But in this case, there is no outlier.

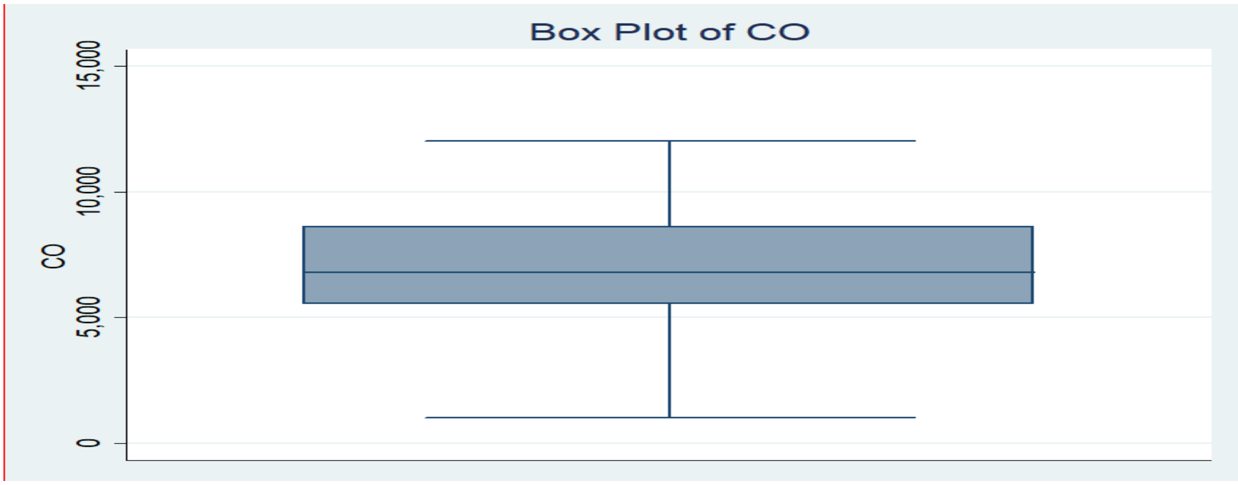


Figure 4.4. 7: Box plot of CO concentration to identify outlier data.

Since the assumption is satisfied, a multiple linear regression model develops for significant factors. The output of regression analysis using Stata for CO, SO2, PM2.5, and PM10 are shown in tables 4.4.2, 4.4.3, 4.4.4, and 4.4.5 respectively.

Table 4.4. 2: Regression analysis of CO concentration from Stata.

Source	SS	Df	MS
Model	868226702	12	72352225.2
Residual	135025252	155	871130.659
Total	1.0033e+09	167	6007496.73

Number of obs=168
F(12,155)=83.06
Prob>F=0000
R-square =0.8654
Adj R-square =0.8550
Root MSE=933.34

CO	Coef	Std. Err.	t	p≥|t|	[95% Conf. Interval]	
Traffic volume	6.80061	0.82712	8.22	0	5.16672	8.4345
% of Heavy vehicle	87.8293	20.1142	4.37	0	48.0958	127.563
Green time	266.077	29.0235	9.17	0	208.745	323.41
Humidity	-13.66	34.5201	-0.4	0.693	-81.85	54.5308
Temperature	166.16	62.3353	2.67	0.008	-289.3	-43.026
Wind speed	-399.13	87.1295	-4.58	0	-571.24	-227.01
Altitude	-74.749	10.2142	-7.32	0	-94.926	-54.572
Lane width	-3110.6	372.805	-8.34	0	-3847.1	-2374.2
Dlifsignalizeddoifroundabout	-23763	2929.64	-8.11	0	-29550	-17976
Dlifmorningdoifafternoon	106.714	176.74	0.6	0.547	-242.42	455.843

DlifEastNorthdoifothers	-3109.5	541.056	-5.75	0	-4178.3	-2040.8
DlifEastSouthdoifothers	-1149.7	436.267	-2.64	0.009	-2011.5	-287.87
_cons	203077	27698.7	7.33	0	148362	257793

Table 4.4. 3: Regression analysis of SO2 concentration from Stata.

Source	SS	Df	MS
Model	2268348.2	13	174488.323
Residual	239605.137	154	1555.87752
Total	2507953.33	167	15017.6846

Number of obs=168
F(13,154)=112.15
Prob>F=0000
R-square =0.9045
Adj R-square =0.8964
Root MSE=39.445

SO2	Coef	Std. Err.	t	p≥|t|	[95% Conf. Interval]	
Traffic volume	0.405274	0.04133	9.81	0	0.323627	0.486922
Of Heavy vehicle	3.765981	0.768983	4.9	0	2.246863	5.285098
Green time	11.16648	0.622039	17.95	0	9.937646	12.39531
Temperature	6.520592	2.72468	2.39	0.018	1.138019	11.90317
Wind speed	-7.6038	3.480404	-2.18	0.03	-14.4793	-0.7283
Altitude	5.524353	0.311818	17.72	0	4.90836	6.140346
App grade	39.44844	5.523634	7.14	0	28.53657	50.36031
Distance	0.696789	0.050293	13.85	0	0.597436	0.796143
Lane width	-204.64	10.8363	-18.88	0	-226.047	-183.233
DlifTuesdayDoifothers	-4.77693	7.546771	-0.63	0.528	-19.6855	10.13162
DlifWednesdayDoifothers Dlifmorningdoifafternoon	-20.4673	7.598829	-2.69	0.008	-35.4787	-5.45594
D1 if morning D0if afternoon	-14.6059	6.939366	-2.1	0.037	-28.3145	-0.89727
DlifEastSouthdoifothers	170.7471	14.00535	12.19	0	143.0797	198.4145
_cons	-13389.1	797.4492	-16.79	0	-14964.4	-11813.7

Table 4.4. 4: Regression analysis of PM2.5 concentration from Stata.

Source	SS	Df	MS
Model	430350.957	13	33103.9198
Residual	40804.6021	70	582.922887
Total	471155.56	83	5676.57301

Number of obs=84
F(13,70)= 56.79
Prob>F=0000
R-square =0.9134
Adj R-square =0.8973
Root MSE=24.144

PM2.5in30min	Coef	Std. Err.	t	p≥|t|	[95% Conf. Interval]	
Traffic volume	0.754906	0.015686	4.81	0	0.442068	0.106774

Of Heavy vehicle	2.593477	0.843046	3.08	0.003	0.912075	4.274879
Green time	2.963997	0.957212	3.1	0.003	1.054899	4.873095
Wind speed	-8.62559	4.237596	-2.04	0.046	-17.0772	-0.17398
Temperature	5.05544	1.890503	-2.64	0.009	-8.82593	-1.28495
Altitude	1.849366	0.553987	3.34	0.001	0.744473	2.954258
Grade	7.549157	2.943059	2.54	0.012	1.679412	13.4189
approach distance b/nmajorintersection	0.282902	0.069983	4.04	0	0.143326	0.422478
lane width	-43.9097	13.95099	-3.15	0.002	-71.7341	-16.0853
DlifTuesdayDoifothers	-8.74257	6.642361	-1.32	0.192	-21.9903	4.5052
DlifWednesdayDoifothers Dlifmorningdoifafternoon	-9.51817	6.684328	-1.42	0.152	-22.8496	3.813303
D1if morningD0 if afternoon	-3.99144	7.082046	-0.56	0.575	-18.1161	10.13326
DlifEastSouthdoifothers	84.17505	9.317104	9.03	0	65.59267	102.7574
_cons	-4287.98	1345.034	-3.19	0.002	-6970.56	-1605.39

Table 4.4. 5: Regression analysis of PM10 concentration from Stata.

Source	SS	Df	MS
Model	512112.228	13	39393.2483
Residual	88362.1889	70	1262.31698
Total	600474.417	83	7234.63153

Number of obs=84
F(13,70)=31.21
Prob>F=0000
R-square =0.8528
Adj R-square =0.8255
Root MSE=35.529

PM10in30min	Coef.	Std. Err.	t	p≥|t|	[95% Conf. Interval]	
Traffic volume	0.0778	0.230822	3.37	0.001	0.031764	0.123836
Green time	6.142149	1.408596	4.36	0	3.332793	8.951506
Of Heavy vehicle	2.807147	1.240595	2.26	0.027	0.33286	5.281435
Wind speed	-16.0558	6.235887	-2.57	0.012	-28.4929	-3.61874
Temperature	7.15696	2.781993	-2.57	0.012	-12.7055	-1.60845
Altitude	3.704088	0.815727	4.54	0	2.078169	5.330007
Grade	19.94423	4.330894	4.61	0	11.30654	28.58193
approach distance between major intersection	0.452918	0.102984	4.4	0	0.247523	0.658314
Lane width	-80.3214	20.52975	-3.91	0	-121.267	-39.3761
DlifTuesdayDoifothers	-9.9827	9.774649	-1.02	0.311	-29.4776	9.512218

DlifWednesdayDoifothers Dlifmorningdoifafternoon	-0.51765	9.836405	-0.05	0.958	-20.1357	19.10044
D1ifmorningD0if afternoon	-16.8505	10.42167	-1.62	0.11	-37.6359	3.934885
DlifEastSouthdoifothers	82.23279	13.7107	6	0	54.88767	109.5779
_cons	-8602.61	1979.301	-4.34	0	-12550.2	-4655.02

Interpretation of the output of the Stata regression analysis for regression model:

R^2 and adjusted R^2, determine how well the regression models fit the data or show the amount of observed variance explained by the model. Adjusted R^2 provides a more honest association between dependent and independent variables than R^2 so adjusted R^2 is preferred for evaluation. The probability of F ratio test (P>F) indicates the statistical significance of the overall regression models while the probability of t-test (P>t) shows the statistical significance of the independent variables and the coefficients indicate how much the dependent variable varies with an independent variable when all other independent variable held constant. Root MSE shows the average distance of the estimator from the mean or the standard deviation of the regression. If P-value is less than 0.05($(p\geq|t|)<0.05$) or the t-value is greater than 1.96($t>1.96$) for a 95% confidence interval or 5% significance level, the coefficients are statistically significant that applied to the regression model. Interpretation of the result for each model presented as shown below.

I. Carbon monoxide

From the result, its adjusted R^2 is 0.855 it shows the regression relationship is very strong since 85.5% of the variance is explained by a linear relationship between the dependent and the predictor variables. Generally, the linear regression model of carbon monoxide air pollutants concentration is well fitted. Since P>F is equal to 0 which is less than 0.05, the model is statistically significant. From the Stata result, the author gets the t and p (t) values to identify the significant factors of the dependent variable. In this case Traffic volume, % of Heavy vehicle, Green time, temperature, wind speed, altitude, lane width, East-South wind direction are significant factors since $p\geq|t|)<0.05$ as shown in table 4.4.2.

The carbon monoxide air pollutants concentration increases by 6.8 when the Traffic volume increase by one unit, by holding all other independent variables constant. The carbon monoxide air pollutants concentration increase 88 when % of Heavy vehicle increase by one unit, by holding all other independent variables constant. The carbon monoxide air pollutants concentration increases by 266 when green time increase by one unit, by holding all other independent variables constant.

The carbon monoxide air pollutants concentration increase by166.16 when temperature increase by one unit, by holding all other independent variables constant. The carbon monoxide air pollutants concentration decrease by 399 when wind speed increase by one unit, by holding all other independent variables constant. The carbon monoxide air pollutants concentration decrease by 3110 when lane width increase by one unit, by holding all other independent variables constant.

II. Sulfur dioxide

From the result, its adjusted R2 is 0.896 it shows the regression relationship is very strong since 89.6% of the variance is explained by a linear relationship between the dependent and the predictor variables. Generally, the linear regression model of carbon monoxide air pollutants concentration is well fitted. Since P>F is equal to 0 which is less than 0.05, the model is statistically significant. In this case Traffic volume, % of Heavy vehicle, Green time, temperature, wind speed, grade, lane width, East-South wind direction are significant factors since p≥|t|)<0.05 as shown in table 4.4.3.

The sulfur dioxide air pollutants concentration increase by 0.41 when the Traffic volume increase by one unit, by holding all other independent variables constant. Sulfur dioxide air pollutants concentration increase by 3.77 when % of Heavy vehicle increase by one unit, by holding all other independent variables constant. The Sulfur dioxide air pollutants concentration increase by 11.17 when green time increase by one unit, by holding all other independent variables constant. The Sulfur dioxide air pollutants concentration increase by 6.52 when temperature increase by one unit, by holding all other independent variables constant. The Sulfur dioxide air pollutants concentration increase by 39.45 when the approach grade increase by one unit, by holding all other independent variables constant. The Sulfur dioxide air pollutants concentration decrease by 7.6 when wind speed increase by one unit, by holding all other independent variables constant. The Sulfur dioxide air pollutants concentration decrease by 204 when lane width increase by one unit, by holding all other independent variables constant.

III. Particular matter 2.5

From the result, its adjusted R2 is 0.897 it shows the regression relationship is very strong since 89.7% of the variance is explained by a linear relationship between the dependent and the predictor variables. Generally, the linear regression model of carbon monoxide air pollutants concentration is well fitted. Since P>F is equal to 0 which is less than 0.05, the model is statistically significant. . In this case Traffic volume, % of Heavy vehicle, Green time, temperature, wind speed, altitude, approach grade, lane width, East-South wind direction are significant factors since p≥|t|)<0.05 as shown in table 4.4.4.

The PM2.5 air pollutants concentration increases by 0.75 when the Traffic volume increase by one unit, by holding all other independent variables constant. The PM2.5 air pollutants concentration increase 2.59 when % of Heavy vehicle increase by one unit, by holding all other independent variables constant. The PM2.5 air pollutants concentration increase 2.96 when green time increase by one unit, by holding all other independent variables constant.

The PM2.5 air pollutants concentration increase by 5.06 when temperature increase by one unit, by holding all other independent variables constant. The PM2.5 air pollutants concentration increase by 7.55 when approach grade increase by one unit, by holding all other independent variables constant.

The PM2.5 air pollutants concentration decrease by 8.63 when wind speed increase by one unit, by holding all other independent variables constant. The PM2.5 air pollutants concentration decrease by 43.91 when lane width increase by one unit, by holding all other independent variables constant.

IV. Particular matter 10

From the result, its adjusted R2 is 0.825 it shows the regression relationship is very strong since 82.5% of the variance is explained by a linear relationship between the dependent and the predictor variables. Generally, the linear regression model of carbon monoxide air pollutants concentration is well fitted. Since P>F is equal to 0 which is less than 0.05, the model is statistically significant. In this case Traffic volume, % of Heavy vehicle, Green time, temperature, wind speed, altitude, approach grade, lane width, East-South wind direction are significant factors since $p \geq |t|) < 0.05$ as shown in table 4.4.5.

The PM10 air pollutants concentration increase by 0.08 when the Traffic volume increase by one unit, by holding all other independent variables constant. The PM10 air pollutants concentration increase by 2.8 when % of Heavy vehicle increase by one unit, by holding all other independent variables constant. The PM10 air pollutants concentration increases by 6.14 when green time increase by one unit, by holding all other independent variables constant.

The PM10 air pollutants concentration increase by 7.16 when temperature increase by one unit, by holding all other independent variables constant. The PM10 air pollutants concentration increase by 19.94 when approach grade increase by one unit, by holding all other independent variables constant. The PM10 air pollutants concentration decrease by 16.06 when wind speed increase by one unit, by holding all other independent variables constant. The PM10 air pollutants concentration decrease by 80 when lane width increase by one unit, by holding all other independent variables constant.

Finally; The concentration of pollutants increases as traffic volume, percentage of heavy vehicle, green time of the approach, approach grade increases whereas the concentration of the pollutants decreases when the lane width, wind speed increase argue the study was done by (Rosca, Costescu, and Rusca, 2014), (Bharadwaj, Ballare and Chandel, 2017), (Saeb, Malekzadeh and Kardar, 2012), (Baldauf et al., 2012).

The regression equation model based on the regression analysis using the Stata program are;

1. Carbon monoxide, CO = 203,077.3 + 6.8 TV + 87.83 % of HV + 266.08 GT+166.16 T-399.13 WS – 74.75 AL – 3110.64 LW – 23763.03 DS – 3109.55 DEN – 1149.67 DES
2. Sulfur dioxide, SO2 = -13,389.05 + 0.405 TV + 3.766 % of HV + 11.166 GT + 6.52 T-7.604 WS + 5.524 AL + 39.448 AG + 0.697 AD – 204.64 LW – 20.467 DW - 14.606 DM + 170.747 DES
3. Particular matter, PM2.5 = -4287.98 + 0.075 TV+2.593 % of HV +2.964 GT – 8.63 WS + 5.055 T + 1.849 AL + 7.549 AG + 0.283 AD – 43.91 LW + 84.175 DES
4. Particular matter, PM10 = -8602.612 + 0.08 TV + 2.807 % of HV + 6.142 GT – 16.056 WS + 7.157 T +3.704 AL +19.944 AG + 0.4529 AD – 80.321 LW + 82.232 DES

Where: TV =traffic volume

HV= % of heavy vehicle (%)

GT= Green Time of the signal of the selected approach(second)

- T= temperature(°C)

WS= Wind Speed (Km/hr)

AL= Altitude(Meter)

AG =Approach Grade between the consecutive major intersections(Meter)

AD = Approach distance between the consecutive major intersections(Meter)

LW= lane width(Meter)

D = Dummy variable

DS = D = 1 if signalized while D = 0 if roundabout

DEN = D= 1 if East North wind direction while D= 0 for others

DES = D= 1 if East south wind direction while D= 0 for others

DM = D= 1 if morning while D= 0 if afternoon (time of day of measurement taken)

The figures 4.4.8 to 4.4.11 illustrate that the model of the pollutants fitted with the measured value with the standard error shown in the Stata output.

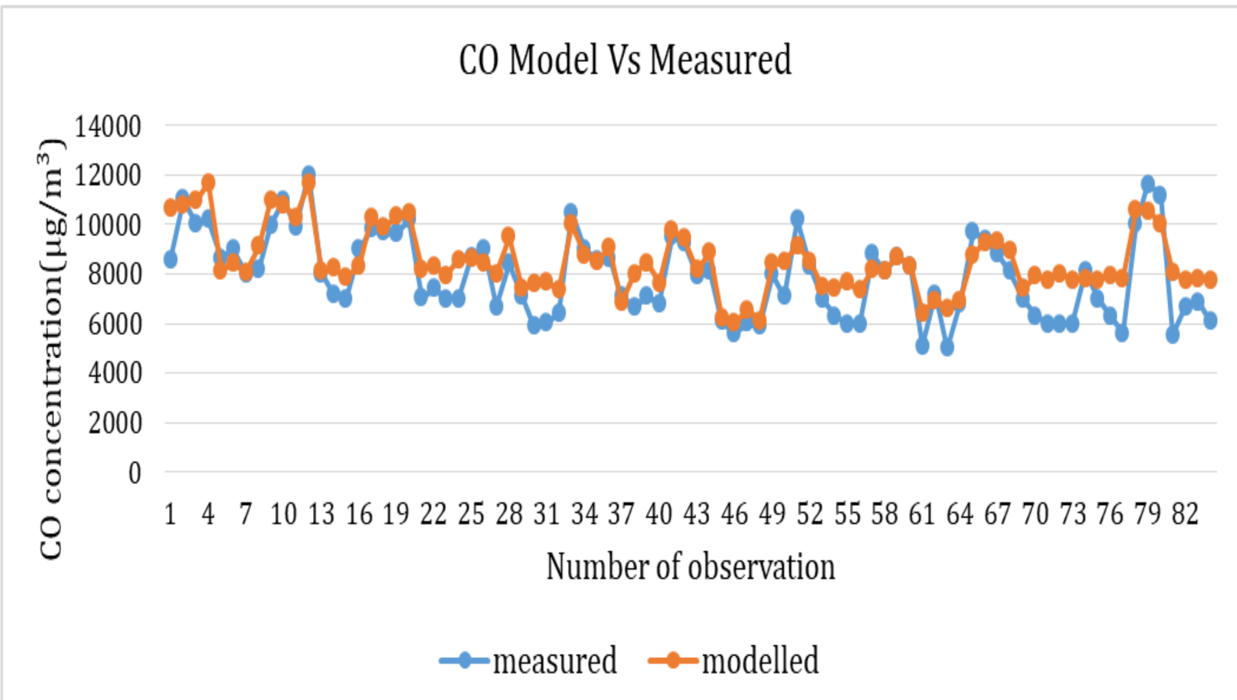


Figure 4.4. 8: CO concentration of Model Vs Measured.

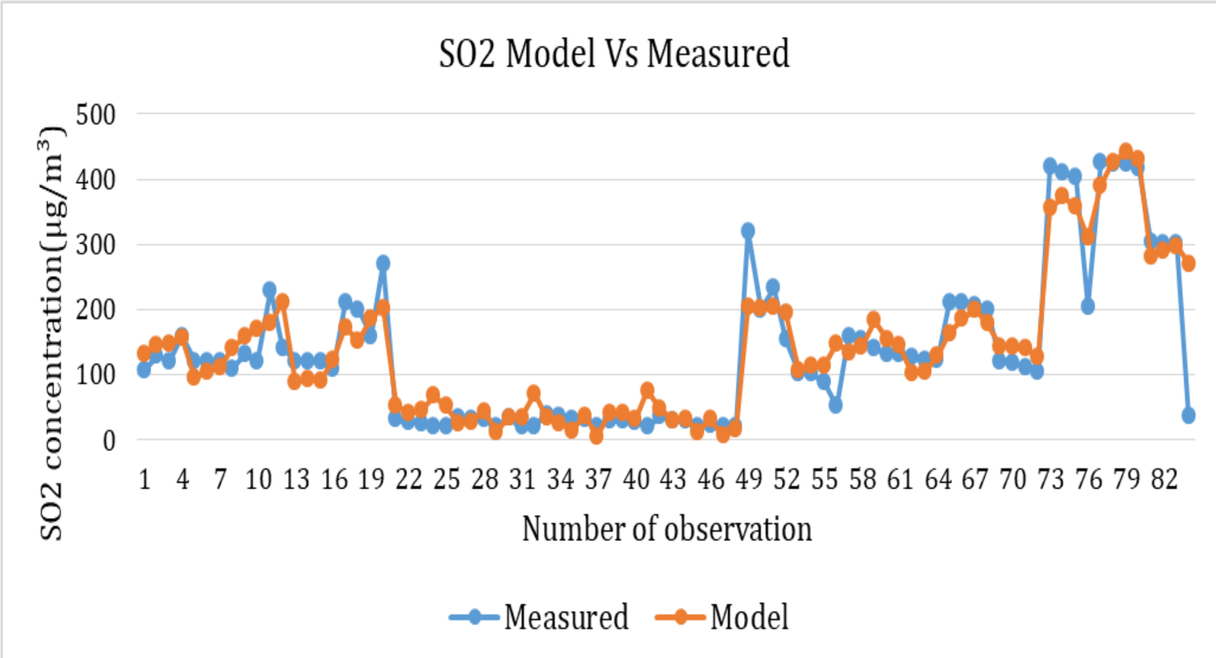


Figure 4.4. 9: SO2 concentration of Model Vs Measured.

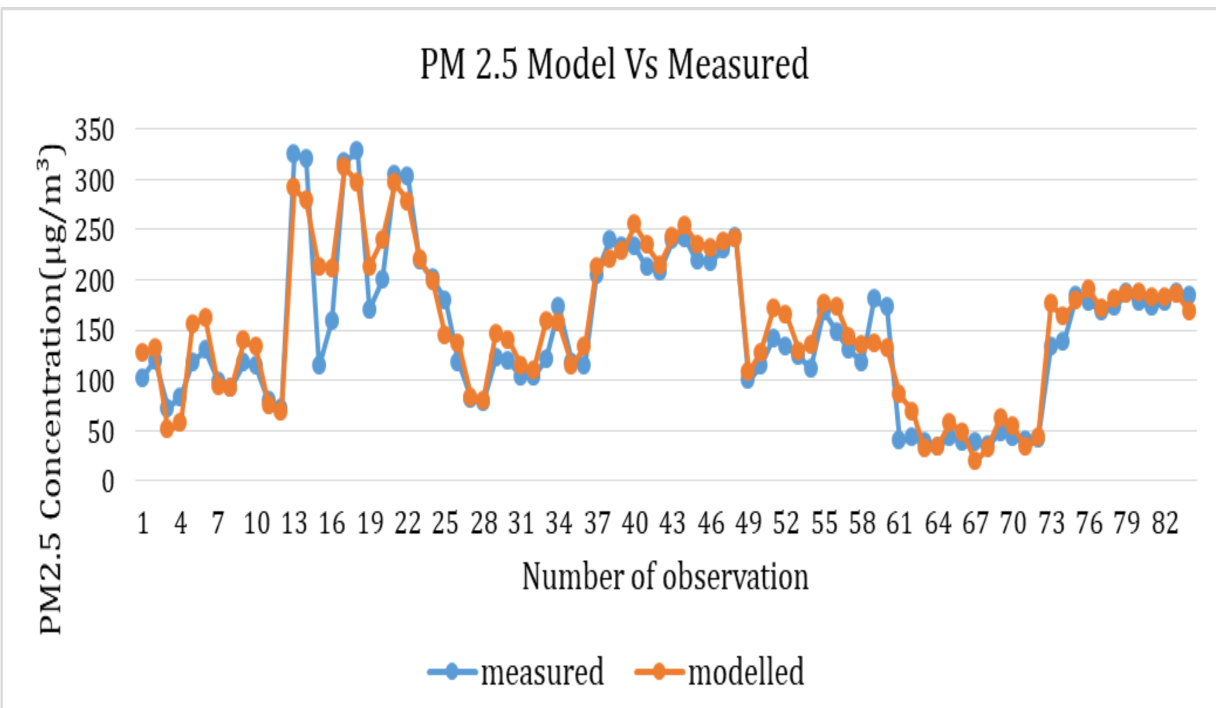


Figure 4.4. 10: PM2.5 concentration of Model Vs Measured.

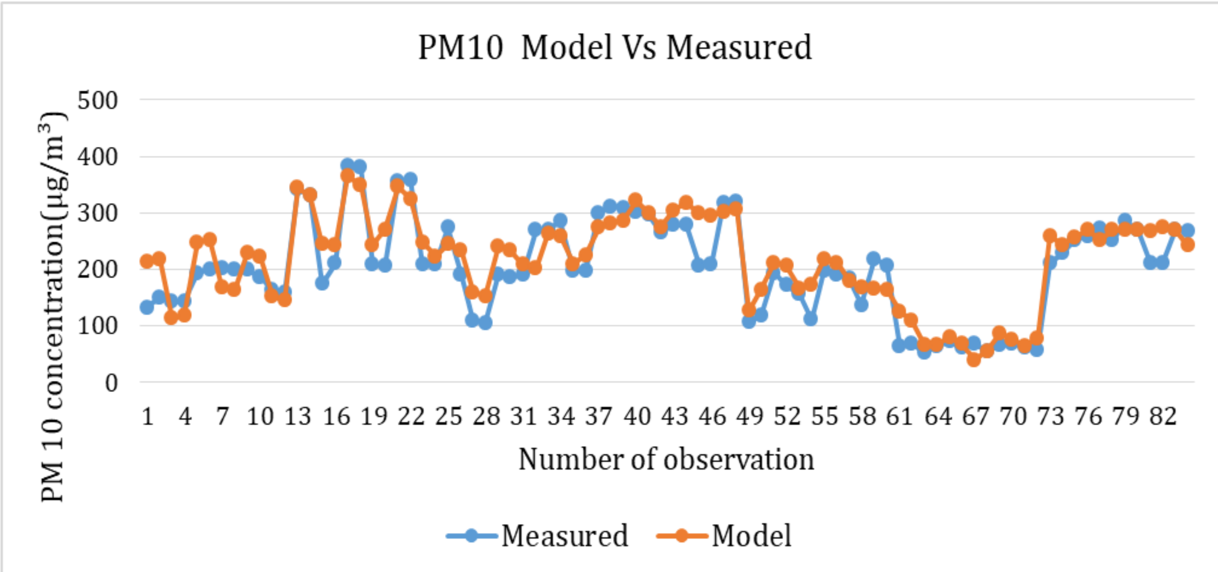


Figure 4.4. 11: PM10 concentration of Model Vs Measured.

The contribution of this study will be;

- This study is very useful to know the current status of the traffic congestion level of the study area.
- The author tried to create a better understanding regarding the determination of the effect of traffic congestion on ambient air quality.
- This study also used to identify the possible factors that contribute to air pollution from road transportation for more consideration to reduce the impact.
- The developed model may be used to determine the concentration of carbon monoxide, sulfur dioxide, particular matter (PM 2.5 and PM10) from different factors as explained in the paper.
- The study will be useful for policymakers, transportation planners, road agencies, government, and communities for planning, identifying, and designing road networks-to minimize air pollution due to traffic from road transportation. And also it may use as a stepping-stone for further research works like evaluating transport planning alternatives to mitigate traffic congestion to reduce its environmental impact.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

- To investigate the effect of traffic congestion on air pollution first, know the level of traffic congestion of the selected intersections, so the level of all selected intersections had a higher congested level based on volume to capacity ratio.
- Vehicular gaseous emissions are one of the major sources of air pollution. The gaseous emission is higher at the intersection rather than the segment since the intersection is the way two or more roads intersect so this area has a higher traffic volume than the segment that has traffic congestion.
- Traffic congestion had an increasing effect on vehicular gaseous emission on an average value of 27-37%, 30-39%, 49-63%, and 45-70% by Car, Minibus, Bus, and Truck respectively. It would have a greater contribution to ambient air pollution due to road traffic transportation.
- There was a little concentration variation on Tuesday, Wednesday, and Thursday due to somehow a constant traffic flow condition among the sampling areas. Carbon monoxide and sulfur dioxide concentration recorded higher at bole approach in Imperial signalized intersection whereas particular matter (PM2.5 and PM10) recorded higher at Jemo1 approach in Jemo Michael signalized intersection due to heavy vehicle congestion and a higher percentage of the heavy vehicle in those sampling areas and also contribution of weathering condition to disperses vehicular emission to the atmosphere.
- The percentage increase of CO, SO2, PM2.5, and PM10 due to congestion at maximum, an average and minimum percentage are (31.97, 19.10 and 51.04%), (9.5, 51.61 and 25%), (37.24, 33.83, and 18.18%) and (23.15, 29.07 and 17.31%) respectively.
- The concentration of the pollutants is influenced not only by traffic data but also by geometric and weather conditions that the measurement was taken.

- The concentration of pollutants increases as traffic volume, percentage of heavy vehicle, green time of the approach, approach grade increases whereas the concentration of the pollutants decreases when the lane width, wind speed increase.
- Generally, traffic congestion affected ambient air quality and it is very essential to measure to reduce air pollution from road transportation by taking into consideration of the recommended mitigations.

5.2. Recommendations

- One of the ways of reducing air pollution due to road transportation is mitigating traffic congestion; the cause of traffic congestion is increasing traffic volume, lower the road network. So I recommend time allocation especially for a heavy vehicle, improving the networks, applied the bus rapid transit system.
- For roundabout that has not transferred to signalized intersection due to heritage, use roundabout metering signal to reduce congestion. Or the author recommended a modern roundabout to reduce air pollution from road transportation. Roundabout has; a channelized approach, a yield control on all entries, a counterclockwise circulation of all vehicles around the central island, and an appro priate geometric curvature to inspire slow speeds through the intersections.
- Expand the railway transport system within the city to reduce air pollution due to congestion from vehicles of road.
- Signal timing consideration of the sequence intersection traffic flow during design may have a contribution of reducing traffic congestion that leads to a decrease in the concentration of air pollutants due to traffic congestion.
- Consider both traffic congestion solution and traffic-related air pollution simultaneously during designing or improvement, one of the major mitigation of reducing air pollution from road transportation. And also Limitation of the vehicular age during importing to the city may contribute to reducing higher emissions due to oldies vehicles during congested traffic conditions.

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APPENDIXES

Appendixes A: Traffic volume data

	Africa union signalized intersection Traffic volume data in PCU											
	Sarbet app.		Mexico app.		Bulgaria approach				Karalo approach(Lideta poly water)			
Time	TH.	R.T.	TH.	R.T.	TH.	R.T.	L.T.	U.T.	TH.	R.T.	L.T	U.T
7:30 - 7:45AM	480	191	307	35	158	14	208	2	184	83	62	1
7:45 - 8:00AM	535	203	339	40	152	13	223	0	207	91	62	3
8:00 - 8:15AM	521	216	328	57	146	13	220	0	182	86	69	0
8:15 - 8:30AM	473	244	348	35	131	12	232	1	200	78	54	0
8:30 - 8:45AM	480	242	341	59	120	16	190	1	130	45	63	1
8:45 - 9:00AM	619	211	344	76	95	24	244	0	165	42	52	1
9:00 - 9:15AM	472	204	403	73	154	24	207	0	143	51	61	0
9:15 - 9: 30AM	475	175	338	79	134	21	196	1	131	42	63	0
9:30 - 9: 45AM	413	154	359	82	124	19	138	0	123	47	66	0
9:45 - 10:00AM	329	179	379	60	128	22	249	1	122	41	53	2
10:00 - 10:15AM	396	199	401	77	120	21	161	0	128	50	53	0
10:15 - 10:30AM	414	166	374	75	131	21	223	0	145	50	58	0
10:30 - 10:45AM	357	179	372	88	120	20	185	0	124	62	45	1
10:45 - 11:00AM	315	153	411	83	113	20	133	0	257	46	66	0
11:00 - 11:15AM	403	159	455	82	135	22	221	3	179	55	38	0
11:15 - 11:30AM	409	159	399	103	132	15	199	0	151	82	69	1
11:30 - 11:45AM	444	142	436	83	133	21	180	0	128	74	62	1
11:45 - 12:00AM	422	143	588	110	150	24	229	0	125	70	66	0

12:00 - 12:15AM	381	136	532	128	128	26	202	0	121	67	45	0
12:15 - 12:30AM	359	155	471	120	158	21	171	0	103	96	47	0
12:30- 12:45AM	335	151	412	110	130	26	179	0	120	81	51	0
12:45- 1:00PM	322	143	431	102	144	22	273	0	127	86	84	1
1:00 - 1:15PM	333	156	507	112	155	24	205	2	132	66	46	0
1:15 - 1:30PM	350	143	450	108	125	21	231	0	138	94	43	0
1:30 - 1:45PM	329	118	361	105	134	26	187	0	145	88	55	0
1:45 - 2:00PM	325	137	394	83	120	24	164	0	128	73	52	0
2:00- 2:15PM	321	153	460	113	134	27	289	0	192	79	54	1
2:15- 2:30PM	396	157	551	114	114	21	202	0	114	74	38	0
2:30 - 2:45PM	347	178	493	97	155	24	219	0	160	89	65	1
2:45 - 3:00PM	350	148	542	121	145	32	184	0	146	71	44	1
3:00- 3:15PM	365	170	340	76	134	19	258	0	141	95	53	3
3:15- 3:30PM	375	155	503	121	144	31	186	3	128	73	46	0
3:30- 3:45PM	423	156	452	113	127	20	186	0	134	75	59	3
3:45- 4:00PM	383	166	433	99	136	19	256	0	218	81	43	0
4:00 - 4:15PM	354	151	503	128	167	26	220	2	96	76	39	0
4:15- 4:30PM	351	174	443	86	129	33	200	0	140	81	42	0
4:30 - 4:45PM	413	268	531	113	133	21	201	0	96	76	27	0
4:45- 5:00PM	307	183	418	101	138	18	222	0	129	77	44	0
5:00- 5:15PM	394	179	567	105	132	22	234	0	134	87	43	0
5:15- 5:30PM	381	133	530	152	136	31	244	0	217	72	73	0
5:30- 5:45PM	357	134	539	106	141	21	168	0	182	78	58	1
5:45- 6:00PM	322	122	384	110	135	12	130	0	121	68	39	0

Appendix B: Geometric data

No	Name of intersection	Name of approach	# lane	Lane w. (m)	Median w.m	Grade (%)	App. D.(m)	Exit. D. (m)	# C. lane	C.w.	Island.
1	Jemo Michael	Ayertena	3	3.5	8.8	-1.6	170	165			
		Lideta	3	3.5	2.5	-1.6	65	50			
		Jemo1	3	3.5	1	2.3	50	65			
		German square	4	3	2.5	1.8	165	170			
2	Africa Union	Mexico	3	3.1	5	-5	42	45			
		Sarbet	3	3.5	1.7	3.6	45	42			
		Karalo	3	3	1.15	-3.6	170	241			
		Bulgaria	3	3	1	2.9	241	170			
3	Legehar	Piassa	3	3.5	1.92	2.6	130	65			
		Kirkos	3	3.5	14	-4.3	65	130			
		Mexico	3	3.5	2.6	-2.4	135	145			
		Meskel square	4	3.5	4.35	3.5	145	135			
4	Sholla	Kebena	4	3	4	-2.6	65	140			
		Megenagna	4	3.6	4	0	140	65			
		Sholla Gebeya	3	3.5	0.9	4.4	70	75			
		Begtera	3	3	0.5	-3	75	70			
5	Imperial	Megenagna	4	3	0.65	-2.5	120	190			

		Bole air port	4	3	1	2.7	190	120			
		Gerji	2	3.6	0	-3.1	70	120			
		Woreda 17 health center	3	3.5	1	3	120	70			
6	Abune petros	Paster	3	3.6	12	-3.3	116	82	3	4.3	36
		Piassa	3	3.5	1.3	0	82	116			
		Merkat o	3	3.5	0.95	2.3	83	116			
		St. Giorgis	3	3.5	0.8	-5	116	82			
7	Teklehaim anot	Merkat o	3	3.2	0	0	107		2	10	40
		Black lion hospital	3	3.6	1.2	5	230				
		Piassa	3	3.6	1	3.3	275				
		Abnet	3	3.2	1	0	130				
		Tewodr os rounda bout	2	3.2	0	3.2	292				

Appendix C: SIDRA Intersection Software analysis

MOVEMENT SUMMARY

Site: 01 [Africa Union]

Four legs signalized intersection
Site Category: (None)
Signals - Fixed Time Isolated Cycle Time = 136 seconds (Site User-Given Phase Times)

Movement Performance - Vehicles												
Mov ID	Turn	Demand Flows Total veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed km/h
South: Mexico												
2	T1	2161	13.6	1.381	227.3	LOS F	146.5	1144.4	1.00	1.77	2.05	1.5
3	R2	497	14.0	0.321	3.9	LOS A	1.7	13.4	0.11	0.58	0.11	42.0
Approach		2658	13.6	1.381	185.5	LOS F	146.5	1144.4	0.83	1.55	1.69	2.5
East: Karalo												
4u	U	7	0.0	1.677	367.4	LOS F	78.3	656.8	1.00	1.78	2.49	3.7
4	L2	260	14.6	1.677	366.4	LOS F	78.3	656.8	1.00	1.78	2.49	2.1
5	T1	813	33.7	1.677	333.3	LOS F	81.4	734.0	1.00	1.82	2.37	3.4
6	R2	355	14.3	0.335	52.3	LOS D	25.2	203.1	1.00	0.93	1.11	12.2
Approach		1435	25.2	1.677	270.0	LOS F	81.4	734.0	1.00	1.59	2.08	3.6
North: Sarbet												
8	T1	2202	11.8	1.523	290.3	LOS F	164.9	1271.3	1.00	1.94	2.26	1.3
9	R2	961	5.7	0.646	4.2	LOS A	5.8	42.7	0.20	0.62	0.20	40.7
Approach		3163	10.0	1.523	203.4	LOS F	164.9	1271.3	0.76	1.54	1.63	2.4
West: Bulgaria												
10u	U	5	0.0	1.936	483.3	LOS F	85.1	623.1	1.00	1.64	2.74	2.9
10	L2	947	5.4	1.936	482.2	LOS F	85.9	634.5	1.00	1.66	2.74	2.0
11	T1	617	25.5	1.936	471.9	LOS F	120.4	1001.1	1.00	2.11	2.72	3.4
12	R2	111	2.4	1.936	477.3	LOS F	120.4	1001.1	1.00	2.12	2.72	2.1
Approach		1680	12.6	1.936	478.1	LOS F	120.4	1001.1	1.00	1.85	2.73	2.5
All Vehicles		8936	14.0	1.936	260.4	LOS F	164.9	1271.3	0.86	1.61	1.93	2.6

MOVEMENT SUMMARY

Site: 02 [Jemo michael]

Four legs signalized intersection
Site Category: (None)
Signals - Fixed Time Isolated Cycle Time = 192 seconds (Site User-Given Phase Times)

Movement Performance - Vehicles												
Mov ID	Turn	Demand Flows Total	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	Distance	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed

		veh/h	%	v/c	sec		veh	m				km/h
South: Jemo 1												
1u	U	26	20.0	2.748	848.0	LOS F	84.0	718.0	1.00	1.54	2.58	0.5
1	L2	336	26.3	2.748	847.0	LOS F	84.0	718.0	1.00	1.54	2.58	0.9
2	T1	1234	18.4	2.189	599.7	LOS F	214.0	1702.3	1.00	1.91	2.35	0.7
3	R2	732	15.0	2.189	601.2	LOS F	214.0	1702.3	1.00	1.62	2.35	1.3
Approach		2327	18.5	2.748	638.6	LOS F	214.0	1702.3	1.00	1.76	2.39	0.9
East: German												
4u	U	94	19.8	1.975	516.7	LOS F	155.0	1229.5	1.00	1.45	2.25	2.2
4	L2	658	15.0	1.975	515.5	LOS F	155.0	1229.5	1.00	1.45	2.25	1.6
5	T1	607	47.4	0.723	66.1	LOS E	25.5	251.1	0.96	0.84	0.96	14.5
6	R2	295	28.3	0.201	6.0	LOS A	0.9	7.7	0.07	0.59	0.07	36.9
Approach		1654	29.5	1.975	259.7	LOS F	155.0	1229.5	0.82	1.07	1.39	3.5
North: Lideta												
7u	U	51	0.0	1.850	459.0	LOS F	77.7	665.2	1.00	1.39	2.20	0.9
7	L2	343	29.9	1.850	457.9	LOS F	77.7	665.2	1.00	1.39	2.20	1.8
8	T1	1120	20.4	1.186	169.9	LOS F	88.9	731.4	1.00	1.31	1.53	2.8
9	R2	125	46.0	1.186	173.1	LOS F	84.3	719.6	1.00	1.28	1.53	4.4
Approach		1639	23.7	1.850	239.3	LOS F	88.9	731.4	1.00	1.33	1.69	2.4
West: Ayer tena												
10u	U	61	30.4	1.296	233.1	LOS F	48.8	392.7	1.00	1.20	1.74	4.6
10	L2	247	14.3	1.296	231.8	LOS F	48.8	392.7	1.00	1.20	1.74	3.2
11	T1	708	34.2	1.291	216.7	LOS F	65.0	571.4	1.00	1.39	1.70	5.0
12	R2	152	21.5	1.291	220.1	LOS F	65.0	571.4	1.00	1.33	1.70	3.5
Approach		1168	28.1	1.296	221.2	LOS F	65.0	581.2	1.00	1.33	1.71	4.4
All Vehicles		6788	24.1	2.748	378.1	LOS F	214.0	1702.3	0.96	1.41	1.86	2.0

MOVEMENT SUMMARY

Site: 03[Legehar signalized intersections]

Four legs signalized intersection
Site Category: (None)
Signals - Fixed Time Isolated Cycle Time = 180 seconds (Site User-Given Phase Times)

Movement Performance - Vehicles												
Mov ID	Turn	Demand Flows Total	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	Distance	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed
		veh/h	%	v/c	sec		veh	m				km/h
South: Kirkos												
1u	U	7	0.0	1.363	251.9	LOS F	29.8	252.1	1.00	1.21	1.88	2.7
1	L2	187	25.3	1.363	250.7	LOS F	29.8	252.1	1.00	1.21	1.88	2.8
2	T1	497	10.8	1.880	456.2	LOS F	90.8	708.1	1.00	1.64	2.29	1.1
3	R2	376	14.1	1.880	452.9	LOS F	90.8	708.1	1.00	1.51	2.28	1.5
Approach		1067	14.5	1.880	417.6	LOS F	90.8	708.1	1.00	1.52	2.21	1.4
East: Meskel Square												

4u	U	201	4.6	1.394	263.5	LOS F	63.9	513.5	1.00	1.22	1.88	3.5
4	L2	203	29.8	1.394	262.6	LOS F	63.9	513.5	1.00	1.22	1.88	3.4
5	T1	1602	13.5	0.989	83.8	LOS F	83.7	653.7	1.00	1.08	1.19	10.9
6	R2	206	1.4	0.198	17.5	LOS B	7.0	49.9	0.44	0.68	0.44	24.3
Approach		2213	13.1	1.394	110.4	LOS F	83.7	653.7	0.94	1.07	1.25	8.1
North: Piassa												
7u	U	35	0.0	1.530	319.2	LOS F	42.9	307.3	1.00	1.30	2.04	2.1
7	L2	221	3.1	1.530	318.2	LOS F	42.9	307.3	1.00	1.30	2.04	2.8
8	T1	545	11.0	1.696	378.4	LOS F	67.1	492.6	1.00	1.58	2.16	2.3
9	R2	182	0.0	1.696	380.6	LOS F	67.1	492.6	1.00	1.55	2.16	2.4
Approach		983	6.8	1.696	363.1	LOS F	67.1	492.6	1.00	1.50	2.13	2.4
West: Mexico												
10u	U	36	7.4	0.815	85.3	LOS F	20.9	151.1	1.00	0.90	1.11	10.2
10	L2	198	3.5	0.815	84.1	LOS F	20.9	151.1	1.00	0.90	1.11	7.9
11	T1	1685	10.3	1.170	149.5	LOS F	127.7	973.0	1.00	1.31	1.51	5.9
12	R2	219	18.0	1.170	153.9	LOS F	123.1	950.8	1.00	1.28	1.51	5.7
Approach		2138	10.4	1.170	142.8	LOS F	127.7	973.0	1.00	1.26	1.46	6.0
All Vehicles		6401	11.5	1.880	211.3	LOS F	127.7	973.0	0.98	1.27	1.62	4.0

MOVEMENT SUMMARY

Site: 04 [Imperial signalized intersection]

Four legs signalized intersection
Site Category: (None)
Signals - Fixed Time Isolated Cycle Time = 185 seconds (Site User-Given Phase Times)

Movement Performance - Vehicles

Mov ID	Turn	Demand Flows Total veh/h	Demand Flows HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed km/h
South: Bole												
1u	U	45	41.2	1.475	300.2	LOS F	44.3	364.2	1.00	1.25	1.96	3.4
1	L2	263	16.0	1.475	297.9	LOS F	110.5	834.5	1.00	1.31	1.95	2.8
2	T1	1561	8.8	1.475	285.9	LOS F	158.4	1192.0	1.00	1.62	1.90	4.3
3	R2	454	12.3	0.285	5.9	LOS A	1.5	11.6	0.08	0.59	0.08	42.1
Approach		2323	10.9	1.475	232.9	LOS F	158.4	1192.0	0.82	1.38	1.55	4.8
East: Gerji												
4	L2	512	12.8	1.224	191.7	LOS F	94.6	697.2	1.00	1.18	1.63	3.5
5	T1	545	5.8	1.224	179.8	LOS F	94.6	697.2	1.00	1.32	1.60	2.8
6	R2	126	7.1	1.224	184.5	LOS F	94.6	697.2	1.00	1.32	1.60	4.7
Approach		1183	8.9	1.224	185.5	LOS F	94.6	697.2	1.00	1.26	1.61	3.3
North: Megenagna												
7u	U	9	0.0	1.703	397.9	LOS F	39.8	300.7	1.00	1.33	2.17	2.6
7	L2	285	9.8	1.703	395.5	LOS F	90.8	694.6	1.00	1.44	2.16	2.1
8	T1	1559	11.0	1.703	367.8	LOS F	199.4	1528.1	0.99	1.73	2.04	2.3

9	R2	143	12.2	0.341	45.4	LOS D	13.2	101.7	0.76	0.74	0.76	11.3
Approach		1997	10.9	1.703	348.8	LOS F	199.4	1528.1	0.97	1.62	1.97	2.4
West: Woreda 17 HC												
10u	U	5	0.0	1.489	304.6	LOS F	38.8	290.4	1.00	1.27	1.98	2.1
10	L2	227	8.1	1.489	303.6	LOS F	38.8	290.4	1.00	1.27	1.98	3.3
11	T1	360	8.8	1.521	305.2	LOS F	88.4	717.6	1.00	1.45	1.98	2.6
12	R2	500	19.6	1.521	289.1	LOS F	88.4	717.6	1.00	1.31	1.96	2.6
Approach		1093	13.6	1.521	297.5	LOS F	88.4	717.6	1.00	1.35	1.97	2.7
All Vehicles		6596	11.0	1.703	270.2	LOS F	199.4	1528.1	0.93	1.43	1.76	3.3

MOVEMENT SUMMARY

Site: 05 [Shola Signalized Intersection]

Four legs signalized intersection
Site Category: (None)
Signals - Fixed Time Isolated Cycle Time = 150 seconds (Site User-Given Phase Times)

Movement Performance - Vehicles

Mov ID	Turn	Demand Flows Total veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed km/h
South: Sholla												
1u	U	119	2.2	1.070	129.7	LOS F	26.0	186.1	1.00	1.06	1.55	4.0
1	L2	403	2.8	1.070	128.0	LOS F	27.8	199.1	1.00	1.08	1.54	5.6
2	T1	93	2.8	1.049	98.7	LOS F	36.4	280.6	1.00	1.09	1.46	4.4
3	R2	293	14.8	1.049	103.4	LOS F	36.4	280.6	1.00	1.09	1.46	4.2
Approach		907	6.6	1.070	117.3	LOS F	36.4	280.6	1.00	1.08	1.51	4.8
East: Megenagna												
4u	U	62	0.0	1.118	149.0	LOS F	31.9	252.2	1.00	1.15	1.65	4.7
4	L2	213	19.4	1.118	148.1	LOS F	31.9	252.2	1.00	1.15	1.65	4.9
5	T1	1669	21.0	1.523	284.1	LOS F	122.5	1012.2	0.99	1.78	2.10	3.4
6	R2	81	28.1	0.305	43.1	LOS D	8.2	69.9	0.80	0.72	0.80	14.4
Approach		2025	20.5	1.523	256.1	LOS F	122.5	1012.2	0.98	1.65	1.99	3.6
North: Begtera												
7u	U	9	0.0	1.286	209.3	LOS F	15.1	118.5	1.00	1.20	1.97	2.5
7	L2	227	15.6	1.286	207.6	LOS F	15.3	121.3	1.00	1.20	1.96	2.5
8	T1	108	14.2	0.760	69.8	LOS E	10.2	78.1	1.00	0.87	1.12	7.6
9	R2	32	0.0	0.760	74.8	LOS E	10.2	78.1	1.00	0.87	1.12	9.8
Approach		377	13.5	1.286	156.9	LOS F	15.3	121.3	1.00	1.08	1.65	3.4
West: Kebena												
10u	U	28	9.4	1.584	328.3	LOS F	131.2	1014.8	1.00	1.86	2.23	2.2
10	L2	21	0.0	1.584	327.2	LOS F	131.2	1014.8	1.00	1.86	2.23	1.6
11	T1	1788	12.6	1.584	296.2	LOS F	133.9	1038.4	0.98	1.77	2.10	1.7
12	R2	501	22.8	0.341	4.8	LOS A	1.8	15.1	0.11	0.59	0.11	32.1

Approach	2339	14.7	1.584	234.4	LOS F	133.9	1038.4	0.80	1.51	1.67	2.1
All Vehicles	5648	15.4	1.584	218.2	LOS F	133.9	1038.4	0.91	1.47	1.76	3.0

MOVEMENT SUMMARY

Site: 06 [Teklehaymanot roundabout]

Roundabout with 5 legs, and 2-lane approaches and circulating road
Site Category: (None)
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flows Total veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed km/h
SouthEast: Black lion hospital												
21	L2	219	5.5	1.079	64.1	LOS E	38.6	280.7	1.00	2.31	4.44	16.1
21a	L1	784	4.3	1.079	54.1	LOS E	38.6	280.7	0.96	2.07	3.80	17.1
23a	R1	342	3.7	0.701	13.5	LOS B	5.9	42.9	0.94	1.10	1.33	41.7
23	R2	63	4.0	0.701	14.2	LOS B	5.9	42.9	0.94	1.10	1.33	41.2
Approach		1408	4.3	1.079	44.0	LOS E	38.6	280.7	0.96	1.83	3.19	21.5
NorthEast: Tewodros roundabout												
24	L2	11	0.0	0.430	44.5	LOS D	2.5	17.2	0.94	1.06	1.23	27.3
25	T1	11	0.0	0.430	39.9	LOS D	2.5	17.2	0.94	1.06	1.23	24.4
26a	R1	50	0.0	0.430	39.5	LOS D	2.5	17.2	0.94	1.06	1.23	23.5
26b	R3	200	0.0	0.814	69.5	LOS E	8.3	57.8	1.00	1.40	2.23	19.6
Approach		271	0.0	0.814	61.9	LOS D	8.3	57.8	0.98	1.31	1.97	20.5
North: Piassa												
7b	L3	2	0.0	0.885	31.2	LOS C	9.4	70.3	0.98	1.34	2.03	33.9
7a	L1	431	7.4	0.885	29.5	LOS C	9.4	70.3	0.98	1.34	2.03	31.1
9a	R1	688	4.2	1.077	49.0	LOS D	34.4	248.7	0.96	2.00	3.79	20.5
9	R2	251	3.3	1.077	61.1	LOS E	34.4	248.7	1.00	2.31	4.63	16.8
Approach		1372	5.0	1.077	45.0	LOS E	34.4	248.7	0.97	1.85	3.38	22.6
West: Merkato												
10	L2	108	2.1	0.302	15.0	LOS B	1.7	12.7	0.88	0.96	0.88	38.4
10a	L1	25	12.9	0.302	14.6	LOS B	1.7	12.7	0.88	0.96	0.88	36.7
12a	R1	990	4.2	1.581	275.7	LOS F	129.3	937.8	1.00	4.73	11.12	4.3
12b	R3	483	40.6	1.497	247.6	LOS F	61.6	581.0	1.00	3.41	7.69	3.3
Approach		1605	15.2	1.581	245.7	LOS F	129.3	937.8	0.99	4.02	9.24	4.5
SouthWest: Abnet												
30b	L3	505	17.2	1.379	190.7	LOS F	94.5	766.2	1.00	4.40	10.09	4.7
30a	L1	583	19.9	1.379	145.3	LOS F	94.5	766.2	0.95	3.54	7.79	9.2
31	T1	33	15.3	0.941	35.0	LOS D	12.4	99.5	1.00	1.52	2.50	25.8
32	R2	409	17.5	0.941	35.3	LOS D	12.4	99.5	1.00	1.52	2.50	22.1

Approach	1530	18.3	1.379	128.5	LOS F	94.5	766.2	0.98	3.24	7.02	8.6
All Vehicles	6187	10.6	1.581	118.3	LOS F	129.3	937.8	0.98	2.73	5.70	10.0

MOVEMENT SUMMARY

Site: 07 [Abune petros roundabout]

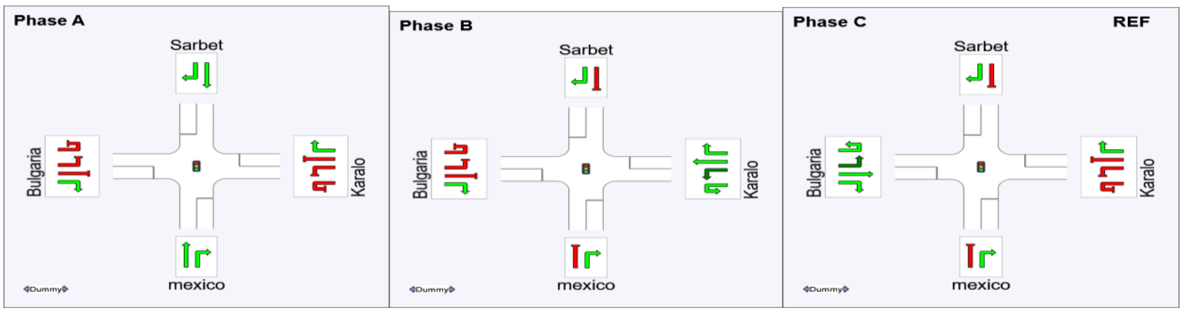
Roundabout with 3-lane approaches and circulating road
Site Category: (None)
Roundabout

Movement Performance - Vehicles

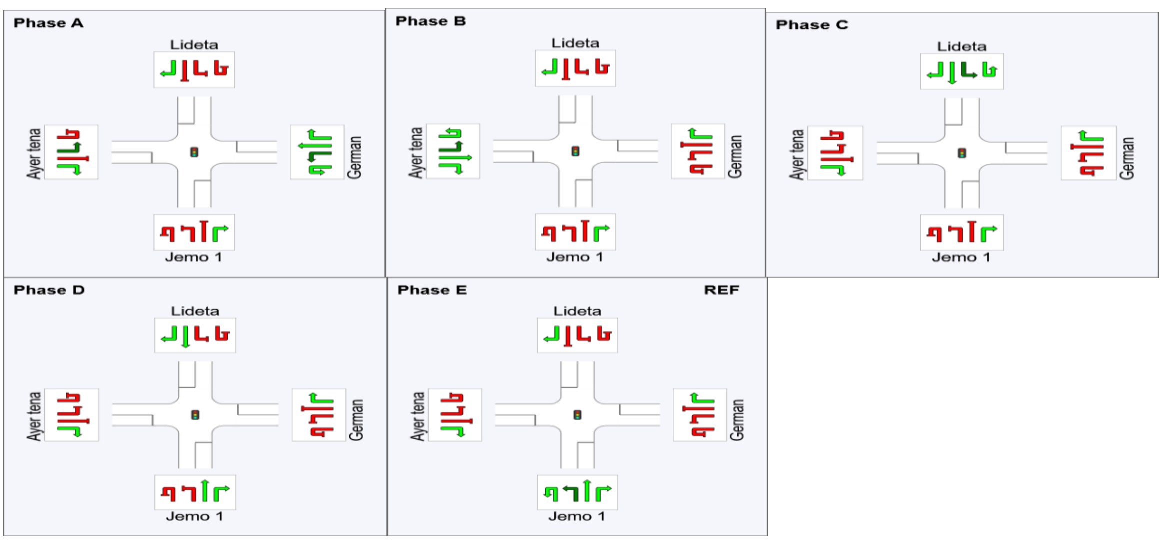
Mov ID	Turn	Demand Flows Total	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	Distance	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed
		veh/h	%	v/c	sec		veh	m				km/h
South: Paster												
1	L2	371	10.7	1.373	188.6	LOS F	70.9	527.0	1.00	3.73	9.31	4.5
2	T1	1564	3.4	1.373	180.7	LOS F	91.6	675.6	1.00	3.92	9.73	5.0
3	R2	436	9.6	1.373	180.2	LOS F	91.6	675.6	1.00	4.29	10.44	4.8
Approach		2370	5.7	1.373	181.9	LOS F	91.6	675.6	1.00	3.96	9.80	4.9
East: Merkato												
4	L2	327	10.2	0.984	38.6	LOS D	11.1	84.6	0.99	1.48	2.52	15.8
5	T1	781	11.9	0.984	30.6	LOS C	13.4	102.2	0.99	1.49	2.53	16.4
6	R2	265	9.8	0.984	28.7	LOS C	13.4	102.2	0.99	1.52	2.56	19.3
Approach		1373	11.1	0.984	32.1	LOS D	13.4	102.2	0.99	1.49	2.54	16.7
North: Piassa												
7	L2	330	15.9	0.975	36.8	LOS D	11.7	92.5	0.99	1.50	2.53	18.0
8	T1	773	12.7	0.975	28.8	LOS C	13.9	108.8	0.99	1.50	2.54	17.4
9	R2	392	14.1	0.975	26.8	LOS C	13.9	108.8	0.99	1.53	2.56	17.4
Approach		1494	13.7	0.975	30.0	LOS D	13.9	108.8	0.99	1.51	2.54	17.6
West: St. Giorgis												
10	L2	143	22.2	0.510	18.4	LOS B	4.5	36.4	0.89	1.06	1.25	29.6
11	T1	715	15.1	0.718	10.9	LOS C	5.1	41.6	0.89	1.05	1.24	36.8
12	R2	251	22.6	0.510	11.0	LOS B	5.1	41.6	0.90	1.06	1.24	31.9
Approach		1109	17.7	0.718	11.9	LOS C	5.1	41.6	0.89	1.05	1.24	34.6
All Vehicles		6346	10.8	1.373	84.0	LOS F	91.6	675.6	0.98	2.34	5.02	8.9

Phasing Summary

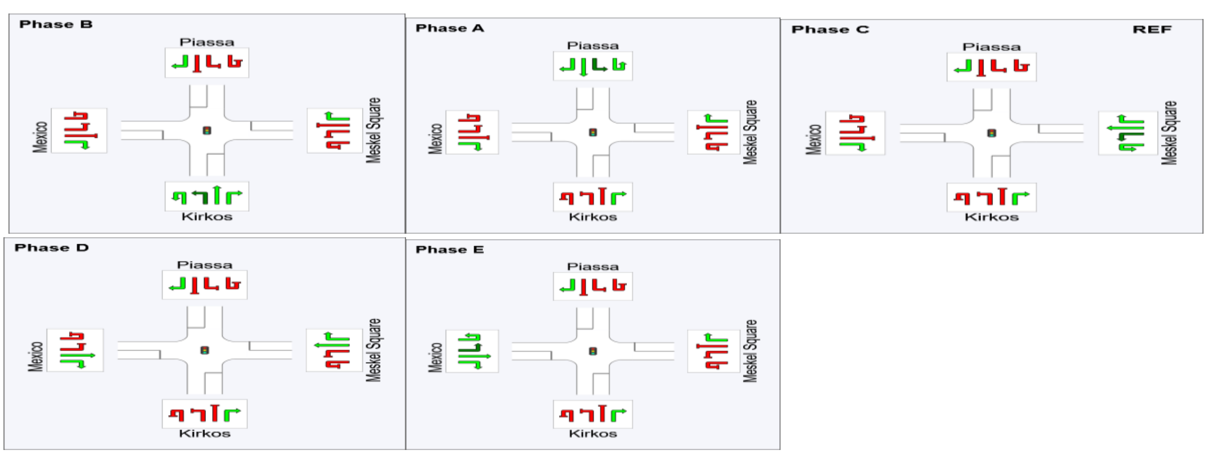
I. Africa union signalized intersection



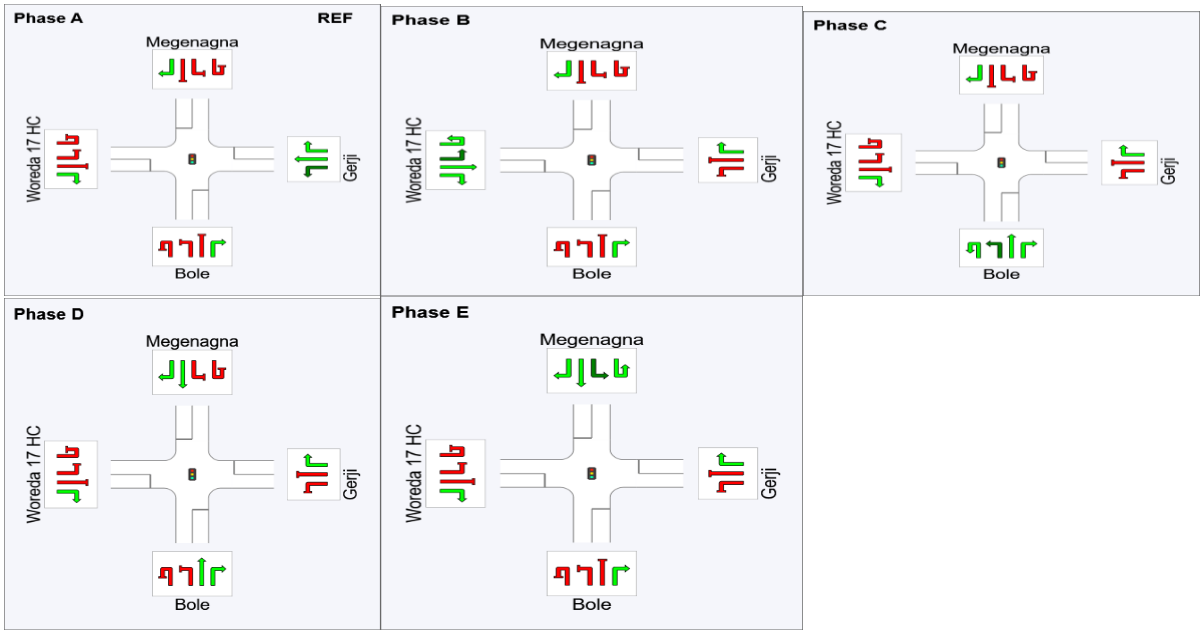
II. Jemo Michael signalized intersection



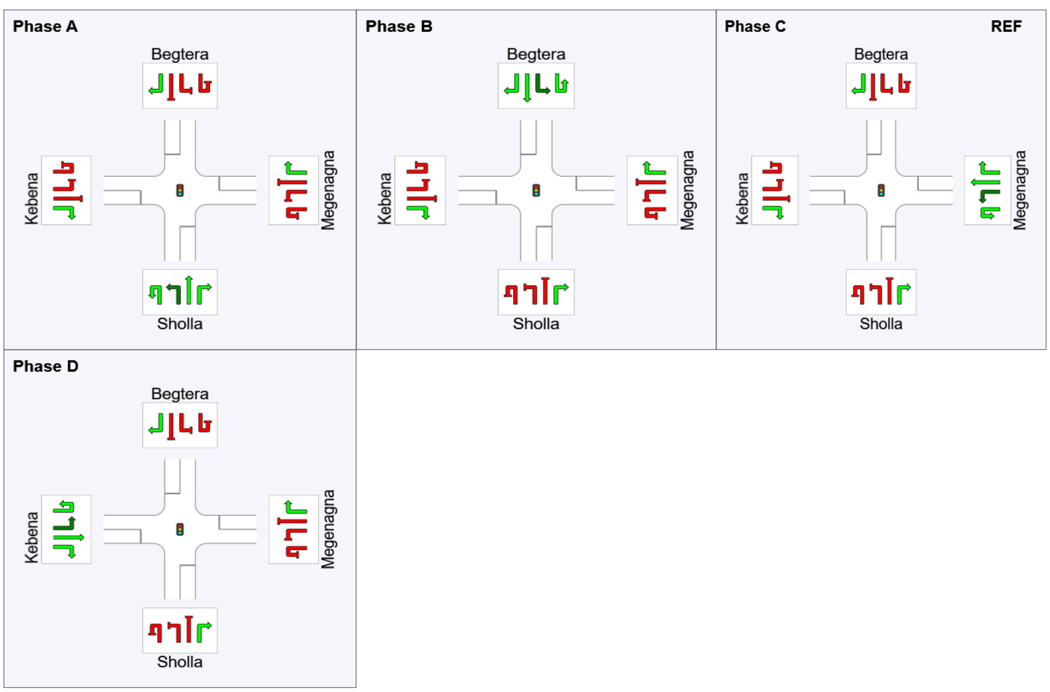
III. Legehar signalized intersection



IV. Imperial signalized intersection



V. Sholla signalized intersection



Appendix D: Gaseous emission with traffic volume at Africa union Signalized intersection (Sarbet approach)

		Africa Union Signalized intersection							
		Gaseous Emission of Car				Gaseous Emission of Minibus			
Time	Car	HC (%)	CO (PPM)	CO2(PPM)	Minibus	HC (%)	CO(PPM)	CO2 (PPM)	Smoke
7:30 - 7:45AM	505	84	1879	3722	107	12	624	948	736
7:45 - 8:00AM	616	103	2292	4540	77	9	449	682	530
8:00 - 8:15AM	590	99	2195	4348	88	10	513	780	605
8:15 - 8:30AM	564	94	2098	4157	94	11	548	833	647
8:30 - 8:45AM	555	93	2065	4090	70	8	408	620	482
8:45 - 9:00AM	630	105	2344	4643	83	10	484	735	571
9:00 - 9:15AM	510	85	1897	3759	79	9	461	700	544
9:15 - 9: 30AM	465	78	1730	3427	94	11	548	833	647
9:30 - 9: 45AM	423	71	1574	3118	74	9	431	656	509
9:45 - 10:00AM	360	60	1339	2653	79	9	461	700	544
10:00 -10:15AM	417	70	1551	3073	94	11	548	833	647
10:15 -10:30AM	405	68	1507	2985	99	11	577	877	681
10:30 -10:45AM	374	62	1391	2756	96	11	560	851	660
10:45 -11:00AM	336	56	1250	2476	51	6	297	452	351
11:00 - 11:15AM	372	62	1384	2742	91	11	531	806	626
11:15 - 11:30AM	429	72	1596	3162	65	8	379	576	447
11:30 - 11:45AM	415	69	1544	3059	95	11	554	842	654
11:45 - 12:00AM	395	66	1469	2911	75	9	437	665	516
12:00 - 12:15AM	354	59	1317	2609	75	9	437	665	516
12:15 - 12:30AM	359	60	1335	2646	82	10	478	727	564
12:30- 12:45AM	328	55	1220	2417	81	9	472	718	557
12:45- 1:00PM	319	53	1187	2351	74	9	431	656	509
1:00 - 1:15PM	310	52	1153	2285	68	8	396	602	468
1:15 - 1:30PM	312	52	1161	2299	97	11	566	859	667
1:30 - 1:45PM	334	56	1242	2462	53	6	309	470	365
1:45 - 2:00PM	345	58	1283	2543	57	7	332	505	392
2:00- 2:15PM	310	52	1153	2285	75	9	437	665	516
2:15-2:30PM	362	60	1347	2668	87	10	507	771	599
2:30 - 2:45PM	353	59	1313	2602	64	7	373	567	440
2:45 - 3:00PM	311	52	1157	2292	95	11	554	842	654

3:00- 3:15PM	389	65	1447	2867	76	9	443	673	523
3:15-3:30PM	360	60	1339	2653	87	10	507	771	599
3:30- 3:45PM	388	65	1443	2860	98	11	571	868	674
3:45- 4:00PM	387	65	1440	2852	83	10	484	735	571
4:00 - 4:15PM	366	61	1362	2697	83	10	484	735	571
4:15- 4:30PM	366	61	1362	2697	67	8	391	594	461
4:30 - 4:45PM	403	67	1499	2970	92	11	536	815	633
4:45-5:00PM	360	60	1339	2653	65	8	379	576	447
5:00-5:15PM	424	71	1577	3125	75	9	437	665	516
5:15-5:30PM	374	62	1391	2756	79	9	461	700	544
5:30-5:45PM	338	56	1257	2491	88	10	513	780	605
5:45- 6:00PM	303	51	1127	2233	92	11	536	815	633

		Africa union Signalized intersection							
		Gaseous Emission of Bus					Gaseous emission of truck		
Time	Bus	(HC %)	CO(PPM)	CO2(PPM)	Smoke density	Truck	(HC %)	CO(PPM)	CO2 (PPM)
7:30 - 7:45AM	15	1.17	88	166	4	9	2	102	63
7:45 - 8:00AM	12	0.94	70	133	3	5	1	57	35
8:00 - 8:15AM	13	1.02	76	144	3	11	2	125	77
8:15 - 8:30AM	12	0.94	70	133	3	12	2	136	84
8:30 - 8:45AM	16	1.25	93	177	4	23	4	261	161
8:45 - 9:00AM	23	1.8	134	254	6	12	2	136	84
9:00 - 9:15AM	21	1.64	123	232	5	15	3	170	105
9:15 - 9: 30AM	23	1.8	134	254	6	21	4	238	147
9:30 - 9: 45AM	11	0.86	64	122	3	21	4	238	147
9:45 - 10:00AM	13	1.02	76	144	3	20	4	227	140
10:00 -10:15AM	12	0.94	70	133	3	34	7	386	239
10:15 -10:30AM	11	0.86	64	122	3	33	6	374	232
10:30 -10:45AM	14	1.09	82	155	3	21	4	238	147
10:45 -11:00AM	7	0.55	41	77	2	27	5	306	190
11:00 - 11:15AM	14	1.09	82	155	3	31	6	352	218
11:15 - 11:30AM	15	1.17	88	166	4	21	4	238	147
11:30 - 11:45AM	13	1.02	76	144	3	33	6	374	232
11:45 - 12:00AM	23	1.8	134	254	6	26	5	295	183

12:00 - 12:15AM	17	1.33	99	188	4	30	6	340	211
12:15 - 12:30AM	12	0.94	70	133	3	25	5	284	176
12:30- 12:45AM	12	0.94	70	133	3	25	5	284	176
12:45- 1:00PM	12	0.94	70	133	3	23	4	261	161
1:00 - 1:15PM	14	1.09	82	155	3	39	8	442	274
1:15 - 1:30PM	14	1.09	82	155	3	28	5	318	197
1:30 - 1:45PM	10	0.78	58	111	2	21	4	238	147
1:45 - 2:00PM	13	1.02	76	144	3	18	3	204	126
2:00- 2:15PM	12	0.94	70	133	3	31	6	352	218
2:15-2:30PM	21	1.64	123	232	5	19	4	215	133
2:30 - 2:45PM	19	1.48	111	210	5	33	6	374	232
2:45 - 3:00PM	19	1.48	111	210	5	34	7	386	239
3:00- 3:15PM	13	1.02	76	144	3	22	4	249	154
3:15-3:30PM	21	1.64	123	232	5	11	2	125	77
3:30- 3:45PM	19	1.48	111	210	5	16	3	181	112
3:45- 4:00PM	15	1.17	88	166	4	21	4	238	147
4:00 - 4:15PM	13	1.02	76	144	3	9	2	102	63
4:15- 4:30PM	24	1.87	140	265	6	12	2	136	84
4:30 - 4:45PM	22	1.72	128	243	5	12	2	136	84
4:45-5:00PM	20	1.56	117	221	5	7	1	79	49
5:00-5:15PM	22	1.72	128	243	5	5	1	57	35
5:15-5:30PM	11	0.86	64	122	3	9	2	102	63
5:30-5:45PM	15	1.17	88	166	4	8	2	91	56
5:45- 6:00PM	12	0.94	70	133	3	8	2	91	56

Appendix E: Ambient air quality, metrological data and traffic volume data at the sampling area

Date	Day of week	Sampling Area	Time	CO (µg/m^3)	Humidity (%)	Temp. (°C)	Wind Speed (Km/hr)	Wind direction	Traffic volume	% of H.V.
Oct 13, 2020	Tuesday	AU	8:00 - 8:15	8600	45	18	7	East N.	754	7
			8:15 - 8:30	11015	52	20	6	East N.	729	10
			8:30 - 8:45	10000	43	19	6	East N.	724	10
			8:45 - 9:00	10200	45	19	6	East N.	820	11
			1:30 - 1:45	8650	40	24	6	East N.	447	9
			1:45 - 2:00	9000	52	24	6	East N.	462	11
			2:00- 2:15	8011	50	25	6	East N.	474	8
			2:15- 2:30	8200	41	24	6	East N.	553	12
Oct 14, 2020	Wednesday		8:00 - 8:15	9989	50	20	7	East N.	774	13
			8:15 - 8:30	11000	45	19	7	East N.	755	10
			8:30 - 8:45	9899	44	20	7	East N.	735	8
			8:45 - 9:00	12010	43	20	7	East N.	873	13
			1:30 - 1:45	8011	50	23	7	East N.	476	9
			1:45 - 2:00	7200	51	23	7	East N.	482	10
			2:00- 2:15	7000	49	24	7	East N.	475	8
			2:15- 2:30	9000	49	24	6	East N.	449	11
Oct 15, 2020	Thursday		8:00 - 8:15	9835	46	19	6	East N.	676	6
			8:15 - 8:30	9705	44	20	6	East N.	632	7
			8:30 - 8:45	9620	43	20	6	East N.	681	8
			8:45 - 9:00	10200	43	20	6	East N.	649	12
			1:30 - 1:45	7038	50	21	7	East N.	404	12

			1:45 - 2:00	7410	53	20	7	East N.	410	11
			2:00- 2:15	7000	48	21	7	East N.	402	9
			2:15- 2:30	7019	49	21	7	East N.	470	11
Nov 24, 2020	Tuesday	Jem o mic hael	7:30 - 7:45	8700	42	20	6	East S.	618	8
			7:45 - 8:00	9000	41	20	6	East S.	550	11
			8:00 - 8:15	6700	40	20	7	East S.	533	12
			8:15 - 8:30	8440	40	20	6	East S.	538	24
			1:00 - 1:15	7100	41	21	7	East S.	351	21
			1:15 - 1:30	5900	41	21	7	East S.	431	17
			1:30 - 1:45	6010	41	21	7	East S.	403	20
			1:45 - 2:00	6420	40	21	7	East S.	437	14
Nov 25, 2020	Wednesda y		7:30 - 7:45	10500	39	19	8	East S.	626	30
			7:45 - 8:00	9000	39	19	8	East S.	575	20
			8:00 - 8:15	8600	40	19	8	East S.	537	20
			8:15 - 8:30	8655	40	19	8	East S.	538	26
			1:00 - 1:15	7100	41	21	8	East S.	353	19
			1:15 - 1:30	6700	40	21	7	East S.	468	19
			1:30 - 1:45	7100	40	21	7	East S.	455	25
			1:45 - 2:00	6800	41	21	7	East S.	449	16
Nov 26, 2020	Thursday		7:30 - 7:45	9500	41	20	7	East S.	581	28
			7:45 - 8:00	9300	41	20	7	East S.	576	25
			8:00 - 8:15	7958	40	20	7	East S.	516	15
			8:15 - 8:30	8100	40	20	8	East S.	510	28
			1:00 - 1:15	6100	40	22	8	East S.	366	13
			1:15 - 1:30	5600	41	22	8	East S.	358	11

			1:30 - 1:45	6011	41	22	8	East S.	402	14
			1:45 - 2:00	5900	41	22	8	East S.	333	14
Oct 20, 2020	Tuesday	Lege har	8:30 - 8:45	8000	46	20	8	South E.	499	6
			8:45 - 9:00	7110	51	21	8	South E.	483	10
			9:00 - 9:15	10200	44	20	8	South E.	542	11
			9:15 - 9: 30	8300	45	22	8	South E.	475	13
			3:00- 3:15	7000	40	21	9	South E.	392	10
			3:15- 3:30	6300	51	21	9	South E.	375	11
			3:30- 3:45	5984	49	21	9	South E.	379	13
			3:45- 4:00	6000	47	21	9	South E.	373	10
Oct 21, 2020	Wednesda y		1:30 - 1:45	8820	50	20	9	South E.	476	10
			1:45 - 2:00	8100	45	20	9	South E.	464	10
			8:30 - 8:45	8700	45	20	9	South E.	525	12
			8:45 - 9:00	8300	44	20	9	South E.	453	13
			9:00 - 9:15	5098	50	23	9	South E.	311	8
			9:15 - 9: 30	7200	50	23	9	South E.	336	12
			3:00- 3:15	5005	49	23	9	South E.	356	7
			3:15- 3:30	6810	50	23	9	South E.	389	8
Oct 22, 2020	Thursday		3:30- 3:45	9700	46	19	9	South E.	519	11
			3:45- 4:00	9405	43	19	8	South E.	525	12
			1:30 - 1:45	8820	42	19	8	South E.	556	10
			1:45 - 2:00	8100	44	19	8	South E.	492	11
			8:30 - 8:45	7000	50	22	8	South E.	347	10
			8:45 - 9:00	6300	51	22	7	South E.	365	10
			9:00 - 9:15	5997	49	22	7	South E.	353	9

			9:15 - 9: 30	6000	48	22	7	South E.	379	10
Nov 17, 2020	Tuesday	Imperial	3:00- 3:15	5997	42	20	7	East S.	411	6
			3:15- 3:30	8100	41	20	6	East S.	346	7
			3:30- 3:45	7002	40	21	7	East S.	395	9
			3:45- 4:00	6310	41	22	7	East S.	374	15
			10:00 - 10:15	5600	40	23	7	East S.	469	8
			10:15 - 10:30	10010	40	19	5	East S.	557	16
			10:30 - 10:45	11640	42	19	5	East S.	601	12
			10:45 - 11:00	11200	41	19	5	East S.	541	11
Nov 18, 2020	Wednesday		5:00- 5:15	5550	40	19	8	East S.	377	15
			5:15- 5:30	6700	40	21	7	East S.	371	11
			5:30- 5:45	6865	40	21	7	East S.	394	10
			5:45- 6:00	6101	40	21	7	East S.	370	11
			10:00 - 10:15	5454	40	21	7	East S.	463	10
			10:15 - 10:30	8784	40	21	6	East S.	546	10
			10:30 - 10:45	9520	40	20	5	East S.	588	13
			10:45 - 11:00	12003	40	20	5	East S.	533	13
Nov 19, 2020	Thursday		5:00- 5:15	6886	43	20	7	East S.	371	11
			5:15- 5:30	8000	41	20	6	East S.	356	13
			5:30- 5:45	8875	40	20	6	East S.	509	14
			5:45- 6:00	6642	41	20	7	East S.	359	14
			10:00 - 10:15	8974	42	20	9	East S.	482	8
			10:15 - 10:30	9700	41	20	9	East S.	567	7
			10:30 - 10:45	10050	40	19	9	East S.	617	9
			10:45 - 11:00	8561	40	20	9	East S.	552	11

Nov 10, 2020	Tuesday	sholla	5:00-5:15	6600	40	21	9	South E.	407	10
			5:15-5:30	6400	41	22	6	South E.	324	14
			5:30-5:45	6400	42	23	6	South E.	378	15
			5:45-6:00	6714	41	23	6	South E.	388	14
			10:00 - 10:15	6800	40	23	6	South E.	517	10
			10:15 - 10:30	5015	41	23	8	South E.	498	12
			10:30 - 10:45	4513	39	23	9	South E.	541	11
			10:45 - 11:00	6700	41	23	7	South E.	518	9
Nov 11, 2020	Wednesday		5:00-5:15	5800	40	23	7	South E.	394	14
			5:15-5:30	6300	42	23	7	South E.	396	12
			5:30-5:45	5598	42	23	7	South E.	389	14
			5:45-6:00	6100	42	23	7	South E.	329	15
			10:00 - 10:15	5500	40	23	7	South E.	504	11
			10:15 - 10:30	5300	40	23	7	South E.	478	11
			10:30 - 10:45	4120	41	24	8	South E.	509	10
			10:45 - 11:00	3800	42	25	9	South E.	461	10
Nov 12, 2020	Thursday		5:00-5:15	6800	41	24	7	South E.	373	13
			5:15-5:30	6700	40	24	7	South E.	309	16
			5:30-5:45	5847	41	25	7	South E.	323	14
			5:45-6:00	6600	41	25	7	South E.	309	15
			10:00 - 10:15	5112	40	27	8	South E.	534	11
			10:15 - 10:30	6231	41	27	7	South E.	520	13
			10:30 - 10:45	5100	40	26	8	South E.	538	10
			10:45 - 11:00	5148	40	25	8	South E.	492	10
Nov	Tuesday	Petr	5:00-	1890	38	19	8	South E.	467	4

3, 2020		os	5:15							
			5:15-5:30	2500	40	20	8	South E.	456	6
			5:30-5:45	3330	39	19	8	South E.	520	5
			5:45-6:00	1905	38	20	8	South E.	257	7
			8:00 - 8:15	1007	40	20	8	South E.	183	11
			8:15 - 8:30	1800	39	21	8	South E.	238	13
			8:30 - 8:45	2010	39	21	8	South E.	262	8
			8:45 - 9:00	2300	40	25	8	South E.	412	8
Nov 4, 2020	Wednesday		1:00 - 1:15	1720	40	20	10	South E.	460	6
			1:15 - 1:30	2365	39	20	10	South E.	433	6
			1:30 - 1:45	1912	38	21	10	South E.	508	4
			1:45 - 2:00	2900	40	20	10	South E.	240	7
			8:00 - 8:15	2010	40	20	10	South E.	191	12
			8:15 - 8:30	1620	40	21	10	South E.	222	12
			8:30 - 8:45	2010	40	19	10	South E.	262	9
			8:45 - 9:00	2101	39	20	10	South E.	394	8
Nov 5, 2020	Thursday		1:00 - 1:15	1845	40	19	10	South E.	482	4
			1:15 - 1:30	2100	39	21	10	South E.	472	6
			1:30 - 1:45	2321	39	20	10	South E.	538	5
			1:45 - 2:00	1521	42	21	10	South E.	231	9
			8:00 - 8:15	2841	41	22	8	South E.	239	7
			8:15 - 8:30	3100	39	22	8	South E.	273	7
			8:30 - 8:45	3945	40	20	8	South E.	417	8
			8:45 - 9:00	2000	48	19	8	South E.	390	9
Oct 27, 2020	Tuesday	`Tekleha yma	1:00 - 1:15	6215	50	19	7	East S.	205	8
			1:15 -	8000	52	18	6	East S.	194	6

		not	1:30							
			1:30 - 1:45	7641	48	21	7	East S.	234	10
			1:45 - 2:00	8011	43	20	7	East S.	173	13
			10:00 - 10:15	7200	51	23	7	East S.	349	5
			10:15 - 10:30	7900	49	21	7	East S.	303	5
			10:30 - 10:45	5401	48	22	7	East S.	308	3
			10:45 - 11:00	7454	46	21	7	East S.	302	7
Oct 28, 2020	Wednesday		5:00-5:15	5310	44	23	7	East S.	214	5
			5:15-5:30	9101	44	20	6	East S.	191	26
			5:30-5:45	8450	43	21	6	East S.	236	23
			5:45-6:00	8800	49	21	6	East S.	178	18
			10:00 - 10:15	6400	50	22	6	East S.	277	13
			10:15 - 10:30	8100	49	21	6	East S.	348	13
			10:30 - 10:45	7300	50	24	6	East S.	302	6
			10:45 - 11:00	8401	46	24	6	East S.	306	12
Oct 29, 2020	Thursday		5:00-5:15	7210	44	20	7	East S.	219	10
			5:15-5:30	6000	45	21	7	East S.	200	18
			5:30-5:45	8121	44	20	6	East S.	228	21
			5:45-6:00	7200	48	22	7	East S.	183	16
			10:00 - 10:15	7845	48	23	6	East S.	241	17
			10:15 - 10:30	6210	49	25	7	East S.	353	4
			10:30 - 10:45	8742	49	24	7	East S.	311	6
			10:45 - 11:00	7910	48	24	7	East S.	308	2

SO2 with corresponding metrological data and traffic volume

Date	Day of week	Time	Sampling Area	SO2 (μg/m³)	Humidity (%)	Temp. (°C)	Wind Speed (Km/hr)	Wind direction	Traffic Volume	% of H.V.
Oct 13, 2020	Tuesday	8:00 - 8:15	Africa union	107	45	20	8	East N.	512	6
		8:15 - 8:30		129	52	21	8	East N.	510	8
		8:30 - 8:45		121	43	22	8	East N.	506	7
		8:45 - 9:00		160	45	23	8	East N.	498	9
		1:30 - 1:45		121	40	22	7	East N.	313	8
		1:45 - 2:00		121	52	23	7	East N.	323	8
		2:00- 2:15		120	50	24	7	East N.	331	7
		2:15- 2:30		110	41	24	7	East N.	387	9
Oct 14, 2020		8:00 - 8:15		131	50	20	7	East N.	542	13
		8:15 - 8:30		121	45	21	7	East N.	528	16
		8:30 - 8:45		230	44	22	7	East N.	515	18
		8:45 - 9:00		141	43	22	7	East N.	578	20
		1:30 - 1:45		121	50	23	7	East N.	333	8
		1:45 - 2:00		121	51	23	7	East N.	337	9
		2:00- 2:15		120	49	24	7	East N.	332	7
		2:15- 2:30		110	49	24	6	East N.	392	7
Oct 15 2020				210	46	20	6	East N.	473	17
		8:15 - 8:30		200	44	22	6	East N.	442	11
		8:30 - 8:45		160	43	23	6	East N.	477	15
		8:45 - 9:00		270	43	24	6	East N.	454	20
		1:30 - 1:45		32	50	21	9	East N.	283	6

		1:45 - 2:00		27	53	20	9	East N.	287	4
		2:00-2:15		26	48	21	9	East N.	282	4
		2:15-2:30		22	49	21	9	East N.	329	5
Nov 24. 2020	Tuesday	7:30 - 7:45	Jemo michael	22	42	20	9	East S.	433	12
		7:45 - 8:00		35	41	20	9	East S.	385	10
		8:00 - 8:15		32	40	20	9	East S.	373	12
		8:15 - 8:30		33	40	20	9	East S.	377	16
		1:00 - 1:15		21	41	21	7	East S.	246	12
		1:15 - 1:30		34	41	21	7	East S.	301	12
		1:30 - 1:45		21	41	21	7	East S.	282	14
		1:45 - 2:00		22	40	21	7	East S.	306	21
Nov 25, 2020	Wednes day	7:30 - 7:45		40	39	20	8	East S.	438	10
		7:45 - 8:00		36	39	21	8	East S.	402	10
		8:00 - 8:15		33	40	21	8	East S.	376	10
		8:15 - 8:30		32	40	22	8	East S.	376	14
		1:00 - 1:15		20	41	23	8	East S.	247	14
		1:15 - 1:30		29	40	23	7	East S.	328	13
		1:30 - 1:45		30	40	24	7	East S.	318	12
		1:45 - 2:00		28	41	24	7	East S.	314	10
Nov 26, 2020	Thursda y	7:30 - 7:45		21	41	20	7	East S.	407	17
		7:45 - 8:00		36	41	20	7	East S.	403	10
		8:00 - 8:15		31	40	20	7	East S.	361	10
		8:15 - 8:30		30	40	20	8	East S.	357	13

		1:00 - 1:15		21	40	22	8	East S.	256	11
		1:15 - 1:30		24	41	22	8	East S.	313	10
		1:30 - 1:45		21	41	22	8	East S.	281	7
		1:45 - 2:00		22	41	22	8	East S.	303	7
Oct 20, 2020	Tuesday	8:30 - 8:45	Legehar	320	46	20	8	South E.	349	18
		8:45 - 9:00		200	51	21	8	South E.	338	17
		9:00 - 9:15		233	44	20	8	South E.	379	15
		9:15 - 9: 30		154	45	22	8	South E.	332	14
		3:00-3:15		103	40	21	10	South E.	207	6
		3:15-3:30		102	51	21	10	South E.	216	7
		3:30-3:45		90	49	21	10	South E.	213	7
		3:45-4:00		52	47	21	10	South E.	292	8
Oct 21, 2020	Wednes day	1:30 - 1:45		160	50	20	10	South E.	333	11
		1:45 - 2:00		154	45	20	10	South E.	325	14
		8:30 - 8:45		140	45	20	10	South E.	368	20
		8:45 - 9:00		132	44	20	10	South E.	317	18
		9:00 - 9:15		131	50	23	10	South E.	292	9
		9:15 - 9: 30		127	50	23	10	South E.	208	7
		3:00-3:15		122	49	23	10	South E.	219	6
		3:15-3:30		122	50	23	10	South E.	282	6
Oct 22, 2020	Thursda y	3:30-3:45		210	46	20	10	South E.	363	10
		3:45-4:00		210	43	21	8	South E.	346	12
		1:30 - 1:45		207	42	20	8	South E.	389	13

		1:45 - 2:00		200	44	20	8	South E. South E.	345	12
		8:30 - 8:45		121	50	23	8		221	7
		8:45 - 9:00		118	51	22	7	South E.	225	6
		9:00 - 9:15		112	49	22	7	South E.	218	6
		9:15 - 9: 30		105	48	21	7	South E.	204	6
Nov 17, 2020	Tuesday	3:00-3:15	Imperial	420	42	20	7	East S.	241	20
		3:15-3:30		410	41	20	6	East S.	240	23
		3:30-3:45		403	40	21	7	East S.	242	19
		3:45-4:00		205	41	22	7	East S.	190	10
		10:00 - 10:15		427	40	23	7	East S.	328	11
		10:15 - 10:30		425	40	20	5	East S.	390	15
		10:30 - 10:45		423	42	21	5	East S.	421	14
		10:45 - 11:00		418	41	22	5	East S.	378	14
Nov 18, 2020	Wednes day	5:00-5:15		305	40	20	8	East S.	220	10
		5:15-5:30		302	40	21	7	East S.	225	8
		5:30-5:45		302	40	21	7	East S.	236	9
		5:45-6:00		36	40	21	7	East S.	205	5
		10:00 - 10:15		452	40	21	7	East S.	424	17
		10:15 - 10:30		432	40	21	6	East S.	382	18
		10:30 - 10:45		432	40	20	5	East S.	412	21
		10:45 - 11:00		429	40	20	5	East S.	393	25
Nov 19, 2020		5:00-5:15		321	43	20	7	East S.	229	14
	Thursda y	5:15-5:30		320	41	20	6	East S.	246	19

		5:30-5:45		305	40	20	6	East S.	237	13
		5:45-6:00		302	41	20	7	East S.	221	10
		10:00 - 10:15		460	42	20	9	East S.	438	16
		10:15 - 10:30		452	41	20	9	East S.	397	15
		10:30 - 10:45		452	40	19	9	East S.	432	16
		10:45 - 11:00		432	40	20	9	East S.	408	18
Nov 10, 2020	Tuseday	5:00-5:15	Sholla	131	40	21	9	South E.	194	12
		5:15-5:30		220	41	22	6	South E.	230	14
		5:30-5:45		194	42	23	6	South E.	208	14
		5:45-6:00		210	41	23	6	South E.	201	16
		10:00 - 10:15		200	40	23	6	South E.	382	17
		10:15 - 10:30		229	41	23	8	South E.	379	18
		10:30 - 10:45		230	39	23	9	South E.	371	18
		10:45 - 11:00		220	41	23	7	South E.	385	7
Nov 11, 2020	Wednes day	5:00-5:15		217	40	23	7	South E.	281	12
		5:15-5:30		215	42	23	7	South E.	215	13
		5:30-5:45		189	42	23	7	South E.	209	14
		5:45-6:00		200	42	23	7	South E.	219	15
		10:00 - 10:15		260	40	23	7	South E.	393	18
		10:15 - 10:30		250	40	23	7	South E.	378	18
		10:30 - 10:45		240	41	24	8	South E.	397	11
		10:45 - 11:00		237	42	25	9	South E.	382	17
Nov 12,	Thursda y	5:00-5:15		120	41	24	7	South E.	201	6

2020		5:15-5:30		180	40	24	7	South E.	204	5
		5:30-5:45		200	41	25	7	South E.	213	5
		5:45-6:00		190	41	25	7	South E.	200	7
		10:00 - 10:15		280	40	27	8	South E.	401	7
		10:15 - 10:30		271	41	27	7	South E.	394	9
		10:30 - 10:45		378	40	26	8	South E.	416	17
		10:45 - 11:00		250	40	25	8	South E.	384	7
Nov 3, 2020	Tuesday	5:00-5:15	Petros	22	38	20	8	South E.	327	3
		5:15-5:30		32	40	20	8	South E.	319	4
		5:30-5:45		54	39	21	8	South E.	364	4
		5:45-6:00		27	38	21	8	South E.	280	5
		8:00 - 8:15		25	40	20	8	South E.	128	8
		8:15 - 8:30		23	39	21	8	South E.	167	9
		8:30 - 8:45		21	39	22	8	South E.	183	6
		8:45 - 9:00		21	40	25	8	South E.	289	6
Nov 4, 2020	Wednes day	1:00 - 1:15		52	40	20	7	South E.	322	4
		1:15 - 1:30		50	39	20	7	South E.	303	4
		1:30 - 1:45		60	38	21	7	South E.	355	3
		1:45 - 2:00		23	40	20	7	South E.	168	5
		8:00 - 8:15		21	40	20	7	South E.	134	8
		8:15 - 8:30		21	40	21	7	South E.	156	9
		8:30 - 8:45		20	40	19	7	South E.	184	6
		8:45 - 9:00		27	39	20	7	South E.	276	5

Nov 5, 2020	Thursday	1:00 - 1:15		26	40	19	7	South E.	337	3
		1:15 - 1:30		25	39	21	7	South E.	331	4
		1:30 - 1:45		23	39	20	7	South E.	377	4
		1:45 - 2:00		20	42	21	7	South E.	161	6
		8:00 - 8:15		16	41	22	8	South E.	167	7
		8:15 - 8:30		17	39	22	8	South E.	191	7
		8:30 - 8:45		21	40	20	8	South E.	292	5
		8:45 - 9:00		19	48	19	8	South E.	273	7
Oct 27, 2020	Tuesday	1:00 - 1:15	Teklehaymanot	144	50	19	7	East S.	144	12
		1:15 - 1:30		105	52	18	6	East S.	136	12
		1:30 - 1:45		122	48	21	7	East S.	163	14
		1:45 - 2:00		52	43	20	7	East S.	121	16
		10:00 - 10:15		210	51	23	7	East S.	244	3
		10:15 - 10:30		160	49	21	7	East S.	212	3
		10:30 - 10:45		154	48	22	7	East S.	216	2
		10:45 - 11:00		140	46	21	7	East S.	211	5
Oct 28 2020	Wednesday	5:00- 5:15		132	44	23	7	East S.	150	14
		5:15- 5:30		105	44	20	6	East S.	133	12
		5:30- 5:45		103	43	21	6	East S.	165	16
		5:45- 6:00		102	49	21	6	East S.	125	18
		10:00 - 10:15		90	50	22	6	East S.	194	23
		10:15 - 10:30		140	49	21	6	East S.	244	5
		10:30 - 10:45		132	50	24	6	East S.	211	5

		10:45 - 11:00		131	46	24	6	East S.	214	2
Oct 28, 2020	Thursda y	5:00- 5:15		127	44	20	7	East S.	153	14
		5:15- 5:30		118	45	21	7	East S.	140	12
		5:30- 5:45		112	44	20	6	East S.	160	12
		5:45- 6:00		40	48	22	7	East S.	128	18
		10:00 - 10:15		207	48	23	6	East S.	169	14
		10:15 - 10:30		200	49	25	7	East S.	247	3
		10:30 - 10:45		160	49	24	7	East S.	218	4
		10:45 - 11:00		154	48	24	7	East S.	216	1

PM2.5 and PM10 with the corresponding metrological and traffic volume data

Day of week	Sampling area	PM2.5 (μg/m³)	PM10 (μg/m³	Humidit y (%)	Tem. (°C)	Wind Speed (Km/hr)	Wind direction	Traffic Volume(pcu/3 0	% of H.V.
Tuesd ay	Africa Union	102	133	45	20	6	East N.	1483	6
Tuesd ay	Africa Union	120	151	52	21	6	East N.	1544	8
Tuesd ay	Africa Union	72	143	43	24	8	East N.	908	8
Tuesd ay	Africa Union	83	144	45	25	8	East N.	1027	9
Wedn esday	Africa Union	118	194	40	19	6	East N.	1529	14
Wedn esday	Africa Union	130	200	52	20	6	East N.	1609	16
Wedn esday	Africa Union	99	202	50	23	7	East N.	958	18
Wedn esday	Africa Union	93	199	41	24	7	East N.	1034	17
Thurs day	Africa Union	117	199	50	20	6	East N.	1308	16
Thurs day	Africa Union	114	187	45	20	6	East N.	1330	13
Thurs day	Africa Union	79	163	44	20	7	East N.	814	9
Thurs	Africa Union	72	159	43	21	7	East N.	872	7

day									
Tuesd ay	Jemo michael	326	343	50	18	5	East S.	1168	16
Tuesd ay	Jemo michael	320	330	51	18	5	East S.	1071	14
Tuesd ay	Jemo michael	114	174	49	23	6	East S.	782	10
Tuesd ay	Jemo michael	159	210	49	24	6	East S.	839	10
Wedn esday	Jemo michael	318	383	46	19	5	East S.	1201	25
Wedn esday	Jemo michael	328	380	44	19	5	East S.	1075	23
Wedn esday	Jemo michael	170	208	43	24	6	East S.	821	11
Wedn esday	Jemo michael	200	206	43	25	6	East S.	904	21
Thurs day	Jemo michael	305	356	50	20	5	East S.	1157	22
Thurs day	Jemo michael	303	359	53	21	5	East S.	1026	21
Thurs day	Jemo michael	219	208	48	26	6	East S.	813	18
Thurs day	Jemo michael	201	209	49	27	6	East S.	835	11
Tuesd ay	Legehar	180	274	42	21	5	South E.	1048	10
Tuesd ay	Legehar	118	191	41	22	5	South E.	1017	10
Tuesd ay	Legehar	82	109	40	24	7	South E.	809	6
Tuesd ay	Legehar	78	105	40	25	7	South E.	814	6
Wedn esday	Legehar	122	191	41	20	6	South E.	1121	10
Wedn esday	Legehar	119	187	41	21	6	South E.	1078	11
Wedn esday	Legehar	104	190	41	23	5	South E.	817	9
Wedn esday	Legehar	103	269	40	24	5	South E.	822	9
Thurs day	Legehar	121	271	39	19	5	South E.	1114	10
Thurs day	Legehar	173	285	39	20	5	South E.	1145	10
Thurs	Legehar	118	197	40	23	5	South E.	824	9

day									
Thurs day	Legehar	114	198	40	25	5	South E.	893	18
Tuesd ay	Imperial	205	300	41	20	5	East S.	814	16
Tuesd ay	Imperial	239	311	40	21	5	East S.	831	21
Tuesd ay	Imperial	233	309	40	23	5	East S.	1026	22
Tuesd ay	Imperial	233	301	41	19	5	East S.	1142	21
Wedn esday	Imperial	212	297	41	19	5	East S.	802	23
Wedn esday	Imperial	208	266	41	21	5	East S.	816	19
Wedn esday	Imperial	239	279	40	21	5	East S.	1111	21
Wedn esday	Imperial	241	280	40	20	5	East S.	1121	23
Thurs day	Imperial	219	207	40	20	5	East S.	815	25
Thurs day	Imperial	218	208	41	20	5	East S.	807	24
Thurs day	Imperial	230	317	41	20	5	East S.	1049	19
Thurs day	Imperial	243	320	41	19	5	East S.	1169	15
Tuesd ay	Sholla	100	108	46	21	9	South E.	792	9
Tuesd ay	Sholla	114	118	51	23	6	South E.	773	11
Tuesd ay	Sholla	142	194	44	23	6	South E.	1015	21
Tuesd ay	Sholla	134	172	45	23	6	South E.	1009	19
Wedn esday	Sholla	124	156	40	23	6	South E.	802	11
Wedn esday	Sholla	112	111	51	23	6	South E.	811	13
Wedn esday	Sholla	169	197	49	23	6	South E.	1089	21
Wedn esday	Sholla	148	190	47	24	6	South E.	1038	23
Thurs day	Sholla	130	183	50	24	6	South E.	807	18
Thurs	Sholla	118	137	45	25	6	South E.	795	17

day									
Thurs day	Sholla	181	218	45	27	6	South E.	1125	12
Thurs day	Sholla	173	207	44	26	6	South E.	1078	10
Tuesd ay	Petros	40	64	50	19	8	South E.	923	8
Tuesd ay	Petros	43	69	50	19	8	South E.	777	6
Tuesd ay	Petros	38	52	49	20	8	South E.	421	4
Tuesd ay	Petros	33	65	50	21	8	South E.	374	8
Wedn esday	Petros	44	72	46	20	10	South E.	893	7
Wedn esday	Petros	39	61	43	21	10	South E.	748	9
Wedn esday	Petros	38	68	42	20	10	South E.	413	6
Wedn esday	Petros	35	56	44	19	10	South E.	456	8
Thurs day	Petros	48	66	50	19	10	South E.	954	5
Thurs day	Petros	43	69	51	20	10	South E.	869	6
Thurs day	Petros	40	62	49	22	8	South E.	432	8
Thurs day	Petros	41	58	48	20	8	South E.	390	9
Tuesd ay	Teklehaym anot	134	210	42	19	7	East S.	399	9
Tuesd ay	Teklehaym anot	138	229	41	21	7	East S.	407	8
Tuesd ay	Teklehaym anot	185	253	40	23	7	East S.	652	11
Tuesd ay	Teklehaym anot	178	259	41	22	7	East S.	687	12
Wedn esday	Teklehaym anot	168	272	40	20	7	East S.	404	9
Wedn esday	Teklehaym anot	173	251	40	20	6	East S.	415	9
Wedn esday	Teklehaym anot	187	285	42	23	6	East S.	650	10
Wedn esday	Teklehaym anot	178	269	41	24	6	East S.	706	11
Thurs	Teklehaym	173	212	40	18	7	East S.	419	9

day	anot								
Thurs day	Teklehaym anot	178	211	40	19	6	East S.	412	8
Thurs day	Teklehaym anot	188	271	40	23	6	East S.	714	8
Thurs day	Teklehaym anot	184	268	40	24	7	East S.	698	7

Appendix F: Ambient air quality pollutants concentration with traffic flow conditions (Stata input)

CO for 15 min (μg/m³	SO2 for 10 min (μg/m³	Traffic flow condition	D= 1 if congested D= 0 if steady	PM 2.5 for 30 min (μg/m³)	Pm 10 for 30 min (μg/m³)	Traffic flow condition (μg/m³)	D= 1 if congested D= 0 if steady
8600	107	Congested	1	102	133	Congested	1
11015	129	Congested	1	120	151	Congested	1
10000	121	Congested	1	72	143	Steady	0
10200	160	Congested	1	83	144	Steady	0
8650	121	Steady	0	118	194	Congested	1
9000	121	Steady	0	130	200	Congested	1
8011	120	Steady	0	99	202	Steady	0
8200	110	Steady	0	93	199	Steady	0
9989	131	Congested	1	117	199	Congested	1
11000	121	Congested	1	114	187	Congested	1
9899	230	Congested	1	79	163	Steady	0
12010	141	Congested	1	72	159	Steady	0
8011	121	Steady	0	326	343	Congested	1
7200	121	Steady	0	320	330	Congested	1
7000	120	Steady	0	114	174	Steady	0
9000	110	Steady	0	159	210	Steady	0
9835	210	Congested	1	318	383	Congested	1
9705	200	Congested	1	328	380	Congested	1
9620	160	Congested	1	170	208	Steady	0
10200	270	Congested	1	200	206	Steady	0

7038	32	Steady	0	305	356	Congested	1
7410	27	Steady	0	303	359	Congested	1
7000	26	Steady	0	219	208	Steady	0
7019	22	Steady	0	201	209	Steady	0
8700	22	Congested	1	180	274	Congested	1
9000	35	Congested	1	118	191	Congested	1
6700	32	Congested	1	82	109	Steady	0
8440	33	Congested	1	78	105	Steady	0
7100	21	Steady	0	122	191	Congested	1
5900	34	Steady	0	``119	187	Congested	1
6010	21	Steady	0	104	190	Steady	0
6420	22	Steady	0	103	269	Steady	0
10500	40	Congested	1	121	271	Congested	1
9000	36	Congested	1	173	285	Congested	1
8600	33	Congested	1	118	197	Steady	0
8655	32	Congested	1	114	198	Steady	0
7100	20	Steady	0	205	300	Steady	0
6700	29	Steady	0	239	311	Steady	0
7100	30	Steady	0	233	309	Congested	1
6800	28	Steady	0	233	301	Congested	1
9500	21	Congested	1	212	297	Steady	0
9300	36	Congested	1	208	266	Steady	0
7958	31	Congested	1	239	279	Congested	1

8100	30	Congested	1	241	280	Congested	1
6100	21	Steady	0	219	207	Steady	0
5600	24	Steady	0	218	208	Steady	0
6011	21	Steady	0	230	317	Congested	1
5900	22	Steady	0	243	320	Congested	1
8000	320	Congested	1	100	108	Steady	0
7110	200	Congested	1	114	118	Steady	0
10200	233	Congested	1	142	194	Congested	1
8300	154	Congested	1	134	172	Congested	1
7000	103	Steady	0	124	156	Steady	0
6300	102	Steady	0	112	111	Steady	0
5984	90	Steady	0	169	197	Congested	1
6000	52	Steady	0	148	190	Congested	1
8820	160	Congested	1	130	183	Steady	0
8100	154	Congested	1	118	137	Steady	0
8700	140	Congested	1	181	218	Congested	1
8300	132	Congested	1	173	207	Congested	1
5098	131	Steady	0	40	64	Congested	1
7200	127	Steady	0	43	69	Congested	1
5005	122	Steady	0	38	52	Steady	0
6810	122	Steady	0	33	65	Steady	0
9700	210	Congested	1	44	72	Congested	1
9405	210	Congested	1	39	61	Congested	1

8820	207	Congested	1	38	68	Steady	0
8100	200	Congested	1	35	56	Steady	0
7000	121	Steady	0	48	66	Congested	1
6300	118	Steady	0	43	69	Congested	1
5997	112	Steady	0	40	62	Steady	0
6000	105	Steady	0	41	58	Steady	0
5997	420	Steady	0	134	210	Steady	0
8100	410	Steady	0	138	229	Steady	0
7002	403	Steady	0	185	253	Congested	1
6310	205	Steady	0	178	259	Congested	1
5600	427	Congested	1	168	272	Steady	0
10010	425	Congested	1	173	251	Steady	0
11640	423	Congested	1	187	285	Congested	1
11200	418	Congested	1	178	269	Congested	1
5550	305	Steady	0	173	212	Steady	0
6700	302	Steady	0	178	211	Steady	0
6865	302	Steady	0	188	271	Congested	1
6101	36	Steady	0	184	268	Congested	1
5454	452	Congested	1				
8784	432	Congested	1				
9520	432	Congested	1				
12003	429	Congested	1				
6886	321	Steady	0				

8000	320	Steady	0
8875	305	Steady	0
6642	302	Steady	0
8974	460	Congested	1
9700	452	Congested	1
10050	452	Congested	1
8561	432	Congested	1
6600	131	Steady	0
6400	220	Steady	0
6400	194	Steady	0
6714	210	Steady	0
6800	200	Congested	1
5015	229	Congested	1
4513	230	Congested	1
6700	220	Congested	1
5800	217	Steady	0
6300	215	Steady	0
5598	189	Steady	0
6100	200	Steady	0
5500	260	Congested	1
5300	250	Congested	1
4120	240	Congested	1
3800	237	Congested	1

6800	120	Steady	0
6700	180	Steady	0
5847	200	Steady	0
6600	190	Steady	0
5112	280	Congested	1
6231	271	Congested	1
5100	378	Congested	1
5148	250	Congested	1
1890	22	Congested	1
2500	32	Congested	1
3330	54	Congested	1
1905	27	Congested	1
1007	25	Steady	0
1800	23	Steady	0
2010	21	Steady	0
2300	21	Steady	0
1720	52	Congested	1
2365	50	Congested	1
1912	60	Congested	1
2900	23	Congested	1
2010	21	Steady	0
1620	21	Steady	0
2010	20	Steady	0

2101	27	Steady	0
1845	26	Congested	1
2100	25	Congested	1
2321	23	Congested	1
1521	20	Congested	1
2841	16	Steady	0
3100	17	Steady	0
3945	21	Steady	0
2000	19	Steady	0
6215	144	Steady	0
8000	105	Steady	0
7641	122	Steady	0
8011	52	Steady	0
7200	210	Congested	1
7900	160	Congested	1
5401	154	Congested	1
7454	140	Congested	1
5310	132	Steady	0
9101	105	Steady	0
8450	103	Steady	0
8800	102	Steady	0
6400	90	Congested	1
8100	140	Congested	1

7300	132	Congested	1
8401	131	Congested	1
7210	127	Steady	0
6000	118	Steady	0
8121	112	Steady	0
7200	40	Steady	0
7845	207	Congested	1
6210	200	Congested	1
8742	160	Congested	1
7910	154	Congested	1

Appendix G: Comparison of air pollutants concentration with different standards

CO(for 15 min average time) in (μg/m³)				SO2(for 10 min average time) in (μg/m³)			
Field measurement	Ethiopian standard	WHO Standard	Pass/Fail	Field measurement	Ethiopian standard	WHO Standard	Pass/ Fail
8600	100,000	-	Pass	107	500	500	Pass
11015	100,000	-	Pass	129	500	500	Pass
10000	100,000	-	Pass	121	500	500	Pass
10200	100,000	-	Pass	160	500	500	Pass
8650	100,000	-	Pass	121	500	500	Pass
9000	100,000	-	Pass	121	500	500	Pass
8011	100,000	-	Pass	120	500	500	Pass
8200	100,000	-	Pass	110	500	500	Pass
9989	100,000	-	Pass	131	500	500	Pass
11000	100,000	-	Pass	121	500	500	Pass
9899	100,000	-	Pass	230	500	500	Pass
12010	100,000	-	Pass	141	500	500	Pass
8011	100,000	-	Pass	121	500	500	Pass
7200	100,000	-	Pass	121	500	500	Pass
7000	100,000	-	Pass	120	500	500	Pass
9000	100,000	-	Pass	110	500	500	Pass
9835	100,000	-	Pass	210	500	500	Pass
9705	100,000	-	Pass	200	500	500	Pass
9620	100,000	-	Pass	160	500	500	Pass
10200	100,000	-	Pass	270	500	500	Pass
7038	100,000	-	Pass	32	500	500	Pass
7410	100,000	-	Pass	27	500	500	Pass
7000	100,000	-	Pass	26	500	500	Pass
7019	100,000	-	Pass	22	500	500	Pass
8700	100,000	-	Pass	22	500	500	Pass
9000	100,000	-	Pass	35	500	500	Pass
6700	100,000	-	Pass	32	500	500	Pass
8440	100,000	-	Pass	33	500	500	Pass
7100	100,000	-	Pass	21	500	500	Pass
5900	100,000	-	Pass	34	500	500	Pass
6010	100,000	-	Pass	21	500	500	Pass
6420	100,000	-	Pass	22	500	500	Pass
10500	100,000	-	Pass	40	500	500	Pass
9000	100,000	-	Pass	36	500	500	Pass
8600	100,000	-	Pass	33	500	500	Pass

8655	100,000	-	Pass	32	500	500	Pass
7100	100,000	-	Pass	20	500	500	Pass
6700	100,000	-	Pass	29	500	500	Pass
7100	100,000	-	Pass	30	500	500	Pass
6800	100,000	-	Pass	28	500	500	Pass
9500	100,000	-	Pass	21	500	500	Pass
9300	100,000	-	Pass	36	500	500	Pass
7958	100,000	-	Pass	31	500	500	Pass
8100	100,000	-	Pass	30	500	500	Pass
6100	100,000	-	Pass	21	500	500	Pass
5600	100,000	-	Pass	24	500	500	Pass
6011	100,000	-	Pass	21	500	500	Pass
5900	100,000	-	Pass	22	500	500	Pass
8000	100,000	-	Pass	320	500	500	Pass
7110	100,000	-	Pass	200	500	500	Pass
10200	100,000	-	Pass	233	500	500	Pass
8300	100,000	-	Pass	154	500	500	Pass
7000	100,000	-	Pass	103	500	500	Pass
6300	100,000	-	Pass	102	500	500	Pass
5984	100,000	-	Pass	90	500	500	Pass
6000	100,000	-	Pass	52	500	500	Pass
8820	100,000	-	Pass	160	500	500	Pass
8100	100,000	-	Pass	154	500	500	Pass
8700	100,000	-	Pass	140	500	500	Pass
8300	100,000	-	Pass	132	500	500	Pass
5098	100,000	-	Pass	131	500	500	Pass
7200	100,000	-	Pass	127	500	500	Pass
5005	100,000	-	Pass	122	500	500	Pass
6810	100,000	-	Pass	122	500	500	Pass
9700	100,000	-	Pass	210	500	500	Pass
9405	100,000	-	Pass	210	500	500	Pass
8820	100,000	-	Pass	207	500	500	Pass
8100	100,000	-	Pass	200	500	500	Pass
7000	100,000	-	Pass	121	500	500	Pass
6300	100,000	-	Pass	118	500	500	Pass
5997	100,000	-	Pass	112	500	500	Pass
6000	100,000	-	Pass	105	500	500	Pass
5997	100,000	-	Pass	420	500	500	Pass
8100	100,000	-	Pass	410	500	500	Pass
7002	100,000	-	Pass	403	500	500	Pass
6310	100,000	-	Pass	205	500	500	Pass

5600	100,000	-	Pass	427	500	500	Pass
10010	100,000	-	Pass	425	500	500	Pass
11640	100,000	-	Pass	423	500	500	Pass
11200	100,000	-	Pass	418	500	500	Pass
5550	100,000	-	Pass	305	500	500	Pass
6700	100,000	-	Pass	302	500	500	Pass
6865	100,000	-	Pass	302	500	500	Pass
6101	100,000	-	Pass	36	500	500	Pass
5454	100,000	-	Pass	452	500	500	Pass
8784	100,000	-	Pass	432	500	500	Pass
9520	100,000	-	Pass	432	500	500	Pass
12003	100,000	-	Pass	429	500	500	Pass
6886	100,000	-	Pass	321	500	500	Pass
8000	100,000	-	Pass	320	500	500	Pass
8875	100,000	-	Pass	305	500	500	Pass
6642	100,000	-	Pass	302	500	500	Pass
8974	100,000	-	Pass	460	500	500	Pass
9700	100,000	-	Pass	452	500	500	Pass
10050	100,000	-	Pass	452	500	500	Pass
8561	100,000	-	Pass	432	500	500	Pass
6600	100,000	-	Pass	131	500	500	Pass
6400	100,000	-	Pass	220	500	500	Pass
6400	100,000	-	Pass	194	500	500	Pass
6714	100,000	-	Pass	210	500	500	Pass
6800	100,000	-	Pass	200	500	500	Pass
5015	100,000	-	Pass	229	500	500	Pass
4513	100,000	-	Pass	230	500	500	Pass
6700	100,000	-	Pass	220	500	500	Pass
5800	100,000	-	Pass	217	500	500	Pass
6300	100,000	-	Pass	215	500	500	Pass
5598	100,000	-	Pass	189	500	500	Pass
6100	100,000	-	Pass	200	500	500	Pass
5500	100,000	-	Pass	260	500	500	Pass
5300	100,000	-	Pass	250	500	500	Pass
4120	100,000	-	Pass	240	500	500	Pass
3800	100,000	-	Pass	237	500	500	Pass
6800	100,000	-	Pass	120	500	500	Pass
6700	100,000	-	Pass	180	500	500	Pass
5847	100,000	-	Pass	200	500	500	Pass
6600	100,000	-	Pass	190	500	500	Pass
5112	100,000	-	Pass	280	500	500	Pass

6231	100,000	-	Pass	271	500	500	Pass
5100	100,000	-	Pass	378	500	500	Pass
5148	100,000	-	Pass	250	500	500	Pass
1890	100,000	-	Pass	22	500	500	Pass
2500	100,000	-	Pass	32	500	500	Pass
3330	100,000	-	Pass	54	500	500	Pass
1905	100,000	-	Pass	27	500	500	Pass
1007	100,000	-	Pass	25	500	500	Pass
1800	100,000	-	Pass	23	500	500	Pass
2010	100,000	-	Pass	21	500	500	Pass
2300	100,000	-	Pass	21	500	500	Pass
1720	100,000	-	Pass	52	500	500	Pass
2365	100,000	-	Pass	50	500	500	Pass
1912	100,000	-	Pass	60	500	500	Pass
2900	100,000	-	Pass	23	500	500	Pass
2010	100,000	-	Pass	21	500	500	Pass
1620	100,000	-	Pass	21	500	500	Pass
2010	100,000	-	Pass	20	500	500	Pass
2101	100,000	-	Pass	27	500	500	Pass
1845	100,000	-	Pass	26	500	500	Pass
2100	100,000	-	Pass	25	500	500	Pass
2321	100,000	-	Pass	23	500	500	Pass
1521	100,000	-	Pass	20	500	500	Pass
2841	100,000	-	Pass	16	500	500	Pass
3100	100,000	-	Pass	17	500	500	Pass
3945	100,000	-	Pass	21	500	500	Pass
2000	100,000	-	Pass	19	500	500	Pass
6215	100,000	-	Pass	144	500	500	Pass
8000	100,000	-	Pass	105	500	500	Pass
7641	100,000	-	Pass	122	500	500	Pass
8011	100,000	-	Pass	52	500	500	Pass
7200	100,000	-	Pass	210	500	500	Pass
7900	100,000	-	Pass	160	500	500	Pass
5401	100,000	-	Pass	154	500	500	Pass
7454	100,000	-	Pass	140	500	500	Pass
5310	100,000	-	Pass	132	500	500	Pass
9101	100,000	-	Pass	105	500	500	Pass
8450	100,000	-	Pass	103	500	500	Pass
8800	100,000	-	Pass	102	500	500	Pass
6400	100,000	-	Pass	90	500	500	Pass
8100	100,000	-	Pass	140	500	500	Pass

7300	100,000	-	Pass	132	500	500	Pass
8401	100,000	-	Pass	131	500	500	Pass
7210	100,000	-	Pass	127	500	500	Pass
6000	100,000	-	Pass	118	500	500	Pass
8121	100,000	-	Pass	112	500	500	Pass
7200	100,000	-	Pass	40	500	500	Pass
7845	100,000	-	Pass	207	500	500	Pass
6210	100,000	-	Pass	200	500	500	Pass
8742	100,000	-	Pass	160	500	500	Pass
7910	100,000	-	Pass	154	500	500	Pass

Appendix H: Check the assumptions of multiple linear regression for SO2, PM2.5 and PM10

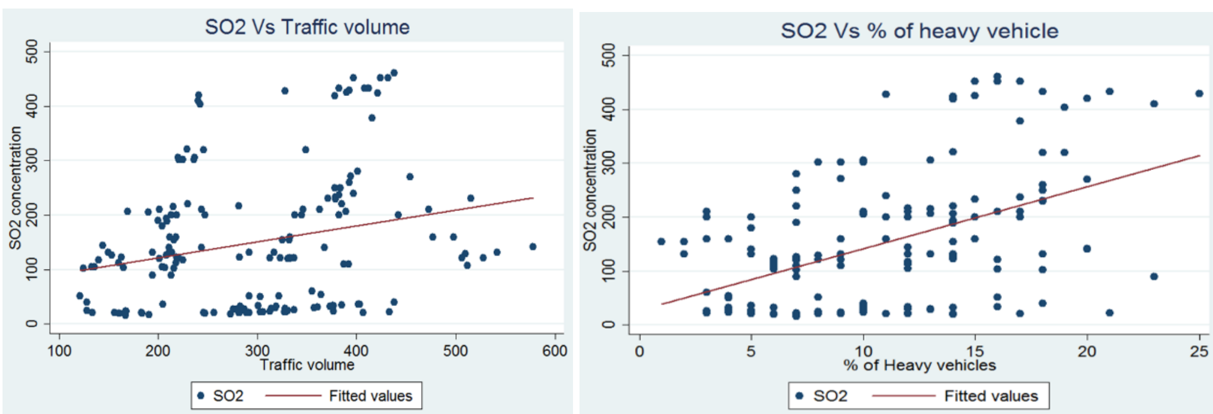


Figure: Scatter plot of SO2 concentration with Traffic volume and % of HV

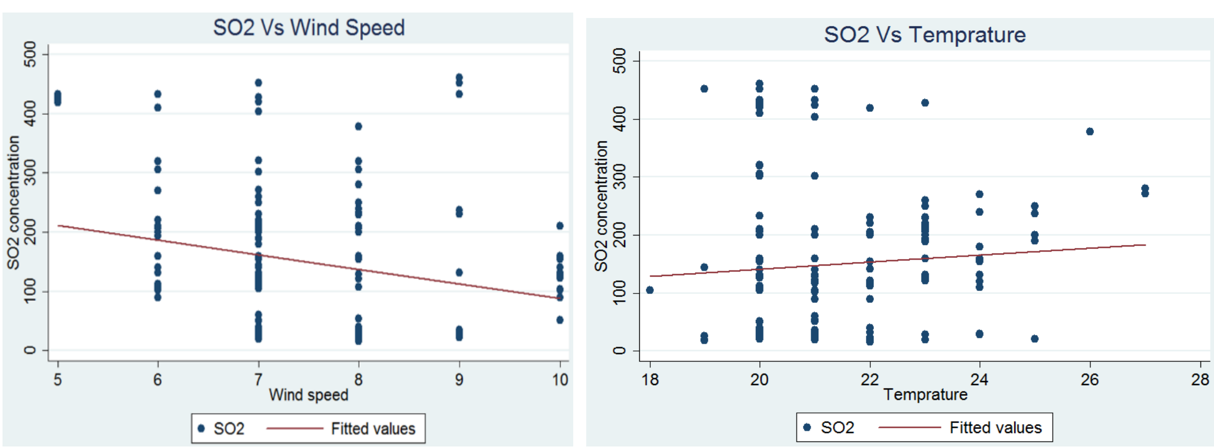
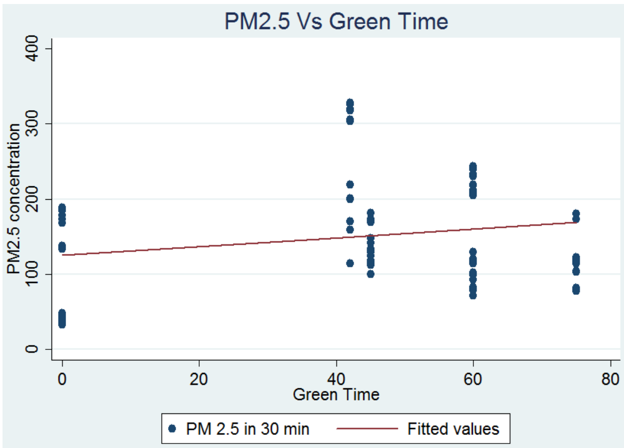


Figure: Scatter plot of SO2 concentration with Wind speed and Temperature



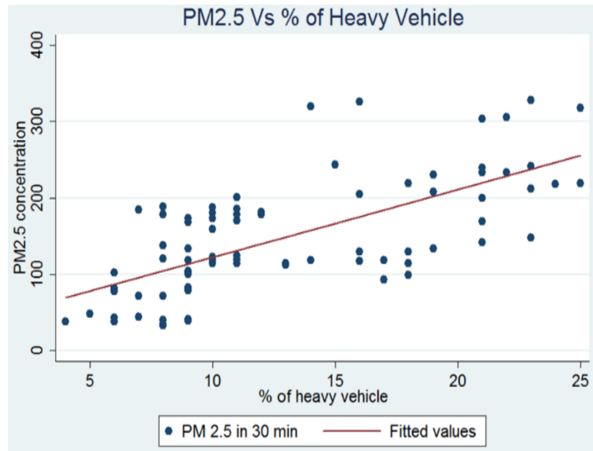
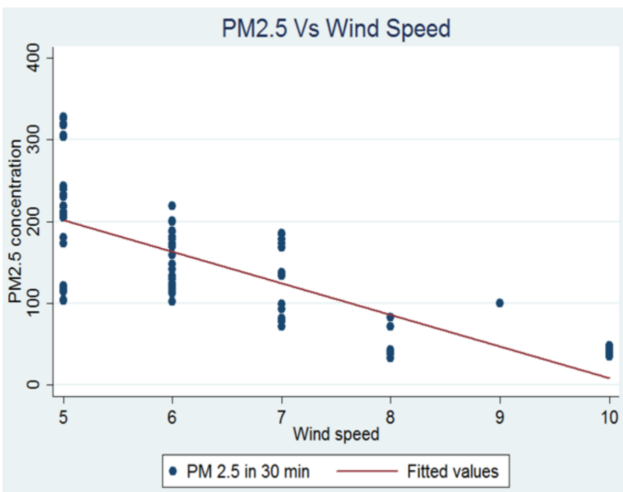
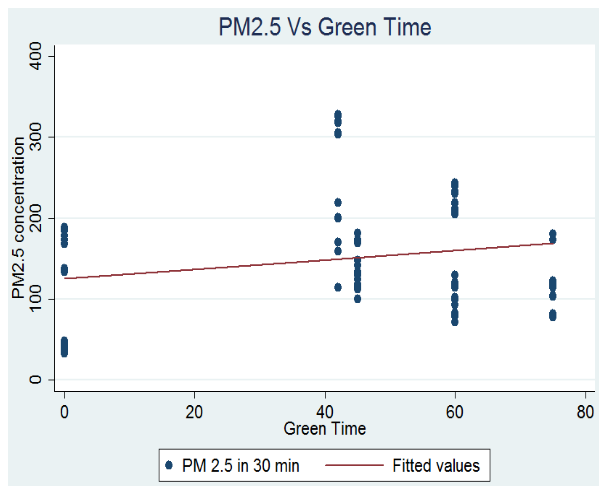
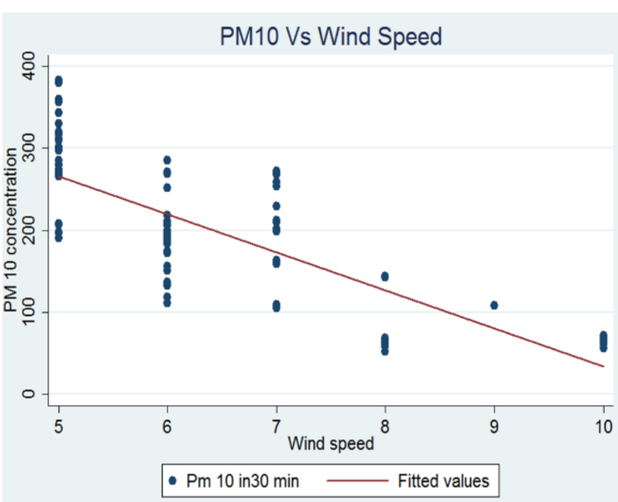
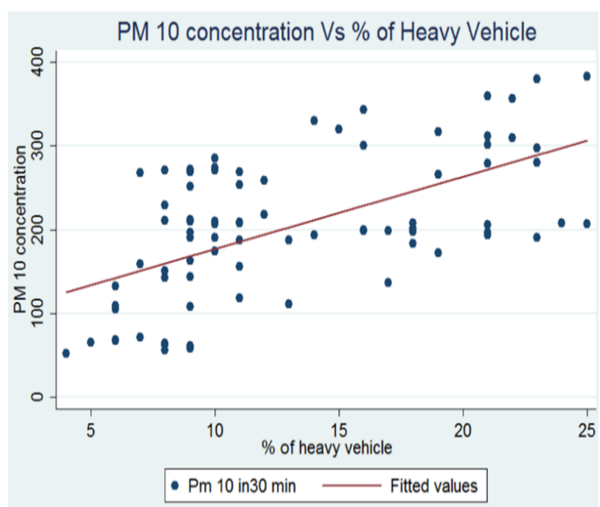


Figure: Scatter plot of PM2.5 concentration with green time % of heavy vehicle









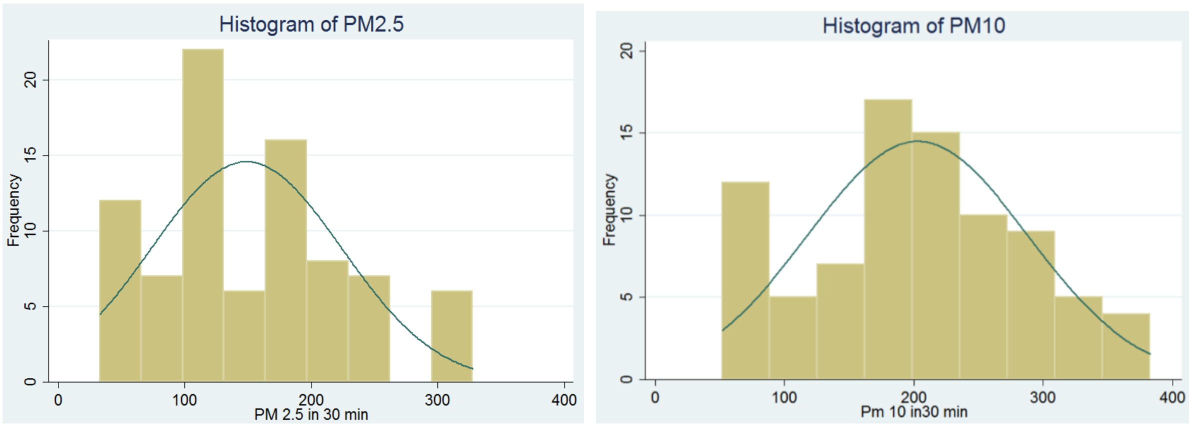


Figure: histogram with normal density curve

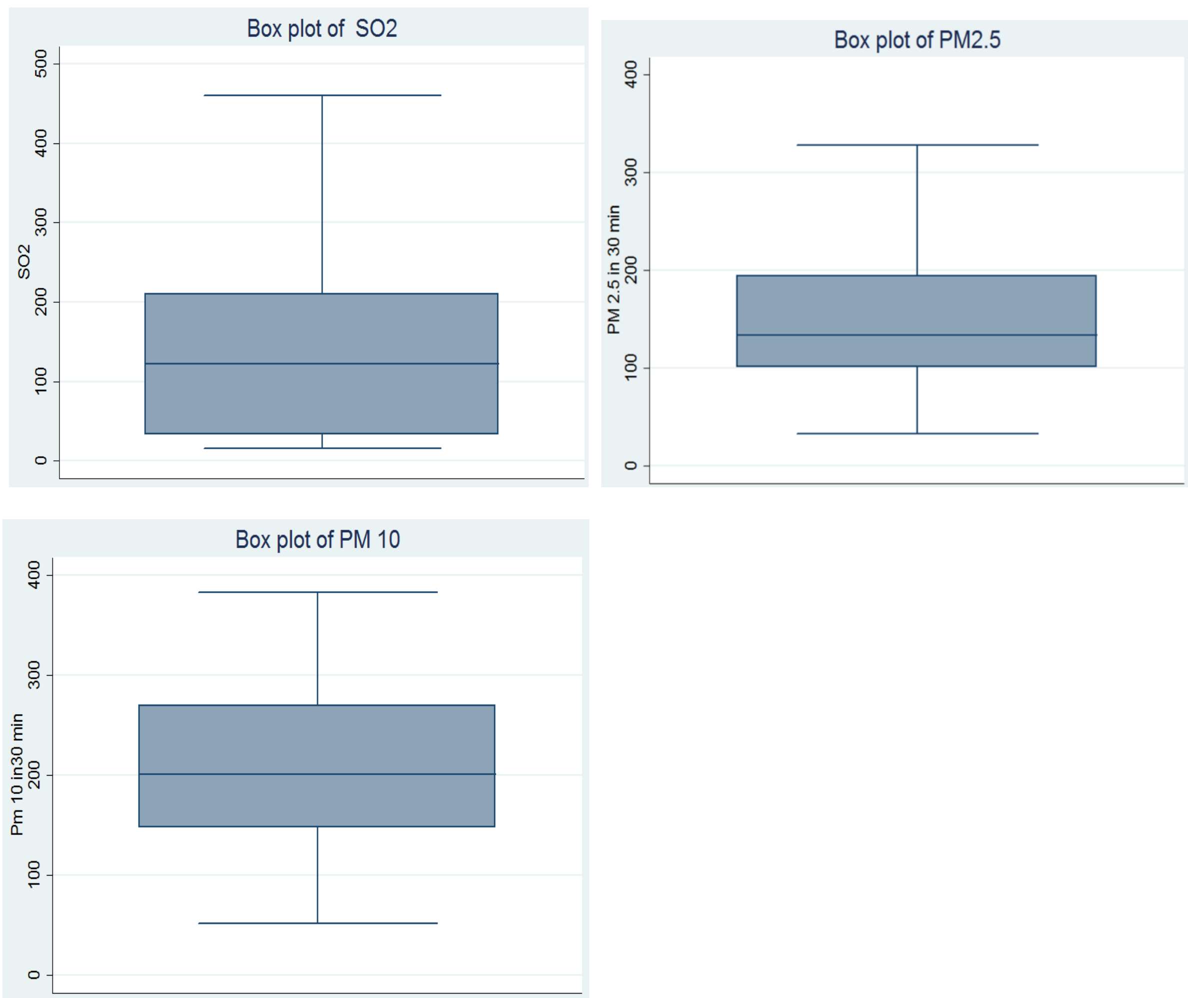


Figure: Box plot that shows the outlier of the data