EVALUATING THE EXTENT AND POTENTIAL EFFECTS OF COMMUNITY NOISE POLLUTION IN NAIROBI CITY

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Evaluating the Extent and Potential Effects of Community Noise Pollution in Nairobi City

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature: …………………………………. Date: ……………………………

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This thesis has been submitted for examination with our approval as the University Supervisors.

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DEDICATION

This work is dedicated to my mum, dad and entire family; for their role in bringing me up, supporting me at all cost, encouraging me and mentoring me all through my life and education.

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LIST OF ACRONYMS & SYMBOLS

ΔP_m	Sound pressure
AC	Asphalt Concrete
ANSI	American National Standards Institute
CBD	Central Business District
CNEL	Community Noise Equivalent Sound Level
CNR	Composite Noise Rating
D	Noise Dose
dBA	A-weighted decibel sound level
EMCA	Environmental Management and Coordination Act, 1999, Kenya
Hz	Hertz
I	Sound intensity
ISO	International Standards Organization
Ldn	Day-night Sound level
Leq	Equivalent sound level
L_I	Sound Intensity Level
L_{NP}	Noise Pollution Level
L_p	Sound Pressure Level
Ls	Sound exposure Level
L_w	Sound Power Level
NEMA	National Environment Management Authority, Kenya.
NER	Noise Exposure Rating
NIHL	Noise Induced Hearing Loss
NIPTS	Noise-induced permanent threshold shift
NITTS	Noise-induced temporary threshold shift
OSHA	Occupational Safety and health Act
PNL	Perceived Noise Level
PSIL	Preferred Speech Interference Level
P_w	Sound power
SENEL	Single Event Noise Exposure Level
SIL	Speech Interference Level

TL	transmission loss
DOSHS	Directorate of Occupational Safety and Health Services, Kenya

DEFINITION OF TERMS

Acoustics -	The science of sound dealing with its vibratory motion perceptible through the organ of hearing
Airport Noise –	Noise emanating from airport operations
Boda boda –	popular name for motor-bicycle taxis in Kenya
Community Noise –	Noise emanating from day-to-day human activities including transportation, entertainment, worship, indoor noise, animals and household appliances. (Also called environmental noise)
Continuous Noise –	Noise with negligibly small fluctuations of level within a period of observation (ANSI S3.20-1995: Stationary noise; steady noise)
Decibel (dB) –	Unit of measurement of sound (sound pressure/intensity/power level)
Exchange Rate –	an increment in sound level that requires halving of exposure time or decrease in sound level that requires doubling of exposure time.
Impulsive Noise –	type of noise characterised by a sharp rise and rapid decay of sound levels in less than one second (also impact noise).
Industrial noise	noise emanating from industrial activities
Intermittent Noise	Noise levels that are interrupted by intervals of relatively low sounds.
Matatu	Popular name for public service vehicles in Kenya
Noise	Unwanted sound that may cause undesirable effects on public health and welfare.
Permanent Threshold Shift (PTS) –	Permanent increase in threshold of audibility for an ear (also permanent hearing loss)
Temporary Threshold Shift (TTS) –	temporary increase in the threshold of audibility for an ear caused by exposure to high intensity acoustic stimuli.

Tinnitus – Ringing or buzzing in the ear. Its onset may be noise exposure but persist after the causative noise has ceased. It can also be induced by drugs.

ABSTRACT

Nairobi City is increasingly being affected by noise from the growing entertainment, commercial, religious, transportation and communication activities. However, unlike other types of pollution such air and water pollution, less attention has been given to the noise problem and noise data is generally missing in Kenya. This study sought to investigate the extent and effects of community noise pollution in Nairobi City, with focus on six key areas prone to noise: inside public service vehicles, bus stations, roads, commercial places, places of worship (churches) and places of entertainment.

Noise measurements were taken using a digital integrating sound level meter from selected locations at the six sites, all of which were found to significantly exceed the corresponding legislated and/or protective noise limits. Using multiple regression analysis in SPSS 20 environment, the measured road traffic noise levels were used to generate a model for predicting traffic noise levels based on traffic volume, traffic composition and traffic speed. The regression indicated that these three variables were sufficient to describe noise pollution emitted by road traffic (R^2=0.783); and that temperature and relative humidity had no significant effects; and thus were eliminated from the final model. Alongside the noise measurements, a questionnaire survey was administered across the various stations, except bus stations and along the roads, to assess the effects of and public reaction to noise. The survey established that Nairobi residents are mainly at risk of suffering noise-related hearing loss, communication interference and headaches.

From the study, it was evident that there is poor enforcement of noise regulations in Nairobi and that the existing law is inadequate to control noise pollution as some of its provisions are unrealistic. Thus, law enforcement agencies should not only intensify enforcement, but the existing law should be relooked against its ability to control noise. This should come alongside increased awareness of noise and it impacts amongst the public as well as undertaking further research to better understand and manage the noise menace.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

In the last four decades, there has been a growing interest in the quality of man's environment. In addition to air and water pollution, noise pollution has been recognized as an issue of serious environmental concern due to increasing noise levels in the environment, which have made the effects of noise pollution more apparent and pervasive (EPA, 1997). The Kenya Legal Notice Number 61 (2009) defines noise as "any undesirable sound that is intrinsically objectionable or that may cause adverse effects on human health or damage to the environment" and noise pollution as "the emission of uncontrolled noise that is likely to cause danger to human health or damage the environment" (p. 3). Sound/noise is measured in decibels (dB) using weighted scales (A, B, C, D or E) in order to approximate human response (EPA, 1999). According to Acardio and Gregoria (2002), noise has been classified among pollutants such as solid waste, wastewater and waste air. Generally, noise pollution is recognized in three categories: community noise, industrial noise and airport noise. Industrial noise and airport noise refer to noise emanating from industrial processes and airport operations, respectively. On the other hand, community noise (also known as environmental noise) refers to noise emanating from human activities such as transportation, recreation, entertainment, worship, business, animal rearing, construction as well as internal domestic activities (Ahmad, 1998). This study focused on the extent and effects of community noise pollution in Nairobi City, within and immediately around the Central Business District (CBD).

All over the world, noise levels have reached alarming levels, particularly in urban areas (Goines & Hagler, 2007). In Varanasi City, India, Ehrampoush *et al.,* (2011) indicate that about 85% of the people are disturbed by traffic noise and 90% consider noise as the main cause of headaches, hypertension, giddiness and lethargy. In Canada, a nationwide survey indicated that half of Canadians are bothered, disturbed or annoyed by noise emanating outside their homes, mainly from road traffic (Goines & Hagler, 2007). In Denmark, studies have revealed that a one (1) dB increase in noise levels results in a corresponding 1.0% decrease in house prices in the given areas of residence. According to Alam (2006), the impact of noise pollution on communities is fast escalating all over the world, especially in densely populated urban areas near very busy roads. In Rawalpindi and Islamabad, the daily maximum and daily equivalent noise levels are higher than the maximum permissible level (Pakistan Environment Programme, 2006).

African urban centres and cities are also afflicted by noise. In most towns/cities of Nigeria, noise emanating from traffic, industry, worship and commercial activities has been listed as an issue of key environmental concern (Ityavyar & Tyav, 2013). In Uganda, Matagi (2002) marked noise as the main source of environmental pollution in the city of Kampala. Additionally, in a study of noise pollution in restaurants of Morogoro town, Tanzania, Samagwa, Mkoma & Tungaraza (2009) recorded between 61 and 64 dBA of noise. This is way above the legislated maximum permissible level of 55 dBA and is associated with music in the restaurants, customer conversations as well as activity on adjacent streets.

In Kenya, not much has been done to study community noise pollution. However, in 2009, the noise problem was recognized and the Noise and Excessive Vibration (Pollution) Control Regulations, 2009 enacted. This legislation, annexed to the EMCA, 1999, provides for relevant noise criteria for different environments and empowers the National Environmental Management Authority (NEMA) to enforce the noise regulations. Noise surveys conducted by, or in cooperation with, NEMA have singled out noise pollution as an issue of grave environmental concern (NEMA, 2011). In addition to NEMA, the Directorate of Occupational Safety and Health Services

(DOSHS), under the Ministry of Labour, Government of Kenya, is tasked with protecting workers from occupational noise. Preliminary noise surveys by DOSHS indicate that workplace noise is also a serious environmental issue in Kenya (DOSHS, 2012). Recently, NEMA (2011) conducted a study in major towns of Kenya and developed a comprehensive noise map showing areas prone to excessive noise. This map identifies areas of heavy traffic, industrial areas, market places, places of worship and places of entertainment as notorious for noise (NEMA, 2011). However, other than mapping, NEMA has neither documented the specific noise sources in the identified areas nor the individual noise levels thereof. Besides, NEMA does not provide an insight into the effects (or possible effects) of noise from these hotspots or how the situation can be controlled. This study sought to bridge these gaps by conducting a detailed noise survey and impact assessment on some of the areas marked by NEMA as alarming noise sources.

Noise pollution poses a wide range of risks to public health and welfare. Adverse effects of noise pollution include annoyance, speech interference, sleep disturbance and hearing loss. Recent studies have also associated noise with cardiovascular diseases such as increased risk of hypertension and myocardial infarction (Acardio & Gregoria, 2002). Boldin *et al.,* (2012) note traffic noise-related annoyance and sleep disturbance as a common problem throughout the world, with adverse effects on life quality and health. Another adverse effect of noise pollution that has been documented since the 16th Century, and is still a problem today, is occupation-related hearing loss. World records estimate that about US $835 million was paid to workers between 1978 and 1987 in compensation for occupation-related hearing loss (Arardio & Gregoria, 2002). It has also been proven that sonic boom can result in physical damage of structures (Salvato *et al.,* 2003). This makes noise pollution an important area upon which scholarly emphasis ought to be laid.

1.2 Statement of the Problem

Nairobi City faces a major problem of noise. Firstly, traffic noise is of particular concern following the rapidly growing traffic volumes in the city. Jogoo Road and Outer Ring Road, for instance, which connect Nairobi CBD to the densely populated East-lands estates, experience up to 87358 and 87000 vehicles per day, respectively (Irungu, 2007). Public service vehicles (PSVs) popularly known as *Matatus* constitute about 36% of the total average traffic volume in Nairobi (Gonzales *et al.,* 2009) and seem to pose the largest threat of traffic noise. In addition to normal vehicular noise resulting from engine and exhaust sounds, Kenyan PSVs are fond of playing extremely loud music, uncontrolled hooting and banging of the vehicle bodies by loudly shouting touts in search of passengers.

As a matter of fact, speech/telephone communication is virtually rendered impossible by noise in some PSVs in Nairobi. The experience annoys and could be a nuisance not only to passengers, but also to residents bordering major roads or bus termini. Furthermore, traffic congestion associated with rush hours (Kere, 2010) lengthens the duration of exposure to vehicular noise. Secondly, Nairobi City hosts a number of commercial activities ranging from hawkers and open-air markets to industries (Gonzales, *et al.,* 2009) all of which are notorious sources of noise. Also worth noting is the growing entertainment industry with entertainment spots that generate disturbing noise in the evenings and at night. It is also important to note the growing number of religious activities and the associated noise resulting from instruments used at places of worship. It is possible that the extent of noise pollution could, in addition to the observed effects, pose serious other threats to public health and welfare in Nairobi. The existing noise legislations and initial attempts by NEMA to control noise pollution seem to have since stalled. This warrants a detailed study of the extent of noise pollution and its effects in Nairobi City in order to provide a framework for noise control.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to evaluate the extent and effects of community noise pollution in Nairobi City.

1.3.2 Specific Objectives

i. To determine the extent of community noise pollution caused by traffic noise as well as noise from markets, places of worship and entertainment facilities, in Nairobi City.
ii. To develop a regression model for predicting traffic noise pollution in Nairobi City.
iii. To evaluate the effects of community noise pollution on public health and welfare in Nairobi City.

1.4 Hypotheses

H_1: The extent of community noise pollution in Nairobi City is significantly higher than the permissible levels.

H_2: Traffic noise pollution in Nairobi City is a function of factors that can be modelled mathematically.

H_3: Community noise pollution in Nairobi City poses significant public health and welfare risks.

1.5 Justification

Kenya faces serious environmental challenges regarding water pollution, air quality deterioration, soil contamination and increasing noise levels. While tremendous attention has been given to water pollution and soil degradation, very little has been done regarding air quality (Chege, 2011) and noise pollution. Most scientific research and development have focused on water and soil quality with respect to agriculture and human consumption. This has built up a reasonable pool of data and information in these areas thereby facilitating objective further research, development and management decisions. However, noise data is generally missing in Kenya.

This calls for a detailed noise study to provide a framework for understanding the actual extent and effects of noise pollution in Nairobi City, with respect to set national and international standards. Such a study would also provide noise data and tools useful for decision making, urban planning and environmental management to the government, private sector and the general public. In particular, the findings of this study would be important for NEMA in enforcing the provisions of the Noise and Excessive Vibration Pollution (Control) Regulations, 2009. Additionally, disseminating the findings of this study would help create awareness on noise and its effects in Nairobi City and lay a basic foundation for comprehensive inclusion of noise pollution in the National Environment Policy, currently under review (National Environment Policy, 2012).

1.6 Scope of the Study

As stated earlier, noise pollution is broadly categorised as community noise, industrial noise and airport noise. This study specifically focused on community noise pollution (also known as environmental noise) with particular attention to the following sources: public road transport; commercial centres; places of worship; and entertainment joints. Noise descriptors used were limited to average equivalent sound levels and statistical measures which can be directly measured by a digital integrating sound level meter, or computed from such measurements, without involving long-term noise analysers. Geographically, the study was conducted in Nairobi CBD and some of its immediate environs.

1.7 Limitations

Only spot noise measurements of between five minutes to thirty minutes were used in the study as opposed to long-term noise analyses of the study sites. This was due to limitations in available equipment. In addition, while collecting traffic noise data for modelling, traffic speed was computed using distance-time method due to unavailability of a definite speed meter to take actual vehicle speed measurements. It is also important to note during this study, it was impossible to conduct night time and indoor noise measurements at residential areas due to the difficulty associated with accessing people's private homes and taking measurements in the night. Thus, any residential noise aspects reported in this study are based on a survey and thus may be subjective.

CHAPTER TWO

LITERATURE REVIEW

2.1. Definition of Community Noise Pollution

Noise pollution is commonly categorised as community, industrial and airport noise. Industrial and airport noise refer to noise emanating from industrial processes and airport operations, respectively (Bruel & Kjaer, 1984). Community noise (also known as environmental noise) refers to noise emanating from such human activities as transportation, recreation, entertainment, worship, business, animal rearing, construction, and indoor domestic activities .Various measures have been developed for assessing community noise levels. They include: statistical measure (L_N), equivalent sound level (L_{eq}) day-night average sound level (L_{dn}) and noise pollution level (L_{NP}) (Arcadio & Gregoria, 2002).

L_{eq} is the most widely used for community noise assessment and it gives an A-weighted average sound level over a given duration. The statistical measure refers to a sound level that is either equalled or exceeded so much percent of the time, based on a probability distribution analysis for instance L_{90}, L_{20} and L_{10}. These refer to noise levels that are equal/exceed 90, 20 and 10% of the time, respectively. The day-night average sound level is the equivalent sound level over a 24 hour period with an additional 10 dBA during the night (10.00 P.M. to 7.00 A.M.). Community noise levels can also be described in terms of another measure known as the community noise equivalent level (CNEL). CNEL is related to L_{DN} except that an additional 5 dBA is imposed between 7.00 P.M. and 10.00 P.M. and 10 dBA is added between 10.00 P.M. and 7.00 A.M. Noise pollution level is the equivalent sound level with a probability of exceedance of 0.5% (Environmental Protection UK, 2008).

2.2. Measurement of Community Noise Pollution

Noise is characterised in terms of sound pressure, sound power and sound intensity (Acardio & Gregoria, 2002). Sound pressure is the maximum pressure differential, above or below the existing atmospheric pressure, which is responsible for sound propagation. Sound power is the rate of change of the total energy content of a travelling sound wave with respect to time, whereas sound intensity is the rate of transmission of sound power per unit area of cross section in the direction of travel of the sound (Arcadio & Gregoria, 2002). However, noise measurements are never reported in the units of power, pressure or intensity. Instead, noise is measured in decibels, a logarithmic scale denoted as dB and used in order to accommodate the extremely wide range of sound intensities and pressures that the human ear is able to perceive. The decibel simplifies this range to a scale of zero to 140 dB (Piccolo, Plutino & Cannistraro, 2005).

The instrument used to measure noise is the sound level meter. The meter is located at a reasonable distance from the sound source to avoid obstruction (EPA South Australia, 2009). Prior to its use, the meter is calibrated by a *calibrator* which is attached to the meter to produce a reference sound that calibrates it. Basically, a sound level meter consists of four parts: a microphone, sound amplifiers, weighting network and a display which shows readings in decibels (Gary *et al.,* 2001). Incoming sound is received by the microphone where its pressure pattern is mimicked by a pressure transducer (diaphragm) and the signal is converted to a small electric current. The resulting electrical signal is then amplified by the amplifiers (Bies & Hansen, 2002). Since the sound pressure received by the meter is not the same as that which the ear perceives, a weighting network (simply an electrical circuitry) is incorporated in the meter to help approximate human response and give a reading as close to it as possible (I-INCE, 2011).

2.3. The Extent of Community Noise Pollution Problem

Research indicates an alarming trend in community noise levels in most cities around the world (Kumar & Murugappan, 2013). Nejadkoorki, Yousefi and Naseri (2010) conducted a study to analyse street traffic noise pollution in Yazd city, Iran. They used a Bruel and Kjaer 2260 sound level meter to measure noise levels on 10 streets during the morning rush-hour (0730-0930 hours) for a total period of one month in 2008. Alongside noise measurements, Nejadkoorki, Yousefi and Naseri (2010) took manual counts of different vehicle types at each sampling point and applied GIS to map the sound levels against measured spatial data. From the study, Yazd city streets were found to have noise levels ranging from 70.9 to 80.7 dBA. This is way beyond the permissible level of 60 dBA. Their modelling also showed a significant relationship between recorded sound levels and traffic flow ($R^2 = 0.5$). Furthermore, Nejadkoorki, Yousefi and Naseri (2010) indicate that although street traffic volume increased between 2002 and 2008, there was a slight decrease in sound levels in Yazd city during the same period. They attributed this to advances in vehicle design.

Nejadkoorki, Yousefi and Naseri's study provides a detailed analysis of street traffic noise pollution in Yazd City. Their findings are in line with other studies which have documented above-permitted noise levels in neighbouring Iranian cities (Golmohammadi *et al.,* 2009; Mohammadi, 2009; Ehrampoush *et al*., 2012). However, Nejadkoorki, Yousefi and Naseri (2010) did not give emphasis to other (than traffic) sources of community noise such as commercial activities, entertainment and worship. Their study also does not give an insight on the effects of noise pollution or how it can be controlled. It is also worth noting that Nejadkoorki, Yousefi and Naseri (2010) only considered noise levels during the morning rush hour, without giving an idea of the evening rush hour and the mid-day non-rush hours. Some of these gaps are covered by Ehrampoush *et al.* (2012) who, in addition to traffic, measured residential and commercial noise levels in 135 sampling points across Yazd City. Ehrampoush *et al.* (2012) reported an average equivalent sound level (LAeq) of 66.7 dBA (above the acceptable 60 dBA) and proposed general technical controls and educational programs for managing noise in the city. This study will combine the methodologies of Nejadkoorki, Yousefi and Naseri (2010) and Ehrampoush (2012) to conduct a more comprehensive evaluation of community noise pollution in Nairobi City, Kenya with reference to both morning and evening rush-hours as well as the midday non-rush hour. Besides, specific focus will be given to effects of noise pollution and noise control.

Another city that is significantly afflicted by noise is Thessaloniki, Greece. This is according to an exploratory traffic noise survey by Georgiadou *et al.,* (2004). Using a digital integrating sound level meter to record morning and evening rush-hour traffic noise levels along the two main streets of Thessaloniki, Georgiadou *et al.* (2004) show that there is a significant noise problem, with a mean daily LAeq of 72.1 dBA, which is likely to intensify if the 6% annual increase in traffic volume, witnessed during the previous decade, is to continue. The documented noise level significantly exceeds the maximum permissible level of 67 dBA for road transportation in Thessaloniki. In addition, Georgiadou *et al.* (2004) reported that, like in Yazd City, all Thessaloniki streets exhibited a diurnal variation of noise levels and traffic volume with a significant correlation (R^2 = 0.92). Georgiadou *et al.* (2004) made a very comprehensive daily noise monitoring covering the period from 0800-2000 hours to give mean hourly, daily, weekly as well as seasonal noise levels over a period of one year. They also recorded a 0.2-1.8 dBA variation in noise levels between weekends and working days. However, Georgiadou *et al.* (2004), like Nejadkoorki, Yousefi and Naseri (2010) focused only in the traffic component of community noise pollution, conspicuously leaving out other key environmental noise sources such as commercial activities and entertainment. Although Georgiadou *et al.* (2004) point out that their findings could have a significant influence on future design of city traffic networks, they make no endeavour to establish the effects of the high traffic noise levels recorded in the city of Thessaloniki. This study will borrow from Georgiadou *et al.* (2004) on the aspect of exploring the diurnal (temporal) variation of noise in Nairobi City, including between week-days and weekends. The scope, however, will be widened to cover entertainment, commercial and noise from places of worship.

Other than traffic volume, there is a significant relationship between noise levels and disordered city plan. This is with reference to a study by Dursun *et al.* (2006) to evaluate the effect of city planning (use of ideal road reserves and building areas as well as buildings-green areas ratio) on noise pollution in Konya City, Turkey. A detailed GIS mapping of noise levels against measured spatial data was done for 366 sampling points across the city. From the study, using a Testo-815 sound level meter, Dursun *et al.* (2006) documented threshold noise levels of 73.1-74.1 dBA in Konya city and showed that increasing building levels has a significant impact on indoor noise pollution near main roads. At all the 366 sampling points, the study found out that noise levels exceeded the threshold 65 dBA limit for Konya City. This represents an alarming noise pollution levels in the city which Dursun *et al.* (2006) majorly associated with poor city planning as exhibited by existence of tall buildings near busy urban roads and the high ration of buildings to green areas in the city. Although the study presents a new dimension (city planning) to the study of urban noise pollution, it is skewed towards road traffic noise pollution. This is despite having a general title "Noise pollution and map of Konya City in Turkey" that could have given the researchers an opportunity to address all possible sources of urban noise pollution.

In Pakistan, the daily maximum and daily equivalent noise levels are higher than the maximum permissible level (Pakistan Environment Programme, 2006). In 2006, the Pakistan Environment Program commissioned a study to evaluate the extent of noise pollution in the twin cities of Rawalpindi and Islamabad. Noise measurements from eight sampling locations indicated a maximum limit of 98 dBA. This is far above the legislated 85 dBA limit for heavy commercial transportation in Pakistan. In a related study, Jahandar *et al.* (2012) conducted a noise assessment to investigate traffic noise levels under "Stop" and "Go" conditions at intersections (viz., crossroads and T-junctions) on major roads in Rawalpindi and Islamabad. A digital integrating sound level meter was used to record noise levels under the two conditions. From the study, Jahandar *et al.* (2012) show that the highest average noise levels are recorded during the "Go" phase for T-junctions (64.4 dB) and "Drive" phase for crossroads (64 dB). This implies that the existence of intersections on roads increases traffic noise levels. Other studies have also indicated that vehicle noise intensity varies with distance from the road, nature of the road and longitudinal slope of the road (Seyed *et al.,* 2012). Despite pointing out the factors affecting traffic noise levels, Jahandar *et al* (2006) and Seyed *et al.* (2012) do not present a detailed modelling to correlate these factors with the level of traffic noise. This study will statistically correlate these factors in order to develop a regression model that can be used to predict noise pollution in Nairobi City.

African urban centres and cities are also afflicted by noise. In most towns/cities of Nigeria, for instance, noise emanating from traffic, industry, worship and commercial activities has been listed as an issue of key environmental concern (Ityavyar & Tyav, 2013). In a recent study to evaluate environmental noise pollution in Abuja, the capital city of Nigeria, Ochuko (2013) surveyed 35 sampling locations around the city using a digital integrated sound level meter CR811C. The sound level measurements were made four times a day – in the morning (0700-0800 hours), midday (1100-1200 hours), evening (1700-1800 hours), and at night (2200-2300 hours). This give a more comprehensive diurnal and night variation in noise levels covering both rush as well as non-rush hours. From the study, Ochuko (2013) reported daytime average LAeq ranging from 73.2 dBA to 83.6 dBA. In the night, the average equivalent noise level was found to be varying between 44 dBA and 56.8 dBA. It is important to note that the daily noise levels exceed the maximum permissible level of 65 dBA (Ityavyar & Tyav, 2013). Ochuko's study clearly identifies the noise problem in Nigeria and calls the attention of relevant authorities. However, it neither discerns the specific causes of the noise problem nor the possible effects thereof.

In Uganda, Matagi (2002), in a comprehensive literature review, marked noise as one of the main sources of environmental pollution in the city of Kampala. He attributed Kampala's noise problem mainly to traffic, industrialization and commercial activities in the city, although his article does not quantify the problem, probably due to lack of extensive noise studies in the country. In Tanzania, researchers have given the noise problem some attention (Samagwa, Mkoma & Tungaraza, 2009; Philimoni, Mkoma & Moshi, 2011; Gaganija, Mkoma & Lema, 2012). Samagwa, Mkoma and Tungaraza (2009) sought to investigate noise pollution from restaurants in Morogoro town. Using a digital integrating sound level meter, they measured outdoor and indoor ambient noise levels from seven restaurants two times daily, three days a week, for a duration of two months. From all the restaurants assessed, Samagwa, Mkoma and Tungaraza (2009) recorded between 61 and 64 dBA of noise. This is way above the legislated maximum permissible level of 55 dBA. Alongside the noise measurements, Samagwa, Mkoma and Tungaraza (2009) conducted a questionnaire survey to investigate the causes of noise in the restaurants. Indoor noise was associated with music in the restaurants, customer conversations as well as activity on adjacent streets. Similarly, they attributed outdoor noise to loud music from adjacent music shops, garage activities and traffic. However, their modelling demonstrated barely any impact of indoor noise on the outdoor noise environment (R^2<=0.3). Though specific to restaurants, Samagwa, Mkoma & Tungaraza's (2009) study is a good attempt at quantifying the noise problem in places of entertainment. In a more general study of community response to environmental noise pollution in Morogoro town, Gaganija, Mkoma and Lema (2012) recorded noise levels in the range of 51.1-75.1 dBA. In order to have a more comprehensive overview of noise from entertainment spots, this study will focus on noise pollution not only in restaurants, but also pubs and social halls. Also, in addition to assessing noise sources, a survey questionnaire will be used in this study to assess the effects of and people's response to measured noise.

Commercial activities are also a significant source of environmental noise pollution (Acardio & Gregoria, 2002). Essandoh and Armach (2011) conducted a study to assess environmental noise levels in Ghana's Cape Coast town's main commercial areas and residents' perceptions in their neighbourhoods. A digital integrating sound level meter was used to record noise levels at 10 sampling points in the town (viz., commercial centres, busy road junctions, bus parks and residential areas). Measurements were taken four times a day to give both day and night-time noise. From the study, Essandoh and Armach (2011) showed that the Cape Coast town of Ghana is afflicted by noise pollution in the range of 58-88, 70-99, 70-105, 58-88 and 53-72 dBA for commercial centres, busy roads, bus stations, high density and low density residential areas, respectively (p.639). This is way beyond the permissible limit of 55-75 dBA. Although Essandoh and Armach's (2011) study did not investigate the specific effects of the measured noise on people, it provides a framework upon which the extent and effects of commercial noise pollution will be evaluated in this study.

In addition to traffic, commercial and entertainment noise, noise from places of worship is also listed as a significant component of environmental noise pollution (Acardio & Gregoria, 2002). Various studies have been conducted to evaluate the extent of noise from places of worship and general religious activities (Al-Zahrani *et al.,* 2007; Silva & Cabral, 2011). Al-Zahrani *et al.* (2007) was commissioned by the government of Saudi Arabia to evaluate noise levels in two holy mosques of Arafat and Mina Valley areas during the Hajj season. Sound levels were measured using a digital integrated sound level meter (CR812B). The study documented high noise levels with a mean maximum equivalent level of 82 dBA. In another study in Brazil, Silva and Cabral (2011) evaluated the level of noise exposure of worshippers and priests in five protestant churches. At each church, the priest was equipped with a noise dosimeter (LD705A) to record noise levels he is exposed to while leading the church service. In order to measure noise exposure of worshippers, one of the researchers posed as a worshipper in each church, equipped with the same dosimeter.

From the study above, Silva and Cabral (2011) noticed that priests in all the churches were exposed to excessive noise, with eight-hour exposure levels of 95.4-99.5 dBA. This is far above the recommended eight-hour exposure level of 85 dBA. For worshippers, Silva and Cabral (2011) recorded noise exposure levels of 75.6-86.5, with two churches exceeding the recommended 85 dBA limit. Silva and Cabral's (2011) study captured only one service in each church despite the fact that each of the churches had an average of four services on main worship days (mainly presided over by the same priest) and many others in the course of the week. Thus, it may be a good indicator of the noise exposure of worshippers but may not accurately reflect the level of noise exposure of the priest. This study will borrow from the methodology of Silva and Cabral (2011) in evaluating the extent of noise exposure of worshippers in Kenyan churches in the city of Nairobi. In addition, a questionnaire survey will be added to assess the effect of worship-related noise on worshippers' as well as their perceptions of such noise.

In 2011, NEMA (Kenya) conducted a study to map noise levels and assess the compliance with the provisions of the Noise and Excessive Vibration Regulations, 2009 in Nairobi Province. Sound level measurements and GPS locations were taken at specific points identified in the law in Dagoretti and Starehe areas of the city. The study recorded the highest level of non-compliance (over 100%) in Nairobi's night clubs and 65-91% among Nairobi's places of worship. These correspond to noise level ranges of 75-87 dBA and 66-79 dBA against the maximum allowable 35 and 40 dBA respectively. For bus stations, NEMA observed noise levels in the range of 65-86 dBA against the permissible 60 dBA. Music shops were also found to be significant violators of the noise regulations with levels of 74-82 dBA versus the recommended 55 dBA (NEMA, 2011). The NEMA study is clear preview of the noise situation in Kenya's capital city. It shows how significant the noise problem is but does not dig deeper into the details of individual noise practices contributing to the problem. The study also doesn't capture the aspect of the impacts of the noise problem on public health and welfare. This study will build on the findings of NEMA (2011) by doing a detailed noise evaluation of the areas already identified by NEMA as notorious noise sources, including the effect of noise, people's perceptions of the noise problem and how it can be predicted.

2.4. Effects of Community Noise Pollution

a) Introduction

Several studies have been conducted to assess the effect of noise pollution on public health and welfare. In Varanasi City, India, Ehrampoush *et al.* (2011) indicate that about 85% of the people are disturbed by traffic noise and 90% consider noise as the main cause of headaches, hypertension, giddiness and lethargy. Through the cross-sectional questionnaire survey across the city, Ehrampoush *et al.* (2011) also noted that people with higher educational and income levels are more aware of the detrimental health effects of noise pollution as compared to their low income and less educated counterparts. In Canada, a nationwide social survey indicated that half of Canadians are bothered, disturbed or annoyed by noise emanating outside their homes, mainly from road traffic (Goines & Hagler, 2007). In Denmark, studies have revealed that a one (1) dB increase in noise levels results in a corresponding 1% decrease in house prices in the given areas of residence. According to Alam (2006), the impact of noise pollution on communities is fast escalating all over the world, especially in densely populated urban areas near very busy roads. Overall, noise has various effects on public health and welfare which can either be auditory or non-auditory. The following sub-sections outline the specific effects of noise pollution on public health and welfare.

b) Noise-induced Hearing Loss

Noise-induced hearing loss (NIHL) loss is a long-term auditory effect of noise pollution resulting from an increase in the threshold of hearing (Scott, Gray & Edwa, 2004). NIHL is predominant in the higher range of frequencies (3000–6000 Hz, with the maximum effect exhibited at 4000 Hz), Yilmaz & Ozer (2005). However, with increasing eight-hour equivalent sound level (LAeq , 8h) and noise exposure duration, NIHL can be experienced as low as at 2000 Hz (Noise Free America, 2010). According to WHO (1999), noise causes hearing impairments at LAeq , 8h levels exceeding 75 dBA or at LAeq , 24h levels exceeding 70 dBA. Exposure to noise below these levels, even for prolonged occupational periods, does not induce any hearing impairments. In addition to LAeq , 8h and duration of exposure, NIHL depends the susceptibility of exposed individuals. Although men and women are at equal risk of suffering NIHL, WHO (1999) recommends a peak limit of 140 dBA for adults exposed to impulse, environmental or leisure-time noise; and 120 dBA for children (Zannin, Calixto, Diniz & Ferreira, 2003; ISO 1999). According to WHO (1999), shooting noise exceeding 80 dBA (LAeq , 24h) increases the risk of NIHL. NIHL is the most prevalent irreversible occupational hazard all over the world, with about 120 million victims suffering the consequences of occupational noise as well as environmental noise (WHO, 1999). In America, 28 million people suffer from noise-related hearing loss (Noise Free America, 2010). Similarly, in African countries, WHO (1999) notes an alarming increase in the prevalence of NIHL due to increasing noise levels in most towns and cities. However, in Kenya, research has not yet focused on establishment of NIHL prevalence and such data is generally missing. This study seeks to bridge this gap.

c) Speech Interference

Speech interference is “a masking process in which simultaneous interfering noise renders speech incapable of being understood”. Other important acoustical signals (e.g., telephone, door bells and alarms) may also be masked (WHO, 1999, p.10). To ease full hearing, the difference in sound level between the speech and the interfering noise (signal-to-noise ratio) should be at least 15 dBA. Normal speech occurs at sound levels of about 50 dBA. This implies that in small rooms, noise levels exceeding 35 dBA extensively interferes with speech (WHO, 1999). For vulnerable individuals (the old or those with hearing disorders), much lower background noise levels and a reverberation time not exceeding 0.6 seconds should be maintained. Speech interference adversely affects learning processes and communication with people who are less conversant with the spoken language (WHO, 1999). Speech interference is one of the most common direct impacts of noise pollution. In Kenya, many people are likely to be afflicted by noise-related speech interference, especially those who live/work in/near industries, major highways, markets, bus stations, airports, places of worship and entertainment spots. The loud music played in most Matatus also renders speech/telephone communication almost impossible for PSV passengers. However, like for NIHL, scholarly/empirical research has not yet focused on noise and its effects on speech. This research will provide scholarly data on such.

d) Sleep Disturbance

Environmental noise pollution, especially in the night, interferes with sleep. This is either by primarily disrupting sleep or through secondary effects that are exhibited by victims in the day after exposure to noise in the previous night (Kryter & Karl, 1994). Undisturbed sleep is a prerequisite not only for good physiological but also mental functioning. Sleep disturbance includes "difficulty in falling asleep; awakenings/alterations of sleep stages/depth; increased blood pressure/heart rate/finger pulse amplitude; vasoconstriction; changes in respiration; cardiac arrhythmia and increased body movements" (WHO, 1999, p. 10). The reaction probability to sleep-interfering noise can be determined by the difference in noise levels between a noise event and the prevailing background sound levels (not by the absolute noise level). WHO (1999) recommends L_{eq} below 30 dBA for a good night sleep. Individual event noise levels should be kept below 45 dBA.

e) Physiological Effects

Environmental noise pollution can cause serious temporary and permanent physiological effects such as hypertension and ischaemic heart disease (WHO, 1999). Unfamiliar/sudden sounds may also evoke certain reflex responses (Kryter & Karl, 1994). Recent studies have shown that prolonged exposure to high industrial noise levels for 5-30 years is responsible for increased blood pressure among the exposed workers (WHO, 1999). It has also been shown that prolonged exposure to traffic noise (LAeq , 24h) of 65-70 dBA may have cardiovascular effects. The association may be weak, but the risk is greater for ischaemic heart disease than for hypertension and they are significant since many people are exposed to dangerous noise levels (Milne, Kendall & Reardon, 1982).

f) Mental Illness

Mental illness is not a direct impact of environmental noise pollution (Acardio & Gregoris, 2002). However, environmental noise is believed to accelerate and intensify the development of certain latent mental disorders. Recent studies have associated exposure to high levels of work-place noise with development of neurosis but associations between noise and mental health effects are still somewhat inconclusive (Kryter & Karl, 1994). "Nevertheless, studies on the use of drugs such as tranquilizers and sleeping pills, on psychiatric symptoms and on mental hospital admission rates, suggest that community noise may have adverse effects on mental health" (WHO, 1999, p. 11). Gary *et al.* (2000) found out that children from noisier environments exhibited higher perceived stress symptoms compared to children from less noisier environments.

g) Effect of Noise on Performance

Gary *et al.* (2000) also showed that noise can adversely impact performance of certain cognitive tasks in children. Such tasks include reading, solving problems, attention and memorization. This is despite the fact that noise-induced arousal can potentially result in better performance of some simple tasks. Noise is also a distractive stimulus, especially impulsive noise which results in startle responses (Arcadio & Gregoria, 2002). In addition, noise may have secondary adverse effects on performance. WHO (1999) has shown a high level of underperformance in proof-reading, challenging puzzles, reading acquisition and motivational capabilities, among children exposed to prolonged air-craft noise. Such children also exhibited heightened sympathetic arousal. Some errors at work and performance-deficit related accidents have also been associated with noise (WHO, 1999).

h) Annoyance, Social and Behavioural Effects

Environmental noise is a common cause for annoyance and some social and behavioural effects (Gary *et al.,* 2000). However, such effects are usually subtle, complex and indirect, mostly believed to be a result of various non-auditory variables (WHO, 1999). Noise-induced annoyance varies with the incident noise characteristics and, largely, with various non-acoustical social, psychological and economic factors (Zannin, Calixto, Diniz & Ferreira, 2003). This explains why an environmental noise event of a given magnitude elicits different levels of annoyance among different recipients. Moreover, annoyance effects of noise seem to be more pronounced at group level, rather than at individual levels (WHO, 1999). Noise above 80 dBA tends to reduce helping behaviour while heightening aggressive behaviour. Continuous exposure to high noise levels has also been shown to raise school children's susceptibility to feelings of helplessness (Gary *et al.,* 2000). Moreover, low frequency noises, accompanied by vibrations and impulsive noises elicit stronger reactions, especially when noise exposure increases with time. The recommended noise exposure approximations used to characterize annoyance are LAeq , 24h and L_{dn} (Kryter & Karl, 1994).

2.5. Theoretical Concepts of Acoustics

This study was based on various theoretical concepts of Acoustics. These include: sound characterisation, sound measurement, and human sound perception.

a) Sound Characterisation

Sound is characterised in terms of three important parameters namely, sound pressure, sound power and sound intensity (Arcadio & Gregoria, 2002). Sound pressure (denoted as ΔP_m) is the maximum pressure differential, above and below the existing atmospheric pressure, which is responsible for sound propagation. This is based on the basic fact that sound results from a differential/disturbance in air pressures caused by the vibration of a sound source. The disturbance leads to formation of two pressure bands, the compression band, characterised by high pressures, and the rarefaction band of low pressures (Liu, 1999). In the absence of sound pressure, no sound transmission occurs and the ear perceives no sound. Sound pressure is expressed as in Equation 2-1 in which Ʊ is the velocity of propagation of sound; ρ is the mass density of air; ω is the angular frequency of the sound wave; S_m is the maximum displacement and β is the bulk modulus of elasticity of air (Arcadio & Gregoria, 2002).

$$\Delta P_m = (\text{Ʊ}\, \rho\omega)\, Sm;\ \text{Ʊ} = \sqrt{\frac{\beta}{\rho}} \qquad (2\text{-}1)$$

Like a compressed spring, the air that propagates a sound wave possesses potential energy, in its compressed state, and kinetic energy in the rarefaction state (Liu, 1999). Neglecting any energy losses, the total energy content of a sound wave equals the sum of the potential and kinetic energy. Sound power (P_w) is the rate of change of the energy (from potential to kinetic) with respect to time as given in Equation 2-2 in which A is the cross-sectional area of propagation of the sound wave (Arcadio & Gregoria, 2002). The rate of transmission of sound power per unit area of cross section (A) in the direction of travel of the sound is known as sound intensity (I). Sound intensity is commonly expressed in terms of the root mean square of the sound wave as shown in Equation (2-3) (Arcadio & Gregoria, 2002).

$$P_w = \frac{1}{2}\ \rho A v \omega^2 S_m^2 \tag{2-2}$$

$$I = \frac{\Delta P_{rms}^2}{\rho v} \tag{2-3}$$

b) Sound Measurement

i. The A-Weighted Decibel Scale

Although sound is characterised in terms of pressure, power and intensity, noise measurements are never reported in the units thereof. This is because sound that a human ear can perceive comprises a wide range of pressures and intensities. Thus, to accommodate these wide variations, a logarithmic scale of zero to 140 units, known as decibels (dB), is used (Piccolo, Plutino & Cannistraro, 2005). A decibel is defined by Equation 2-4 in which: x is sound pressure/sound power/sound intensity; y refers to some arbitrary reference values which depend on the type of decibel being defined. The arbitrary reference values are 10^{-12} W for sound power; $2(10^{-5})$ Pa for intensity and 10^{-12} W/m^2 for sound pressure as shown in equations 2-5, 2-6 and 2-7, respectively (Richard, Daniel & Maguire, 2004).

$$dB = 10\log\frac{x}{y} \tag{2-4}$$

$$L_w = 10\,log\frac{P_w}{10^{-1}}\ dB \tag{2-5}$$

$$L_I = 10\log\frac{I}{10^{-1}}\ dB \tag{2-6}$$

$$L_p = 10\log\frac{\Delta P_{rms}^2}{(2\times10^{-5})^2}\ dB \tag{2-7}$$

Most sounds comprise of a wide range of frequencies which determine human ability to hear them. Humans readily hear sounds whose frequencies range from 1000 to 6000 Hz. Sounds dominated by frequencies below 100 Hz and above 10,000 Hz are difficult to hear (Bies & Hansen, 1996). Sound measurements need to be done in a way that approximates human response by giving more weight to readily heard frequencies. In order to achieve this, several weighting scales have been developed for sound measurement. These include A, B, C, D and E-weighted scales (Richard, Daniel & Maguire, 2004). The A-weighted scale has been conventionally adopted for environmental noise measurements due to its convenience and accuracy for most purposes. A-weighted sound level measurements are reported in units of dBA (Arcadio & Gregoria, 2002).

ii. Decibel Addition

A given sound spectrum may consist of various decibel readings. These must be added up to give rise to an overall reading. The addition is performed logarithmically such that the overall/total decibel readings (L_{pT}) for a sound spectrum comprising of sound pressures ranging from L_{p1}, L_{p2}, … to L_{pn} is given as shown in equation (2-8). Similarly, the total decibel readings corresponding to sound power level and sound intensity levels are computed as shown in equations 2-9 and 2-10, respectively.

$$L_{pT} = 10\log\left(\sum_{i=1}^{i=n}\sqrt{10^{\frac{L_{pi}}{10}}}\right)^2 \qquad (2\text{-}8)$$

$$L_{wT} = 10\log\sum_{i=1}^{1=n}10^{L_{wi}/10} \qquad (2\text{-}9)$$

$$L_{IT} = 10\log\sum_{i=1}^{1=n}10^{L_{Ii}/10} \qquad (2\text{-}10)$$

The logarithmic additions described above have been summarized as shown in Table 2-8 (Bies & Hansen, 1996).

Table 0-1: Decibel addition

L1 – L2, dB	Add to L1
0 or 1	3 dB
2 or 3	2 dB
4 – 8	1 dB
9 or more	0 dB

iii. Miscellaneous Measures of Noise

In practice, three miscellaneous measures of noise have evolved. This enables noise pollution to be regarded in three dimensions namely, community noise, industrial noise and airport noise. Industrial noise and airport noise refer to noise emanating from industrial processes and airport operations respectively (Bruel & Kjaer, 1984). Community noise (also known as environmental noise) refers to noise emanating from common day-to-day human activities such as transportation, recreation, entertainment, worship, business, animal rearing, construction and domestic activities. Most often, noise from a combination of these sources add up to give rise to overall community/environmental noise and it may not be easy to discriminate and quantify the individual point sources. Thus, as a measure of noise, community/environmental noise seeks to conceptualize the noise environment in which human beings are exposed in their day-to-day life.

Various measures have been developed for quantifying community noise. These include: the statistical measure (L_N), continuous equivalent sound level (L_{eq}) day-night average sound level (L_{dn}) and noise pollution level (L_{NP}).Out of these measures, the continuous equivalent sound level is the most widely used for community noise assessment. L_{eq} is preferred for describing sound levels which vary over time to result in a single decibel reading. It accounts for the total sound energy involved over the given period of time and gives an A-weighted average equivalent for the period. L_{eq} is expressed as shown in equation 2-11 in which: p_0 is the reference pressure level (typically taken as 20 μPa); p_A is the acquired sound pressure; t_1 and t_2 are the start time and end time for measurement, respectively (Acardio & Gregoria, 2002).

$$L_{eq} = 10\log\left[\frac{1}{t_1 - t_2}\int_{t_1}^{t_2}\frac{p_A^2}{p_0^2}dt\right] \quad (2\text{-}11)$$

The statistical measure refers to a sound level that is either equalled or exceeded a given percent of the time, based on a probability distribution analysis. For instance, L_{90}, L_{20} and L_{10} refer to noise levels that are equalled/exceeded 90%, 20% and 10% of the time, respectively. The day-night average sound level is the equivalent sound level over a 24 hour period with an additional 10 dB (A) during the night (10.00 P.M. to 7.00 A.M.). Community noise levels can also be described in terms of another measure known as the community noise equivalent level (CNEL). CNEL is related to L_{DN} except that an additional 5 dB (A) is imposed between 7.00 P.M. and 10.00 P.M. and 10 dB (A) is added between 10.00 P.M. and 7.00 A.M. Noise pollution level is the equivalent sound level with a probability of exceedance of 0.5% (Environmental Protection UK, 2008).

iv. The Sound Level Meter

The instrument used to measure noise is the sound level meter. The meter should be located at a reasonable distance from the sound source to avoid obstruction (EPA South Australia, 2009). The sound level meter is first calibrated by a *calibrator.* When attached to the sound level meter, the calibrator produces a reference sound that calibrates the meter. Basically, a sound level meter consists of four parts namely, a microphone, sound amplifiers, weighting network and a display which shows readings in decibels (Gary *et al.,* 2001). The sound pressure of an incoming sound is received by the microphone where the pressure pattern of the sound is mimicked by a pressure transducer (such as a diaphragm) and the signal is converted to a small current of electricity. The resulting electrical signal if amplified by the amplifiers and an equivalent reading shown on the screen (Bies & Hansen, 2002).

It is important to note that the sound pressure received by the meter is not the same as that which the ear perceives. As a result, a weighting network (A, B, C, D and E) – simply an electrical circuitry – is incorporated in the meter to help approximate human response and give a reading as close to it as possible (I-INCE, 2011). The work of the weighting network circuitry is to electronically subtract the actual sound pressure level, at a particular frequency, received at the microphone with respect to the network upon which the meter is set (Bies & Hansen, 1996). A sample plot of weighting networks for scale A, B and C is shown in the Figure 2-2. The difference between the actual pressure level and a given frequency-dependent value, from the weighting network plot, is displayed as the sound level reading. The units of this reading depend on the scale used thus it may be reported as dBA, dBB or dBC for scales A, B and C, respectively. While the A-network is recommended for most community noise measurements, the D network is best suited for approximating human response to airport noise (Acardi & Gregoria, 2002).

v. Sound Perception

The human ear is divided into three parts namely, the outer ear, the middle-ear and the inner ear, as shown in Figure 2-3. The outer ear comprises the pinna, the auditory canal and the tympanic membrane. The pinna collects and concentrates sound waves transmitted through the air or other medium into the auditory canal. The sound waves are further transmitted through the auditory canal to hit the tympanic membrane, setting it into vibration. In the air-filled middle ear, there are three tiny bones known as ossicles which include the malleous, incus and stapes onto which the vibrations of the tympanic membrane are transmitted (Eco-Healthy Child Care, 2010). Further inside is the inner ear which houses the semi-circular canals and the cochlea and is filled by a fluid known as perilymph (Guyton, 1987). The semi-circular canals are responsible for body balance whereas the cochlea is the sense organ for hearing. The inner ear is preceded by an element called the oval window at its entrance. Its cross-section also reveals other membranes namely, Reissner's membrane, basilar membrane (divides the cochlea into two galleries, the upper and lower galleries) and tectorial membrane. About 23,500 hair cells constitute the area between the tectorial and basilar membranes (American Speech-Language-Hearing Association, 1991).

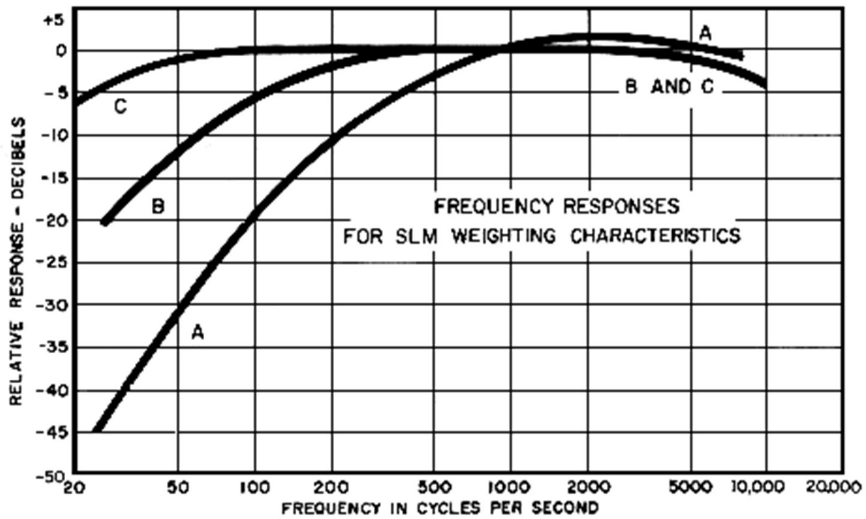

Figure 0-1: Plot of weighting networks
Adapted from: Acardio & Gregoria (2002)

The vibrations from the middle ear enter the inner ear via the ova window and generate waves in the perilymph fluid. The waves are further transmitted the upper cochlea gallery , through the lower gallery to the round window, displacing the basilar membrane and generating straining effect on the hair cells. The straining effect generates electric signals which are transmitted though the auditory nerves to the brain for interpretation thus constituting sound perception. The ear has an inbuilt ability (Acoustic reflex) to protect itself from intense noise provided the sound does not propagate as a sudden impact. Acoustic reflex is facilitated by the tensor tympani and stapedius muscles which stiffen the tympanic membrane to minimize vibrations (Murthy, Ahmad and Nath, 2007). Sound pressures that the ear can perceive range from 2(10-5) Pa to 200 Pa.It is important to note that the ear receives the physical effects of sound in form of pressure, power and intensity. However, what the ear perceives depends on the ear's perception of the received effect.

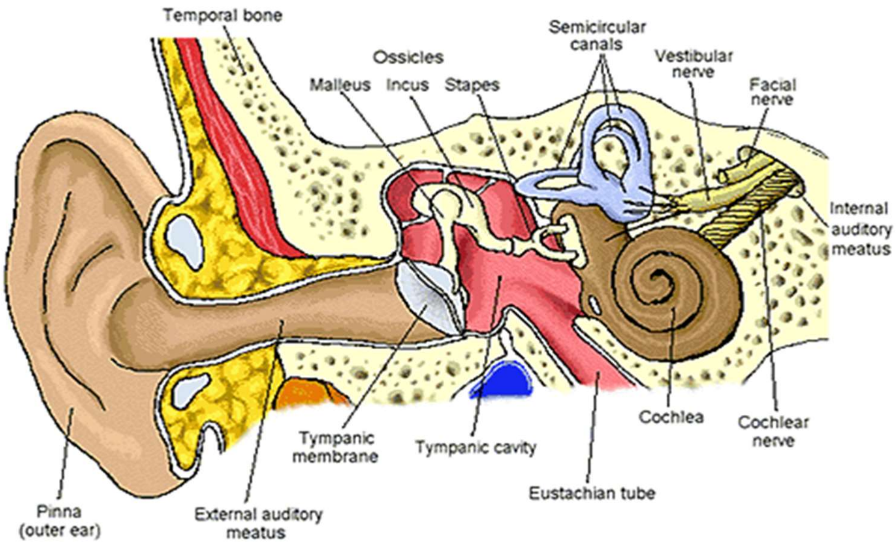

Figure 0-2: The human ear
Adapted from: Acardio & Gregoria (2002)

Loudness describes how the brain perceives the magnitude of the sound levels; high sound levels are perceived as high and vice versa. In other words, the ear does not hear the decibels, but their perception thus; loudness is measured in terms of units called the *phon* and *sone*. Sounds normally consist of a combination of many frequencies, with the audible range being between 16 and 20000 Hz. Sounds below and above this range are referred to as *infrasound* and *ultrasound,* respectively. "*Phon* describes the loudness of a sound that is numerically equal to the corresponding sound pressure level when heard at a frequency of 1000 Hz" (Arcadio & Gregoria, 2002, p. 694). Thus, a sound pressure level of 40 dB is 40 *Phons* when heard at 1000 Hz. At other frequencies, the decibel level may be different. On the other hand, the Sone describes "the loudness of 40 Phons made arbitrarily equal to 1" as shown in equation 2-12 in which P is the number of phons.

$$Sone, S = 2^{(P-4\ )/10} \qquad (2\text{-}12)$$

2.6. Noise Pollution Control

a) Noise Pollution Control Measures

Generally, there are four methods by which noise pollution can be controlled namely, enclosing the source of noise, enclosing the noise receiver, installing a barrier between the source of noise and the receiver and regulating noise generation as illustrated in Figure 2-1. Enclosing the noise source/receiver requires that an enclosure that does not vibrate when hit by sound waves is used at the source to contain the noise or around the receiver to protect them from the noise. Vibration of materials vary inversely with their mass hence ideal enclosures are materials with high densities (Arcadio & Gregoria, 2002). On the other hand, noise barrier between the source and the receiver uses a physical barrier that prevents noise transmission that is installed between the noise source and the receiver. This is mostly used in highways to minimize traffic noise pollution. Landscaping, though not particularly a good barrier, may also be used for the psychological purpose of blocking the sight of the highway (Thumman & Miller, 1986).

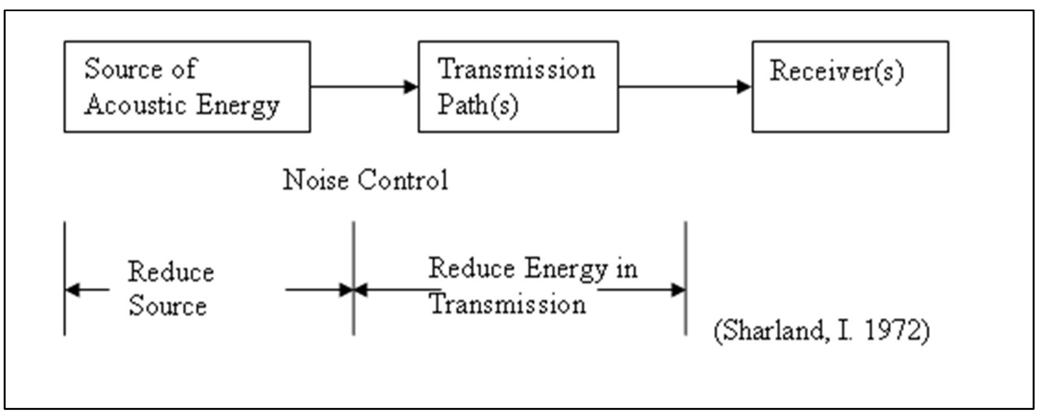

Figure 0-3: Noise pollution control measures.

Noise can be controlled at the source by use of regulating noise generators such as silencers/mufflers or isolating the noise source by vibration control (Acardio & Gregoria, 2002). Silencers used may be absorptive silencers, reactive expansion chambers or diffusers. Absorptive silencers are ducts (straight, bent or plenum chambers) lined directly on the interior with an acoustic material which attenuates/dissipates the noise by absorbing it. Unlike absorptive silencers, reactive expansion mufflers are not lined with absorptive materials. Rather, they reflect the sound waves such that the waves of incoming noise source are cancelled (destructive interference) thus attenuating the noise. Reactive silencers are mainly used in trucks and automobiles. Diffusers are used to attenuate noise by reducing the air velocity i.e. diffusing the source air into a series of low-velocity small flows using a suitable mechanism (Arcadio & Gregoria, 2002). Finally, the use of noise vibration control helps isolate the noise source by preventing vibrations that transmit noise. Vibration isolators in use include: springs, rubber mounts, ceiling mounts, suspended mounts and composite mounts (Thumman & Miller, 1986).

b) Noise Pollution Control Criteria

Various noise control criteria have been developed to control noise pollution as presented in Tables 2.2 to 2.7. They prescribe noise levels/standards for various activities which should be maintained for protection of public health and welfare. This study will focus mainly on WHO, EPA and NEMA standards. Table 2.2 presents WHO general guidelines to prevent health effects of noise for people in specific environments. In Table 2.3, the noise criteria are more specific and indicate a range and time-base over which critical health effects are observed as suggested by the WHO (1999). Similarly, Table 2.4 outlines EPA average yearly noise criteria that would protect public health and welfare with an adequate margin of safety. A summarised version of Table 2.4 is given in Table 2.5 for quick general reference. In Kenya, the Noise and Excessive Vibration Pollution (Control) Regulations, 2009 provides noise criteria to protect people from adverse impacts of health in specific environments (viz. construction sites, places of worship, commercial centres, residential areas, mixed zones as well as special areas such as hospitals). The Kenyan noise criteria are summarised in Tables 2.6 and 2.7.

Table 0-2: WHO summary guidelines for community noise in specific environments

Average night noise level over a year $L_{night,Outside}$	**Health effects observed in the population**
Up to 30 dB	No Substantial Biological Effects (Although Individual Sensitivities and Circumstances May Differ) $L_{night,Outside}$ of 30 dB is equivalent to NOEL for night noise.
30 – 40 dB	Various effects on sleep: body movements, awakenings, self-reported sleep disturbance, and arousals. Intensity of effect depends on nature of the source and number of noise events. Vulnerable groups (Children; Elderly; The chronically ill) are more susceptible However, even in the worst-case scenario, effects are modest $L_{night,Outside}$ of 40 dB is equivalent to LOAEL for night noise.
40 – 55 dB	Adverse Health Effects Many have to adapt their lives to cope with the noise at night Vulnerable Groups are more severely affected
Above 55 dB	Increasingly dangerous for public health (frequent adverse health effects) Many are highly annoyed and Sleep Disturbed Evidence of increased risk of cardiovascular disease

Adapted from: WHO (2009) Night Noise Guidelines for Europe, pg. 108

Table 0-3: WHO guidelines for community noise in specific environments

Specific Environment	Critical Health Effect(s)	LAeq [dB(A)]	Time Base [Hours]	L_{Amax} Fast [dB]
Outdoor living area	Serious annoyance (daytime & evening)	55	16	-
	Moderate Annoyance (Daytime & Evening)	50	16	-
Dwelling, Indoors	Speech Intelligibility;	35	16	
Inside Bedrooms	Moderate Annoyance (Daytime & Evening)			
	Sleep Disturbance (Night Time)	30	8	45
Outside Bedrooms	Sleep Disturbance, Windows Open (Outdoor Values)	45	8	60

Specific Environment	Critical Health Effect(s)	LAeq [dB(A)]	Time Base [Hours]	L_{Amax} Fast [dB]
School Class Rooms & Pre-schools, indoors	Speech Intelligibility; Disturbance of Information Extraction, Message Communicatio n	35	During Class	-
Pre-School Bedrooms, Indoors	Sleep Disturbance	30	Sleepin g Time	45
School Playground, Outdoor	Annoyance (External Source)	55	During Play	-
Hospital, Ward Rooms, Indoors	Sleep Disturbance (Night Time)	30	8	40
	Sleep Disturbance (Daytime & Evenings)	30	16	-
Hospitals, Treatment Rooms, Indoors	Interference With Rest and Recovery	#1		
Industrial, Commercial Shopping and Traffic Areas, Indoors and Outdoors	Hearing Impairment	70	24	11 0
Ceremonies, Festivals and Entertainment Events	Hearing impairments (Patrons: <5 times/year)	10 0	4	11 0
Public Addresses, Indoors and Outdoors	Hearing Impairment	85	1	11 0
Music and Other Sounds through headphones/earphon e	Hearing Impairment (Free-Field Value)	85 #4	1	11 0
Impulse Sounds from Toys,	Hearing Impairment (Adults)	-	-	14 0 #2

Specific Environment	Critical Health Effect(s)	LAeq [dB(A)]	Time Base [Hours]	L_{Amax} Fast [dB]
Fireworks and Firearms	Hearing Impairment (Children)	-	-	120 #2
Outdoors in Parkland and Conservation Areas	Disruption of Tranquillity	#3		

In the table: #1 = as low as possible; #2 = peak sound pressure (not LAF, max) measured 100mm from the ear; #3 = existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low; #4 = under head-phones, adapted to free-field values.Adapted from: WHO (1999) Guidelines for Community Noise pg. 16.

Table 0-4: EPA Yearly average noise levels to protect public health and welfare with an adequate margin of safety

	Measure	Indoor (protect against)			Outdoor (protect against)		
		Activity Interference	Hearing loss	Both effects	Activity Inteference	Hearing loss	Both effects
Residential with Outside Space and Farm Residences	Ldn	45		45	50		55
	Leq (24)		70			70	
Residential with No Outside Space	Ldn	45		45			
	Leq (24)		70				
Commercial	Leq (24)	(a)	70	70 (c)	(a)	70	70 (c)
Inside Transportation	Leq (24)	(a)	70	(a)			
Industrial	Leq (24)	(a)	70	70 (c)	(a)	70	70 (c)
Hospitals	Ldn	45		45	55		55
	Leq (24)		70			70	
Educational Areas	Ldn	45		45	55		55
	Leq (24)		70			70	
Recreational Areas	Leq (24)	(a)	70	70 (c)	(a)	70	70 (c)
Farmland and General Unpopulated Land	Leq (24)				(a)	70	70 (c)

Adapted from: US EPA (1974). Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, pg. 29.

Table 0-5: EPA Summary of noise levels that protect public health and welfare with an adequate margin of safety

Effect	Level	Area
Hearing Loss	Leq (24 h) < 70 dB A	All Areas
Outdoor Activity Interference and Annoyance	Ldn < 55 dB A	Outdoors: Residential areas; Farms; Other outdoor areas where people spend widely varying amounts of time; Other places in which quiet is a basis for use
	Leq (24 h) < 55 dB A	Outdoors where people spend limited amounts of time e.g. school yards, playgrounds etc.
Indoor Activity Interference and Annoyance	Ldn < 45 dB A	Indoor Residential Areas
	Leq (24 h) < 45 dB A	Other indoor areas with human activities e.g. schools etc.

Adapted from: US EPA (1974). Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, pg. 3.

Table 0-6: Maximum permissible noise levels for various areas (NEMA, Kenya)

Zone	Sound Level Limits dB(A) (Leq. 14 h)		Noise Rating Level (NR) (Leq. 14 h)	
	Day	**Night**	**Day**	**Night**
Silent Zone	40	35	30	25
Places of Worship	40	35	30	25
Residential: Indoor	45	35	35	25
Residential: Outdoor	50	35	40	25
Mixed Residential (With some commercial and places of entertainment)	55	35	50	25
Commercial	60	35	55	25

Adapted from: The Environmental Management and Coordination (Noise and Excessive Vibration Pollution) (Control) Regulations, 2009, Kenya.

Table 0-7: Maximum permissible noise levels for special areas (NEMA, Kenya)

Facility	Maximum Permissible Noise Level (Leq) dB(A)	
	Day*	Night**

Health Facilities; Education Institutions; Homes for disabled etc.	60	35
Residential	60	35
Areas other than those described in (i) and (ii)	75	65

In the table: *6.01 am – 8.00 pm (Leq 14 h); **8.01 pm – 6.00 am (Leq 10 h); adapted from: The Environmental Management and Coordination (Noise and Excessive Vibration Pollution) (Control) Regulations, 2009, Kenya

CHAPTER THREE

MATERIALS AND METHODS

3.1.Introduction

This chapter presents the methodology adopted to meet of the three objectives. Overall, the methodology adopted included experimental measurements of noise levels as well as comparisons with secondary data reviewed in Chapter 2 as presented below.

3.2. Assessing the Extent of Community Noise Pollution in Nairobi City

3.2.1. Research Design

Experimental research design was used to assess the extent of community noise pollution in Nairobi City. The data was acquired at selected roads, streets, bus stops, commercial centres, entertainment spots and places of worship in Nairobi City as is summarized in Figure 3-1. Sound level measurements were taken using a digital integrating sound level meter (SVANTEK 971). This is a Class 1 sound level meter that conforms to the IEC 61672-1:2002 standards. Prior to its use, the sound level meter was calibrated, as per the manufacturer's manual, using a calibrator model SV34. As Robert Thorne (2007) notes, purpose-design calibration provides test signals required for verification of the instrumentation and for ensuring that recorded sound levels are set to a known level. The calibration system constitutes a sound source and a microphone interphase unit. The sound source comprises a series of recorded sound levels/compilations/frequencies stored on a disk. In order to calibrate the instrument, the microphone system was first fitted into the interface unit then the sound source played. A LED signal was observed when a particular calibration sound was produced at a known level (Thorne, 2007).

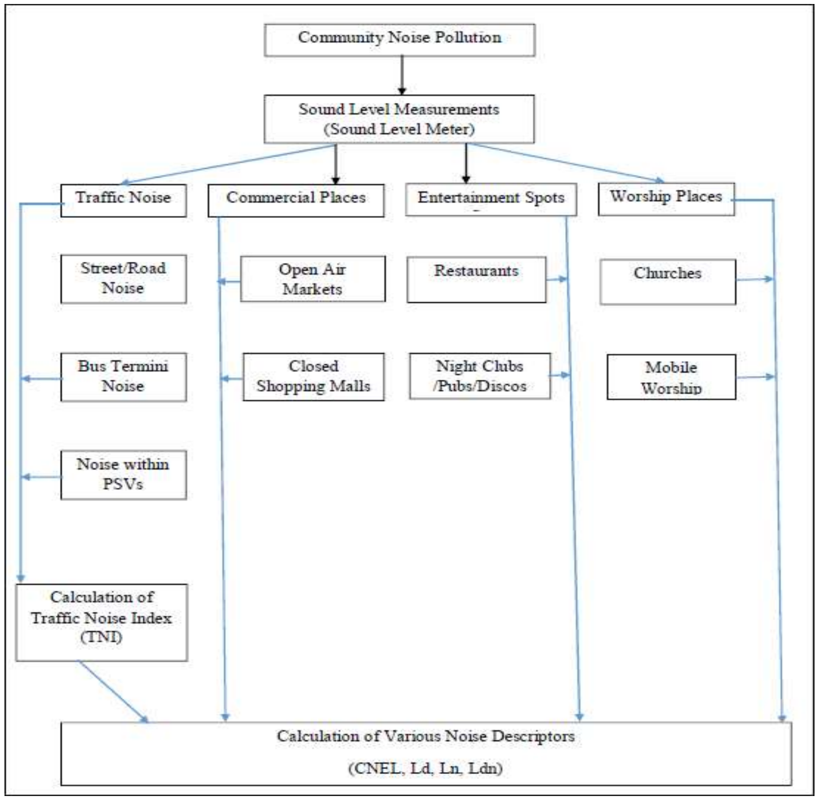

Figure 0-1: Layout of noise sources of interest.

After calibration, the meter was set to "Fast" mode and the weighting network switched to "A". EPA (1999) recommends the A-weighted scale due to its convenience, accuracy for most purposes, and conventional use all over the world. For all outdoor noise measurements (viz. bus stations, road traffic and open-air markets) the sound level meter was mounted on a tripod stand and set at about 1.5m above the ground level with the microphone pointing at the perceived sound source. A height of 1-1.5m is recommended for consistency of measurements and to approximate the average height of the human ear (Jamrah & Omari, 2005; Piccolo *et al.,* 2005; Ramis, Alba & Hernandez, 2003; Alam, 2006). For indoor, and the other noise measurements, the tripod was not used thus the instrument was set at a convenient height and position for the researcher. In addition, the SLM was set at a distance of 3m from the noise source wherever possible. Various studies recommend a distance of 1-3m from the noise source to prevent attenuation and/or reverberation effect that may compromise the accuracy of recorded measurements (Piccolo *et al.,* 2005; Ramis, Alba & Hernandez, 2003; Ehrampoush *et al.,* 2012; Ochuko, 2013). The meter was set to simultaneously record values of: Lmax, Lmin, Ln (L_{10}, L_{30}, L_{50}, and L_{90}), CNEL and L_{eq}. The sound meter (SVAN 971) gave detailed time-histories of all these noise measures simultaneously. A layout of the experimental set-up is illustrated in Figure 3-2. In addition to sound level measurements, a hand-held GPS receiver was set to record the geographical location of each sampling point.

3.2.2. Data Collection Procedure

a) Measuring Road Traffic Noise Levels

A total of 172 sets of traffic noise measurements were made for 26 days between the periods of 5th December, 2014 and 25th January, 2015. On each day, hourly measurements were made for four to eight hours resulting in a total of 172 measurements. The measurements were taken on three major roads namely, *Jogoo Road,* Mombasa Road and sections of *Thika Superhighway*. The following parameters were measured: average equivalent sound level, LAeq (dB A); L_{10}; M_{min} and L_{max}. Preliminary site visits were conducted to identify sampling stations on each road upon which an average noise level for the road was to be deduced. The criteria for selecting sampling stations involved identifying areas in which traffic was the dominant source of noise and thus other noise sources were negligible, as well as areas where there is relatively free flow of traffic (Alam, 2006).

At each sampling station, noise levels were recorded on both sides of the road at 10 minute intervals for one hour (30 minutes on either sides of the road) using the sound level meter. In order to establish the temporal distribution of noise levels, noise measurements were made, at each sampling station, three (3) times a day to capture the morning rush-hour (0630-0930 hours), the mid-day non-rush hour (1230-1530 hours) and the evening rush-hour (1730-203 hours) as recommended by (Ramis, Alba & Hernandez, 2003; Ehrampoush *et al.,* 2012; Ochuko, 2013). The measurements were replicated for three (3) days a week i.e. Tuesdays, Wednesdays and Thursdays. Figure 3-3 illustrates the roadside noise measurement set up.

Figure 0-2: Experimental set-up.

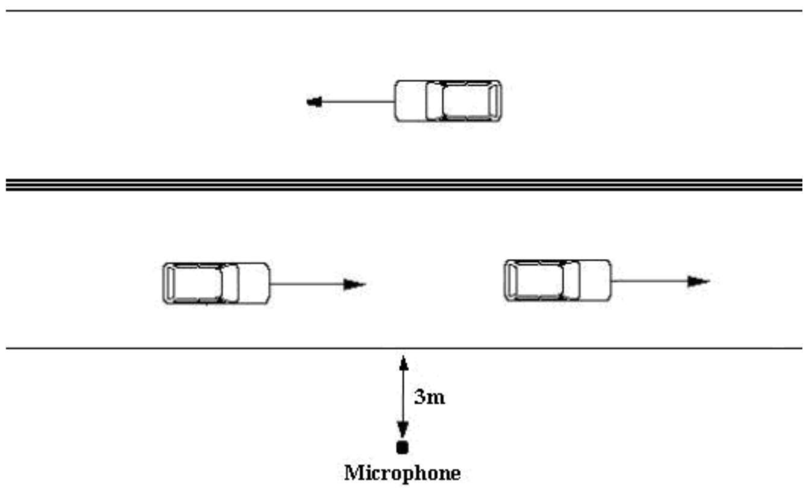

Figure 0-3: Road traffic noise measurement on highways.

Alongside noise measurements, other parameters perceived to affect noise levels (from literature) were measured. These included: Traffic volume, Q (vehicles per hour); Traffic Composition (Kenya Roads Act, 2007 defines small vehicles as vehicles below 3050kg, and heavy vehicles above 3050 kg); average vehicle speed, V (km/hour); air temperature, T (^oC); and relative humidity, RH (%). Q was determined by direct count method; average speed of vehicles was measured by distance/time method. Moreover, the prevailing air temperature and relative humidity were measured using an infrared/thermocouple handheld meter (Omega RH511). This meter is capable of measuring both air temperature, relative humidity and non-contact surface temperature. These factors were important because they affected the resultant ambient noise level emitted by traffic and were useful in modelling traffic noise (Kumar & Murugappan, 2013).

Similarly, a total of 15 bus stations within/around Nairobi Central Business District (CBD) were sampled for the study. These include: *KBS Bus Station; Tusker (Ronald Ngala Street); Ambassador Stage; Commercial; Kencom; Odeon; Railways 1; Railways 2; Muthurwa 1; Muthurwa 2; Machakos Country Bus Station; Posta Stage (Tom Mboya Street); Tea Room Stage (Accra Road) and Old Nation Stage.* Figure 3-4 shows some of the main bus stations in Nairobi CBD. Noise measurements were made twice a day, i.e., morning (09:00 – 13:00 hours) and evening (16:00-19:00 hours) during weekdays at three to five (3-5) points lasting one hour each. An average noise level for each bus station was then computed. Only 15 bus stations were chosen to help raise the required sample size for traffic noise investigations (see Section 3.2.4) and to allow adequate time for detailed analysis of each station. Similar approaches have been applied in other past studies such as Ochuko (2013), Alam (2006) and Thorne (2007) with reasonable success.

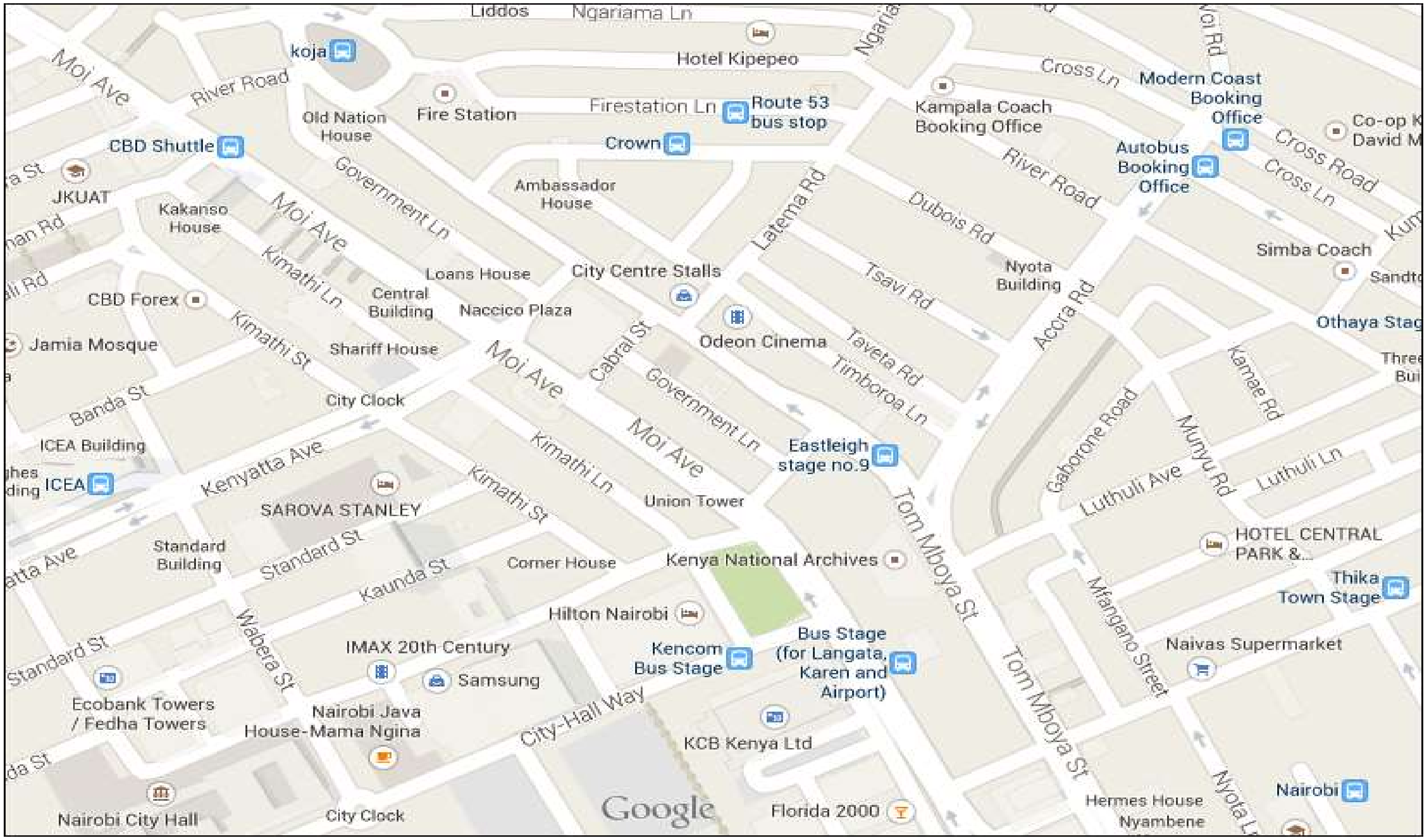

Figure 0-4: A map showing the main bus stations in Nairobi CBD.
(Source: Google Earth, 2015)

In addition to highway traffic noise and noise at bus stations, noise inside PSVs was also surveyed. To assess noise within PSVs, the area of study was categorised into four geographical routes, namely, Nairobi CBD-Nairobi East, Nairobi CBD-Nairobi West, Nairobi CBD-Nairobi North and Nairobi CBD-Nairobi South as shown in Figure 3-5. A total of 60 PSVs, 15 in every route (comprising buses, mini-buses and 14-seater PSVs) were randomly sampled. Posing as passengers in every PSV, noise measurements (L_{Aeq} and L_{90}) were taken using the SLM for the duration of travel (which ranged from 15-60 minutes). In order to enhance the integrity of measured noise levels, PSVs were assessed for noise pollution anonymously, without the consent of their crew. This was due to fear that some may deliberately regulate, particularly, the level of music playing in their vehicles if they knew they were under study. Data collection was achieved by posing as a passenger in randomly selected vehicles while recording noise levels at five (5) minute intervals during the duration of travel. Unless otherwise necessary, the PSV crews' consent was not sought before taking measurements in order to avoid controlling their music systems, unusually, which would have compromised the reliability of measured noise levels.

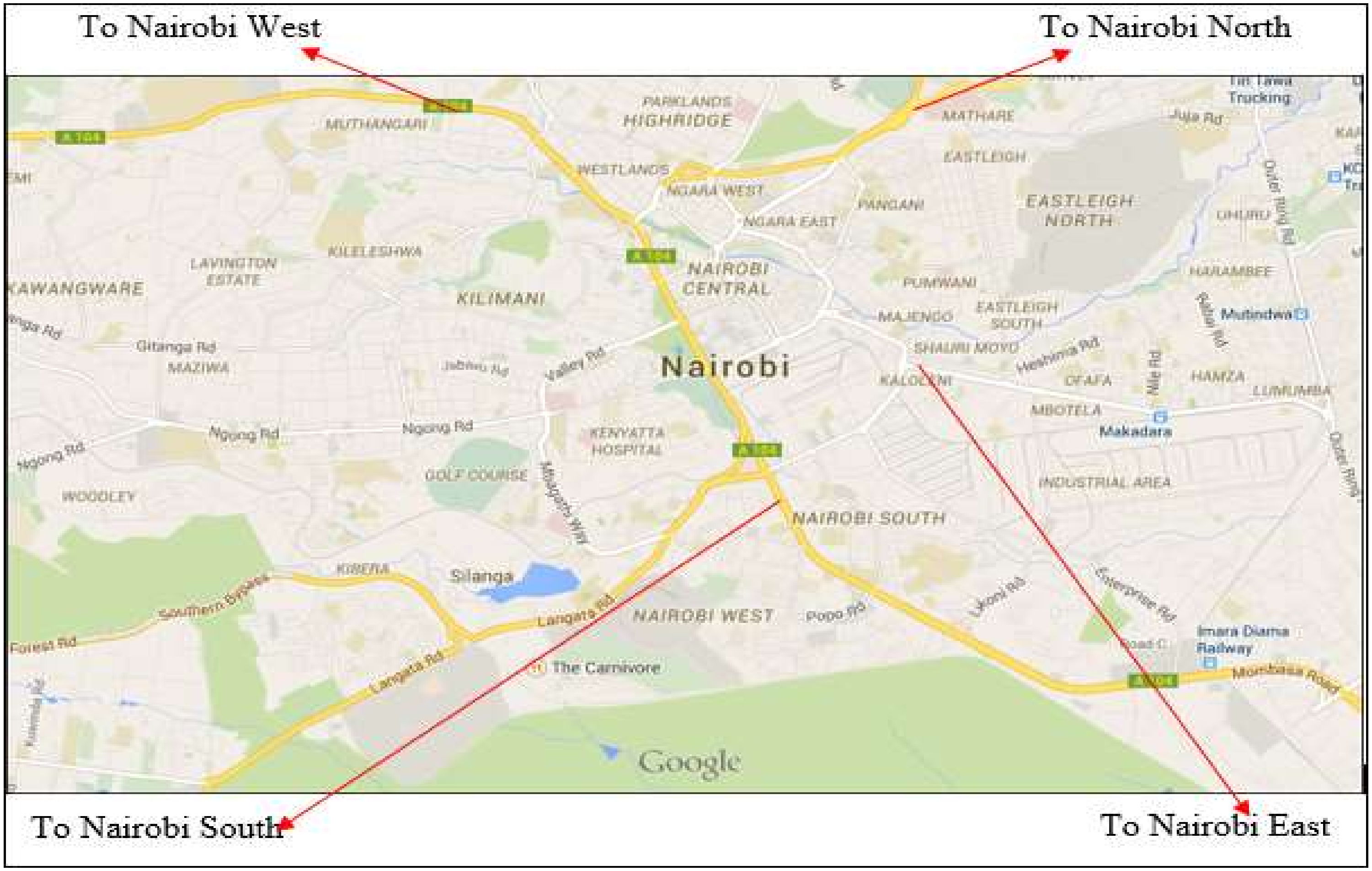

Figure 0-5: A map showing the main PSV routes in Nairobi City.
(Source: Google Earth, 2015)

b) Measuring Noise Levels at Commercial Centres

A total of 15 markets were selected by simple random sampling for the study. These included 10 open air markets namely, *Muthurwa, Gikomba, City, Ngara, Kariokor, Kangemi, Eastleigh, Majengo Stage, KBS Stage and Ngara Garage*; four indoor shopping malls namely, *Cianda Shopping Mall, Tuskys Supermarket (Imara), Naivas Supermarket (Westlands), and Nakumatt Supermarket (Galleria);* and one commercial roadshow promotion for Chase Bank, a local commercial bank in the city. Posing as shoppers, noise measurements were made once at each market for a period of one hour at 3-5 selected points, depending on the size of the market, during weekdays (Monday-Friday). The 3-5 measurements were then used to compute a representative average equivalent noise level for each market. Such a procedure has been used in past studies such as Essandoh and Armarch (2011), Dursun (2006), Zannin and Ferreira (2009), and Alam (2006) and is recommended for an accurate assessment of temporal and spatial distribution of commercial-based community noise pollution. Besides overall ambient noise measurements, the individual sources of noise in the market were noted.

c) Measuring Noise Levels at Entertainment Joints

Fifteen pubs and/or restaurants were randomly sampled for the study. Since these places are most active in the night and during weekends, noise measurements were first taken in the evenings (18:00-22:00 hours) for a period of 30-60 minutes between Thursdays and Saturdays. After unsuccessful initial attempts to seek consent of the pub managers, the researchers opted to pose as clients and take noise measurements anonymously. After a complete round of night measurements, the stations were visited during the day (09:00-16:00 hours) and a single 5-15 minute noise measurement recorded for temporal comparison. Seven of the sampled entertainment places were within Nairobi CBD including: *Tribeka (Kimathi Street); Zodiak Lounce (Tom Mboya Street); Mist Bar & Restaurant (Tom Mboya Street); Lazaru Inn (Moi Avenue); Samba Pub (Moi Avenue); Dodi's Pub (Kenya Cinema); and Heritage Grill (Moi Avenue).* The rest were staggered in the four regions east, west, north and south of the CBD including: *Chomabase (Doonholm); Savanna Pub (Greenfields); The Green Side Pub (Kasarani); The Vantage Place (Kasarani); The Bulls Pub (Kasarani); Pints Makuti (Kahawa); Hunters Grill (Dagoretti); and Tacos Club (Westlands).*

In order to establish the temporal variation of noise levels, each joint was visited at three different times in a day (mornings, afternoons and evenings). However, to avoid suspicion, the different times were staggered over different days such that if a joint is visited in the morning on one day, the following day it will be visited in the afternoon and in the evening the day after. Such a procedure had been successfully utilized to study noise at places of entertainment in Morogoro Town, Tanzania (Samagwa, Mkoma & Tungaraza, 2009), with a reasonable degree of success.

d) Measuring Noise Levels at Places of Worship

A total of 15 protestant churches were randomly sampled from Nairobi CBD and from its four surrounding regions for the study. From a database of over 100 churches listed by NEMA (2011), simple random sampling yielded the following churches which were included in the study: *Cathedral of Power (CBD); Jesus is Alive Ministries (CBD); Neno Evenagelism Centre (CBD); Deliverence (Doonholm); PEFA (Doonholm); Mavuno Mashariki (Doonholm); SDA KTTC (Gigiri); SDA Sportsview (Kasarani); PCEA (Kasarani); Mountain of Fire (CBD); Soldiers of Faith (Huruma); Redeemed Gospel (South B); Full Gospel (River Road); Full Gospel (Kinoo); and Deliverence Church (Jinja Road).*

Posing as worshippers, noise levels were measured in each of the churches using the SLM, carried at a sitting position. These measurements were taken during the churches' respective worship days which were Sundays and Saturdays. The measurements were done for a period of 60 minutes, 30 minutes during singing, praise and worship sessions (P&W) and 30 minutes during preaching sessions. Both LAeq and L90 were used to characterise noise in these churches. Each of the churches was sampled only once, assuming that worship services are carried out in a similar fashion using same instruments every other worship day, thus there was no need for multiple replications. Noise measurements were made anonymously (without consent) to avoid possible unusual alteration of noise levels during the measurement times, as suggested by Silva and Cabral (2011).

3.2.3. Data Processing and Analysis

Mean values of the measured noise levels were obtained to provide an overall temporal and spatial distribution of noise at each sampling site. The mean levels were compared with legislated standards (NEMA) and the extent and effects of noise pollution quantified by the degree of deviation from the standards. A one sample t-test was also conducted to assess the statistical significance of the deviations reported between actual noise levels and legislated standards. Both 5 and 1% level of significance were considered for the statistical tests since noise has an implication on public health. In addition, the noise measurements taken were used to compute various noise descriptors, used to quantify noise pollution, particularly, L_d and L_n as shown in equations (3-1), and (3-2), respectively, in which: L_d is day time noise level; L_n is night time noise level; $LAeq_M$, $LAeq_A$, $LAeq_E$ and $LAeq_N$ denote the equivalent sound pressure level for the morning, afternoon, evening and night measurements respectively (Ochuko, 2013).

$$L_d = 10\log\left[\frac{1}{2}\left\{\left(10^{\frac{L_{AeqM}}{10}}\right) + \left(10^{\frac{L_{AeqA}}{10}}\right)\right\}\right] \quad (3\text{-}1)$$

$$L_n = 10\log\left[\frac{1}{2}\left\{\left(10^{\frac{L_{AeqE}}{10}}\right) + \left(10^{\frac{L_{AeqN}}{10}}\right)\right\}\right] \quad (3\text{-}2)$$

The results of equations (3-1) and (3-2) were used to determine the day-night noise level (L_{dn}) as shown in equation (3-3), Ochuko (2013).

$$L_{dn} = 10\log\left[\frac{1}{24}\left\{\left(15 \times 10^{\frac{L_d}{10}}\right) + \left(9 \times 10^{\frac{L_{n+10}}{10}}\right)\right\}\right] \quad (3\text{-}3)$$

Another important community noise descriptor was determined, for traffic noise assessment, is the traffic noise index (TNI) as shown in equation (3-4). In the equation, L_{10} and L_{90} denote the A-weighted decibel levels exceeded 10 and 90% of the time, respectively, (Acardio & Gregoria, 2002). TNI is used to measure the degree of nuisance resulting from traffic and traffic related noise sources.

$$TNI = 4(L_{10} - L_{90}) + (L_{90} - 30) \quad (3\text{-}4)$$

3.3. Development of a Regression Model for Predicting Traffic Noise Pollution

The traffic noise parameters measured in Section (3.1) were divided into two portions, the modelling dataset (80%) and the validating dataset (20%) (Jamrah *et al.,* 2006). The modelling dataset was used to develop a regression model for predicting traffic noise pollution levels. According to past studies it has been proved that traffic noise level (LAeq) is a function of Q, P, V, T and RH, which were then adopted as the independent variables for the desired model (Golmohammadi *et al.,* 2009; Mishra, Parida & Rangnekar, 2010; Jamrah *et al.,* 2006; Rawat, Katiyar & Pratibha, 2009; Pachiappan & Govindaraj, 2013). These studies (Golmohammadi *et al.,* 2009; Mishra, Parida & Rangnekar, 2010; Jamrah *et al.,* 2006; Rawat, Katiyar & Pratibha, 2009; Pachiappan & Govindaraj, 2013) recommend the multiple regression modelling as a useful methodology for modelling L_{Aeq}.

Thus, the measured values of LAeq were plotted against each of the independent variables (Q, P, V, T, and RH) to obtain scatter plots of LAeq against Q, LAeq against P, LAeq against V, LAeq against T and LAeq against RH. From the scatter plots, the individual relationships between LAeq and each of the independent variables were established. Such relationships were in the form of the correlation equation (3-5) in which ∝, n, β and C were constants to be determined, X_i denoted the independent variables and E is the error term, accounting for any errors in measurement and/or human error (Jamrah *et al.,* 2006).

$$L_{Aeq} = C + \propto X_i^n + \beta X_i + E \quad (3\text{-}5)$$

Regression modelling was achieved in the statistical package for social scientists (SPSS Version 20) software environment. The resulting coefficient of determination (R^2) was used to assess the strength of correlation and thus select the best model between LAeq and each independent variable. In a stepwise manner, a general regression model was then fitted to predict LAeq from a combination of all the independent variables, after eliminating variables with insignificant effects From past studies (Golmohammadi *et al.,* 2009; Mishra, Parida & Rangnekar, 2010; Jamrah *et al.,* 2006; Rawat, Katiyar & Pratibha, 2009; Pachiappan & Govindaraj, 2013), it was initially projected that the model would be in the general form of equation (3-6) in which A, B, C, D, E, F, G, H_1 and a, b, c, d, e, f, g are constants to be determined.

$$L_{Aeq} = A + BQ^a + CP^b + DV^c + ED^d + FT_a^e + GT_s^f + H_1H^g \qquad (3\text{-}6)$$

Performance of the developed model was tested based on a 5% residual error interval. Residual error (ε) was computed using equation (3-7), and the performance of the model was determined by equation (3-8). In the equations, θ_a and θ_p are actual and predicted LAeq values, respectively, and N_i and N_t are the number of data with residual errors within the interval and total number of data in the dataset, respectively.

$$\varepsilon(\%) = 100\left(\frac{\theta_p - \theta_a}{\theta_a}\right) \qquad (3\text{-}7)$$

$$\eta(\%) = 100\left(\frac{N_i}{N_t}\right) \qquad (3\text{-}8)$$

For validation purposes, the developed model was then used to predict values of LAeq by substituting the measured independent variables (Q, P, V, D, T and RH) from each of the corresponding traffic sampling stations in the validation dataset. The predicted noise values were subjected to a paired t-test against actual noise levels at 5 and 1 % level of significance to establish whether they were statistically different.

3.4.Evaluating Effects of Community Noise Pollution

3.4.1. Research Design

The study employed both descriptive and cross-sectional research designs to evaluate the effects of community noise pollution on public health and welfare. A descriptive study is a type of observational study in which the researcher observes events occurring in a population without any manipulation or interruption. It is recommended for preliminary assessment of disease prevalence and/or exposure to risk factors with regards to spatial or temporal distribution, which are the bases of this study (Creswell, 2012; Alam, 2006). In a cross-sectional study, the investigator conducts a single examination of a proportion of the population at one point in time and the results of the examination are extrapolated over the entire population as long as the sampling is done randomly (Creswell, 2012). The descriptive cross-sectional design was preferred for this study since, due to time and resource constraints, it was impossible to conduct long-term examination and/or biological experiments on the entire population of Nairobi City to determine public health effects of noise pollution. Furthermore, this research was more or less aimed at providing a snapshot of the noise situation in Nairobi city and the prevalence of noise effects on public health and welfare, as a foundation for further research in the area of noise pollution. Thus, as suggested by Creswell (2012), the descriptive cross-sectional research design was a suitable methodology for evaluating the effects of noise pollution in Nairobi City.

The key effects of noise which were evaluated included: NIHL; speech interference; sleep disturbance; physiological effects; mental illness; performance reduction; annoyance; psychological; and behavioural effects. Both qualitative and quantitative data were collected and analysed with reference to set standards and regulations for protecting public health and welfare. Qualitative data refers to all data that can be collected that is non-numerical in nature. It describes the nature/attributes of the population that cannot be measured and is important for explaining social phenomena in the population (Creswell, 2012). On the other hand, quantitative data refers to numerical data that represents the extent/quantity of a phenomena and can be used to establish cause-effect relationships (Creswell, 2012). Both qualitative and quantitative data were useful for this study since apart from quantifying the extent of noise pollution and its effects, the study sought to capture the social attributes of the affected population such as age, gender, education levels, vulnerability, level of awareness and individual attitudes towards community noise so as to provide a logical explanation for the observed noise phenomenon.

3.4.2. Target Population

The target population for this study constituted the residents of Nairobi City. According to the latest national census, the Nairobi administrative area (now Nairobi County) is home to some 3.138 million people with an estimated annual population growth rate of 3% (KBS, 2009). Eighty-five percent (85%) of this population relies on about 20000 privately owned PSVs (Matatus) for transportation in the city while the remaining 15% rely on personal vehicles (McGregor and Malingha, 2014). Going by the 2009 national census, in terms of religion, 82.5% of Nairobi residents are Christians (protestant 47.4%, catholic 23.3%, other 11.8%), 11.1% Muslims, 1.6% traditionalists, 1.7% other. Only 2.4% do not belong to any religion (KBS, 2009). Figure 3-6 shows a Google map of Nairobi City.

3.4.3. Sampling Frame

Sampling frame refers to the actual set of units within the target population, or the source materials/devices, from which a sample is drawn (Creswell, 2012). The sample for this survey was drawn from four areas of the target population. First are road users (people who are directly exposed to traffic noise, viz., PSV passengers, PSV crew, pedestrians, residents and/or traders along roads. The second category includes bus station users (traders, workers, passengers, passers-by). Thirdly, the sampling frame comprises users of commercial centres (including shoppers, traders and passers-by). Finally, worshippers from various churches within Nairobi CBD were considered. Two main data files were used to establish the sample namely, the geographical map of Nairobi City/CBD and the NEMA (2011) noise map. The geographical map ensured that the sample was spatially representative of Nairobi City whereas the NEMA (2011) noise map helped the researcher in identifying areas marked by NEMA as notorious noise sources and which require a detailed noise evaluation.

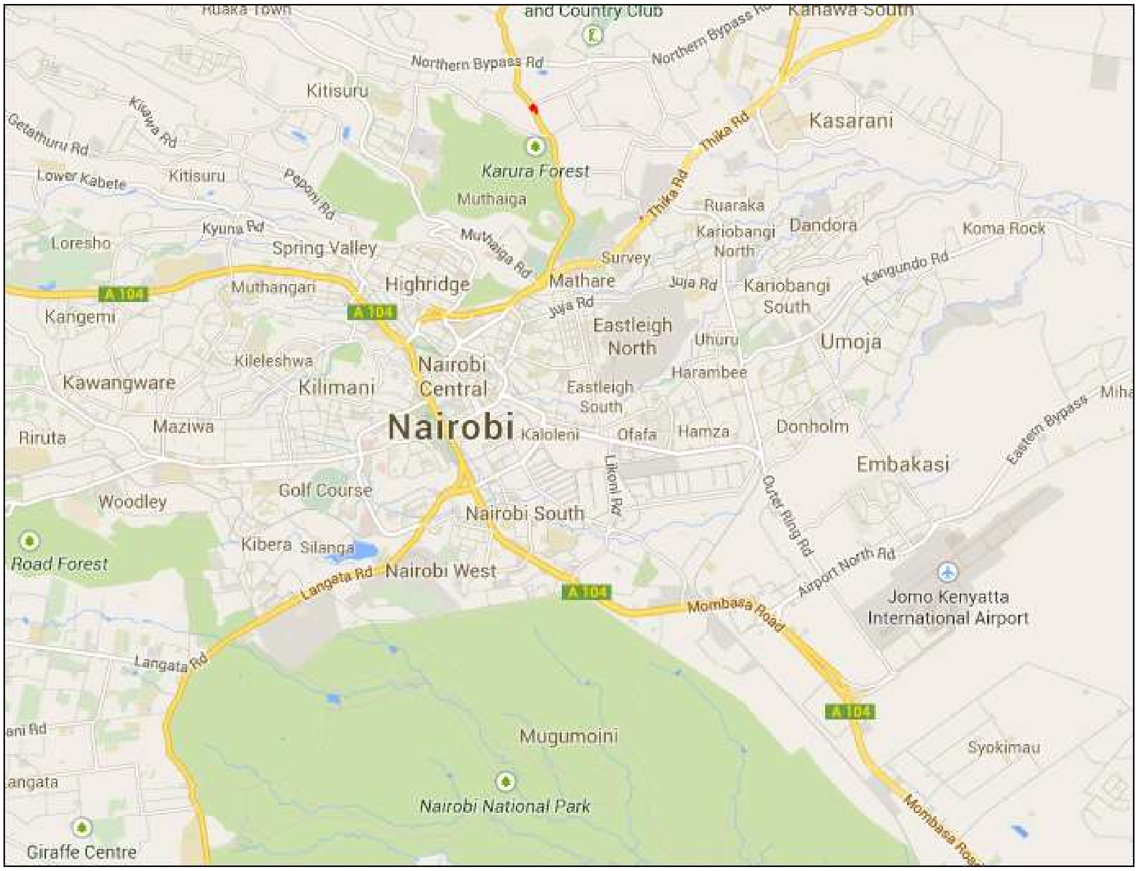

Figure 0-6: A Google map of Nairobi City
(Source: Google Earth, 2016)

3.4.4. Data Collection Instruments

The study made use of both primary and secondary data. Primary data was collected by a structured questionnaire which comprised of closed questions (Appendices 1-6). The questionnaires were developed and verified by Statistics experts for validity, reliability and professionalism. These were multiple-choice questions showing all the expected responses or response categories; for which respondents were to select a particular answer(s). Closed questions are recommended for such a survey as they show the level of detail the respondents are expected to provide. Besides, closed questions yield easily analysable results and do not require the respondents to have special skills to construct and present their responses (Czaja, 1998). The response categories were summarised into a two to five (5) point Likert scale showing the extent of agreement, frequency of behaviour or level of importance of an issue. A maximum of five to six (5-6) points is preferred in order to exhaust all possible responses that would not confuse the respondents (Czaja, 1998). Besides the Likert-scale type of responses, some questions required ranking of responses, for instance, to rank the effects of various noise sources in order of their importance. However, such questions are normally subject to confusion, even among the most educated respondents, and were minimized where possible, as suggested by (Creswell, 2012).

The survey questionnaire was divided into four (4) sections. The first section captured the background information about the respondents such as gender, age and education. These provided variables against which noise effects and awareness would be compared. In the second section, the respondents' duration of exposure to noise, from the sources under study, was assessed. Thirdly, the questionnaire assessed the prevalence of adverse effects of community noise pollution on health and welfare of the respondents as well as their opinion on experienced noise levels. This section also evaluated the level of awareness, of the respondents, of adverse noise effects on their health and welfare. This would be useful in designing appropriate control interventions to various target groups. Lastly, the questionnaire evaluated the level of exposure of the respondents to noise back at their respective places of residence. This gave the study an insight into the residential noise pollution, which due to technicalities involved in measuring domestic noise, was impossible to measure.

In addition to the primary data (obtained from the questionnaires), secondary data was obtained from past noise surveys, noise control laws, regulations and standards. In particular, the NEMA (2011) noise report was of essence. This report presents the results of a noise survey conducted in Nairobi, and other major towns/cities in Kenya, including a comprehensive noise map. The Kenya Noise and Excessive Vibration Pollution (Control) Regulations, 2009 was also an important source of secondary data. The legislation outlines local noise standards for various environments aimed at protecting public health and welfare. In order to make the study internationally relevant, reference was made to international noise criteria, particularly those of the WHO and EPA. The WHO and EPA was preferred in this study due their conventional use in the international arena, as was noted during the literature review for this research.

3.4.5. Pretesting and Pilot Survey

Prior to their administration, the questionnaire was pretested for clarity, validity and reliability and a pilot survey conducted to ascertain their practicability. The pretesting was conducted in Juja Town where the designed questionnaire was administered to 10 respondents as suggested by Czaja (1998). The 10 respondents were asked to fill the questionnaires, under close observation by the researcher, while thinking aloud to point out areas that are unclear or ambiguous and areas in which respondents encountered difficulties. Difficulties were noted and used to clarify/adjust the questionnaire for the final survey to ensure that responses obtained were relevant, accurate and unbiased (Neuman, 2001).

Thereafter, a pilot survey was conducted to test the questionnaires for practicability. This helped to identify major bugs in the questionnaires, or the general survey design, that would have compromise the study (Czaja, 1998). This involved testing all the survey steps, from the beginning to the end, with a reasonably larger sample of 40 people as is recommended by Bullen (2014). The pilot survey was conducted in Nairobi City where 40 respondents were sampled from among the sample frame. The results of the pilot survey were analysed so as to ascertain that the survey yielded the expected outcomes using SPSS 20. Based on the outcome of the pilot survey, the questionnaires were revised accordingly as recommended by Atmaca *et al.,* (2005), Guerra *et al.,* (2005), Ahmed *et al.,* (2004) and Bedi (2006).

3.4.6. Data Collection Procedure

a) Sampling Technique and Sample Size

Simple random sampling was used to select a representative sample from the sampling frame. This is a probabilistic sampling technique in which each element, or combination of elements, in the sampling frame has an equal chance of being selected (Creswell, 2012). In this study, the lottery method was applied since the sampling was conducted in the field during data collection, thus, it would be impossible to apply the random number method. In such an arrangement, willing respondents were required to pick lots marked with numbers. Those who pick even numbers were sampled for the study until the required sample size was obtained. The method of simple random sampling was preferred for this study since it is statistically acceptable as a way of minimising human bias in the sampling process. This enhances the external validity of statistical inferences made on the entire population on the basis of the selected sample (Creswell, 2012; Alam, 2006). Besides, the sampling technique has been used in several similar noise surveys with satisfactory success (Ochuko, 2013; Piccolo *et al.,* 2005; Ramis, Alba & Hernandez, 2003).

The sample size was determined using Fischer *et al.,* (1998) equation (3-7). In the equation, N is the required sample size; Z is the value of standard variance of 1.96 at 5% significance level; P is the proportionate target population with the particular characteristics being measured, d is the statistical significance level set and q is equivalent to 1-p. The equation gives a well representative sample for a wide range of qualitative studies and is recommended by Atmaca *et al.,* (2005); Bedi (2006); Ochuko (2013) and Ramis, Alba & Hernandez, 2003 for evaluating noise pollution effects. For this study, the sample size obtained was 486.

$$N = Z^2 Pq/d^2 \qquad (3\text{-}7)$$

b) Data Collection

Alongside the noise measurements (see Section 3.1), the questionnaires were administered to selected respondents to capture the view and awareness of noise effects. The questionnaires were self-administered (i.e., the respondents were required to personally fill in their responses unless in circumstances where respondents are completely unable to do so). In such cases, the respondents were interviewed and their responses appropriately filled in the questionnaires. Before administering the questionnaires, the objectives of the study were clearly outlined to the respondents in order to obtain informed and voluntary consent from the participants. In addition, data on permissible noise levels, for protecting public health and welfare in various environments, were obtained from the Noise and Excessive Vibration Pollution (Control) Regulations, 2009, WHO, EPA and any other relevant environmental noise standards.

c) Data Processing and Analysis

Mean noise levels, obtained earlier for every measurement site, were compared with respective permissible noise levels to establish the risk of adverse effects of noise on public health and welfare. Public welfare effects included all non-health effects such as annoyance/irritation, sleep disturbance, speech interference and interruption of cognitive tasks such as reasoning and concentration. The questionnaires were analysed using the statistical package for social scientists (SPSS, version 20) so as to establish the prevalence of adverse noise effects. Other parameters to be established included: the vulnerability of the population to adverse noise effects, as indicated by the prevalence of chronic diseases/conditions among the respondents. Data interpretation was conducted to determine frequencies, percentage proportions and cross-tabulations among various parameters (Jamrah *et al.,* 2006). This helped to draw appropriate conclusions on noise effects, the risk of noise effects, level of compliance to respective noise laws, standards and what parts of the noise criteria could be improved to protect public health and welfare in specific noise environments.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. The Extent of Community Noise Pollution in Nairobi City

4.1.1 Traffic Noise Pollution inside PSVs

a) Nairobi CBD– Nairobi North Route PSVs

Figure 4-1 shows the noise levels observed among PSVs operating between Nairobi CBD and various destinations north of the CBD such as *Githurai 45*, *Kahawa, Kenyatta University (KU), Kasarani, Lucky Summer, Mwiki and Thika (46;237),* among others. The main road serving this route is the Nairobi-Thika superhighway which connects to various feeder roads. According to this study, noise levels inside PSVs plying Nairobi North were found to exceed the maximum permissible noise level of 60 dBA. On average, the noise level inside these PSVs was found to be 92.2±9.4 dBA. This represents a 54.0% extent of non-compliance to the Noise Act. Two *Githurai 45* buses exhibited the highest noise level in this route, 108.8 and 108.2 dBA, respectively. These were followed closely by a Thika-bound minibus (Route 237) in which 107.3 dBA was recorded. Other significantly high noise levels were measured inside a Kenyatta University (KU) 45 Minibus (98.8 dB A) and a Mwiki 17 bus (96.6 dB A).

In contrast, a 14-seater KU-bound Matatu and a Thika 237 minibus exhibited the lowest noise levels in this route: 76.6 dBA and 84.4 dBA, respectively. However, these were still significantly higher than the maximum permissible level of 60 dBA indicating 28.0 and 41.0% levels, respectively, of non-compliance with the Noise Act.

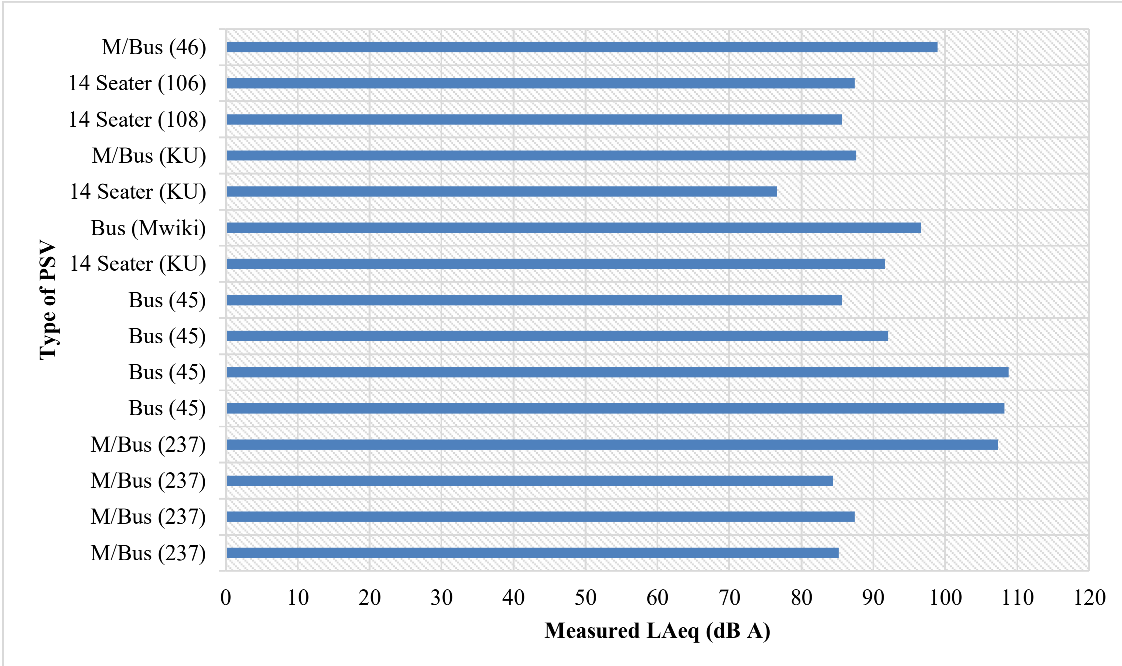

Figure 0-1: Noise inside Nairobi CBD-Nairobi North route PSVs.

Regarding the causes of noise inside PSVs, this study further revealed that the high noise level in northern Nairobi PSVs is a direct result of loud music/radio played inside the vehicles using sound amplifying equipment. This renders communication endeavours (speech or telephone communication) virtually impossible while travelling in the PSVs. In addition, touting (banging of the vehicle bodies by touts; whistling; shouting; and uncontrolled hooting) was also observed to be another major source of noise, especially among Githurai 45 buses and minibuses plying the Nairobi CBD-Nairobi North route. Other than communication interference, the high noise levels in PSVs put passengers at risk of suffering noise-induced hearing loss, physiological and psychological defects (WHO, 1999).

b) Nairobi CBD-Nairobi South Route PSVs

The extent of noise pollution observed inside Matatus operating between Nairobi CBD and various destinations south of the city (such as: *South B, South C, Hazina, Langata, Ngong, Karen, Kibera, Kiserian, Ongata Rongai* and *Bomas*, among others) is presented in Figure 4-2. The main roads serving the southern area are Langata Road and Ngong Road and their associated feeder roads. From the results, it is clear that like in the northern region, all Matatus sampled in the south exceeded the maximum permissible noise level of 60 dBA. On average, a noise level of 83.1±6.3 dBA was recorded in these Matatus. This represents a 39.2% extent of non-compliance with the Noise Act, which is a direct representation of the extent of noise pollution. It can further be noted, from Figure 4-2, that a South B (Route 11B) minibus and Ngong Minibus exhibited the highest level of noise (96.5 dB A) in this route. This signifies a high of 61.0% non-compliance with the Noise Act. The high noise levels are directly attributable to loud music played in the Matatus using sound amplifying equipment. To a little extent, touting could also be pointed out as a noise source in Nairobi South Route Matatus, though not as extensive as witnessed in the north.

In contrast, the lowest noise level recorded in this region was 75.2 dBA. This was observed in a mini bus plying Nairobi CBD-South B Estate (route 11B). Unlike the matatus that exhibited the highest noise levels, this minibus played radio without the aid of sound amplifying equipment. Thus, the 75.2 dBA noise level could be attributed to other factors observed in the matatus such as: touting, normal vehicle engine sounds, human (passenger) sounds and possible sounds from the outside environment. This shows that the use of sound-amplifying equipment inside PSVs greatly increases the noise pollution situation therein. Other matatus, in this region, that exhibited relatively lower noise levels include: an 11B bus (76.6 dBA); an 11B Minibus (77.7 dBA); and an 11B 14-seater (78.1 dBA).

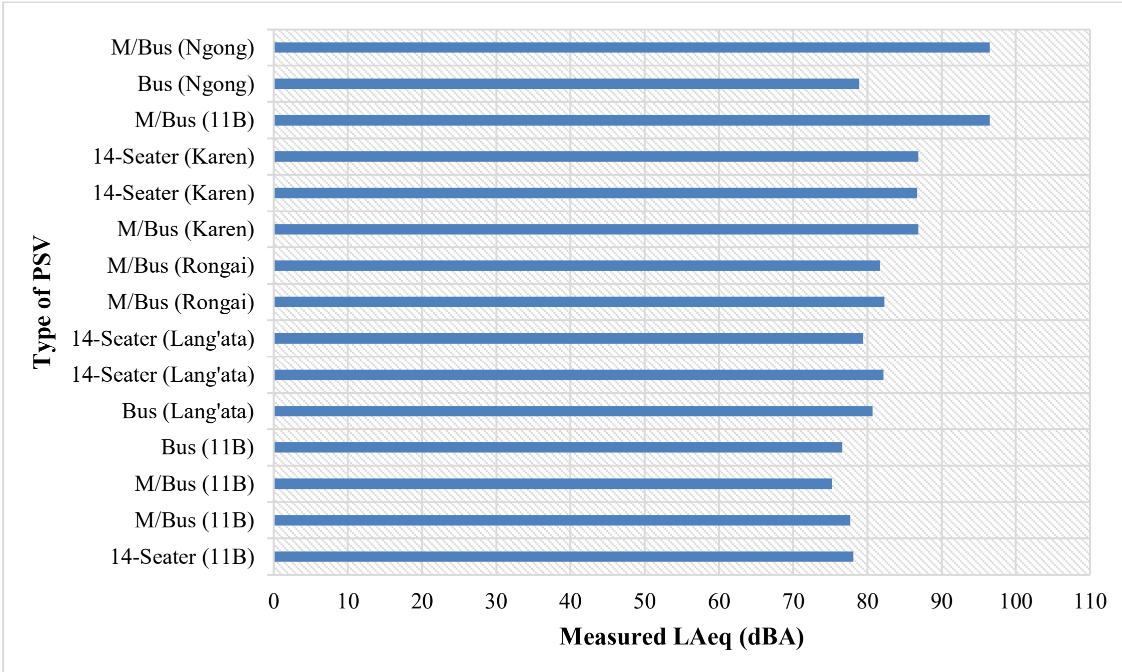

Figure 0-2: Noise inside Nairobi CBD-Nairobi South route PSVs.

c) Nairobi CBD-Nairobi East Route PSVs

The Nairobi CBD-Nairobi East route serves the vast eastern Nairobi region (popularly known as East-lands). The main roads traversing these region include: *Jogoo Road*, *Mombasa Road* and *Juja Road* and their associated feeder roads. Major estates in these region include: *Buruburu, Doonholm, Kariobangi, Umoja, Makadara, Pipeline, Kayole* and *City-Kabanas*, among others. East-lands' route matatus recorded an average internal noise level of 81.2±7.7 dBA, signifying 35.0% average non-compliance with the Noise Act (Figure 4-3). This level of non-compliance signifies the extent of noise pollution. Some three (3) minibuses exhibited the highest noise levels in this region, one plying *Buruburu* Route 58 (94.6 dBA); the second plying *Kayole* Route (94.6 dBA) and another *Buruburu* Route 58 minibus (91.2 dBA). Like in the north and south, the high noise in eastern matatus is a direct result of amplified music in the vehicles. This is in contrast to matatus without amplified music such as Double M (Route 33/34) which exhibited the lowest noise level of 68.8 dBA. This represents a low of 15% non-compliance with the Noise Act and is attributed mainly to normal vehicular traffic sounds such as engine sounds, human sounds and possible sounds from the outside environment. However, it is important to note that even in these least noisy matatus, the noise levels exceed legislated limits, giving a clear picture of how noisy Nairobi PSVs are. While inside these less noisy matatus, it was observed that, unlike inside the noisy ones, speech/telephone communication could go on uninterrupted.

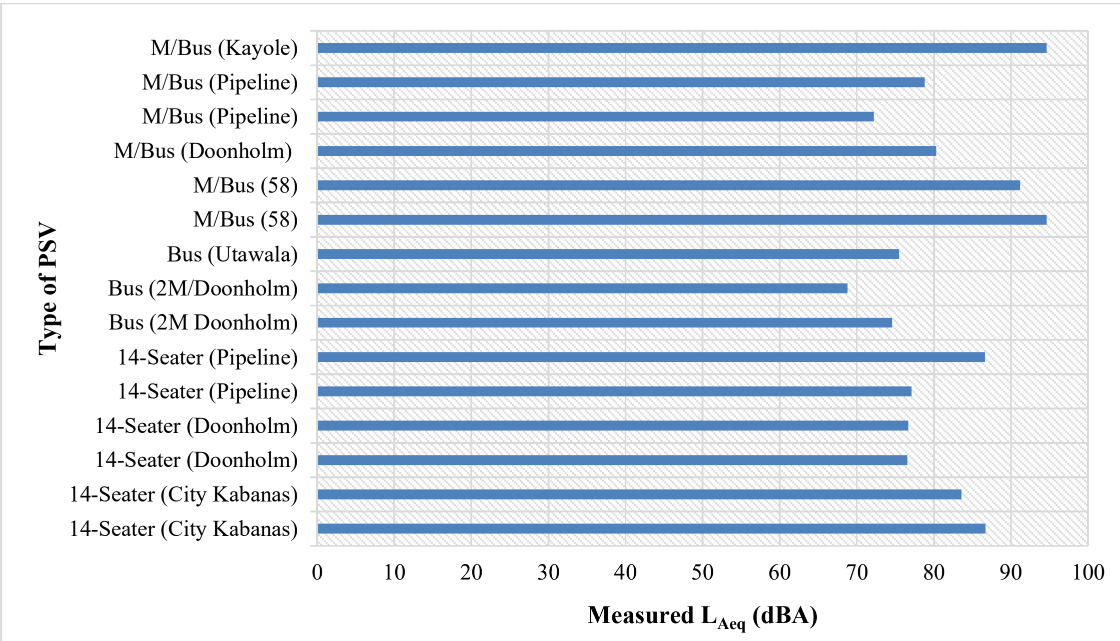

Figure 0-3: Noise pollution inside Nairobi CBD-Nairobi East route PSVs.

d) Nairobi CBD-Nairobi West Route PSVs

The Western region of Nairobi includes areas such as *Westlands*, *Kabete*, *Uthiru*, *Kinoo*, *Parklands, Mountain View, Satellite and Kikuyu*, among others. The main road serving this area is *Waiyaki Way,* which is also the gateway to western Kenya, and its associated feeder roads. The average noise level measured inside matatus in this region was 88.7±9.6 dBA. This represents a 48.1% non-compliance with the Noise Act and is a direct measure of noise pollution levels in these matatus. Figure 4-4 summarizes the extent of noise pollution inside Nairobi CBD-Nairobi West route PSVs. From the figure, two minibuses (Star Bus) plying this route exhibited the highest noise level of 107.2 and 104.1 dBA, respectively. These were followed closely by a third minibus in which 98.9 dBA was recorded. Like the other regions, it was observed that the high noise levels in these matatus is a direct result of the use of sound-amplifying equipment to play extremely loud music in the vehicles. In fact, the loud music overpowered all the other noise sources such as engine and human sounds and it was practically impossible to make speech/telephone communication while traveling on the vehicles. On the other hand, some PSVs in the Western region exhibited relatively low noise levels. These were buses operating in the Nairobi-Kabete route and their observed noise levels varied from 75-77 dBA. They played either no music at all or very low music/radio without using sound-amplifying devices. As opposed to their counterparts with loud noise, it was possible to communicate easily and make calls in these matatus without shouting.

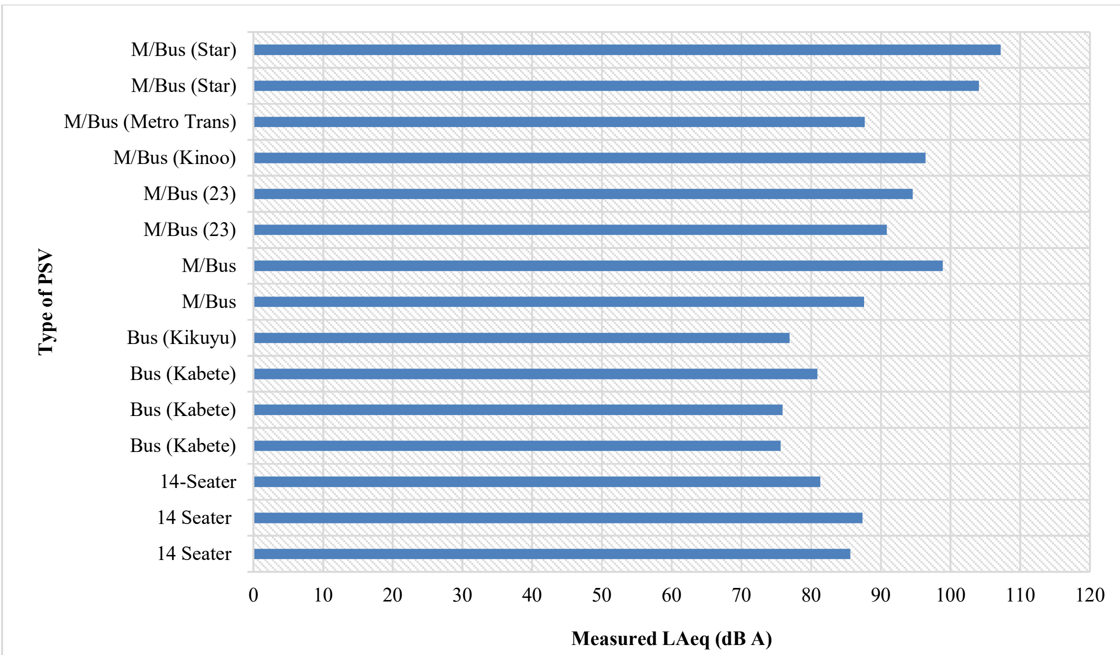

Figure 0-4: Noise inside Nairobi CBD-Nairobi West route PSVs.

e) Comparison of Noise Levels among Various PSV Routes

Figure 4-5 compares the mean noise levels measured in PSVs plying routes in the four regions of Nairobi City. The results show that the Nairobi CBD-Nairobi North PSVs are the noisiest, with an average noise level of 92.2±9.4 dBA. The second noisiest matatus are those in the Nairobi-Nairobi West route at 88.7±9.6 dBA. These are in turn followed by matatus in the southern region which recorded an average of 83.1±6.3 dBA. The lowest noise levels were observed in the eastern region whose matatus average 81.2±7.7 dBA. This implies that, in terms of compliance to the Noise Act, the most non-compliant route is Nairobi North at 54.4% followed by: Nairobi West

(48.1%); Nairobi South (38.0%); and Nairobi East (35.2%). As shown in Table 4-1, these deviations from legislated noise limits are statistically significant, as per one-sample t-tests conducted both at 5 and 1% significance levels.

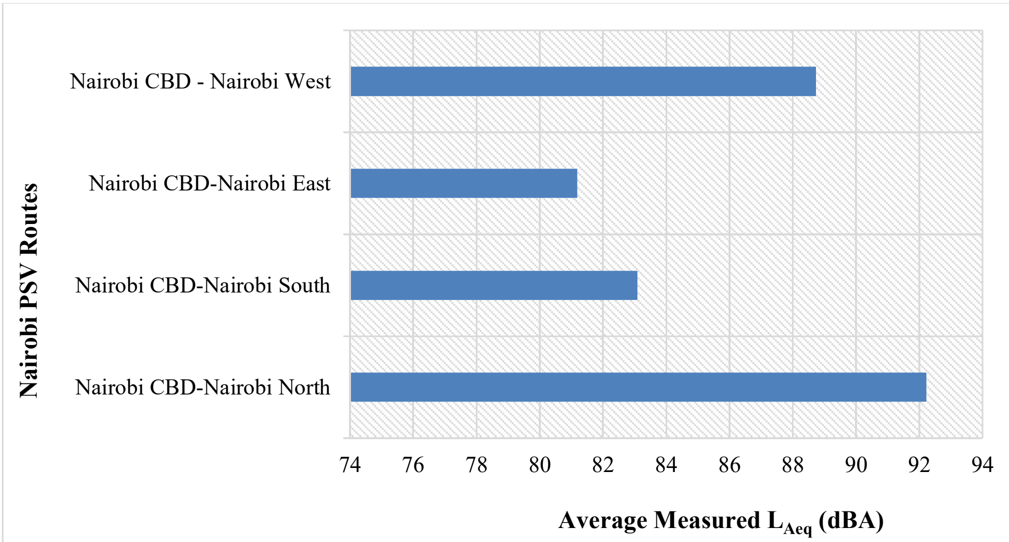

Figure 0-5: Comparison of noise pollution levels for different PSV routes in Nairobi City.

Table 0-1: T-test results for noise pollution for different PSV routes

		Significance Level			
		P =0.05		**P =0.01**	
t	**df**	**Mean**	**Significance**	**Mean**	**Significance**
10.395	3	26.300	0.002	26.300	0.002

Note: Test value = 60 dBA; one-sample t-test

4.1.2 Traffic Noise Pollution at Bus Stations in Nairobi City

a) The extent of Traffic Noise Pollution at Bus Stations

The extent of noise pollution at bus stations in Nairobi city is quantified in Figure 4-6. All the bus stations studied exceeded the maximum permissible noise level of 60 dBA. On average, the noise level in bus stations was found to be 79.7±6.0 dBA. This implies a 32.8% level of non-compliance with the Noise Act. Some of the noisiest bus stations observed include: Railways Bus Station (88 dBA; 46.7% non-compliance); Commercial Bus Station (87.2 dBA; 45.3% non-compliance); Odeon Bus Station (88.6 dB A; 44.0% non-compliance); and Tusker Stage on Ronald Ngala Street (85.5 dBA; 43.1% non-compliance). In comparison, the lowest noise levels were recorded at *Old Nation* bus stop (67.4 dB A; 12.0% non-compliance); *Tea Room* stage on Accra Road (72.8 dB A; 21.0% non-compliance); and *Muthurwa* bus stop (72.7 dBA; 21.1% non-compliance). One sample t-tests measured against permissible noise limits at bus stations indicated that the observed deviations are statistically significant both at 5 and 1% significance levels, as shown in Table 4-2.

These results are in tandem with those of a study by NEMA (2011) which reported between 8 and 42.0% levels of non-compliance with the Noise Act among bus stations in Nairobi City. As observed in this study, NEMA also attributed the noise in bus stations to vehicular traffic sounds, use of sound amplifying equipment in PSVs and growing commercial activities in the stations. This implies also that there is a high number of people (particularly, passengers, traders and PSV crew) who are continuously exposed to dangerous noise levels due to the long time they spend at bus stations. Furthermore, these bus stations are located near offices, residences and other establishments housing people thereby making noise from bus stations a bother and a health risk to many more people.

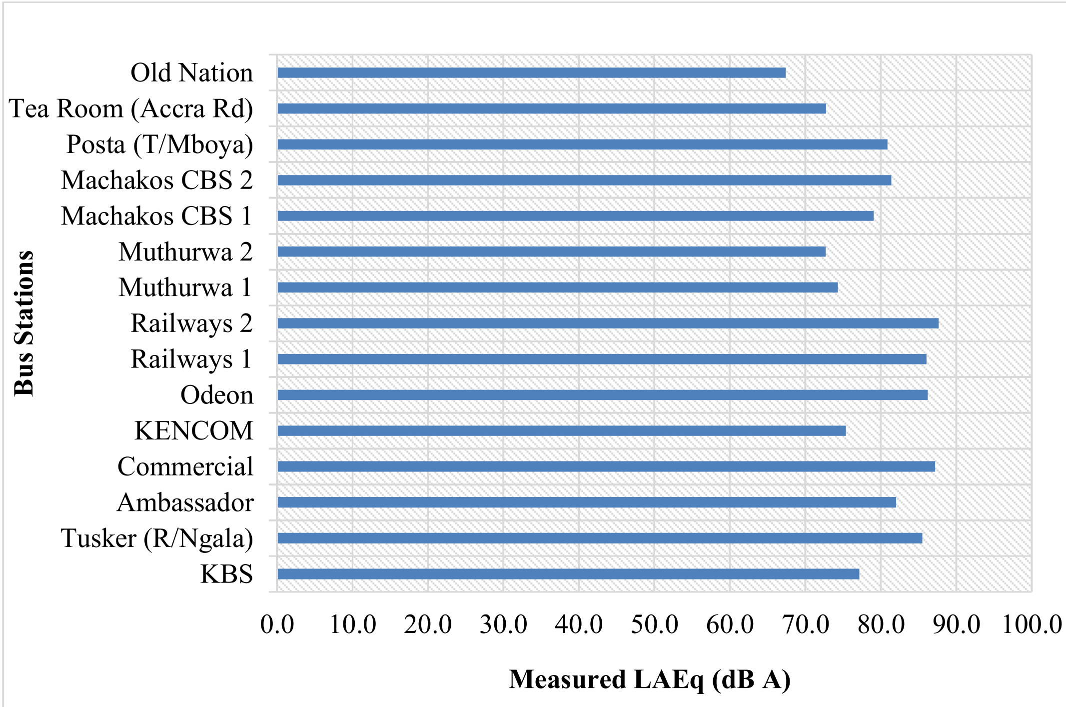

Figure 0-6: Extent of noise pollution at bus stations in Nairobi city.

Table 0-2: T-test results for noise pollution for different bus stations

		Significance Level			
		P =0.05		**P =0.01**	
t	**df**	**Mean**	**Significance**	**Mean**	**Significance**
12.218	14	19.733	0.000	19.733	0.000

Note: Test value = 60 dBA; one-sample t-test

b) Temporal Variation of Noise Levels at Bus Stations

Figure 4-7 illustrates the temporal distribution of noise at the main bus stations in Nairobi city.The figure indicates three general trends; first, some bus stations recorded higher noise levels in the morning (0600-0900) and evening (1600-1900) rush hours, and low levels during mid-day non-rush hours. This could be attributed to heavy human and vehicular traffic experienced as people rush to and from work in the mornings and evenings, as compared to the middle of the day when most city residents are settled at their work places and there is relatively less activity at the bus stations.

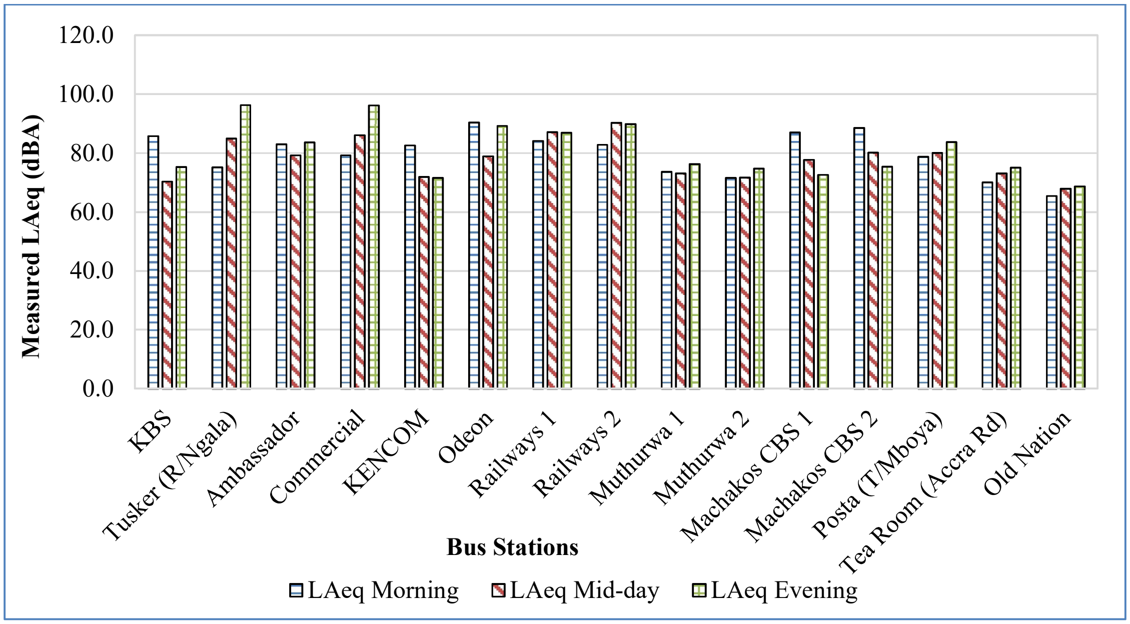

Figure 0-7: Temporal variation of noise at bus stations in Nairobi.

Secondly, some bus stations in the CBD recorded higher noise levels in the mid-day than mornings and evenings. This is due to high level of commercial activities (mainly hawking) and vehicular traffic that reach their peak around mid-day. It was also observed that at this time, there are relatively less passengers, hence, PSVs engage more in touting and uncontrolled hooting in search of passengers. Additionally, in the morning, most PSVs are stuck on traffic as they rush to ferry people between residential estates and the CBD leaving most CBD bus stations with less activity. In the evenings, there is a relatively higher number of passengers in the CBD bus stations creating a high demand for public transport thus PSVs do not have to tout and hoot anyhow in search of passengers. Instead, in most CBD bus stations, passengers queue to board PSVs relatively more quietly. Lastly, some bus stations recorded low noise levels in the morning followed by high levels in the mid-day and highest in the evenings. Overall, the average noise levels measured in the bus stations in the morning, mid-day and evening were 79.9±7.0, 78.2±7.0 and 81.1±9.0 dBA, respectively. This general trend is characteristic of CBD bus stations and could be attributed to the fact that both human and vehicular traffic and associated commercial activity in the city increases with time in the course of the day (NEMA, 2011).

4.1.3 Noise Pollution at Places of Worship in Nairobi City

Churches were found to be the most non-compliant with the legislated noise regulations which set the maximum permissible noise level at 40 dBA during the day and 35 dBA at night, respectively (Kenya Legal Notice Number 61, 2009). The average noise level recorded in the 15 churches was 93.5±7.0 dBA during singing, praise and worship (P&W), and 85.3±8.0 during preaching (P) sessions. This represents a 124.0% average level of non-compliance with legislated noise criteria, indicating a very high level of noise pollution. Overall, statistical tests both at 5 and 1% significance levels indicated that there is a significant difference between actual noise levels in Nairobi Churches and the legislated standards thereof, as shown in Table 4-3.

Generally, singing, praise and worship sessions were found to be noisier than preaching sessions, as detailed in Figure 4-8. From the results, the highest noise level was discovered in a CBD-based church in which 101.9 dB A (P&W) and 98.1 dBA (P) was measured. This represents the highest level of non-compliance (150.1%) with the noise law. This was followed closely by another church in the CBD at 100.1 dBA and 95.6 dBA during P&W and P sessions, respectively (145.4% non-compliance).

In comparison, the lowest noise levels were realized in two churches based in Kasarani (Northern Nairobi) which recorded 78.9 dBA (P&W); 77.6 dBA (P) and 83.6 dBA (P&W); 80.1 dBA (P), representing 96.0 and 105.0% levels of non-compliance, respectively. Noise in churches is largely attributed to the use of amplified sound instruments and public address systems in the churches. This is accompanied by singing, handclapping as well as shouts of acclamation during worship. Highest noise levels were recorded in churches with the most sophisticated sound equipment. Similar results have been reported in other countries such as Nigeria, Uganda and Tanzania in which noise from places of worship is a significant source of pollution (Ityavyar & Tyav, 2013; Matagi, 2002). Similarly, in Brazil, a study estimated the noise exposure level of priests (and by extension, worshippers) in protestant churches at 95.4-99.5 dBA (Silva & Cabral, 2011). This points to similarities in the nature of worship services occurring in churches across these countries, particularly due to the use of music instruments in worship. It also shows that the people at the greatest risk of noise-induced health and non-health effects are worshippers and worship leaders.

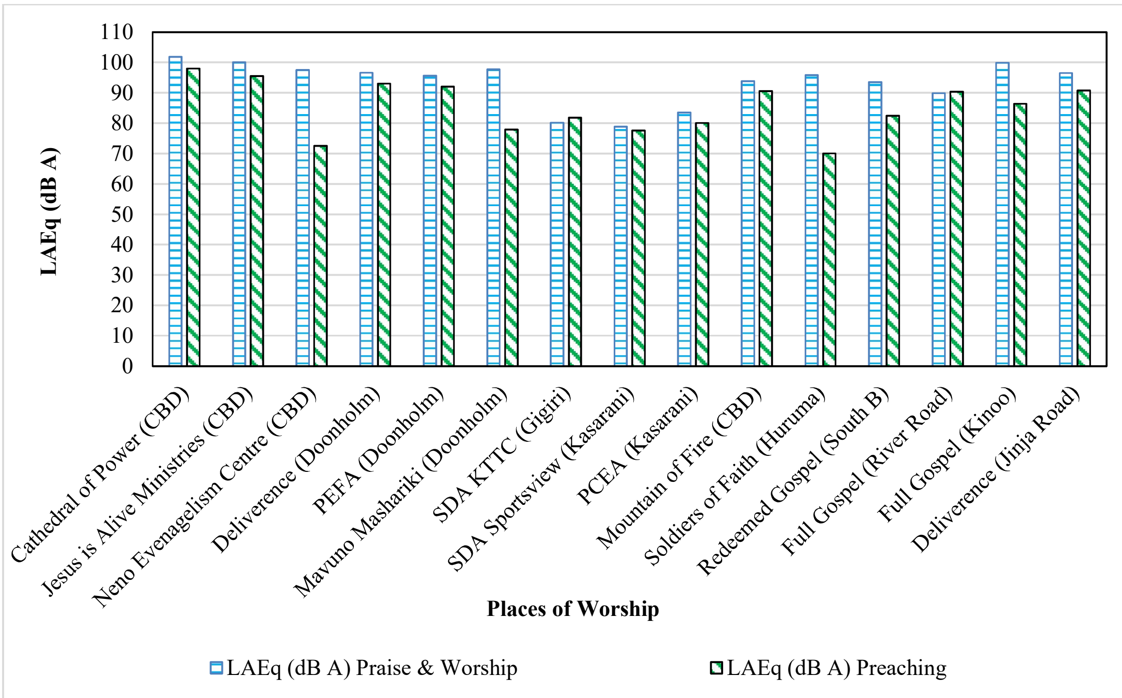

Figure 0-8: Noise pollution at places of worship in Nairobi city.

Table 0-3: T-test results for noise pollution for different places of worship

		Significance Level			
		P =0.05		**P =0.01**	
t	**df**	**Mean**	**Significance**	**Mean**	**Significance**
29.522	14	49.433	0.000	49.433	0.000

Note: Test value = 40 dBA; one-sample t-test

4.1.4 Noise Pollution at Places of Entertainment in Nairobi City

Figure 4-9 summarises the extent of noise pollution from places of entertainment in Nairobi City. Kenyan law sets the maximum permissible noise level for places of entertainment at 55 dBA during the day (0600-1800 hours), and 35 dBA for the night (1800-0600 hours). However, as evident by the results, all the places of entertainment sampled in this study exceeded the maximum permissible levels both during the day and at night. Furthermore, most entertainment activities concentrate in the night and towards the weekend. Thus, the average noise level recorded during the day was 68.1±5.0 dBA. This implies a 24.0% level of non-compliance and pollution. Statistically, the day-time noise levels at entertainment joints were found to deviate significantly from the respective legislated noise limits (Tables 4-4)

Table 0-4: T-test results for noise pollution for different places of entertainment during the day

		Significance Level			
		P =0.05		**P =0.01**	
t	**df**	**Mean**	**Significance**	**Mean**	**Significance**
5.193	14	8.087	0.000	8.087	0.002

Note: Test value = 55 dBA; one-sample t-test

During the night, however, the mean noise level recorded in the entertainment joints was 96.9±5.0, representing 177.1% non-compliance to the law. On average, this study sets the extent of noise pollution at Nairobi's entertainment places at 82.5±4.0 dBA. The highest noise levels of 100.5-101.2 dBA were recorded on Friday and Saturday nights amongst some five entertainment places, three of which are located in Nairobi CBD and the other two in Kasarani and Kahawa estates, respectively (Northern Nairobi). This is in comparison to the lowest noise levels of 84.2-89.9 dBA recorded on Wednesday nights among two entertainment spots in Eastern and Southern Nairobi. It is also important to note that Thursday nights recorded significantly high noise levels

(90-99 dBA), especially, among places of entertainment within Nairobi CBD. During the day, the noise levels ranged between 59.9 and 77.3 dBA. Like during the day, the deviation of actual noise levels from recommended standards was found to be statistically significant both at 5 and 1% significance levels, as shown in Tables 4-5.

Table 0-5: T-test results for noise pollution for different places of entertainment at night

		Significance Level			
		P =0.05		**P =0.01**	
t	**df**	**Mean**	**Significance**	**Mean**	**Significance**
24.191	14	33.087	0.001	8.087	0.000

Note: Test value = 35 dBA; one-sample t-test

During the study, it was observed that much of the noise at entertainment places is directly attributed to playing of music with sound amplifying equipment, with most places playing much louder music in the night as compared to the day. Additionally, some entertainment places are characterised with live performances (live bands) at night, with a wide range of music instruments thus increasing noise in the night. This is coupled with high level of activity occasioned by high customer turnout in the night, especially on weekends. In contrast, during the day, and weekday nights, most entertainment places experience low activity due to low customer populations as people engage more in their day-to-day jobs.

This study compliments the findings of a similar study by NEMA (2011) which reported that night clubs and restaurants in Nairobi flout legislated noise criteria by 100-147%. In comparison, a study of noise pollution in restaurants of Tanzania's Morogoro Town reported between 61 and 64 dBA of noise, which although is above the legislated maximum permissible level of 55 dBA, is significantly lower than in Kenya. The levels in this Tanzanian study denote a mere 11-17% non-compliance with Tanzanian legislated noise criteria (Samagwa, Mkoma & Tungaraza, 2009). Like in Kenya, the noise in Tanzanian restaurants was associated with music in the restaurants, customer conversations and activity on adjacent streets.

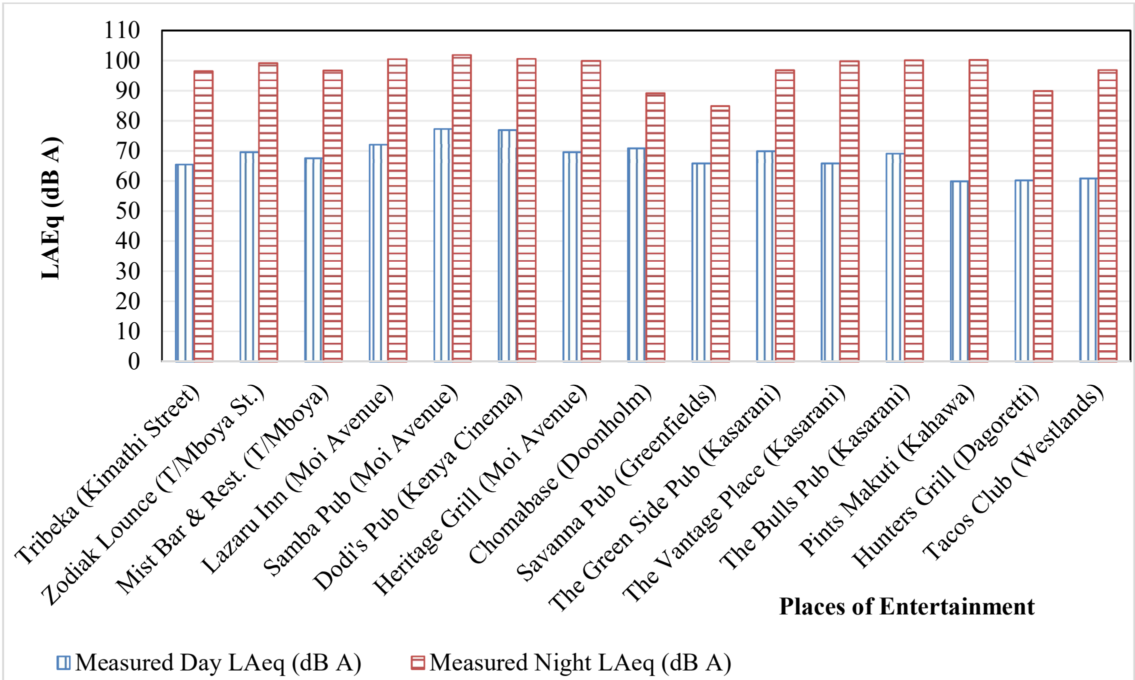

Figure 0-9: Noise pollution at places of entertainment in Nairobi city.

4.1.5 Noise Pollution at Commercial Centres in Nairobi City

Open-air markets were found to be noisier (71-101 dBA) as compared to shopping malls in which a noise range of 62-69 dBA was observed. Generally, all the markets exceeded the maximum permissible noise level of 55 dBA for commercial places, with an average noise level of 78.5±11 dBA, and a non-compliance rate of 43.1%. A roadshow commercial promotion, surveyed twice during the study, registered the highest level of noise of 100.4 dBA, exceeding the maximum limit by 83.0%. This was associated with the use of public address systems with sound amplifying equipment. Eastleigh was found to be the noisiest market place at 96.5 dBA, followed by Muthurwa Market (93.3 dBA) and Gikomba Market (88.0 dBA). In Muthurwa and Gikomba, the dominant sources of noise observed include hawking, music, street-preaching, adjacent traffic, informal industrial activities (such as welding, woodworking, among others) and general human sounds resulting from high population.

The lowest noise levels were recorded in shopping malls: Tuskys Supermarket Imara (62.9 dBA); Nakumatt Supermrket Galleria (66.3 dB A); Cianda Shopping Mall (67.6 dBA); and City Market (69.3 dBA). Figure 4-10 details the extent of noise pollution in Nairobi's commercial places. The 90th percentile (L_{90}, indicated by the black bars) was used to characterise the near-background noise that market users (especially traders who spend longer hours in the markets) are exposed to. From the results, it is clear that commercial places exceed the maximum permissible level both in terms of L_{90} and LAeq. The average L_{90} registered was 65.9±7.0 dBA. According to a study by NEMA (2011), Nairobi's commercial places registered between 64 and 80 dBA of noise. Like in this study, all the commercial places sampled by NEMA exceeded their maximum permissible level of 55 dBA. T-tests at 5 and 1% significance levels indicated statistically significant deviations of actual noise levels from legislated standards, as shown in Tables 4-6.

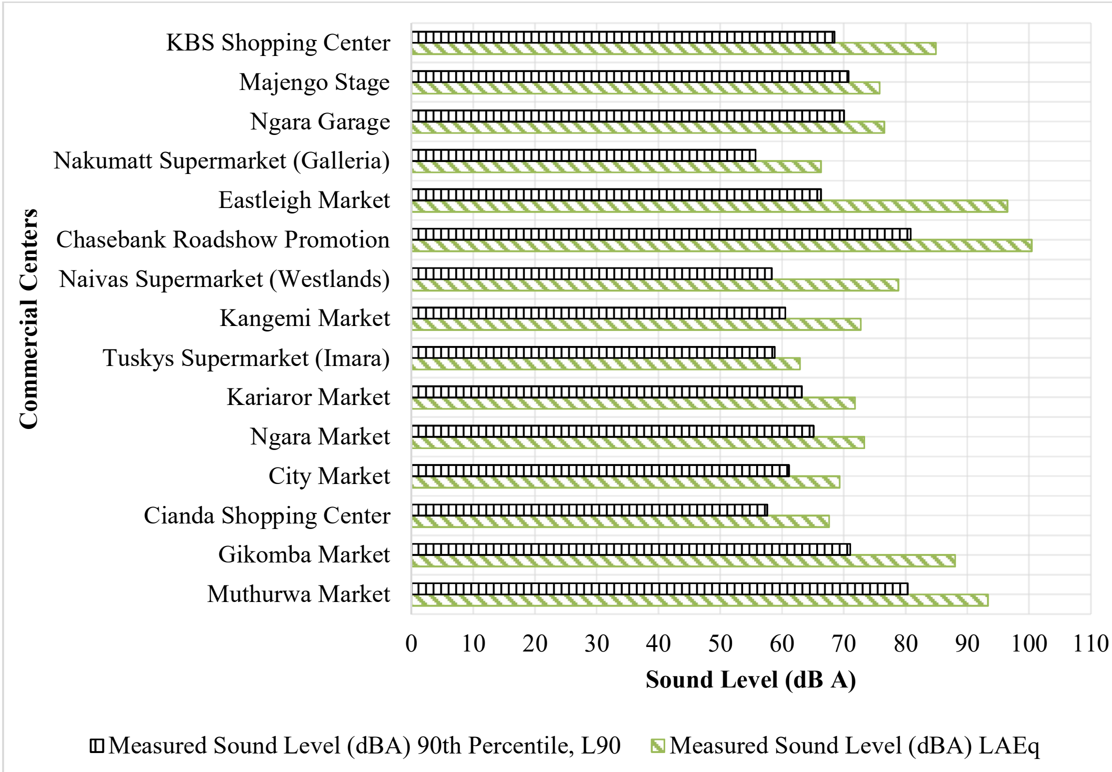

Figure 0-10: Extent of noise pollution at commercial centres in Nairobi City.

Table 0-6: T-test results for noise pollution for different commercial centres

		Significance Level			
		P =0.05		P =0.01	
t	df	Mean	Significance	Mean	Significance
24.191	14	33.087	0.000	33.087	0.000

Note: Test value = 55 dBA; one-sample t-test

4.2 A Regression Model for Predicting Traffic Noise Pollution

4.2.1 Summary Statistics of Collected Data

A total of 172 traffic noise measurements were made for 26 days between the periods of 5th December, 2014 and 25th January, 2015. On each day, hourly measurements were made for 4 to 8 hours resulting in a total of 172 data. The measurements were taken on three (3) major roads namely, *Jogoo Road, Mombasa Road* and sections of *Thika Superhighway*. The following parameters were recorded: average equivalent sound level or traffic noise, LAeq (dBA); L_{10}; Mmin; Lmax; traffic volume, Q (vehicles per hour); traffic composition (small vehicles below 12000kg, and heavy ones above 12000 kg); average vehicle speed, V (km/hour); air temperature, T (^{0}C); and relative humidity, RH (%). Out of the 172 data, 80% (138) were used to develop the general noise pollution model while the rest were set aside for its validation. Table 4-7 gives summary statistics of the measured data. From the results, the average traffic noise level was 77.6 dBA while the mean traffic volume was 1434 vehicles per hour. Out of the mean traffic volume, 43.0% comprised of heavy vehicles (over 12000kg) while the remaining 57.0% were small vehicles (less than 12000 kg). The overall average traffic speed was found to be 44 km/hour while the average temperature and humidity were found to be 23± ^{0}C and 68.0± %, respectively.

One critical observation made was that traffic volume was highest between 0900 to 1100 hours and 1500 and 1700 hours. These are critical hours surrounding the morning and evening peak traffic periods. In contrast, traffic volume was lowest at the midday ours of 1100 to 1500 hours. From the noise level measurements, it was also observed that noise level, LAeq, increased with increase in traffic volume. Furthermore, heavy vehicles were seen to generate more noise since LAeq was seen to increase with increase in the number of heavy vehicles passing the data collection points. At some instances, Lmax increased up to over 100 dBA as heavy vehicles passed.

Table 0-7: Summary statistics of traffic data

Variable	Q, No./hour	P, %	V, km/h	LAeq, dBA	L10, dBA	Lmax, dBA	Lmin, dBA	T, ^0C	RH, %
Mean	1433.9	42.4	43.8	77.656	79.7	97.5	53.9	23.1	68.2
Std error	3.31	0.32	0.107	0.07	0.07	0.16	0.11	0.11	0.59
Median	1440	42.3	44.1	77.7	79.7	97.7	53.6	23.5	66
Mode	1450	41.0	44	77.1	79	98	53	22	74
Stdev	43.4	4.13	1.41	0.87	0.87	2.04	1.46	1.45	7.70
Var	1884.8	17.17	1.98	0.75	0.76	4.16	2.14	2.11	59.26
Range	245	19	10	4.9	5	12	7	7	22
Min	1295	31	40	75	78	91	50	20	59
Max	1540	50	50	79.9	83	103	58	27	81

In the table: Q, traffic volume; P, proportion of heavy vehicles; V, average vehicle speed; T, air temperature; RH, relative humidity; std error, standard error of mean; stdev, standard deviation; var, variance; min, minimum, max, maximum

4.2.2 Multiple Regression Modelling

a) Relation between Traffic Noise and Traffic Volume

Figure 4-11 shows the scatter plot of measured L_{Aeq} against total traffic volume. The results show that the relationship between traffic volume and the emitted noise is linear. This implies that the higher the traffic volume, the greater resulting traffic noise. The relatively high coefficient of determination (R^2) of 0.730 implies that the model, as presented in equation (4-1), can estimate about 73.0% of traffic noise. Generally, R^2 values less than 0.5 are considered to denote weak correlations whereas those over 0.8 imply strong correlations (Creswell, 2012). Similar results have been obtained in other studies. For instance, Chandra (2010) obtained an R^2 of 0.747 in a study to develop a traffic noise model for main highways in India. Most recently, a study of traffic noise pollution on major highways of Ahvas City, Iran, obtained R^2 values ranging from 0.4 to 0.6 (Esmaeelpour, Sekhavatjou, & Ahwazi, 2014). The unexplained variation could be as a result of the fact that no additional measures (other than site selection) were put in place to discriminate traffic noise from other possible sources of environmental noise in the study site.

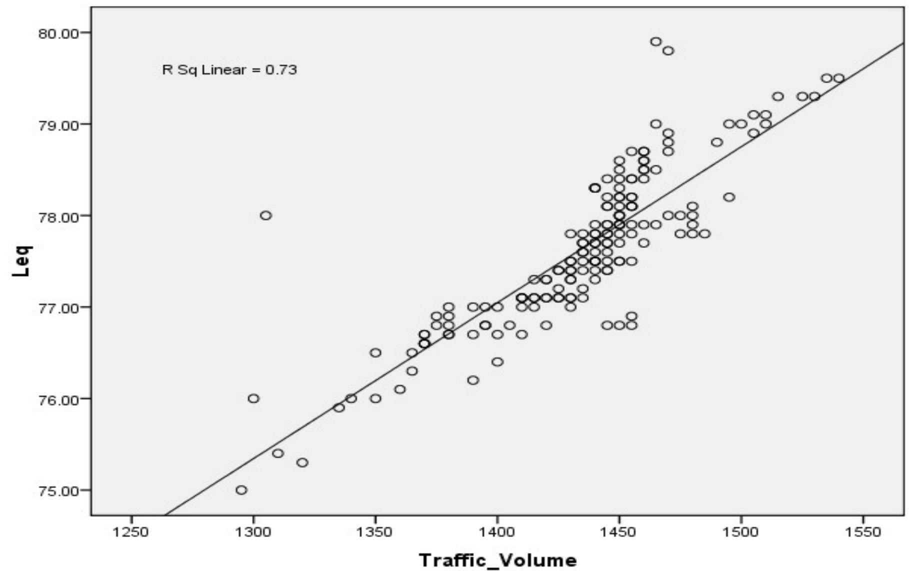

Figure 0-11: Relationship between LAeq and traffic volume.

$$LAeq = 0.0167Q + 54.1667 \qquad (4\text{-}1)$$

b) Relation between Traffic Noise and Traffic Speed

Figure 4-12, on the other hand, presents the scatter plot of L_{Aeq} against average traffic speed while equation (4-2) is the corresponding linear regression model obtained. A moderately low value of R^2 = 0.344 obtained suggests that 34.4% of traffic noise can be accounted for by traffic speed. However, in comparison to the R^2 value of 0.73 obtained between traffic noise and traffic volume above, it can be stated that traffic speed accounts for about half as much of traffic noise as traffic volume would. Thus, despite the wide unexplained variation, traffic speed remains an important contributor to the resulting traffic noise.

$$LAeq = 0.5V + 55 \qquad (4\text{-}2)$$

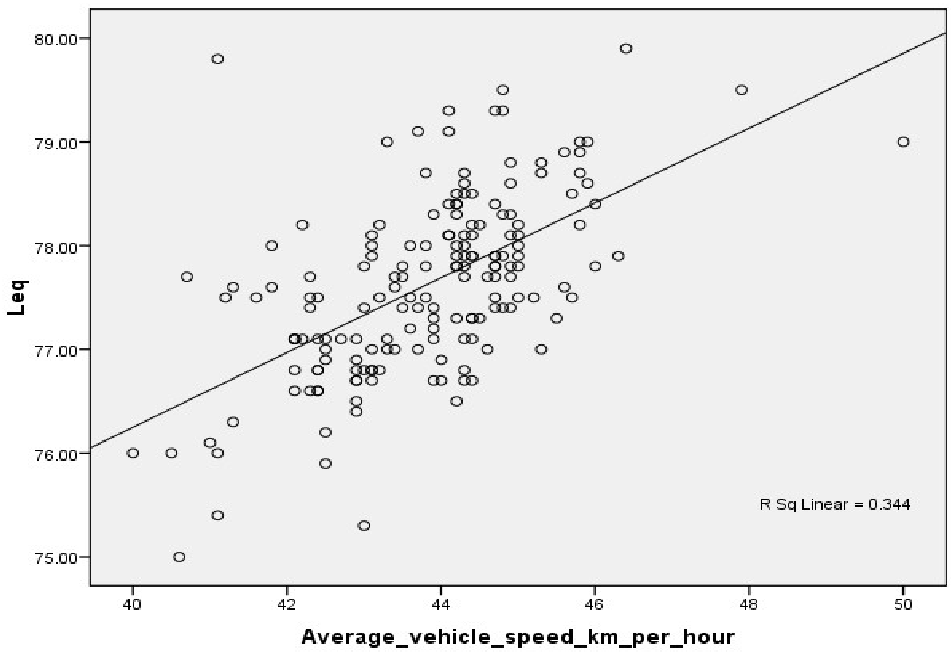

Figure 0-12: Relation between LAeq and traffic speed.

In a traffic noise modelling study of major highways in India, Chandra (2010) reported R^2 values of 0.3740. Chandra concluded that the relation between traffic speed and traffic noise is complex to explain as some vehicles made more noise at low speeds whereas others were noisier at higher speeds. Esmaeelpour, Sekhavatjou, and Ahwazi (2014) reported even a lower value (R^2=0.5) in Ahvaz City, Iran. Both Chandra (2010) and Esmaeelpour, Sekhavatjou, and Ahwazi (2014) considered traffic speeds of individual categories of vehicles such as small vehicles, heavy vehicles and heavy commercial vehicles, among others. However, in this study the regression model, equation (4-2), was directly developed from overall traffic speeds, irrespective of the individual vehicle categorization. The unexplained variation could also be as a result of the indirect method of computing speed used in this study as opposed to measuring actual vehicle speeds using a speed measuring gadget.

c) Relationship between LAeq and Proportion of Heavy Vehicles in Traffic

The scatter plot of LAeq against the proportion of heavy vehicles obtained in this study is shown in Figure 4-13, whereas the corresponding regression model is presented in equation (4-3). The moderately high value of R^2 of 0.593 indicates that 59.3% of traffic noise variation can be accounted for by the proportion of heavy vehicles in the traffic. According to Creswell (2012), an R^2 value of 0.593 can reasonably be used to infer that traffic noise is significantly dependent on the proportion of heavy vehicles in the traffic volume. Various other scholars have attempted to relate traffic speed and traffic composition. Chadra (2010) suggested a model with R^2=0.595 for most major highways in India. Similarly, a traffic noise model for highways in Ahvaz City, Iran, reported R^2=0.54 (Esmaeelpour, Sekhavatjou, & Ahwazi, 2014). However, it is important to note that most traffic noise models such as Esmaeelpour, Sekhavatjou, & Ahwazi (2014) are based on a consideration of specific types of vehicles in traffic, in which case, R^2 values ranged from 0.2-0.4. Chandra (2010) explored and discovered that heavy vehicles (above 12,000 kg) contributed more to traffic noise pollution. Chandra, therefore, singled out and statistically proved that the percentage of heavy vehicles in traffic is a better variable in the resulting model. This study proves Chandra's assertion.

$$LAeq = 0.2P + 69 \qquad (4\text{-}3)$$

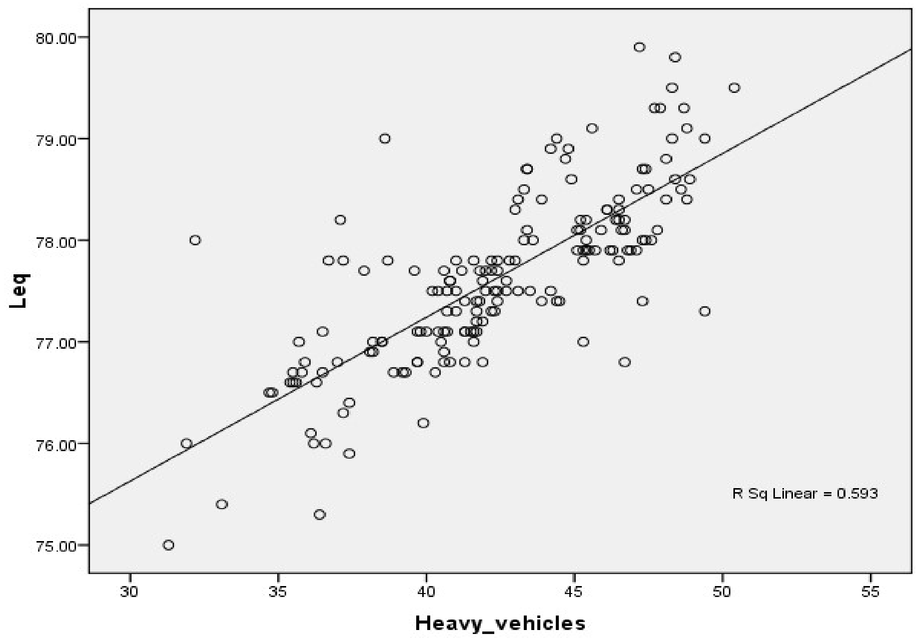

Figure 0-13: Relationship between L_{Aeq} and proportion of heavy vehicles.

d) Relation between Traffic Noise and Ambient Air Temperature

The relationship between LAeq and ambient air temperature is shown by the scatter plot in Figure 4-14. Regression analysis resulted in a low R^2 value of 0.000189, indicating that hardly any variation in traffic noise can be accounted for by the prevailing ambient air temperatures. Additionally, it is imperative to note that during the study, temperature remained relatively constant (20-27^{0}C) at the respective times of the day. Therefore, the results of this study indicated that ambient air temperature should not be included in the general noise pollution model. This findings compare well with those of Georgiadou *et al*. (2004) and Creswell (2012) who indicated that there is need for further statistical tests to ascertain the significance of temperature in predicting traffic noise. Additional studies to model traffic noise pollution with respect to ambient air temperature resulted in similar low values of R^2=0.00321 (Chandra, 2010); R^2=0.044 (Esmaeelpour, Sekhavatjou, & Ahwazi, 2014) and R^2=0.000971 (Georgiadou *et al*., 2004).

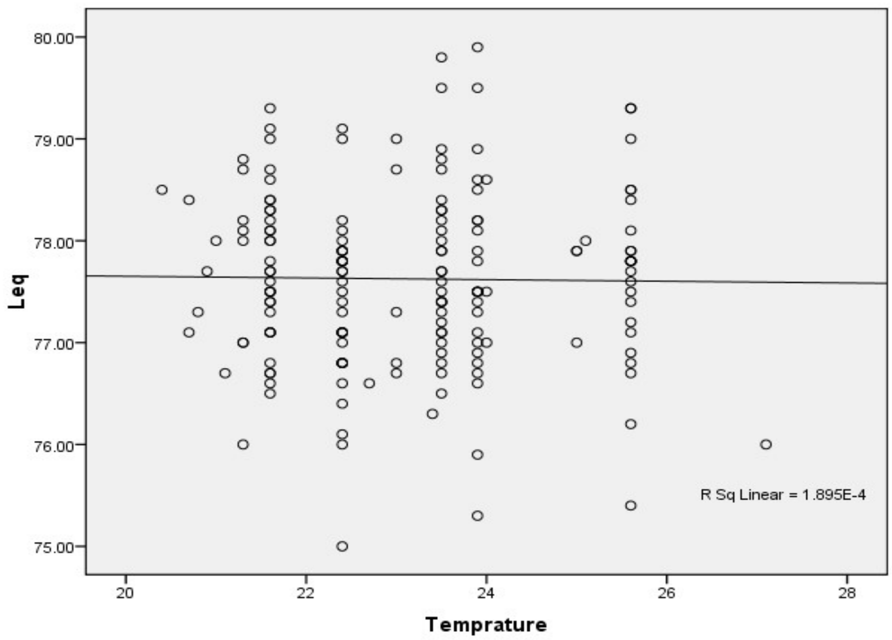

Figure 0-14: Relation between L_{Aeq} and temperature.

e) Relationship between L_{Aeq} and Ambient Relative Humidity

Finally, the relation between L_{Aeq} and relative humidity is shown by the scatter plot in Figure 4-15. Like temperature, relative humidity was found to have hardly any effect on traffic noise emission. The R^2 value obtained was 0.012 indicating that only 1.2% of variations in traffic noise can be accounted for by the prevailing relative humidity. This is not satisfactory to qualify RH for inclusion in the traffic noise model, necessitating further significance tests. The results obtained in this study are in tandem with those of a similar study in Ahvaz city, Iran, which reported an R^2 value of 0.033 for most highways in the city. Similarly, Esmaeelpour, Sekhavatjou, and Ahwazi, (2014) reported R^2=0.039 in a study to model traffic noise against relative humidity in main highways of India. These further show that variations in traffic noise can barely be explained by prevailing ambient air temperature and relative humidity.

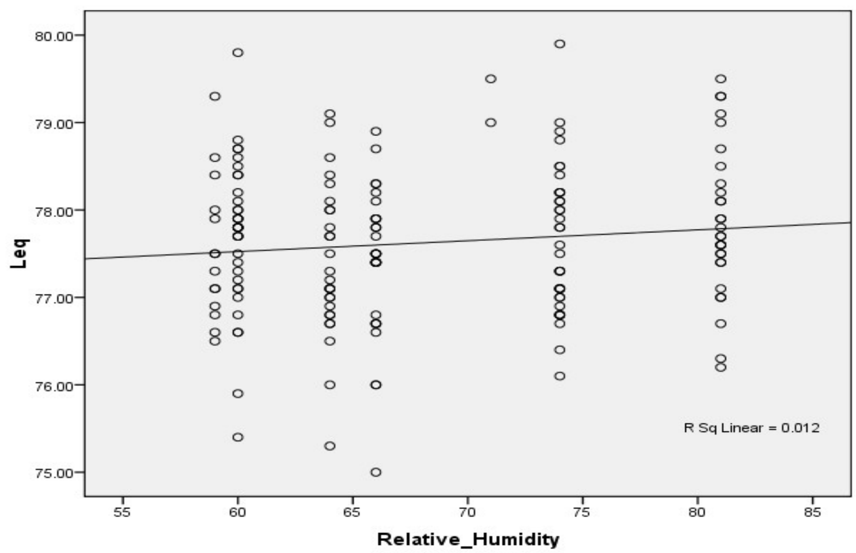

Figure 0-15: Relationship between LAeq and relative humidity.

4.2.3 General Model for Traffic Noise Pollution

Stepwise regression modelling technique was utilized to identify the best fitting model for LAeq against the various variables discussed in Section 4.2.2. This is a process of building a model by successively adding or removing variables based on the t-statistics of their estimated coefficients and by observing the value of the coefficient of determination. The study selected a model that had the highest value of R^2 based on their standard error and significance levels. Table 4-14 shows the performance of the various stepwise regression analyses. The corresponding governing equations are also shown alongside the variables evaluated against LAeq.

Table 0-2: Stepwise regression for various variables against LAeq

Variables	R	R^2	Adjusted R^2	Std. error of est.	Changed R^2	Equation
Q	0.855	0.730	0.729	0.4509	0.730	LAeq = 53.2+0.017Q
Q, P	0.876	0.767	0.764	0.4205	0.037	LAeq = 56.9+0.013Q+0.061P
Q, P, V	0.883	0.783	0.776	0.4100	0.013	LAeq = 55.3+0.011Q+0.060P+0.085V
Q, P, V, T	0.885	0.783	0.778	0.4083	0.000	LAeq =56.1+0.011Q+0.060P+0.086V-0.033T
Q, P, V, T, RH	0.85	0.783	0.778	0.4083	0.003	LAeq = 56.0+0.056Q+0.289P+0.14V-0.033T+0.001RH
Q,P,V,RH	0.83	0.780	0.775	0.41104		LAeq =55.297+0.011Q+0.060P+0.085V +0.002RH

Based on the results in the table, the study first adopted the model shown in equation (4-4) to relate L_{Aeq} and the various variables (viz., Q, P, V, T and RH).

$$L_{Aeq} = 56.0 + 0.056Q + 0.289P + 0.14V - 0.033T + 0.001RH \qquad (4\text{-}4)$$

The R^2 value is 0.783, thus indicating that 78.3% of the variation of LAeq can be modelled by Q, P, V, T and RH. However, to decide on the final model, the statistical significance of each independent variable was further probed, with a view to eliminating insignificant variables from the model. Table 4-8 summarizes the statistical test results thereof. In addition to having low R^2 values, the effect of T and RH on the emitted traffic noise level was not found to be statistically significant (p-values for T and RH were 0.788 and 0.129, respectively, which are greater than 0.05 at 5% significance level). Thus, this study concluded that the T and RH can be dropped from the model, as presented in equation (4-5).

$$LAeq = 55.3+0.011Q+0.060P+0.085V \qquad (4\text{-}5)$$

The coefficient of determination for the final model was found to be 0.783. This implies that 78.3% of variations in traffic noise emissions can be accounted for by traffic volume, percentage of heavy vehicles in traffic and traffic speed. This is satisfactory (Georgiadou et al., 2004) although the remaining margin of 21.7% of traffic noise cannot be accounted for by this model. Since weather parameters have proved to have no significant contributions, other factors need to be explored that may account for this discrepancy. Nevertheless, similar results have been obtained by a few other studies seeking to model traffic noise (Esmaeelpour, Sekhavatjou, and Ahwazi, 2014; Chandra, 2010 ;) as shown in Table 4-9.

Table 0-8: Statistical tests of independent variables at 5% significance level

	B	Std. Error	T	Sig
(Constant)	56.034	1.430	39.175	.000
Relative Humidity	.001	.004	.269	.788
Proportion of Heavy Vehicles	.060	.012	5.231	.000
Traffic Speed	.086	.027	3.175	.002
Traffic Volume	.011	.001	9.264	.000
Temperature	-.033	.022	-1.527	.129

Table 0-9: Comparison with other similar traffic noise models

Model	**Parameters**	**R^2 Value**
LAeq = 55.3+0.011Q+0.060P+0.085V (Final model from this study)	Q = Traffic Volume; P = Proportion of heavy vehicles in traffic; V = Traffic Speed	R^2=0.783
Leq =64.67 + 3.93 logN1 + 2.69logN3 -1.048log N4 - 3.84log V1 + 1.71logV3 – 0.034RH – 0.042T –0.011W – 0.04H (Esmaeelpour, Sekhavatjou, and Ahwazi, 2014; Main Highways in India)	N1, N2, N3 = Traffic Volumes for small to heavy vehicles V1, V3 = Traffic Speeds for small and heavy vehicles RH=Relative Humidity T=Ambient Air Temperature W=Width of the road H=Height of adjacent buildings	R^2=0.82
L_{eq}=55.1781+0.0113Q+0.0544P+0.0907V (Chandra, 2010; Main Highways in Ahvaz City, Iran)	Q = Traffic Volume, computed from individual vehicle classes P=Proportion of Heavy vehicles in Traffic	R^2=0.7942

4.2.4 Validation of the Developed Multiple Regression Model

The 20% (N_t = 34) dataset that was set aside was used to validate the developed general noise pollution model, as presented in equation (4-4), and the results comparing actual and predicted LAeq values are as shown in Table 4-10. A performance of 100% was obtained for the model based on a 5% residual error interval. Residual error (ε) was computed using equation (4-5), and the performance of the model was determined by equation (4-6). In the equations, θ_a and θ_p are actual and predicted LAeq values, respectively, and N_i and N_t are the number of data with residual errors within the interval and total number of data in the dataset, respectively.

$$\varepsilon(\%) = 100\left(\frac{\theta_p - \theta_a}{\theta_a}\right) \tag{4-5}$$

$$\eta(\%) = 100\left(\frac{N_i}{N_t}\right) \tag{4-6}$$

Another comparison to test the performance of the general noise pollution model utilised paired t-tests. Paired t-test is a statistical technique that is used to compare two population means in the case of two samples that are correlated (Creswell, 2013). The study's null hypothesis assumed that the mean of the two paired samples (i.e., actual and predicted LAeq values) were equal while the alternative one assumed that the means were not equal. As shown in Table 4-10, the actual and predicted mean values are highly correlated. The results are supported by those in Table 4-11 which presents t-test results for paired samples at 5% ($p < 0.05$) and 1% ($P<0.01$) significance levels, respectively. This indicates that there is no significant difference between predicted and measured LAeq values. Thus, the developed model can be used to accurately predict traffic noise levels.

Table 0-10: Comparison between actual and predicted LAeq values

S. No	Variable			LAeq		Residual error
	Q	P	V	Actual	Predicted	(%)
1.	1455	45.7	44.7	77.9	80.0	2.7
2.	1370	35.6	42.1	76.6	78.9	3.0
3.	1440	42.8	44.7	77.8	79.8	2.6
4.	1435	41.8	42.3	77.7	79.7	2.6
5.	1365	34.8	42.9	76.5	78.9	3.1
6.	1370	35.5	42.9	76.7	78.9	2.9
7.	1395	38.2	43.1	77	79.2	2.9
8.	1430	42.2	44.7	77.8	79.6	2.3
9.	1430	40.4	42.4	77.5	79.6	2.7
10.	1370	36.5	43.1	76.7	78.9	2.9
11.	1440	42.0	43.2	77.5	79.8	3.0
12.	1420	40.7	43.9	77.3	79.8	3.2
13.	1455	46.5	44.3	77.8	79.7	2.4
14.	1450	43.6	44.3	78.0	78.9	1.2
15.	1440	46.1	44.8	78.3	78.9	0.8
16.	1415	41.6	43.3	77.0	79.2	2.9
17.	1425	42.4	43.9	77.4	79.6	2.8
18.	1375	38.2	44.0	76.9	79.6	3.5
19.	1450	42.7	45.0	77.5	78.9	1.8
20.	1380	38.9	44.4	76.7	79.8	4.0
21.	1435	42.7	43.4	77.6	78.5	1.2
22.	1430	42.2	44.7	77.8	79.6	2.3
23.	1430	40.4	42.4	77.5	79.6	2.7
24.	1370	36.5	43.1	76.7	78.9	2.9
25.	1440	42.0	43.2	77.5	79.8	3.0
26.	1420	40.7	43.9	77.3	79.8	3.2
27.	1440	46.1	44.8	78.3	78.9	0.8
28.	1415	41.6	43.3	77.0	79.2	2.9
29.	1425	42.4	43.9	77.4	79.6	2.8
30.	1375	38.2	44.0	76.9	79.6	3.5
31.	1450	42.7	45.0	77.5	78.9	1.8
32.	1440	42.0	43.2	77.5	79.8	3.0
33.	1420	40.7	43.9	77.3	79.8	3.2
34.	1440	46.1	44.8	78.3	78.9	0.8

Table 0-11: Paired sample statistics

	Mean	No. of samples	Stdev	Std. error of mean	p-value*	p-value**
LAeq predicted	79.3850	20	0.40817	0.09127	0.000	0.002
LAeq actual	77.3300	20	0.53420	0.11945		

4.3 Effect of Community Noise Pollution

4.3.1 Effects Based on Comparison with Protective Noise Limits

As already indicated, 100.0% of PSVs and bus stations in Nairobi city violate the legislated noise regulations. This poses a wide range of risks to public health and welfare, particularly among passengers. Also, most of the PSV roads and bus stations are located in/near residential estates, offices, hospitals or schools. It is also important to note that Nairobi faces a serious problem of traffic congestion thereby increasing the duration for which passengers, pedestrians and near-road users/dwellers are exposed to traffic noise. Considering the average noise levels established in this study, an average Nairobi resident is exposed to 79.7±6.0 dBA of noise while awaiting to board a PSV in a bus station; followed by 86.3±9.6 dBA while travelling in a matatu and as the PSV manoeuvres through slow traffic to and from work, daily. If the same person passes by a market place or shopping mall, he/she experiences an average noise level of 78.5±11 dBA while in an entertainment joint or restaurant, the person is further exposed to 82.5±4.0 dBA of noise. In the weekend, this same person is likely to attend a worship service in a church somewhere in Nairobi city during which he/she is subjected to 93.5±7.0 dBA.

To predict the possible noise impacts, an overall average value was computed for all the measured noise levels in this study, as shown in Table 4-14. The value was found to be 84.1 dBA. To predict possible effects of noise, Table 4-15, compares this overall average noise level with various international standards recommended to protect public health and welfare against respective noise effects, with an adequate margin of safety (WHO, 1999; WHO, 2009; EPA, 1974). From the results, it is evident that Nairobi residents face high risk of various adverse noise effects. These include: NIHL, physiological effects (e.g., hypertension and cardiovascular disease), psychological effects, annoyance and behavioural effects. This is because the overall average value (84.1 dB A) exceeds the maximum permissible levels of 70; 65-70; 70; and 80 dBA, respectively. In addition, the study established that there is a very high risk of other effects of noise such as speech interference, sleep disturbance, and activity interference whose recommended limits are 35-55; 30; and 45-55, respectively.

Table 0-14: Average noise levels

Place	Average Noise Level, LAeq (dB A)
Bus station	79.7
Inside PSVs	86.3
Commercial places	78.5
Places of entertainment/restaurants	82.5
Places of worship	93.5
Overall Average Noise Level in Nairobi	**84.1**

Table 0-15: Effects of noise pollution on public health and welfare

Effect of noise	Protective noise limit (LAeq , 24h, dBA)	Duration of exposure (Years)	Measured noise level (LAeq , 24h, dBA)	Inference (level of risk)
Noise Induced Hearing Loss (NIHL)	70	20-40	84.1	High Risk
Physiological Effects (Hypertension, Cardiovascular Disease, etc.)	65-70	5-30	84.1	High Risk
Psychological/Mental Illness/Stress	70	ST-LT	84.1	High Risk
Speech Interference (Indoors)	35	ST	84.1	Very High Risk
Speech Interference (Outdoors)	55	ST	84.1	Very High Risk
Sleep Disturbance	30	ST	84.1	Very High Risk
Activity Interference	45-55	ST	84.1	Very High Risk
Annoyance/Social/Behavioural Effect	80	ST	84.1	High Risk

In the table: ST, short-term (instant) effects; LT, long-term effects (WHO, 1999; EPA, 1974)

4.3.2 Effects Based on Public Perception

a) Demographic Information

Although a total of 400 questionnaires were administered during this study, only 240 responses were received, resulting in a response rate of 60.0%. The proportions of the respondents were more or less equally distributed among commercial centres (either traders or shoppers); entertainment joints (mainly customers); matatu/PSV passengers; and worshippers in various churches as shown in Table 4-16. Overall, majority of the respondents were male except in churches where females dominated and in PSVs where the male to female ratio was nearly one (Figure 4-16).

Table 0-16: Gender distribution of respondents as per the various study categories

Gender	**Commercial**	**Entertainment**	**PSV**	**Worship**	**Total**
	Percent				
Male	70.3	72.0	51.3	28.0	
Female	29.7	28.0	48.7	72.0	
Total	**100.0**	**100.0**	**100.0**	**100.0**	
Sample size	**64**	**50**	**76**	**50**	**240**
Percentage of overall	**26.7**	**20.8**	**31.7**	**20.8**	**100.0**

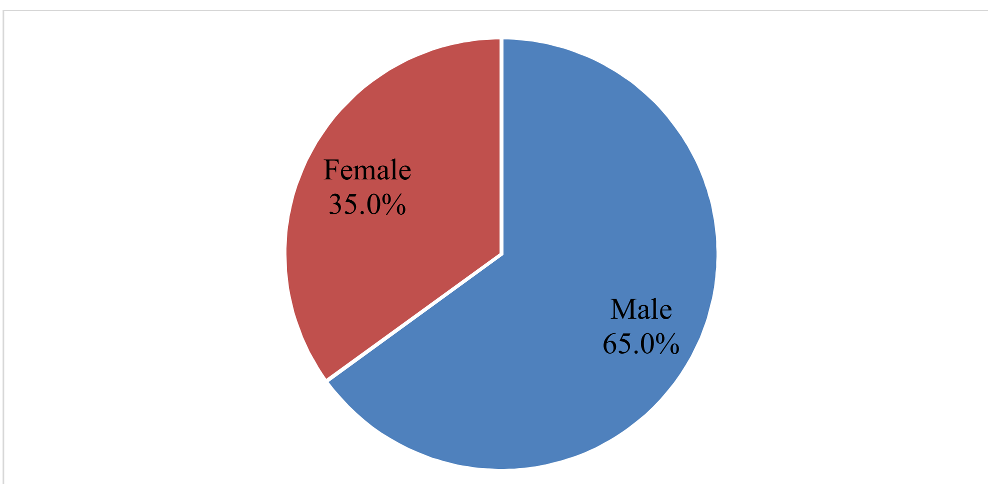

Figure 0-16: Overall distribution of respondents based on gender.

The results further show that majority (90.0%) of the respondents were youth (18-45 year), see Figure 4-17. Regarding level of education, majority of the respondents were fairly educated, with 47.1% having attained university education, 20.8% tertiary and 25.0% secondary (Figure 4-18).

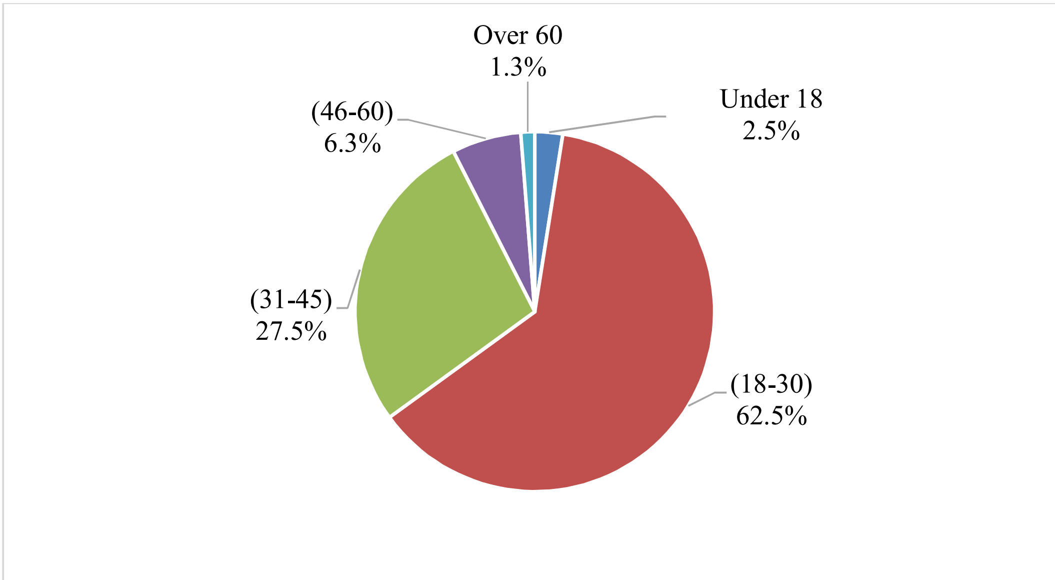

Figure 0-17: Distribution of respondents based on age.

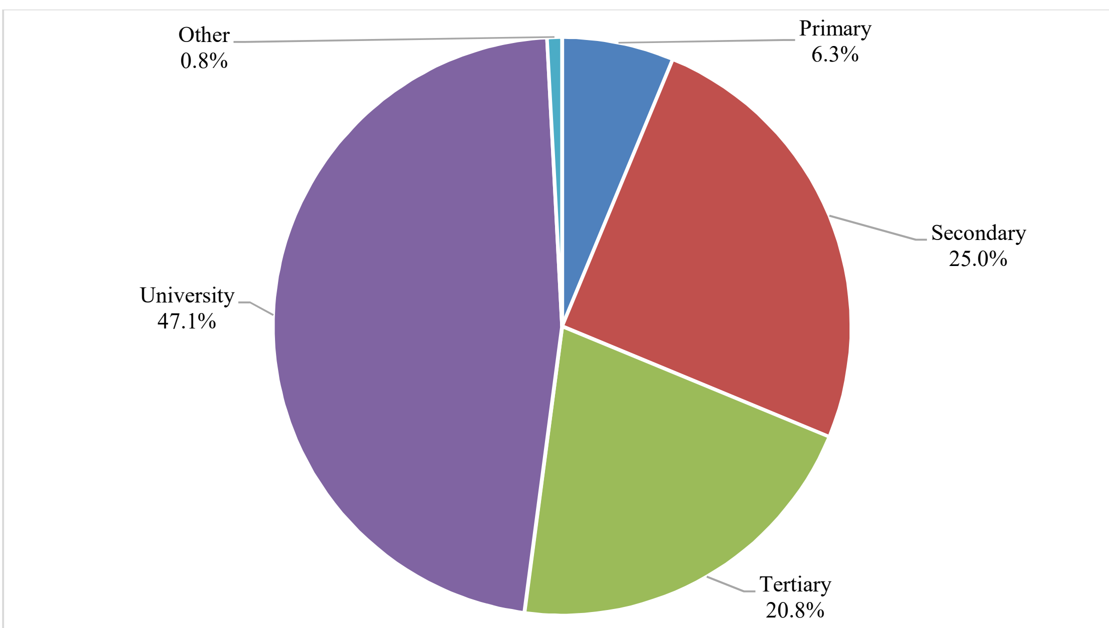

Figure 0-18: Distribution of respondents based on education levels.

b) Frequency and Duration of Exposure to Noise Pollution from Various Sources

This study established that Nairobi residents are frequently exposed to prolonged noise levels, depending on how much time they spend in PSVs, bus stations, churches and places of entertainment. At commercial centres, 65.6% of the respondents indicated that they use the market daily while a further 17.2% use the market at least five (5) days a week and they are mainly traders (Figure 4-19). The rest, who visit the markets fewer times a week, are predominantly shoppers. Furthermore, 84.4% of the respondents revealed that every day, or on every visit to the market, they spend over four (4) hours in the market and most of them who are traders spend the entire day (at least 8 hours) in the market. This puts them at higher risk of suffering negative consequences of prolonged exposure to dangerous noise levels characteristic of commercial places.

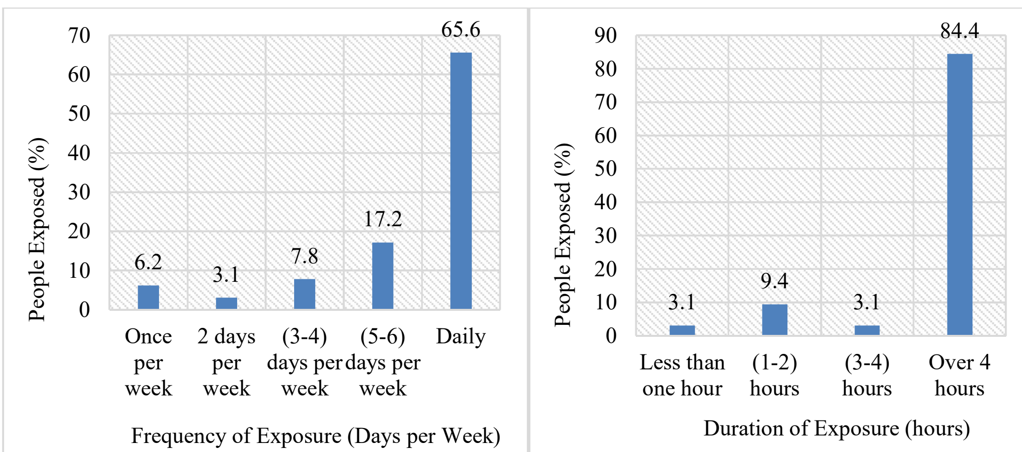

Figure 0-19: Frequency and duration of exposure to noise at commercial centres.

At places of entertainment, this study established that majority of Nairobi residents visit entrainment joints between one and four times a week (Figure 4-20). It is important to note that the 34.0, 8.0 and 4.0% who spend time in entertainment places 3-4 times, 5-6 times and daily, respectively, are more vulnerable to the high levels of noise pollution reported in entertainment spots (Section 4.1.4).

Similarly, it was found that 46.1% of Nairobi residents use PSVs for transport 5-6 days a week, with only 6.6% using public transport daily (Figure 4-21). On a single day, these people use PSVs twice, presumably to and from work with 56.6% spending between one (1) and two (2) hours to and from the same time from work. This can be attributed to rampant traffic congestion at peak traffic hours in most routes. The net effect is that this prolongs the duration of exposure to such destructive noise levels as reported in PSVs (Section 4.1.1), which puts their health and welfare at great risk.

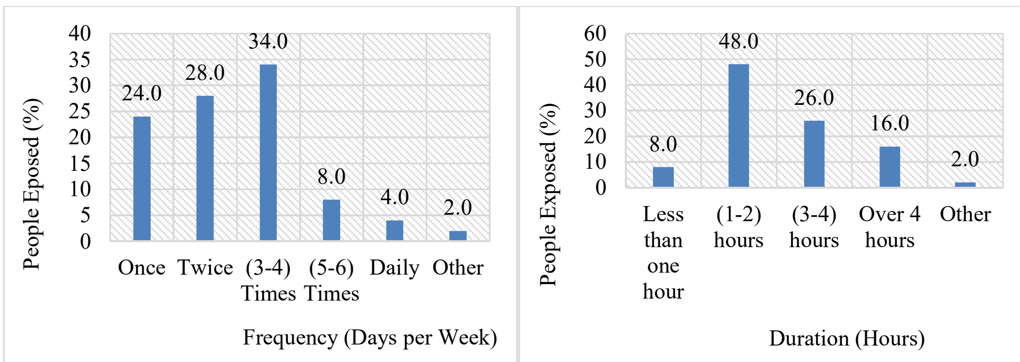

Figure 0-20: Frequency and duration of exposure at entertainment places.

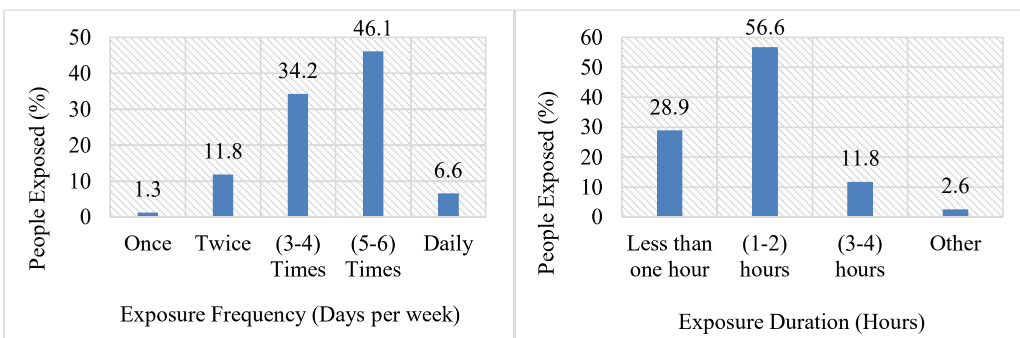

Figure 0-21: Frequency and duration of exposure to traffic noise inside PSVs.

Finally, 60.0% of the respondents indicated that they attend church worship services at least once. However, some 18.0% of the people attend services at least three (3) times a week (Figure 4-22) and are therefore exposed to more noise. In terms of time spent in church, 57.0% of the respondents indicated that their church services take between one (1) and two (2) hours whereas 11.8% attend church services which run for 3-4 hours. It was further established that about 30.0% attend church services which run for less than one hour, most of which are short midweek worship sessions. Overall, Nairobi residents are exposed to prolonged noise from churches and places of worship.

Considering the degree of noise pollution reported in churches (Section 4.1.3), this poses significant risk to the health of the worshippers.

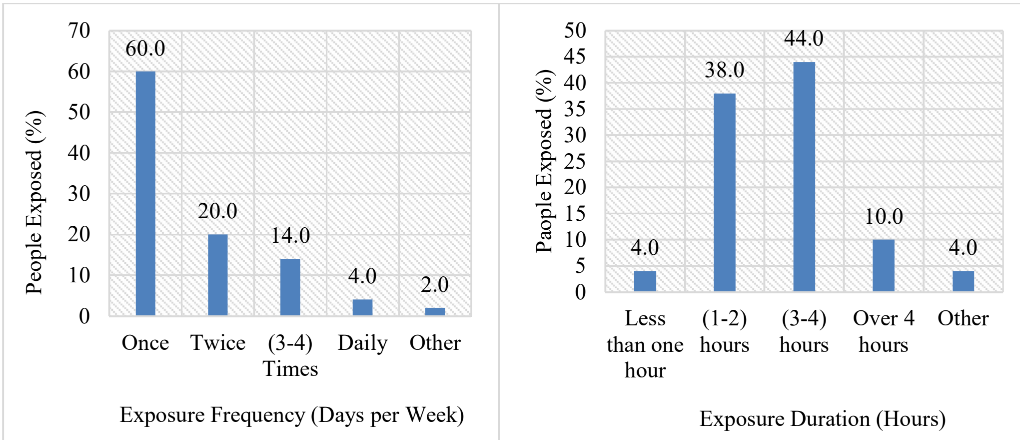

Figure 0-22: Frequency and duration of exposure to noise at places of worship.

Overall, the high frequencies and duration of exposure to various aspects of community noise can be attributed to the rapid growth in community activities such as transportation, commercial, religious and entertainment. Nairobi City is not only the capital city of Kenya and Nairobi City County, but also stands a significant economic hub for East and Central Africa (NEMA, 2011). As already stated, Nairobi experiences a serious problem of traffic congestion with peaks in the morning and evening as most people rush to and from work. Majority (about 85.0%) of these people rely on public transport. With a population of about 4 million, the resulting high number of vehicles leads to traffic congestion in most city roads thereby slowing traffic and increasing duration of exposure of PSV users to noise (NEMA, 2011). Additionally, religious activities are on the rise with churches developing everywhere in the city. Most of these churches no longer follow the traditional one-day-a-week worship system but have introduced daily and midweek fellowships. This prolongs the frequency and duration of exposure of worshippers to noise associated with worship services. Similar trends are true of the growing entertainment industry with night clubs and pubs mushrooming everywhere and staging noisy entertainment activities throughout the week.

c) Respondents' Rating of Overall Sound Volumes in Nairobi

Generally, Nairobi residents feel that the level of noise pollution in the city is significantly high. At commercial centres, while 43.8% felt that the noise there was moderate, 48.4% of the respondents rated the same sound as either high or too high (Figure 4-23). Nearly similar results were obtained in entertainment places where 44.0% rated the noise thereof as moderate whereas 46.0% felt the same noise was high or too high. In contrast, 96.0% of the respondents rated noise at places of worship as high and extremely high.

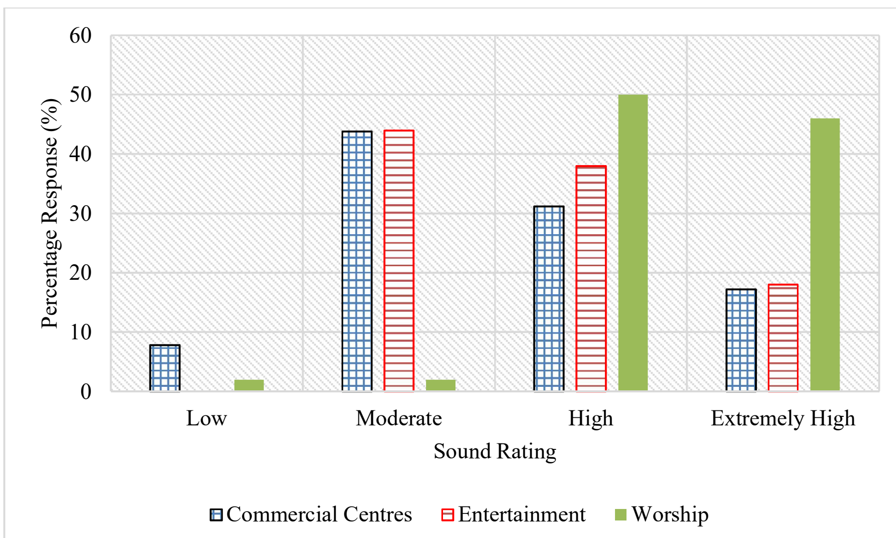

Figure 0-23: Loudness rating of overall noise levels in Nairobi City.

Figure 4-24 presents the respondents' rating of overall volume of music played inside PSVs in Nairobi city. This section was specific to music only, music having been established (Section 4.1) as the leading source of noise pollution in PSVs. The results reveal that 63.0% of the respondents rated the volume of music in PSVs as either high or extremely high.

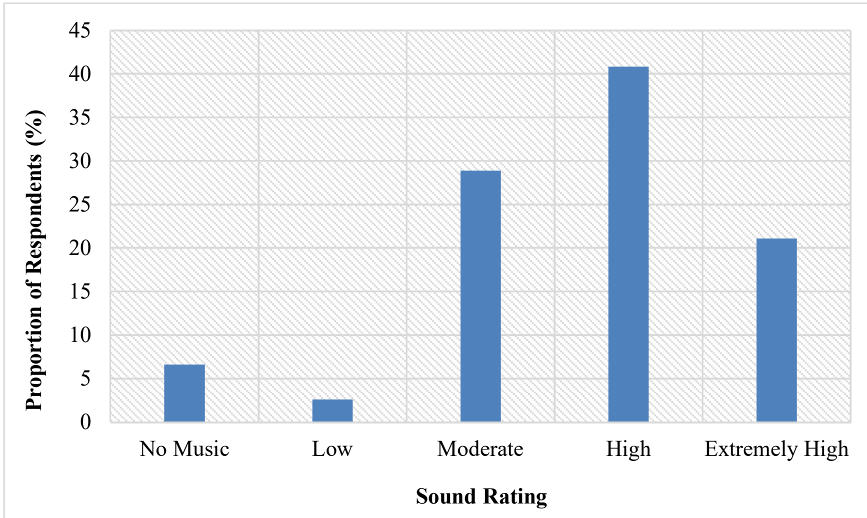

Figure 0-24: Loudness rating of music-related noise levels inside PSVs.

The results obtained in this section are commensurate with the high levels of sound measured at the various places in Section 4.1, which revealed that all churches, markets/malls and entertainment joints exceed their legislated maximum noise limits. It is interesting to note the mixed reactions people exhibit towards noise. This is attributable to the subjective way in which noise is perceived among various groups of people across various genders, ages and physical state, among others. For instance, Acardio and Gregoria (2002) assert that a sick or old person may consider a given noise environment as high whereas someone in his/her right state of health or a young person may not.

d) Sources of Noise Pollution in Nairobi City

It was established that the noise pollution in Nairobi city results from a variety of sources (Figure 4-25). At commercial centres, the loudest sounds include music/radio (played in shops or music shops – 35.9%) and human sounds (mainly traders shouting to advertise their merchandise – 34.4%). These findings are in agreement with NEMA (2013) which also singled out music shops as a leading source of noise pollution in the city. Such music is also accompanied by a growing trend of using public address systems by traders in the markets. Roadshow promotions also play a very key role in the resulting sound emanating from the very loud music often played.

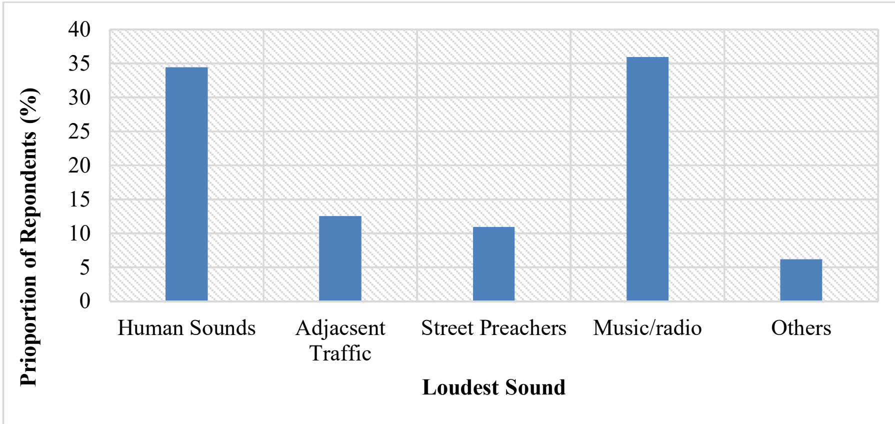

Figure 0-25: Loudness rating of sounds at commercial centres.

Table 4-17 compares the various commercial noise sources based on their relative importance index (RII). The results show that street preaching is the most significant source of noise pollution (RII=0.590), closely followed by music/radio (RII=0.572). This implies that despite human sounds having been listed as a significant noise source in the market, the level of importance associated with it is relatively lower, as compared to street preaching. In other words, street preaching causes a higher degree of nuisance or distraction to market users than the other noise sources. The principal explanation for this trend would be that in the market, users' business is predominantly limited to trading activities, selling or shopping, and not worshipping or entertainment (listening to music). This is why trading activities, such as hawking and industries, being part of the reason they are in the markets are regarded as a less significant sources of noise to market users as per the RII index.

Table 0-17: Relative importance index of sound sources at commercial centres

Rank	Source of noise	Relative importance index
1.	Worshippers/street preachers	0.590
2.	Music/radio	0.571
3.	Adjacent traffic/vehicles	0.553
4.	Hawkers/traders shouting	0.518
5.	Industries	0.478

At places of entertainment, music (played with sound amplifying equipment) is the dominant source of sound (80.0%), see Figure 4-26. Other sources of noise at entertainment joints include: human sounds (resulting from human conversations inside the joint) and sounds from adjacent outside joint (e.g., adjacent traffic, industries, etc.). Table 4-18 presents the relative importance of the various sources of entertainment noise. According to the results, music/radio is the most significant source of noise pollution at entertainment places. This is understandable as the loud music played in entertainment places is the sole most significant source of noise there.

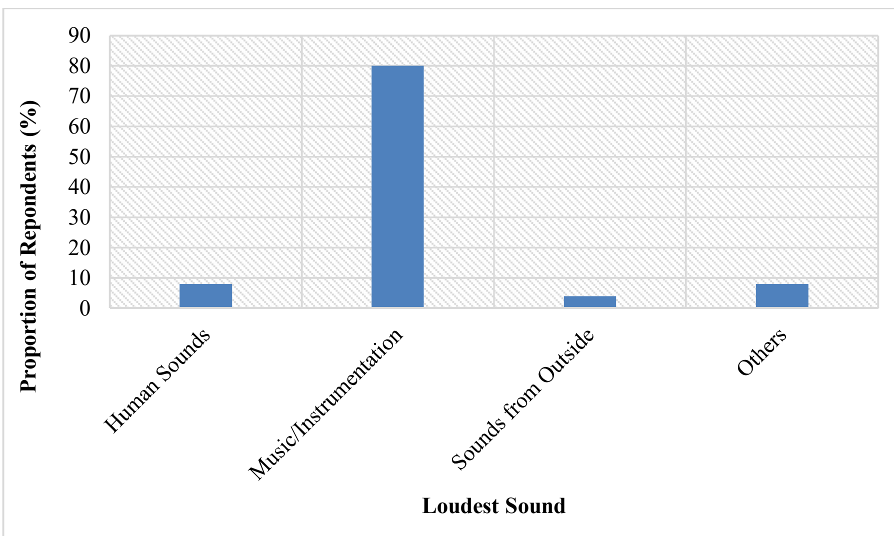

Figure 0-26: Loudest sound at entertainment places.

Table 0-18: Relative importance index of entertainment sound sources

Rank	Source of noise	Relative importance index
1.	Music/radio/TV/Instrumentation/Live band	0.776
2.	Sounds from Outside	0.484
3.	Human Sounds	0.448
4.	Sounds from the Kitchen	0.408

Like at commercial and entertainment places, 78.0% of the respondents ranked music/radio as the leading source of noise pollution in PSVs (Figure 4-27). Other sources of noise pollution enlisted include: passenger conversations; vehicle/engine sounds; touting (touts banging the vehicles and shouting in search of passengers); and hooting. In addition, the sound sources were ranked in terms of their relative importance as shown in Table 4-19. The results indicate that the most significant source of noise pollution inside PSVs was found to be music/radio (RII=0.613) whereas the least significant sound source was touting (RII=0.421). These results correspond with noise measurements obtained in Section 4.1, which also established that noise inside PSVs was alarmingly above recommended limits and that the principal source of this noise is loud music played with sound amplifying equipment. The high RII associated with this music indicates that it is a principal source of nuisance/distraction/disturbance as compared to other sources.

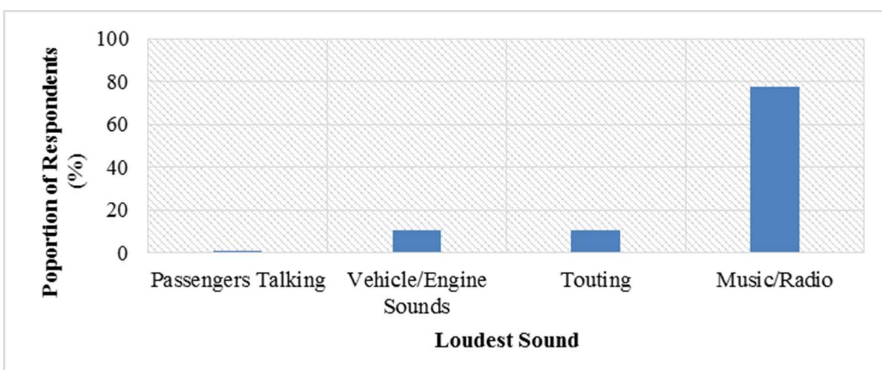

Figure 0-27: Loudest sounds in PSVs in Nairobi.

Table 0-19: Relative importance of sound sources in PSVs

Rank	Source of Sound	Relative importance index
1.	Music/Radio	0.613
2.	Passengers Talking	0.494
3.	Vehicle/Engine Sounds	0.444
4.	Vehicles hooting	0.434
5.	Touts Banging Vehicles and Shouting	0.421

Finally, at places of worship, 60.0% of respondents considered instrumental accompaniments used in worship as the leading source of noise (Figure 4-28). Others include: singing by worshippers; preaching/sermons; hand clapping; and prayers. In terms of their relative importance, singing was found to be the most significant source of noise at places of worship (RII=0.832), see Table 4-20. In contrast, hand clapping was found to be the least significant source of noise pollution at worship places (RII=0.576). Like in PSVs, churches in Nairobi have mastered the art of using very sophisticated instruments and public address systems. The amplified sound dominates over all other sources of noise. The high RII value indicates the level of concern that the use of such equipment/instruments raises among worshippers.

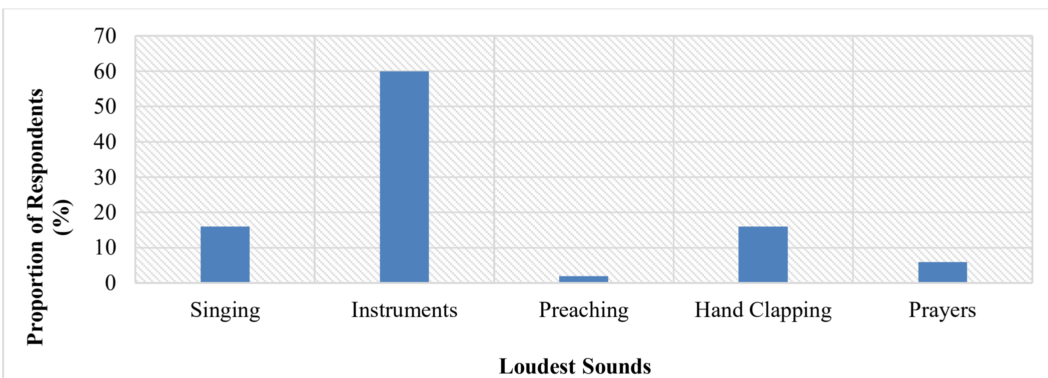

Figure 0-28: Loudest sounds at places of worship in Nairobi City.

Table 0-20: Relative importance of sound sources at places of worship

Rank	Type of sound	Relative importance index
1.	Singing	0.832
2.	Instruments	0.724
3.	Preaching	0.700
4.	Prayers	0.692
5.	Hand Clapping	0.576

e) Public Reaction to Existing Sounds

The respondents displayed mixed reactions to the noise situation in Nairobi City, which was summarised in terms of their level of comfort/discomfort with the prevailing noise conditions. First, at markets/malls, 44.0% indicated that they were comfortable with the noise environment while 27.0% described their reaction to the noise as "just bearable" (Figure 4-29). Most of these people claimed that they are used to the high noise level in the market to an extent that they are either comfortable with it or they can live with it. This is true from a layman's point of view. However, technically speaking, these people are likely to be suffering from noise-induced-hearing loss (NHIL), an auditory effect of noise in which the hearing threshold changes with respect to the sound levels one is exposed to. The threshold shift may be temporary to permanent depending on the duration of exposure to high noise levels, making the victims feel like they are used to the noise environment and therefore they feel comfortable so that they can bear with the high noise condition (Acardio & Gregoria, 2002). This ignorance can be attributed to lack of awareness of noise and its destructive impacts amongst many local people, leading to irresponsible noise behaviour in the city.

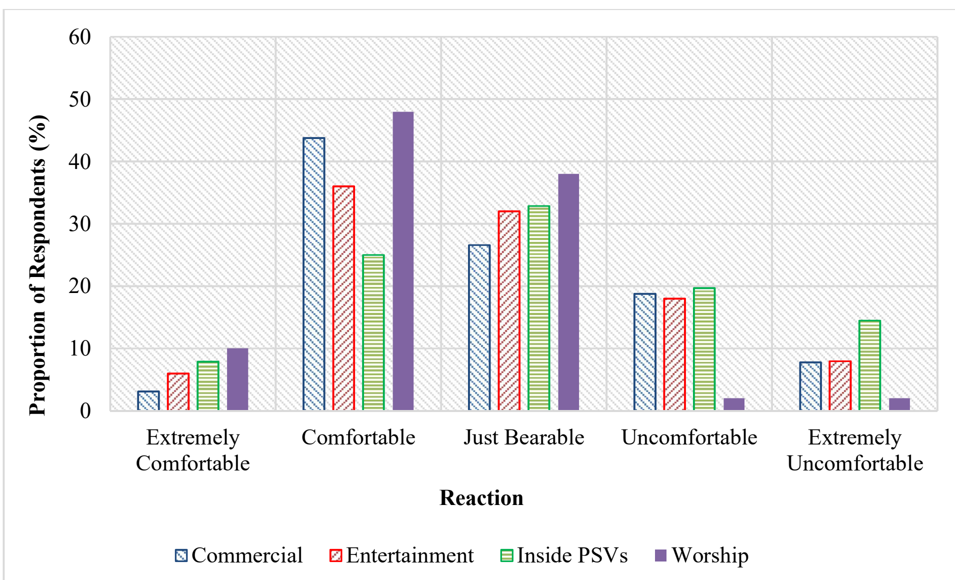

Figure 0-29: Public reaction to community noise pollution in Nairobi City.

At entertainment places, 36.0 % of the respondents indicated that they are comfortable with the noise environment, with 6.0% describing their experience as "extremely comfortable". Only 26.0% of the respondents indicated that they were either uncomfortable or extremely uncomfortable. This revelation may be attributed to various factors. First, majority (85.0%) of the respondents from entertainment places were young people within the 18-35 years age bracket. These youngsters seem to enjoy loud music characteristic of entertainment joints. Secondly, there is a possibility that these people are already suffering hearing threshold shifts, which makes them feel like they are used to the high sounds. Finally, this survey was largely carried out within places of entertainment. It is unlikely that one would voluntarily visit entertainment joints while he/she does not enjoy what happens therein. All in all, even if they are not aware of it, entertainment lovers in Nairobi are exposed to dangerous noise levels that are detrimental to their health.

Similarly, Figure 4-29 shows that inside PSVs, 32.0% of the respondents enjoy (are either comfortable or extremely comfortable with) the high noise levels reported in Section 4.1.1. Only 26.0% of the respondents stated that they were uncomfortable or extremely uncomfortable. Again, like for entertainment places, this study established that majority (57.0%) of PSV users are the youth within the 18-35 years age bracket. Such people tended to be comfortable with the loud music characteristic of most Nairobi PSVs, as compared to older people. In fact, during the study, it was observed that most young people throng PSVs that play loud music, as compared to those without sophisticated music systems. This is despite the fact that most of these young people are well educated and would thus be expected to be aware of the detriments of exposure to excessive noise. Only 35.0% of the respondents expressed a degree of discomfort with the high noise in Nairobi PSVs. However, since they have no other alternative for transport, they are forced to bear with the situation.

Finally, regarding noise at places of worship, 48.0% of worshippers were comfortable with the high noise levels characteristic of church worship services in Nairobi. A further 10.0% are extremely comfortable while 38.0% can bear with the noise situation. Only 4.0% do not like the high noise at church. The high level of comfort with worship noise is not necessarily an indication that worshippers enjoy the high noise. Instead, the study noted that most respondents were reluctant to express dislike for church-related activities due to perceived reverence, fear of God and allegiance to religious activities. In other words, as long as it is God's work, it does not matter how noisy it gets to worship him. It is imperative to note, however, that this firm believe in religion does not alleviate the detrimental effects of noise. Thus, worshippers who continue to be exposed to high noise levels are bound to suffer its negative effects.

As already stated, public perception of noise is dependent upon various factors, including age, gender, level of education, physical/heath status and psychological state (mood), among others (Acardio & Gregoria, 2002). To account for the mixed reactions reported in this section, a cross-tabulation was carried out between age, gender and level of education against perception of the existing noise environment in Nairobi. The results indicated that young people expressed a higher degree of comfort in high noise environments as compared to older people (Figure 4-30). Women also expressed a higher degree of comfort in high noise environments as compared to men (Figure 4-31). However, no significant trend was observed between level of education and people's perception of noise (Figure 4-32).

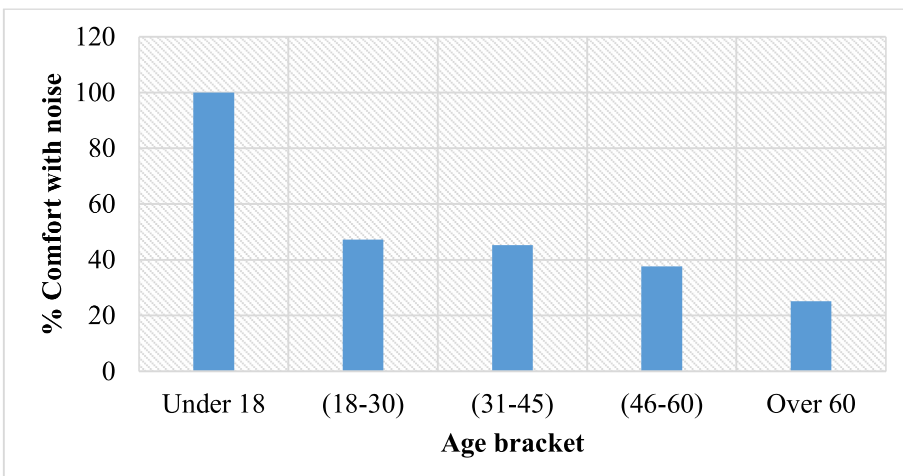

Figure 0-30: Age versus perception cross tabulation.

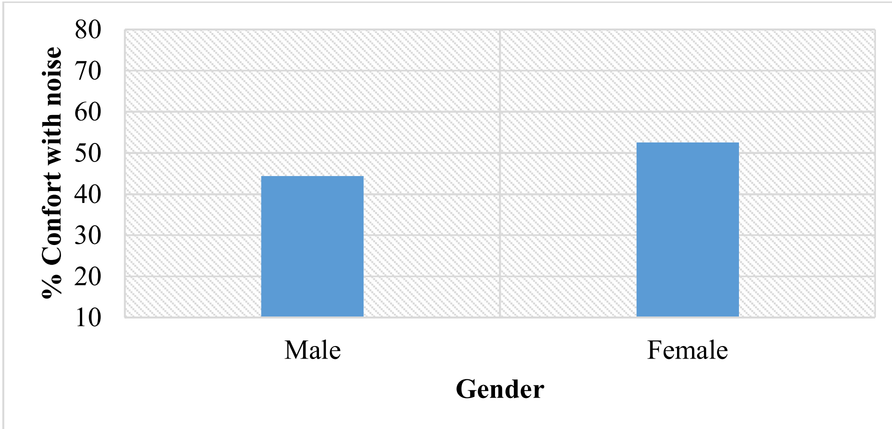

Figure 0-31: Gender versus perception cross tabulation.

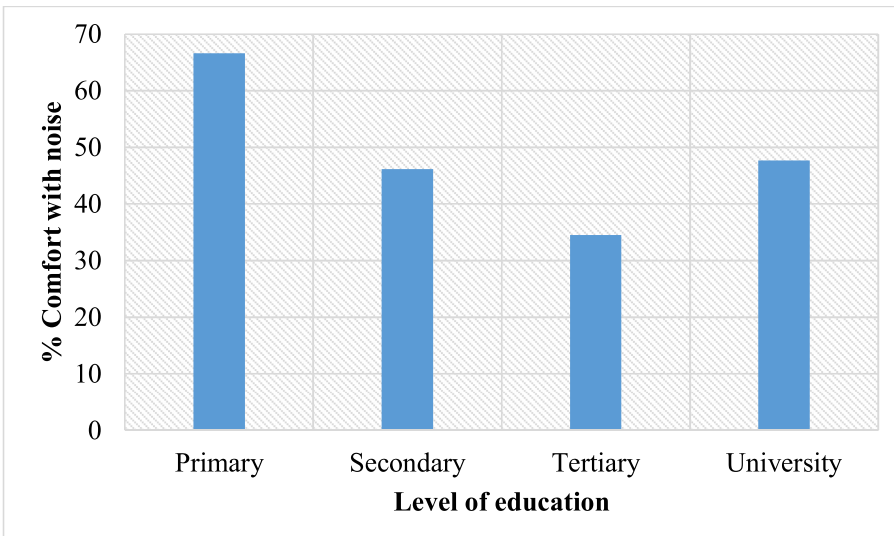

Figure 0-32: Age versus perception cross tabulation.

f) Effects of Noise Pollution on Public Welfare and Health in Nairobi City

As already established in this study, all the study sites exceed their maximum permissible noise levels thus putting the health and welfare of people at risk. This section sought to find out from the people themselves the prevalence of specific public welfare and health effects of noise. Public welfare effects studied were: interference with telephone communication; interference with speech communication; interference with concentration; annoyance/irritation; and, headache.

i. Interference with Telephone Communication

Figure 4-33 presents response rate based on the prevalence of noise-related telephone communication interference in Nairobi city. From the results, it is evident that this effect is most experienced inside PSVs (63.2%) as compared to entertainment and commercial centres. In fact, the study indicates that telephone communication interference is least experienced at commercial centres. This is attributed to the fact that the noise inside PSVs was found not only to be higher than the maximum permissible level (86 dBA), but also far much exceeds the limit for speech intelligibility which is 35 dBA indoors and 45 dBA outdoors (WHO, 1999; EPA, 1974). At commercial centres, although the noise is higher than permissible limits, it is relatively lower, hence, does not significantly interfere with telephone conversation among market users.

ii. Interference with Speech Communication

Figure 4-34 shows the response rate for the prevalence of speech communication interference among various places in Nairobi City. Like telephone communication interference, speech interference begins to occur at sound levels exceeding 35 dBA indoors and 45 dBA outdoors (WHO, 1999; Acardio & Gregoria, 2002). As per this study, speech interference is most prevalent in matatus/PSVs whereas it is least experienced at commercial places. As noted earlier, speech communication is nearly rendered impossible by the high noise in most PSVs in Nairobi. In order to communicate, one must shout and/or speak very close to another person's ear.

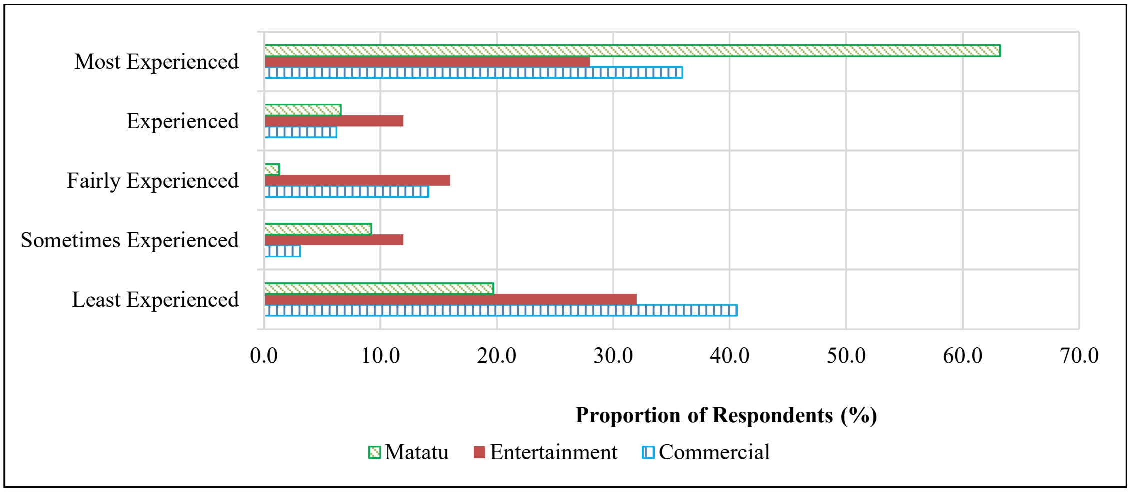

Figure 0-33: Response rate for interference with telephone communication.

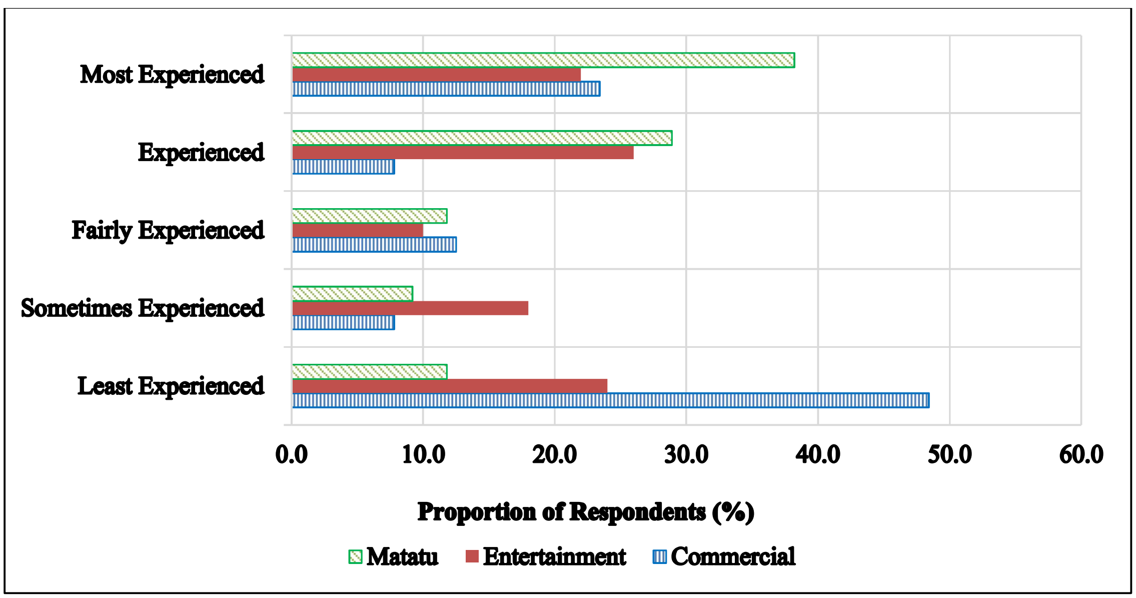

Figure 0-34: Response rate for interference with speech communication.

iii. Interference with Concentration

Interference with concentration, also commonly referred to as activity interference, is a public welfare noise effect which occurs when noise levels exceed 45 dBA indoors and 50-55 dBA outdoors (WHO, 1999; EPA, 1974). This study established that activity/concentration interference occurs mostly inside matatus while it is least experienced at commercial centres, as shown in Figure 4-35. Both noise levels measured in matatus and in markets exceed the 45-55 dBA range for activity interference hence the high prevalence of this effect. However, in markets, most market users are focused on one activity (mainly either shopping or selling) and there are hardly any other cognitive tasks that require their concentration. In matatus, sometimes one needs to concentrate to read a newspaper, a novel or a book or just to think but due to the loud noise (over 80 dBA), meaningful concentration is hard to achieve.

iv. Annoyance/Irritation

Noise begins to irritate/annoy when its levels rise above 35 dBA (indoors; moderate annoyance) and 55 dBA (outdoors; serious annoyance). However, noise-induced annoyance varies with the incident noise characteristics and, largely, with various non-acoustical social, psychological and economic factors (Zannin, Calixto, Diniz & Ferreira, 2003). Noise above 80 dBA elicits annoyance reactions among many people. According to this study, noise-induced annoyance is most experienced in matatus while it is least experienced at commercial centres (Figure 4-36). The average noise level measured in matatus was about 86 dbA while that at commercial centres averaged about 73 dBA. This, with respect to the 35-45-80 dBA limit for annoyance, explains the difference in prevalence of this effect in matatus and at commercial places.

v. Headache

Prolonged exposure to noise above 70 dBA may cause headaches among most people (Acardio & Gregoria, 2002). Results of this study show that noise-related headaches are most experienced as a result of noise from matatus while it is least experienced in commercial centres (Figure 4-37). This can be attributed to the fact that the average noise level measured in matatus averaged 86 dBA while that in the markets was relatively lower. The high number of incidences of headaches in matatus could be attributable to the nearly 20% of respondents who indicated strong dislike and discomfort for noise inside PSVs.

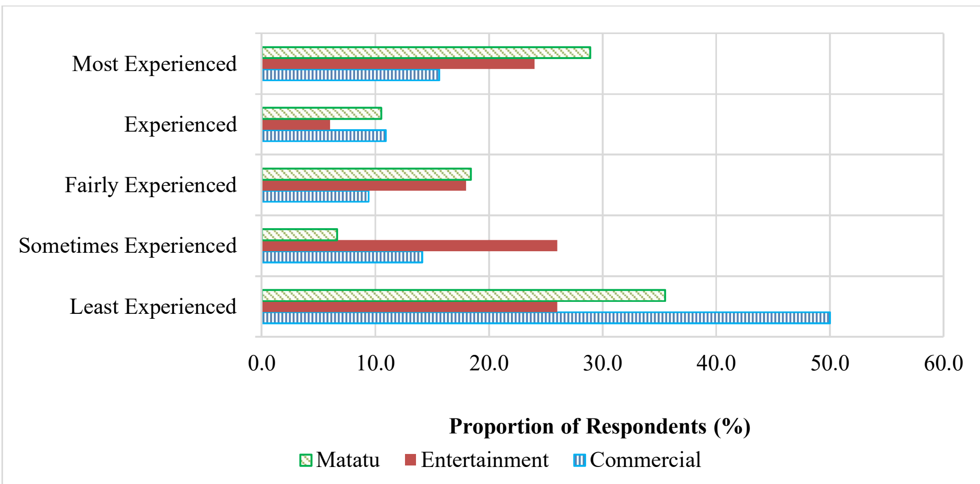

Figure 0-35: Response rate for interference with concentration.

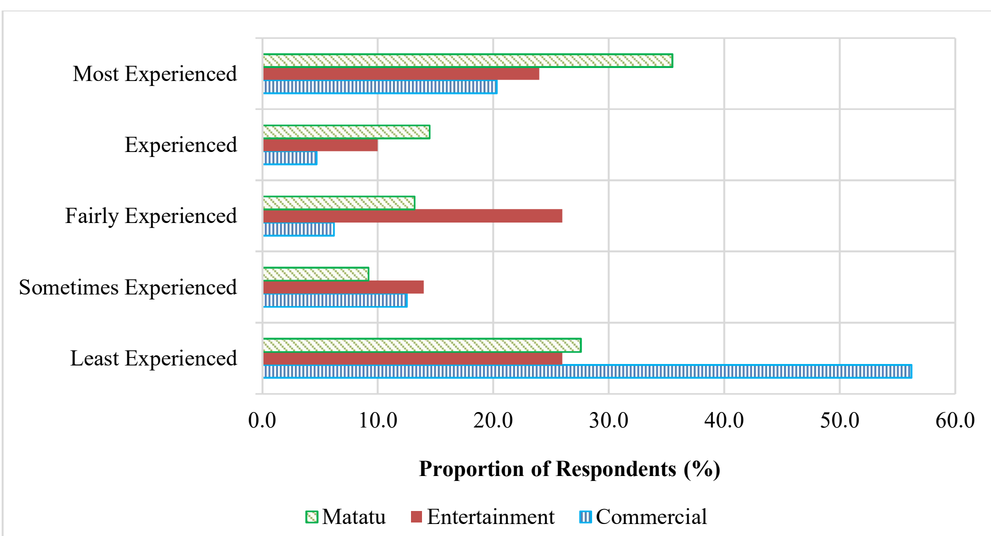

Figure 0-36: Response rate for noise-induced annoyance/irritation.

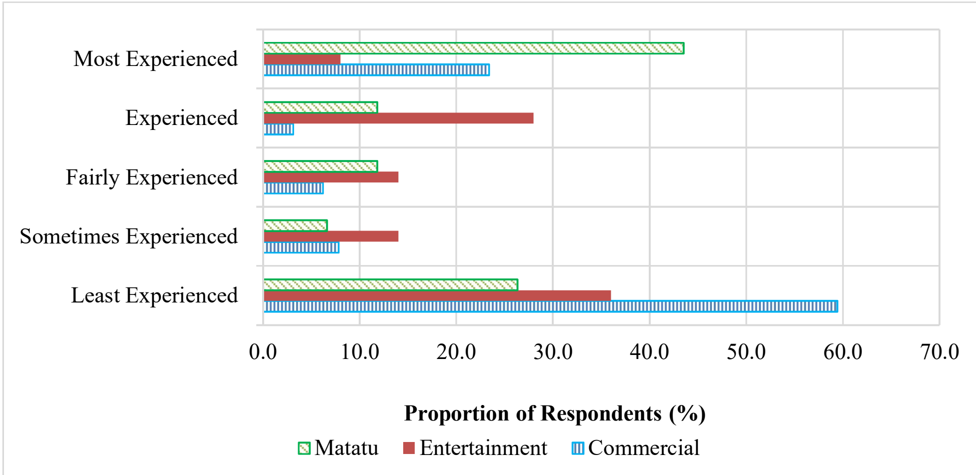

Figure 0-37: Response rate for noise-induced headaches in Nairobi City.

vi. Chronic Health Conditions and Vulnerability to Noise

In addition to the public welfare effects above, this study sought to establish the prevalence of health-related noise effects among the respondents. The results are detailed in Table 4-21 and they reveal that the most prevalent noise-related health effect is frequent headache which was reported among some 39.0% of the respondents. Secondly, 14.0% of the respondents reported some form of hearing impairment that could be noise-induced. Other health effects reported include hypertension/high blood pressure, heart disease (myocardial infarction) and stress. These health conditions are not only attributed to noise (as one of their possible causes), but also increase the vulnerability of victims to the detrimental effects of noise pollution (Acardio & Gregoria, 2002). In order to qualify the possibility of the chronic conditions being a result of noise pollution, the respondents were probed to specify the possible causes of their conditions. As shown in Table 4-22, 27.0% of all the reported health conditions were acquired over life time while only 1.0% were hereditary. So it is possible that, as Acardio and Gregoria (2002) noted, noise could be one of the possible causes of some of these conditions. But most importantly, patients of these conditions tend to be more vulnerable to the effects of noise, which worsens their situation.

Table 0-21: Response rate based on prevalence of health-related noise effects in Nairobi City

Chronic health condition	Response rate (%)
Any hearing impairment	13.7
Hypertension/High blood pressure	5.8
Any form of heart disease	1.1
Stress/Depression	5.8
Frequent Headaches	39.5
None	34.2
Total	100.0

Table 0-22: Response rate for the causes of health-related noise effects in Nairobi City

Cause of Condition	Response rate (%)
Inherited at Birth	0.5
Acquired over life time	26.8
Not sure	10.5
Missing/None	62.1
Total	100.0

g) Residential Noise Pollution

i. The Extent of Residential Noise Pollution

Asked whether they are bothered by noise back at their places of residence, 13.7% of the respondents indicated that they are extremely bothered (Table 4-23). Only 22.1% indicated that they are not bothered at all by noise at their places of residence. Although this study did not manage to conduct actual noise measurements at residential areas, the degree at which people are bothered by noise reflects the high noise pollution in Nairobi city as generally reported in other areas. Furthermore, this can be attributed to growth in commercial, religious, entertainment and transportation activities in the city. As a matter of fact, most bus stations, main roads, markets, places of worship and entertainment joints are located in residential areas and could be responsible for the high noise levels.

Table 0-23: Response rate for the extent of residential noise pollution in Nairobi City

Status	Response rate (%)
Extremely Bothered	13.7
Bothered	15.3
Sometimes Bothered	46.3
Not Bothered	22.1
Not Sure	2.6
Total	100.0

(ii) Sources of Residential Noise Pollution

Asked to identify and rank the sources of noise they experience at home in order of their intensity, majority (52.1%) of the respondents indicated that the most dominant source of residential noise pollution is adjacent places of entertainment and adjacent road traffic whereas the least significant source was airport noise (Table 4-24). As further shown in Table 4-25, noise from places of entertainment is the greatest concern for the people at their places of residence. This can be attributed to the fact that unlike the other sources, entertainment places make much higher noise most of which happens in the night and during the weekends when majority of people are at home. Besides, the impact of noise has been noted to be much more at night when the environment is relatively quiet (with respect to other noise sources) (Acardio & Gregoria, 2002). This poses a greater risk to sleep and other home-based cognitive tasks such as reading. In addition, disturbed sleep in turn results in activity interference among victims, especially on the following day when they are at work.

Table 0-24: Percentage response rate for the extent of residential noise pollution

Rank	Source of Sound	Response rate (%)
1.	Sounds from adjacent places of entertainment	52.1
2.	Traffic sounds	10.0
3.	Sounds from noisy neighbours	15.5
4.	Sounds from adjacent places of worship	15.1
5.	Sounds from adjacent industries	2.6
6.	Sounds from adjacent markets	2.6
7.	Airport noise	2.1
Total		100.0

Table 0-25: Relative importance index of residential noise sources

Rank	Source of Sound	RII
1.	Sounds from adjacent places of entertainment	0.569
2.	Traffic sounds	0.529
3.	Sounds from noisy neighbours	0.481
4.	Sounds from adjacent places of worship	0.479
5.	Sounds from adjacent industries	0.434
6.	Sounds from adjacent markets	0.383
7.	Airport noise	0.337

(iii) Effects of Residential Noise Pollution

The most dominant effect of residential noise pollution in sleep disturbance (65.0%) as shown in Table 4-26. As already stated, most Nairobi residents are at home during the night and that is the time they feel the impact of the noise environment around them. After a hard day's work, the effect of noise on sleep becomes more apparent (Lui, 1999). Similarly, the respondents ranked the effects of noise that they experience as a result of residential noise as shown in Table 4-27. From the result sleep disturbance was marked as the most significant effect of residential noise pollution (RII=0.609). In contrast, stress/depression ranked as the least intense noise-induced impact at homes (RII=0.466).

Table 0-26: Response rate for effects of residential noise pollution in Nairobi City

Rank	Effect of sound	Response Rate (%)
1.	Sleep Disturbance	65.0
2.	Annoyance/Irritation	18.5
3.	Interference with Concentration	10.0
4.	Speech/Communication interference	3.6
5.	Stress/Depression	2.9
Total		100.0

Table 0-27: Response rate for effects of residential noise pollution in Nairobi City

Rank	Effect of sound	RII
1.	Sleep Disturbance	0.609
2.	Annoyance/Irritation	0.592
3.	Interference with Concentration/reading/working	0.567
4.	Speech/Communication interference	0.488
5.	Stress/Depression	0.466

g) **Level of Awareness of Noise and Its Effects**

The level of awareness of noise pollution and its detrimental effects is relatively high in Nairobi City. As was established in this study, and as shown in Figure 4-38, 67.9% of the respondents are generally aware of noise and its effects. Only 17.0% exhibited total unawareness. A further 15.0% exhibited indifference concerning the noise problem and its effects, raising the proportion of those who may be considered unaware to about 32.0%. The high level of awareness can be directly attributed to high literacy levels among the respondents (over 90.0% having at least secondary education). However, it is imperative to note that despite the high level of awareness and literacy, the level of irresponsible exposure to noise pollution remains extremely high.

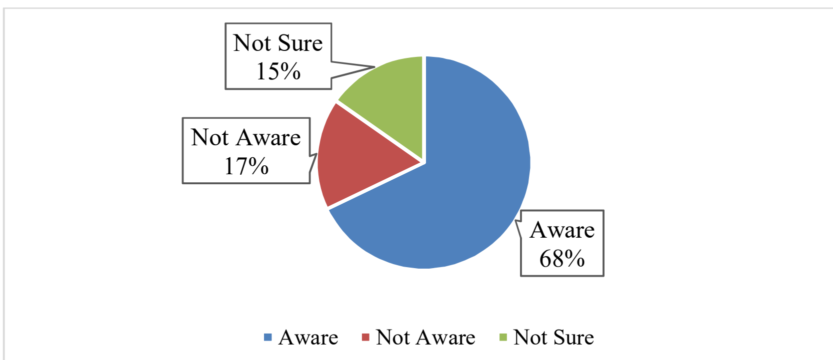

Figure 0-38: Response rate for level of awareness of noise and its effects in Nairobi City.

Statistical cross tabulation was further conducted to probe how the level of awareness varied amongst the respondents with respect to their age, gender and level of education. The results revealed that the level of awareness generally reduced with increase in age of the respondents (Figure 4-39). With respect to gender, there was no significant difference in awareness levels as males and female's awareness levels were more or less the same (62.0% and 63.0% respectively) (Figure 4-40). Additionally, the level of awareness was found to increase with increase in level of education (Figure 4-41). However, despite the high levels of awareness, Nairobi residents are still exposed to high levels of noise pollution, either by choice or against their will as indicated in this study. This implies that all, aware or not, are still exposed to a high degree of risk to the detrimental effects of noise on their health and welfare and further awareness efforts should thus target all members of the community alike.

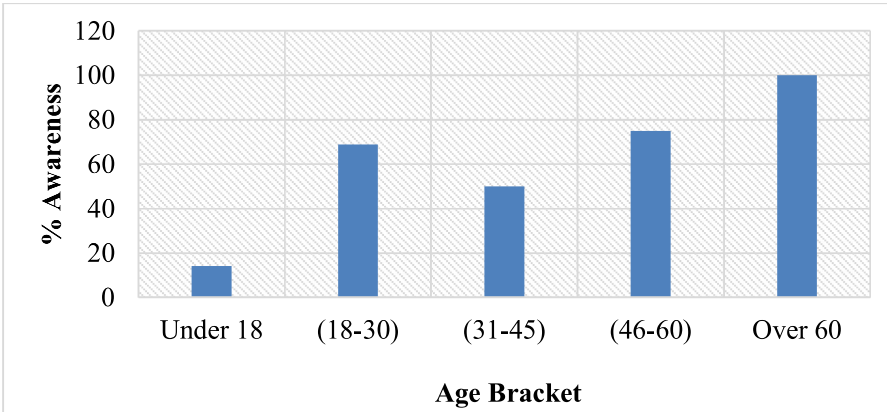

Figure 0-39: Level of awareness with respect to age.

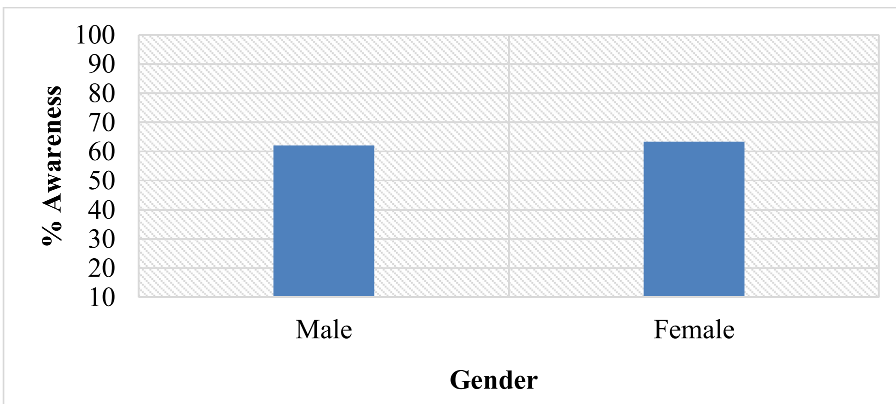

Figure 0-40: Level of awareness with respect to gender.

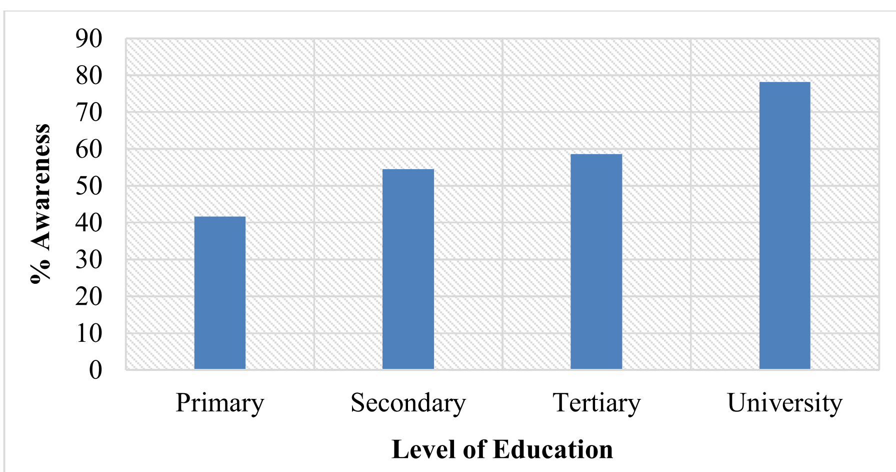

Figure 0-41: Level of awareness with respect to level of education.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

1. The extent of noise pollution in Nairobi City is very high. The highest average noise level was reported in churches, which was 89.4 dBA. This was followed by PSVs at 86.3 dBA; places of entertainment at 82.5 dBA; bus stations at 79.7 dBA; and commercial places at 78.5 dBA. In addition, this study established that there is 100% non-compliance with the provisions of the Noise and Excessive Vibration Pollution (Control) Regulations (2009), with all the sampled sites significantly exceeding their corresponding legislated limits. Churches were found to be the most non-compliant with the noise act with the level of non-compliance quantified at 124%. This was followed by entertainment spots at 101%; PSVs at 44%; commercial centres at 43% and bus stations at 43%. The high levels of noise pollution and outright non-compliance with the noise act signify poor law enforcement in the city.

2. This study further established that traffic noise pollution in Nairobi City can be modelled by multiple linear regression The model relates traffic noise level with traffic volume , percentage of heavy vehicles in the traffic, and traffic speed. Prevailing ambient air temperature and relative humidity were found to have no significant effect on the resulting traffic noise. A satisfactory coefficient of determination of 0.783 was obtained, indicating that a strong correlation exists between traffic noise and the stated parameters. The model achieved a 100% prediction performance based on a 5% residual error interval. In addition, there

was no significance difference between actual and predicted noise levels based on a paired t-test at 5% significance level.

3. Noise pollution poses a wide range of risks to public health and welfare in Nairobi city. The Main public welfare effects include telephone communication interference, speech disturbance, sleep disturbance, activity/concentration interference, annoyance/irritation and headaches. In addition, the most prevalent noise-related health effect is frequent headache followed by hearing impairment. Other effects include heart disease (myocardial infarction) and stress/depression. This study also established that the population at high risk of destructive noise effects are the youth who are majority at most noise-prone places.

5.2. Recommendations

1. The attention of law enforcement agencies, particularly NEMA and DOSHS, should be called to the high extent of noise pollution in Nairobi city. Subsequently, these agencies should intensify environmental law enforcement in the city. In particular, the noise regulations of 2009 should be properly enforced to achieve their intended aim of controlling the level of noise pollution.
2. The noise act of 2009 should be relooked not only against its effectiveness to control noise pollution but also in terms of whether its provisions are achievable to law keepers. One such provision is that which sets noise limits for entertainment places at 55 dBA during the day and 35 dBA at night whereas most entertainment places are busiest and make the highest noise at night.
3. There is need to pay more scholarly attention to the study and understanding of noise pollution so as to incorporate professional input in community noise management in Kenya and to promote availability of noise data for the country.
4. Environment management agencies should intensify awareness creation of noise and its impacts on public health and welfare to help reduce irresponsible behaviours for and exposure to dangerous noise levels.
5. Further research should focus more on noise control measures that could be adopted to reduce the risk of noise pollution. These should be geared towards placing noise control should as a fundamental component of the design of structures such as roads and buildings, as happens for other design parameters such as fire and durability, among others.

LIST OF REFERENCES

Acardio, P.S. & Gregoria, A.S. (2002). *Environmental Engineering: A Design Approach*. London: Routledge.

Ahammed, M., Alaudin, S.T. & Klement, T. (2010). Quiet and durable pavements: Findings from an Ontario Study. *Can. J. Civ. Eng. 37*(1), 1035-1044.

Ahmad, J., Abbas, A. & Reem, S. (2006). Evaluation of Traffic Noise Pollution in Amman, Jordan. *Environmental Monitoring and Assessment, 120*(1), 499–525.

Ahmad, K., (1998). A study of noise pollution in Dhaka City, Department of Environment (DOE), Bangladesh.

Ahmed, H.O., Dennis, J.H. & Ballal, S.G. (2004). The accuracy of self-reported high noise exposure level and hearing loss in a working population in Eastern Saudi Arabia. *International Journal of Hygiene, Environment and Health*, *207*, 227-234.

Alam, J. B. (2006). Study on traffic noise level of sylhet by multiple regression analysis associated with health hazards, *Iranian Journal of Environmental Health, Science and Engineering, 3*(2), 71-78.

Al-Zahrani, A.M. (2007). Study of noise pollution during Hajj season 1427 H: Senior Project Report. Umm Al-Qura University, Working Paper No. 2, 2007.

American Speech-Language-Hearing Association (1991) *Combating Noise in the 90's: A national strategy for the United States.* Symposium final report and recommendations from the professional community to the 102nd Congress.

Atmaca, E., Peter, I. & Altin, A. (2005). Industrial Noise and its effects on humans. *Polish Journal of Environmental Studies, 14*(6), 721-726.

Barczewski, B. (2013). *How well do environmental regulations work in Kenya? A case study of the Thika Highway Improvement Project*. Nairobi: University of Nairobi

Bedi, R., (2006). Evaluation of occupational environment in two textile plants in northern India with specific reference to noise. *India Health, 44* (1), 112-116.

Bies, D.A. & Hansen, C.H. (1996). *Engineering Noise Control: Theory and Practice (2nd Edition).* E and FN SPON: London.

Bodin, E.M. (2012). Survey context and question wording affects self-reported annoyance due to road traffic noise: a comparison between two cross-sectional studies. *Environmental Health, 11*(14), 234-239.

Bruel, A. & Kajer, C. (1984). *Measuring Sound*. Larson and Son Printers: Denmark.

Bruel, A. & Kajer, C. (2002). *Standard Operation Manual of Digital Sound Level Meters*. Larson and Son Printers: Denmark.

Bullen, P.B. (2014). How to pre-test and pilot a survey questionnaire. Retrieved from: http://www.tools4dev.org/resources/how-to-pretest-and-pilot-a-survey-questionnaire/

Chege, E.K. (2011). Pollution control in developing countries with a case study on Kenya: A need for consistent stable regimes. *Revista International de Direito e Cidadania, 1*(9), 29-42.

Creswell, J.W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research.* (4th Ed). Boston: Pearson.

Czaja, R. (1998). Questionnaire pretesting comes of age. *Marketing Bulletin, 19*(5), 52-66.

Dursun, S., Ozdemir, C., Karabork, H. & Kocak, S. (2006). Analysis of Noise Pollution in Turkey. *Journal of International Environmental Application & Science*, *1*(1-2), 63-72.

Eco-Healthy Child Care (2010). *Noise Pollution.* Washington DC: Children's Environmental Health Network.

Ehrampoush, M.H., Halvani, H.G., Barkhordari, A. & Zare, M. (2011). Pollution in urban environments: A study in Yazd City, *Iran. Pol. J. Environ. Stud. 21*(4), 1095-1100.

Environmental Protection UK (2008). *Noise Pollution.* Brighton: UK.

EPA South Australia (2009). *Guidelines for the use of the Environment Protection (Noise) Policy, 2007.* Government of Australia.

Esmaeelpour, M.R., Sekhavatjou, M.S. & Ahwazi, Z.C. (2014). Designing a Traffic Noise Prediction Model for Highways in Iranian Megacities (Case study: Ahvaz City). *International Journal of Environmental Research, 8*(2), 427-434.

Essandoh, P.K. & Armach, F.A. (2011).Determination of Ambient Noise Levels in the Main Commercial Area of Cape Coast, Ghana. *Research Journal of Environmental and Earth Sciences, 3*(6), 637-644.

Fischer, A., Laing, J. & Townsend, J. (1998). *Handbook of family planning operations research design (2nd Edition)* Population Council, New York. 1-45.

Gaganija, M.S., Mkoma, S.L. & Lema, E.S. (2012). Attitudes of Community to Urban Traffic Noise in Morogoro, Tanzania. *Ethiopian Journal of Environmental Studies and Management, 5*(3), 218-224.

Gary, W.E., Lercher, P., Meis, M., Ising, Harmut & Kofler, W.W. (2001). Community noise exposure and stress in children. *Journal of Acoustical Society of America,* 109(3), 1023-1027.

Georgiadou, E., Kourtidis, K. & Ziomas, K. (2004). Exploratory noise traffic noise measurements at five main streets of Thessaloniki, Greece. *Global Nest: the Int. J. 6*(1), 53-61.

Gholami, A., Nasiri, P., Monazzam, M., Alireza, G., Masoud, S.M. & Afrous, A. (2012). Evaluation of traffic noise levels in in a central area of Tehran through noise mapping in GIS. *Advances in Environmental Biology, 6*(8), 2365-2371.

Goines, L. & Hagler, L. (2007). Noise Pollution: A modern plague. *Southern Medical Journal, 100*(3), 2345-2356.

GoK (2009). The Environmental Management and Coordination (Noise and Excessive Vibration Pollution) (Control) Regulations, 2009. Legal Notice No. 61.

Golmohammadi, R., Abbaspour, M., Nassiri, P. & Mahjub, H. (2009). A compact model for predicting road traffic noise. *Iran. J. Environ. Health. Sci. Eng*., *6*(3), 181-186.

Gonzales, E.J., Celeste, C., Yuwei, L. & Carlos, F.D. (2009). Multimodal transport modelling for Nairobi, Kenya: Insights and recommendations with an evidence-based model. *UC Berkeley Centre for Future Urban Transport*, Working Paper August 25, 2009.

Government of India (1972). Noise Control Act of 1972. New Delhi: Indian affairs Management

Government of India (2000). The Noise Pollution (Regulation and Control) Rules, 2000. The Gazette of India February 2 2000.

Government of Kenya (2012). *National Environment Policy*. Ministry of Environment and Mineral Resources, Republic of Kenya.

Gupta, S. & Ghatak, C. (2011).Environmental noise assessment and its effect on human health in an urban area. *International Journal of Environmental Sciences*, *1*(7), 1954-1965.

Guyton, A.C. (1987). *Human Physiology and mechanisms of diseases (4^{th} Edition)*. Staff Inc: Washington DC.

I-INCE (2011). *Guidelines for community noise impact assessment and mitigation.* Final report of the I-INCE Technical Study Group on Community Noise: Environmental Noise Impact Assessment and mitigation, March 2011.

Irungu, K.Z. (2007). Nairobi urban transportation challenges: Learning from Japan.

JICA Training Course Comprehensive Urban Transportation Planning and Project (JFY2007).

Ismail, N. & Elias, A. (2006). Noise-Induced hearing loss and compliance with the hearing conservation program in Malaysia. *Asian Pacific Newsletter on OHS, 13*(2), 33-34.

Jahandar, N., Amin, H. & Ali, M.S. (2012). Traffic noise under Stop and Go conditions in intersections: A case study. *Journal of World Academy of Sci. Eng. Tech. 12*(1), 465-468.

Jamrah, A. & Al-Shobaki, H. (2008). A Study of Noise Pollution in Zarqa and Irbid, Jordan. *Jordan Journal of Civil Engineering, 2*(3), 279-301.

Jamrah, A., Al-Omari, A. & Sharabi, R. (2006). Evaluation of traffic noise pollution in Amman, Jordan. *Environmental Monitoring and Assessment, 120*(1), 499-525.

Jamrah, A.A. & Omari, R.S. (2005). Evaluation of traffic noise pollution in Amman, Jordon. *Environmental Monitoring and Assessment, 120*(1), 499-525.

Kere, M.O. (2010). *Transport Impact Assessment.* Nairobi: NEMA.

Kryter, K. & Karl, D. (1994). *The handbook of hearing and the effects of noise: physiology, psychology and public health.* Academic Press: Boston.

Kumar, S.G. & Murugappan, A. (2013).Analysis of Urban Transport Noise Level – A Case Study of Chidambaram Town, Tamilnadu. *Journal of Environmental Science, Computer Science and Engineering & Technology, 2*(4), 1185-1195.

Liu, D. (1999). *Environmental Engineers Handbook: Noise Pollution.* CRC Press LLC: New Jersey.

McGregory, S. & Malingha, D.D. (2014). Traffic Costs Nairobi $570,000 a Day as No. 2 Africa Hub Clogs. Retrieved from: http://www.bloomberg.com/news/2014-03-25/nairobi-traffic-loses-570-000-

a-day-as-no-2-africa-hub.html.

Miller, J., Watson, C. & Cowel, W. (2006). Deafening Effects of noise on cats. *Acta Ontolanyngologica (Stock holding), 176*(1), 1-91.

Milne, G., Kendall, B. & Reardon, C. (1982). Protective Noise Levels: Condensed Version of EPA Levels Document. EPA: Washington.

Mishra, R.K., Parida, M. & Rangnekar, S. (2010). Evaluation and analysis of traffic noise along bus rapid transit system corridor *Int. J. Environ. Sci. Tech., 7*(4), 737-750.

Mohammadi, G. (2009). An investigation of community response to urban traffic noise. *Iranian Journal of Environmental Health, Science and Engineering, 6*(2), 137-142.

Murthy, K.V., Ahmad, K.M. & Nath, S.K. (2007). Assessment of traffic noise pollution in Banepa, a semi urban town of Nepal. *Kathmandu University Journal of Science, Engineering and Technology, 1*(4), 1-9.

National Coordinating Agency for Population and Development (2009). Migration, Urbanization and Environment in Kenya. Policy Brief No. 4.

Nejadkoorki, F., Yousefi, E. & Naser, F. (2010). Analyzing street traffic noise pollution in the city of Yazd, *Iran. J. Environ. Health. Sci. Eng. 7*(1), 53-62.

Neuman, W.L. (2001). *Social Research Methods: qualitative and quantitative approaches*, 4th edition. Massachusetts: Allyn and Bacon.

Noise Free America (2010). *How to Fight Noise: A guide to reducing community noise pollution.* Noise Free America: New York.

Ochuko, A. (2013). Evaluation of environmental noise pollution in Abuja, the capital city of Nigeria. *IJRRAS*, *4*(2), 470-477.

Ozer, S., Yilmaz, H. & Yesil, P. (2009). Evaluation of Noise Pollution caused by vehicles in the city of Tokat, Turkey, *Sci. Res. Essay, 4*(11), 1025-1212.

Pachiappan, Y. & Govindaraj, B. (2013). Regression modelling of traffic noise pollution. GRAĐEVINAR, *65*(12), 1089-1096.

Pakistan Environmental Program (2006). Measurement of Noise levels at different locations of Rawalpindi and Islamabad. Retrieved from: <www.environment.gov.pk/pub-pdf/noise%20%study%20isb-rpindi.pdf>

Passchier-Vermeer, W. & Passchier, W.F. (2000). Noise exposure and public health. *Environ. Health Perspectives, 108*(1), 123-131.

Piccolo, A., Plutino, D. & Cannistraro, G. (2005). Evaluation and analysis of the environmental noise of Messina, Italy. *Applied Acoustics, 66*(1), 447-465.

Ramis, J., Alba, D.G. & Hernandez, F. (2003). Noise effects of reducing traffic flow a Spanish city. *Appl. Acoustic*, *64*(3), 343-364.

Rawat, K., Katiyar, K.V. & Pratibha, V. (2009). Mathematical Modelling of Environmental Noise Impact. *Indian Journal of Biomechanics*, Special Issue (NCBM 7-8 March 2009), 75-83.

Richard, L., Pierre, S.T. & Maguire, D.J. (2004). *The impact of A-weighting Sound Pressure Level measurements during the evaluation of noise exposure.* MARC Inc: UK.

Salvato, E.L. (2003). *Environmental Engineering (Fifth Edition).* John Wiley & Sons, Inc: Hoboken, New Jersey.

Samagwa, D., Mkoma, S.L. & Tungaraza, C. (2009). Investigation of Noise Pollution in Restaurants in Morogoro Municipality, Tanzania, East Africa. Journal of Applied Science and Environt Management, *13*(4), 29 – 33.

Schwela, H. (1995). Adverse health effects in relation to urban residential landscapes. *J. Sound Vib.* 200, 16-39.

Scott, D., Gray, S.R. & Edwa, R. (2004). Disease and Illness in US Mining, 1983. *J. of Occup. & Env. Medicine, 46*(12), 1272.

Seyed, A.H., Aidin, P. & Roya, S. (2012). Investigating the effects of technical parameters of forest road planning and building on traffic noise reduction. *Pol. J. Environ. Stud. 21*(5), 1217-1222.

Silva, L.F. & Cabral, G. (2011). Noise exposure levels of priests and worshippers in protestant churches. *International Journal of Occupational Safety and Ergonomics (JOSE), 17*, 79–86.

Skanberg, A. & Ohrstrom, E. (2002). Adverse health effects in relation to urban residential soundscapes. *J. Sound. Vib. 250*(1), 151-155.

Stanfeld, S. & Matheson, M. (2003). Noise Pollution: non-auditory effects on health. *British Medical Bulletin, 68*(1), 243-257.

Subramini, T., Kavitha, M. & Sivaraj, K.P. (2012). Modelling of traffic noise pollution. *International Journal of Engineering Research and Applications, 2*(3), 3175-3183.

Sukru, D., Celalletin, O., Hakan, K. & Saim, K. (2006). Noise Pollution and map of Konya City in Turkey. *J. Int. Environmental Application and Sci. 1*(1-2), 63-72.

Szeremeta, B. & Zannin, P.H.T. (2009). Analysis and evaluation of soundscapes in public parks through interviews and measurement of noise. *Science of the Total Environment, 407*(1), 6143–6149.

Tewksbury, E. (2007). Qualitative versus quantitative methods: Understanding why qualitative methods are superior for Criminology and Criminal Justice. *Journal of Theoretical and Philosophical Criminology, 1*(1), 38-59.

Thorne, R. (2007). Assessing intrusive noise and low amplitude sound. Unpublished Thesis Submitted to Massey University, Wellington.

Thumann, A. & Miller, R.K. (1986). *Fundamentals of Noise Control Engineering.* Prentice Hall: England Cliffs N.J.

United States Department of Labor (2012). Occupational Health and Safety Administration: Safety and health regulations for construction, Retrieved from: <https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10625>

US Environmental Protection Agency (1971). *Community Noise.* National Technical Information Service: Washington DC.

US Environmental Protection Agency (1979). *Community Noise Assessment Manual: Social Survey Workbook.* Office of Noise Abatement and Control: Washington DC.

US EPA (1974). *Information on Levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety.* US Government Printing Office: Washington DC.

WHO Europe (2009). *Night Noise Guidelines for Europe.* WHO Regional Office in Europe: UK.

World Health Organization (1999) *Guidelines for Community Noise.* WHO: Geneva, Switzerland.

Yilmaz, H. & Ozer, S. (2005). Evaluation and analysis of environmental noise pollution in the city of Erzurum, Turkey. *Int. J. Environ. Pollut, 23*(4), 438-448.

Zannin, P., Calixto, A., Diniz, F. & Ferreira, J. (2006). Evaluation of noise pollution in urban parks. *Environ. Mon. Asses., 118*(1), 423-433.

APPENDICES

Appendix 1 Introductory Letter

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
DEPARTMENT OF BIOMECHANICAL AND ENVIRONMENTAL ENGINEERING
P.O. BOX 62000-00200, NAIROBI.

July 10th, 2014

TO WHOM IT MAY CONCERN.

Dear Sir/Madam,

RE: EVALUATION OF ENVIRONMENTAL NOISE POLLUTION IN NAIROBI CITY

We, Jomo Kenyaata University of Agriculture and Technology (JKUAT), are undertaking a research project to evaluate the extent and effects of environmental noise pollution in Nairobi City. To this end we kindly request that you complete the following short questionnaire regarding your habits, opinion and awareness of noise and its effects. It should take no longer than 20 minutes of your time.

Although your response is of the utmost importance to us, your participation in this survey is entirely voluntary. Please do not enter your name or contact details on the questionnaire. It remains anonymous. Information provided by you remains confidential and will be reported in summary format only and used solely for academic purposes.

Kindly cooperate with our researcher by signing the consent form, filling in the questionnaire and returning it to the researcher on the ground.

Summary results of this research will be published in local academic media as well as reputable international academic journals. It will also be available in our website: www.jkuat.ac.ke later this year (2014). Should you have any queries or comments regarding this survey, you are welcome to contact our researchers at +254721818029 or e-mail us at dancanthomas@gmail.com.

Yours sincerely

Christopher L. Kanali

Prof. of Engineering, JKUAT.

Appendix 2: Consent Note (Sample)

My name is Dancan O. Onyango. I am a post-graduate student at Jomo Kenyatta University of Agriculture and Technology (JKUAT). As part of my Master of Science degree in Environmental Engineering and Management, I am conducting an environmental safety survey, focusing on sounds in Nairobi City. Towards this end, I would like you to help me gather some information by way of filling this questionnaire.

Kindly note that information gained through this study will only be used for academic and related purposes only. Also note that you do not have to indicate your personal identification details e.g. name on the questionnaire. Your participation in this survey is fully voluntary and you reserve the right to withdraw, for any reason, at any time.

However, information gained from you will be of great help and will be highly appreciated. Many thanks for your time. If you would like to proceed with this survey, kindly sign here below and proceed to the next page.

Signature ______________________________ **Date** _________________________

Location __________________________ **Identification Code** _____________

Appendix 3: Survey Questionnaire (PSVs)

SECTION A: BACKGROUND DATA

Answer the following questions by ticking (√) the correct answer in the box provided.

1. Indicate your gender.

1 = Male [ ]	= Female [ ]

2. How old are you?

1 = Under 18 [ ]	2 = 18-30 [ ]	3 = 31-45 [ ]	4 = 46-60 [ ]	5 = Over 60 [ ]

3. Indicate your level of education

1 = Primary [ ]	2 = Secondary [ ]	3 = Tertiary [ ]	4 = University [ ]	5 = Other [ ]
If other, please specify here; [ ]				

SECTION B: RESPONDENTS' USAGE PROFILE

Answer the following questions by ticking (√) the correct answer in the box provided.

4. For how many days do you use Matatus (PSVs) in a week?

1 = None [ ]	2 = 1-2 days [ ]	3 = 3-4 days [ ]	4 = 5-6 days [ ]	5 = Daily [ ]
If none, what means of transport do you use; [ ]				

5. On average, what is the total time you spend in a Matatu daily, to and from your destination?

To	1 = Less than one hour [ ]	2 = 1-2 hours [ ]	3 = 2-3 hours [ ]	5 = Over 3 hours [ ]
From	1 = Less than one hour [ ]	2 = 1-2 hours [ ]	3 = 2-3 hours [ ]	5 = Over 3 hours [ ]

SECTION C: OPINION AND AWARENESS

Answer the following questions by ticking (√) the correct answer in the box provided.

6. Consider the sounds you are hearing right now. Which of them are you able to identify?

1 = Passengers Talking [ ]	2 = Vehicle/Engine Sounds [ ]	3 = Music/Radio [ ]	4 = Other [ ]
If other, please specify; [ ]			

7. Which of these sounds you hear in the Matatu is most **PLEASANT** to you?

1 = Passengers Talking [ ]	2 = Vehicle/Engine Sounds [ ]	3 = Music/Radio [ ]	2 = None [ ]

8. Which of these sounds you hear in the Matatu is most **UNPLEASANT** to you?

1 = Passengers Talking [ ]	2 = Vehicle/Engine Sounds [ ]	3 = Music [ ]	3 = None [ ]

9. How would you rate the volume of music/radio played in this Matatu?

1 = No Music [ ]	2 = Low [ ]	3 = Moderate [ ]	4 = High [ ]	5 = Extremely High [ ]

10. Do you feel comfortable with the volume of music/radio playing in this Matatu?

1 = Extremely Comfortable [ ]	2 = Comfortable [ ]	3 = Just Bearable [ ]

4 = Uncomfortable [ ]	5 = Extremely Uncomfortable [ ]	6 = I don't mind [ ]

11. How do the sounds you hear in this Matatu bother/affect you?

1 = Interference with telephone communication [ ]
2 = Interference with speech communication/conversation [ ]
3 = Interference with concentration (e.g. reading/messaging/surfing) [ ]
4 = Annoyance/Irritation [ ]
5 = Headache [ ]
6 = Other [ ] Please specify:

12. Are you aware of any health effects of exposure to excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]
If Yes, please specify:		

13. Kindly indicate whether you suffer from any of the following chronic health conditions.

1 = Any Hearing Impairment (whether temporary or permanent) [ ]
2 = Hypertension/high blood pressure [ ]
3 = Any form of heart disease [ ]
4 = Stress/Depression [ ]
5 = None [ ]
6 = Other [ ] Please specify:

If you suffer from any of the chronic conditions in (13) above, kindly proceed to question 14. If not, then proceed to question 15.

14. Please indicate whether the condition was inherited at birth or acquired over life time.

1 = Inherited at Birth [ ]	2 = Acquired over life time [ ]	3 = Not Sure [ ]

SECTION D: GENERAL QUESTIONS

Answer the following questions by ticking (√) the correct answer in the box provided or by ranking as instructed.

15. Generally, back at your home/residence, are you bothered by excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]

If your answer for question (15) above is yes, kindly proceed to question 16. If not, then proceed you are done.

16. Identify and rank the sounds that bother you in their order of importance beginning with 8 for the sound that bothers you most, 7 for that which bothers you second-most until you finally enter one (1) for the sound that bothers you least.

Traffic Sounds (e.g. from adjacent bus stations, roads etc.)	[ ]
Sounds from adjacent places of worship (e.g. churches, mosques, crusades etc.	[ ]
Sounds from adjacent places of entertainment (e.g. restaurants/night clubs/pubs)	[ ]
Sounds from adjacent industries (e.g. factories, Jua Kali Artisans etc.)	[ ]

Sounds from adjacent markets	[ ]
Sounds from noisy neighbors (e.g. schools, music, domestic animals etc.)	[ ]
Airport noise	[ ]
Others	[ ]
If others, please specify:	

17. How do the sounds mentioned in (16) above bother you at home?

1 = Sleep Disturbance	[ ]
2 = Speech/communication Interference	[ ]
3 = Interference with Concentration/reading/working	[ ]
4 = Annoyance/Irritation	[ ]
5 = Stress	[ ]
6 = Others	[ ]
If others, please specify:	

END. THANK YOU!!!!

Appendix 4: Survey Questionnaire (Places of Worship)

SECTION A: BACKGROUND DATA

Answer the following questions by ticking (√) the correct answer in the box provided.

1. Indicate your gender.

1 = Male [ ]	2= Female [ ]

2 How old are you?

1 = Under 18 [ ]	2 = 18-30 [ ]	3 = 31-45 [ ]	4 = 46-60 [ ]	5 = Over 60 [ ]

3 Indicate your level of education

1 = Primary [ ]	2 = Secondary [ ]	3 = Tertiary [ ]	4 = University [ ]	5 = Other [ ]
If other, please specify here; [ ]				

SECTION B: RESPONDENTS' USAGE PROFILE

Answer the following questions by ticking (√) the correct answer in the box provided.

4 For how many days in a week do you attend worship services at this church?

1 = Once per week [ ]	2 = 2 days per week [ ]	3 = 3-4 days per week [ ]
4 = 5-6 days per week [ ]	5 = Daily [ ]	6 = Other [ ]

5 On average, what is the total time you spend in church during every worship service?

Main	1 = Less than one hour [ ]	2 = 1-2 hours [ ]	3 = 3-4 hours [ ]	5 = Over 4 hours [ ]
Others	1 = Less than one hour [ ]	2 = 1-2 hours [ ]	3 = 3-4 hours [ ]	5 = Over 4 hours [ ]

SECTION C: OPINION AND AWARENESS

Answer the following questions by ticking (√) the correct answer in the box provided.

6 With regard to the sounds involved during worship services, which one do you consider loudest?

1 = Hand Clapping [ ]	2 = Singing [ ]	3 = Instruments [ ]	4 = Preaching [ ]
5 = Other [ ]	If other, please specify:		

7 Which of these sounds do you consider most **PLEASANT**?

1 = Hand Clapping [ ]	2 = Singing [ ]	3 = Instruments [ ]	4 = Preaching [ ]
5 = None [ ]	6 = Other [ ]	If other, please specify:	

8 Which of these sounds do you consider most **UNPLEASANT**?

1 = Hand Clapping [ ]	2 = Singing [ ]	3 = Instruments [ ]	4 = Preaching [ ]
5 = None [ ]	6 = Other [ ]	If other, please specify:	

9 How would you rate the volume of music/instrumentation played in this church?

1 = Too Low [ ]	2 = Low [ ]	3 = Moderate [ ]	4 = High [ ]	5 = Extremely High [ ]

10 Do you feel comfortable with the volume of sounds involved in the worship?

1 = Extremely Comfortable [ ]	2 = Comfortable [ ]	3 = Just Bearable [ ]
4 = Uncomfortable [ ]	5 = Extremely Uncomfortable [ ]	6 = I don't mind [ ]
If uncomfortable or extremely uncomfortable, please specify how it bothers you;		

11 In your own evaluation, which worship program involves the loudest sounds?

1 = Praise and Worship [ ]	2 = Preaching [ ]	4 = All [ ]	5 = None [ ]

12 Are you aware of any health effects of exposure to excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]
If Yes, please specify:		

13 Kindly indicate whether you suffer from any of the following chronic health conditions.

1 = Any Hearing Impairment (whether temporary or permanent) [ ]
2 = Hypertension/high blood pressure [ ]
3 = Any form of heart disease [ ]
4 = Stress/Depression [ ]
5 = None [ ]
6 = Other [ ] Please specify:

If you suffer from any of the chronic conditions in (13) above, kindly proceed to question 14. If not, then proceed to question 15.

14 Please indicate whether the condition was inherited at birth or acquired over life time.

1 = Inherited at Birth [ ]	2 = Acquired over life time [ ]	3 = Not Sure [ ]

SECTION D: GENERAL QUESTIONS

Answer the following questions by ticking (√) the correct answer in the box provided or by ranking as instructed.

15 Generally, back at your home/residence, are you bothered by excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]

If your answer for question (15) above is yes, kindly proceed to question 16. If not, then you are done.

16 Identify and rank the sounds that bother you in their order of importance beginning with 8 for the sound that bothers you most, 7 for that which bothers you second-most until you finally enter one (1) for the sound that bothers you least.

Traffic Sounds (e.g. from adjacent bus stations, roads etc.)	[ ]
Sounds from adjacent places of worship (e.g. churches, mosques, crusades etc.	[ ]
Sounds from adjacent places of entertainment (e.g. restaurants/night clubs/pubs)	[ ]
Sounds from adjacent industries (e.g. factories, Jua Kali Artisans etc.)	[ ]
Sounds from adjacent markets	[ ]
Sounds from noisy neighbors (e.g. schools, music, domestic animals etc.)	[ ]
Airport noise	[ ]
Others	[ ]
If others, please specify:	

17 How do the sounds mentioned in (16) above bother you at home?

1 = Sleep Disturbance	[ ]
2 = Speech/communication Interference	[ ]
3 = Interference with Concentration/reading/working	[ ]
4 = Annoyance/Irritation	[ ]

5 = Stress	[ ]
6 = Others	[ ]
If others, please specify:	

END. THANK YOU!!!!

Appendix 5: Survey Questionnaire (Commercial Centres)

SECTION A: BACKGROUND DATA

Answer the following questions by ticking (√) the correct answer in the box provided.

2. Indicate your gender.

1 = Male [ ]	= Female [ ]

3. How old are you?

1 = Under 18 [ ]	2 = 18-30 [ ]	3 = 31-45 [ ]	4 = 46-60 [ ]	5 = Over 60 [ ]

4. Indicate your level of education

1 = Primary [ ]	2 = Secondary [ ]	3 = Tertiary [ ]	4 = University [ ]	5 = Other [ ]
If other, please specify here; [ ]				

SECTION B: RESPONDENTS' USAGE PROFILE

Answer the following questions by ticking (√) the correct answer in the box provided.

5. How frequently do you use/visit this market/mall?

1 = Once per week [ ]	2 = 2 days per week [ ]	3 = 3-4 days per week [ ]
4 = 5-6 days per week [ ]	5 = Daily [ ]	6 = Other [ ] Specify:

6. On average, what is the total time you spend at this market/mall at each visit?

1 = Less than 1 hour [ ]	2 = 1-2 hours [ ]	3 = 3-4 hours [ ]	5 = Over 4 hours [ ]

SECTION C: OPINION AND AWARENESS

Answer the following questions by ticking (√) the correct answer in the box provided.

7. With regard to the sounds you are hearing right now, which ones can you identify? (*You may indicate more than one choice*)

1 = Hawkers/Traders shouting [ ]
2 = Industries (Including Jua Kali/welding etc) [ ]
3 = Adjacent Traffic/Vehicles [ ]
4 = Worshippers/Street preachers [ ]
5 = Music/Radio [ ]
6 = None [ ]
7 = Other [ ]
If other, please specify:

8. Which of these sounds do you consider most **PLEASANT**?

1 = Hawkers/Traders shouting [ ]
2 = Industries (Including Jua Kali/welding etc) [ ]
3 = Adjacent Traffic/Vehicles [ ]
4 = Worshippers/Street preachers [ ]
5 = Music/Radio [ ]
6 = None [ ]
7 = Other [ ]
If other, please specify:

9. Which of these sounds do you consider most **UNPLEASANT**?

1 = Hawkers/Traders shouting [ ]
2 = Industries (Including Jua Kali/welding etc) [ ]
3 = Adjacent Traffic/Vehicles [ ]

4 = Worshippers/Street preachers [ ]
5 = Music/Radio [ ]
6 = None [ ]
7 = Other [ ]
If other, please specify:

10. How would you rate the volume of sounds you hear in this market/mall?

1 = Too Low [ ]	2 = Low [ ]	3 = Moderate [ ]	4 = High [ ]	5 = Extremely High [ ]

11. Do you feel comfortable with the volume of sounds you hear in this market/mall?

1 = Extremely Comfortable [ ]	2 = Comfortable [ ]	3 = Just Bearable [ ]
4 = Uncomfortable [ ]	5 = Extremely Uncomfortable [ ]	6 = I don't mind [ ]

12. How do the sounds in this market bother/affect you?

1 = Interference with telephone communication [ ]
2 = Interference with speech communication/conversation [ ]
3 = Interference with concentration (e.g. reading/messaging/surfing) [ ]
4 = Annoyance/Irritation [ ]
5 = Headache/Stress [ ]
6 = None [ ]
7 = Other [ ] Please specify:

13. Are you aware of any health effects of exposure to excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]
If Yes, please specify:		

14. Kindly indicate whether you suffer from any of the following chronic health conditions.

1 = Any Hearing Impairment (whether temporary or permanent) [ ]
2 = Hypertension/high blood pressure [ ]
3 = Any form of heart disease [ ]
4 = Stress/Depression [ ]
5 = None [ ]
6 = Other [ ] Please specify:

If you suffer from any of the chronic conditions in (13) above, kindly proceed to question 14. If not, then proceed to question 15.

15. Please indicate whether the condition was inherited at birth or acquired over life time.

1 = Inherited at Birth [ ]	2 = Acquired over life time [ ]	3 = Not Sure [ ]

SECTION D: GENERAL QUESTIONS

Answer the following questions by ticking (√) the correct answer in the box provided or by ranking as instructed.

16. Generally, back at your home/residence, are you bothered by excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]

If your answer for question (15) above is yes, kindly proceed to question 16. If not, then you are done.

17. Identify and rank the sounds that bother you, at home, in their order of importance beginning with 8 for the sound that bothers you most, 7 for that which bothers you second-most until you finally enter one (1) for the sound that bothers you least.

Traffic Sounds (e.g. from adjacent bus stations, roads etc.)	[ ]
Sounds from adjacent places of worship (e.g. churches, mosques, crusades etc.	[ ]
Sounds from adjacent places of entertainment (e.g. restaurants/night clubs/pubs)	[ ]
Sounds from adjacent industries (e.g. factories, *Jua Kali* Artisans etc.)	[ ]
Sounds from adjacent markets	[ ]
Sounds from noisy neighbors (e.g. schools, music, domestic animals etc.)	[ ]
Airport noise	[ ]
Others	[ ]
If others, please specify:	

18. How do the sounds mentioned in (16) above bother you at home?

1 = Sleep Disturbance	[ ]
2 = Speech/communication Interference	[ ]
3 = Interference with Concentration/reading/working	[ ]
4 = Annoyance/Irritation	[ ]
5 = Stress/Headache	[ ]
6 = Others	[ ]
If others, please specify:	

END. THANK YOU!!!!

Appendix 6: Survey Questionnaire (Places of Entertainment)

SECTION A: BACKGROUND DATA

Answer the following questions by ticking (√) the correct answer in the box provided.

1. Indicate your gender.

1 = Male [ ]	= Female [ ]

2. How old are you?

1 = Under 18 [ ]	2 = 18-30 [ ]	3 = 31-45 [ ]	4 = 46-60 [ ]	5 = Over 60 [ ]

3. Indicate your level of education

1 = Primary [ ]	2 = Secondary [ ]	3 = Tertiary [ ]	4 = University [ ]	5 = Other [ ]
If other, please specify here; [ ]				

SECTION B: RESPONDENTS' USAGE PROFILE

Answer the following questions by ticking (√) the correct answer in the box provided.

4. How often do you visit/use this entertainment facility in a week?

1 = Once [ ]	2 = Twice [ ]	3 = 3-4 Times [ ]	4 = 5-6 Times [ ]	5 = Daily [ ]
6 = Other [ ] Please specify:				

5. On average, what is the total time you spend at this place every time you visit?

1 = Less than one hour [ ]	2 = 1-2 hours [ ]	3 = 3-4 hours [ ]	5 = Over 4 hours [ ]

SECTION C: OPINION AND AWARENESS

Answer the following questions by ticking (√) the correct answer in the box provided.

6. Consider the sounds you are hearing right now. Which of them are you able to identify?

1 = Human sounds [ ]	2 = Music/Radio/TV [ ]	3 = Kitchen Sounds [ ]	4 = External [ ]
5 = Other [ ] please specify; [ ]			

7. Which of the sounds you hear in this place is most **PLEASANT** to you?

1 = Human sounds [ ]	2 = Music/Radio/TV [ ]	3 = Kitchen Sounds [ ]	4 = External [ ]
5 = None [ ]	6 = Other [ ] Please specify:		

8. Which of the sounds you hear in this place is most **UNPLEASANT** to you?

1 = Human sounds [ ]	2 = Music/Radio/TV [ ]	3 = Kitchen Sounds [ ]	4 = External [ ]
5 = None [ ]	6 = Other [ ] Please specify:		

9. How would you rate the volume of sounds you hear in this place?

1 = No Sounds [ ]	2 = Low [ ]	3 = Moderate [ ]	4 = High [ ]	5 = Extremely High [ ]

10. Do you feel comfortable with the volume of music/radio playing in this Matatu?

1 = Extremely Comfortable [ ]	2 = Comfortable [ ]	3 = Just Bearable [ ]
4 = Uncomfortable [ ]	5 = Extremely Uncomfortable [ ]	6 = I don't mind [ ]

If your answer to question ten (10) is "uncomfortable" or "extremely uncomfortable", proceed to question (11). Otherwise proceed to question (12)

11. How do the sounds you hear in this place bother/affect you?

1 = Interference with telephone communication [ ]
2 = Interference with speech communication/conversation [ ]
3 = Interference with concentration (e.g. reading/messaging/surfing) [ ]
4 = Annoyance/Irritation [ ]
5 = Headache [ ]
6 = Other [ ] Please specify:

12. Are you aware of any negative health effects of exposure to excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]
If Yes, please specify:		

13. Kindly indicate whether you suffer from any of the following chronic health conditions.

1 = Any Hearing Impairment (whether temporary or permanent) [ ]
2 = Hypertension/high blood pressure [ ]
3 = Any form of heart disease [ ]
4 = Stress/Depression [ ]
5 = None [ ]
6 = Other [ ] Please specify:

If you suffer from any of the chronic conditions in (13) above, kindly proceed to question 14. If not, then proceed to question 15.

14. Please indicate whether the condition was inherited at birth or acquired over life time.

1 = Inherited at Birth [ ]	2 = Acquired over life time [ ]	3 = Not Sure [ ]

SECTION D: GENERAL QUESTIONS

Answer the following questions by ticking (√) the correct answer in the box provided or by ranking as instructed.

15. Generally, back at your home/residence, are you bothered by excessive sounds?

1 = Yes [ ]	2 = No [ ]	3 = Not Sure [ ]

If your answer for question (15) above is yes, kindly proceed to question 16. If not, then proceed you are done.

16. Identify and rank the sounds that bother you in their order of importance beginning with 8 for the sound that bothers you most, 7 for that which bothers you second-most until you finally enter one (1) for the sound that bothers you least.

Traffic Sounds (e.g. from adjacent bus stations, roads etc.)	[ ]
Sounds from adjacent places of worship (e.g. churches, mosques, crusades etc.	[ ]

Sounds from adjacent places of entertainment (e.g. restaurants/night clubs/pubs)	[ ]
Sounds from adjacent industries (e.g. factories, Jua Kali Artisans etc.)	[ ]
Sounds from adjacent markets	[ ]
Sounds from noisy neighbors (e.g. schools, music, domestic animals etc.)	[ ]
Airport noise	[ ]
Others	[ ]
If others, please specify:	

17. How do the sounds mentioned in (16) above bother you at home?

1 = Sleep Disturbance	[ ]
2 = Speech/communication Interference	[ ]
3 = Interference with Concentration/reading/working	[ ]
4 = Annoyance/Irritation	[ ]
5 = Stress	[ ]
6 = Others	[ ]
If others, please specify:	

END. THANK YOU!!!!

Appendix 7: Noise Measurements inside PSVs

Nairobi-Nairobi North Route PSVs				
S/N	**Type**	**LAeq (dBA)**	**L90 (dBA)**	**Remarks**
1	M/Bus (237)	85.2	78.8	Radio
2	M/Bus (237)	87.4	80.1	Music
3	M/Bus (237)	84.4	78.9	Music
4	M/Bus (237)	107.3	85.3	Music/Touting
5	Bus (45)	108.2	85.7	Music/Touting
6	Bus (45)	108.8	79.5	Music/Touting
7	Bus (45)	92.1	86.2	Music/Touting
8	Bus (45)	85.6	76.2	Radio/Old Vehicle
9	14 Seater (KU)	91.6	84.6	Music/Old Vehicle
10	Bus (Mwiki)	96.6	87.2	Music
11	14 Seater (KU)	76.6	73.1	Low Radio
12	M/Bus (KU)	87.6	81.3	Music
13	14 Seater (108)	85.6	79.9	No Music/Old
14	14 Seater (106)	87.4	82.1	Music
15	M/Bus (46)	98.9	94.6	Music
Nairobi-Nairobi West Route PSVs				
S/N	**Type**	**LAeq (dBA)**	**L90 (dBA)**	**Remarks**
1	14 Seater	85.6	79.9	
2	14 Seater	87.4	82.1	
3	14-Seater	81.3	76.2	Music/Old
4	Bus (Kabete)	75.6	67.4	Low Music/Old
5	Bus (Kabete)	75.9	69.9	No Music
6	Bus (Kabete)	80.9	77.8	Music
7	Bus (Kikuyu)	76.9	70.9	Low Music/Old
8	M/Bus	87.6	81.3	
9	M/Bus	98.9	94.6	Music
10	M/Bus (23)	90.9	84.7	
11	M/Bus (23)	94.6	85.1	
12	M/Bus (Kinoo)	96.4	90.1	
13	M/Bus (Metro Trans)	87.7	76.2	Music
14	M/Bus (Star)	104.1	79.5	Music/Touting
15	M/Bus (Star)	107.2	85.6	Music/Touting
Nairobi-Nairobi East Route PSVs				
S/N	**Type**	**LAeq (dBA)**	**L90 (dBA)**	**Remarks**
1	14-Seater (City Kabanas)	86.7	81.3	Music
2	14-Seater (City Kabanas)	83.6	78.8	No Music

3	14-Seater (Doonholm)	76.6	74.6	No Music
4	14-Seater (Doonholm)	76.7	71.5	No Music
5	14-Seater (Pipeline)	77.1	71.3	Music
6	14-Seater (Pipeline)	86.6	81.6	Music/Old/Touting
7	Bus (2M Doonholm)	74.6	64.6	Low Music
8	Bus (2M/Doonholm)	68.8	61.1	Music
9	Bus (City Shuttle/Utawala)	75.5	68.8	Music
10	M/Bus (58)	94.6	86.6	Moderate Music
11	M/Bus (58)	91.2	76.9	Low Music
12	M/Bus (Embassava/Doonholm)	80.3	73.9	Music
13	M/Bus (Embassava/Pipeline)	72.2	63.2	No Music
14	M/Bus (Embassava/Pipeline)	78.8	74.8	Moderate Music
15	M/Bus (Kayole)	94.6	88.6	Music
Nairobi-Nairobi South Route PSVs				
S/N	**Type**	**LAeq (dBA)**	**L90 (dBA)**	**Remarks**
1	14-Seater (11B)	78.1	72.3	Low Music
2	M/Bus (11B)	77.7	74.1	Low Radio/Old
3	M/Bus (11B)	75.2	54.8	No Music/Old
4	Bus (City Shuttle/11B)	76.6	70.9	Low Radio
5	Bus (Lang'ata)	80.7	66.9	Low Music/Old
6	14-Seater (Lang'ata)	82.2	75.5	Music/No Passengers
7	14-Seater (Lang'ata)	79.4	74.1	Moderate Music
8	M/Bus (Rongai)	82.3	77.4	Music
9	M/Bus (Rongai)	81.7	76.2	Music
10	M/Bus (Karen)	86.9	81.3	Music
11	14-Seater (Karen)	86.7	81.3	Music
12	14-Seater (Karen)	86.9	81.4	Music
13	M/Bus (11B)	96.5	90.3	Music
14	Bus (Ngong)	78.9	75.3	Low Music
15	M/Bus (Ngong)	96.5	90.1	Music/Touting

Appendix 8: Noise Measurements at Bus Stations

Name of Bus Station	Average Sound Level, LAeq (dBA)		
	Morning	Mid-day	Evening
KBS	85.8	70.4	75.3
Tusker (R/Ngala)	75.2	85.0	96.3
Ambassador	83.1	79.3	83.7
Commercial	79.3	86.1	96.2
KENCOM	82.7	71.9	71.6
Odeon	90.4	79.0	89.3
Railways 1	84.2	87.1	86.9
Railways 2	82.9	90.3	89.9
Muthurwa 1	73.7	73.1	76.3
Muthurwa 2	71.6	71.7	74.8
Machakos CBS 1	87.0	77.7	72.6
Machakos CBS 2	88.6	80.2	75.4
Posta (T/Mboya)	78.8	80.1	83.8
Tea Room (Accra Rd)	70.1	73.1	75.1
Old Nation	65.5	67.9	68.8

Appendix 9: Noise Measurements at Commercial Centres

S/N	Commercial Centre	Measured Sound Level (dBA)	
		LAeq	L90
1	Muthurwa Market	93.3	80.3
2	Gikomba Market	88	71
3	Cianda Shopping Center	67.6	57.6
4	City Market	69.3	61.1
5	Ngara Market	73.3	65.1
6	Kariaror Market	71.8	63.2
7	Tuskys Supermarket (Imara)	62.9	58.8
8	Kangemi Market	72.7	60.5
9	Naivas Supermarket (Westlands)	78.8	58.3
10	Chasebank Roadshow Promotion	100.4	80.8
11	Eastleigh Market	96.5	66.3
12	Nakumatt Supermarket (Galleria)	66.3	55.7
13	Ngara Garage	76.5	70
14	Majengo Stage	75.8	70.7
15	KBS Shopping Center	84.9	68.5

Appendix 10: Noise Measurements at Entertainment Centres

S/N	Name	Measured Day Noise (dB A)	Measured Night Noise (dB A)
1.	Tribeka (Kimathi Street)	65.5	96.5
2.	Zodiak Lounce (T/Mboya St.)	69.6	99.2
3.	Mist Bar & Rest. (T/Mboya)	67.6	96.7
4.	Lazaru Inn (Moi Avenue)	72.1	100.5
5.	Samba Pub (Moi Avenue)	77.3	101.9
6.	Dodi's Pub (Kenya Cinema)	76.9	100.6
7.	Heritage Grill (Moi Avenue)	69.6	99.9
8.	Chomabase (Doonholm)	70.9	89.2
9.	Savanna Pub (Greenfields)	65.9	84.9
10.	The Green Side Pub (Kasarani)	69.9	96.8
11.	The Vantage Place (Kasarani)	65.9	99.8
12.	The Bulls Pub (Kasarani)	69.1	100.1
13.	Pints Makuti (Kahawa)	59.9	100.2
14.	Hunters Grill (Dagoretti)	60.2	89.9
15.	Tacos Club (Westlands)	60.9	96.9

Appendix 11: Noise Measurements at Places of Worship

	Places of Worship	LAeq (dB A) Praise & Worship	LAeq (dB A) Preaching
1	Cathedral of Power (CBD)	101.9	98.1
2	Jesus is Alive Ministries (CBD)	100.1	95.6
3	Neno Evenagelism Centre (CBD)	97.6	72.6
4	Deliverence (Doonholm)	96.7	93.1
5	PEFA (Doonholm)	95.7	92.1
6	Mavuno Mashariki (Doonholm)	97.8	77.9
7	SDA KTTC (Gigiri)	80.2	81.9
8	SDA Sportsview (Kasarani)	78.9	77.6
9	PCEA (Kasarani)	83.6	80.1
10	Mountain of Fire (CBD)	93.9	90.6
11	Soldiers of Faith (Huruma)	95.9	70.1
12	Redeemed Gospel (South B)	93.6	82.5
13	Full Gospel (River Road)	89.9	90.4
14	Full Gospel (Kinoo)	99.9	86.5
15	Deliverence (Jinja Road)	96.6	90.8