



**ADDIS ABABA UNIVERSITY**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**ANALYSIS AND EVALUATION OF URBAN ROAD  
TRAFFIC NOISE POLLUTION IN ADDIS ABABA CITY**

**By**

**TESFAYE ABDISSA BULTO**

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for Degree of Masters of Science in Civil and Environmental Engineering (Road and Transport Engineering)

***Advisor: Getu Segni Tulu (PhD)***

June, 2019

Addis Ababa, Ethiopia

**ADDIS ABABA UNIVERSITY**

**Addis Ababa Institute of Technology**

**M.Sc. Thesis in Civil and Environmental Engineering**

**(Road and Transport Engineering)**

On

**ANALYSIS AND EVALUATION OF URBAN ROAD TRAFFIC NOISE**

**POLLUTION IN ADDIS ABABA CITY**

*By*

*Tesfaye Abdissa Bulto*

June, 2019

**Approved by Board of Examiners**

**Getu Segni Tulu (PhD)**

**Advisor**

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

**Dr. Bikila Teklu**

**Internal Examiner**

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

**Ato Abel Kebede**

**External Examiner**

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

\_\_\_\_\_

**Chairman**

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

**Declaration**

I the undersigned, declare that this thesis entitled “*Analysis and Evaluation of urban road traffic noise pollution in Addis Ababa City*” is my original work. This thesis has not been presented elsewhere for assessment and award of any degree or diploma, and all sources of material used for the thesis have been duly acknowledged.

**Candidate Name: Tesfaye Abdissa Bulto**

**Signature:** -----

**Email:** *aautab@gmail.com*

Place: Addis Ababa Institute of Technology (**AAiT**)

Addis Ababa University

**Addis Ababa; Ethiopia**

Date of submission: **June**, 2019 G.C

## Table of Contents

Declaration .....	ii
List of Figures.....	i
List of Tables .....	ii
Glossary of terms and Acronyms .....	iii
Acknowledgements .....	v
Abstract .....	vi
Chapter One.....	1
Introduction .....	1
1.1 Background .....	1
1.2 Statement of Problems .....	3
1.3 Research questions .....	4
1.4 Objectives of the Study .....	5
1.4.1 General objective .....	5
1.4.2 Specific Objectives .....	5
1.5 Scope of the Study .....	5
1.6 Significance of the Study .....	5
1.7 Strengths of the Study .....	6
1.8 Limitations of the Study.....	6
1.9 Study Frame Work.....	7
Chapter Two .....	8
Literature Review .....	8
2.1 Characteristics of Sound .....	8

2.2	General Aspect of Noise Pollution .....	10
2.3	Sources of Urban Environmental Noise Pollution.....	11
2.4	Effects of Noise Pollution.....	12
2.4.1	Physical Effects of Noise .....	13
2.4.2	Sleep Disturbance and Annoyance.....	13
2.4.3	Physiological Effects of Noise .....	14
2.4.4	Psychological and Communication effects .....	14
2.5	Urban Traffic Noise .....	15
2.5.1	Factors affecting Traffic Noise Pollution.....	15
2.5.2	Characteristic relationships between traffic flow and induced noise level ...	17
2.5.3	Temporal and Spatial traffic noise level variations .....	18
2.6	Traffic Noise Descriptor parameters.....	19
2.7	Traffic Noise Measurement Methods .....	20
2.8	Reducing and Controlling traffic noise pollution .....	22
2.9	Summary of literature review and research gap .....	24
	Chapter Three .....	26
	Research Methodology.....	26
3.1	Study Area.....	26
3.2	Sampling Method .....	27
3.2.1	Road categorization.....	28
3.2.2	Land use .....	30
3.3	Sampling Number and sampling period.....	33
3.4	Data Collection Methodology .....	35

3.4.1	Primary data .....	35
3.4.1.1	Noise Level Reading.....	37
3.4.1.2	Traffic flow and vehicles Composition.....	40
3.4.1.3	Site Condition .....	40
3.4.2	Secondary data .....	41
3.5	Data processing and description of noise parameters .....	42
3.6	Data Analysis .....	43
Chapter Four .....		45
Results and Discussion .....		45
4.1	Assessment and Analysis of Noise Descriptors .....	45
4.1.1	Spatial Assessment of Noise Descriptors.....	45
4.1.2	Temporal Analysis of Equivalent Continuous Noise Level.....	50
4.2	Noise indices assessment and analysis under land use categories .....	52
4.3	Model Development.....	60
4.4	Traffic noise analysis under route categorization .....	63
Chapter Five .....		67
Conclusions and Recommendation .....		67
5.1	Conclusions .....	67
5.2	Recommendation.....	69
	Future research work direction.....	70
	References .....	71

**List of Figures**

Figure 2.1 Source of vehicle related noise..... 16

Figure 3. 1 Study area (All subcity of Addis Ababa) ..... 27

Figure 3. 2 Addis Ababa subcity and route category map ( Source AACRA,2018) ..... 30

Figure 3. 3 Addis Ababa City Land use map (Source AACPPO, 2016) ..... 32

Figure 3. 4 Sampling site locations in Addis Ababa City..... 37

Figure 3. 5 Digital Sound Level Meter (SLM- 816)..... 38

Figure 3. 6 Traffic noise study plan view or site sketch ..... 39

Figure 4. 1 Different noise descriptor fluctuations of studied site..... 50

Figure 4. 2 Temporal Leq (dBA) for each site per category..... 51

Figure 4. 3 The overall temporal variation of measured Equivalent Noise Level ..... 52

Figure 4. 4 Overall Variation of Equivalent noise pollution with land use ..... 53

Figure 4. 5 Leq (dBA) as a function of the logarithm of the total traffic flow (Q) ..... 61

Figure 4. 6 Box and whisker diagram of Leq dBA by route categories for Addis Ababa city.... 64

**List of Tables**

Table 2. 1 Environmental noise standards as prescribed by Guideline or Standards. .... 11

Table 2. 2 WHO guideline for community noise in specific environment ..... 12

Table 3. 1 Profile of Addis Ababa City ..... 26

Table 3. 2 Number of sampling Points taken for each Land use category ..... 31

Table 3. 3 Study site Matrix (Sampling Points taken for each category in studied Sub city) ..... 34

Table 3. 4 Selected sites name and code with their geographical locations ..... 35

Table 3. 5 Selected sites with category class and land use type for measuring road traffic noise in Addis Ababa city..... 36

Table 4. 1 Consolidated values of noise descriptors and traffic data of study location at each sub city (dBA) ..... 46

Table 4. 2 Descriptive statistics result of temporal Leq, dBA ..... 50

Table 4. 3 ANOVA test result for Leq temporal variation ..... 52

Table 4. 4 Difference between observed values and Environmental noise standards as prescribed by guideline or standards. .... 54

Table 4. 5 Noise pollution levels, LNP in dB (A) for all site locations at different Land use..... 55

Table 4. 6 Equivalent continuous noise levels, Leq in dB (A) for all site locations at different land use ..... 56

Table 4. 7 Means and Standard Deviations of Equivalent noise Pollution Levels ..... 57

Table 4. 8 ANOVA Source table ..... 58

Table 4. 9 Table of pairwise difference Scheffe’s Post Hoc critical Value ..... 59

Table 4. 10 Regression parameters between  $LA_{eq}$  (dBA) and the logarithm of the total traffic flow (log Q) for study area in Addis Ababa City..... 61

Table 4. 11 Regression parameters between  $LA_{eq}$  (dBA) and the volume of heavy transport vehicle ( $Q_{HTV}$ ) and total number of other traffic vehicle ( $Q_{OTV}$ ) for study area in Addis Ababa City..... 62

Table 4. 12 Values of the Leq median (dBA) for each category in Addis Ababa City ..... 64

Table 4. 13 ANOVA source table..... 65

Table 4. 14 Table of pair wise difference results of the Tukey-type test applied to the different categories of the study Area..... 65

## **Glossary of terms and Acronyms**

AACA	Addis Ababa City Administration
AACPPO	Addis Ababa City Planning Project Office
AACRA	Addis Ababa city Roads Authority
AU	African Union
CS	Collector streets
CSA	Central Statistical Agency
DALYs	Disability-Adjusted Life Years
dB	decibel
dB (A)	A weighted decibels
DVLCA	Driver and Vehicle Licensing and Control Authority
EDRI- ECRC Center	Ethiopia Development Research Institute-Environment and Climate Research Center
EPA	Environmental Protection Authority
EUD	European Union Directive
FDRE	Federal Democratic Republic of Ethiopia
FDRETA	Federal Democratic Republic of Ethiopia Transport Authority
FHWA	Federal Highway Administration
GAESFE	<i>Guideline</i> Ambient Environment Standards for Ethiopia
GPS:	Global Positioning System
ha	hectare
HZ	Hertz
IBRD-WB	International Bank for Reconstruction and Development of the World Bank

*Analysis and Evaluation of Urban Road Traffic Noise pollution in Addis Ababa City*

JCGM	Joint Committee for Guides in Metrology
Km	Kilometer
L10:	A-weighted sound level exceeded for 10% of the time, during period of measurement
L50:	Level in dB (A) exceeded for 50% of time.
L90:	Level exceeded for 90% of time; it is often referred to background noise level.
LNP	Noise pollution level
LS	Local Streets
MoEFCC	Ministry of Environment, Forest, Climate Change
NC	Noise climate
PAS	principal Arterial Streets
RR	Ring Road
SAS	Sub arterial streets
SLM	Sound Level Meter
SMILE	Sustainable Mobility Initiatives for Local Environment
SPL	Sound Pressure Level
TNI	Traffic Noise Index
WHO	World Health Organization

## **Acknowledgements**

First of all, I would like to thank Almighty **GOD** for his Blessings, Mercy and Power. Without his provisions and guidance, this study could have never been accomplished. **GOD, take the whole credit!**

Then my appreciation goes to my advisor Dr. Getu Segni, for all his encouragement, understanding, criticism, and Supervisions. In doing so, he brought out the best in me by supporting me to use my potential. I really appreciate his enormous patience and unreserved commitment towards the betterment of this research.

Special thanks goes to Ministry of Environment, Forest and Climate Change (MoEFCC) who provides the equipment for the noise recording and I also express my appreciation to all other government who help me by giving different documents relevant for this study.

I also express my gratitude to my brother Mr. Ashenafi A. and staff of MoEFCC Mr. Birhanu for their support whenever needed during data collection.

Finally, my special appreciations are to all my beloved family, for their endless love and unconditional support. Very special thanks to my brothers Mr. Mammo W. aka Abba Kenna and Gizachew A (Ass. Prof.) for your encouragement during the challenging times. Gratitude fails to say it all.

Finally yet importantly, I would like to express my gratitude for all my friends who either directly or indirectly contributed to the successful accomplishment of this research. Also, I would like to thank Ethiopia Roads Authority (ERA) for funding my graduate study of Road and Transport Engineering stream at the Addis Ababa University Institute of Technology. **Thank you all!**

**Tesfaye Abdissa**

June, 2019

## **Abstract**

Addis Ababa city like most of the cities of developing countries are, facing serious environmental traffic noise pollution problem, due to the increasing at an alarming rate of motor vehicles, the expansion of the road network, and poor urban planning. This study is directed to examine the status of highway traffic noise level at different land use areas along different road class moreover, relationship between noise level and traffic flow is developed. In this study, four main categories of the traffic route and land use are established. Traffic noise levels and traffic volume were conducted 9 times at each 41 selected spots on different days of weeks across four various land use areas of the city for 15 minutes with 3 readings per each period of the day time; morning (7AM-10AM), afternoon (11AM-3PM) and evening (4 Pm-7PM). Statistical analysis of daytime traffic noise in the city was carried out and results are presented in terms of average percentage of exceeded noise level:  $L_{10}$ ,  $L_{50}$  and  $L_{90}$ . Main noise descriptors viz. Equivalent continuous noise level ( $L_{eq}$ ), traffic noise index (TNI), noise pollution level (LNP) and noise climate (NC) are determined and discussed for each spot per road category and land use. Results of this study indicated that the highest range of  $L_{eq}$  77.2 to 80.7 dBA was observed in industrial zone followed by 75.1 dBA-80.1 dBA in commercial zones, 71.7 - 80.0 dBA in sensitive zones, and 70.0 - 79.1 dBA in residential areas. Observed  $L_{eq}$  (dBA), at all measurement points exceeds national and international standard limit values by 2.2 to 25.0 dB (A) and 12.2 to 35.0 dBA, respectively. ANOVA test shows that there is a significant difference ( $P < 0.05$ ) in noise pollution levels and equivalent noise level in established land use areas. Also, result parameters F-test statistics implies there is no significant difference between overall morning, afternoon, evening time traffic noise level in the city as  $F_{calculated} (0.005) < F_{critical} (3.07)$ . A linear regression analysis performed between the  $L_{eq}$  and logarithm of total traffic volume ( $\log Q$ ) produced a coefficient of determination  $r^2$  of 0.851. A multi regression analysis carried out between the  $L_{eq}$  and two classes of traffic vehicle types resulted in a correlation coefficient of 0.7502. Results of this study clearly revealed that total traffic volume and number of heavy transport vehicles are the most significant factors of cities traffic noise pollution. Spearman rank correlation coefficients with value of -0.812 again proved that the classification of urban street noise as a meaning of the road hierarchy is an appropriate part of the design of studies of urban noise caused by traffic. In order to reduce alarming condition traffic induced noise levels within the city, both technical actions and non-technical approaches were also presented.

## **Chapter One**

### **Introduction**

#### **1.1 Background**

Although there can be no doubt about the many advantages that the technological revolution has brought to human livelihood, not everything has been beneficial. Transport has a powerful impact on health and that influence on health is growing globally along with increased mobility. Contamination of the environment is one of the most relevant problems associated with technological advance and transportation. One major kind of contamination and among the most familiar health risks of transport include exposure to noise emissions from motorized vehicles, which is a notable annoyance in our daily lives (Dora et al., 2011). Noise pollution hence needs to be characterized and, in as much as possible, minimized.

World Health Organization, (1999) define noise as “sound that is unwanted or disturbs ones quality of life and state that as noise must be recognized as a major threat to human well- being”. When there is a lot of noise in the environment beyond the certain limit, it is termed a noise Pollution. Sound becomes undesirable when it disturbs the usual activities such as working, sleeping, and during Conversations. It is an underestimated Environmental Problem because of the fact that it can’t be seen, smelt, or tested (Dasarathy, 2015). Community noise or environmental noise is noise emitted from all sources except noise at the industrial work-place. (World Health Organization, 1999). This report additionally emphasized that as noise pollution is also serious problem in developing countries and which are mainly by road traffic. As (World Health Organization, 2011) recent publication report states noise pollution, rank the second among a series of environmental stressors for their public health.

Specifically, road traffic is considered to be the main source of community noise pollution. Environmental noise is pervasive in everyday life and can cause both auditory and non-auditory health effects and the evidence for the non-auditory effects is increasing (Basner *et al.*, 2014). All people are not equally sensitive to the disturbing aspects of noise and there is a small but significant minority which is more sensitive than others (Environmental Protection Authority (EPA) et al., 2003). In developing country the vehicle population increasing at an alarming rate, the residents of cities are

experiencing severe environmental problems that results from road traffic in particular from motor vehicles (Saadu et al., 1998). Vehicles exported to developing countries are often older and more polluting even though, these problems can be offset to some extent by improvements in vehicle and road design, (Davis and Kahn, 2010). Actions to control noise effects have been remains limited in the cities of developing countries, and Addis Ababa of Ethiopia has not yet established a practical policy to manage or cope with the situation (Dewelle, 2014).

The study is conducted in Addis Ababa, capital City of Ethiopia. In Addis Ababa, there have been very few studies and researches conducted on the subject of noise pollution. It is because the awareness towards the noise pollution is still below normal. The study by (Dewelle, 2014) discusses that noise should be stated as one of the major environmental problems of the city primarily around schools. Addis Ababa city like most of the cities of developing countries are facing serious noise pollution problem, due to the concentration of motor vehicles and human population within the limited urban areas.

Currently in the city, traffic noise is the most rigorous type of urban noise pollution and represents a serious environmental problem because of inadequate urban planning of the cities (UN-Habitat, 2017). Noise pollution in the city had reached a limit where it was enough to call for proper attention from all concerned bodies, according to the participants (Yibeltal, 2014).

As study reports by (AACPPO, 2017) shows, noise pollution has become a serious problem in Addis Ababa and it is the second major source of environmental complaints lodged in Addis Ababa after air pollution. Traffic noise were identified as one of the major sources of noise pollution in the city. On the other hand, serious weaknesses are observed in terms of enforcing noise pollution control regulations as manifested by the widespread generation of loud noises in living and working areas both during the day and night (AACPPO, 2017). In the last decades, the urban development has experienced significant structural changes due to the incessant growth in the number of motor vehicles, the expansion of the road network, the urbanization and the realization of great infrastructures (UN-Habitat, 2017). These changes had probably leads to an increase in the transport noise pollution levels with its adverse health effects on the exposed residents.

Thus, road traffic noise have to become an issue of immediate concern to each corresponding authorities. Anti-noise laws, major highway control regulations and other governmental laws that concern environmental noise cannot be decreed without a priori empirical considerations. So, it is necessary to carry out extensive site measurements, in order to assess and analyze road traffic noise

levels in the city. Therefore, in order to develop strategies for controlling traffic noise pollution, extensive research has to be conducted. From which this research aims to evaluate and analyze traffic related noise pollution level of the city.

## **1.2 Statement of Problems**

Addis Ababa like most of the cities of developing countries are facing serious traffic noise pollution problem, due to the rapidly increasing and concentration of old motor vehicles within the poor urban planning of the city. A victim of rapid unplanned urbanization has been the urban environment, as the current city growth is worsening the environmental pollution and weakening urban ecosystems (UN-Habitat, 2017).

In Addis Ababa, there are several other indicators that noise pollution is really a problem. For instance, comments of noise discussion events, professional field observations, and noise complaints indicate the existence of the problem in the city (Yibeltal, 2014). Preliminary noise pollution study in the city have been conducted recently by MoEFCC and does also point out that as the city has been engaging the problem (MoEFCC, 2017). Moreover, road vehicles are one among the top and major noise pollution sources which is leading Environmental problem in the metropolis (Tsegaye, 2017). Noise pollution is the second major source of environmental complaints lodged in Addis Ababa after air pollution and therefore, has become a serious problem in Addis Ababa. The major and dominant sources of urban noise pollution are identified to be motorized vehicles (AACPPPO, 2017). (Dewelle, 2014) discussed that in Addis Ababa, most noise sensitive locations /institutes/ like schools, health care institutes and courts are located randomly around main traffic roads, and by his assessment study, revealed as traffic is the most dominant contributor or source of the city noise which accounts more than 48 %.

The largest source of environmental pollution in Addis Ababa is the rapid increase in the number of road motorized vehicles. As Forum for Environment report in 2010 (Forum for Environment, 2010); Environmental pollution has increased over time as motor vehicle increases in Addis Ababa which shares more than 75% of Ethiopian vehicle population. The situation is exacerbated by the use of old and poorly maintained vehicles that operating on the city's road network. More than 53% of the total vehicles in Addis Ababa are more than 20 years old (Forum for Environment, 2010). The number of vehicles entering towns and cities in Ethiopia is growing at 20 percent per a year (Forum for Environment, 2010) and currently the number of vehicles operating in the city is estimated to be more

than 561,490. Added to this, the indiscriminate importation and use of (used) old vehicles, according to (Benjaminson et al., 2012), the average age of 17 years of vehicles on the city's streets elucidates the high number of wastefully functioning motor vehicle that are major contributors to Addis Ababa's environmental pollution. Although vehicle taxes depend on engine size, original car price when new, and purpose (commercial or personal use), the existing taxation system encourages the import of old cars by giving tax discounts for older cars, which tend to be more polluting (IBRD World Bank, EDRIECRC and MoFECC, 2017). Furthermore, there is no age limit on imported vehicles to Ethiopia. Excessive noise has been widely recognized as a major cause of disturbance to living and working environments in the city and therefore as a key determining factor of urban amenity (AACRA, 2004a).

Therefore, to convince road and transport officials, policy makers and concerned government bodies about the status and source of road traffic noise in sensitive areas, baseline information on status transport noise pollution levels in the city along different road class and at different land use areas, measurement methodology and its relationships with traffic flow are very essential. However, so far there is no research information regarding on the traffic noise pollution level analysis and evaluation along vicinity of traffic routes, in Addis Ababa at different land uses. Accordingly, these initiated the researcher to study the traffic noise level in different land use areas, relationship between traffic induced noise level and traffic flow in Addis Ababa City and also parameters used in traffic noise analysis.

### **1.3 Research questions**

The major research questions are follows:

- What are the main sources and present status of traffic noise level along vicinity of road way in different land use areas of Addis Ababa city?
- What is spatial or temporal variation of traffic noise pollution along traffic routes at different land use?
- What is the characteristics relationship between traffic flow and its induced noise level?

## **1.4 Objectives of the Study**

### **1.4.1 General objective**

The overall goal of this research is to quantify traffic noise pollution along highway vicinity at different land use areas of Addis Ababa City.

### **1.4.2 Specific Objectives**

- To assess the sources and status of traffic related noise pollution at various land use in Addis Ababa.
- To quantify temporal and spatial dynamics of traffic induced urban noise pollution along highway in city by recording the noise intensity at various land use locations during morning, day and evening time of the day.
- To study statistical characteristics between traffic induced noise level and traffic flow on selected section of the routes.

## **1.5 Scope of the Study**

The scope of the research conducted based on the above objectives was limited to evaluation and analysis of urban traffic noise pollution along selected traffic routes at different land use areas within all sub cities of Addis Ababa. Studies of noise pollution are very general and this paper will only include Evaluation road traffic noise pollution problem in the Addis Ababa city. Survey has been done by performing day time (7:00 AM – 7:00 PM) physical measurement at each selected traffic routes located around different land uses namely; noise sensitive zones, residential area, commercial and business areas, and Industrial zones within the city.

In general, the scope of this research is analyses and evaluation of daytime (7:00 AM- 7:00 PM) traffic noise level along the traffic routes in 4 main land use areas of Addis Ababa city using appropriate and commonly used noise indicators.

## **1.6 Significance of the Study**

This research tries to evaluate and analyze road traffic noise pollution in Addis Ababa city. It is very useful to give suggestions or ideas for controlling traffic noise pollution at vicinity of traffic routes surrounding different land use mainly noise sensitive and residential land use areas. Planning and constructing of highway along vicinity noise sensitive land use areas (Educational establishment, Health center, and residential areas) is not a worthy idea. Thus, this studies helps by giving clues and

encourages the concerned bodies while planning new roads in new areas, as care should be taken to minimize the effect of motor vehicle noise through appropriate controlling method. This study will have the following significance:

- The study review and indicates the factors related to urban traffic noise pollution that affect the city's environment.
- The study investigated the status of city's traffic noise pollution, procedures & parameters for city's traffic noise pollution studies.
- The findings of the study will help and encourages the concerned bodies mainly transport and city planning sector to reconsider their road and transport environment and improve it.
- The study also acts as a basis to other researchers for further research in field of urban highway traffic noise pollution.

### **1.7 Strengths of the Study**

Strengths of this study include considering of various site characteristics with different road class and land use sampled site for primary data collection in order to conduct the study. Existing recent land use map and road network data of the city have been used for site sampling and selection. Each surveyed site condition have been confirmed with research methodology before primary data collection. Thus, the other strength of this study could be selection of appropriate spot for data collection and methodology for traffic related noise study. This study also consider and take measurement data at each selected spots more than twice on different days which helps to consider actual urban traffic condition and helps to achieve higher accuracy in the study. The study conducted was city wide including all existing sub cities. Actual traffic data collection have been done by recruiting 4 research assistance. Several statistical analysis of both descriptive analysis and inferential statistics have been used.

### **1.8 Limitations of the Study**

There are some limitations of this study.

In this study there are two mainly independent primary data collected i.e. traffic volume and composition to identify the factors that affects urban traffic noise pollution. But as one of the limitations of this work was that, speed, longitudinal slope of the road; actual atmospheric conditions were not considered.

The other limitations of this research is that study of night time noise pollution level was not considered. The other limitations of this study was development of noise map not conducted. Because, it requires integration of GIS and noise data models which potentially could increase the generation of noise data models from spatial data in an automated manner. For above mentioned limitations, data required for such comprehensive study are not possible to obtain considering the time and resources available to do this research. Limitations encountered in this research can be interesting study areas to overcome and consider for future research work.

## **1.9 Study Frame Work**

This study was subdivided to five chapters those cover the whole project here.

**Chapter 1. Introduction:** This chapter aimed at informing the reader about the context of the study i.e. background of the study. In addition it comprises a problem, objectives of the study, research questions, and significance of the study, scopes, strength and limitation of the study, and organization of the study.

**Chapter 2. Literature review:** a brief explanation about sound characteristics, general aspect of noise pollution, sources of urban environmental noise pollution, effects of noise pollution, urban traffic noise pollution, traffic noise descriptor parameter, traffic noise measurement method and Traffic noise abatement method are provided under this chapter by collecting information of different secondary data. It also includes past and recent literatures regarding urban traffic noise pollution.

**Chapter 3. Research Methodology:** in this chapter, the study area, sampling methodology, sampling number, sampling procedure, the collected data and equipment used are clarified. Also, description of the selected study spots and noise parameters are discussed. Furthermore, statistical method used in this research for data analysis are clearly and briefly discussed.

**Chapter 4. Result and Discussion:** this chapter includes analyses and briefly discussed research results.

**Chapter 5. Conclusion and Recommendation:** this chapter contains a number of conclusions drawn from the research findings. Also proposed recommendations, strength and limitation the study, and future research work directions were addressed in this chapter.

## **Chapter Two**

### **Literature Review**

#### **2.1 Characteristics of Sound**

Sound is an environmental factor, and it is relevant to look at human exposure to and effects of noise. A sound wave is a physical disturbance of molecules within a medium – air, water or solid – that can be detected by a listener. Sound waves result from a vibrating object, a sound source. These different waves combine and reach the listener via numerous direct and indirect pathways. The listener’s inner ear contains organs that vibrate in response to these molecular disturbances, converting the vibrations into changing electrical potentials that are sensed by the brain allowing the phenomenon of hearing to occur. The physical qualities of sounds can be described by quantitative values (World Health Organization, 1999). Sound is the vibrations of the molecules in air that propagates as a mechanical wave of pressure and detected by our ears (Federal Highway Administration (FHWA), 2010).

The vibration of sound pressure waves in the air produces sound. Sound pressure levels used to measure the intensity of sound are described in terms of decibels. The decibel (dB) is a logarithmic unit, which expresses the ratio of the measured sound pressure level to a standard reference level. Sound is composed of various frequencies, but the human ear does not respond to all frequencies. Frequencies to which the human ear does not respond are filtered out when measuring highway traffic noise levels. Sound level meters are usually equipped with weighting circuits, which filter out selected frequencies. The A-scale on a sound level meter best approximates the frequency response of the human ear. Sound pressure levels measured on the A-scale of a sound meter are abbreviated dB (A) (Federal Highway Administration (FHWA), 2010).

Sound is what we hear when our ears are exposed to small pressure fluctuations in the air. There are many ways in which pressure fluctuations are generated, but typically they are caused by vibrating movement of a solid object. Sound waves are characterized by their generic properties such as amplitude (loud or soft) and frequency (pitch) (FTA, 2018).

**Amplitude of Sound Wave:** Loudness of a sound depends on the amplitude of the fluctuations above and below atmospheric pressure associated with a particular sound wave. The quietest sound that can be heard by most humans, the “threshold of hearing,” is a sound pressure of about 20 micro pascals,

and the loudest sounds typically found in our environment range up to 20 million micro pascals or more. Because of the difficulty in dealing with such an extreme range of numbers, acousticians use a compressed scale based on logarithms of the ratios of the sound energy contained in the wave related to the square of sound pressures instead of the sound pressures themselves, resulting in the “sound pressure level” in decibels (dB). Commonly Sound pressure is proportional to the square root of sound power. Because of dealing with large range of numbers, a logarithmic measure called decibel (db) is used to describe sound level. Generally, source of noise, is in fact a combination of Intensity and Frequency which can be measured in Decibels (Lawrence K. Wang et al., 2005). The level of sound is usually expressed in terms of the Sound Pressure Level (SPL) in decibels.

Sound pressure level (SPL) is defined as:

$$\text{SPL} = 10 \log_{10} (\mathbf{P}_{\text{rms}}^2 / \mathbf{P}_{\text{ref}}^2) = 20 \log_{10} (\mathbf{P}_{\text{rms}}/\mathbf{P}_{\text{ref}}) \text{ dB.}$$

Where; SPL = sound pressure level (dB)  $\mathbf{P}_{\text{rms}}$  = RMS sound pressure (Pa);  $\mathbf{P}_{\text{ref}} = 20 \times 10^{-6}$  - reference sound pressure (Pa)

**Frequency of Sound Wave:** Frequency is the number of times the fluctuation of air pressure or sound occurs in one second. Noise is made up of many frequencies, all blended together in a spectrum. Human hearing covers the frequency range of **20 Hz to 20,000 Hz**. Our human hearing system does not respond equally to all frequencies of sound. For sounds normally heard in the environment, low frequencies below 250 Hz and very high frequencies above 10,000 Hz are less audible than the frequencies in between. Acoustical scientists measured and developed frequency response functions that characterize the way people respond to different frequencies. These are the so-called A, B- and C-weighted curves, representing the way people respond to sounds of normal, very loud and extremely loud sounds, respectively. Environmental noise generally falls into the “normal” category so that the **A- weighted sound level** is considered best to represent the human response. The human being ear is mainly aware in the frequency range of 1 to 4 KHz. In addition to sound varying in frequency, sound intensity fluctuates with time. The most common descriptor of environmental noise is the equivalent (energy average) sound level. The equivalent sound level is the steady state, A-weighted sound level which contains the same amount of acoustic energy as the actual time varying, A-weighted sound level over a specified period of time, which is widely used by highway agencies as a descriptor of highway traffic noise (FHWA), 2010).

## **2.2 General Aspect of Noise Pollution**

(World Health Organization, 1999) define noise as Sound that is unwanted or disrupts one's quality of life. When there is a lot of noise in the environment beyond certain limit, it is termed as noise pollution. Sound becomes undesirable when it disturbs the normal activities such as working, sleeping, and during conversations. It is an underrated environmental problem because of the fact that it can't be seen, smelt, or tasted. (World Health Organization, 2011) report stated that "Noise must be recognized as a major threat to human wellbeing" and rank second among a series of environmental stressors for their public health.

Noise is normally defined as 'unwanted sound'. A more precise definition could be: noise is audible sound that causes disturbance, impairment or health damage. The terms 'noise' and 'sound' are often synonymously used when purely acoustical dimension is meant (e.g., noise level, noise indicator, noise regulation, noise limit, noise standard, noise action plan, road traffic noise, occupational noise, etc.). In its Guidelines for community noise (World Health Organization, 1999), the WHO defined environmental noise (Community or domestic noise ) as "noise emitted from all sources except for noise at the industrial workplace". European Union Directive 2002/49/EC on the management of environmental noise (European Union, 2002) defines environmental noise as "unwanted or harmful outdoor sound created by human activities, including noise from road, rail, air ports and from industrial sites".

FDRE, Proclamation No. 300/2002 on Environmental Pollution Control primarily aims to ensure the right of citizens to a healthy environment and to impose obligations to protect the environment of the country. This proclamation addresses noise as one source of environmental pollution and it seeks for standards and limits for it providing for the maximum allowable noise level taking into account based on the land use type and also considering the availability of scientific and technological capacity of the country. Furthermore, it empowers the MoEFCC for developing and implementation of Noise standards and/or the Regional Environmental Authority to assign environmental inspectors with the duties and responsibilities of controlling environmental pollution. MOEFCC have already developed guideline called ambient Environment Standards for Ethiopia which is helpfull for controlling and managing environmental noise pollution. This guide line recommends noise level of 75, 65, 55, and 55 dBA at industrial, commercial ,residential and sensetive zones, respectively.

Table 2.1 shows the Ethiopian Ambient Environment Standards and WHO Guidelines values for community noise listing as per land use category.

Table 2. 1 Environmental noise standards as prescribed by Guideline or Standards.

Day Time standard Limits of Leq ( dBA ) at different Land Use					
S.No	Industrial Zones	Commercial Zones	Residential Zones	Sensitive Zones	Source
Ethiopia	75	65	55	55	(EPA and UNIDO, 2003)
WHO	65	55	55	45	(Rao, 2014)

### **2.3 Sources of Urban Environmental Noise Pollution**

Noise can be generated internally within a building (e.g., noise from surrounding neighbors' voices, music or appliances) or externally (e.g., traffic noise from automobiles, buses, trains, aircraft, industrial activities or surrounding construction activities). Among most noise sources that are of concern to civil engineers (e.g. transport related, construction equipment, etc.) transportation related is a major contributor of urban noise pollution. During the transport operation, noise is generated by the engine and exhaust systems of vehicle, aerodynamic friction, and the interaction between the vehicle tire and the pavement. Urbanization and associated growth in mobility and industrialization have resulted in the intensification of noise in densely populated areas causing an increase in noise exposure. As the population increases in an urban area, urbanization activities also increase to meet people's needs; this result increased the noise levels (Wawa and Mulaku, 2015).

The general noise level increases in urban, mainly due to traffic. (Chepesiuk, 2005) discussed that the noise comes from different sources; the most substantial source is from transportation, predominantly traffic noise has played a dominant role in causing environmental noise, which can have ill effects on urban communities. (Saadu et al., 1998) performed a noise survey for eight cities in Nigeria and results of the survey revealed that road traffic is a major source of environmental noise pollution.

As Studies done by (Cameron et al., 2004) indicates the continuous expansion of the world urban areas causes road networks to expand as well. Moreover, the steadily increasing traveling distances aggravate the noise problem. Transportation systems are the main source of noise pollution in urban areas. Due to a rapid industrialization, commercialization and urbanization apparent by South-Eastern Nigeria, road traffic noise is a major environmental problem in cities of and noise levels are higher than those measured in cities in well planned and developed countries (Onuu, 2000).

As reports (AACPPPO, 2017) indicates noise pollution has become a second serious problem in Addis Ababa and vehicles were identified major sources of it. As studies performed by (Dewelle, 2014), in eight schools of Addis Ababa city, road traffic noise is the major noise source outside the selected surveyed schools in particular vehicles. Another empirical study done by (Tsegaye, 2017), show that the principal noise pollution sources in mixed commercial zones through a case study of the Yeka sub-city in the Addis Ababa are road vehicles, though there are also sources such as music from boutiques and music shops.

## **2.4 Effects of Noise Pollution**

Globally, many studies on traffic noise being undertaken today shows that such noise can also lead to serious health problems. Sufficient evidence from large-scale epidemiological studies indicates that environmental noise adversely affects human health and well-being. Table 2.2 shows the WHO Guidelines values for community noise listing also critical health effects ranging from annoyance to hearing impairment in different specific environment.

Table 2. 2 WHO guideline for community noise in specific environment

Source: (World Health Organization, 1999)

<b>Environment</b>	<b>Critical health effect</b>	<b>Sound Level (dBA)</b>	<b>Times (hours)</b>
Outdoor living areas	Annoyance	50-55	16
Indoor dwellings	Speech intelligibility	35	16
Bedrooms	Sleep disturbance	30	8
school classrooms	Disturbance of communication	35	During class
Industrial, commercial and traffic areas	Hearing Impairment	70	24

In addition, the social costs of traffic noise are significant. The World Health Organization (WHO, 2011) has estimated the burden of traffic noise related disease in the European Union (EU) as a loss

of 1.6 million disability-adjusted life years (DALYs) per year. DALYs are the sum of the potential years of life lost due to premature death and the equivalent years of “healthy” life lost by virtue of being in states of poor health or disability. This means that around 1.6 million healthy life years are lost every year from traffic-related noise in the western European countries and it is claimed that only air pollution imposes a larger disease burden.

Many studies have already proven that noise is principally responsible for many risk factors for physical and mental health in humans. This problem has not been well recognized despite the fact that it is steadily increasing in developing countries.(Murat and Ebru, 2017). Environmental noise causes both psychological and physiological non-auditory health effects and the evidence for the non-auditory effects is growing (Basner *et al.*, 2014). Noise produces direct and cumulative adverse effects that impair health and that degrade residential, social, working, and learning environments with corresponding real (economic) and intangible (well-being) losses. The study result by (UN- Habitat, 2017) shows the links between the environmental noise pollution and public health and confirms that the prevailing environmental noise problems in the city threaten not only the health and wellbeing of the population but also the rights of the future generation.

#### **2.4.1 Physical Effects of Noise**

Noise of a high enough intensity will cause temporary or permanent damage to hearing. High levels of noise giving rise to noise-induced hearing deficits can be experienced in various situations (e.g. in occupational situations, from loudspeakers or headphones within dwellings (World Health Organization, 1999). This risk is considered to be negligible at equivalent noise exposure levels below 75 dB (A) over an exposure period of eight hours (World Health Organization, 1999).

#### **2.4.2 Sleep Disturbance and Annoyance**

The review of the literature indicates that noise has a series of health effects, in addition to hearing impairment. Some of these, such as sleep deprivation, are important in the context of environmental noise and other consequences of workplace noise, such as annoyance have also been described by (de Hollander *et al.*, 2004). The most important non-auditory effects of traffic noise are annoyance and sleep disturbance (Goines and Hagler, 2007; Pirrera, Valck and Cluydts, 2010). Annoyance is a feeling of displeasure that can result in adverse emotions including irritability, stress, fear, and even depression and it is associated with health-related quality of life (Moudon, 2009; Braubach *et al.*,

2015). Generally, many studies confirm as the noise pollution interferes with sleep, concentration, communication, and recreation.

### **2.4.3 Physiological Effects of Noise**

A growing concern in the current world is the effect of environmental noise on human health and well-being. The adverse health effects of noise can be as severe as increasing the risk of cardiovascular diseases, as shown by (Babisch, 2005) with studies conducted as Auditory and non-auditory effects of noise on health. Reports of (World Health Organization, 2011) based on many research evidences suggests that noise pollution may be a risk factor for cardiovascular disease. The evidence from epidemiological studies on the association between exposure to road traffic noise and hypertension and ischaemic heart disease has increased during recent years (World Health Organization, 2011). Continuing exposure to environmental noise could therefore result in permanent changes to the vascular system, with elevated blood pressure and heart diseases as potential outcomes.

### **2.4.4 Psychological and Communication effects**

Noise can be bothersome and can give rise to psychological and psychosomatic symptoms in the form of headaches, fatigue and irritability. Biochemical reactions indicating a general stress effect from noise have also been reported in human and animal studies (Holmes, 1995). As Studies done by (Singhvi, 2013) with Analysis of noise pollution in Tirupur city; Depression and fatigue (reduces the efficiency of a person); Insomnia (result of lack of undisturbed and refreshing sleep); frustration and is associated with difficulty in concentration, disturbance of rest, physical and mental fatigue are some of Psychological effects caused by noise. In addition, noise can interfere with the teaching and learning process; disrupt the performance of certain tasks, and increase the incidence of anti-social behavior (Dewelle, 2014) and specifically, road traffic is considered to be the main source of community noise pollution. It can thus affect the efficiency of offices, schools, and other place where communication has been of vital importance.

Generally, with observational and experimental studies other researchers also have revealed that noise exposure leads to annoyance, disturbs sleep and causes daytime sleepiness, affects patient outcomes and staff performance in hospitals, increases the occurrence of hypertension and cardiovascular disease, and impairs cognitive performance in schoolchildren (Basner et al., 2014).

## **2.5 Urban Traffic Noise**

Urban traffic noise is the sum of total noise produced from all moving vehicles on the roads at the observer point of view. Motor vehicles are one of the major contributors to the urban road traffic noise; which is one of the most pervasive types of noise pollution and generally considered more intrusive than other types of noise (Nejadkoorki et al., 2010). As Studies done in developing country like India where roads are in bad condition, and poorly maintained and has considerable number of vehicles of outdated technology, the road traffic noise assumes much more importance (Marathe, 2012). Also as studies conducted in Nashik City of Maharashtra India, indicates that traffic related noise pollution is about two third of the total noise pollution in urban area (Vilas and Prashant, 2015).

Also as case study conducted by (Tsegaye, 2017) to study status of mixed-commercial zone day-time ambient noise pollution in Yeka sub-city of Addis Ababa, Ethiopia; it is identified that road vehicles are among one of the major noise pollution sources in the Addis Ababa city during day as well as night.

### **2.5.1 Factors affecting Traffic Noise Pollution**

Road traffic noise is the most significant source of community noise especially near an important road with high volume of traffic of any major city of the world. As studies of (Marathe, 2012) revealed, type of traffic flow and speed, tyre-road surface interaction, road surface condition, various parts of vehicle, types of vehicles are main factors that affect urban traffic noise. Mainly as traffic flow and speed, increases, the noise level increases. The significant parts of vehicle that generate noise are, engine inlet exhaust, propulsion & transmission including gears, brakes, horns, chassis body structure, load in vehicle, etc. In addition (Marathe, 2012) discusses that older vehicles emit higher noise pollution. Further as the vehicle grow older and their mechanical condition deteriorates the noise generated in more. Motor cycles, scooter, tempos, and minibuses are generally noisier as compared to passenger cars. It is also identified as large H.P diesel engine vehicle, commercial truck, tractor, transport vehicles are the main source of noise (Marathe, 2012).

For a precise assessment of the noise produced by motor vehicles, it is essential to know every detail about the noise source or factors that affects traffic noise. First, the road vehicle type may vary from various types of passenger cars to various types of trucks. Secondly, the characteristics of the road surface are of great influence on the tire/road noise production. Factors affecting urban road traffic noise can be classified in to two main class as discussed by (Farcaş, 2008), direct vehicle related

sources (Engine, Exhaust, tire-road interaction, aerodynamic effects, air intake and cooling fan ) and non-vehicle or external sources (Traffic conditions, road type and condition, site condition, weather and climate, other infrastructure). All noise sources operate simultaneously to produce the total noise emitted by a vehicle and source of vehicle related is shown in figure 2.1.

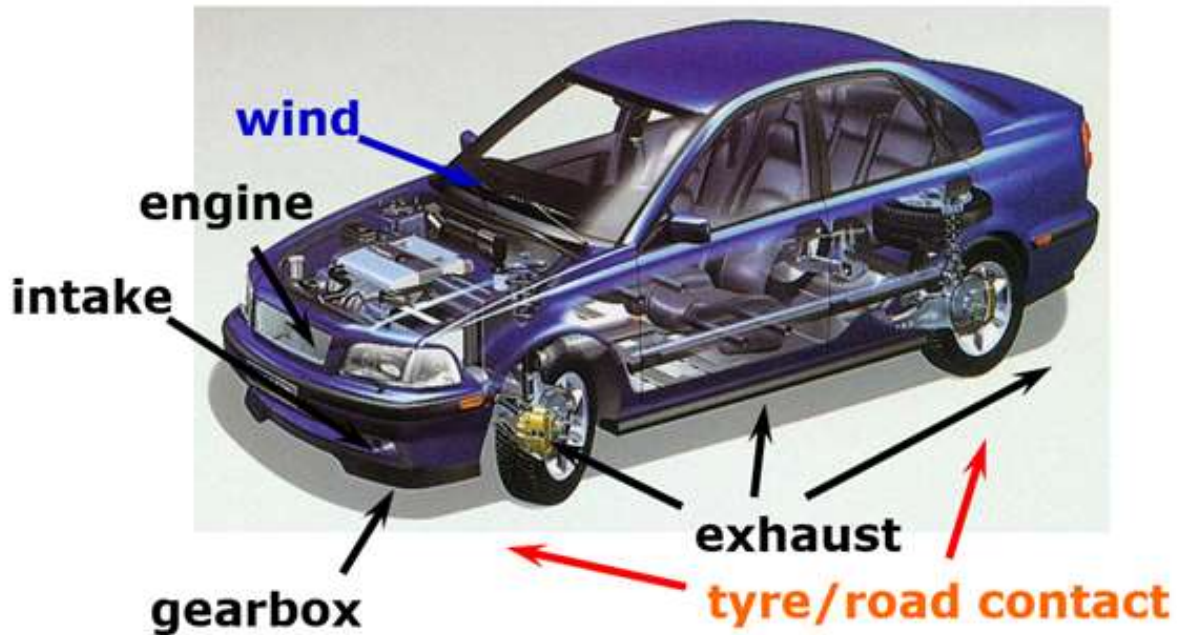


Figure 2.1 Source of vehicle related noise

Source: (Vrom, 2006)

As studies done by (Huang, 2014), three main factors are recognized for traffic noise pollution occurrence: traffic factors, road factors and environmental factors. In fact, the traffic factors mainly involve traffic flow, average traffic speed, traffic composition, and driving conditions (free-flowing). The road factors include road gradient, road pavement surface type and texture, road corridor cross section (whether the road layout is at grade, depressed or elevated). The environmental factors mainly contain road conditions, including distance between the source and reception point, type of intervening ground cover between source and reception point (e.g. grass, water or concrete), natural or artificial obstructions, and weather conditions, including temperature, wind speed, humidity, precipitation and so on. Heavier traffic flow, higher speeds, and a greater number of trucks are expected to increase the loudness of traffic noise (Saad and Alhiary, 2004).

As studies conducted by (Golebiewski et al., 2003) to investigate traffic noise reduction due to the porous road surface; the traffic noise levels can be directly or inversely influenced by many factors, in which the principal parameters include traffic flow rate, composition, velocity, surface roughness index, and distance between the source and the receiver. The most important variables that traffic noise depends on and considered in the development of mathematical models are traffic flow rate and vehicle composition (Filho et al., 2004) as studies conducted in Brazil to examine the effects of traffic composition on road noise.

As reports of (Federal Highway Administration (FHWA), 2011), the volume of the traffic, the speed of the traffic, and the number of trucks in the flow of the traffic are the main variables that affect the level of highway traffic noise. Defective mufflers or any other defective equipment on vehicles can increase the loudness of highway traffic noise. Longitudinal slope (i.e. steep incline) other road condition that causes heavy laboring of motor vehicle engines will also increase highway traffic noise levels. Generally, heavier traffic volumes, greater numbers of trucks and higher speeds, increase the loudness of highway traffic noise. Vehicle noise is predominantly a combination of the noises produced by the engine, exhaust, and tires and mainly depends on traffic volume, percentage of heavy trucks and speed.

### **2.5.2 Characteristic relationships between traffic flow and induced noise level**

Studies were conducted to investigate the impact of traffic flow on traffic noise emissions as the traffic noise pressure levels is significantly affected by traffic flow. (To et al., 2002) studied the roadside traffic noise surveys in heavily built-up urban areas along 18 major roads of Hong Kong in 1999, in which the measurement data included  $L_{10}$ ,  $L_{50}$ ,  $L_{90}$ ,  $L_{eq}$ ,  $L_{max}$ , the number of light vehicles, the number of heavy vehicles, the total traffic flow, and the average speed of vehicles. Using the analysis of variance (ANOVA) and the Tukey test ( $p < 0.05$ ), it was revealed that the total traffic flow and the number of heavy vehicles are the most significant factors of urban traffic noise (To et al., 2002). (Zannin, 2003) explored the impact of the traffic composition and traffic flow on noise emitted by typical Brazilian roads. The result of the study shows as matrix of coefficient correlation among traffic flow, percentage of heavy vehicles,  $L_{10}$ ,  $L_{90}$ , and  $L_{eq}$  indicated that the traffic flow posed highest impact on traffic noise emission.

Also (Morillas et al., 2005) have conducted studies in five towns of Spain to check the hypothesis that traffic is the most important source of noise in the towns and the main reason for its variability and revealed by his studies as there was a strong linear correlation between  $L_{eq}$  and the logarithm base 10 of the traffic flow (Q) in vehicles per hour. As studies conducted in Klang Valley, Malaysia by (Halim and Abdullah, 2014) they compared equivalent noise level response to number of vehicles between a high traffic flow and low traffic flow highway. The results of this study showed that the heavy traffic flow highway recorded a higher noise level compared to the low traffic flow highway, due to the higher number of vehicles on the heavy traffic flow highway.

Logarithmic relationships between the traffic flow and traffic noise pressure level were established under investigation by (Huang, 2014) via a series of field experiments along the Trans-Canada Highway in Regina. The results predicted by the logarithmic functions agree well with the experimental data, with correlation coefficients all above 0.75 were confirmed by the researcher. Thus, researchers have revealed that as there was strong linear correlation between  $L_{eq}$  and the logarithm base 10 of the traffic flow (Q) which implies traffic is a major factor for induced noise level in urban areas.

### **2.5.3 Temporal and Spatial traffic noise level variations**

Studies conducted in Karachi City, Pakistan, (Raza et al., 2011) to examine spatial and temporal patterns of noise exposure due to road traffic found that levels of noise were generally higher during mornings and evenings because of the commuting pattern of residents of the city. In addition, the researcher discusses that the peak traffic noise levels were not spatially related to road density in the city instead, the driver's behavior (frequently use their vehicle horns), traffic congestion and crowd to resulted in the high intensity of peak noise over 80 dB in most of the city.

Study conducted by (Doygun and Gurun, 2008) which aimed at quantifying noise pollution from urban traffic under "residential areas", "residential and commercial areas" and "industrial areas" by having measurements at 38 urban locations according to the national regulations in the city of Kahramanmaraş, Turkey. With a total of 114 measurements for the equivalent noise level ( $L_{Aeq}$ ) were made, during morning, mid-day and evening hours and finds out that mean noise level in "residential and commercial areas" was highest relative to the other land-use types. Minimum and

maximum values of noise pollution were recorded during the mid-day and evening hours, irrespective of the land-use types (Doygun and Gurun, 2008).

In Asansol city of West Bengal, India a total of 35 locations were selected for collection of data, classified as industrial, commercial, residential, sensitive and mixed areas according to the national regulatory standards aims to compute the temporal and spatial distribution of urban road traffic induced noise pollution (Banerjee et al., 2009). Observed Leq noise pollution varies between 51.2-89.0 dB (A) and 43.5 - 81.9 dB (A) during day and night time, respectively. Based on the finding, it can be mentioned that the population in this industrial town are exposed to significantly high noise level, which is caused mostly due to road traffic. Also, service area like schools and hospitals are subjected to significantly high noise level throughout the day and all the locations exceeds the prescribed limit (Banerjee et al., 2009). As studies done previously in different countries; urban induced noise level varies both spatially and temporally based on diverse urban conditions.

## **2.6 Traffic Noise Descriptor parameters**

The basic unit of noise is Decibel. Noise levels generated by transport facilities show a significant amount of variability with respect to space and time. (Lee and Fleming, 1996) discusses that frequency weighting is used to account for changes in sensitivity of the human ear as a function of frequency. A-weighting is the most widely used system for assessing transportation related Noise. Currently, this parameter is the default descriptor for environmental noise measurement which is widely used throughout the world for measuring noise sources and it is an very versatile parameter (EHP, 2013). Since noise frequency and intensity fluctuates with time, the equivalent noise level ( $L_{eq}$ ) was used in this study as the descriptor of environmental noise.

Leq (A) is the equivalent continuous noise level expressed in dB (A) which is the average rate at which energy is received by human ear during the period mentioned. (Marathe, 2012; Pradhan, Swain and Goswami, 2012). It is calculated by using equation:

$$LA_{eq} = L_{50} + \frac{(L_{10} - L_{90})^2}{56}$$

Equivalent noise level is the steady state sound level that contains the same amount of associate energy as the actual sound level varying over a specified period of time. And ( $L_{Aeq}$ ) should be used to describe continuous sounds, such as relatively dense highway traffic (Cynthia S Y Lee and Fleming, 1996).

The other main parameter used for traffic noise pollution analysis and evaluation are percentile exceeded sound Level, noise pollution level, Traffic Noise Index. **Percentile exceeded sound Level** is the noise level exceeded for x per cent of the time and is denoted by  $L_x$ .  $L_{10}$ ,  $L_{50}$ , and  $L_{90}$  are noise level exceeded 10, 50 and 90 percent of time, respectively. The most common noise exceeded level used is  $L_{10}$  i.e. noise level exceeding for 10 per cent of time. It is an indication of the peak level of the intruding noise, whereas  $L_{90}$  level is an indicator of the background noise level.  $L_{50}$  is the level that were exceeded during 50% of the measuring time in dB(A) (Marathe, 2012; Dasarathy, 2015).

It is found that  $Leq$  on an energy basis is not sufficient to describe the degree of annoyance caused by fluctuating noise. Another parameter, termed as **Noise Pollution Level (LNP)**, takes into account the variations in the sound signal and hence serves as better indicator of the pollution in the environment for physiological and psychological disturbance of the human system (Pradhan, Swain and Goswami, 2012, Vilas and Prashant, 2015). This new parameter, noise pollution level is given by:

$$LNP = Leq + (L10 - L90)$$

**Traffic Noise Index (TNI):** This index attempts to make an allowance for noise variability with respect to  $L_{10}$  level which indicates the degree of variation in a traffic flow. Traffic noise index (TNI) is another parameter, which indicates the degree of variation in a traffic flow (Pradhan, Swain and Goswami, 2012). This is also expressed in dB (A) and can be computed using the following relation:

$$TNI = 4(L10 - L90) + L90 - 30dB (A)$$

**Noise climate (NC)** is the range over which the sound levels are fluctuating in an interval of time and was calculated using the following formula:  $NC = (L10 - L90)$  (Pradhan, Swain and Goswami, 2012).

## **2.7 Traffic Noise Measurement Methods**

As different studies executed in other countries, different approaches or strategies have been used for urban traffic noise Evaluation and Analysis, such as computation methods or studies carried out with in situ measurements. Since even computation methods need to be validated and calibrated using in situ measurements, therefore use of an appropriate sampling method is vital for the precision of noise evaluation. Accuracy of assessing and managing environmental noise, largely depends on the sampling method used (European Commission Working Group, 2007) and currently, there are

different strategies for studying environmental noise in an urban area. The sampling methods more commonly used in noise assessment were based on systematic random sampling using a regular grid or on the stratification of urban roads ( Escobar *et al.*, 2012; Zambon, Benocci and Brambilla, 2016). There is also other researches that carry out a stratification of land use after selecting any of the previous sampling strategies (Doygun and Gurun, 2008).

Nowadays the sampling methods more widely used in traffic noise assessment are based on systematic random sampling using on the stratification of urban roads and it is an increasingly popular method (Morillas *et al.*, 2005); Gozalo and Morillas, 2016; Zambon, Benocci and Brambilla, 2016). It is mainly based on mostly accepted assumption that road traffic is the significant source of noise in cities, and for most traffic routes, it can be considered the main cause of the spatial and temporal variability of that noise. Also researchers have been used stratification of urban roads which is based on information from the relevant ministries of transport for sampling method (Ko, Chang and Lee, 2011; Doygun and Gurun, 2008). These transport organizations classify the roads according to their main function and especially according to their design features.

In this study, the last method has been adopted for the selection of measurement sites in the city of Addis Ababa. The aim is to pre-classify the study area considering road functions and considering land-use types. Sampling locations for evaluation and analysis traffic noise pollution in Addis Ababa city were selected in a way that includes noise measurement points for selected sections of road categories relevant to the transited land use area: sensitive zones, residential, educational, recreational and commercial areas.

The duration of the monitoring period is based on the characteristics of the noise source. (Cynthia S.Y. Lee and Fleming, 1996) generally suggests sampling periods that range from 8 to 15 minutes, depending on the range of noise levels anticipated and the temporal nature of the noise sources. The objective of establishing a sampling period is to obtain a steady-state equivalent noise level. Measurement repetitions at all sampling positions are required to ensure statistical reliability of measurement results and three (3) repetitions of for like conditions is recommended by FHWA, with based on the temporal nature and the range in sound level fluctuations of the noise source. Sound levels should be measured and/or recorded simultaneously with the collection of traffic data, including the logging of vehicle types. Many recent research conducted on studies of urban traffic

noise pollution were taken readings on working days for time interval of 15 minutes ( Morillas *et al.*, 2005; Doygun and Gurun, 2008; Alesheikh and Omidvari, 2010; Singhvi, 2013). Generally, the traffic noise under assessment should be measured for sufficient time to establish that the measured value adequately represents the subject noise source. Therefore, in this study, the above method is adopted so that the traffic noise and traffic data is measured for more than two (2) different days over a time interval of 15 minutes and with three (3) repetitions per day (i.e. morning, afternoon, evening) for each sample study spots.

## **2.8 Reducing and Controlling traffic noise pollution**

The purpose of noise reduction and control is to minimize the noise pollution and its effects on human being. (Dasarathy, 2015) discusses that as noise control method can be classified as noise control at source, during transmission and at the receiver. The two basic ways of eliminating noise at sources involves through the design or modification of machinery itself or through isolation or enclosure of the noise source. Noise can be controlled along the path through separation of peoples from noise sources and use of barriers or reflector. Acoustical control or using protective equipment. is one of most popular technique available for absorbing noise (Dasarathy, 2015). Study conducted in Ilorin metropolis of Nigeria by (Olayinka, 2013) have discussed that noise mapping, technical, planning, behavioral, and educational solutions are among the effective noise control measures or action plans that have to be taken in order to abate the environmental (traffic) noise pollution in urban area.

Noise maps describe spatial distributions of noise levels and allow an efficient visualization of the noise distributions in areas where the land uses are sensitive to noise. Noise mapping is a very efficient tools for noise assessment in urban areas. A noise map is recognized as a tool to improve or to preserve the quality of the urban environment regarding noise pollution, permitting a comprehensive look at the problem of multiple sources and receivers (Olayinka, 2013; Gozalo and Morillas, 2016). Noise map is also an excellent tool for urban planning. Noise Mapping or measuring makes the government aware and hence enables them to take suitable measures to mitigate the pollution, thus leading to proper urban planning (Joshi *et al.*, 2015).

The review reports by (SMILE, 2003) discuss and disseminate innovative and successfully implemented measurements of noise abatement planning in 86 selected European towns and cities. As this guidelines reports reduction of traffic density; reducing percentage of heavy goods vehicles;

reduction of speeds; renewal of public transport and (heavy) goods vehicles; changing road surfaces etc.; noise screening or noise barrier; sound-proof windows and urban planning are principal noise reducing measures recommended. And also non-technical issues, organizational and strategic approaches, are equally relevant and as an organizational approach is essential for integrating noise abatement planning into current planning processes at local level and cooperating with stakeholder and the public within a city (SMILE,2003).

According to reports of (SMILE, 2003) traffic reduction remedial measure implies that promoting environmentally friendly means of transport, e.g. combine walking, cycling and public transport; traffic management and parking; which focus on encouraging and linking environmentally friendly modes of transport is one of the measures plans that is recommended and should be implemented to combat road traffic noise in urban. Noise barrier which is the structure, or structure together with other material, that potentially alters the noise at a site from a before condition to an after condition (Cynthia S Y Lee and Fleming, 1996). Additionally, it is recommended as emphases have to be given for implementation of noise abatement strategy which is a process that includes internal coordination, external cooperation, public relations and stakeholder participation in the realization and management of a comprehensive noise strategy for the successful implementation of overall mentioned measurement (SMILE, 2003).

Some recommendations have been suggested by (Dewelle, 2014), in order to improve schools environments in Addis Ababa reduce noise effects. Plantation of trees and vegetation buffer zone, construction of sound barriers, providing sound proof materials and absorbent on school buildings are some other recommended measures to reduce noise and effects of it. As Studies done in Yeka Sub city of Addis Ababa by (Tsegaye, 2017), awareness raising on the issue to commercial sectors and car drivers; better enforcement of noise standards; regular inspection of principal noise sources and incorporation of noise prevention issues in business licensing are the suggested measures to reduce noise pollution.

Also (UN- Habitat, 2017) discusses that, as the Addis Ababa city administration has given significant recognition to the quality of the urban environment over the past decade. Assign clear responsibilities and create institutional awareness on existing policies and regulations for better implementing strategies are the principal measures suggested by the study to tackle pollution. Introducing taxes and/or penalties for cars that are too old to match acceptable emissions standards and encouraging

non-motorized transport by Supplying pedestrian walk way and bike lanes for all urban roads are also play as significant role in tackling the environmental pollution of the city (UN- Habitat, 2017). In addition to addressing the immediate noise problems through strict enforcement of applicable standards and law, it is important to develop strategic noise map for the city. (AACPPO, 2017).

Reduction of traffic noise at the source is the most effective controlling method of traffic noise. The pavement type influences noise generation, and open graded asphalt or porous pavement reduces noise levels compared to conventional asphalt, concrete, or surface dressing treatments. Encouraging compatible adjacent land use near known highway locations is another option to minimize the effect of highway traffic noise through appropriate land use control and management. (AACRA, 2004a). Generally, urban traffic noise mitigation measures should be considered for traffic related or motor vehicles including tire/road interaction, road structures, propagation process and roadside buildings, respectively. Besides such technical actions, legislative/administrative measures are also essential to tackle the problem.

## **2.9 Summary of literature review and research gap**

In this chapter, literature review of characteristics of sound, general aspect of noise pollution, source of noise pollution, effects of noise pollution, urban traffic noise, urban traffic noise parameters or indicators, discussed. Moreover, urban traffic noise sampling and measuring method, countermeasures for abating the traffic noise pollution were presented and it shows that several past studies have been devoted globally to urban traffic noise pollution assessment and analysis. Noise is unwanted sound which cause health damage and must be recognized as a major threat of human wellbeing. Sufficient evidence from large-scale epidemiological studies indicates that environmental noise adversely affects human health and well-being. Also the social costs of traffic noise are also significant. Findings from many researchers around the globe show that traffic noise causes auditory effects like temporary or permanent damage to hearing and non- auditory stress effects such as changes in the physiological systems, e.g., elevated blood pressure, various cognitive deficits, poor sustained attention, memory/concentration problems, sleep disturbances, psychosocial stress disturbance. Road traffic noise is the most significant source of community noise in any major city of both developing and developed countries around world. Additionally, it has been proven by many previous studies that traffic flow and traffic composition (percentage of heavy trucks) are among the major impact factors on urban traffic noise pollution levels than others such as traffic speed, road

condition, grade of the road, climate condition, etc. In order to minimize the noise pollution and its effects on human being, different technical noise reduction and control measurement have discussed and non-technical issues i.e. organizational and strategic approaches, legislative and administrative measures are equally pertinent.

Despite very few studies indicating that Addis Ababa city has entertaining the noise pollution problem (Yibeltal, 2014; Dewelle, 2014; Tsegaye, 2017), no reports or studies on traffic noise pollution along different traffic route and at various land use have been done. So far there is no research information regarding to evaluation and analysis of the traffic noise pollution along vicinity of traffic routes, at different land uses in Addis Ababa city. Also, there is no evidence about the relationship between traffic flow and the traffic induced noise level in the city along different road (traffic route) class. So, this study assess the main source and status of traffic related noise pollution at various land use in Addis Ababa. Also by this research it is aimed to quantify temporal and spatial variation of urban traffic induced noise pollution along traffic routes in city by recording the noise intensity at various land use or selected locations. And this research also investigate the relationship between the traffic flow and traffic induced noise level at selected route section.

## Chapter Three

### Research Methodology

#### 3.1 Study Area

The study is conducted in Addis Ababa, capital City of Ethiopia, which is located at the center of the country. The city has an area of 527 km<sup>2</sup> is divided into 10 sub-cities and 116 woredas. According to the CSA July 2015 estimate, Addis Ababa hosts an estimated 3,433,999 people in 2016, which is a 17% share of Ethiopia's total urban population. As study report of (UN-Habitat, 2017), the city is experiencing an annual population growth rate of 3.8% and is projected to reach 4.7 million inhabitants by 2030. It is where the African Union and its predecessor the OAU are based. It also hosts the headquarters of the United Nations Economic Commission for Africa (UNECA). It is also home to many aid and development organizations, as well as over a hundred embassies. Table 3.1 shows summarized related data of the city and geographical map of study area is shown in figure 3.1.

Table 3. 1 Profile of Addis Ababa City

Type of Info	Values	Source
Estimated Population in 2019	3.840 Million	(UN- Habitat, 2017)
Area of the Municipality	527 Km <sup>2</sup>	AACPPO, 2017
Perimeter of the City	113.109 Km	
No. of Subcity and woredas	10 and 116	
Center Line Length of Streets (km)	3,698.20	AACRA
Total Equivalent Length of Streets (km)	5,783.21	
Total No and Equivalent Length (km) of High Road Class (RR,PAS,SAS,CS) as per AACRA (Have Unique Route ID)	391 No and 2409.15 KM	
Total No and Equivalent Length (km) of Local Streets (LS road Class) as Per AACRA (Have Unique Route ID)	15000 No and 3374.58 KM	
Total Area of the City covered by road (km <sup>2</sup> )	40.48	
Number of Vehicles registered in the Ethiopia	977,349.00	FDRETA
Number of Vehicles registered with "AA" code	574,636.00	
Estimated Number of Vehicles Operating in the City	561,490.00	(AACADVLCA, 2010)



Figure 3. 1 Study area (All subcity of Addis Ababa)

### **3.2 Sampling Method**

The important aspects required with regarding to this study is collecting information about noise levels, noise sources which are mainly traffic volume and composition from where noise is created, type of route class or land use at which measurements have been conducted. For the success full work of this study a well-recognized sampling method for data collection process where used so as to ensure that data gathered are sufficient, defined and accurate that helps subsequent decisions based on arguments embodied in the findings are valid.

As generally accepted assumption that traffic is the most important of the different sources of urban noise also many researchers found that in urban noise studies, traffic is the main reason for the

temporal and spatial variability of noise. This study, therefore, formulates the stratification noise by means of categories of streets based on their functional classification or hierarchy (Gozalo and Morillas, 2016) relevant to the transited area.

To determine noise measurement locations, urban noise surveys have been performed by adopting a sampling method called source oriented route categorization method. The aim was to pre classify the study area considering both road functions and also different land-use types. This divides the study area into parts according to road functions such as importance of roads (Benocci and Brambilla, 2016) and also types of land-uses relevant to the transited area (Morillas et al., 2005). For this study, sampling points are selected in a random manner in representative locations of the streets according to the established traffic route categorization per each sub city at different land use. The number of observations is different in each sub city which is proportional to the total number and length of asphalt Street of each route category and also the land use to be considered. Thus, sampling locations for analysis and evaluation traffic noise pollution in Addis Ababa city were selected in a way that includes noise measurement points for selected sections of established road category or hierarchy and relevant to the type of transited land use area.

### **3.2.1 Road categorization**

Route categorization of the city road network is according to their functional classification which mainly based on traffic volume, length and width of the road, type of connection and land use (activity) that they are going to serve. Basically, hierarchy refers to the level of importance of the street which is determined by grouping roads according to the character of service they provide (AACRA, 2004b).

The level and the variability of urban noise is identified principally due to variations in traffic flow and type of traffic. It also varies with the hours of day as the volume and mix of traffic are different. In this sense, it could be useful that in traffic noise studies to stratify the noise based on road functional classification that takes this variability including hourly variation into account. Traffic flow is implicit in the definition of the categories or road functional classifications used in the present work, even though it does not appear explicitly. While the other factors mentioned above were not explicitly included in the definition because this would have to an excessive number of categories, they either are implicit at least in part e.g. width of the street, partially the vehicle speeds and traffic type or will be included as an averaged effect in the statistical. Currently, five road hierarchies is being commonly

accepted and implemented in the city Roads Authorities (AACRA). Accordingly, for this study the following group of route category were established, based on types of Addis Ababa City Roads Authority's road functional classifications or road hierarchy and their basic definition are:

**Category 1:** Route with class of ring road. And is controlled access and high speed routes with width of 40m and above.

**Category 2:** These are generally controlled access roads or should be controlled access roads in the future. These roads serve a pure traffic movement function. That is, they transport Vehicles from one point to another without interaction or reference to adjacent land use. Such routes are belongs to Principal Arterial Streets (PAS) road Class.

**Category 3:** these roads have predominately traffic movement function; there is some limited access to these roads generally for adjacent businesses. And this category corresponds to Sub arterial Streets (SAS).

**Category 4:** these roads are transitional in function and they are Collector street (CS) road class as AACRA road classification. That is they serve traffic function, distributing traffic in to local, residential areas from the sub arterial and arterial; road network. These roads also serve an access function to land abutting these roads.

**Category 5:** is a route with local streets (LS) road class as per AACRA's road classification methodology. These are roads serve predominately property access function. They serve as access to property within the city and not used in this study because of no or very small traffic flow.

Therefore, in this study top four route class namely category 1, category 2, category 3 and category 4 are used for sampling methodology and the category network map is shown in figure 3.2. Site selection criteria for traffic noise pollution assessment is primarily based on road class and land use area in order to incorporate and identify the source of it and affected area in all sub cities of Addis Ababa. For the selection of sampling points, first the total equivalent length of route corresponding to each selected traffic route category (i.e. category 1, 2, 3 and 4) were collected for all sub cities of Addis Ababa. Number of observations is different for each established route class which depends on the total equivalent length and number of Asphalt Street of each sub city and also land use type. With this protocol, section of the routes at different land use in a given sub cities had the same probability of being chosen; in particular, the sub cities with denser high road network, is the more likely that one of its points would be sampled.

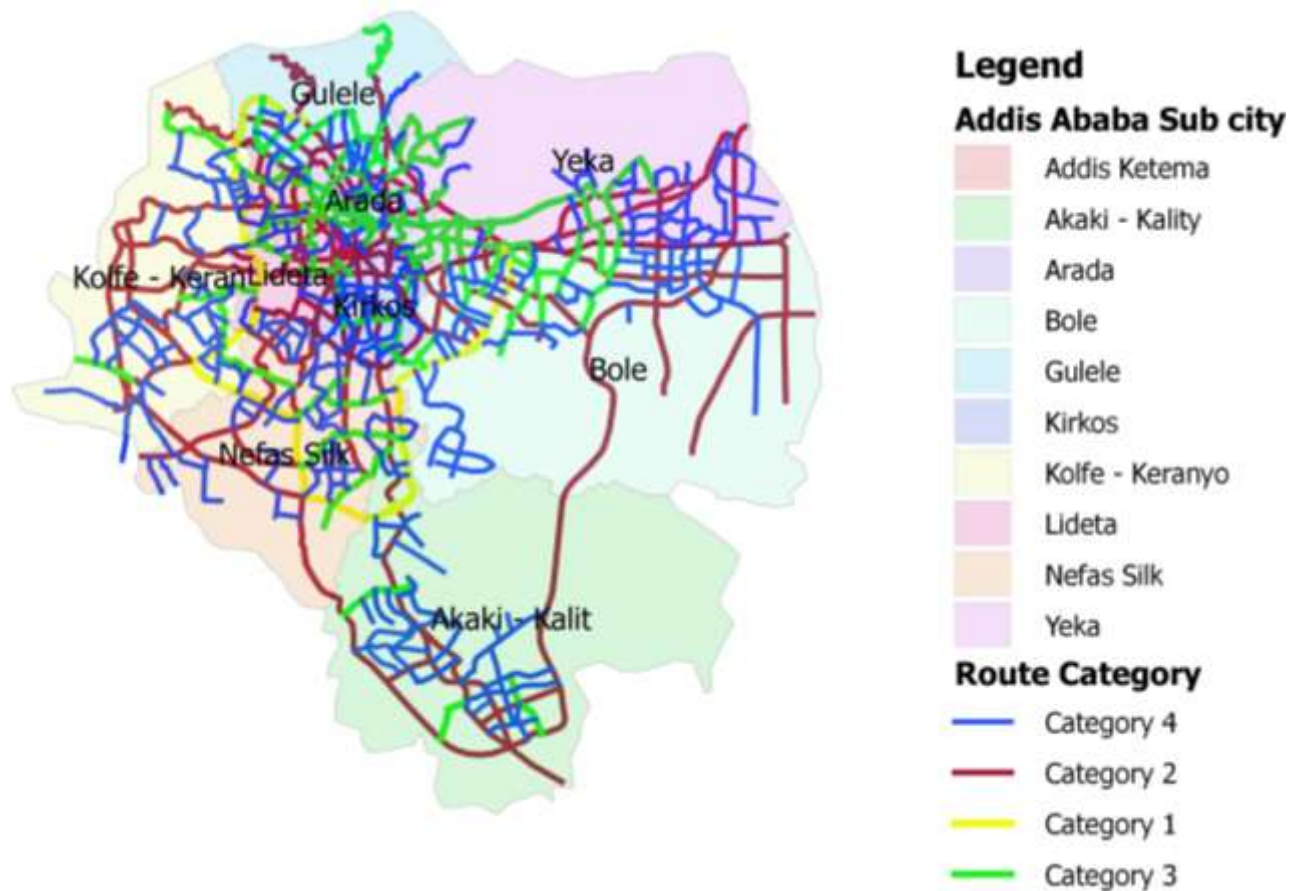


Figure 3. 2 Addis Ababa subcity and route category map ( Source AACRA,2018)

### 3.2.2 Land use

In addition to the sampling method called classification of the study area based on road functional classification; land use have been considered to choose sampling points. Along the total length of each section of road hierarchy, type of relevant transited land use viz. industrial, commercial, residential, sensitive zones) have been carefully noted. In all sub cities more than three types of land use primarily those that are noise sensitive zones (where the impact of noise is high) schools, hospitals, and government and non-government offices, tourist places) where considered for this study.

By reviewing document of city's planning project office AACPPO, 2016; 4 main land use have been established and their basic definition are briefly discussed below. Industrial zone is an area where enterprises specializing in the production of industrial goods and in the provision of services for industrial production are concentrated. It is manufacturing and storage area along the section of the

route. Commercial land use is the most vibrant and active part of an urban area and that comprises most commercial activities, retail and other commercial offices. In this study highly dense and mixed commercial-residential areas also considered under commercial category. Also in this studies residential land use is considered separately. It contains inhabitants or housing units in a defined area and it can be area of single family residential or multi-family residential. Low and medium density residential land zones in the city categorized under residential area land use category for this study purposes. Social services areas contains such as education, government offices, and health centers that are very crucial areas of urban that helps to create a healthy and economically productive society (AACPPO, 2017). In this study social service areas are adopted as sensitive zones where people are receiving instruction, or are receiving health care and where the impact of noise is high.

A desktop review of the land use of study area is conducted using google earth and GIS map of existing land use of 2016 from Addis Ababa City Project Planning Office (AACPPO) as shown in figure 3.3 were used so as to conduct site selection, and also compared and confirmed with actual field visit. In this study the number of observations per land use zone or category is different which is mainly depends on adopted sampling method of source oriented. This sampling method gives priority for route functional classification rather than land use type. For sampling even though priority is given for route category type, the number of spots selected at each land use category of Addis Ababa is proportional to the percentage of the land uses share. Type of the zones and number of samples per category to be considered in this study is shown in table 3.2.

**Table 3. 2 Number of sampling Points taken for each Land use category**

<b>S. No.</b>	<b>Land use category</b>	<b>Number of Sampling locations</b>
1	Industrial	2
2	Commercial	14
3	Residential	14
4	Sensitive Zones	11
	Total	41

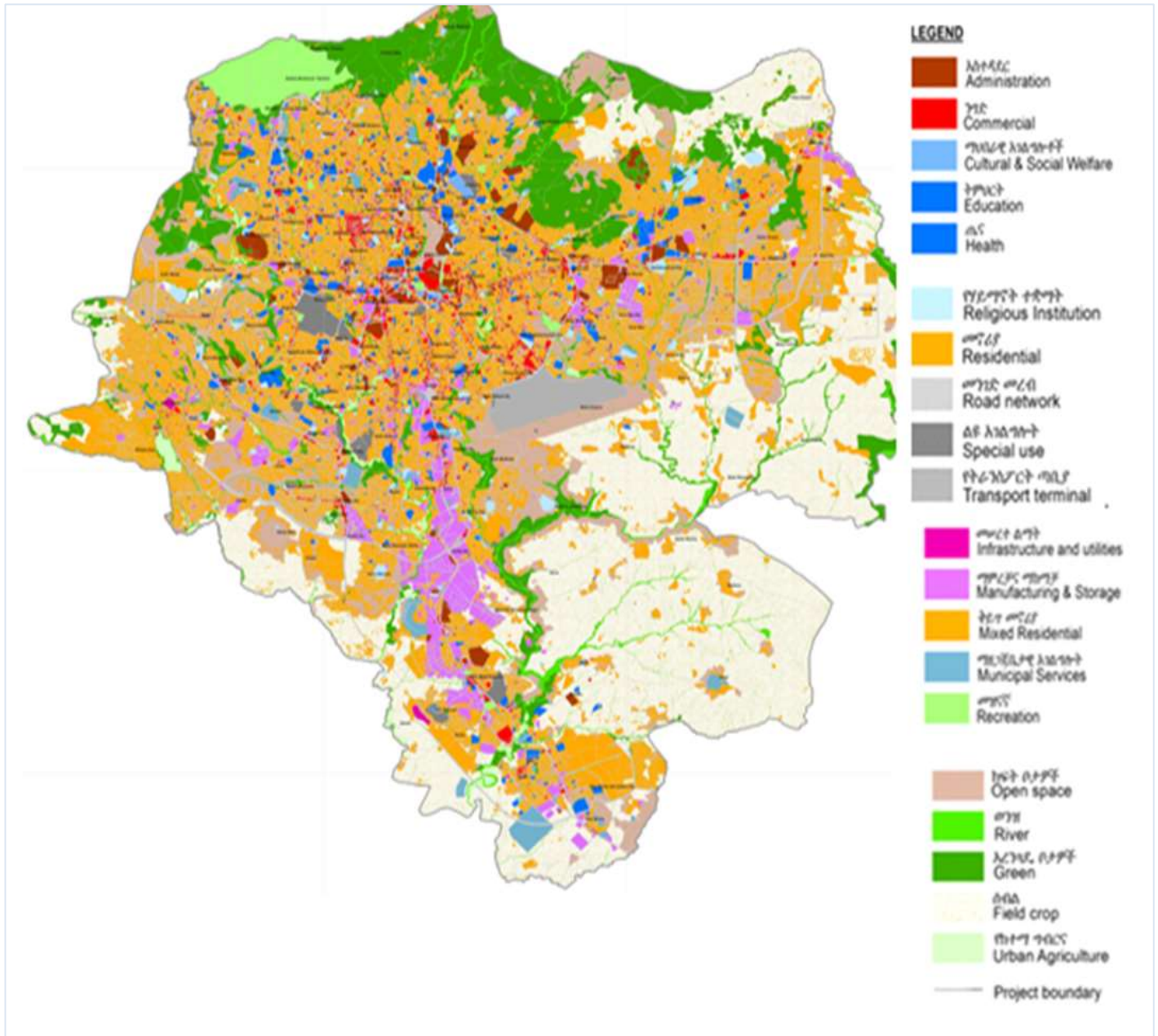


Figure 3. 3 Addis Ababa City Land use map (Source AACPPO, 2016)

Primary data at each selected specific locations (segments of the routes) within the study sub city were recorded depending on the activities is existed around selected segments of the routes. This helps to consider the impact of traffic noise (where and when non traffic noise is at minimum) throughout the section of road for each corresponding land use so that it is compared with the National Ambient Environment Standards and International WHO standards.

### **3.3 Sampling Number and sampling period**

The sampling points were then randomly selected along the total length of study road category considering primarily the route class and relevant land use. For the selection of sampling points, first the available route category (i.e. Category 1, 2,3,4 ) with total street section and length of each corresponding selected road class have collected mainly in way to include the routes (source-oriented and density-oriented) and relevant land use for all sub cities of Addis Ababa.

For study of traffic noise events, number of samples categorical study is calculated at 95% confidence interval by using equation

$$N = \left( \frac{10 * \gamma}{\epsilon} \right)^2 \dots\dots\dots \text{Eqn. (3.1)}$$

Where,  $\gamma$  is coverage factor and  $\epsilon$  is a desired expanded measurement uncertainty (Jagniatinskis et al., 2016). The magnitude of the uncertainty ( $\epsilon$ ) associated with a short term measurement of Leq is 4.2 dB for road traffic noise (95% confidence) by following the guidelines of ISO 1996-2 (Craven and Kerry, 2007; Alves and Waddington, 2014). Coverage factor ( $\gamma$ ) is numerical factor used as a multiplier of the combined standard uncertainty (uncertainty of the result of a measurement expressed as a standard deviation) in order to obtain an expanded uncertainty. This expanded uncertainty implies that quantity of an interval about the result of a measurement that may be expected to encompass coverage probability or level of confidence of the interval. Usually, coverage factor value is 1.645 and 1.96 at 90% and 95% confidence interval respectively (JCGM, 2008). In this study cover factor of 1.96 at 95% confidence interval is adopted.

Therefore, using the above equation the calculated minimum number of sampling study spots were 22 and decided to have minimum of 5 spots per each category i.e. category 1, category 2, category 3, category 4, respectively. But, in order to take equivalent and minimum of 2 or more sampling section with 2 or more land use type in each sub city, it is needed to increase the sampling number to 41. This in turn, helpful to get more sample data that represent the actual and diverse conditions of the city.

The corresponding sampling number for the study of traffic noise pollution in Addis Ababa city along vicinity of each high road class are listed in table 3.3. In the study city area, minimum number of sampling points for each sub city was not uniform as it depends primarily on the road density of each sub city and also land use type coverage area. Study spots selected in all sub city of Addis Ababa on all corresponding available traffic route class with minimum of two (2) and maximum of five (5)

sections with different land use mainly noise sensitive zones studied in all existed 10 sub cities of Addis Ababa.

The measurements were taken at three different times during day time (between 7Am to 7 PM) with a minimum of two or more day reading repetitions is recommended for each measurement periods on selected site points for noise assessment with each sampling periods of 15 minutes per measurement. Consequently, 369 total number of 15 minute reading was taken, which is 41 spot by more than 2 days and 3 repetitions per day. During each 15 minute survey noise reading values have taken at each minutes. Generally, 5,535 noise reading value is collected. The measurement period will be at Morning (7Am-10 AM), afternoon (11AM-2PM) and evening (4PM-7PM) in order to incorporate the temporal variability of traffic Noise (Cynthia S.Y.et al, 1996). But exact measurement time for each sampling point were depending on the conditions and activities held there. The details number of measurement sites and their reading repetition spread over all sub city of Addis Ababa is shown in the following Table 3.3.

The number of observations is different for each established route class which is depends on the total equivalent length and number of Asphalt Street of each sub city and also on land use type. It is known that arterial streets are the dominant route class of the city network. It is logically needed to decide the maximum sampling number per one of the category have to be less than or equal to one third of the total sampling number and which is 14. And the left statistically determined sampling number were distributed as per share of equivalent length the other established route. And the final accepted sampling number per each route category is shown in table 3.3 which is proportional to the kilometer length the route class.

Table 3. 3 Study site Matrix (Sampling Points taken for each category in studied Sub city)

S. No	Road functional classification of Addis Ababa City road network (Source: AACRA)	Category Class	No. of Sampling locations	Minimum Number of measurement repetitions per study locations
1	Ring Road (RR)	<b>Category 1</b>	6	Minimum of two day readings by each spot were taken at three different times during day time [Morning (7Am-10 AM), afternoon (11AM-2PM) and evening (4PM-7PM)].
2	Principal Arterial Streets (PAS)	<b>Category 2</b>	14	
3	Sub Arterial Streets (SAS)	<b>Category 3</b>	13	
4	Collector Streets (CS)	<b>Category 4</b>	8	
	Total		41	

### 3.4 Data Collection Methodology

The important aspect with respect to traffic noise pollution is collecting information about noise levels, source which are mainly traffic volume and composition from where noise is created and its time of exposure. Since the well-recognized problem was identified about transport noise pollution a formal data collection process is necessary so as to ensures that data gathered are both defined and accurate and that subsequent decisions based on arguments embodied in the findings are valid. For the success full work of this studies both primary and secondary data needed were collected carefully. And site information viz. site name, land use type and category class of each spot studied were tabulated in table 3.4 based on data obtained from AACRA and AACPPO.

#### 3.4.1 Primary data

Globally many studies have been conducted and discussed that urban noise pollution is mainly due to traffic induced noise levels, which are mainly based on the road traffic characteristics (traffic volume, composition). In this study the following data such as noise level, traffic volume or traffic composition, GPS location of the study spots were collected at each selected 41 study spots.

Table 3. 4 Selected sites name and code with their geographical locations

Code	Site Name	Latitude coordinate	Longitude coordinate	Code	Site Name	Latitude coordinate	Longitude coordinate
1	Gurd Shola to Zefemsh	9.0208	38.7979	22	Terro	9.0510	38.7070
2	Anchorcha	9.0353	38.8172	23	Yeshi Debelle	9.0183	38.6978
3	Wessan	9.0266	38.8287	24	Saris Adey Abeba	8.9573	38.7653
4	Minilik Hospital	9.0383	38.7738	25	Gelan Condominum	8.8797	38.7678
5	Yekatit 12 hospital	9.0425	38.7603	26	Bulbula School	8.9524	38.7684
6	AAiT student Dormitary	9.0405	38.7619	27	Sefera	8.9208	38.7353
7	Janmeda to Kidist Mariam junction	9.0381	38.7658	28	Melka Sheno	8.8725	38.8147
8	Piassa around Jewellery houses	9.0347	38.7549	29	Jemmo Kuter 1	8.9574	38.7126
9	Tsihon Condominium	9.0629	38.7326	30	Kefetegna 23 high School Bisrate Gabriel	8.9936	38.7275
10	Semen Mezegeja	9.0561	38.7435	31	Haile Garement	8.9395	38.7346
11	St Petros Hospital	9.0737	38.7588	32	Amigo cafe	8.9774	38.7237
12	Phoulos at Gulalle	9.0489	38.7258	33	CP-021-Lideta Tsebhal	9.0073	38.7351
13	Ayat Hospital	8.9944	38.7955	34	Tikur Anbessa Hopital	9.0210	38.7488
14	Birhane Zare School	9.0094	38.7842	35	Torhailoch	9.0157	38.7190
15	Atlas	9.0026	38.7814	36	Abinet S-206 sect_3	9.0217	38.7373
16	Ayat Zone 5 Residence Area	9.0184	38.8793	37	Arake Febrica	9.0127	38.7426
17	Sembia Nekersia Hospital	9.0394	38.7211	38	Gahndi Hospital	9.0158	38.7557
18	Abyysinia Primary School	9.0463	38.7247	39	Kazanchis at InterContinental Hotel	9.0164	38.7686
19	Gedem Yesus to Amanuel Road	9.0235	38.7200	40	Bambis to Dembel	9.0061	38.7688
20	Atena Tera up side of 18 RA	9.0387	38.7132	41	Lancha	8.9901	38.7625
21	Bethel	9.0039	38.6894				

Table 3. 5 Selected sites with category class and land use type for measuring road traffic noise in Addis Ababa city

**Source:** (AACPPO, 2017) and (AACRA, 2018) and **NB:** \*Codes represents the corresponding route category type.

Subity and Specific Location	Site Code	Category Class ↓			
	Land Use →	Commercial Zones	Industrial Zones	Residential Zones	Sensetive Zones
<b>Addis Ketema</b>					
Abyysinia Primary School	18				4
Gedem Yesus to Amanuel Road	19	3			
Sembia Nekersia Hospital	17				2
<b>Akaki Kality</b>					
Bulbula School	26				1
Gelan Condominum	25			2	
Melka Sheno	28			4	
S-028-Saris Adey Abeba	24	3			
Sefera	27	2			
<b>Arada</b>					
AAiT student Dormitary	6			2	
Janmeda to Kidist Mariam junction	7			3	
Piassa around Jewellerry houses	8	3			
Yekatit 12 hospital	5				4
<b>Bole</b>					
Atlas	15	2			
Ayat Zone 5 Residence Area	16			4	
Ayat Hospital	13				1
Birhane Zare School	14				3
<b>Gulalle</b>					
Phoulos at Gulalle	12	2			
Semen Mezegeja	11			4	
St Petros Hospital	9				3
Tsihon Condominium	10			1	
<b>Kirkos</b>					
Bambis to Dembel	40	3			
Gahndi Hospital	38				2
Kazanchis at InterContinental Hotel	39	2			
Lancha	41			4	
<b>Kolfe Kerenyo</b>					
Atena Tera up side of 18 RA	20	1			
Bethel	23			3	
Terro	22			4	
Yeshi Debelle	21			2	
<b>Lideta</b>					
Abinet S-206 sect_3	36	3			
Arake Febrica	34		3		
Lideta Tsebhal	35			4	
Tikur Anbessa Hopital	37				2
Torhailoch	33	1			
<b>Nifas Silk Lafto</b>					
Amigo cafe	32	3			
Bisrate Gebriel Highschool	31				2
Haile Garement	29		1		
Jemmo Kuter 1	30			2	
<b>Yeka</b>					
Anchorcha	2			3	
Gurd Shola to Zefemsh	1	3			
Minilik Hospital	4				2
Wessan	3	2			

As shown in table 3.4 code have been given for each study site with local site name. And other necessary site condition, were collected are also discussed in the other section of this study. And techniques used for each primary data collection were briefly discussed in the other section of this chapter. Table 3.5 shows the information i.e. site name, site code, land use type and route category class under which the study spots are selected for the noise level measurements in the city. Figure 3.4 shows an overview of the locations of noise measurements in Addis Ababa city for this study.

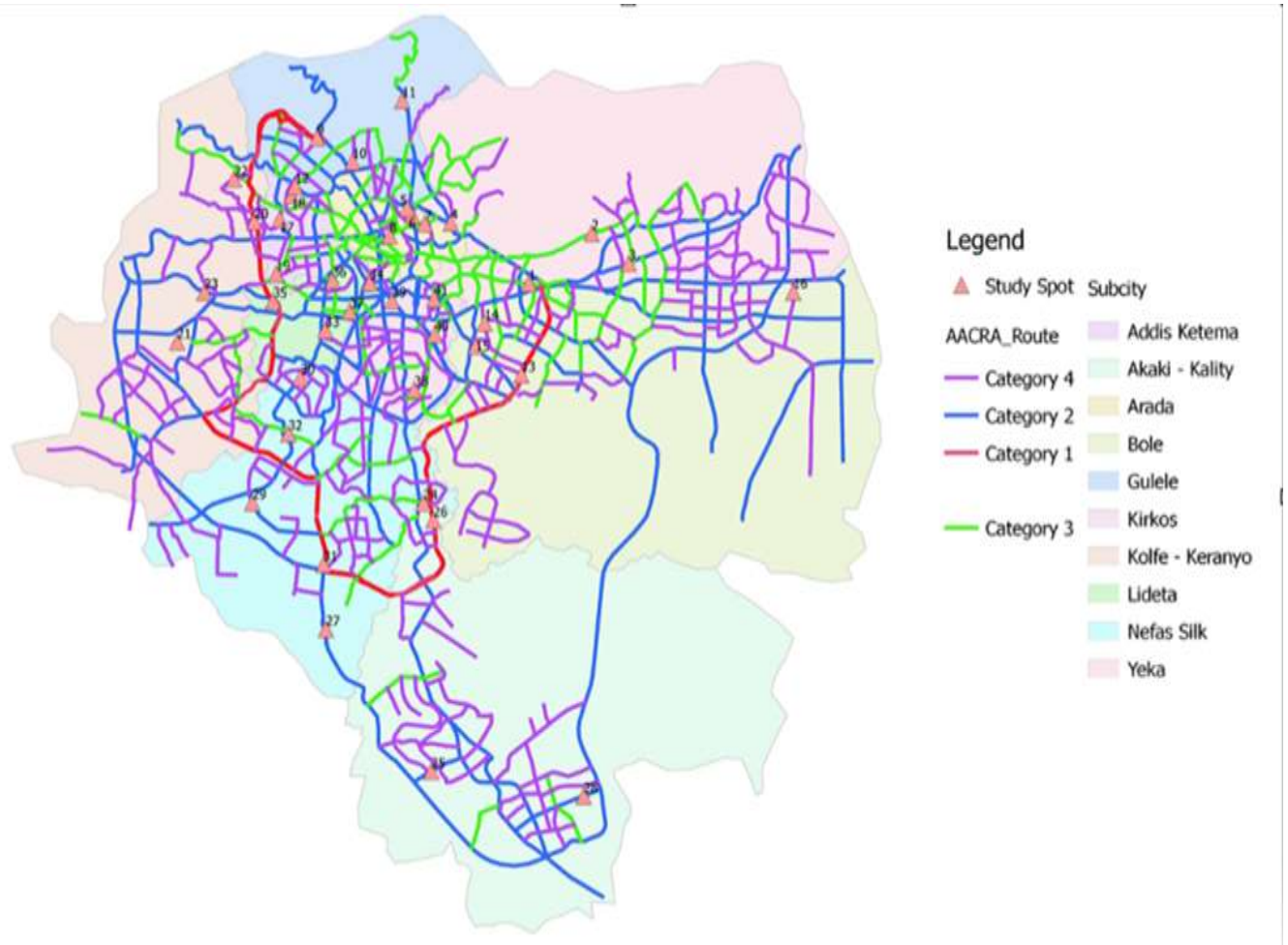


Figure 3. 4 Sampling site locations in Addis Ababa City

### 3.4.1.1 Noise Level Reading

Transport related Noise pollution (Sound levels) at each selected area were measured using calibrated sound level meter device of model SLM-816 (shown in figure 3.5) and all the measurements will be taken at different time of day. The measurement methodology were by following the standard field

measurement method from end of February to April, 2019. It is known that Noise measurement is the main diagnostic tool in noise control technology. The sound pressure level or sound level measured in decibel (**dB**) is a logarithmic measure of the effective sound pressure of a sound relative to a standard reference value. Sound Pressure Level (SPL) is ten times the logarithm to the base 10 of the ratio of the time-mean-squared pressure of a sound, in a stated frequency band, to the square of the reference sound pressure of 20  $\mu$ Pa, the threshold of human hearing.

Measuring the physical data were done using Sound Level Meter (SLM) of model: Testo-816 Digital Sound Level Meter (shown in figure 3.5) that was borrowed from FDRE, Ministry of Environment, Forest and Climate Change (MoEFCC). A sound level meter consists basically of a microphone and an electronic circuit including an attenuator, amplifier, weighing networks or filters and a display unit. Testo 816 is a sound meter with the sound level measurement ranges 30-80dB, 30-130dB, 50-100dB and 80-130dB, automatic range switchover, two time weightings, two frequency weightings, a level reading function, display light. The microphone consists of the sound signal to an equivalent electrical signal. The signal is passed through a weighing network which provides a conversion and gives the sound pressure level in dB (A). When measuring long term noise exposure, the noise level is not always steady and may vary considerably, in an irregular way to over the measurement period. This uncertainty can be solved by measuring the continuous equivalent level, which is defined as, the constant sound pressure level which would have produced the same total energy as the actual level over the given time  $L_{eq}$  dB (A).



Figure 3. 5 Digital Sound Level Meter (SLM- 816).

This instrument measures the sound pressure level in dB (A) i.e. decibels in **A** weighted scale as recommended by ISO-1996/1:2003 standard. All measurements were made at slow response mode. The sound pressure level or sound level measured in decibel (dB) is a logarithmic measure of the effective sound pressure of a sound relative to a standard reference value. The dB (A)  $L_{eq}$  denotes

the time weighted average of the sound pressure level in decibels on scale ‘A’ which is relatable to human hearing. The sound level meter used, can measure the sound frequency from 31.5 Hz to 8 kHz and from 30 dB to 130 dB in A weighted scale at four ranges. i.e., 30 to 80 dB (A) for low; 50 to 100 dB (A) for medium; 80 to 130 dB (A) for slightly high and 30 to 130 dB (A) auto-measurement range. To achieve higher accuracy, sampling was done on the random day strategy. So, at each sampling point, the data is collected on more than two randomly selected days in a week. Data collection time will be during working hours from 7Am to 7Pm on different days of the week from Monday to Saturday at different hours of the day by following the standard guidelines of ISO-1996/1:2003: Morning (7Am-10 AM), afternoon (11AM-2PM) and evening (4PM-7PM)). But, exact time for data collection in some cases depending on the activities held on there.

The noise level were recorded for every minutes and the sampling procedure were based on 15-min measurements at each selected points. Also, this is the usual sampling and measurement procedure employed by other workers (Morillas et al., 2005; Doygun and Gurun, 2008; Irfan, 2012). All the data measured were analyzed and compared with the standard and guideline of national (Ambient Environment Standards for Ethiopia) and international i.e. WHO that has been used widely. Another important part of noise assessment is the actual measurement of the noise levels during operation.

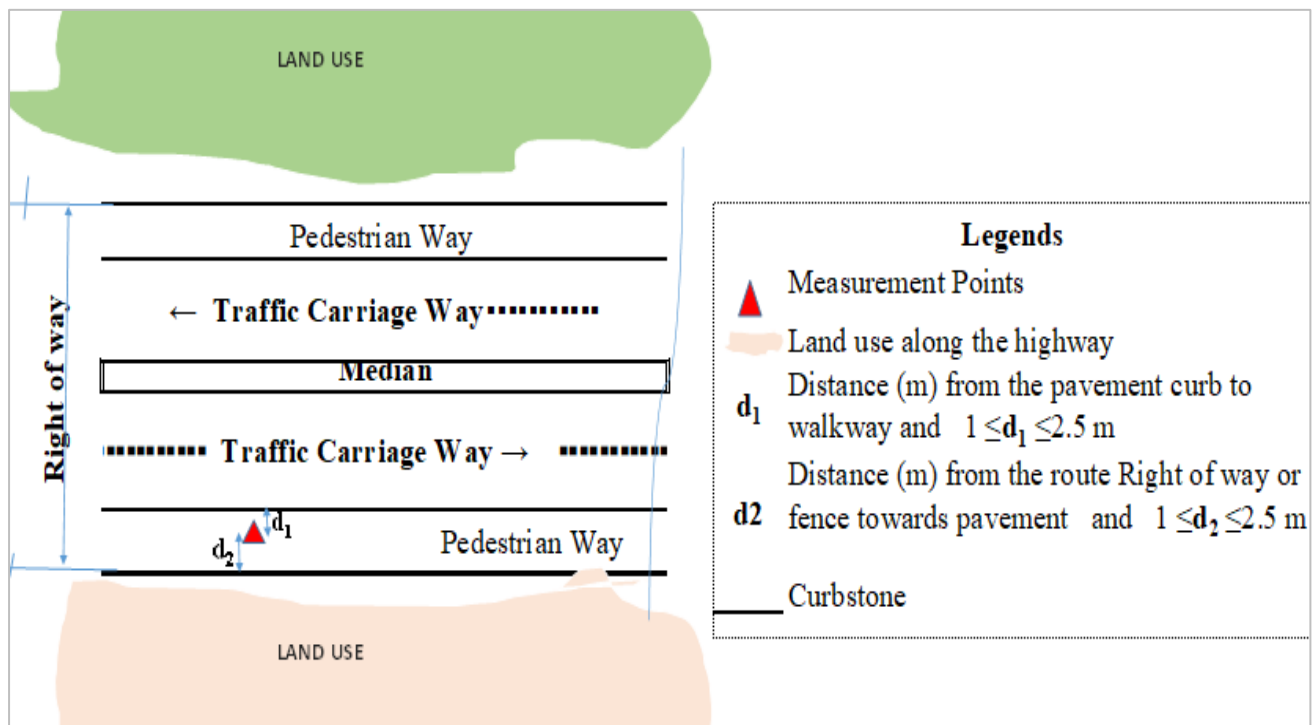


Figure 3. 6 Traffic noise study plan view or site sketch

The sound level meter were handled at proper orientation to receive the maximum sound intensity by placing at a height of 1.2 to 1.5 m above the ground corresponding to the ear level of an average human height and at a distance of between 1 to 2.5 m from the curb or fence as per site condition. And for primary data collection, site sketch along the traffic highway were shown in figure 3.6.

#### **3.4.1.2 Traffic flow and vehicles Composition**

The most important variables or primary data considered in this study are traffic flow rate and composition; Increased traffic flow, in terms of vehicles per hour, causes an increase in the noise level (Filho et al., 2004) given constant traffic composition, speed and driving patterns. Noise measurements were conducted at selected points of different route class and land use in all sub cities of Addis Ababa city. Therefore, in this study relevant information such as 15 minutes count of traffic volume and number of heavy vehicles or buses were also conducted with careful strict time synchronization between the acoustic instrumentation in order to assess the effect of traffic on noise pollution. For each selected route category developed for this study, ambient noise levels measured, and assessed their correlation with simultaneously measured vehicle counts. The level of highway traffic noise primarily depends on; the volume of the traffic and the number of heavy trucks in the flow of the traffic (Federal Highway Administration (FHWA), 2011). For the purpose of highway traffic noise analyses, in this study two main categories of motor vehicles were adopted for count based on the relation of their noise emission level. All other traffic vehicles such as automobiles, medium trucks, motorcycles, taxis counted as one class of traffic vehicle. Buses and heavy trucks considered in other class or as heavy vehicle. For this study, Bus is any vehicle public transport vehicle with 37 seats or more. And Heavy trucks are any trucks with axle number of three or more.

Therefore, at each measurement site, simultaneously with the traffic noise reading or measurement, number of heavy vehicles (buses and heavy trucks) and all other types of traffic vehicle counts were conducted separately which were used in the analysis and discussion of the study.

#### **3.4.1.3 Site Condition**

Additionally, each site location were geocoded with a GPS measurement obtained using the GPS machine with model of Garmin GPS 72H so that specific study points and study traffic route category were displayed using QGIS. Necessary other road or site condition (driving behavior, vehicles and traffic conditions, speed humps, failed pavements, etc.) is noted which were used in discussion of the

study result. In conducting the field experiments on the highway, the following conditions should and were assured. **i.** Non-roadway noises such as industry, airport, rail line, huge Market, were not close to the experimental locations. **ii.** During the measurement, there is no rain or snow on the road surface. **iii.** Unexpected activities and incidents such as building or road construction, noise from parking or garages, truck loading, loud music from stores, special vehicle passing nearby were noted and no reading nearby there. In the case of special vehicle i.e. ambulance and fire trucks, the measurement was paused and re-started the measurement after they drove away.

### **3.4.2 Secondary data**

The necessary data like Sub city's road network coverage and map will be also collected from Addis Ababa City Roads Authority (AACRA). This data is needed for the study in order to identify road class information that will be used for sample point Selection. Land use shape file data of each sub city and other necessary related documents were collected from AACPPO and used for identification of land use types at selected study route section. And also average daily metrological data (temperature, humidity, precipitation, wind speed) of the city were collected from metrological website called AccuWeather.com. All noise monitoring study were carried out under ideal and suitable metrological conditions as per recommendation of (USDOT and FHWA, 2018) and average observed values of it is shown in table 3.5. As many researcher study result revealed, a very weak negative correlation were accounted between air temperature and prevailing traffic noise level. Also it have been proved as wind speed had very weak negative correlation with equivalent traffic noise level by others previously conducted studies. On the other hand a very weak positive correlation exist between relative humidity and equivalent traffic noise level. (Bueno *et al.*, 2011; (Subramani, PSivaraj and Kavitha, 2012; (Chowdhury *et al.*, 2015).

Table 3.5 Metrological aspects of Addis Ababa city during the study period

Source: (website called AccuWeather.com)

S.No	Parameters	Values
1	Precipitation (mm)	36
2	Maximum Temperature (C°)	24±1
3	Minimum Temperature (C°)	13±1
4	Humidity (%)	50±6
5	Wind Speed (Km/hr)	13.5±0.5

From the above discussion it is clear that meteorological condition had a very little impact on prevailing urban traffic noise level and insignificant influence of meteorology on traffic noise level close to road were proved. For this reason the meteorological variables were exempted in principal analysis and discussion section of this study.

### **3.5 Data processing and description of noise parameters**

An important part of noise assessment is the actual measurement of the noise levels and analysis parameter and methodology. Noise levels generated by transport facilities show a good amount of variability with respect to time. It is, therefore, necessary to establish meaningful statistical noise measures that describe the magnitude of the problem while capturing the variability.

Noise level data collected at each different selected locations on working days from Monday to Saturday (7AM to 7PM) by using sound level meter of SLM-816. Using noise level recorded data, percentile exceeded noise level  $L_x$ , were analyzed using Gaussian percentile and from which other main noise parameters were calculated from subsequently  $L_{eq}$ , NC, LNP and TNI.

- **Percentile exceeded sound Level ( $L_x$ )** in decibel: is the noise level exceeded for  $x$  per cent of the time is denoted by  $L_x$ .  $L_{10}$ ,  $L_{50}$ , and  $L_{90}$  noise level exceeded for 10%, 50%, and 90% of the time in noise recording respectively. The most common noise exceeded level used is  $L_{10}$  i.e. noise level exceeding for 10 percent of time. It is an indication of peak level of the intruding noise, whereas  $L_{90}$  level is an indicator of the background noise level. Noise descriptors will be identified and based on it remedial measures are also to be suggested to control the noise level.
- **Equivalent continuous noise level:** The noise levels are variable over time, going up and down continuously, making it difficult to evaluate. In order to make things easier the equivalent level was defined as a continuous sound level that would produce the same effect on the human ear if compared to the actual noise observed during the measurement, with all the variations. So, the  $L_{eq}$  can substitute by a single value all the variations of the noise level. The equivalent sound level is also given by dB (A). The parameter universally used in discussions of noise pollution in environment is  $L_{eq}$ , the energy **equivalent continuous noise level** expressed in **dB(A)** which is the average rate at which energy is received by human ear during the period mentioned (Vilas and Prashant, 2015; Pradhan, Swain and Goswami, 2012). The  $L_{eq}$  **dB (A)** denotes the time weighted average of the sound pressure level in decibels on scale 'A' which is relatable to human hearing.

$$L_{eq} = L_{50} + \frac{(L_{10} - L_{90})^2}{56}$$

- **Noise pollution level ( $L_{NP}$ ):** is also used to express varying level of noise (Vilas and Prashant, 2015). It can be computed from the time varying noise level using following equation:

$$L_{NP} = L_{eq} + (L_{10} - L_{90})$$

Noise pollution level ( $L_{NP}$ ) takes in to account the variations in sound signal and hence serves as better indicator of noise pollution in the environment for physiological and psychological disturbance of the human system.

- **Traffic Noise Index (TNI)** is another parameter which indicates the degree of variation in a traffic flow. This Index attempts to make an allowance for noise variability with respect L10 level. This is also expressed in dB (A) and can be computed by using equation:-

$$TNI = L_{90} + 4(L_{10} - L_{90}) - 30$$

- **Noise climate (NC)** provides the range over which the sound levels fluctuate in an interval of time and is given by the following equation.

$$NC = (L_{10} - L_{90})$$

### **3.6 Data Analysis**

The data collected for all the 41 surveyed sites were analyzed by grouping into classes of different scenarios based on time of the day, road categories, and land use. The variable chosen for the different statistical tests used to analyze the results and evaluate the quality of the methodologies used for noise study will be the equivalent continuous noise level ( $L_{eq}$ ) since this is the most commonly used in noise studies.  $L_{eq}$  is a non-additive variable (it is a logarithmic variable) and, therefore, not linearly additive. The statistical analysis have been done using excel and SPSS software.

Fisher's test (ANOVA test) statistical analysis were applied to noise data collected in order to study significant difference ( $P < 0.05$ ) in noise pollution levels and equivalent continuous noise level between different land use zones. Also Fisher's test statistical analysis were applied to in order to test significant difference ( $P < 0.05$ ) in equivalent continuous noise level between different periods of the day. To resolve the hypothesis that different strata or road class in this case have significant differences in sound values first, a descriptive analysis through a box plot was carried out. The box-and-whisker plots and nonparametric Kruskal Wallis analysis of variance test were be used to test for

significant differences ( $p$ -value  $< 0.001$ ) among the medians of each road categories. This significance implies that the average noise level value and its variability will determine acceptability of the stratum formed by road categories or road functional classification. Moreover, linear regression models were used to assess the association between traffic flow and the measured noise level. In this research, it is first assumed that the logarithmic values of the total traffic flow ( $\log Q$ ) to be the most significant factors. Thus, a regression analysis was performed to investigate the relationship between  $L_{eq}$  (dBA) and logarithm of traffic volume ( $\log Q$ ) using the total average traffic volume counted at each surveyed spot.

The correlation between the equivalent continuous noise level ( $L_{eq}$  dBA) and two class of traffic vehicle (i.e. (i). Heavy Transport vehicles (Bus/Heavy trucks) and (ii). all other vehicle types) was also studied in this work. For this purpose, a multi regression model was developed using the equivalent noise level as the dependent variable and the vehicle types as the independent variable.

## **Chapter Four**

### **Results and Discussion**

#### **4.1 Assessment and Analysis of Noise Descriptors**

##### **4.1.1 Spatial Assessment of Noise Descriptors**

Traffic related noise measurements were done where and when the effects of noise sources from other activities or sources are at minimum. Various noise pollution indices were calculated using Gaussian percentile to obtain the noise pollution levels. Different percentile exceeded values like  $L_{10}$ ,  $L_{50}$  and  $L_{90}$  were computed from the sampled data. These parameters were used for the evaluation of Equivalent Continuous Noise Level (Leq), Noise Pollution Level (LNP), Noise Climate (NC), and Traffic Noise index (TNI). The average noise descriptors were determined per location. Table 4.1 depicts the average values of noise descriptors for all the sites surveyed at various time intervals 7:00AM to 7:00PM. The sites are designated with numbers of site code from **1 to 41**.

A glance look at table 4.1 shows that the average Equivalent Continuous Noise Level (Leq) and noise pollution level (LNP) of the locations surveyed ranges from 70.6 dBA to 80.8 dBA and 77.5 dBA to 87.5 dBA, respectively. From table 4.1, location with site code **29** (Haile Garment) has the highest values of LAeq (80.75 dBA),  $L_{10}$  (82.2 dBA),  $L_{50}$  (80.4 dBA),  $L_{90}$  (77.8 dBA), LNP (85.1 dBA), TNI (65.2 dBA), NC (4.3 dBA). This site is located near an industrial Land use with a manufacturing and storage area of 59.24 ha which have perimeter of 5.23 km. In addition site is located along the route with study of category 1 which called Ring Road class as per city's road functional classification. The section of the route is controlled access and high speed routes with carriage width of greater than 40m. It serves for traffic including heavy truck travelling to and out of downtown of the city. During the site inspection, it have observed that almost all the traffic operates at high speed and on the section of this route. And some drivers reasonably and unreasonably uses horns improperly. The factors responsible for high in noise level at this site include site location near main highway. Therefore, apart from noise due to traffic volume and existence of many heavy truck or buses operating at high speed, there is traffic noise due to improper vehicle horns.

*Analysis and Evaluation of Urban Road Traffic Noise pollution in Addis Ababa City*

Table 4. 1 Consolidated values of noise descriptors and traffic data of study location at each sub city (dBA)

Subcity↓ / SiteCode↘	Leq (dBA)	L90 (dBA)	L50 (dBA)	L10 (dBA)	NC (dBA)	LNP (dBA)	TNI (dBA)	Average of Total Traffic Flow (Q/45 min)	Average Number Heavy Truck and Bus (HT/45 min)
<b>Addis Ketema</b>									
17	76.5	72.7	76.0	78.0	5.2	81.7	63.6	375	5
18	73.7	70.0	72.9	76.5	6.5	80.2	66.0	167	1
19	77.1	74.1	76.7	79.2	5.1	82.3	64.6	556	6
<b>Akaki Kality</b>									
24	75.1	72.6	74.8	77.0	4.4	79.5	60.1	268	1
25	77.5	74.4	77.1	79.2	4.8	82.3	63.5	581	19
26	78.0	74.9	77.5	79.9	5.0	83.0	64.9	919	27
27	80.1	77.9	79.8	81.5	3.6	83.6	62.2	1,203	72
28	75.1	71.7	74.5	77.5	5.8	80.9	64.9	338	7
<b>Arada</b>									
5	71.7	67.7	71.1	73.5	5.8	77.5	60.9	81	-
6	77.0	73.0	76.4	78.5	5.5	82.4	64.8	530	8
7	75.1	68.9	73.6	77.9	9.1	84.1	75.1	167	1
8	76.5	72.7	75.8	79.0	6.3	82.8	67.9	696	4
<b>Bole</b>									
13	80.0	76.5	79.6	81.3	4.7	84.7	65.5	1,197	31
14	73.9	70.8	73.5	75.8	5.0	78.9	60.7	206	-
15	78.3	75.6	78.0	79.5	3.9	82.2	61.3	724	4
16	76.0	72.4	75.4	77.5	5.2	81.2	63.1	508	1
<b>Gulalle</b>									
9	73.8	71.2	73.3	76.3	5.1	79.0	61.7	123	2
10	78.4	75.9	78.2	79.7	3.8	82.2	61.0	493	16
11	73.3	70.5	72.9	75.2	4.7	78.1	59.4	112	-
12	79.9	76.7	79.5	81.1	4.4	84.3	64.4	711	14
<b>Kirkos</b>									
38	77.9	75.6	77.6	79.7	4.1	82.1	62.1	627	4
39	78.8	75.9	78.4	80.9	5.0	83.8	66.0	749	6
40	78.1	74.6	77.6	79.4	4.8	82.9	64.0	534	2
41	70.0	66.6	69.6	71.7	5.1	75.0	56.8	110	-
<b>Kolfe Kerenyo</b>									
20	79.8	76.0	79.1	82.0	6.0	85.8	70.1	1,217	53
21	77.0	73.3	76.4	79.2	5.9	83.0	67.0	519	20
22	73.0	69.7	72.6	74.7	5.0	78.0	59.7	164	-
23	77.0	71.7	76.2	78.2	6.5	83.5	67.8	570	-
<b>Lideta</b>									
33	79.2	74.4	78.4	81.2	6.8	86.0	71.5	950	39
34	77.2	74.8	76.9	78.9	4.0	81.2	60.9	319	5
35	72.7	68.5	71.8	75.3	6.9	79.5	65.9	112	-
36	75.7	72.0	75.2	77.7	5.6	81.3	64.5	267	0
37	77.0	73.9	76.6	78.6	4.7	81.7	62.7	511	4
<b>Nifas Silk Lafto</b>									
29	80.7	77.8	80.4	82.2	4.3	85.1	65.2	1,230	42
30	79.1	74.3	78.4	80.2	5.8	84.9	67.6	970	36
31	77.5	71.0	75.7	80.7	9.8	87.3	80.0	649	10
32	75.7	72.4	75.3	77.6	5.2	80.9	63.2	312	3
<b>Yeka</b>									
1	78.6	76.4	78.4	79.9	3.5	82.2	60.5	1,142	8
2	73.7	71.2	73.4	75.4	4.2	77.9	58.0	242	2
3	79.3	74.7	78.7	80.4	5.7	85.0	67.5	896	24
4	78.9	76.1	78.6	80.3	4.2	83.1	63.0	722	20

Location **27** (Sefera) has the second highest values of LAeq (80.17 dBA), L<sub>10</sub> (81.5 dBA), L<sub>50</sub> (79.8 dBA), L<sub>90</sub> (77.9 dBA), LNP (83.6 dBA), TNI (62.2 dBA), NC (3.6 dBA). This site is categorized under commercial land use of study category as it is located near high density mixed commercial-residential area. In addition, the site is located along the route with study category 2 which called Principal Arterial Streets route class as per city's road classification. This section of the route is characterized by serving for traffic including loaded and unloaded heavy truck entering and exiting the city. On this route, traffic operates at high speed as it surrounds outskirts of the city by south and east side. In addition at this section there was many construction trucks i.e. dump truck frequently travelling along. So, the responsible factors for noise level at this site include traffic volume operating at high speed, including many heavy trucks and improper vehicle horns.

With order of high Leq dBA noise Parameter, next to these two locations is site with code number of **13** (Ayat Hospital). And the average values of noise descriptors of this spot (Ayat Hospital) is LAeq (79.98 dBA), L<sub>10</sub> (81.3 dBA), L<sub>50</sub> (79.6 dBA), L<sub>90</sub> (76.5 dBA), LNP (84.7 dBA), TNI (65.5 dBA), NC (4.7 dBA). This Site were located on the ring road and classified under study category of sensitive land use and route category of 1. The spot where located near the hospital and around medium density residential area. Large number of traffic operating on it including number of heavy transport vehicles frequently travelling at high speed.

As one can see from table 4.1, the highest equivalent noise level were recorded at corresponding sites with high traffic flow and vice versa. From above discussion it can be understand easily as high noise levels exposure in the city occurs in the day time at sites near major highway, mainly on routes that are belongs to category 1 and category 2. So, this is mainly due to high number of traffic volume and high percentage of heavy transport vehicles operating on such routes. The highest two Peak noise level where recorded at locations 29 and 20. These noisiest spots were found in Category 1 with the peak noise levels (L<sub>10</sub>) of 82.2 dB (A) and 82.0 dB (A), respectively. These Sites are on the ring road where huge number traffic operating on. Locations 27 were found in Category 2 which is the with peak noise levels (L<sub>10</sub>) of 81.5 dB (A). In addition the route is found at outskirts of the city by which heavy and loaded trucks enter in to the city. The major sources of noise at these locations include road traffic, vehicle horn, rolling tires at higher speed. Generally, the high noise pollution values at these locations is due to the proximity of these sites to the high traffic density of roads and also as a result of the noise produced by higher number of heavy trucks or busses operating on the routes. Also

it have been observed during the data collection as traffic induced noise level at such sites were due to rolling tires at high speed and also drivers behaviors since they use horns improperly. The high noise levels at highway vicinity, confirm once more the previous findings of many researchers (Saad and Alhiary, 2004)) pointing to the existence of a very close association between the sound levels measured at a given urban location and the road traffic volume flowing by that location. Field observations during the data collection have been also indicated that poor road conditions i.e. distress or poor placement of speed hump on the roads have an effect on the vehicle generated noise.

Again using the values of versatile noise parameter, Leq dBA, the lowest noise values were recorded at location with site code of 41 (Lancha) and have value of Leq (70.0 dBA), L<sub>10</sub> (71.7.0 dBA), L<sub>50</sub> (69.6 dBA), L<sub>90</sub> (66.6 dBA), LNP (75.0 dBA), TNI (56.8 dBA), NC (5.1 dBA). These sites were found along the route of category 4 with low traffic volume travelling to medium density residential area from and to arterial streets. Low volume of automobiles vehicles were travelling on the route.

And the second lowest noise descriptor values were recorded at site of code 5 (Yekatit); Leq (71.7 dBA), L<sub>10</sub> (73.5 dBA), L<sub>50</sub> (71.1 dBA), L<sub>90</sub> (67.7 dBA), LNP (77.5 dBA), TNI (60.9 dBA), NC (5.8 dBA). The site were located along route category of 4 which is collector route class as per city road authority's route classification method. Also site were surrounded by social service institution with area of 5.234 ha and perimeter of 1.518 km which is classified under sensitive zone land use of study category. This route serve traffic function, distributing traffic in to local, residential areas, social service areas from the sub arterial and principal arterial streets.

The third lowest noise descriptor values were recorded at location with code of 35 (Lideta Tsebal) with value of LAeq (72.7 dBA), L<sub>10</sub> (75.3 dBA), L<sub>50</sub> (71.8 dBA), L<sub>90</sub> (68.5 dBA), LNP (79.5 dBA), TNI (65.9 dBA), NC (6.9 dBA). These sites were also found along the route with category 4 of low traffic volume travelling to medium density residential area from and to principal arterial streets. Low volume of automobiles vehicles were travelling on the route. No heavy trucks or busses have been observed during the site inspection and data collection at sites of above three with lowest recorded noise descriptors. The main sources of noise at these locations include road traffic volumes of automobiles. Generally, the lower noise pollution values were recorded at sites along routes where there was low traffic flow of motor vehicles.

During the primary data collection it have been observed that honking is a common occurrence in Addis Ababa, irrespective of road types, and even land use. Driving attitude which includes impatience, sudden braking, over accelerating, traffic flow obstruction etc. are the factors that may aggravate honking. Some domestic drivers of open air motorcycle, dump trucks and taxis use horns frequently and improperly. It is noted that improper use of horn is another reason for increase of noise level reading and which in turn increase equivalent noise level. This implies, there is a need to consider such diverse factors during planning of noise abatement measures as traffic induced ambient noise level can be reduced by careful driving and proper use of horns.

Noise Climate (NC) provides the range over which the noise levels fluctuate in an interval of time and is expressed in dBA. In Addis Ababa, NC, in all land use of surveyed sites indicates the greater fluctuations in the noise levels. The minimum NC was 3.5 dBA, while maximum was 9.8 dBA. The other indicator called noise pollution level (LNP), takes into account both NC and Leq indices. It gives a clue of noise pollution with fluctuations in the noise level or varying levels of noise expressed in dBA. It is considered as the best indicator of physiological and psychological impact of noise. The highest top five observed LNP was at site with code of 31, 33, 20.0, 29 and 3 with value of 87.3, 86.0, 85.80, 85.09 and 84.97 dBA, respectively.

Figure 4.1, shows the values and variations for noise descriptors for all the studied sites of Addis Ababa city. Traffic Noise Index (TNI dBA) is a parameter which indicates the degree of variation in a traffic flow expressed in dB (A). And it is the best indicator of to estimate the annoyance response due to traffic noise. The top three minimum values of TNI, dBA were recorded at site with code 41 (Lancha), 2 (Anchorcha), and 11 (Semen Mezegeja) with value in dBA of 56.8, 58.0 and 59.4, respectively. All this three sites are classified under study category of residential land use. And the top three highest TNI (dBA) were observed at site with code of 31 (Kefteгна 23 high school of Bisrat Gabriel), 7 (Janmeda to Kidist Merriam Junction), 33 (Torhailoch) with value of 80.0, 75.1 and 71.5 dBA, respectively. The noise level of 74 dBA TNI has been indicated as representing a reasonable standard of amenity in present day urban conditions. It may be predicted that at this level there is only one chance in that the average person living in the vicinity of main road traffic is likely to be dissatisfied. From all studied sites in the city two of them have TNI value of greater 74 dBA and annoyance response due to traffic is very high at these locations.

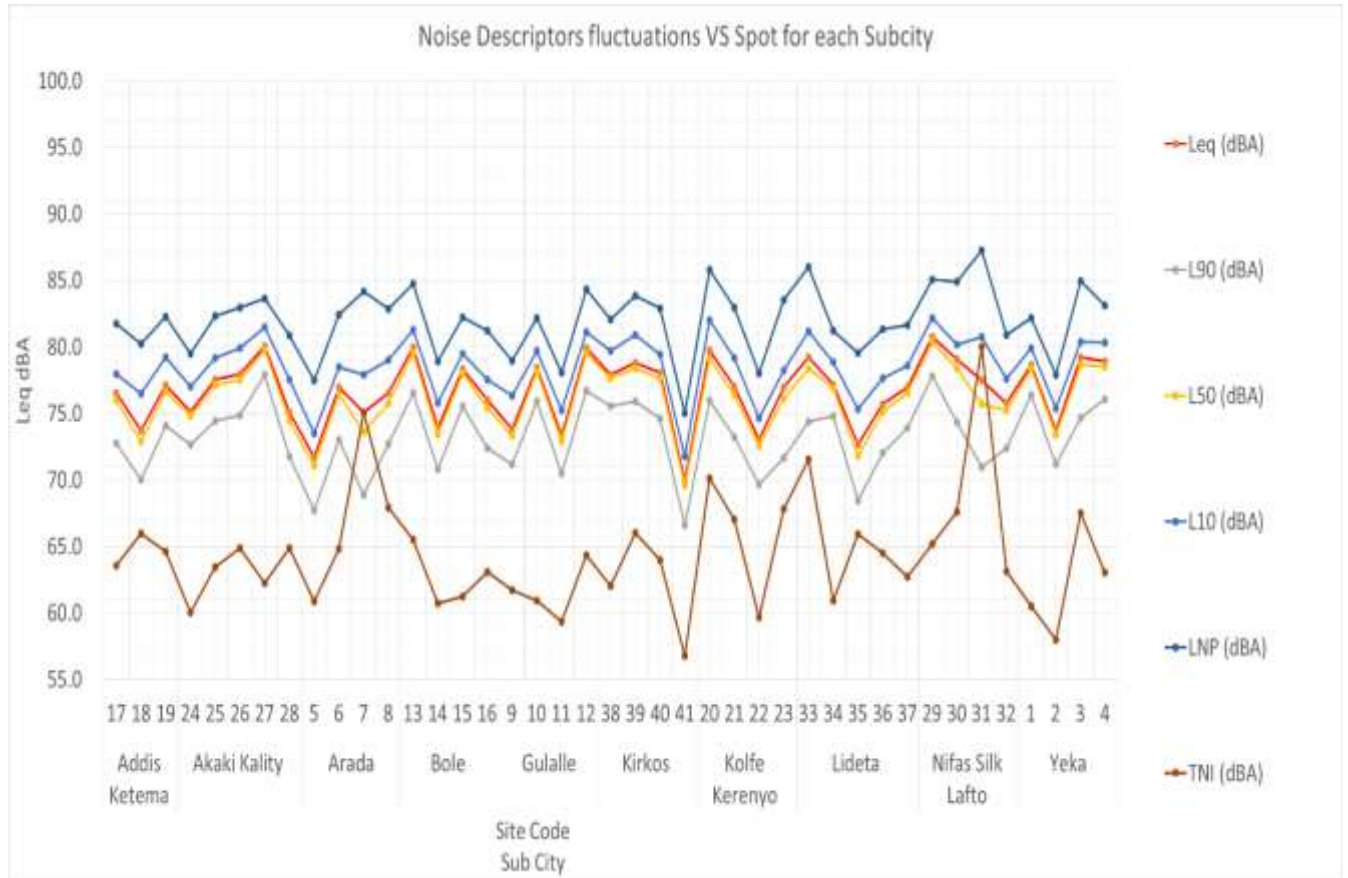


Figure 4. 1 Different noise descriptor fluctuations of studied site

#### 4.1.2 Temporal Analysis of Equivalent Continuous Noise Level

Descriptive analysis of morning, afternoon and evening time Leq dBA values of study spots were calculated. And table 4.2 shows, result of the mean of 76.69 dBA and the standard deviation is **2.568 dB (A)**. This means that most of the time road traffic noise levels in urban centers of studied locations in Addis Ababa ranges averagely between 74.12 and 79.25 dBA.

Table 4. 2 Descriptive statistics result of temporal Leq, dBA

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Leq dBA	123	69	81	76.69	2.568

Figure 4.2, shows the variation of all the  $LA_{eq}$  values during morning, afternoon and evening measurements obtained in the 41 surveyed sites. The distribution shows that decrease in  $LA_{eq}$  with increase in route category number or index.

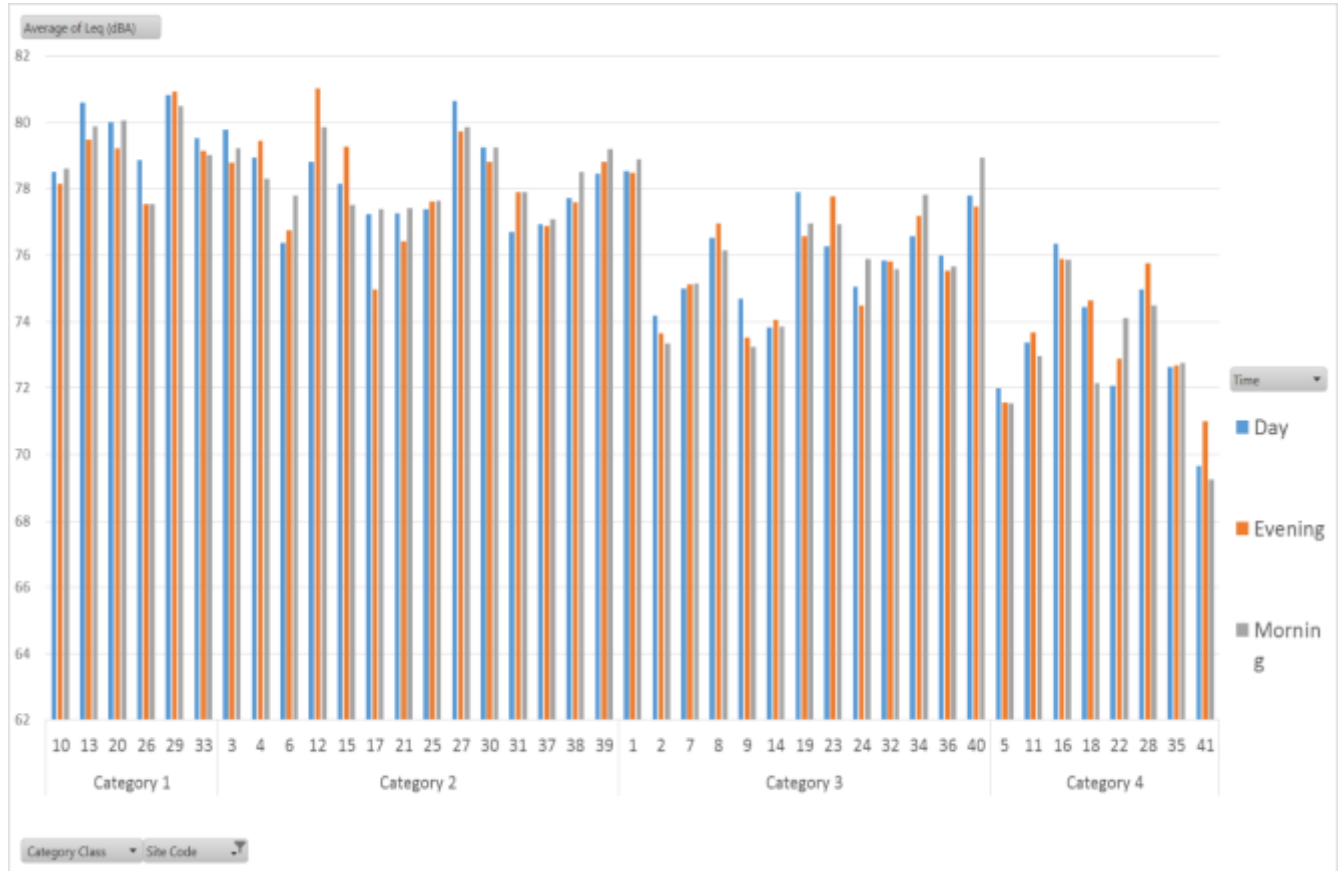


Figure 4. 2 Temporal  $Leq$  (dBA) for each site per category

As shown in figure 4.3 , city of Addis Ababa city were experienced high noise levels averagely ( $Leq > 76.7$  dBA), interestingly, the noise levels of during afternoon (11:00 AM- 2:00 PM) appeared to be relatively higher than noise level during morning and evening period. After, it is checked by F-test statistics and result parameters are shown in table 4.3. Using one-way analysis of variance, a null hypothesis of the first test is

$H_0: \mu_{Morning Leq} = \mu_{Day Leq} = \mu_{Evening Leq}$  and with alternative hypothesis of  $H_1$ : At least two of the means  $\mu_{Morning Leq}, \mu_{Day Leq}, \mu_{Evening Leq}$  are not equal.

As one can see from result of one way ANOVA shown in table 4.3; the calculated F-ratio test value is 0.005. The tabulated values of  $F_{(0.05, 5, 41)}$  at 95% confidence level is 3.07. Since as calculated sample F value of 0.005 is much less than  $F_{critical(2, 120, 0.05)}$  of 3.07; we fail to reject null hypothesis at 5% level of significance, and conclude that all the means are equal. So, there is no significant difference between overall morning, afternoon, and evening time equivalent continuous noise level in the city.

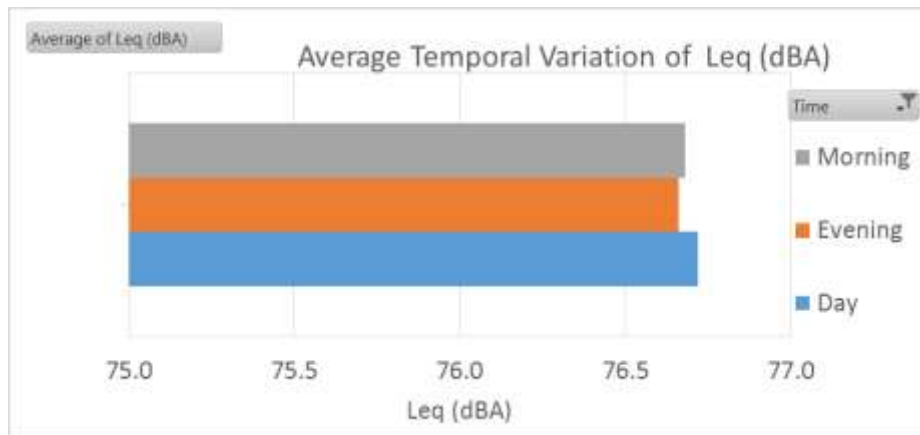


Figure 4. 3 The overall temporal variation of measured Equivalent Noise Level

Table 4. 3 ANOVA test result for Leq temporal variation

Temporal Leq					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.065	2	.033	.005	.995
Within Groups	803.294	120	6.694		
Total	803.359	122			

#### 4.2 Noise indices assessment and analysis under land use categories

According to Noise Standards by *Guideline Ambient Environment Standards for Ethiopia*, the outdoor and acceptable limit values during day time for industrial areas, commercial, residential and sensitive zones were 75 dB (A), 65 dB (A), 55 dB (A) and 55 dB (A), respectively. The World Health Organization (WHO) has also suggested a standard guideline value for average outdoor values for

such zones and the values are shown on figure 4.4. WHO recommends noise value of 65 dB (A), 55 dB (A), 55 dB (A) and 45 dB (A) for industrial areas, commercial, residential and sensitive zones, respectively. However, compared to the standards as shown on figure 4.4; the observed values at all surveyed location of covering different land use of Addis Ababa city viz. industrial, commercial, residential and sensitive zones in the day time are higher than the permissible limits.

In Industrial Area the measured Equivalent continuous noise Level (Leq dBA) were ranges from 77.2 to 80.7 dBA. Based on the Ethiopian *Ambient Environment Standards* in this zone observed values exceeds by values of range 2.2 to 5.7 dBA. In commercial zones the measured Leq dBA were ranges from to 75.1 dBA to 80.1 dBA and exceeds the limit standards by values of range from 10.1 to 15.1 dBA. In residential and sensitive zones the measured value of **Leq** dBA ranges from to 70.0 dBA - 79.1 dBA and 71.7 – 80.0 dBA respectively. Based on the national ambient standard limit, observed noise data within the city exceeds by values of 15 to 25 dBA both in residential and sensitive zones. This indicates that the traffic noise level is quiet high in all zones there by causing annoyance among the residents.

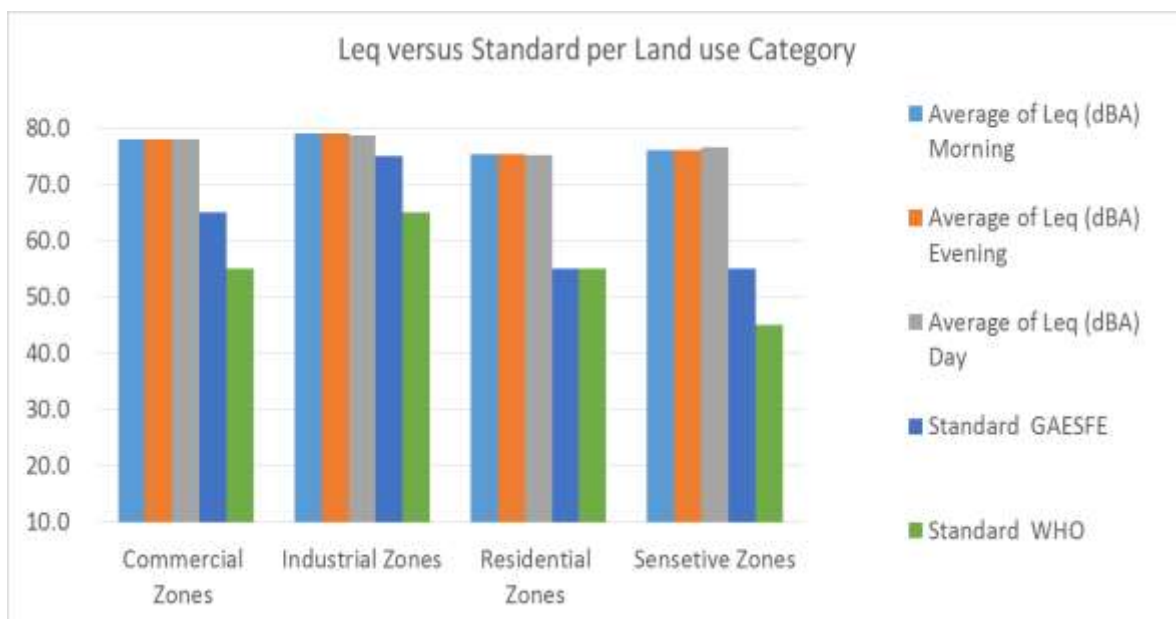


Figure 4. 4 Overall Variation of Equivalent noise pollution with land use

According to Noise Standards by *WHO* the outdoor and acceptable limit values during day time for industrial areas, commercial, residential and sensitive zones were 65 dB (A), 55 dB (A), 55 dB (A) and 45 dB (A) respectively. Also this investigation reveals that Leq dB(A) at all 41 measurement

sites in Addis Ababa city exceeds recommended level by WHO (in table 4.4) by values of 12.2 to 35 dB(A). Sufficient evidence from large-scale epidemiological studies indicates that noise adversely affects human health and well-being. Referring to the international guide lines WHO and previous epidemiological studies, the present status of noise pollution in Addis Ababa poses severe health risk to the residents. Furthermore, discomfort and irritation being caused by the traffic noise pollution can severely reduce productivity, both in public service and private sectors in the city. With the present status of traffic noise within the city; depression and fatigue, Insomnia, physical and mental fatigue, daytime sleepiness, increases in the occurrence of hypertension and cardiovascular disease, and impairment of cognitive performance in schoolchildren are some of the effects which Addis Ababa city residents may exposed for.

Table 4. 4 Difference between observed values and Environmental noise standards as prescribed by guideline or standards.

Standard	Ethiopia	WHO
Land Use Category	Range of Difference	Range of Difference
Commercial Zones	10.1 - 15.1	20.1 - 25.1
Industrial Zones	2.2 - 5.7	12.2 - 15.7
Residential Zones	15 - 24.1	15 - 24.1
Sensitive Zones	16.7 - 25	26.7 - 35

In addition, this study have conducted to compare the noise level in different study land use category. For this case, two noise descriptors i.e. Equivalent noise level (Leq dBA) and noise pollution levels (LNP dBA) were used for comparison at different land use (commercial, industrial, residential areas and sensitive zones) in the city of Addis Ababa. To achieve this objective, one-way analysis of variance Fisher's test, were used.

The results for complete data set of Noise Pollution Level (Lnp dBA) and Equivalent noise pollution Leq (**dB**A) in all the locations surveyed are presented in table 4.5 and table 4.6, respectively. A glance look at Table 4.5, shows that the average noise pollution level at each locations surveyed fluctuates from 75.0–87.3 dB (A). By using one-way ANOVA, a null hypothesis of the first test is

**H<sub>0</sub>:**  $\mu Lnp @Industrial = \mu Lnp @commercial = \mu Lnp@residential = \mu Lnp@ sensitive$ , which mean that, the means of populations from which the samples are drawn are equal. And, alternative hypothesis;

**H<sub>1</sub>:** At least three of the means  $\mu Lnp @Industrial$   $\mu Lnp @commercial$ ,  $\mu Lnp@residential$ ,  $\mu Lnp@ sensitive$  are not equa

Table 4. 5 Noise pollution levels, LNP in dB (A) for all site locations at different Land use

Commercial Zones		Industrial Zones		Residential Zones		Sensetive Zones	
Site Code	LNP (dBA)	Site Code	LNP (dBA)	Site Code	LNP (dBA)	Site Code	LNP (dBA)
1	82.2	29	85.1	2	77.9	4	83.1
3	85.0	34	81.2	6	82.4	5	77.5
8	82.8			7	84.1	9	79.0
12	84.3			10	82.2	13	84.7
15	82.2			11	78.1	14	78.9
19	82.3			16	81.2	17	81.7
20	85.8			21	83.0	18	80.2
24	79.5			22	78.0	26	83.0
27	83.6			23	83.5	31	87.3
32	80.9			25	82.3	37	81.7
33	86.0			28	80.9	38	82.1
36	81.3			30	84.9		
39	83.8			35	79.5		
40	82.9			41	75.0		

In this test, there are two independent estimates of the population variance are (a)  $MS_W$ , the variance within groups (mean square within group) estimate which deals with how different each of the values in a given sample is from other values in the same group (b)  $MS_B$ , the variance between groups (mean square between group) estimates which deals with how different the means of various samples (or groups) are from each other. Based on the computed mean squares between and within groups,

Fisher's ratio (F calculated) were computed. As the test result shown in table 4.8, the computed Fisher's ratio (F-values) is 4.69. While the tabulated values ( $F_{0.05, 3, 119}$ ) at 95% confidence level is 2.68. Since, the calculated F-value is greater than the tabulated, we reject null hypothesis and conclude that there is a significant difference in population means among the four groups. Hence, depending on analyzed data, there is a significant difference ( $p < 0.05$ ) in noise pollution levels LNP, in all the locations at corresponding land use surveyed.

Based on the values of the result listed in table 4.6, equivalent continuous noise level of the study area ranges between 70.0 dBA to 80.7 dBA. The lowest and highest Equivalent continuous noise pollution levels were recorded at site with code of 41 (low density residential areas) and site with code of 29 (industrial areas), respectively. In order to check the significant difference between equivalent continuous noise levels between different land use categories, one-way ANOVA, were used. A null hypothesis of the this test is;

**$H_0$ :**  $\mu Leq @Industrial = \mu Leq @commercial = \mu Leq@residential = \mu Leq@ sensitive$ , which mean that, the means of populations from which the samples are drawn are equal. And, alternative hypothesis;

**$H_1$ :** At least three of the means  $\mu Leq @Industrial$ ,  $\mu Leq @commercial$ ,  $\mu Leq@residential$ ,  $\mu Leq@ sensitive$  are not equal.

The computed Fisher's ratio (F-values) were 11.97 for Leq, as shown in table 4.8. While the tabulated values ( $F_{0.05, 3, 119}$ ) at 95% confidence level is 2.68. Since, the calculated F-value is greater than the tabulated or p-value ( $0.000 < 0.05$ ), we reject null hypothesis. Hence, there is a significant difference ( $p < 0.05$ ) in equivalent continuous noise levels Leq (dBA) in all the locations surveyed at land use zones based on the data surveyed and analyzed.

Table 4. 6 Equivalent continuous noise levels, Leq in dB (A) for all site locations at different land use

Commercial Zones		Industrial Zones		Residential Zones		Sensetive Zones	
Site Code	Leq (dBA)	Site Code	Leq (dBA)	Site Code	Leq (dBA)	Site Code	Leq (dBA)
1	78.6	29	80.7	2	73.7	4	78.9
3	79.3	34	77.2	6	77.0	5	71.7
8	76.5			7	75.1	9	73.8
12	79.9			10	78.4	13	80.0
15	78.3			11	73.3	14	73.9
19	77.1			16	76.0	17	76.5
20	79.8			21	77.0	18	73.7
24	75.1			22	73.0	26	78.0
27	80.1			23	77.0	31	77.5
32	75.7			25	77.5	37	77.0
33	79.2			28	75.1	38	77.9
36	75.7			30	79.1		
39	78.8			35	72.7		
40	78.1			41	70.0		

And the calculated descriptive statistics parameter of equivalent continuous noise levels (Leq) and noise pollution levels (LNP) of each surveyed locations is listed in table 4.7. The test result, shows the mean number and standard deviation of equivalent continuous noise levels (Leq) and noise pollution levels (LNP) of all the surveyed locations at each corresponding land use area. Averagely, noise pollution levels of 83.05, 83.15, 80.94 and 81.74 dBA were recorded at commercial, industrial, residential and sensitive zones, with standard deviation of 2.045, 2.17, 3.081, and 3.052, respectively. And the mean and standard deviation of Leq dBA at commercial, industrial, residential and sensitive zones were; 78.02 (1.703), 78.97 (1.991), 75.35 (2.54) and 76.27 (2.589), respectively.

**Table 4. 7 Means and Standard Deviations of Equivalent noise Pollution Levels**

	LNP			Leq		
	N	Mean	Std. Deviation	N	Mean	Std. Deviation
Commercial Zones	42	83.05	2.045	42	78.02	1.703
Industrial Zones	6	83.15	2.17	6	78.97	1.991
Residential Zones	42	80.94	3.081	42	75.35	2.54
Sensitive Zones	33	81.74	3.052	33	76.27	2.589

Table 4. 8 ANOVA Source table

		Sum of Squares	df	Mean Square	F	Sig.
→	LNP Between Groups	104.272	3	34.757	4.688	.004
	Within Groups	882.357	119	7.415		
	Total	986.629	122			
	Leq Between Groups	186.491	3	62.164	11.974	.000
	Within Groups	617.812	119	5.192		
	Total	804.303	122			

In order to ascertain the pair wise difference which is responsible for significant difference (if any) in obtained F-values of Fisher's distribution test (ANOVA test), second test, known as Scheffe's Post Hoc Test is carried out on the data set which is an appropriate measure for all comparisons of mean after Fisher's test (ANOVA test). The calculated value of critical Scheffe's Post Hoc is listed in table 4.9. From the test result any pair responsible for the significant difference have identified.

Table 4. 9 Table of pairwise difference Scheffe’s Post Hoc critical Value

Scheffe					
Dependent Variable	(I) Land Use Code	(J) Land Use Code	Mean Difference (I-J)	Std. Error	Sig.
Average of LNPdBA	Commercial	Industrial	-.097	1.188	1.000
		Residential	2.117*	.594	.007
		Sensitive	1.317	.633	.235
	Industrial	Residential	2.213	1.188	.330
		Sensitive	1.413	1.209	.714
	Residential	Sensitive	-.800	.633	.661
Average of Leq dBA	Commercial	Industrial	-.948	.994	.823
		Residential	2.667*	.497	.000
		Sensitive	1.754*	.530	.015
	Industrial	Residential	3.616*	.994	.006
		Sensitive	2.702	1.011	.073
	Residential	Sensitive	-.913	.530	.400

From Table 4.9, the pair wise differences between commercial and residential with mean of 2.117 is responsible for significant difference between noise pollution levels; hence, these pairs are responsible for the significant difference in F-value at  $P < 0.05$ . This result of analysis reveals that there is significant difference ( $p < 0.05$ ) in noise pollution levels between commercial and residential zones. But there is no significant difference ( $p > 0.05$ ) in noise pollution levels between commercial and sensitive; industrial and sensitive; Industrial and residential; commercial and industrial; and residential and sensitive.

Also based on the parameters of Scheffe’s Post Hoc test results shown in table 4.9, the pair wise mean differences ( of dependent variable Leq ) between commercial and residential (2.667); commercial and sensitive (1.754); industrial and residential (3.616); are responsible for the significant difference in F-value at  $P < 0.05$ . But there is no significant difference in equivalent noise level ( $p < 0.05$ ) between commercial and industrial; industrial and sensitive; sensitive and residential zones.

Generally, in urban areas of Addis Ababa city, traffic noise exposure levels vary from one location to another due to wide variety of traffic and urban conditions of the site. Noise pollution exposure in industrial and commercial zones are relatively high when compare with that of at sensitive and

residential zones. Due to major traffic routes that pass through different land use areas, traffic noise contributes as a major source of environmental noise pollution mainly in outskirts locations and also in downtown. In the center of the city, there are concentrations of shops, markets, and clustered buildings with high traffic volume and population along the vicinity of main traffic routes. All these are also responsible for high noise exposure levels; therefore, the residents living or trading in these areas are exposed to excessive noise pollution noise levels of 75.0–87.3 dB (A) or more every day. This is very dangerous to the health of the people in these areas and these group of people are prone to various noise induce problems. According to the World Health Organization, generally 60 dB (A) sounds can result in temporary hearing impairment and 100 dB (A) sounds can cause permanent impairment. The noise levels of Addis Ababa city are similar to those reported for other cities around the world by other authors in Nigeria (Oyedepo and Saadu, 2009); in Taiwan (Tsai et al., 2009); in India (Singh, ReenaRajiv B. Hunashala and Shekar, 2012).

### **4.3 Model Development**

To check the hypothesis that traffic is one of the most important source of noise in the city and the main reason for its variability, the relationship between  $L_{eq}$  and the logarithm of traffic flow were studied using linear regression analysis. A regression analysis was performed to investigate the relationship between  $L_{eq}$  (dBA) and logarithm of total traffic volume ( $\log Q$ ) using the total average traffic volume recorded at each study spot. The regression analysis disclosed that the coefficient of determination ( $R^2$ ) value of 0.851 which confirms the role of traffic noise as the major source for the variation in noise levels in the study area. Figure 4.5 shows the relationship between Equivalent Continuous noise Level ( $L_{eq}$  dBA) and the logarithm of the total counted traffic flow ( $Q$ ), including all motor vehicles (Heavy trucks, buses, Automobiles, Medium trucks, motor cycle, etc.). The result of fit given by table 4.10 and Equation (4.1) showed that there was a highly significant or 92.3 % correlation (i.e.,  $r = 0.923$ ) between  $L_{eq}$  (dBA) and logarithmic of total traffic Volume. The coefficient of determination obtained ( $r^2 = 0.851$ ) confirms the role of traffic noise as one of the major source for the noise pollution levels in the study area. This result is coherent with the results reported by other researchers; towns in Spain (Morillas et al., 2005), cities of Regina, Saskatchewan (Huang, 2014).

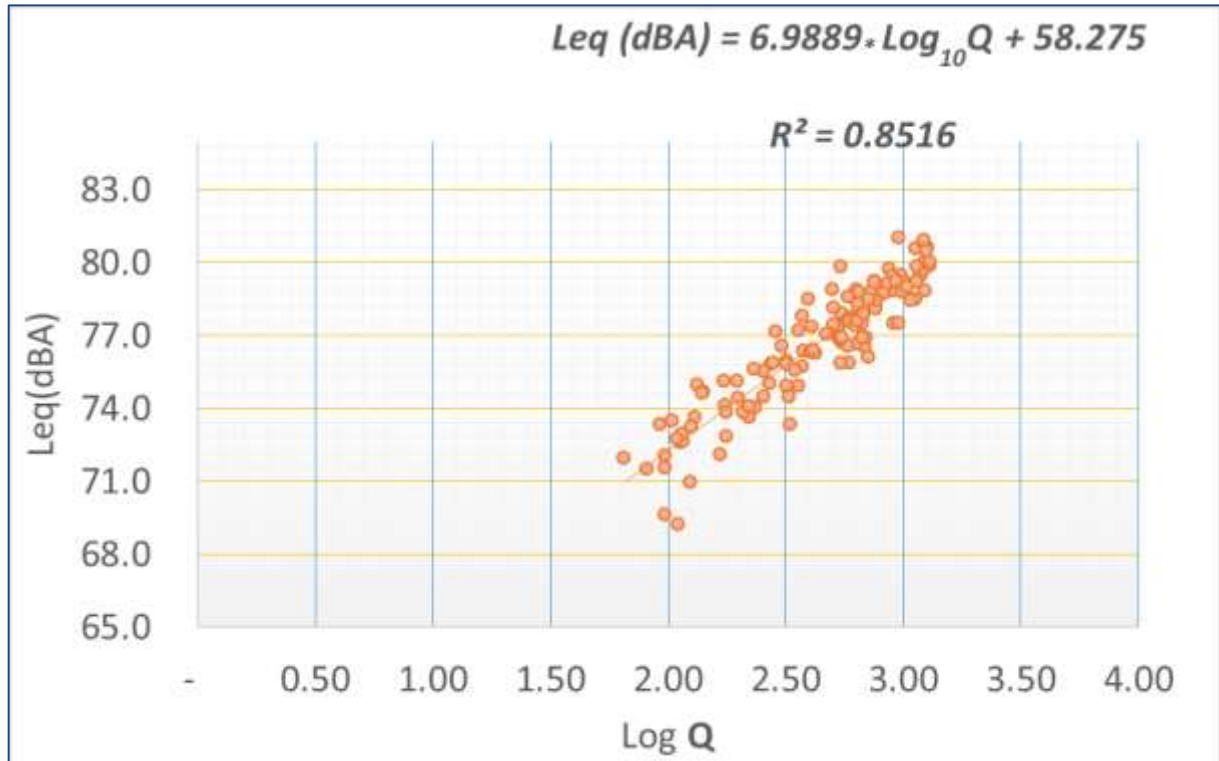


Figure 4. 5 Leq (dBA) as a function of the logarithm of the total traffic flow (Q)

$$Leq = 6.99 * \log_{10}Q + 58.275 \quad \text{Equation 4. 1}$$

Leq (dBA) implies equivalent continuous noise level in dBA and  $\log_{10}Q$ , represents logarithmic base 10 of average recorded traffic volume. This equation works only for traffic volume (Q) of different from 0 vehicle.

Table 4. 10 Regression parameters between  $LA_{eq}$  (dBA) and the logarithm of the total traffic flow (log Q) for study area in Addis Ababa City.

Study Area	Slope	Constant or Origin	Correlation coefficient ( r )	Coefficient of determination
	(Log Q)			(R <sup>2</sup> )
Addis Ababa	6.989	58.274	0.923	0.851

From this developed model and because decibels are on a logarithmic scale, doubling traffic flow is equivalent to increasing equivalent continuous noise level by more than 2.3 dBA, regardless of other factors viz. vehicle composition, speed, driving conditions and etc. Based on above model result the highway traffic noise is closely related to the traffic flow along the road in the city area.

In addition, correlation between the equivalent noise level and traffic composition was also examined in this work. For this purpose, a multi regression model was developed using the equivalent noise level as the dependent variable and the vehicle types (bus/heavy truck in one variable) and all other traffic vehicle types as second variable) as an independent variable. The model classified the traffic vehicles to two categories i.e. Buses/trucks in one class of independent variable and all other vehicles types (i.e. automobiles, taxis, medium trucks, motorcycles/others) in the second independent variable. As can be seen from of statistical analysis done and summarized in table 4.11, there was a strong linear correlation between Leq (dBA) and the volume of heavy transport vehicles (HTV) i.e. buses/trucks and total vehicle count of other traffic vehicle (automobiles, medium trucks, motorcycles/others). The result of parameters of fit shown in table 4.11 and given by Eq. (4.2) showed that there was a coefficient of determination ( $R^2$ ) 0.7502 between Leq (dBA) and vehicle composition.

Table 4. 11 Regression parameters between  $LA_{eq}$  (dBA) and the volume of heavy transport vehicle ( $Q_{HTV}$ ) and total number of other traffic vehicle ( $Q_{OTV}$ ) for study area in Addis Ababa City.

<b>Correlations</b>					
Dependent Variable is Leq (dBA) and Independent Variable are $Q_{OTV}$ and $Q_{HT}$					
Pearson Correlation			Slope	Constant	Coefficient of Determination $R^2$
		Leq			
Model Summary	$Q_{OTV}$	0.86683	0.00634	73.17	0.75020
	$Q_{HT}$	0.63937	0.00628		

$$Leq = 0.00634 * Q_{OTV} + 0.00628 * Q_{HT} + 73.17 \text{ dBA} \dots \dots \dots \text{Equation 4.2}$$

$Q_{HT}$ , implies total number of bus or heavy Trucks and  $Q_{OTV}$ , implies total number of 45 minute traffic volume of other traffic Vehicle (.e. automobiles, taxis, medium trucks, motorcycles). Correlation matrix indicates that the highest correlation were found for other traffic volume ((automobiles, medium trucks, motorcycles/others) with  $r = 0.87$ . It was followed by Heavy transport Vehicles (Bus and heavy trucks) with  $r$  value of 0.64.

Depending on the values of the regression coefficient and the sufficient number of samples taken in each sub cities at different land use, we can conclude that there was a highly significant correlation between sound level and the volume of traffic flow. Thus, these results are clearly revealed that total traffic volume and number of heavy transport vehicles are the most significant factors of cities traffic noise pollution. In addition, during the data collection on site it have been easily observed that some vehicles, especially domestic and old ones motor vehicles produce high noise level. Also field observations showed that road surface condition, mainly distress or poorly placed speed hump have also an impact on reading of noise level. This result is coherent with the results reported by other workers for diverse parts of the world; cities of Hong Kong (To et al., 2002); Brazilian roads ((Zannin, 2003; towns in Spain (Morillas et al., 2005); in Regina, Saskatchewan (Huang, 2014), in cities of Malaysia (Halim and Abdullah, 2014).

#### **4.4 Traffic noise analysis under route categorization**

Statistics results using Box and whisker diagram of the  $Leq$  for each category were presented in figure 4.6. In this section  $Leq$  parameter have been compared in the four study route categories using appropriate statistical tests. A variable chosen for this analysis was the energy averaged sound level or so called Equivalent continuous noise level ( $Leq$ ) since it is the usual variable employed in acoustical studies. By observation, category 1 and category 2 seem to present with higher results, whereas categories 3 and 4 seem to be shifted to somewhat lower noise levels. To check these qualitative observations quantitatively, a statistical analysis was carried out. The theoretical bases for the statistical tests used can be found in the standard literature (Brase and Brase, 2012).

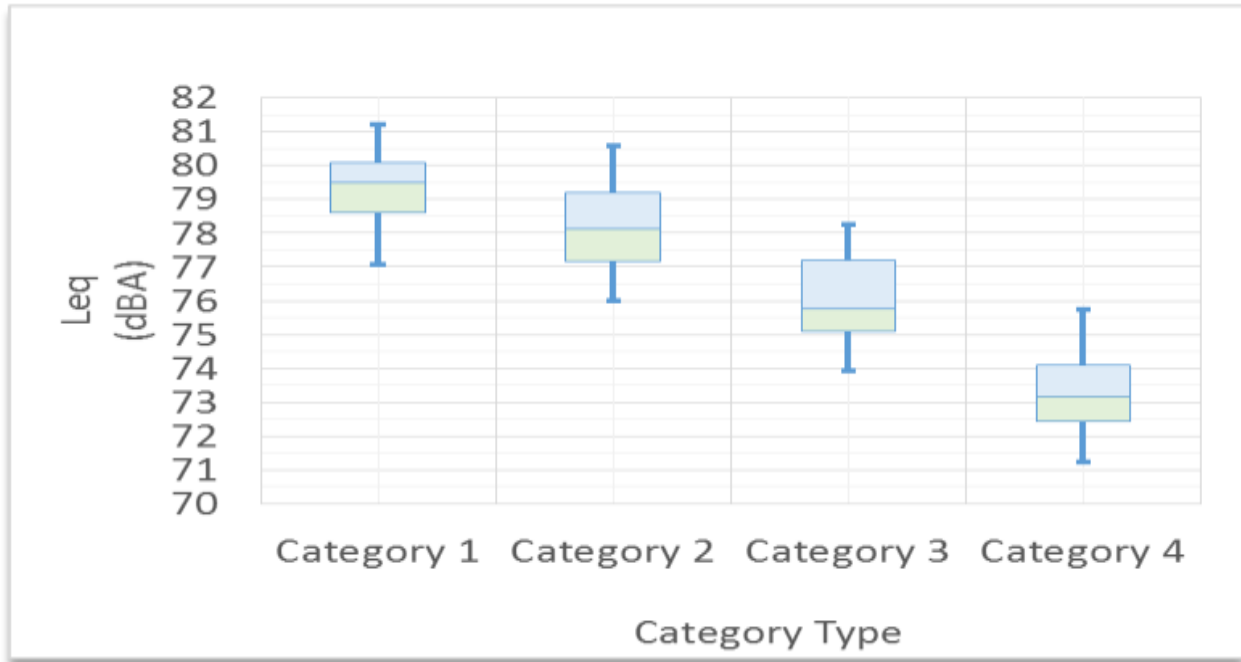


Figure 4. 6 Box and whisker diagram of Leq dBA by route categories for Addis Ababa city

Based on the values of the medians listed in Table 4.12, one also can observe that there are clear differences in the noise structure of the city. The equivalent sound level decreases only gradually with increasing category index i.e. equivalent noise level Leq (dBA) of Category4 < Leq (dBA) of Category3 < Leq (dBA) of Category2 < Leq (dBA) of Category1.

Table 4. 12 Values of the Leq median (dBA) for each category in Addis Ababa City

	Category 1	Category 2	Category 3	Category 4
Median (dBA)	79.49	78.13	75.74	73.18

ANOVA test result of Equivalent noise levels (Leq dBA) of all the surveyed locations were shown in table 4.13. The F-values for the relationship between category and sound level have calculated ( $F = 77.29$ ) and as one can be observed, the coefficient is highly significant. The tabulated or critical value of F-values ( $F_{0.001, 3, 37}$ ) is 6.70. Since the calculated F-value is greater than the tabulated, hence, there is a significant difference ( $P < 0.001$ ) in Equivalent noise pollution levels between all categories based on the analyzed data. Therefore, the study results of the test confirm that there is a decrease in noise level with increasing category index.

Table 4. 13 ANOVA source table

Dependent Variable: LeqdBa					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	533.761	3	177.920	77.296	.000
Within Groups	273.913	119	2.302		
Total	807.675	122			

Nonparametric Kruskal-Wallis analysis of variance test were applied and used to test for significant differences among the medians of each category. The calculated values obtained from this test which is chi-square test statistics with 3 degrees of freedom were 80.84, for the study area. As one can be observed the calculated F-values is much higher than the critical chi-square  $\chi_{0.001; 3}$  values of this test which is near 12.84.

Table 4. 14 Table of pair wise difference results of the Tukey-type test applied to the different categories of the study Area.

Test: Tukey HSD					
Dependent Variable: LeqdBa					
(I) Category Class	(J) Category Class	Mean Difference (I-J)	Std. Error	Sig.	Tukey q-statistics
1	2	1.230*	.427	.024	3.806
	3	3.393*	.432	.000	11.038
	4	6.194*	.473	.000	18.414
2	1	-1.230*	.427	.024	3.806
	3	2.163*	.337	.000	9.323
	4	4.964*	.388	.000	18.248
3	1	-3.393*	.432	.000	11.038
	2	-2.163*	.337	.000	9.323
	4	2.801*	.394	.000	10.007
4	1	-6.194*	.473	.000	18.414
	2	-4.964*	.388	.000	18.248
	3	-2.801*	.394	.000	10.007
*. The mean difference is significant at the 0.05 level.					

Thus, the Kruskal-Wallis test showed significant differences between the four groups of medians in the city with a probability higher than 99.0% ( $p < 0.001$ ). The Tukey-type test was then used to analyze the significance of differences between mean ranks of proposed categories in the city and the results are listed in Table 4.14. These differences were further studied by means of the Tukey-type test critical value to ascertain which pair wise responsible for significant difference. The critical values of this test is near 3.63 corresponding to alpha of 0.05. Next, we compare this value of q statistics value of Tukey. Any pair with difference more than critical q-value is responsible for the significant difference. Among pairs of adjacent categories (Category 1 and Category 2; Category 2 and Category 3; Category 3 and Category 4) gave results above the critical, indicating that significant differences can be expected to exist between them at  $p < 0.05$ . Both adjacent and nonadjacent pairs of categories was the result of the test above the critical q value of 3.63. This is an important result as it confirms the stratification of the noise in this city, so that the categorization of streets according to their use in functional classification. Generally, the statistical analysis of the study result using noise level data proved that the classification of urban street noise as a meaning of the road hierarchy (road functional classification) is an appropriate part of the design of studies of urban noise caused by traffic.

## **Chapter Five**

### **Conclusions and Recommendation**

#### **5.1 Conclusions**

In this study, comprehensive assessment of day time environmental noise levels due to road traffic vehicles in Addis Ababa city has been carried out and the following conclusions are drawn.

Noise levels obtained at different land use locations in the city viz. industrial, commercial, residential and sensitive zones were found exceeding the noise level limits prescribed both by the Ethiopian Ambient Environment Standards and WHO.

In Industrial zones the measured equivalent continuous noise Level (Leq dBA) were ranges from 77.2 to 80.7 dBA. Based on the Ethiopian *Ambient Environment Standards* in this zone observed values exceeds by values of range 2.2 to 5.8 dBA. In commercial zones the observed Leq dBA were ranges from to 75.1 dBA to 80.1 dBA and higher than the limit standards by values of range from 10 to 15 dBA. In residential and sensitive zones the measured value of **Leq** dBA ranges from 70.0 - 79.1 dBA and 71.7 -80.0 dBA, respectively. Based on the national standard limit values at both residential and sensitive land use areas of the city, the traffic induced noise level exceeds by values of 15 dBA to 25 dBA. Generally, the result of this study shows that noise levels at all measurement points exceeds national standard limit by range of values 2.2 to 25.0 dB (A).

And also the traffic induced noise level at different surveyed locations in the city were higher than the international standard limit which sets by WHO, with values of range between 12.2 to 35.0 dBA. Findings of this research study had shown that level of traffic generated noise pollution in Addis Ababa city at different land use area is high enough to adversely affect the welfare activities and healthy of its residents. This has serious implication on the general health and well-being of the residents of the city.

Based on ANOVA and the parameters of Scheffe's Post Hoc test results, there is significant difference in traffic induced equivalent continuous noise level between commercial and residential; commercial and sensitive; and industrial and residential are responsible for the significant difference in F-value at  $P < 0.05$ . But there is no significant difference in equivalent noise level ( $p < 0.05$ ) between commercial and industrial; industrial and sensitive; sensitive and residential zones.

Using the result of one way ANOVA test result, it have been revealed that as there is no significant difference at 5% level of significance between overall morning, afternoon, and evening time equivalent continuous noise level in the city since the calculated p-value of 0.995 is much higher than the 0.05. The city entertaining noise from traffic equally during both peak hour and peak off traffic.

Moreover, model between the traffic flow and traffic noise level are established. The result of this fit showed that there was a highly significant or 92.3 % correlation (i.e.,  $r = 0.923$ ) between Leq (dBA) and logarithmic of total traffic volume. The coefficient of determination obtained ( $r^2 = 0.851$ ) confirms the role of traffic noise as one of the major contributors to noise pollution in all the urban areas of the city. In addition, there was a strong linear correlation between Leq (dBA) and the volume of heavy transport vehicles (HTV) i.e. buses/trucks and total vehicle count of other traffic vehicle (automobiles, medium trucks, motorcycles/others) with coefficient of determination ( $R^2$ ) 0.7502. Thus, these model results are clearly revealed that total traffic volume and number of heavy transport vehicles are the most significant factors of cities traffic noise pollution with correlation value of  $r$  equal to 0.87 and 0.64, respectively. By this study it is revealed that highway related noise level in the city is closely related with the number road traffic volume and heavy transport vehicles.

Thus, it is concluded that the city noise levels along high road class are more related to high traffic density, high number of heavy transport vehicle, and illegal behavior of drivers for horn used, the poor mechanical states of vehicles, road surface condition and vehicle over exhaust during speeding. Hence, based on the findings of this study, urgent remedial measures should be taken to control the level of traffic noise or other environmental noise pollution in the city.

Also, the Kruskal-Wallis test showed that there is a significant differences between the four groups of medians in the city with a probability higher than 99.0% ( $p < 0.001$ ). This is an important result as it confirms that the stratification of the noise in this city, so that the categorization of streets according to their use in functional classification. Generally, the statistical analysis of this study result using noise level data proved that the classification of urban street noise as a meaning of the road hierarchy (road functional classification) is an appropriate study methodology for urban noise studies caused by traffic.

The results of this study mainly helpful and will provide highway Engineers, city policy makers, traffic management Agencies, Environmental Protection Authorities or other related stake holders with several interventions and applications.

## **5.2 Recommendation**

Based on the outcomes of this research and critical reviewing of different related studies, the following measurements are recommended:

- ✚ Banning and discouragement of importing and operating of very old and high noise producing vehicles would be helpful in reduction of the present noise level in Addis Ababa City. The city administration should have to strictly discourage or ban of outdated and old vehicles in the city. The annual vehicle inspection program should also include, in its inspection package, the inspection of vehicles for excessive noise.
- ✚ Limitations or restrictions on traffic (heavy transport vehicles, hours of access, speeding) that running mainly through residential areas and sensitive zones.
- ✚ Prohibition of use of horns and multi tone horns mainly at sensitive zones and residential areas should be notified well with traffic sign of 'no horn zone'.
- ✚ Construction of noise barriers along the sides of heavily travelled highways running through sensitive zones and residential areas.
- ✚ Constructing low noise pavements (quitter or porous pavement) type and also keeping higher routes smoother by proper management and maintenance of highways.
- ✚ Plantation of vegetation along the road side is one that will reduce the noise intensity by creating obstruction in its transmission path and in addition it can reduce load of air pollution.
- ✚ Developing strategic noise maps: The noise map is useful by providing baseline data for city planners, highway engineers, and other professionals for the planning and execution of their projects concerning the environmental pollution protection. So, developing noise maps at sub city or woreda level for city is essential, thus leading to proper urban planning.
- ✚ Proper enforcement of legislation: The city administration with concerned authorities must try to strengthen its capacities in environmental planning, policy formulation and implementation management by strict effective implementation of existing policies and strategies on controlling the urban noise pollution.
- ✚ Appropriate designing and placing of quieter speed humps: Concerned authority should have to focus on quieter speed hump designs and placement unfortunately, due to existing and poor placement of speed humps.

- ✚ Noise compatible land use planning: Unfortunately, the development of noise sensitive land uses adjacent to existing heavy traffic routes continues to be a widespread problem in the city. Therefore, concerned bodies of the city administrations should be give attention for it by encouraging effective land use planning near known highway locations to minimize the effect of highway vehicle noise through appropriate land use control.
- ✚ Education and Awareness: Residents should be educated about the raising of noise pollution, adverse health effect of noise pollution and how to abate it. Since noise also results from the driver's driving behavior, awareness creation and education campaigns for and by concerned authorities should be made through grass root training. As a whole, the role of researchers and professionals, NGOs, media and concerned individuals is significant in minimizing the environmental hazard of traffic noise pollution and concerned government authorities have to work closely with all those bodies.

In this study, motor vehicles have been recognized as one of the major sources of environmental noise pollution in Addis Ababa city. Hence, technical actions (reduction of traffic density; banning of very old aged vehicles; reduction of speeds; renewal of old public transport; improving road surfaces; constructing of noise abatement; urban planning, etc.) and non-technical approaches (Educational, effective legislative solutions, organizational and strategic) on the road traffic, are equally relevant and can produce interesting results.

### **Future research work direction**

In light of this research study, further studies that can be performed where developing traffic noise model by considering all of other factor i.e. traffic speed, longitudinal slope of the traffic route, pavement condition, different pavement surface type, etc. can be embarked upon for future work.

Also urban environmental noise assessment study by considering different noise sources and night time noise level status is suggested for future work to enhance the result of this study. I addition, investigation of quiet and safe pavement surface type is another scientific research recommended. Further work is needed in development of noise mapping software and system for the city at sub city or woreda level. Study of traffic induced noise pollution at major intersection in Addis Ababa city and also investigation of the adverse effects of traffic noise pollution on public health is another suggested studies in future by concerned field of science.

## References

- AACPPO, 2017. Addis Ababa City Structure Plan Draft Final Summary Report. Addis Ababa; Ethiopia.
- AACRA, 2004a. Geometric Design Manual Section 3 Environment & Landscaping. Addis Ababa; Ethiopia.
- AACRA, 2004b. Guideline 3 AACRA Geometric Design Manual: section 1 Planning & Design Framework. Addis Ababa , Ethiopia.
- Alves, S., Waddington, D., 2014. Estimation of Uncertainty Using Revised Draft ISO 1996-2 Estimation of Uncertainty Using Revised Draft ISO 1996-2. <https://doi.org/10.13140/RG.2.1.2506.2480>
- Babisch, W., 2005. Guest Editorial: Noise and Health. *Environ. Heal. Perspect.* 113, 14–15.
- Banerjee, D., Chakraborty, S.K., Bhattacharyya, S., A.Gangopadhyay, 2009. Appraisal and mapping the spatial-temporal distribution of urban road traffic noise 6.
- Barrigón Morillas, J.M., Gómez Escobar, V., Méndez Sierra, J.A., Vílchez-Gómez, R., Vaquero, J.M., Trujillo Carmona, J., 2005. A categorization method applied to the study of urban road traffic noise. *J. Acoust. Soc. Am.* 117, 2844–2852. <https://doi.org/10.1121/1.1889437>
- Basner, M., Babisch, W., Davis, P.A., Brink, M., Clark, C., Janssen, S., Stansfeld, S., 2014. Auditory and non-auditory effects of noise on health. *NIH Public Access* 383, 1325–1332. [https://doi.org/10.1016/S0140-6736\(13\)61613-X](https://doi.org/10.1016/S0140-6736(13)61613-X)
- Benjaminson, R., Shankute, D., Torgerson, G., Gebre, G., Gallavan, R., 2012. The Effect of Gasoline-fueled Vehicle Emissions on Air Pollution in Addis Ababa, Ethiopia : Baseline Study performed by Vehicular-Smogless Air for Ethiopia (V—SAFE) in collaboration with the Addis Ababa Environmental Protection Authority (AAEPA). Addis Ababa , Ethiopia.
- Brase, C.P., Brase, H.C., 2012. *Understandable Statistics Concepts and Methods*, Tenth Edit. ed. Richard Stratton.
- Braubach, M., Tobollik, M., Mudu, P., Hiscock, R., 2015. Development of a Quantitative Methodology to Assess the Impacts of Urban Transport Interventions and Related Noise on Well-Being 5792–5814. <https://doi.org/10.3390/ijerph120605792>
- Bueno, M., Luong, J., Viñuela, U., Terán, F., Paje, S.E., 2011. Pavement temperature

influence on close proximity tire-road noise. *Appl. Acoust.* 72, 829–835. <https://doi.org/10.1016/j.apacoust.2011.05.005>

Cameron, I., Lyons, T.J., Kenworthy, J.R., 2004. Trends in vehicle kilometres of travel in world cities, 1960-1990: Underlying drivers and policy responses. *Transp. Policy* 11, 287–298. <https://doi.org/10.1016/j.tranpol.2004.01.002>

Chepesiuk, R., 2005. Decibel Hell: *Environmental Health Perspectives* 113, 34–41.

Chowdhury, A.K., Debsarkar, A., Chakrabarty, S., 2015. Critical assessment of day time traffic noise level at curbside open-air microenvironment of Kolkata City , India. *J. Environ. Heal. Sci. Eng.* 1–6. <https://doi.org/10.1186/s40201-015-0219-6>

Dasarathy, A.K., 2015. Noise Pollution : Causes , Mitigation and Control Measures for Attenuation. Dr. M.G.R. EDUCATIONAL AND RESEARCH INSTITUTE UNIVERSITY. <https://doi.org/10.1007/s004210050211>

Davis, L.W., Kahn, M.E., 2010. International Trade in Used Vehicles: The Environmental Consequences of NAFTA. *Am. Econ.* 2, 58–82.

Dewelle, Z.K., 2014. Evaluation of Noise Pollution in Educational Institutes of Addis Ababa. Addis Ababa, Ethiopia.

Dora, C., Hosking, J., Mudu, P., Fletcher, E.R., 2011. Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities, in: GmbH, D.G. für I.Z. (GIZ), P. O. Box 5180 65726 Eschborn, G. <http://www.giz.d.>, Division 44 Water, Energy, T., Urban (Eds.), Urban Transport and Health. On behalf of Federal Ministry for Economic Cooperation and Development (BMZ), Bonn, Germany, pp. 1–60.

Doygun, H., Gurun, D.K., 2008. Analysing and mapping spatial and temporal dynamics of urban traffic noise pollution : a case study in Kahramanmaraş , Turkey 65–72. <https://doi.org/10.1007/s10661-007-9908-7>

EHP, 2013. Noise Measurement Manual, in: Environmental Performance and Coordination Branch, Department of Environment and Heritage Protection Creative Commons Attribution 3.0 Australia. State of Queensland as, pp. 1–33. <https://doi.org/10.1021/cm00013a036>

Environmental Protection Authority (EPA), and United Nations Industrial Development Organization, (UNIOD), 2003. GUIDLINE AMBIENT ENVIRONMENT STANDARDS FOR ETHIOPIA. Ecologically Sustainable Industrial Development (ESID), Addis Ababa.

Escobar, G., Miguel, J., Morillas, B., Gozalo, G.R.E.Y., R, J.C., Endez, J.A.M., 2012.

Analysis of the Grid Sampling Method for Noise Mapping 37, 499–514. <https://doi.org/10.2478/v10168-012-0062-z>

European Commission Working Group, 1, 2007. Assessment of Exposure to Noise Position Paper Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure 1–129.

EUROPEAN UNION, 2002. Relating to the Assessment and Management of Environmental Noise. Off. J. Eur. Communities 12–25.

Farçaş, F., 2008. Road Traffic Noise ; A study of Skåne region, Sweden. Linköping University Department of Computer and Information Science. <https://doi.org/LIU-IDA/FFK-UP-A--08/015--SE>

Federal Highway Administration (FHWA), 2011. Highway Traffic Noise : Analysis and Abatement Guidance.

Filho, J.M.A., Lenzi, A., Zannin, P.H.T., 2004. Effects of traffic composition on road noise : a case study 9, 75–80. <https://doi.org/10.1016/j.trd.2003.08.001>

Forum for Environment, 2010. Forum for Environment: Ethiopian Environment Review No 1. Forum for Environment, Addis Ababa , Ethiopia.

FTA, 2018. Transit Noise and Vibration Impact Assessment Manual. U.S. Department of Transportation Federal Transit Administration and Office of Planning and Environment 1200.

Golebiewski, R., R., M., Nowak, M., Preis, A., 2003. Traffic noise reduction due to the porous road surface 64, 481–494. [https://doi.org/10.1016/S0003-682X\(02\)00124-X](https://doi.org/10.1016/S0003-682X(02)00124-X)

Goswami, S., 2017. Measurements and model calibration of traffic noise pollution of an industrial and intermediate city of india.

Gozalo, G.R., Morillas, J.M.B., 2016. Analysis of sampling methodologies for noise pollution assessment and the impact on the population. Int. J. Environ. Res. Public Health 13. <https://doi.org/10.3390/ijerph13050490>

Halim, H., Abdullah, R., 2014. Equivalent noise level response to number of vehicles : a comparison between a high traffic flow and low traffic flow highway in Klang Valley , Malaysia 2, 1–4. <https://doi.org/10.3389/fenvs.2014.00013>

Henrique, P., Zannin, T., Calixto, A., Diniz, F.B., Giovanini, C.R., 2002. Influence Of The Traffic Composition And Traffic Flow On Noise Emitted By Typical Brazilian

Roads. Can. Acoust. 30.

Holmes, H., 1995. Building Healthy Communities for Children: The Transportation Link 103, 71–72.

Huang, K., 2014. Analysis of impact factors for Traffic Noise in Urban Areas. University of Regina.

IBRD world Bank, EDRIECRC, MoFECC, 2017. Federal Democratic Republic of Ethiopia Country Environmental Analysis (CEA); Ethiopia Realizing Green Transformation; Ministry of Environment, Forest and Climate Change.

Jagniatinskis, A., Fiks, B., Zaporozhets, O., 2016. Annual Assessment of Transport Noise Using Representative Time Measurements 134, 301–308. <https://doi.org/10.1016/j.proeng.2016.01.011>

JCGM, 2008. Evaluation of measurement data — Guide to the expression of uncertainty in measurement.

Joshi, A.N., Joshi, N.C., Rane, P.P., 2015. Noise Mapping in Mumbai City , India Noise Mapping in Mumbai City , India . Int. J. Innov. Sci. Eng. Technol. 2.

Ko, J.H., Chang, S. Il, Lee, B.C., 2011. Noise impact assessment by utilizing noise map and GIS : A case study in the city of Chungju , Republic of Korea. Appl. Acoust. 72, 544–550. <https://doi.org/10.1016/j.apacoust.2010.09.002>

Lawrence K. Wang, Pereira, N.C., Hung, Y.-T., 2005. Advanced Air and Noise Pollution Control. Humana Press, Totowa, New Jersey 07512.

Lee, Cynthia S Y, Fleming, G.G., 1996. Measurement of Highway-Related Noise Federal Highway Administration.

Lee, Cynthia S.Y., Fleming, G.G., 1996. Measurement of Highway-Related Noise. U.S. Department of Transportation, Washington, D.C.

Marathe, P.D., 2012. Traffic noise pollution. Ijed 9, 63–68.

MoEFCC, 2017. Cities noise pollution condition report Survey in 2017 (የ2009 ዓ.ም በከተሞች የድምፅ ብክለት ሁኔታ ክትትል ሪፖርት ሰኔ 2009 ዓ . ም አዳማ). Adama.

Morillas, J.M.B., Escobar, V.G., Sierra, J.A.M.R.V.-G., Vaquero, J.M., Carmona, J.T., 2005. A categorization method applied to the study of urban road traffic noise A categorization method applied to the study of urban road 2844, 2844–2852.

<https://doi.org/10.1121/1.1889437>

Moudon, A.V., 2009. Real Noise from the Urban Environment How Ambient Community Noise Affects Health. *Am. J. Prev. Med.* 37, 167–171. <https://doi.org/10.1016/j.amepre.2009.03.019>

Murat, O., Ebru, S.E., 2017. Determination of traffic noise pollution of the city of tekirdag. *Res. Gate* 17, No 4, 1276–1284.

Nejadkoorki, F., Yousefi, E., Naseri, F., 2010. Analysing Street Traffic Noise Pollution in the City of Yazd. *Iran. J. Environ. Heal. Sci. Eng.* 7, 53–62. [https://doi.org/10.1061/\(ASCE\)EE.1943-7870.0000523](https://doi.org/10.1061/(ASCE)EE.1943-7870.0000523)

Olayinka, O.S., 2013. Effective Noise Control Measures and Sustainable Development in Nigeria. *Environ. Eng.* 1, 5–15. <https://doi.org/10.12691/wjee-1-1-2>

Onuu, M.U., 2000. Road traffic noise in Nigeria: measurements, analysis and evaluation of nuisance. *J. Sound Vib.* 233, 391–405. <https://doi.org/10.1006/jsvi.1999.2832>

Oyedepo, O.S., Saadu, A.A., 2009. A comparative study of noise pollution levels in some selected areas in Ilorin Metropolis , Nigeria 155–167. <https://doi.org/10.1007/s10661-008-0570-5>

Pirrera, S., Valck, E. De, Cluydts, R., 2010. Nocturnal road traffic noise : A review on its assessment and consequences on sleep and health. *Environ. Int.* 36, 492–498. <https://doi.org/10.1016/j.envint.2010.03.007>

Pradhan, A.C., Swain, B.K., Goswami, S., 2012. Road traffic noise assessment and modeling of Sambalpur city, India: A comprehensive, comparative and complete study. *J. Ecophysiol. Occup. Heal.* 12.

Raza, M., Kim, M., Chang, J., Hassan, M., 2011. Spatio-temporal patterns of road traffic noise pollution in Karachi , Pakistan. *Environ. Int.* 37, 97–104. <https://doi.org/10.1016/j.envint.2010.08.003>

Saad, A.-Q., Alhiary, A., 2004. Effect of distance from road intersection on developed traffic noise levels. *Can. J. Civ. Eng.* 538, 533–538. <https://doi.org/10.1139/L04-016>

Saadu, A.A., Onyeonwu, R.O., Ayorinde, E.O., Ogisi, F.O., 1998. Road traffic noise survey and analysis of some major urban centers in Nigeria 46.

Singh, ReenaRajiv B. Hunashala, Y.B.P., Shekar, S., 2012. Assessment of noise Pollution Indices in the City of Patna, *Indian Journal of Environmental Protection.*

<https://doi.org/10.1016/j.sbspro.2012.03.310>

Singhvi, N., 2013. An Analysis of noise pollution in Tirupur city. *Sch. J. Eng. Technol. Sch. J. Eng. Tech* 1, 154–168.

SMILE, (SMILE), 2003. *Guidelines for Road Traffic Noise Abatement*. Berlin, Germany Europea.

Subramani, T., PSivaraj, K., Kavitha, M., 2012. Modelling Of Traffic Noise Pollution. *Eng. Res. Appl.* 2, 3175–3182.

To, W.M., Rodney C W Ip, Lam, G.C.K., Yau, C.T.H., 2002. A multiple regression model for urban traffic noise in Hong Kong 112, 551–556. <https://doi.org/10.1121/1.1494803>

Tsai, K.T., Lin, M. Der, Chen, Y.H., 2009. Noise mapping in urban environments: A Taiwan study. *Appl. Acoust.* 70, 964–972. <https://doi.org/10.1016/j.apacoust.2008.11.001>

Tsegaye, A.B., 2015. *International Journal of Modern* 2, 108–120.

UN- Habitat, 2017. *The State of Addis Ababa 2017. The Addis Ababa We Want*. Kenya.

USDOT, FHWA, 2018. *Noise Measurement Handbook Final Report - FHWA-HEP-18-065*. Washington, D.C.

Vilas, P., Prashant, N.P., 2015. Measurement and Analysis of Noise At Signalised Intersections. *J. Environ. Res. Dev. J. Environ. Res. Dev.* 9, 662–667.

Vrom, 2006. Application of Low Noise Road surfaces in the Netherlands 5, 4–6.

Wawa, E.A., Mulaku, G.C., 2015. Noise Pollution Mapping Using GIS in 486–493. <https://doi.org/10.4236/jgis.2015.75039>

World Health Organization, 2011. *Burden of disease from environmental noise*. WHO European Centre for Environment and Health, Bonn Office, WHO Regional Office for Europe, Copenhagen, Denmark.

World Health Organization, 1999. *Guideline for community noise* WHO. Stockholm University and Karolinska Institute. <https://doi.org/10.1260/0957456001497535>

Yibeltal, K., 2014. *Noisy Addis Abeba - Addis Standard*. Addis Ababa , Ethiopia.

Zambon, G., Benocci, R., Brambilla, G., 2016. Cluster categorization of urban roads to optimize their noise monitoring. *Environ. Monit. Assess.* 188. <https://doi.org/10.1007/s10661-015-4994-4>

Zannin, P., 2003. Influence of the traffic composition and traffic flow on noise emitted by typical Brazilian roads. *Acta Acust.* 89.

*Analysis and Evaluation of Urban Road Traffic Noise pollution in Addis Ababa City*

Appendices

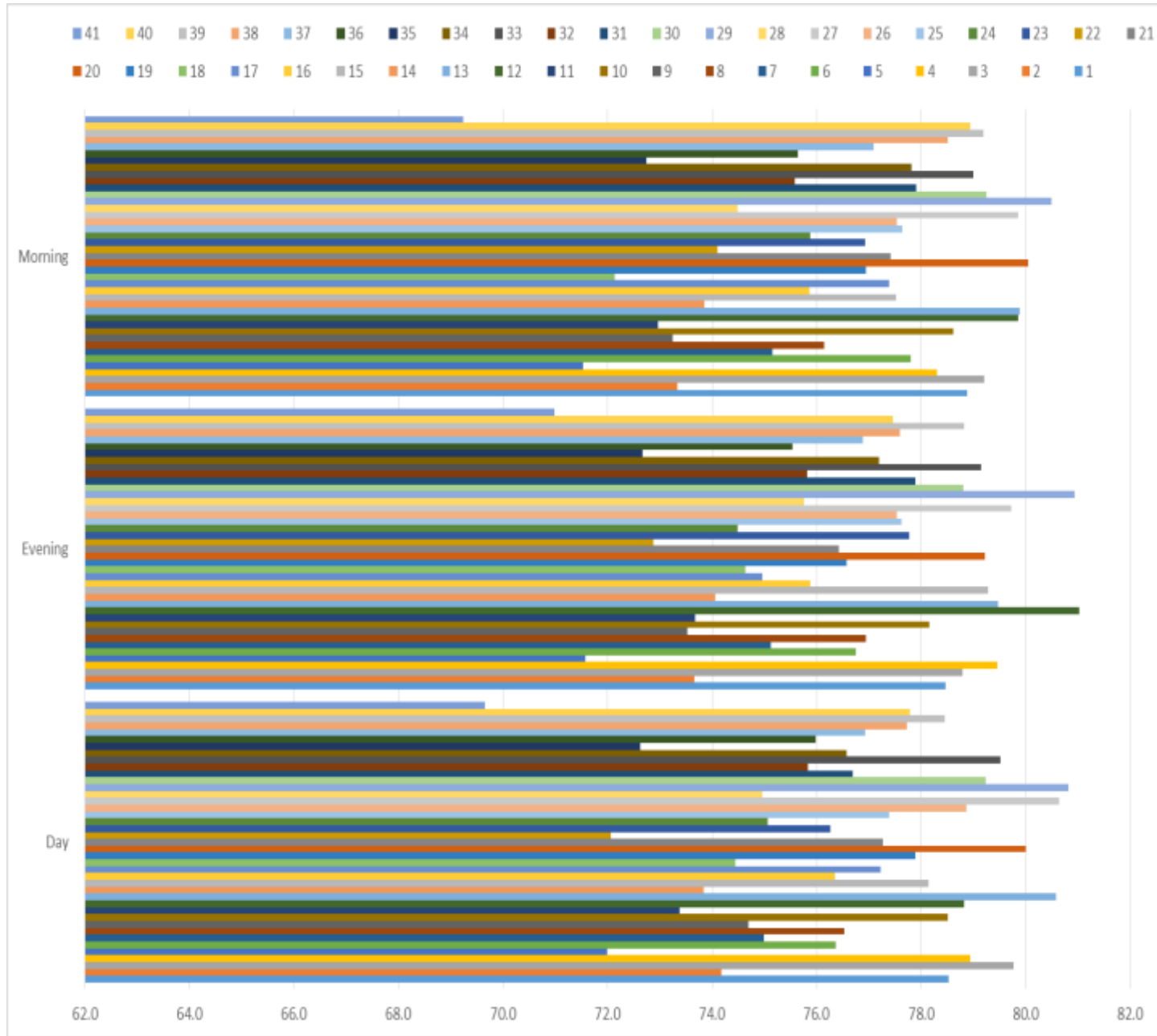
**Appendix A**

**Noise descriptors for each surveyed Spots**

Subcity / SiteCode	Leq (dBA)	L90 (dBA)	L50 (dBA)	L10 (dBA)	NC (dBA)	LNP (dBA)	TNI (dBA)	Average of Total Traffic Flow (Q/45 min)	Average Number Heavy Truck and Bus (HT/45 min)
<b>Addis Ketema</b>									
17	76.5	72.7	76.0	78.0	5.2	81.7	63.6	375	5
18	73.7	70.0	72.9	76.5	6.5	80.2	66.0	167	1
19	77.1	74.1	76.7	79.2	5.1	82.3	64.6	556	6
<b>Alaki Kaliti</b>									
24	75.1	72.6	74.8	77.0	4.4	79.5	60.1	268	1
25	77.5	74.4	77.1	79.2	4.8	82.3	63.5	581	19
26	78.0	74.9	77.5	79.9	5.0	83.0	64.9	919	27
27	80.1	77.9	79.8	81.5	3.6	83.6	62.2	1,203	72
28	75.1	71.7	74.5	77.5	5.8	80.9	64.9	338	7
<b>Arada</b>									
5	71.7	67.7	71.1	73.5	5.8	77.5	60.9	81	-
6	77.0	73.0	76.4	78.5	5.5	82.4	64.8	530	8
7	75.1	68.9	73.6	77.9	9.1	84.1	75.1	167	1
8	76.5	72.7	75.8	79.0	6.3	82.8	67.9	696	4
<b>Bole</b>									
13	80.0	76.5	79.6	81.3	4.7	84.7	65.5	1,197	31
14	73.9	70.8	73.5	75.8	5.0	78.9	60.7	206	-
15	78.3	75.6	78.0	79.5	3.9	82.2	61.3	724	4
16	76.0	72.4	75.4	77.5	5.2	81.2	63.1	508	1
<b>Gulalle</b>									
9	73.8	71.2	73.3	76.3	5.1	79.0	61.7	123	2
10	78.4	75.9	78.2	79.7	3.8	82.2	61.0	493	16
11	73.3	70.5	72.9	75.2	4.7	78.1	59.4	112	-
12	79.9	76.7	79.5	81.1	4.4	84.3	64.4	711	14
<b>Kirkos</b>									
38	77.9	75.6	77.6	79.7	4.1	82.1	62.1	627	4
39	78.8	75.9	78.4	80.9	5.0	83.8	66.0	749	6
40	78.1	74.6	77.6	79.4	4.8	82.9	64.0	534	2
41	70.0	66.6	69.6	71.7	5.1	75.0	56.8	110	-
<b>Kolfe Kerenyo</b>									
20	79.8	76.0	79.1	82.0	6.0	85.8	70.1	1,217	53
21	77.0	73.3	76.4	79.2	5.9	83.0	67.0	519	20
22	73.0	69.7	72.6	74.7	5.0	78.0	59.7	164	-
23	77.0	71.7	76.2	78.2	6.5	83.5	67.8	570	-
<b>Lideta</b>									
33	79.2	74.4	78.4	81.2	6.8	86.0	71.5	950	39
34	77.2	74.8	76.9	78.9	4.0	81.2	60.9	319	5
35	72.7	68.5	71.8	75.3	6.9	79.5	65.9	112	-
36	75.7	72.0	75.2	77.7	5.6	81.3	64.5	267	0
37	77.0	73.9	76.6	78.6	4.7	81.7	62.7	511	4
<b>Nifas Silk Lafto</b>									
29	80.7	77.8	80.4	82.2	4.3	85.1	65.2	1,230	42
30	79.1	74.3	78.4	80.2	5.8	84.9	67.6	970	36
31	77.5	71.0	75.7	80.7	9.8	87.3	80.0	649	10
32	75.7	72.4	75.3	77.6	5.2	80.9	63.2	312	3
<b>Yeka</b>									
1	78.6	76.4	78.4	79.9	3.5	82.2	60.5	1,142	8
2	73.7	71.2	73.4	75.4	4.2	77.9	58.0	242	2
3	79.3	74.7	78.7	80.4	5.7	85.0	67.5	896	24
4	78.9	76.1	78.6	80.3	4.2	83.1	63.0	722	20

**Appendix B**

Temporal Variation of Leq dBA of each surveyed spot



**Appendix C**

**ANOVA Test Result for Temporal Variation of Leq dBA**

Leq									
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Between-Component Variance
					Lower Bound	Upper Bound			
Day Time	41	76.72	2.581	.403	75.90	77.53	70	81	
Evening Time	41	76.67	2.485	.388	75.89	77.46	71	81	
Morning Time	41	76.67	2.692	.420	75.82	77.52	69	81	
Total	123	76.69	2.566	.231	76.23	77.15	69	81	
Model	Fixed Effects		2.587	.233	76.23	77.15			
	Random Effects			.233 <sup>a</sup>	75.68 <sup>a</sup>	77.69 <sup>a</sup>			-.162

a. Warning: Between-component variance is negative. It was replaced by 0.0 in computing this random effects measure.

**Test of Homogeneity of Variances**

Leq			
Levene Statistic	df1	df2	Sig.
.150	2	120	.861

**ANOVA**

Leq					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.065	2	.033	.005	.995
Within Groups	803.294	120	6.694		
Total	803.359	122			

**Appendix D: Model Development Test Result**

a. Regression Model Test Result between Leq and Log of total Traffic Volume

**Descriptive Statistics**

	Mean	Std. Deviation	N
LeqdBA	76.68650	2.567615	123
LogQ	2.6344	.33910	123

**Correlations**

		LeqdBA	LogQ
Pearson Correlation	LeqdBA	1.000	.923
	LogQ	.923	1.000
Sig. (1-tailed)	LeqdBA	.	.000
	LogQ	.000	.
N	LeqdBA	123	123
	LogQ	123	123

**Variables Entered/Removed<sup>a</sup>**

Model	Variables Entered	Variables Removed	Method
1	LogQ <sup>b</sup>	.	Enter

a. Dependent Variable: LeqdBA

b. All requested variables entered.

**Model Summary<sup>b</sup>**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.923 <sup>a</sup>	.852	.851	.991485	.852	697.176	1	121	.000

a. Predictors: (Constant), LogQ

b. Dependent Variable: LeqdBA

*Analysis and Evaluation of Urban Road Traffic Noise pollution in Addis Ababa City*

**ANOVA<sup>a</sup>**

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	685.355	1	685.355	697.176	.000 <sup>b</sup>
	Residual	118.948	121	.983		
	Total	804.303	122			

a. Dependent Variable: LeqdBA

b. Predictors: (Constant), LogQ

**Coefficients<sup>a</sup>**

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations		
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	58.274	.703		82.886	.000	56.882	59.665			
	LogQ	6.989	.265	.923	26.404	.000	6.465	7.514	.923	.923	.923

a. Dependent Variable: LeqdBA

**Coefficient Correlations<sup>a</sup>**

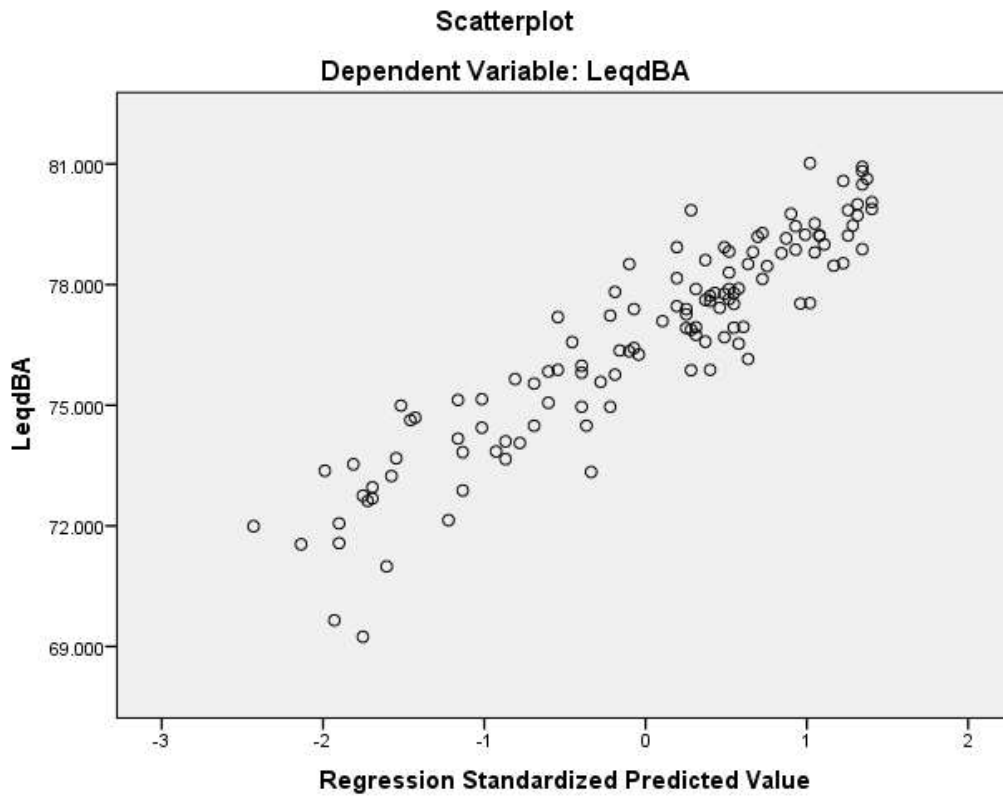
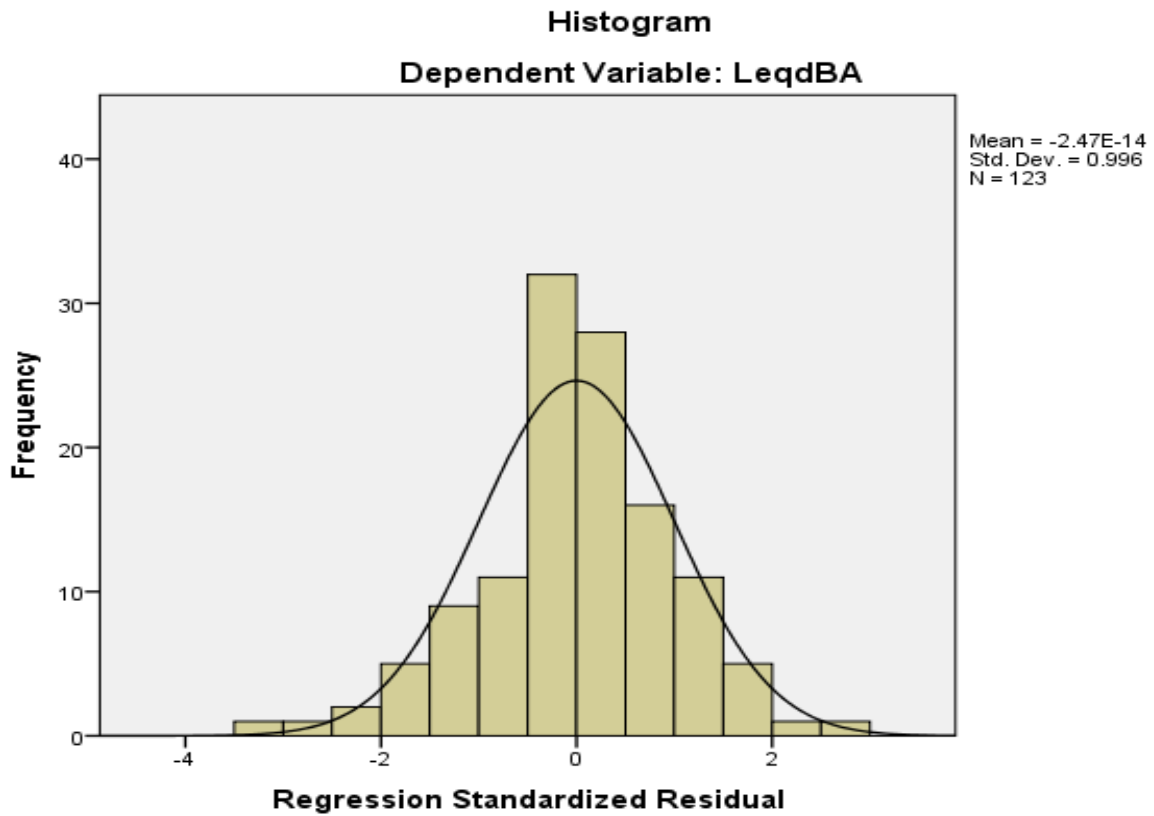
Model		LogQ	
1	Correlations	LogQ	1.000
	Covariances	LogQ	.070

a. Dependent Variable: LeqdBA

**Residuals Statistics<sup>a</sup>**

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	70.92446	80.01076	76.68650	2.370160	123
Residual	-3.292035	2.495235	.000000	.987414	123
Std. Predicted Value	-2.431	1.403	.000	1.000	123
Std. Residual	-3.320	2.517	.000	.996	123

a. Dependent Variable: LeqdBA



- b. Regression Model Test Result between Leq and Log of Bus/ Heavy Truck and other total Traffic Volume

Variables Entered/Removed <sup>a</sup>			
Model	Variables Entered	Variables Removed	Method
1	HT, OTV <sup>b</sup>	.	Enter

a. Dependent Variable: Leq  
b. All requested variables entered.

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.866 <sup>a</sup>	.750	.746	1.290

a. Predictors: (Constant), HT, OTV

ANOVA <sup>a</sup>						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	594.500	2	297.250	178.688	.000 <sup>b</sup>
	Residual	197.958	119	1.664		
	Total	792.459	121			

a. Dependent Variable: Leq  
b. Predictors: (Constant), HT, OTV

Coefficients <sup>a</sup>				
Model		Unstandardized Coefficients		Standardized Coefficients
		B	Std. Error	Beta
1	(Constant)	73.171	.236	
	OTV	.006	.000	.835
	HT	.006	.010	.043

**Appendix E**

Category Test Result

**Descriptive Statistics**

	N	Mean	Std. Deviation	Minimum	Maximum
LeqdBA	123	76.74	2.573	69	81
CategoryClass	123	2.56	.968	1	4

**Kruskal-Wallis Test**

**Ranks**

CategoryClass	N	Mean Rank
1	18	103.14
2	42	82.15
3	39	48.33
4	24	18.08
Total	123	

	LeqdBA
Chi-Square	80.841
df	3
Asymp. Sig.	.000

a. Kruskal Wallis Test  
b. Grouping Variable: CategoryClass

**Median Test**

**Frequencies**

	CategoryClass				
	0	1	2	3	4
LeqdBA > Median	0	18	29	8	0
LeqdBA <= Median	0	0	13	31	24

**Test Statistics<sup>a</sup>**

	LeqdBA
N	123
Median	77.00
Chi-Square	60.966 <sup>b</sup>
df	3
Asymp. Sig.	.000

a. Grouping Variable: CategoryClass

**ANOVA**

LeqdBa

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	533.761	3	177.920	77.296	.000
Within Groups	273.913	119	2.302		
Total	807.675	122			

**Post Hoc Tests**

**Multiple Comparisons**

Dependent Variable: LeqdBa  
Tukey HSD

(I) CategoryClass	(J) CategoryClass	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.230 <sup>*</sup>	.427	.024	.12	2.34
	3	3.393 <sup>*</sup>	.432	.000	2.27	4.52
	4	6.194 <sup>*</sup>	.473	.000	4.96	7.43
2	1	-1.230 <sup>*</sup>	.427	.024	-2.34	-.12
	3	2.163 <sup>*</sup>	.337	.000	1.28	3.04
	4	4.964 <sup>*</sup>	.388	.000	3.95	5.98
3	1	-3.393 <sup>*</sup>	.432	.000	-4.52	-2.27
	2	-2.163 <sup>*</sup>	.337	.000	-3.04	-1.28
	4	2.801 <sup>*</sup>	.394	.000	1.78	3.83
4	1	-6.194 <sup>*</sup>	.473	.000	-7.43	-4.96
	2	-4.964 <sup>*</sup>	.388	.000	-5.98	-3.95
	3	-2.801 <sup>*</sup>	.394	.000	-3.83	-1.78

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

**Mean Plots**

