ASSESSMENT OF THE EXTENT AND PERCEIVED EFFECTS OF NOISE POLLUTION IN MANUFACTURING INDUSTRIES IN NAIROBI CITY

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Assessment of the Extent and Perceived Effects of Noise Pollution in Manufacturing Industries 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.

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DEDICATION

This work is dedicated to my friends, colleagues and entire family; for their encouragement and support during the course of my study.

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I acknowledge the Lord God almighty maker of heaven and earth and the Lord Jesus. For the gift of life, grace and wisdom; and the men and women he allowed to assist me go through this period of study.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABR Auditory Brainstem Response

ANSI American National Standard Institute

CDC Centre for Disease Control and Prevention

dBA A-weighted decibel sound level

EMCA Environmental Management and Coordination Act, 1999, Kenya.

EPA Environmental Protection Agency

Hz Hertz

$L_{Aeq,15minute}$ 15 minutes equivalent continuous A-weighted sound pressure level in dBA referenced to 20 micropascals

$L_{Aeq,8h}$ Eight-hour equivalent continuous A-weighted sound pressure level in dBA referenced to 20 micro-Pascal

$L_{AT}(DW)$ The equivalent continuous A-weighted downwind sound pressure level at the receiver location

L_{dn} Day-night Sound level

L_{eq} Equivalent sound level

$L_{EP,d}$ Daily personal noise exposure

$L_{fT}(DW)$ The equivalent continuous downwind octave band sound pressure level at a receiver location.

L_p	Sound Pressure Level
L_s	Sound exposure Level
L_w	Sound Power Level
OSHA	Occupational Safety and Health Act
NEMA	National Environment Management Authority
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
NIPTS	Noise-Induced Permanent Threshold Shift
PSIL	Preferred Speech Interference Level
REL	Recommended Exposure Limit
TTS	Temporary Threshold Shift

ABSTRACT

Noise is generally defined as the unpleasant sounds which disturb the human being psychologically and physiologically. High levels of occupational noise remain a problem in all regions of the world and there's evidence of its increasing prevalence in the work place. A great majority of people working in and around the manufacturing industries in Nairobi, Kenya, could also be exposed to noise levels that may pose a risk to their health. A study was carried out to establish the level and perceived effects of industrial noise in the City of Nairobi. The purpose of this study was to assess and document the extent and effect of industrial noise pollution in the City of Nairobi through measurement. Noise pollution levels within the work places, its perceived effects on the workers and its progression outside the industrial boundaries was monitored within metal, plastic, wood, grain mills and (non-formal metal) *jua kali* industries. Noise measurement was done according to ISO 1996-2002 using digital integrating sound level meter, SLM (SVANTEK 971). Questionnaires were used to assess the perceived effects of the noise pollution on workers. A hand-held GPS receiver was used to determine the coordinates of sources of noise. Within the workplace, flour mills, non formal metal and metal industries emitted hazardous noise levels L_{Aeq}, above 85dBA, while plastic and wood/furniture industries released L_{Aeq}, 82.8 and 83.3 dBA, respectively, all exceeding WHO guidelines and local standards safe limits for noise levels within the work place. Perceived effects of the noise on workers were significant. Some 36% complained of persistent headaches, 18.9% complained of ringing in the ears, 14.7% anger and 9.2% of sleeplessness. The study found that 65.2% of the workers did not use any protective gears against injury, 60.4% were not aware of the existence of safety committees in their work places and 47.6% had never been trained on noise pollution and its effects on public health. The Noise prevention and control programmes as required by OSHA 2007 were not in place. In 100% of the industrial sites sampled in this study, workplace noise levels exceeded acceptable limits. It is recommended that Directorate of Occupation Safety and Health Services (DOSHS) and National Environment

Management Authority (NEMA) should make every effort to address the high noise level in the manufacturing sector by regulating the applied technology and intensifying law enforcement especially Legal notice number 25 of 2005 and Legal notice number 61 of 2009. The factories management should ensure the workers are provided with appropriate ear protective gear.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Physically, there is no difference between sound and noise. Sound is a sensory perception and noise corresponds to undesired sound. Noise is generally defined as the unpleasant sounds which disturb the human being psychologically and physiologically. It causes environmental pollution by destroying environmental properties (Melnick, 1979). By extension, noise is any unwarranted disturbance within a useful frequency band (NIOSH, 1991). Noise is classified either as occupational noise (i.e., noise in the workplace), or as environmental noise, which includes noise in all other settings, whether at the community, residential, or domestic level (e.g., traffic, playgrounds, sports, music). Although noise is associated with almost every work activity, occupations at highest risk for Noise Induced Hearing Loss (NIHL) include those in manufacturing, transportation, mining, construction, agriculture and the military (WHO, 2004).

The sources of industrial noise include riveting guns, stamping presses, power saws, pumps and compressors; machine tools, conveyor systems, lift-trucks, steam and air relief valves; signal or alarm systems, and many others mixed into an unidentifiable loud confused noise. High levels of occupational noise remain a problem in all regions of the world and there’s evidence of its increasing prevalence in the work place (Mithanga, 2013). In the United States of America (USA), for example, more than 30 million workers are exposed to hazardous noise levels (NIOSH, 1998). In Germany, 4-5 million people (12-15% of the workforce) are exposed to noise levels defined as hazardous by WHO (WHO, 2001).Data for developing countries are scarce, but available evidence suggests that average noise levels are well above the recommended safe limits in many developed nations (Boateng & Amedofu, 2004; WHO, 2001; Mithanga, 2013) and industrialization is not always accompanied by protection measures (WHO, 2004).

Studies done in Egypt indicate that maximum daily exposure durations to noise levels set by Egyptian law to protect public health of workers were not taken in consideration for any level of industrial noise in Egyptian factories. The industrial noise levels ranged from 70 to 100 dBA (Ali, 2010). In the same study, 70% of respondents were found to be subjected to industrial noise levels in the range of 85 to 100 dBA (Ali, 2010). In another study done on noise pollution levels in the manufacturing sector in Thika District, Kenya, 62.5% of the manufacturing industries were not compliant to set standards on noise (Mithanga, 2013). Most of the employees in these industries, 75.8 %, worked in the production areas where the noise levels in most companies were above the standards. Only 25% of companies had a noise control programme in place (Mithanga, 2013).

The World Health Organization defines health as a state of complete physical, mental, and **s**ocial well-being, not just as the absence of disease (WHO, 1947). Working environment and conditions for over three billion workers worldwide do not meet the minimum standards and guidelines set by the World Health Organisation and the International Labour Organisation for occupational health, safety and social protection (WHO, 2007). Adverse effects of noise on communities are well reported in the literature (Berglund & Lindvall, 1995; Melnick, 1979; Jensen, 1992) and noise pollution is one of the physical environmental and commonest occupational hazards affecting our health in today's modern world. The general effect of noise on the hearing of workers has been a topic of debate among scientists for a number of years (Jensen, 1992; Johnson, 1991; Alton, 1990). These effects are generally of a physiological and psychological nature. Hearing losses are the most common effects among the physiological ones. The psychological effects of noise are more common compared to the physiological ones and they can be seen in the forms of annoyance, sleep disturbance, stress, anger and concentration disorders as well as difficulties in resting and perception (Cheung, 2004; Öhrström, 1989). High noise level is considered to be the commonest reason of annoyance & permanent hearing loss (Koffeman & Kerkers, 2000). It occurs with exposure to continuous and extensive noise at a level higher than 85dBA (Niquette & Aud., 2013). Studies have shown that for the 90th percentile exposed population, the risk of presumed noise induced hearing loss (NIHL) increases exponentially for noise levels beyond 85dBA and over a prolonged period (Gierke & Johnson, 1978).

Continuous hearing loss differs from person to person with the level, frequency and duration of the noise exposed (USEPA, 1973). It is possible to classify the perceived effects of noise on ears in three groups: acoustic trauma, temporary hearing losses and permanent hearing loss (Melamed *et al.,* 2001). Barreto (1997) showed that the risks attributed to noise and hearing loss together accounted for nearly half the injuries. Noise therefore interferes with working efficiency, by hindering communication between employees; it may also be a cause of accidents, by masking warning signals. In a study done in the manufacturing sector in Thika District in Kenya, the majority of the participants agreed to having problems working and concentrating when heavy and noisy machines were running (Mithanga, 2013). In the same study, the majority of the employees indicated that high occupational noise levels in the manufacturing industries affected the work performance and communication among them.

The noise pollution situation is improving in developed countries, as more widespread appreciation of the hazard has led to the introduction of protective measures. Regulations limiting noise emission to the environment have been instituted in many places. For example, in the U.S., the Occupational Noise Exposure Regulation states that industrial employers must limit noise exposure of their employees to 90 dBA for one 8-hr period (USEPA, 1973). This permitted maximum noise exposure dose is similar to the Turkey Standard, which is less than 75 dBA for one 7.5 hour period (Republic of Turkey Ministry of Environment, 1986). In Kenya, the Environmental management and coordination (Noise and Excessive Vibration Pollution) control regulations (2009) has regulations on maximum permissible noise levels for various functions at designated times of the day with commercial areas limited to 60 dBA. Legal Notice No. 25-Factories and other Places of Work Act, 2005 set limits noise exposure to not more than 90 dBA for eight hours duration and requirements for noise control and hearing conservation programme to prevent noise induced hearing loss in workplaces (Occupational Safety and Health Act, 2007).

With rapid industrialization, a great majority of people working in and around the manufacturing industries in many developing countries including Kenya could be exposed to noise and yet, the perceived effects of noise as an environmental issue has not been given sufficient attention due probably to lack of awareness. Therefore, this study was carried out to determine the levels of industrial noise, its extent and perceived effects on the environment, the adequacy and compliance to recommended control measures to be put in place and recommend technical and management solutions.

1.2 Statement of the Problem

Industrialization and urbanization exposes the population to excessive noise. Studies indicate that in Germany 12-15% of the work force in industrial cities is exposed to noise pollution. In another study in Egypt, 70% of respondents reported exposure to hazardous industrial noise and 62.5% of the manufacturing industries in Thika do not comply with the set standards on noise pollution control. A great majority of people working in and around the manufacturing industries in Nairobi, Kenya, could also be exposed to noise levels that may pose a risk to their health. Nairobi is not only the commercial, industrial and administrative capital city of Kenya; it is also a leading business hub for East and Central Africa and hosts a number of industries. However, no conclusive studies have been made to establish the effect and extent of the noise pollution or assess the level of compliance, yet studies done elsewhere have shown that noise pollution causes annoyance, disturbance during sleep, headaches, accidents and noise induced hearing loss among others at work places. Since the Noise and Excessive Vibration (Pollution) Control Regulations Act came into force in 2009, various attempts have been made to enforce it through arrests and prosecutions. However, the effects of noise as an environmental issue have not been given sufficient attention. There is also likely to be lack of awareness among workers in Nairobi and the general public about the negative effects of exposure to excessive noise. Little action has been put in place to control industrial noise, hence increased exposure of workers and the general public to excessive noise. The purpose of this study was to assess and document the extent and effect of industrial noise pollution in the City of Nairobi through measurement.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to assess the extent and perceived effects of industrial noise pollution in Nairobi City.

1.3.1 Specific Objectives

1. To evaluate the current extent of noise pollution in manufacturing industries in Nairobi city.
2. To assess the perceived effects of industrial noise pollution on workers in Nairobi city.
3. To make recommendations on the organisation and management of noise in the manufacturing industry.

1.4 Research Questions

a) Are noise pollution levels in the manufacturing industries in Nairobi higher than the permissible limits?
b) Do noise pollution levels in the manufacturing industries in Nairobi have negative effects on the workers?

1.5 Justification of the Study

Manufacturing sector makes an important contribution to the Kenyan economy and currently employs 265,000 people, which represents 13% of total employment with an additional 1.4 million people employed in the informal side of the industry (KNBS, 2015). A great majority of these people could be exposed to noise.

According to WHO, noise is the most common workplace hazards in the world and is the major avoidable cause of permanent hearing impairment worldwide (WHO, 1997). The occupational and environmental impact of noise generated by manufacturing industries in Nairobi and the adequacy of available industrial noise control measures have not been fully investigated. Generally, little has been done regarding noise pollution in Kenya, as compared to other environmental issues such as water, air or soil pollution.

This research sought to bridge the above mentioned gap and provided data that can be used for decision making by urban planners, the National Environment Management Authority, Developers and the public. The information that was gathered included evaluation of compliance with the existing laws for managing noise and public safety as well as an indication of the expected short, mid and long term impacts on the environmental and public health and the required mitigation measures from best practice experienced elsewhere. Situations that require specific control and mitigation measures have been pointed out and directed to the Directorate of Occupational Health and National Environment Management Authority for redress.

1.6 Scope of the Study

The research was conducted to investigate the noise levels in different manufacturing industries in the city of Nairobi. It covered twelve manufacturing industries and three sections of Kamukunji non formal (*jua kali*) industry. The total sample size was 400 participants all drawn from the production department. The noise levels were measured in all the production departments of fifteen sites and compared accordingly.

1.7 Limitations of the Study

Some of the limitations in this study were; failure by respondents to return the filled questionnaires in time, management very hesitant in allowing measurement of noise levels in the industries.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Definition of Industrial Noise

Noise is unwanted sound that can cause undesirable effect (NIOSH, 1991). Noise is present in every human activity, and when assessing its impact on human well-being, it is usually classified either as occupational noise (i.e., noise in the workplace), or as environmental noise (community, residential, or domestic level, e.g., music, traffic, playgrounds, sports, among others) (Kujawa & Liberman, 2009). Industrial noise pollution is the unwanted sound produced by industries that produces a jarring or displeasing effect which interferes with human communication, comfort and health (Bahita, 2001). In many manufacturing operations there is no one principal noise source, but rather a composite of sounds from machine tools, conveyor systems, lift-trucks, pumps and compressors, steam and air relief valves, signal or alarm systems, and many others blended into an unidentifiable mixture of sounds (Cohen *et al.*, 1986).

2.1.2 Theoretical Concept of Sound

Sound is produced by vibrations which causes small fluctuations in air pressure. For example, the sound from a guitar string results from fluctuations in air pressure caused by the movement or vibration of the string. The vibrations results into the formation of compression and rarefaction bands in the air. This is the mechanism through which sound is propagated. Pressures are high in the compression band and are lower in the rarefaction band. What accounts for the propagation of sound is the differential of these pressures above and below existing atmospheric pressure. Without these differentials, no sound can be transmitted as the ear will perceive no change. The eardrum is able to perceive these fluctuations with great sensitivity (Arcadio & Gregoria, 2002).

The loudness of a sound is predominantly related to the size of the fluctuations (amplitude), but is also related to their frequency, or the rate at which they are produced. The loudness of sounds can range from those which the human ear can just detect (the threshold of hearing) to those that exceed a threshold of pain. Given that sound is produced by changes in air pressure, the international standard unit of acoustic pressure is based on that for pressure measurement, the micropascal (μPa) (Barron, 2003). The acoustic pressure for a plane simple harmonic sound wave moving in the positive x-direction may be represented by equation (2-1) (Arcadio & Gregoria, 2002) where pmax is the amplitude of the acoustic pressure wave, x is the wavelength, f is the frequency and t is the time (Arcadio & Gregoria, 2002).

$$P(x,t) = p \max \sin(2\,ft - kx) \tag{2-1}$$

Acoustic instruments, such as a sound level meter, generally do not measure the amplitude of the acoustic pressure wave; instead, these instruments measure the root-mean-square (rms) pressure, which is proportional to the amplitude. The relation between the pressure wave amplitude and the rms pressure is demonstrated in the equation (2-2) (Arcadio & Gregoria, 2002). If we define the variable ϴ= 2t/τ, so dϴ=dt/τ; the rms pressure is defined as the square root of the average of the square of the instantaneous acoustic pressure over one period of vibration τ:

$$(p_{rms})^2 = \int_0^{\tau} \mathrm{p}^2(x,t)dt = \frac{(p\max)^2}{2\pi}\int_0^{\pi} \sin^2(\theta - kx)d\theta \tag{2-2}$$

Integration of equation (2-2) results into equation (2-3), (2-4) and (2-5).

$$(p_{rms})^2 = \frac{(p\max)^2}{2\pi}\left[\frac{1}{2}(\theta - kx) - \frac{1}{4}\sin(2\theta - 2kx)\right]_0^{2\pi} \tag{2-3}$$

$$(p_{rms})^2 = \frac{1}{2}(p\max)^2 \tag{2-4}$$

$$p_{rms} = \frac{p\max}{\sqrt{2}} \tag{2-5}$$

2.1.3 Measurement of Industrial Noise Pollution

The range between the faintest audible sound and the loudest sound the human ear can stand is so large (20 µPa to 63 million µPa) that it would be cumbersome to express sound pressure fluctuations in these units. Instead, this range is compressed by expressing the sound pressure in the unit which is the more commonly known decibel (dB), named after Alexander Graham Bell. Decibels are measured on a logarithmic scale of 0-140 using a sound level meter (EPA, 2007), which means that a small change in the number of decibels results in a huge change in the amount of noise and the potential damage to a person's hearing. The human ear is not equally sensitive to sounds at different frequencies (Mcbride, 2010). To account for the perceived loudness of a sound by the ear, a spectral sensitivity factor is attained by building and incorporating a weighting network (simply an electrical circuitry) in the noise meter to help approximate human response and give a reading as close to that of the ear as possible (Occupational Safety & Health, Hong Kong, 2005).This is called an A-weighting filter because it conforms to the internationally standardized A-weighting curves (Charante *et al.*, 1990). Measurements done with this filter are usually reported in units of dBA (Charante *et al.*, 1990). The typical sound level meter has three different frequency-weighting networks, identified as the A, B, and C scale networks (Jensen *et al.*, 1978). From studies that have been done, it has been agreed that the high frequency noise passed by the A weighting network correlates well with annoyance effects of the noise on people (McBride, 2010).

(i) Sound Pressure

The decibel is relative to $2(10^{-5})$ atmospheres. In the metric system, this reference pressure is $2x10^{-5}$ Newton/m^2. The unit "pascal" is defined as 1N/m^2, so the sound pressure reference is currently expressed as $2x10^{-5}$pascal or 20 micropascal. Thus to be technically correct, one should say, "The sound pressure level is 75 decibels relative to 20 micropascal (Jensen *et al.*, 1978).

In defining the decibel, arbitrary reference values are chosen, depending on the type of decibel to be defined. For power, the reference value is 10^{-12}w. For pressure and intensity, the references are respectively, $2(10^{-5})$ pa and 10^{-12}w/m^2. In terms of general definition, the decibel is expressed by equation (2-6) where x is any one of pressure, power, and intensity and y relates to the respective reference values (Arcadio & Gregoria, 2002)

$$Decibel(dB) = 10 \log {}^{x}\!/_{y} \tag{2-6}$$

For sound pressure P_w, x= (P_{rms} sound pressure measured)^2; y=(20 micropascal)^2 (Jensen et al.1978). Using the respective decibels, the word level is used for references to sound power, pressure and intensity. For power, the decibel is the sound power level L_w as expressed in equation (2-7), and for pressure and intensity, the decibels are sound pressure level L_p and sound intensity level L; as expressed in equations (2-8) and (2-9) respectively(Arcadio & Gregoria, 2002).

Sound Power Level; $L_W = 10\log\frac{P_W}{10^{-12}} dB$ (2-7)

Sound Pressure Level; $L_p = 10\log\frac{p^2{}_{rms}}{(2x10^{-5})^2}$ (2-8)

Sound Intensity Level; $L_I = 10\log\frac{I}{10^{-12}} dB$ (2-9)

In practice, a sound level meter is calibrated to read decibels relative to 20 micropascal, so a person is seldom aware of rms pressure of the actual sound(that is, how many millionths of an atmosphere it is or how many Newtons per m^2, or Ib per In^2, or dynes per cm^2). Yet we are aware that very quiet sounds (a quiet whisper or the rustling of grass in a very slight breeze) may range from 10 to 20dB, while very loud sounds (a nearby diesel truck or an overhead aircraft shortly after takeoff or a loud clap of thunder) may range from 85dB to over 130dB.

Instantaneous sound pressure levels of 160dB can rupture the eardrum, and the risk of permanent hearing impairment increases as a function of sound levels above 80dB (Jensen et al. 1978).

(ii) Sound Power

An oscillating sound wave like a compressed spring has potential and kinetic energy. If you neglect frictional losses, the kinetic energy equals potential energy at the start. The sound power (energy in terms of time) of travelling sound wave equals the sum of potential and kinetic energy and is expressed in equation (2-10) where S_m is the amplitude; ρ is the density of the air; A is the cross section area of propagation of sound wave; ω is the angular frequency and v is the velocity (Arcadio & Gregoria, 2002).

$$P_W = \frac{1}{2}\rho AV\omega^2 S^2{}_m$$ (2-10)

(iii) Sound Intensity

The intensity of Sound wave is the average rate of sound power transmission per unit area of cross section (A) in the direction of travel of the sound is given in equation (2-11) (Arcadio & Gregoria, 2002).

$$I = \frac{\frac{1}{2}\rho A\omega^2 S^2{}_m}{A} = \frac{1}{2}\rho V\omega^2 S^2{}_m = \Delta\frac{P^2 m}{2\rho v} \qquad (2\text{-}11)$$

Sound intensity is commonly expressed in terms of the *root mean square* of the sound wave as expressed in equation (2-12).

$$I = \frac{\Delta P^2{}_{rms}}{\rho v} \qquad (2\text{-}12)$$

There are many situations in which we need to determine the sound level produced by several sources of sound acting at the same time. For example, we may need to determine the sound level produced by two machines in a room, but we may have only information about the sound level produced by each machine separately. Because all levels are defined in terms of energy-like quantities, all ‘‘levels’’ (sound pressure level, intensity level, power level, etc.) will combine in the same manner. The total intensity, for example, is the sum of the intensities for the individual sources, if the sources produce sound waves that are not exactly in-phase or out-of-phase.

It is quite likely that the noise generated by machinery is not correlated, because the noise involves a wide range of frequencies and not a single frequency only (Baron, 2003). Suppose we have two sources of sound that produce the following intensity levels when operating alone. The general expression for determining the combination of any set of ‘‘level’’ quantities is given by equation (2-13) where L_i could be $L_W, P_W,$ or I.

$$L = 10 \log \sum_i \frac{L_i}{10} \quad (2\text{-}13)$$

This expression is valid for all types of levels including sound pressure levels because the total pressure is not the sum of the individual pressures if the waves are not correlated. The square of the pressure is proportional to energy (the intensity, for example), so the individual sound pressures must be combined in an ‘‘energy-like’’ manner as expressed in equation (2-14).

$$(P_{total})^2 = p_1^2 + p_2^2 + p_3^2 + \dots \quad (2\text{-}14)$$

The reference quantity is the same for each intensity level, so the previous calculation could be carried out using the intensity ratio (Barron, 2003). The total intensity when the two sources are operating at the same time is the sum of the intensities as expressed in equation (2-15) (Barron, 2003):

$$I = I_1 + I_2 \quad (2\text{-}15)$$

The human ear can only perceive sounds having frequencies in the range between about 16Hz to 20 kHz (the sound spectrum). It also responds more to frequency ratios than to frequency differences, so the frequency ranges generally have terminal frequencies (upper and lower frequencies of the range) that are related by the same ratio. As a result of these, the measuring devices also measure the acoustic energy included in a range of frequencies (Barron, 2003).

The frequency interval over which measurements are made is called the bandwidth. The bandwidth may be described by the lower frequency of the interval (f_1) and the upper frequency of the interval (f_2) as shown in Table 2-1. In acoustics, the bandwidths are often specified in terms of octaves expressed as equation (2-16), where an octave is a frequency interval such that the upper frequency (f_2) is twice the lower frequency (f_1).

$$f_2 = 2f_1 \text{ or } \frac{f_2}{f_1} = 2 \qquad (2\text{-}16)$$

Table 2-1: Standard Octave Bands

Band No.	Lower f_1	Centre f_0	Up f_2 per
12	11	16	22
15	22	31.5	44
18	44	63	88
21	88	125	177
24	177	250	355
27	355	500	710
30	710	1000	1420
33	1420	2000	2840
36	2840	4000	5680
39	5640	8000	11360
42	11360	16000	22720

Source: ANSI S1.6 (1967)

The procedure of measuring pressure levels using band analysis is to set the meter at the geometric mean frequency and take the reading. The geometric mean is the average logarithm of the upper and lower frequencies and is expresses as equation (2-17) (Arcadio & Gregoria, 2002).

$$\log f_c = \frac{1}{2}(\log f_2 + \log f_1) = \log\sqrt{f_2 f_1} \quad f_c = \sqrt{f_2 f_1} \qquad (2\text{-}17)$$

In some cases, a more refined division of the frequency range is used in measurement such as 1/3-octave bands, in which $(\frac{f_2}{f_1}) = 2^{1/3} = 1:260$, $f_1 = \frac{f_0}{2^{1/6}}$, $f_2 = 2^{1/6} f_0$ and $f_0 = (\frac{f_2}{f_1})^{1/2}$ and $f_2 = 2^{1/2}$ (Baron, 2001). The subdivision into smaller bands assists in obtaining a more accurate characterization of the sound spectrum (Arcadio & Gregoria, 2002).

2.1.4 The Hearing Mechanism

The ear is shown in Figure 2-1 is comprised of three main parts; the external ear (Pinna); middle ear (Ossicles) and the inner ear (Cochlea). Sound waves collected by the Pinna travel down the ear canal to the eardrum; which vibrates in response**.** The vibrations are amplified and transmitted across the middle ear by the Ossicles (three small bones, called the hammer, anvil and stirrup). The base of the stirrup touches the oval window of the Cochlea (the inner ear). The vibrations are then passed into the fluid contained within the spiral cavity of the Cochlea (Acardio & Gregoria, 2002**).**

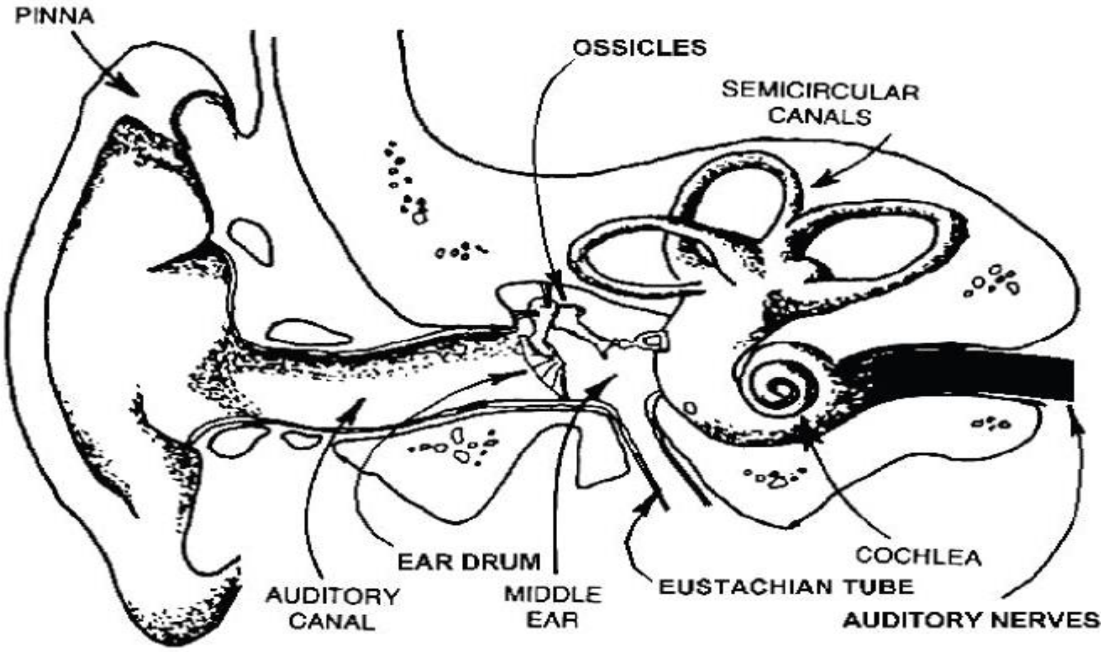

Figure 2-1: The Human Ear

Source: (Acardio & Gregoria, 2002**).**

The Cochlea is divided along almost the entire length by a skin (the Basilar Membrane) in which some 30,000 hair cells are imbedded like strings in a piano. Nerve endings in the hair cells are cabled together to form the auditory nerve that leads to the brain. The ear sends messages to the brain in digital code (like a computer) where it is interpreted as words, music, sound and/or noise. The brain also sends sound impulses to the ear, allowing us to cancel out sounds that we are not interested in and listen to those sounds that are of greater interest to us.

The ear is an incredible instrument with a frequency range of 20 to 20,000 Hz and a dynamic range of 0 to 140 dBA. Because the inner ear is extremely sensitive, it has a “blink” mechanism that automatically protects it from short duration loud noise events. However, permanent hearing loss can result when repeated loud noises override the safety mechanism and damage the hair cells in the Cochlea (Melnick, 1979).The following is the general guide; a whisper is about 30 dBA, normal conversation is 60–70 dBA, and power tools are often between 90–110 dBA. If two people at arm’s length must raise their voices to be heard, the noise level is above 85 dBA (Arcardio & Gregoria, 2002).

2.2 Empirical Literature Review

2.2.1 Extent and Effects of Industrial Noise Pollution

Noise pollution is a menace in most parts of the world and recent studies indicate the problem is on the increase especially at places of work (Mithanga, 2013). It’s reported that in countries like Germany, more than 4-5 million people (12-15% of the workforce) are exposed to noise levels defined as hazardous by WHO (WHO, 2001). Similarly the United States of America (USA) has many cases of its citizen being exposed to noise pollution with studies quoting more than 30 million workers are exposed to hazardous noise levels (NIOSH, 1998). Although data for third world countries are not as comprehensive, available evidence suggests that average noise levels are well above the recommended standards in many developed nations (Boateng & Amedofu, 2004; WHO, 2001; Mithanga, 2013), and that industrialization is not always accompanied by protection measures from excessive noise (WHO, 2004).

Ali (2010) carried out studies in Egypt on industrial noise and found that equivalent continuous noise levels ranged from 70 to 100 dBA and had varying outcomes; most of the respondents,70%, faced industrial noise levels that ranged from 85 to 100 dBA; almost half of the respondents were highly annoyed and there was a strong relationship between industrial noise levels and percentage of highly annoyed respondents; the same study found that the required maximum daily noise exposure durations set by Egyptian law to safeguard public health of workers were not adhered to for any level of industrial noise in Egyptian factories (Ali, 2010). Atmaca *et al.* (2005) also evaluated noise level and its physiological effect on workers of several industries in Turkey, including cement, steel, and textile industries. They found that the noise levels in all these industries were higher than 80 dBA. In addition, 77.8% of workers in the industries were dissatisfied with their workplaces, 61% were suffering from anxiety, and 31% experienced some degree of hearing loss. Farouk *et al.* (1996) studied hearing loss in 70 workers in the textile industry in Turkey and found that the rate of hearing loss was 30% in the exposed group and 8% in the non-exposed group. Hearing loss increased as the level of noise increased and reached 73% in the 95 dBA range (Farouk *et al.,* 1996).

A study done at Kamukunji *Jua Kali* sheds, Nairobi Kenya, shows the noise levels are way above the recommended limits (Kimani, 2011). In yet another study by the National Environmental Authority (NEMA) on bus stations, churches and night clubs in Nairobi, the conclusion is that most sites where noise was measured do not adhere to noise regulations (NEMA, 2009). The same study done by NEMA reveals a huge disparity between the actual noise levels with standards set in the regulations. It concludes that much needs to be done to make organizations associated with production of high noise levels comply. According to the report, complaints related to noise are also increasing suggesting that cases of non-compliance are increasing.

The most prevalent effect of noise is noise-induced hearing loss (NIHL). Studies suggest that NIHL has progressive consequences that may not manifest until much later (Kujawa & Liberman, 2009). The damage may be expressed as difficulty hearing in noise and/or in associated auditory disorders (tinnitus, hyperacusis, among others). The implication of the research done by Kujawa and Liberman is that noise can produce subclinical damage that goes undetected, progresses unnoticed, and finally manifests itself long after the effect (Kujawa & Liberman, 2009). Other studies have shown that this subclinical damage cannot be measured using audiometric tests, including the "gold standard" for testing NIHL: pure tone hearing thresholds (Bruel & Kjaer, 1992). Data collected over many years from persons exposed to industrial noise shows that most NIHL develops over the first 10-15 years of noise exposure and then asymptotes (levels off) (Atmac *et al.,* 2005).

From a preventive standpoint, the sooner the hearing risk is identified and minimized the better. To do this, it's recommended that noise exposures be monitored and risks assessed using hearing protection when necessary to reduce the risk of NIHL (Jensen *et al.,* 1978).

Studies have also shown that jobs higher in complexity typically require the use of greater cognitive capacity compared with jobs lower in complexity. The information over load model argues that individuals' capacity for information processing is limited with higher noise levels (Cohen, 1980; Mithanga, 2013). Stressors such as noise increase cognitive load because they require a share of cognitive capacity in addition to that allocated to job requirements. For simple jobs (i.e., jobs of low complexity), the cognitive demands are low, so that the effect of noise on job performance is likely to be relatively small (Cohen *et al.,* 1986). In contrast, high ambient noise is likely to produce cognitive overload on complex jobs that impose high cognitive demands and thus decrease performance on such jobs (Baron, 1994; Cohen *et al.,* 1986). Moreover, increased cognitive overload is likely to lead to adverse psychological (e.g., lower job satisfaction) and physiological (e.g., higher blood pressure) reactions.

The association between increased cognitive load and physiological responses has been demonstrated in numerous laboratory studies (Callister *et al.,* 1992; Fournier *et* al., 1999; Svebak, 1982; Veltman & Gaillard, 1993, 1996, 1998). Also, in several cross sectional studies, job satisfaction was found to be negatively associated with occupational noise exposure (Melamed *et al.,* 1992; Verbeek *et al.,* 1986). Another study by Melamed *et al.* (2001), came up with two findings; that lead to two conclusions. First; exposure to occupational noise has a greater effect on changes in blood pressure over time among those performing complex jobs. These workers also showed the highest prevalence of elevated blood pressure.

In Table 2-2, illustrations are made on the noise criteria limit and the timelines over which critical health effects are observed as suggested by the (WHO, 1999). It indicates exceedance of the protective limits over the stipulated number of years will result into various observed health effects.

Table 2-2: Effects of noise pollution on public health and welfare

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

Source: Arcardio and Gregoria, 2002; WHO, 1999; OSHA, 1983. In the table: ST, short-term (instant) effects; LT, long-term effects

2.2.2 Engineering Control and Management of Industrial Noise

Noise control is done at the source, transmission path and the receiver (worker). In the USA, Environmental Protection Agency (EPA) has drawn up guidelines for industrial noise that sets limits for licensed facilities. The licensed facility is required to minimize the noise impact of its activity and specifies that, “Best Available Techniques” (BAT), should be used in the selection and implementation of appropriate noise mitigation measures and controls (Melamed *et al.,* 2001). Application of BAT is based on the realization that best controls are implemented in original design (ISO, 11690) and where noisy machines are supplied, the effective “adds on” noise control technology can be achieved either by modification of the transmission path or the receiver and sometimes the source(Hansen & Snyder, 1996). When noise cannot be controlled adequately at source, attempts should be made to control it during its propagation path and as a last resort, the noise control element may be approached at the level of the receiver. Where BAT is adequately applied, the noise attributable to on-site activities should not exceed a free field $L_{Aeq,T}$, value of 55 dBA by daytime (08:00-22:00), at any noise sensitive location. At night time (22:00-08:00), the noise attributable to on-site activities should not exceed a free field $L_{Aeq, T}$, value of 45 dBA (Melamed *et al.*, 2001).

(i) Regulations and Standards

Various regulations and standard have been developed to help regulate noise exposures in the workplace. In the United States, Guidelines for occupational noise exposure were established by the Occupational Safety and Health Administration (OSHA, 1983) and the National Institute for Occupational Safety and Health (NIOSH, 1998). Both OSHA and NIOSH were created by the Occupational Safety and Health Act of 1970 (Niquette & Aud, 2013).Other agencies concerned with effect of noise at workplaces are Environmental Protection Agency (EPA), American National Standard Institute (ANSI, 1991), International Standard Organization (ISO, 1990), National Institute for Occupational Safety and Health (NIOSH, 1998), World Health Organization (WHO) and International Labor Organization (ILO, 1976) have all established regulations for maximum allowable noise exposure. The main challenge that these agencies try to address is about how long and how loud one can listen to sound without risking hearing damage. Damage-risk criteria provide the basis for recommending noise exposure limits based on noise level and exposure time. The ILO recommended noise limits (Occupational Exposure Level) to reduce hearing loss in workplaces (Occupational Deafness) as 90 dBA for eight (8) hours daily. Table 2-3 shows WHO recommended limits, while Table 2- 4 presents the OSHA and NIOSH criteria.

Table 2-3: Recommended noise exposure limit

Location/Position	Threshold Limit Values (Standards)
Speech, Comfort and work interference	60dBA
Workshop and Plant area where occasional communication is required	75dBA
Workshop office, control room, laboratories and workshops where easy communication is required.	55dBA
Offices, Mess rooms and canteen	50dBA
Prestigious offices and conference rooms	35dBA
Industrial and commercial area at day time	70dBA
Industrial and Commercial area at night	55dBA
Residential area at day time	55dBA
Residential area at night	45dBA

(Source: WHO, 1999)

OSHA permits exposures of 85dBA for 16 hours per day, and uses a 5dB time-intensity tradeoff: For every 5 dB increase in noise level, the allowable exposure time is reduced by half. For every 5 dB decrease in noise level, the allowable exposure time is doubled. All time/intensity values shown on the OSHA PEL line in

Table 2-4 are assumed to have equal risk to each other, i.e., 16 hours at 85 dB carries the same auditory risk as 8 hours at 90 dB, 4 hours at 95 dB, 2 hours at 100 dB, and so on (Niquette & Aud, 2013). NIOSH recommends

Table 2-4: Duration (in hours) of allowable exposures based on OSHA and NIOSH criteria

Level, in dBA	85	88	90	92	94	95	100	105	110	115
OSHA PEL	16		8			4	2	1	0.5	0.25
NIOSHREL	8	4			1		0.25			0.25

In the table: PEL, permissible exposure limit; REL, recommended exposure limit.

Source: Niquette & Aud., (2013)

an exposure limit of 85 dBA for 8 hours per day, and uses a 3 dBA time-intensity tradeoff; for every 3 dBA increase in noise level, the allowable exposure time is reduced by half. For every 3 dBA decrease in noise level, the allowable exposure time is doubled. The time/intensity values shown on the NIOSHREL line in Table 2-4 are assumed to have equal risk to each other, i.e., 8 hours at 85 dBA carries the same auditory risk as 4 hours at 88 dBA, 2 hours at 91 dB, and so on (Niquette & Aud, 2013).

The differences in OSHA criteria and NIOSH recommendations for exposure limits produce different outcomes. The more lenient OSHA values allow for higher exposures for longer durations and the more conservative NIOSH values recommend lower exposures for shorter durations. NIOSH uses a 3dBA exchange rate and is based on scientific data relating noise exposure to hearing loss, and are more protective of hearing. On the other hand, the OSHA standards use a 5 dBA exchange rate and reflect compromise between risk reduction and cost implementation of a work force. It should be noted that both standards are based on the assumption that the noise occurs as part of a work environment, and both assume non-occupational quiet. The limits are based on an 8-hour workday, five days per week over a 40-year working lifetime, and the time the individual is not at work (the other 16 hours in a day, as well as weekends) is assumed to be quiet. The standards do not account for noisy activities and hobbies (e.g., concerts, ATVs, snowmobiles, power tools, car races, live music, etc.) which may increase risk for NIHL (Niquette & Aud, 2013).

Table 2-5: Equivalent unexpected noise exposures that produces a 100% noise dose

OSHA (1983)			NIOSH (1998)		
Level, dBA	Duration	Dose (%)	Level, dBA	Duration	Dose (%)
90	8	100	85	8	100
95	4	100	88	4	100
100	2	100	91	2	100
105	1	100	94	1	100
110	30 min	100	97	30 min	100
115	15 min	100	100	15 min	100

Source: Niquette and Aud, (2013)

Noise dose is expressed as a percentage of a predetermined maximum (Table 2-5), defined by the standard one chooses (e.g., OSHA or NIOSH). Dose is calculated based on the criterion level, threshold level and exchange rate. Criterion level is the sound level which, if continuously applied for 8 hours, would result in a 100% noise dose. Threshold level is the level below which the dosimeter produces no noise dose accumulation (values below that level are effectively considered to be zero). The differences in the OSHA and NIOSH standards become noticeable at high noise levels: OSHA allows a 100 dB noise exposure for two hours, while NIOSH limits it to 15 minutes. An important point about noise dose is that it is cumulative; noise dose never decreases over time. While sound levels may go up and down over time, noise dose only increases or plateaus over time. This is because one can’t remove the exposure once it has occurred, much the same way one can’t undo sun exposure after the fact. When the combination of sound levels and duration exceed those shown in Table 2-6, noise dose increases to values greater than 100% (Niquette & Aud, 2013).

Table 2-6: Noise levels, dose and duration

OSHA (1983)			NIOSH (1998)		
Level, dBA	Duration	Dose (%)	Level, dBA	Duration	Dose (%)
105	1	100	94	1	100
105	2	200	94	2	200
105	4	400	94	4	400
105	8	800	94	8	800
105	16	1600	94	16	1600

Source: Niquette & Aud., (2013)

In Kenya, various measures have been put in place to regulate noise at the workplace. “The factories and Other Places of Work Act” currently (Occupational Safety and Health Act, 2007) and its subsidiary legislation “Noise Prevention and Control Rules Legal Notice Number 25 of 2005” was established and took effect on March 2005. It stipulates that for workplaces with noise levels above 85 dBA, there should be noise control and hearing conservation program in place. The aim was to prevent noise induced hearing loss. Methods adopted include:-frequency of noise measurements, education and training, engineering noise control measures, use of hearing protectors and posting warning notices in noisy areas. This law strictly forbids any worker to exposures to noise levels above 90 dBA for more than eight hours duration. Other laws regulating emissions of noise in Kenya are the traffic Act which prohibits hooting near places like schools, hospitals and law courts.

On general environment, Kenya adopted the Environment Management and Coordination Act 1999 (EMCA) as a policy framework law on environment management and conservation in 2002. A subsidiary legislation to EMCA; (Noise and Excessive Vibration Pollution) control regulations, 2009, legal notice number 61 was enacted and it gives provisions relating to noise from certain activities like fireworks, demolitions and any other activities likely to generate noise which will be a nuisance or affect people in the surroundings. It sets permissible noise levels in various places at different times of the day as shown in Table 2-7.

Table 2-7: Maximum permissible noise levels in Kenya

		EMCA Sound level limits, dBA ($L_{eq} 14h$)	
		Day	Night
A	Silent zone	40	35
B	Places of worship	40	35
C	Residential: Indoor Outdoor	45 50	35
D	Mixed residential (with some commercial and places of entertainment)	55	35
E	Commercial	60	35

Day 6.01a.m-8.00p.m L_{eq} *14h; Night: 8.01-6.00a.m* L_{eq} *10h*

Source: GoK, The Environmental management and Coordination (Noise and Excessive Vibration Pollution) control regulations, 2009

In order to effectively protect the environment, EMCA provides for Environment Impact Assessment (EIA) as a key instrument. This instrument is based on a number of directives. The first EIA directive was published in 1999 (EMCA, 1999). The law requires that before a project is implemented, an EIA must be carried out in line with the laid out guidelines. The subject of this directive was “the assessment and remedy of the perceived effects of certain public and private projects on the environment”. But in spite of these elaborate statutory provisions in Kenyan, recent studies done in Thika indicate that 62.5% of the manufacturing industries do not comply with set standards on noise (Mithanga, 2013).

(ii) Engineering Control

Occupational health and safety officials have recommended a hierarchy of controls to determine on how to implement effective noise pollution control and management in order to reduce exposure. The best approach for noise hazard control in the work environment is to eliminate or reduce the hazard at its source of generation, either by direct action on the source -substitute the louder equipment with the quieter one or by its confinement (Bies & Hansen, 1996). The government of Hong Kong, for example, recommends elimination through the purchase of the quietest equipment, machinery and plant and isolation by segregating the equipment in a noise-proof enclosure (GovHK, 2005). Equipment that are overly aged or damaged will produce louder noise (ISO, 11690; Bies & Hansen, 1996). Also the installed equipment should be checked regularly to ensure its operating properly.

General control of noise at source will involve;-

a) Maintenance:-replacement or adjustment of worn out parts; balancing equipment; lubrication of moving parts; use of properly shaped or sharpened parts (ISO, 11690).
b) Substitution of materials:-replacement of steel sprockets in chain drives with sprockets made from flexible polyamide plastics (ISO, 11690).
c) Substitution of equipment;-use hydraulic rather than mechanical presses; presses rather than hammers; belt conveyors rather than roller conveyors (ISO, 11690).
d) Substitution of parts of equipment;-replace spur gears with helical gears (reduces noise by 10dBA); for wood replace straight cutters with helical cutters (reduces noise by 10dBA); replace gear drives with belt drives (Noise reduction in the range of 20dB (A) is possible) (Harris, 1991).
e) Change of work method;-use remote control of noisy equipment such as pneumatic tools; may prefer batch process for continuous process, select slowest machine speed appropriate for a job - also select large; slow machines rather than smaller faster ones(Harris, 1991).

f) Lining a significant proportion of the inside of the ductwork with acoustic absorbent (Foam, Rockwool/Fiberglass) will reduce the noise “trapped” by the duct. Consequently, less noise will escape through any gaps (Hansen & Snyder, 1996).

h) General duty motors are available (at little or no cost premium) that are up to 10 dBA or more quieter than typical motors used in a large of industrial appliances from fans to pumps (Hansen & Snyder, 1996).
i) In most cases, it is possible to replace existing nozzles (usually simple copper pipe outlets) for quiet, high efficiency units. These not only reduce noise levels by up to 10 dB, but also use less compressed air (Hansen & Snyder, 1996).
j) Pneumatic exhaust noise can permanently be reduced by 10 - 30 dBA by fitting effective silencers. A well designed silencer will not increase system back pressure (ISO, 11690; Bies & Hansen, 1996).
k) Mounting motors, pumps, gearboxes and other items of plant on rubber bonded cork (or similar) pads can be a very effective way of reducing transmission of vibration and therefore noise radiated by the rest of the structure. This is particularly the case where vibrating units are bolted to steel supports or floors. There are many types of off-the-shelf anti-vibration mounts available, for instance rubber/neoprene or spring types (Hansen & Snyder, 1996).

Multiple techniques have also been developed to address interior sound levels, many of which are encouraged by local building codes. When sound reflects within boundaries, it "accumulates" as a result of the addition of the reflected sound to the original sound. Sound may continue even after the original source stops (Hansen & Snyder, 1996).When the enclosure boundaries are hard and reflective, the reverberant field can easily dominate the sound arriving directly (without reflection) from a particular sound source. This will become increasingly likely as the distance from the sound source is increased (Hansen & Snyder, 1996).

In the best case of project designs, planners are encouraged to work with design engineers to examine tradeoffs of architectural designs (GovHK, 2005; Harris, 1991). These techniques include design of exterior walls, party walls, and floor and ceiling assemblies; moreover, there are a host of specialized means for damping reverberation. Many of these techniques rely upon materials science applications of constructing sound baffles or using sound-absorbing liners for interior spaces (Hansen & Snyder, 1996).This method is appropriate and works best at reducing noise for machineries in operation phase and is highly applied in Hong Kong (GovHK, 2005).

Correction of the internal environment absorption coefficient using the absorption method for the base absorbent has been found to be most efficient for high frequencies but shows limited success at low frequencies (low frequencies, sound waves have long wavelengths, the thickness of the sheet absorber is negligible compared to the wavelength of incoming sound) (GovHK, 2005).

Monazzam *et al*. (2013) observed that increasing the thickness of the absorbent helps, but is not an economical alternative. The solution proposed in the study, Monazzam *et al*. (2013), (leaving an air gap of varying thickness between the absorbent and the wall or ceiling surface) can remove this constraint and improve the performance of the absorbent at low frequencies (Monazzam *et al*., 2013).

The noise generated by a source can be prevented from reaching a worker by means of an Obstacle to its propagation, conveniently located between the source and worker. The transmission loss is defined as in equation (2-18) where the transmission coefficient, τ, is defined as the ratio of transmitted to incident energy (on the obstacle) (Bies and Hansen, 1996; ISO 9613-2; ISO 10847; ISO 11821).

$$TL = 10\log_{10}\tau, \qquad (2\text{-}18)$$

If the receiving space is outdoors in a "free" field, the noise reduction is equal to the transmission loss(ignoring, for now the transmission of sound around the edges of the partition). If the receiving space is indoors, the noise reduction is given by equation (2-19) where A_{Wall} is the surface area of the partition and $S\overline{\alpha}$ is the absorption of the receiving space (Bies and Hansen, 1996).

$$NR = TL - 10\log_{10}\left(\frac{A_{Wall}}{S\overline{\alpha}}\right) \tag{2-19}$$

It can be seen from these equation that the performance of the partition in reducing noise levels is improved as the amount of absorption in the receiving room is increased.

Transmission loss through a partition depends on the type of material of which it is made and it varies as a function of frequency. For usual industrial noise, the transmission loss through a partition increases by about 6 dB for each doubling of its weight per unit of surface area. Therefore, the best sound isolating materials are those which are compact, dense, and heavy (ISO 10847; ISO 11821).

(iii)Administrative Control

If engineering techniques fail to reduce excessive noise levels, protective hearing devices should be provided to employees (Bies & Hansen, 1996). The use of hearing protection in industries and construction works is to reduce exposures to high noise levels. The main problems lie in ensuring that the devices fit adequately to provide the rated sound attenuation and that the devices are properly worn (Bies & Hansen, 1996). Extensive education programs are needed in this regard. Hearing protection is also uncomfortable for a large proportion of the workforce; it can lead to headaches, fungus infections in the ear canal, a higher rate of absenteeism and reduced work efficiency (Harris, 1991). It is worth remembering that the most protection that a properly fitted headset/earplug combination will provide is 30 dBA, due to conduction through the bone structure of the head. In most cases, the noise reduction obtained is much less than this. According to Niquette and Aud (2013), all hearing protectors are to be labeled with a Noise Reduction Rating (NRR), which is a laboratory estimate of how much noise the hearing protector will block (Niquette & Aud, 2013). Provision of hearing protection limits noise exposures during working shifts. If noise levels are above 85 decibels, the best option is to rotate the workers so that they do not experience exposure for more than 8 hours. They may need to be transferred to other department within the company if they experience ill effects of noise pollution. Another option which is sometimes practical for receiver control is to enclose personnel in a sound reducing enclosure (ISO, 11957).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

This study focused on the industrial area of Nairobi City as shown in Figure 3-1. Nairobi is not only the commercial, industrial and administrative capital city of Kenya, it is also a leading business hub for East and Central Africa with the population standing at about three (3.5)million people (United Nations Statics Division, 2016). Also, the recently delineated Nairobi metropolitan area formed an appropriate study area because it captures a large and diverse firm population that is on the rise and that can be easily accessed. Government statistics indicates that, 56% of all formal medium and large enterprises are located in Nairobi and its surrounding areas (Kenya, 2006)

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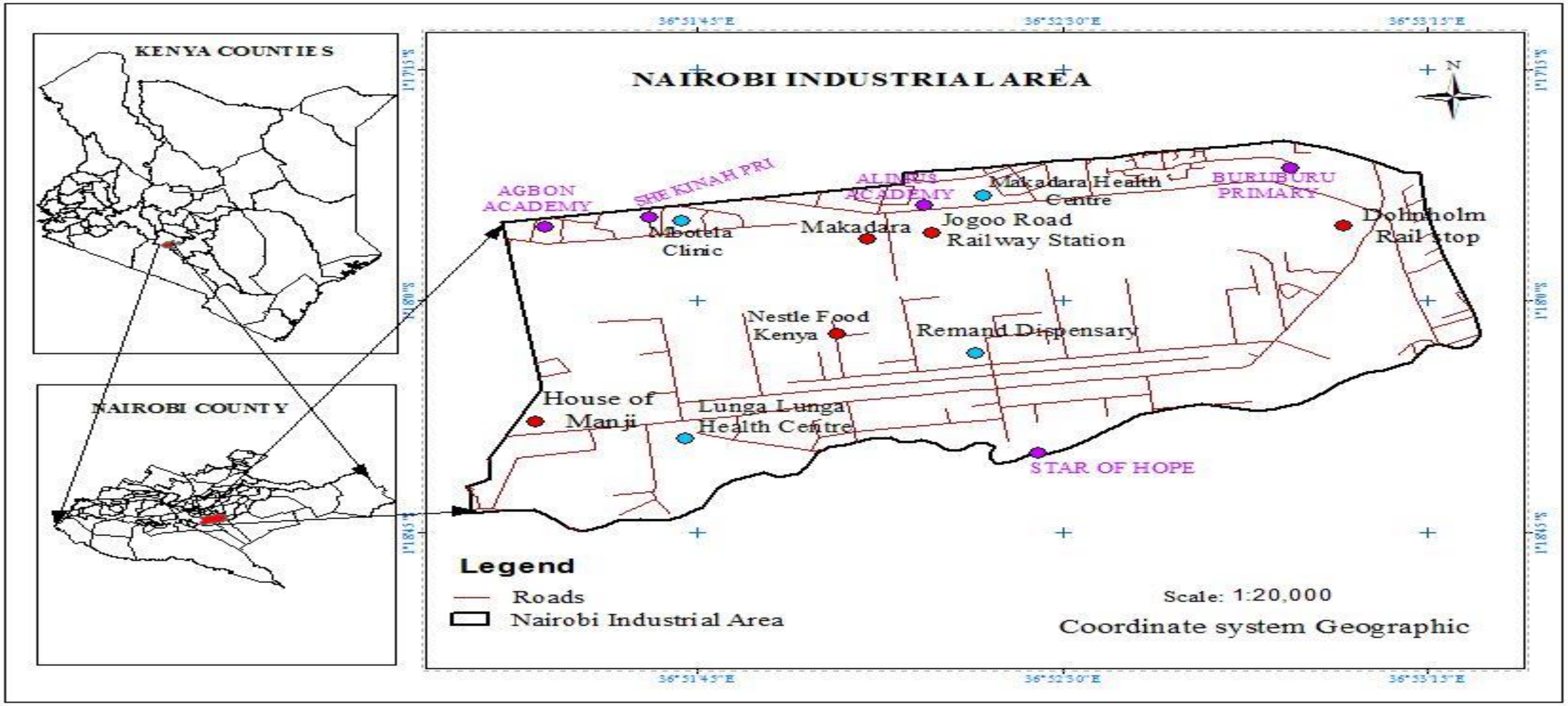


Figure 3-1: Map of the study area, Nairobi Industrial Area

3.2 Target Population and Sampling Frame

The study targeted industries registered at Directorate of Occupational Safety and Health Services (DOSHS) and industrial workers in Nairobi City. Data was collected from metal, plastic, wood, grain mills; and non-formal metal (*Jua kali*) industries as indicated in Table 3-1.These were identified through discussions with government officers at DOSHS and from literature as leading producers of occupational noise. A total of 400 workers were surveyed (Section 3.3).This comprised of machine operators, the general workers and management staff.

Table 3-1: Sampled Industries for noise pollution study

Type of Industry	No. of Industries	No. of Workers	Sampled Industries	Sampled Workers
Metal	9	283	3	95
Non Formal Metal - *Jua Kali*	9	240	3	80
Plastic	9	298	3	100
Wood	9	157	3	53
Grain Millers	7	214	3	72
Total	43	1192	15	400

3.3 Sampling Procedure and Sample Size

Fifteen (15) industries, three (3) each from metal, plastic, wood and furniture, grain millers, and non formal metal (*Jua Kali*) industries were sampled for the purpose of taking sound pressure measurements by random sampling from among 45 industries selected through stratified sampling using the register of industries at Director of Occupation Safety and Health (DOSH) as per Table 3.1.

In each industry, respondents were selected by random sampling from among the employees working in the production section. This was in accordance with the study done by Mithanga, (2013), in which the production section was found to be the noisiest part of the industries. Willing respondents were required to pick lots marked with numbers. Those who picked odd numbers were sampled for the study until the required sample size was obtained. One of the biggest advantages with simple random sampling was the ease of assembling the sample and unbiased random selection of a representative sample which was important in drawing conclusions from the results of the study (Creswell, 2012).

The sample size (n_n) was determined using equation (3-2), Fisher *et al*. (1998) in which Z is the value of standard variance of 1.96 at 95% confidence interval while *p* is the proportionate target population with the particular characteristics, taken to be 50% (0.5) as recommended by Fisher *et al.* (1998), *d* is the level of statistical significance set at 0.5% and $q = 1-p$. The equation uses the prevalence but in this study the prevalence was not known and therefore proportion which uses 50% was used.

$$n_n = \frac{Z^2 pq}{d^2} \qquad (3\text{-}1)$$

Based on the equation (3-2), a sample size of 385 was computed for this study. Allowing for 5% attrition, a sample size of 400 was adequate with expected return rate of 100%.

3.4 Evaluating the Extent of Industrial Noise Pollution

3.4.1 Experimental Set-Up

Sound level measurements were carried out as illustrated in Figure 3-2 using a digital integrating sound level meter, SLM, (SVANTEK 971). This is a Type 1 SLM which measures sound levels in accordance with IEC 61672-1:2002 Standards. Before use, the meter was calibrated using an SV 34 sound calibrator, as per the manufacturer's instructions. The calibration system included a source of sound and a microphone system. For calibration, the microphone system was mounted on the interface unit and the sound source played to produce a series of pre-recorded sounds/frequencies. When a specific calibration sound was produced at a known level, a LED signal appeared, indicating that the meter was successfully calibrated (Occupational Safety & Health Hong Kong, 2005).

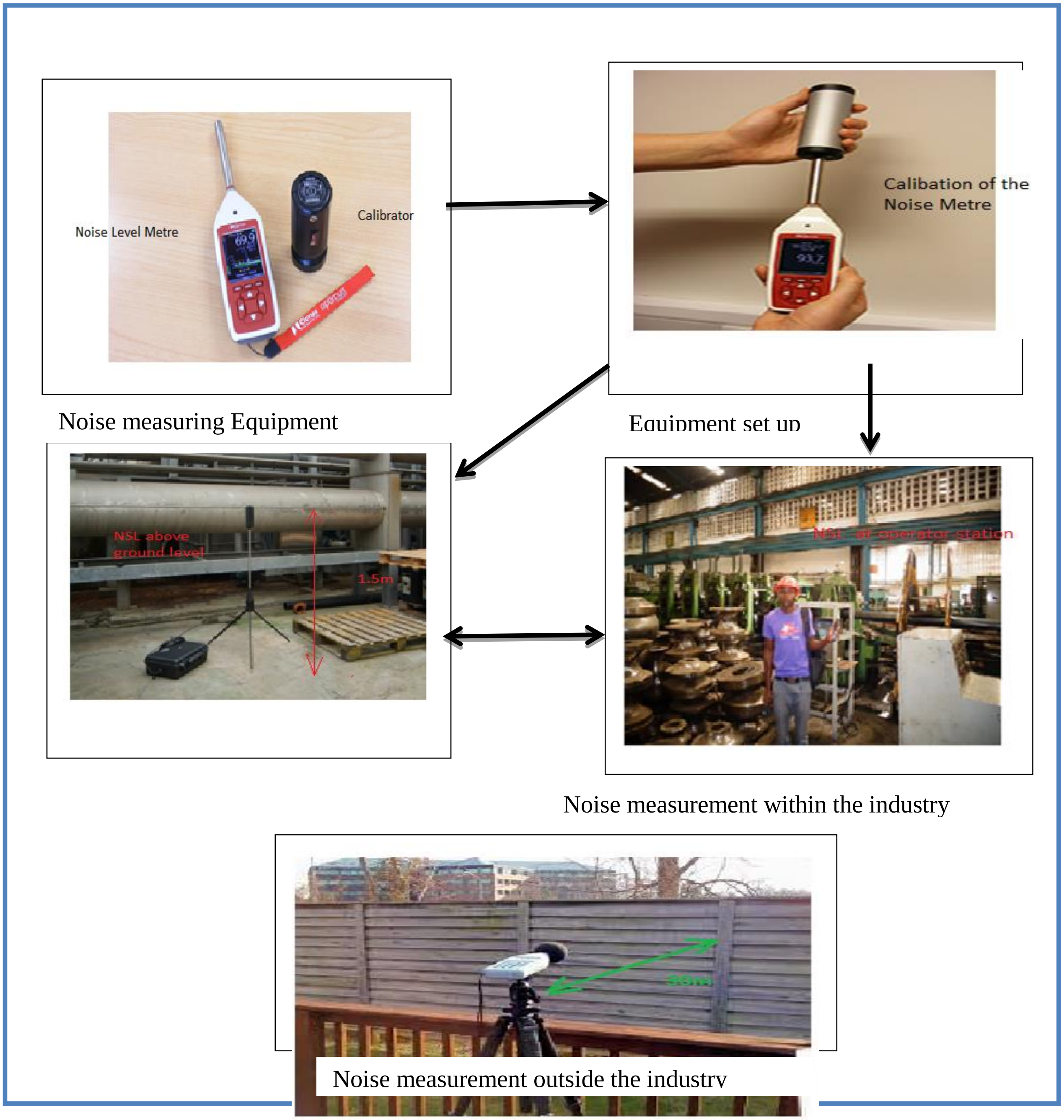


Figure 3 -2: Experimental set up

3.4.2 Data Collection Procedure

To determine the occupational noise levels, measurements were taken in the production section of the industries at the operator's station for the following sites:

Table 3-2: Factories sampled for the study

Category of Industries	Factories selected
Metal	1. Insteel Ltd 2. Shangi Engineering 3. Choda Fabricators
Plastic Industries	1. DOSH Ltd 2. Plastic & Rubber 2005 3. Polyflex Industries
Furniture and Wood Industries	1. Wood Makers 2. Wood Manufacturers 3. Nairobi Timber Project
Grain Milling Industries	1. Baraka Flour Mills 2. Pembe Mills 3. Kifaru Millers
Non Formal Metal (*Jua Kali*) Industries	1. Site A 2. Site B 3. Site C

The microphone was held at a height of 1.5 m and at least 1 m from reflecting surfaces for a duration of 10 minutes for each of the three (3) samples at (9-10hours), (12-13hours) and (15-16hours). Three sampling times selected in this study were based on the previous study (Tsai *et al*., 2009). The sound meter recorded the A- weighted sound pressure levels for specific time intervals which were downloaded onto the supervisor software on the PC and the readings taken (Stephenson, 2003). This gave an insight into the temporal distribution of noise in the industry. The procedure was repeated for the second and third day. Measurements were taken according to the provisions of the International Standard for Assessment of Environment Noise ISO-1996.

To determine the extent of the noise into the environment, measurements were taken at 10minterval from the industrial boundary in the available exterior direction marked by a GPS. The critical point was the distance of 30 m from the industrial boundary as recommended by Noise and Excessive Vibration Pollution (Control) Regulations (2009). The SLM was set at a height of 4m and measurements taken for 10minutes duration at each grid point, for at least a set of three (3) readings at an interval of three (3) hours from 8 a.m. to 5 p.m. This provided for temporal distribution of noise into the environment. The procedure was repeated for the second and third day. Alongside noise pressure measurements, each industry was located using a hand-held GPS (Garmin Montana 600).

3.4.3 Data Analysis and Presentation

Average noise levels were obtained from the noise measurements made at the respective industries at different times and days. The typical environmental noise measurement parameters in this study were as follows; $L_{Aeq8-17}$ (the average noise level during the measurement period (8-17hours), which includes all noise events); L_{APeak} (peak sound level which is the maximum instantaneous sound level in dBA).

Using the specific interval measurements for 8 hours from 8 to 17 hours, $L_{Aeq8\text{-}17}$ was calculated for each noise source using equation (3-1) in which $L_{Aeq8\text{-}17}$ is the continuous equivalent A weighted noise pressure level from 8 to 17 hours; *n* is the number of 10 minutes measurements between 8.00 and 17.00 hours; $L_{Aeq(i/10)}$ is the A weighted continuous noise pressure measurement in the one 10 minutes instant; i is the frequency of the measurement where i varies from 1 to n.

$$L_{Aeq8-17} = 10\log\frac{1}{n}\left(\sum_{i=1}^{n}10^{L_{Aeq\frac{i}{10}}}\right) \qquad (3\text{-}2)$$

The results of $L_{Aeq8\text{-}17}$obtained provided a representation of overall temporal and spatial distribution of noise levels at each type of industry sample site. By use of tables and graphs, the $L_{Aeq8\text{-}17}$ were compared to the national legislated standards OSHA, NEMA and WHO guidelines and their extent were determined by the level of deviations from the standards (Where the national standards were not very clear, WHO guidelines were used). A one tailed t-test was used to determine whether the deviations of the observed noise levels from recommended safe limits were statistically significant. The Analysis of Variance (ANOVA) (Larsen *et al*., 1986) was applied to check whether variations in noise levels from various sources within the group and at different times of the day were significant. Given the significance of noise to the public welfare, the 5% level of significance was appropriate for the statistical tests.

3.5 Assessing the Perceived Effects of Industrial Noise Pollution on Workers

3.5.1 Research Design

The evaluation of the prevalence of industrial noise pollution effect on public health employed a descriptive cross-sectional research design. This is the same approach used by Monazzam *et al.* (2013); Momir *et al.* (2008); Bullen (2012) among others. In descriptive study, the researcher makes observation on a population without influencing or interfering with the processes (Creswell, 2012). The study is used to describe some features of the population such as prevalence of an illness or they may support inferences of cause and effect (Scott & Delbert, 2006). In cross-sectional research design study, an investigator makes a single examination at a specified time on a representative sample of a population. The aim is to provide data on the entire population under study and the results obtained extrapolated over the entire population (Scott & Delbert, 2006). Qualitative and quantitative data on key effects of noise on pollution was collected, analysed and compared to the set standards. Both qualitative and quantitative data was significant in that besides capturing the perceived effects and extent of industrial noise pollution, they also provided a pointer to the social attributes of workers in terms of age, gender, level of education, experience, attitude and inclination to industrial noise which assisted in making conclusions regarding the current nature of the situation.

3.5.2 Data Collection Instrument and Piloting Survey

a) Data Collection Instruments

Primary and secondary data was collected by means of a structured questionnaire, observation and literature. The questionnaire was based on a one to five point Likert scale so as to offer respondents various choices and alternatives, clearly outlining the extent of the problem and exhaustively capturing all possible outcomes (Appendix 1). The survey questionnaire was divided into three sections. The first part captured respondents' background information (education, gender, age and marital status) as a baseline against which comparisons of noise level effects was rated. The second part evaluated the awareness of the respondents of noise and its effects which includes sleeplessness, headaches, hearing loss, anger, ringing in the ears among others. The last section devoted to assess availability of management systems and their level of compliance to the set government regulations.

b) Pilot Survey

The main survey was preceded by the pilot survey to about 30 workers drawn from the Maisha Mabati Rolling industry in the neighboring Ruiru town. This was in accordance with the study done by Czaja, (1998). The objective of doing the pilot survey was to establish the amount of time required to complete each questionnaire and to enhance its clarity and validity.

3.5.3 Data Collection Procedure

The process of administering the questionnaire was done at the following industries which were sampled as mentioned in Section 3.3: metal and non formal metal (*Jua kali)* industries; plastic industries; furniture and wood industries; grain milling industries. It began by first explaining to the respondents the objectives of the exercise so as to elicit their informed and voluntary consent. The respondents were then requested to personally fill in their responses except in instance where for some reason they were incapacitated. Additional data required to enhance the study was obtained from Noise and Excessive Vibration Pollution (Control) Regulations, 2009, WHO, EPA and EMCA. A total of 400 questionnaires were administered for this study allowing 5% for attrition and distribution according to the level of exposure to noise and size of employees per company with a return rate of 100% (Section 3.3). Each of the five groups of the industries was allocated questionnaires in proportion to the number of sampled workers. The questionnaire was distributed by hand and the respondents completed it themselves. Out of a total of 400 questionnaires distributed, 282 were finally collected. This was 70.5% acceptable return rate (Larsen *et al*., 1986).

3.6 Data Processing and Analysis

The continuous equivalent and the average peak noise levels determined at the site measurement were compared with permissible noise levels and the associated risks of excess to public health established. The psychological and physiological effects considered sleep disturbance, annoyance, ringing in the ears, headaches among others. To ascertain the widespread adverse noise effects, questionnaires were analyzed by use of statistical software for social scientists (SPSS 20) and the results tabulated to determine the frequencies, percentage proportions among others. Also vulnerability of the population to noise and their level of awareness was adduced from observations and side discussions.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Industrial Noise Levels

4.1.1 Extent of Noise Pollution from Non Formal Metal Industries

Results of the level of noise pollution in Kamukunji non-formal metal industries are summarized in Table 4-1. Across sections A,B and C of the industry (see Figure 4-1), the $L_{Aeq8-17}$values were 93.8,90.5 and 92.2 dBA, and these exceeded the maximum permissible level of 75 dBA (WHO,1999) by 25.1,20.7 and 22.9%, respectively. Statistically the variations across the sites were not significant (F=5.01 and p-value=0.14). On daily basis, the average levels were 91.6±1.5dBA in the morning, 90.6±3 dBA at mid-day, and 93.0±0.67 dBA in the evening (Figure 4-2). The morning and evening sessions were the loudest though statistical these variations were also not significant (F=0.17 and p-value=0.82).

Table 4-1: Noise level variations in non formal metal industries during the day

Site	Time of day	L_{peak}	L_{max}	L_{eq}	$L_{Aeq8-17}$
NFM A	9.00-10.00 am	115.0	102.0	93.0	93.8
	12.00-1.00 pm	116.0	105.0	94.6	
	15.00-4.00pm	114.8	104.3	93.7	
NFM B	9.00-10.00 am	112.4	99.2	89.5	90.5
	12.00-1.00 pm	113.1	101.0	87.7	
	15.00-4.00pm	112.4	105.3	92.8	
NFM C	9.00-10.00 am	114.6	103.0	92.3	92.2
	12.00-1.00 pm	113.3	100.2	88.9	
	15.00-4.00pm	116.5	104.8	93.9	

The levels indicated in the table are in dBA

NFM A-Non Formal Metal at Location A.,
NFM A-Non Formal Metal at Location B.
NFM A-Non Formal Metal at Location C.

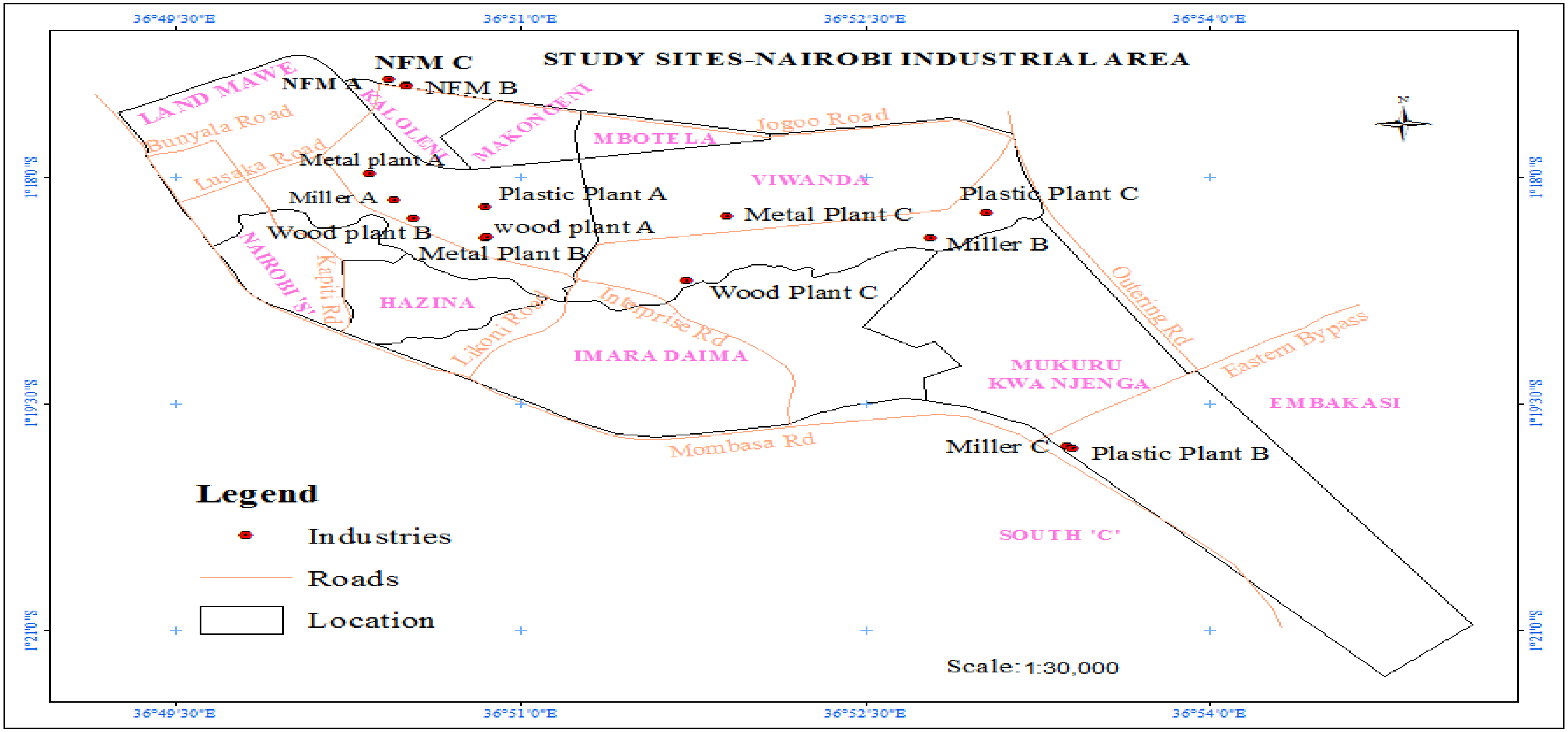


Figure 4-1: Map showing study sites in Nairobi industrial area

The average continuous equivalent noise level ($L_{Aeq8-17}$) for the non-formal metal industry was 92.2±1.6 dBA. This was significantly higher (t-value=202.1 and p-value=0.00) than the recommended maximum limit (85 dBA) set by the WHO (1999) guidelines and the Kenyan law (Legal Notice No. 25, the factories and other places of work (Noise Prevention and Control), 2005). The recorded peak noise level was 114.2±0.5 dBA. Kimani (2011) also reports the noise level in Kamukunji non formal ranged from 72.0 to 113.8 dBA. These high levels imply workers in all sites in Kamukunji non formal industry are exposed to dangerous noise levels which are likely to have serious health implications.

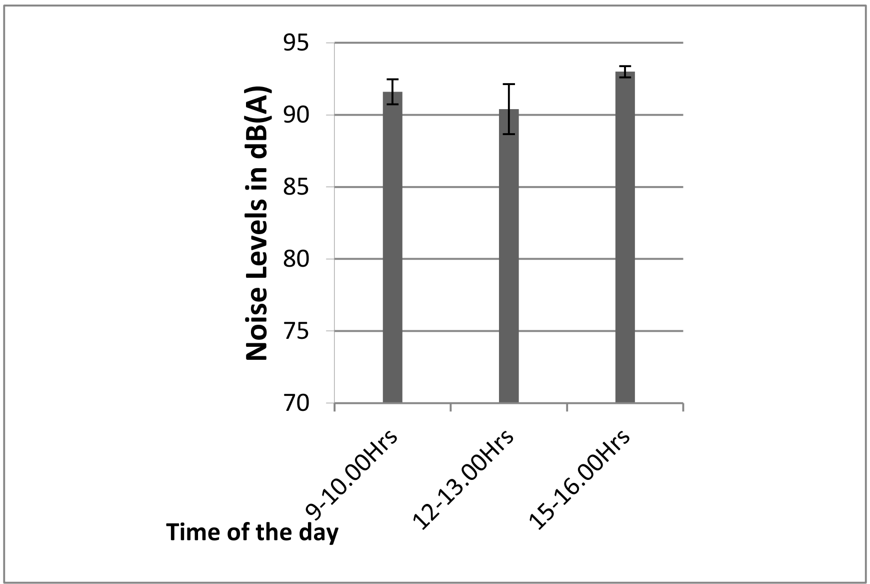


Figure 4-2: Variations in noise levels for non formal metal industries during the day

The workers at point A and C (Figure 4-1) were exposed to more extreme levels. The processes at the noisiest point involved bludgeoning pans and other metal utilities from thick rail bars and other thick metals. Observations also revealed that these artisans worked for much longer periods upto 9 hours than stipulated by the law. Occupational Safety and Health Association (OSHA) defines continuous equivalent noise levels beyond 90 dBA and stipulates that for L_{Aeq} of 92 dBA, exposure limits should be less than 6 hours (OSHA,1983). Literature also describes exposure to these kind of noises as having instant to long myriad of health effects (Table 2-2) that's is likely to result to hearing loss, speech interference and annoyance (Kujawa & Liberman, 2009). On 25th October 2014, the chairman ofKamukunji *jua kali* while speaking during the launch of a two day free medical camp complained that"The level of noise these artisans are exposed to each day is far beyond the recommended levels". He goes on to say, "Some artisans have been working in such conditions for so long that some of them have lost sense of hearing totally"(http://kassfm.co.ke/hme/index.php/component/k2/item). This corroborates well with the findings of this study on the dangerous levels that these noise pollution has attained.

As per Figure 4-3, the mean noise level transmitted from Kamkunji *Jua Kali* industries towards Landhis Road of 73.0 dBA and is 4.3% higher than the recommended street noise level of 70 dBA. The transmission level was also higher than the recommended value of 60 dBA from a business premise into the environment by 21.7% (the Environment Management and Cordination (Noise and Excessive Vibration Pollution control, 2009). This contributed to raising the background noise beyond the street noise limit of 70 dBA.

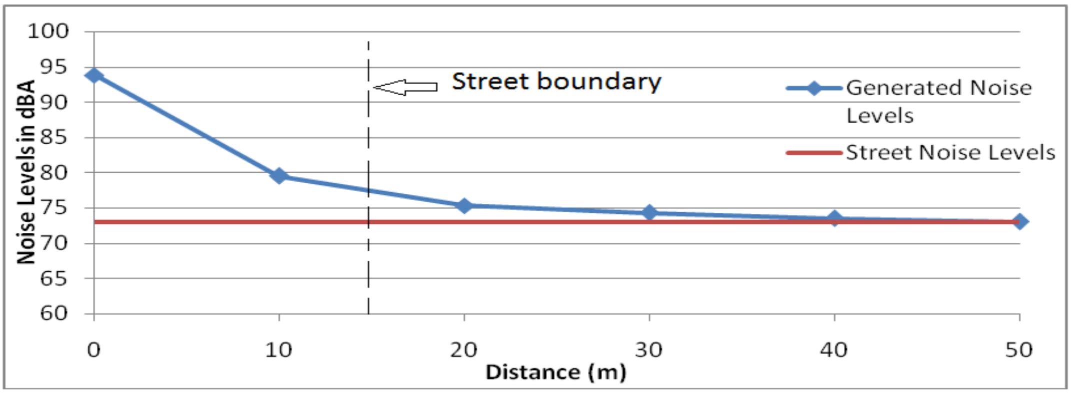


Figure 4-3: Noise level variation from Kamukunji non formal sheds towards Landhis road

4.1.2 Extent of Noise Pollution from Grain Milling Industries

Grain millers were among the industries that generated high noise levels in contravention of the law (Legal Notice No. 25), and the WHO (1999) guidelines. Across the mills A,B and C (Figure 4-1), the, $L_{Aeq8\text{-}17,}$ in the pneumatic grinder section were 93.0, 95.6, and 94.6 dBA) and were found to be 24.0, 27.5 and 26.1%, respecitvely, above the the maximum permissible noise level of 75 dBA (WHO, 1999) (Figure 4-4 and Table 4-2). These variationswere not signficantacross the mills (F=3.07 and p-value=0.12) and at all times (F=0.12 and p-value=0.89). This implies that in the grain industrythe level of technology, the processes and noise controls mechanism were the same. The average measured L_{Aeq} for the grain mill industry of 94.4±1.3 was significantly higher than the recommended limits(t-value=197.4 and p-value=0.00) and classified as hazardous. The peak noise level recorded was 109.9±1.5 dBA.

OSHA (1983) limits exposure durations of 94 dBA to 4.6 hours while NIOSH (1998) limits exposure duration of 94 dBA to 1 hour. The length of time a worker is able to work is reduced by half for every 3 dBA increase in noise levels above 90 dBA (OSHA, 1983; NIOSH, 1998). In the current study, the workers exposed to this kind of noise should have been allowed maximum exposure of less than 4 hours in a 24 hour cycle. However, as observed, the exposure duration of 94.5 dBA was for the eight hour work shift and this was highly detrimental to the well being of the workers. This noise level is also classified as having instant to long term effects to the public health and welfare (Table 2-2).

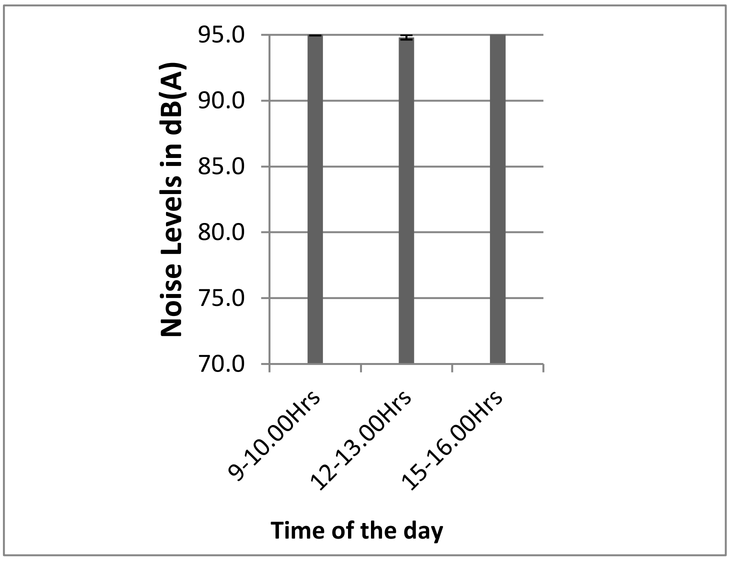


Figure 4-4: Noise level variations in flour mills in Nairobi Industrial area.

Table 4-2: Noise level variations in grain milling industries during the day

Miller	Time of day	L_{peak}	L_{max}	L_{eq}	$L_{Aeq8-17}$
A	9.00-10.00 am	110.5	98.3	91.0	93.0
	12.00-1.00 pm	105.6	97.8	92.1	
	15.00-4.00pm	110.5	98.5	95.0	
B	9.00-10.00 am	110.1	97.5	96.5	95.6
	12.00-1.00 pm	107.0	96.5	94.7	
	15.00-4.00pm	110.6	98.4	95.4	
C	9.00-10.00 am	112.0	95.5	94.9	94.6
	12.00-1.00 pm	112.3	96.5	95.2	
	15.00-4.00pm	110.5	94.5	95.1	

The levels indicated in the table are in dBA

The results of the current study were slightly higher than the 87 dBA that Ali, (2010) recorded for the same type of industry. The difference could have beenthat Ali, (2010) is likely to have recorded his measurements in the packaging section, which had similar readings to the 87.4 dBA as recorded in the same section in the current study. The findings in this study, however, concur with those for a study done on feed mills in Ibadan, Nigeria in which Yahaya *et al.* (2012) measured noise levels from 82.5-113.9 dBA.

As shown in Figure 4-5, the mean noise level,75.4 dB), transmitted by Mill B into the environment was 7.7% higher than the recommended street noice level of 70 dBA for industrial and commercial area at day time (WHO, 1999). The transmission level is also higher than the recommended value of 60 dBA from a business premise into the environment by 25.7% and just like in the non formal metal sector, the grain millers were contributing to higher street background noise levels in industrial area of Nairobi.

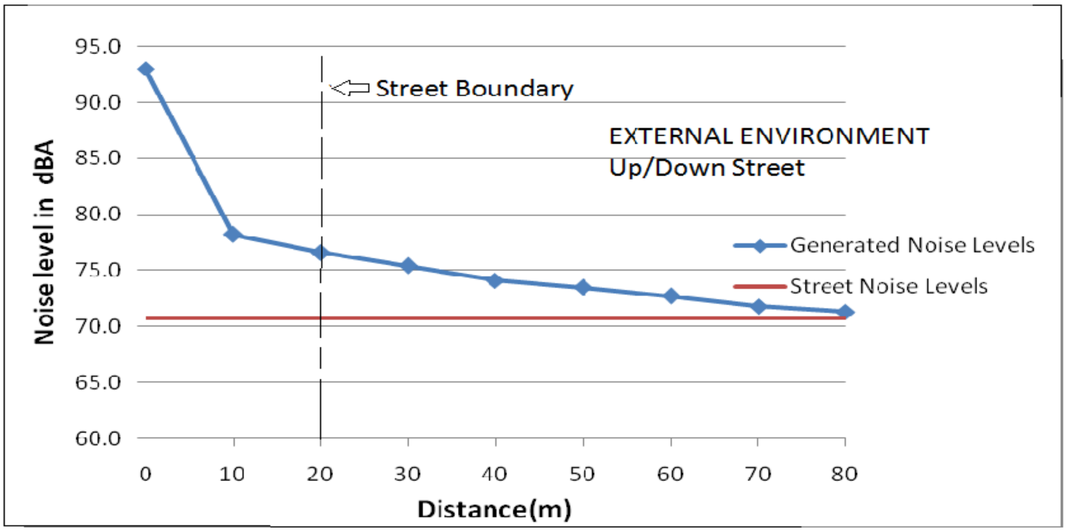


Figure 4-5: Progression of noise from Grain Mill into the street.

4.1.3 Extent of Noise Pollution from Plastic Industries

In Figure 4-6, illustrations is on the varying levels of noise in the plastic industries at different times of the day and across the industries. The daily measured noise levels averaged 84.9±1, 80.2±4,81.9±0.6 dBA in the morning, mid day and afternoon, respectively. Across the industries A, B and C, the $L_{Aeq8-17}$ valueswere 84.3, 82.1, 83.2 dBA and violated the maximum permissible level of 75 dBA set by WHO (1999) guidelines by 12.4, 9.5 and 10.8%, respectively (Table 4-3). Plant A generated steady noise levels than plants B and C. The noise levels emitted in plant C varied with time and day and hence a low $L_{Aeq8-17}$than A. This was because the layout in plant C was batch process type with the grinding activities, which were the noisiest, taking place mainly in the morning and on specific days subject to demand by the sebsequent processes. This is one way of managing the L_{Aeq} and could have contributed to statistically no significant differences in the noise levels at all times of the day (F=2.0 and p-value=0.22) as well as across factories (F=0.78 and p-value=0.50). Nevertheless, the average$L_{Aeq8-17}$was significantly higher than the recommended levels (t-value=6.8 and p-value=0.00).

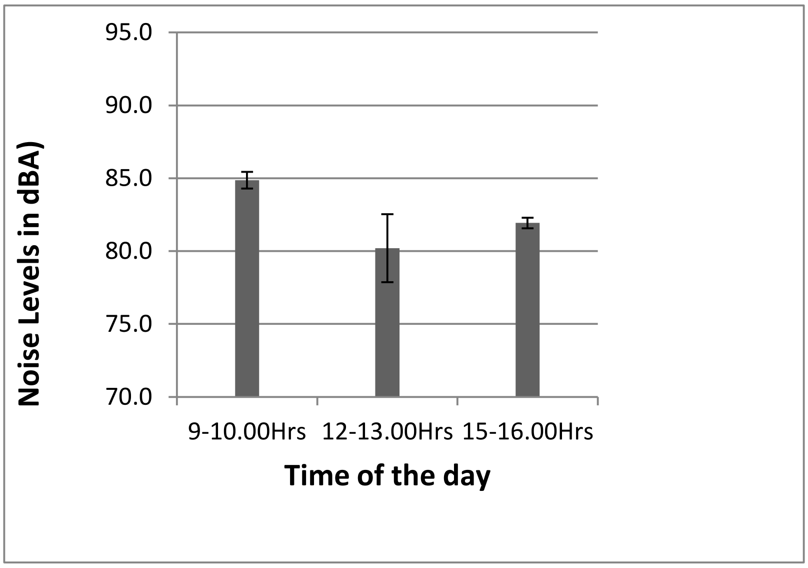


Figure 4-6: Noise level variations in Plastic industry

The peak noise levels ranged from 96-120 dBA second only to metal and higher than millers, non formal metal and furniture/wood industries. Though $L_{Aeq8-17}$ of 83.2 dBA is below hazard limit, it is classified as high risk (Table 2-2) and causes interference with speech, annoyance, sleep disturbance (Cohen *et al.*, 1986).

Table 4-3: Noise level variations in plastic industries

Plastic plant	Time of day	L_{peak}	L_{max}	L_{eq}	$L_{Aeq8-17}$
A	9.00-10.00 am	115.5	99.1	84.5	84.3
	12.00-1.00 pm	112.2	98.8	84.2	
	15.00-4.00pm	112.6	99.2	84.1	
B	9.00-10.00 am	120.8	105.4	83.1	82.1
	12.00-1.00 pm	119.5	105.3	78.5	
	15.00-4.00pm	120.6	105.1	83.2	
C	9.00-10.00 am	121.4	106.0	87.0	83.2
	12.00-1.00 pm	96.0	84.6	77.9	
	15.00-4.00pm	105	86.1	78.5	

The levels indicated in the table are in dBA

These results agree with the ones obtained in a study in Taiwan in a chemical manufacturing plant, where noise levels ranged from 70-85 dBA (Tsai *et al*., 2009). The results are however lower than the ones obtained in Zimbabwe, in which the average noise levels in the plastic manufacturing industries recorded 89-96 dBA (Patricia & Tatenda, 2015). This was due to differences in the production process. Whereas in the current studythe manufacturing process was by batch production, with the noisy processes only occuring at specific times of the day, the Zimbabwe case was flow production. The $L_{Aeq8\text{-}17}$ is below 85dBA, not classified as hazardous in spite of high variations and high peaks during different processes. The transmission of the noise into the environment was not dicernable beyond the background street noise at 70 dBA. It can therefore be concluded that noise emissions from the plastic industry had no effect to the external environment.

4.1.4 Extent of Noise Pollution from Wood and Furniture Industries

The recorded noise levels in the wood/furniture industries had variations with highest average noise levels in the morning at 84.6±0.86 dBA, followed by low levels in the mid-day at 81.1±4.1 dBA and afternoon having the least average noise levels at 79.1±1.84 dBA (Figure 4-7). The noisiest activity, sawing and planning, took place mainly in the morning. Though these processes generated high peaks upto 110.1±1.2 dBA, it had corresponding low $L_{Aeq8\text{-}17}$ due to the intermittent processes lasting from 5 to 30 minutes.Across the industries (viz., A,B and C), the continuous equivalent noise levels ($L_{Aeq8\text{-}17}$) were 83.3, 83.0, 82.1 dBA(Table 4-4), beyond the WHO, (1999) limit by 11.1, 10.7 and 9.5%, respectively. Nevertheless these variations were not significant throughout the day (F=2.19 and p-value=0.193) and across factories (F=0.13 and p-value=0.880), implying the processes remained basically the same. The average $L_{Aeq8\text{-}17}$was 82.8 dBA and statistical analysis confirms the noise levels were significantly higher than the recommended (t-value=5.4 and p-value=0.001) but could not be classified as hazardous.

Figure 4-7: Noise level variations in Furniture/Wood industries

Table 4-4: Variations in noise levels in Furniture/Wood industries during the day

Wood plant	Time of day	L_{peak}	L_{max}	L_{eq}	$L_{Aeq8-17}$
A	9.00-10.00 am	112.0	102.0	83.5	83.3
	12.00-1.00 pm	109.0	101.5	85.4	
	15.00-4.00pm	112.2	109.7	78.2	
B	9.00-10.00 am	115.0	100.6	85.6	83.0
	12.00-1.00 pm	104.0	94.0	82.4	
	15.00-4.00pm	107.0	98.0	77.5	
C	9.00-10.00 am	114.0	108.0	84.7	82.1
	12.00-1.00 pm	103.0	96.0	75.6	
	15.00-4.00pm	114.2	97.0	81.7	

The levels indicated in the table are in dBA

Although the continuous equivalent noise level were below the hazardous levels of 85 dBA, the intermitent processes that occasionally exceed these levels and the high peak levels can cause annoyance, interference with speech, disturbance during sleep and concentration disorders (Koffeman & Kerkers, 2000). This implies that hundreds of workers engaged in this activity are subect to these risks.This findings are in agreement with Ali, (2010) who recorded levels of 83 dBA for furniture and 80.7 dBA for wood/timber. Papadopoulos and Ntalous, (2005) in a study on noise emision levels in Greece wood industry recorded 83.5-92.9 dBA in workshops and 88-103.2 dBA in production areas.Like in the plastic industry, the transmission of noise into the environment was not discernable beyond the background street noise at 70 dBA. It can therefore be concluded that emissions from the wood/furniture industry had no effect to the external environment.

4.1.5 Extent of Noise Pollution from Metal Industries

The metal industries were less noisier than grain millers. The measured noise levels averaged 90.4±1.3,90.0±1.4 and 90.3±1.2 dBA in the morning, mid-day and evening. The continuous equivalent noise levels ($L_{Aeq8-17}$)across industries A, B and C were 93.3, 89.3, 88.1dBA, respectively(Figure 4-8 and Table 4-5). Thesevalues were higher than the WHO (1999) guidelines by 24.4, 19.1 and 17.4%, respectively. Aone tailed t-test also shows the average $L_{Aeq8-17,}$ 90.2±2.7 dBA was significantly higher than the recommended levels (t-value=19.31 and p-value=0.000) and exceded the hazardous limit of 85 dBAas by the Kenyan law (Legal notice no. 25). However, there were no significant differences in the noise levels at different times of the day (F=0.02 and p-value=0.983) but there were significant differences across factories (F=247.11 and p-value=0.000). Though the activities were continuous throughout the day, the processes were different from one plant to another. The peak noise level recorded was 123.8±2.5 dBA.

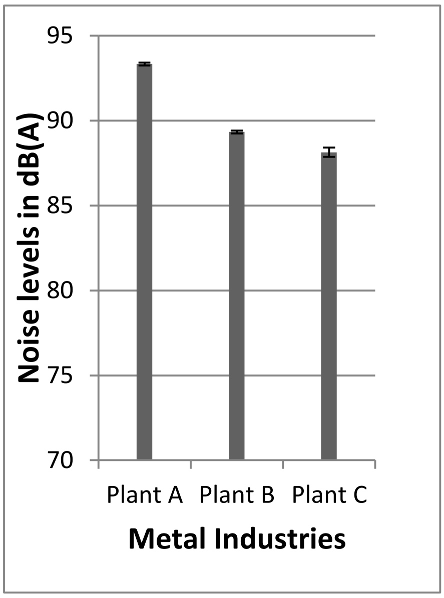


Figure 4-8: Variation in noise levels in metal industries during the day.

These results are in agreement with Ali (2010) who recorded an average noise level of 92.6 dBA for metal workshops in Egypt. The noise levels in metal industries are also classified as having instant to long term health effects (Table 2-2) and like in the case of millers and non-formal industries, hundreds of workers who are continuously exposed to these noise levels will ultimately pay the risk of induced noise hearing loss among other physiological effects. Studies have shown that for the 90th percentile exposed population, the risk of presumed noise induced hearing loss (NIHL) increases exponentially for noise levels beyond 85 dBA and over a prolonged period (Gierke & Johnson, 1978). Besides, the workers also experience many other side effects of noise pollution including speech interference, annoyance, disturbance duringsleep and concentration disorders as well as difficulties in resting and perception (Cheung *et al.*, 1989; Cohen *et al*., 1986).

Table 4-5: Noise level variations in metal industries during the day

Metal plant	Time of day	L_{peak}	L_{max}	L_{eq}	$L_{Aeq8-17}$
A	9.00-10.00 am	125.5	105.4	93.5	93.3
	12.00-1.00 pm	125.3	105.6	93.2	
	15.00-4.00pm	125.4	105.3	93.3	
B	9.00-10.00 am	121.3	100.3	89.5	89.3
	12.00-1.00 pm	120.8	101.4	89.3	
	15.00-4.00pm	120.7	99.8	89.2	
C	9.00-10.00 am	125.0	113.0	88.3	88.1
	12.00-1.00 pm	125.2	113.3	87.6	
	15.00-4.00pm	125.1	112.7	88.5	

The levels indicated in the table are in dBA

The mean noise level of 73.2 dBA transmitted by metal industry into the environment measured at a distance of 30 m from the industrial boundary was 4.6% higher than the recommended street noise level (Figure 4-9). This was also higher than the recommended maximum noise transmisson level of 60 dBA from a business premise into the environment by 33.1% contrary to Section 4(a) of the Environment Management and Coordination Act (Noise and Excessive Vibration Pollution Control Regulation, 2009).

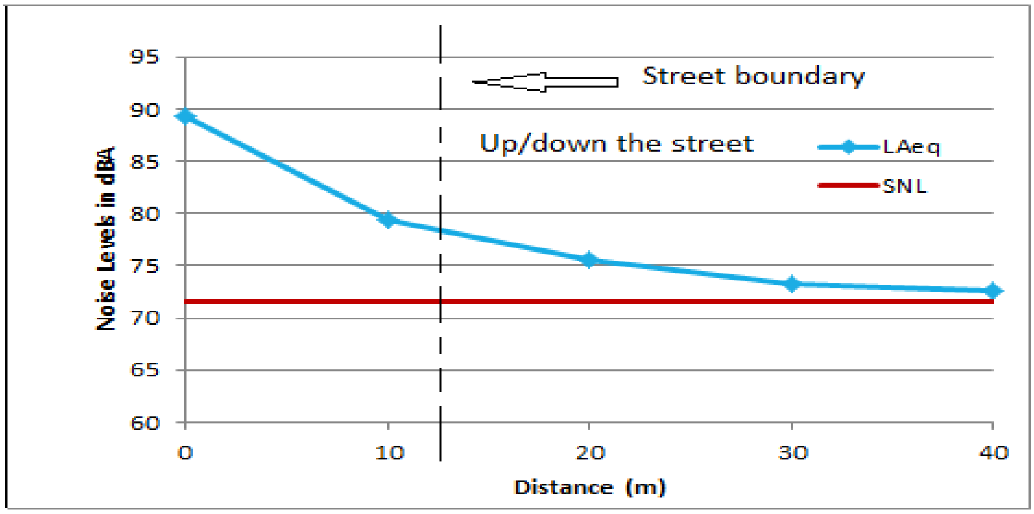
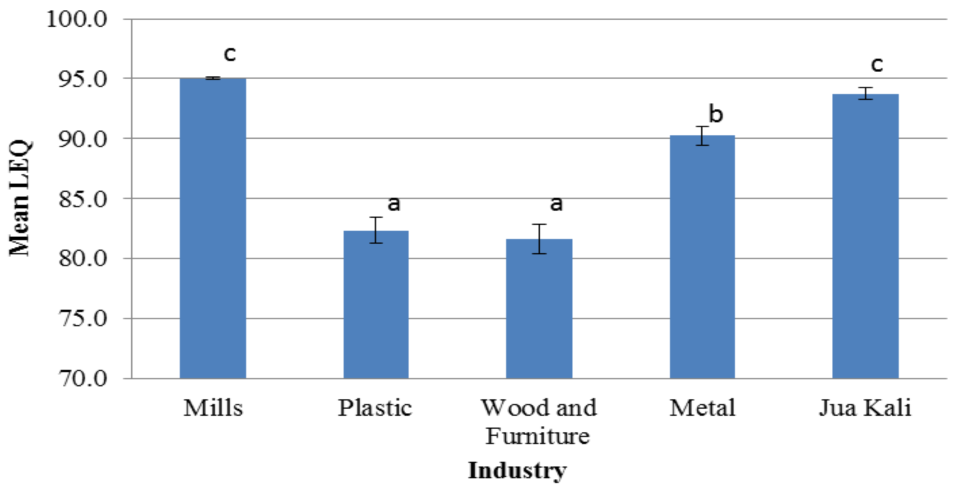


Figure 4-9: Progression of noise level from metal industry into the street

4.1.6 Comparative Noise Pollution from all Industries

Comparisons of the continuous equivalent A-weighted noise pressure level (LA_{eq8-17}) measurement for the various industrial noise sources in Nairobi are illustrated in Figures 4-10 and 4-11. In Figure 4-10 comparisons are made of noise levels from different sources. The highest continuous noise level of 94.4±1 dBA was generated by grain mills which was 25.9% above the recommended level, followed by Jua Kali industries (92.2±1.6 dBA) at 22.9% beyond excedence limits. The third highest continuous noise level (90.2±2.7 dBA) was generated by the metal industries at 20.0%. The lowest noise level emanated from plastic and wood industries at 83.1±1.1 dBA and 82.1±0.6 dBA at 10.7 and 6.6% above the recommended level, respectively. A one tailed t-test at 0.05% level of significance (t-value =21.23 and p-value=0.0025) confirms the recorded noise levels were significant. Results from ANOVA showed there was significant differences in the $L_{Aeq8-17}$ across the industries (F=31.8; p-value =0.00).



Key: c & b - Very High Risk; a- High Risk

Figure 4-10: Comparison between various sources of industrial noise pollution in Nairobi city.

With the exception of the wood and plastic industries, all other categories from 9 sites out of 15 sampled (representing 60%) had noise levels in excess of 90 dBA, exceeding the hazardous level of 85 dBA. The grain mills, non-formal metal andmetal industries, are classified as generating noise levels that have instant to long term effects, while plastic and wood/furniture industries generate noise levels that only have long term effects with regard to public health and welfare (Table 2-2).

In Figure 4-11, a comparison is made between the continuos equivalent and peak noise level for each source of noise. Across all the industries, peak noise levels were quite high including in wood and plastic which had lower continuous equivalent noise levels. The highest peak noise level (123.8±2.52 dBA) was recorded in metal industries, followed by 114.2±1.44 dBA in non formal metal, 113.7±6.41 dBA in plastics, 110.1±1.23 dBA in wood/furniture and 109.9±1.48 dBA in grain millers.

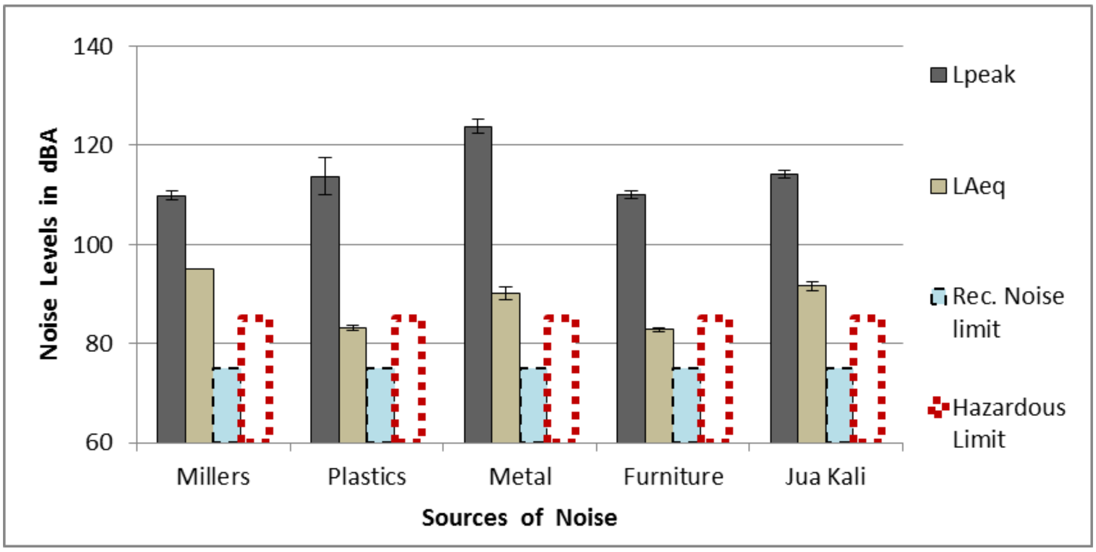


Figure 4-11: Comparison of peak and continuous equivalent noise levels among various noise sources

4.1.7 Leading Causes of Noise Pollution in Manufacturing Industries

Observation showed that higher peaks in metal industries were recorded during the processes that involved metal clatter, shearing and pipe cutting/sawing processes. Grinding and extrusion processes in the plastic industries were noisiest while planing/sawing processes in the wood/furniture industries contributed a lot to noise pollution. In wood/furniture and plastic industries,these processes were done intermittently with varying durations and not forlong enough to raise LA_{eq8-17} beyond the hazard levels. The grain millers on the other hand, with higher $L_{Aeq8-17}$ had the lowest peak noise levels indicating uniformity in noise generation. High instantaneous peak noise levels below 140 dBA may not have permenent effect on workers but they cause annoyance and interfer with communication. Their frequency of occurrence contribute to high $L_{Aeq8-17}$.

It was also observed that over 70% of the equipment in use in the manufacturing sector are over 40 years of age. Most of them were manufactured and installed in 1960 and 1970's. For *jua kali* industries there was no visible attempt to dampen the noise by provision of layer damping. In all the sites visited, the workers continuous bludgeoned their ware on bare anvil structure. Provision of a layer of viscoelastic material sandwiched between the structure and a layer of steel or aluminium would have considerably reduced the vibration.

The main sources of noise in the metal industries arose from straight edge cutters, mechanical presses and hammers. As discussed in section 2.2.2, replacement of these technologies with lesser noisy equipment like spiral cutters and hydraulic presses would go a long way in reducing noise pollution. The same applies to the grain milling industries where roller conveyors were in use and very high noise emanated from pneumatic conveyor section which had noise levels beyond 100 dBA. This section was completely enclosed with interior hard surfaces. It would have been very appropriate for noise enclosures to be provided to safeguard the few workers who are required to stay in there and keep vigil on some operation indicators, and provision of acoustic materials to dampen the reverberations. Belt conveyors would also be the most suitable replacement for roller conveyors.

4.2 Health Effects of Industrial Noise Pollution

Since sound does not become 'noise' until it reaches and is appreciated by a person, it was important to consider the subjective effect of noise. Considering that noise is a hazard which cannot be seen but experienced, perception of the noise hazard differs between individuals. This section therefore sought to find out from the people themselves the prevalence of specific public welfare and health effects of noise. The information gained is useful as a baseline from which to design and assess the effectiveness of control strategies.

From Table 2-2, it can be deduced that all industries under investigation exceeded the protective limit beyond which the workers were at various level of risk to developing various health effects associated with noise. The study sought to establish the effect of industrial noise on public health. The measured data indicated that all the industries exceeded the maximum permissible occupational noise levels thus putting public health at risk. While the observed noise levels require that a working shift should not exceed 8 hours in a 24 hour day for a five-day working week (Legal Notice No. 25), over 50.0% of the workers worked for over 8 hours. This is contrary to Section 4(1) which states that 'No worker shall be exposed to a noise level in excess of (a) the continuous equivalent of 90 dBA in 8 hours within any 24 hours duration and (b) 140 dBA peak sound level at any given time. Some 48.1% of the respondents had the opinion that industrial noise ranged between severe and very severe (Table 4-6). However, 15.5% of the respondents felt that the noise was mild and therefore had no problem with it. This suggests that industrial workers have accepted hazardous noise as part of their work environment.

Table 4-6: Rating of noise generated by an organization

Rating Response rate (%)				
Very Mild	Mild	Moderate	Severe	Very severe
3.7	15.5	32.7	30.1	18.0

The health effects were manifested in the form of headaches, interference with communication, interference with concentration, annoyance/irritation and sleeplessness. From Figure 4-12, 86.5% of the workers were in one way or the other affected by noise with the majority, 36.2% experiencing headache and 7.4% complained of hearing loss. Noise induced hearing loss starts to manifest after 10-15 years of exposure (Arcadio & Gregoria, 2002). The 7.4% manifestation of hearing loss in this study is a big percentage considering that only 33.0% of the respondents had worked for more than 10 years. In response to another question, 80.0% of the workers reported difficulties communicating with fellow workers when the noise was on.

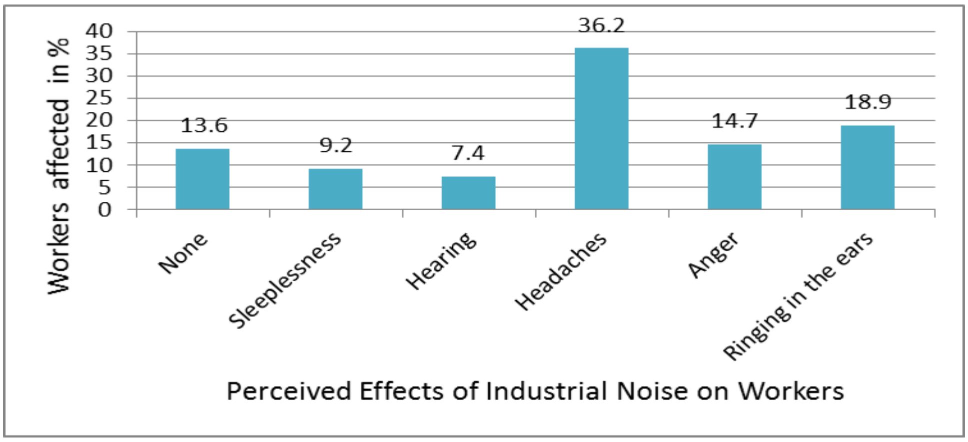


Figure 4-12: The perceived health effects of noise on workers

Noise-induced hearing loss is the most common occupational health problem in industrialized countries (Boateng & Amedofu, 2004). One of the ways of offsetting this negative health impact is to wear hearing protection devices (HPDs) (CSA Z94.2). This study sought to find out whether the respondents used HPDs and determined that 65.2% of the workers did not use any protective devices for the ears. This is an understatement for the observations made during the study did not spot any worker wearing HPDs even in areas with the highest noise levels. Most of them when asked casually said, “we only had problems at the beginning, but since we need the job we consider the noise as part of our work”. As per Table 4-7, the reasons for not wearing protective hearing equipment were further explored and a majority (44.8%) indicated that they did not wear HPDs because they were not available. Workers further indicated that the available HPDs were of low quality and uncomfortable to wear. Among the 34.8% of the respondents who used HPDs, 59.0% indicated that they used the equipment for less than 8 hours with only 12.7% of the workforce using the equipment effectively. This is a very insignificant ratio considering that 86.5% of the workers experienced negative health effects of noise (Figure 4-12).

Table 4-7: Reasons for not wearing a hearing protection device

Reason	Percentage (%)
Not available	44.8
Equipment is uncomfortable	35.1
Equipment is Expensive	4.0
Not aware I need the equipment	9.8
No reason	6.3
Total	100.0

The management of the industries plays a key role in the control of noise. This study found that 54.2% of the workers were dissatisfied with the efforts made by their management to control noise and only 36.0% of the workers indicated that there were annual occupational health and safety audits. In an answer to another question, 49.3% of the workers claimed that their industries had never executed a noise level assessment. The study also established that noise complaints were registered by 82.4% of the respondents from fellow workers. The results are consistent with the number of workers (86.5%) who reported to have been affected by industrial noise in one way or the other, as established above.

Health and safety training is necessary in ensuring safety of worker in noisy environment. According to the findings of this study (Table 4-8), a large proportion of the workers, 47.6%, had never received any occupational health and safety training.

Table 4-8: Percentage of employment training in safety and health

Never Trained	Trained last 2 years	Trained last 1 year
47.6	31.3	21.1

When asked on the existence of safety committee, most of them, 60.4% of the workers indicated that they were not aware of any (Figure 4-13). A similar number had not participated in safety committee elections as per Legal Notice No. 25 Factories and other places of work 2005 regulations which require that elections should be done once every three years.

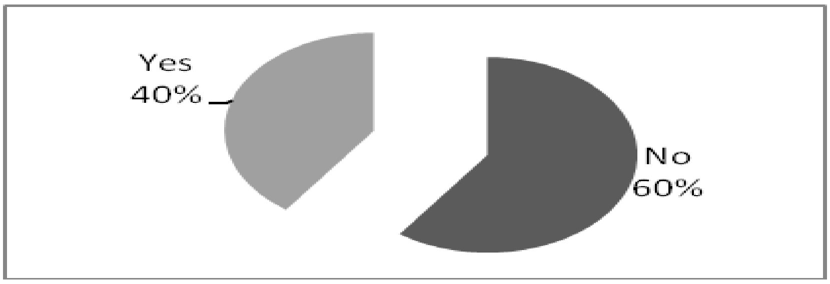


Figure 4-13: Awareness on existence of the safety committees.

The law OSHA (2007) stipulates that safety committees should be formed in workplaces with at least 20 regular employees. By this provision, the law ignores places like the non formal metal works which have no formal employees but employs hundred of casual workers who are continuosly subjected to high noise levels. Observations also indicated that a number of factories were vibrant with fewer regular members and relied on alarge base of casual labour. The law is also silent on exposure durations for noise levels above 90 dBA as this study revealed most industries had noise levels above this limit.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Industrial noise levels in the study area exceeded safe levels and in 60% of work places the workforce was exposed to continuous equivalent noise levels higher than 90 dBA for longer durations than provided for by the Kenyan law and international guidelines. Noise emission into the environment from millers, metal industry and non formal metal (*Jua Kali*) industries exceeded the recommended transmission level of 60 dBA at a distance of 30m from the boundary of the industry.
2. About 87% of workers were affected by noise with about 36% of them claiming to suffer from persistent headaches. Some 80% of the workers claimed that they had difficulties communicating in the work area and that made them prone to accidents in their work stations. Furthermore, workers claimed that the existing noise control programs were not effective and that the safety and health committees in place did not discharge their mandate effectively. Most workers (65%) found available hearing protection devises to be uncomfortable and therefore, failed to use them.
3. About (70%) of the equipment in use in the manufacturing sector were over 40 years of age. Out dated technologies that are are associated with noise production like straight edge cutters, mechanical presses and hammers were predominantly in use in metal works. In most industries visited there was very little evidence on availability of modern equipment with low rated noise production nor usage of recommended application of other noise reduction techniques.

5.2 Recommendations and Technical Solutions

1. Environmental monitoring agencies such as the Directorate of Occupational Safety and Health Services (DOSHS) and National Environment Management Authority should make every effort to address the high noise level in the manufacturing sector by intensifying law enforcement especially Legal Notice Number 25-Factories and other places of work Act, 2005 and Legal notice Number 61-Environmental Management and Coordination Act (Noise and Excessive Vibration Pollution Control Regulation), 2009.
2. The Legal notice number 25 of and Legal notice number 61 of 2009 should also be reviewed to enhance its effectiveness in addressing the noise pollution menace. For example, there should be appropriate regulations on the age limit of specific technologies to install in the manufacturing sector. All older noisy equipment should be replaced and importation of second hand machines should be regulated.
3. Environment management agencies should intensify inspection on the quality of ear protective devices in use in the manufacturing sector and create awareness of noise and its impacts on public health and welfare to help reduce irresponsible behaviors and exposure to dangerous noise levels.
4. National Environment and Management Agency should strictly ensure that noise control measures are included in the factory design, location of industries and selection of production processes.

5.3 Suggested Areas for Further Research

The study suggests further research on noise control measures for specific industries that could be adopted to reduce the risk of noise pollution. Noise control should be adopted as a fundamental component of the design for any new manufacturing industry.

REFERENCES

Ali, S.A. (2010). Industrial Noise Levels and Annoyance in Egypt. *Applied Acoustics (2010),* doi:10.1016/j.apacoust.2010.11.001

Alton, B., & Ernest, J. (1990). Relationship between loss and noise exposure levels in a large industrial population: a review of an over looked study. *JAcousticSoc.Am,88.*

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

ANSI S1.25, (1991). Specification for Personal Noise Dosimeters. Retrieved from: https://law.resource.org/pub/us/cfr/ibr/002/ansi.s1.25.1991.pdf

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

Badrul, B.B. (2012). *Noise-Induced Hearing Loss: A Senseless Workplace Hazard In Kilang Gula Felda Perlis Sdn. Bhdi*. Unpublished MSc Thesis, Malaysia: University Utara.

Bahita, S.C. (2001). Environmental pollution and control in chemical process industries. *Khana journal,* 365-391.

Baron, R.A. (1994). The physical environment of work settings: Effects on task performance, interpersonal relations, and job satisfaction. *Research in Organizational Behavior, 16,* 1-46.

Barreto, S.M., Swerdlow, A.J., Smith, P.G. & Higgins, C. D. (1997). A nested case control study of fatal work related injuries among Brazilian steel workers. *Occupational and Environmental Medicine, 4*, 599-604.

Barron, R.F. (2003). *Industrial Noise Control and Acoustics*. New York, NY: Marcel Dekker, Inc.

Berglund, B., & Lindvall, T. (1995). *Community Noise. Archives of the Center for Sensory Research* Vol 2, No. 1. Stockholm: Center for Sensory Research.

Bies, D.A. & Hansen, C.H. (1996). *Engineering noise control: theory and practice*. London: E &FN Spon.

Boateng, C. A., & Amedofu, G.K. (2004). Industrial Noise Pollution and its effects on the hearing capabilities of workers: A study from saw mills, printing presses and corn mills. *African Journal of Health Sciences, 11*(1–2), 55.

Broner, N. (1971). *The Effects of Low Frequency Noise on People*. London: university of London.

Bruel, F. & Kjaer, B. (1992). Sound and Vibration Measurement. Retrieved from: http://www.cav.psu.edu/workshops/2014/B&K%20Intro.pdf

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

BS 4142. (1997). Method for rating industrial noise affecting mixed residential and industrial areas. Retrieved from: http://www.devon.gov.uk/plandoc_144032.pdf.

Bullen, R. (2012). The Harmonoise noise prediction algorithm: Validation and use under Australian conditions. Proceedings of Acoustics 2012 – Fremantle. Sound Science P/L, Level 4, 272 Pacific Hwy, Crows Nest, NSW, Australia.

Bublić, I., Tudor, I. & Skelin, D. (2010). Small scale noise mapping of industrial plants.1st EAA-Euro Region 2010 Congress on Sound and Vibration 15-18 September 2010, LjubIjana, Slovenia. Retrieved from: http://bib.irb.hr/datoteka/685757.EAA-Euroregio-042.pdf.

Callister, R., Suwamo, N.O., & Seals, D.R. (1992). Sympathetic activity is influenced by task difficulty and stress perception during mental challenge in humans. *Journal of Physiology (London), 454,* 373-387.

Charante, A.W., Moll, V. & Mulder, P.G.H. (1990). Perceptual Acuity and the Risk of Industrial Accidents. *American Journal of Epidemiology, 131*(4), 652-663.

Cheung, Y.K., Cai, C.W. & Chan, H.C. (1989). Sound and Vibration, *Journal of Sound and Vibration***, *133*(1),** 1-191.

Cheung, C.K. (2004). Organizational Influence in Working People's Occupational Noise Protection in Hong Kong. *Journal of Safety Research*, 35, 465.

Cirac, D.C., García, J.R., & Kidner, M. (2010). Multisource Industrial Plant Inverse Noise Modeling and Assessment against ISO 8297. Proceedings of 20th International Congress on Acoustics, ICA 2010 23-27 August 2010, Sydney, Australia. Retrieved from: http://www.acoustics.asn.au/ conference proceedings/ICA2010/cdrom-ICA2010/papers/p562.pdf.

Cohen, S. (1980). After effects of stress on human performance and social behavior: A review of research and theory. *Psychological Bulletin, 88,* 82-108.

Cohen, S., Gary, W., Evans, G., Stokols, D. & Krantz, D. S. (1986). *Behavior, health and environmental stress*. New York: Plenum Press.

Craven, N.J., & Kerry, G. (2007). *A Good Practice Guide on the Sources and Magnitude of Uncertainty Arising in the Practical Measurement of Environmental Noise.* DTI Project: 2.2.1 - National Measurement System Programme for Acoustical Metrology. Salford: The University of Salford M5 4WT.

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.

Day Design PTY Ltd (2012). Industrial Noise Control. Association of Australian Acoustical Consultants.Retrieved from: http://www.daydesign.com.au/downloads/industrial%20noise%20control.pdf.

Department of Labour, (2009). *Workplace Health and Safety Service. Classified hearing protectors*. Wellington: Department of Labour.

DeGagne, D. (2013). Are Quieter Communities Possible? Retrieved from http://www.noisesolutions.com/images/Are%20Quieter%20Communities%20Possible%20-.pdf.

Department of Environmental and Occupational Health Sciences, DEOHS, (2013). Noise and Hearing Loss in Construction Study. University of Washington School of Public Health and Community Medicine Ruston, Louisiana, U.S.A. Marcel Dekker, Inc. 270 Madison Avenue, New York, NY 10016. Retrieved from: http://depts.washington.edu/occnoise/content/generaltradesIDweb.pdf.

Economou, P., & Charalampous, P. (2012). A comparison of ISO 9613-2 and advanced calculation methods using Olive Tree lab-Terrain, an outdoor sound propagation software application: Predictions versus experimental results. Proceedings of the Institute of Acoustics. Vol.34. pt.1.2012.

EEMUA 140 (2013). Noise procedure Specification Publication No.140. Revised Edition 3. Retrieved from: http://softingo.com/clp/freepdfz01? sc=smb &sn =Eemua . 140&sd=http://download.filesfrog.com/software.

Eleftheriou, P.C. (2002). Industrial noise and its effects on human hearing. *Applied Acoustics*, ***63*(1)**, 35–42.

Environmental Management and Coordination Act, EMCA, (1999). *Environmental Management and Coordination Act*. Nairobi: Government of Kenya.

Environmental Protection Authority, EPA. (2009). Guidelines for the use of the Environment Protection (noise) Policy 2007. Environment Protection Authority GPO Box 2607 Adelaide SA 5001. *Environ Study*, ***14*(6),** 721-726.Environmental Protection Agency, EPA, (2007). *Guidance Note for Noise in Relation to Scheduled Activities.* (2nd ed.) New York: EPA.

Environmental Protection Agency, EPA, (2006). *Guidance Note for Noise in Relation to Scheduled Activities.* (2nd ed.) New York: EPA.

Explorable.com, (2009). Random Sampling. Retrieved from: https://explorable.com/simple-random-sampling.

Fair Fax County Department of Neighborhood and Community Services. (2012). Survey Questionnaire Design. Information Brochure.

Farouk, M., Meliksah, E., & Ersen, I. (1996). Noise Induced Hearing Loss among Cotton Textile and Carpet Mill Workers. *Tr. J. of Medical Sciences 28* 561-565. Retrieved from: http://journals.tubitak.gov.tr/medical/ issues/ sag-98-28-5/sag-28-5-18-96168.pdf.

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

Fournier, L. R., Wilson, G. F. & Swain, C. R. (1999). Electrophysiological, behavioral, and subjective indexes of workload when performing multiple tasks: Manipulations of task difficulty and training.

International Journal of Psychophysiology, ***31*****(2),** 129-145. http://dx.doi.org/10.1016/S0167-8760(98)00049-X

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

GovHK, (2005). Occupational Safety & Health. Occupational Safety and Health Branch of the Labour department. Guidance Notes on Factories and Industrial Undertakings. Noise at Work Regulations. Retrieved from: http://www.labour.gov.hk/eng/public/os/C/NoiseGN.htm.

Gierke, H. & Johnson, L. (1978). *Summary of present day criteria. Effects of noise on hearing;* New York: Ravens press.

Guide to Predictive Modeling for Environmental Noise Assessment. (2007). National Physical Laboratory. Department of Trade Industry (DTI). Retrieved from: http://www.npl.co.uk/upload/pdf/guide-to-predictive-modelling-env-noise-assessment.pdf.

Hansen, C.H. and Snyder, S.D. (1996). *Active control of sound and vibration*. London: Chapman and Hall.

Harris, C.M. (1991). *Handbook of Acoustical Measurements and Noise Control*. (3^{rd} ed.) London: Chapman and Hall.

ISO 9613-2. (1996). First edition Acoustics — Attenuation of sound during propagation outdoors — Part 2: General method of calculation. Retrieved from: http://www.cevreselgurultu.cevreorman.gov.tr/dosya/noise_maps/assessment_methods/industry_ISO_9613-2.pdf.

ISO 11690-1, (1996). Acoustics- Recommended Practice for the Design of Low-Noise Workplaces Containing Machinery - Part 1: Noise control strategies

ISO 11690-2,(1996). Acoustics- Recommended Practice for the Design of Low-Noise Workplaces Containing Machinery - Part 2: Noise control strategies.

ISO 11821, (1997). Acoustics - Measurement of the in situ sound attenuation of a removable screen.

ISO 11957. (1996). Acoustics- Determination of sound insulation performance of cabins -- Laboratory and in situ measurements.

ISO 8297. Acoustics – Determination of sound power levels of multi-source industrial plants for evaluation of sound pressure levels in the environment – Engineering method.

ISO 1999, (1990). Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment.

ISO 10847. (1997). Acoustics - In-situ determination of insertion loss of outdoor noise barriers of all types.

ILO, (1976). *Activities of the ILO, 1976 . Report of the Director-General*. (Part 2) Geneva: ILO.

Jansen, G. (1992). Effects of noise on human beings. *VGB (German) 72*(1), 60.

Jensen, P., Jokel, C. R., & Miller, L.N. (1978). *Industrial Noise Manual –Revised* Edition. U.S. Department of Health, Education and Welfare. Public Health Service. Centre for Disease Control. Cincinnati, Ohio: National Institute for Occupational Safety and Health.

Johnson, D. (1991). Field studies: Industrial exposure. *J. Acoust. Soc. Am*, ***90*(1),** 170.

John, C. (1988). *Applied Multivariate Statistical Analysis*. New Jersey: Prentice Hall.

Kanali, C.L. (1997). Prediction of axle loads induced by sugarcane transport vehicles using statistical and neural-network models. *Journal of Agricultural Engineering Research*, ***68*(3),** 207–213. Retrieved from: www.sciencedirect.com/science/.../S0021863497901992.

Kenya Vision 2030, (2007). *Kenya Vision 2030: The Government of Kenya. Ministry of Planning and National Development.* The National Economic and Social Council and the Office of the President. Nairobi: Kenya Vision 2030.

Kenya Facts and Figures, (2006). *Kenya Facts and Figures. Central Bureau of Statistics*. Ministry of Planning and National Development. 2006 Edition. Nairobi: Kenya Facts and Figures.Kenya National Bureau of Statistics. (2009). *Kenya Population and Housing Census*. Nairobi: KNBS.

Kenya National Bureau of Statistics. (2015). *Population Distribution by Political Units*. Nairobi: KNBS.

Kenya Economic Survey, (2010).Kenya Economic Survey. Central Bureau of Statistics. Ministry of Planning & National Development. Nairobi: Kenya Economic Survey.

Kimani, M.J. (2011). *Evaluation of Occupational Noise Exposure among Workers in Metal fabricating sector in Kamukunji Nairobi*. Unpublished PhD MSc thesis, Juja: Jomo Kenyatta University of Agriculture and Technology.

Koffeman, A., & Kerkers A. (2000). *Cost optimal reduction of noise in large industrial area. A method to select measures, noise-con.* California: Newport Beach.

Kotus, J., & Szczodrak, M., (2012). Distributed System For Noise Threat Evaluation Based On Psychoacoustic Measurement. *Metrology and Measurement Systems, XIX*(2), 219-230.

Kujawa, S.G., & Liberman, M.C. (2009). Adding Insult to Injury: Cochlear Nerve Degeneration after "Temporary" Noise-Induced Hearing Loss. *J Neurosci, 29***(45),** 14077-14085.

Kyongo, J.J.W. (2010). *The status and performance of Workplace health and safety Information System in Nairobi Province, Kenya.* Unpublished MSc thesis, Juja: Jomo Kenyatta University of Agriculture and Technology.

Lamancusa, J.S. (2009). Outdoor Sound Propagation. Noise Control. Penn. State. Retrieved from: http://www.me.psu.edu/lamancusa/me458/10_osp.pdf.

Arsen C. (1986). *An Introduction to Mathematical Statistics and its Applications*,, New Jersey: Prentice-Hall.

Liu, D. (1999). *Environmental Engineers Hand book. Noise Pollution.* (Eds), pp. 470-525. New Jersey: CRC Press LLC.

Maekawa, Z. (1968). Noise reduction by screens, *Applied Acoustics, 1*, 157-173.

Maercke, D.K. (2007). European Commission. Final Report - IMAGINE (Improved Methods for the Assessment of the Generic Impact of Noise in the Environment). Community Research & Development Information Service. IMAI0-TR250506-CST305.doc

Martz, G. (2017). *Understanding t-test: Minitab Inc*.

McBride, D. (2010). Noise effects and duration. Guideline or diagnosing occupational noise-induced hearing loss. University of Otago. Accessed through Retrieved from: http://www.acc.co.nz/PRD_EXTCSMP/ groups/ external communications/documents/reference_tools /wpc091005 .pdf.

Melamed, S., Yitzhak, F., & Froom, P. (2001). The Interactive Effect of Chronic Exposure to Noise and Job Complexity on Changes in Blood Pressure and Job Satisfaction: A Longitudinal Study of Industrial Employees. *Journal of Occupational Health Psychology*, ***6*****(3),** 182-195.

Melamed, S., Luz, Y., & Green, M.S. (1992). Noise exposure, noise annoyance and their relation to psychological distress, accident and sickness absence among blue-collar workers: The CORDIS study. *Israel Journal of Medical Sciences*, ***28*****,** 629-635.

Melnick, W. (1979). *Hearing loss from noise exposure; Handbook of Noise Control*, Harris, C. M (Ed.), New York: Mc. Grow Hill.

Mithanga, J., Gatebe, E., & Gichuhi, M. (2013). *Evaluation of Noise Levels in Manufacturing Sectors in Thika District, Kenya.* Unpublished MSc thesis, Juja: Jomo Kenyatta University of Agriculture and Technology.

Momir, P., Dragan, C., & Darko, M. (2008). Industrial Noise Modeling and Mapping - The Case of A Cement Factory. *Working and Living Environmental Protection, 5*(1), 11 – 23.

Monazzam, E., Hashemi, Z., Golmohammadi, R., & Zaredar N. A. (2013). Passive Noise Control Approach Utilizing Air Gaps with Fibrous Materials in the Textile Industry. *J Res Health Sci.* **14(x),** xxxx.

Moore, D.S., & McCabe, G.P. (2006). *Introduction to the Practice of Statistics*. (5^{th} ed). P. 219.

NEMA, (2009). *Assessment of compliance to noise and excessive vibration regulations in*

Nairobi province. Nairobi: NEMA

NIOSH. (1991). *Criteria for a recommended standard: Occupational noise exposure*. Revised criteria 1998. Cincinnati: OH, National Institute for Occupational Safety and Health Retrieved from: http://www.cdc.gov/niosh/2014-126.html.

NIOSH. (1998). Criteria for a recommended standard: Occupational noise exposure. Revised criteria 1998. Cincinnati: OH, National Institute for Occupational Safety and Health Retrieved from: http://www.cdc.gov/niosh/2014-126.html.

NIST/SEMATECH. (2013). e-Handbook of Statistical Methods. Retrieved from: http://www.itl.nist.gov/div898/handbook/

Niquette, P.A., (2013). *Noise Exposure: Explanation of OSHA and NIOSH Safe* - Exposure Limits and the Importance of Noise Dosimeter. New jersey: Etymotic Research Inc.

Occupational Safety and Health Act, (2007). *Occupational Safety and Health Act,* Nairobi: Government printer.

Occupational Safety and Health Administration, OSHA. (2007). Noise Standard, Define Hazard, Protection. Retrieved from:www.*multimedia.3m.com/mws/media/.../oshas-noise-standard-defines-hazard-protection.pd.*

Occupational Safety and Health Administration, OSHA. (2007). Occupational noise exposure regulation. Retrieved from: www.osh.gov./pls/osha/owadisp.show-document.

Öhrström, E. (1989). Sleep Disturbance Psycho-Social and Medical Symptoms a Pilot Survey Among Person Exposed to High Levels of Road Traffic Noise. *Journal of Sound and Vibration*, *133*, 117.

Onyango, O.O. (2010). *Occupational Safety and Health Status of Jomo Kenyatta University of Agriculture and Technology: A case study of Engineering Workshop*. Unpublished MSc thesis, Juja: Jomo Kenyatta University of Agriculture and Technology.

Özer, S. & Irmak, M. (2008). Determination of roadside noise reduction effectiveness of Pinussylvestris L. and Populusnigra L. in Erzurum, Turkey. *Environ. Monit. Assess.*, *144*, 191-197.

Patricia, D.V. & Tatenda, J.(2014). An Assessment of Occupational Noise Levels in a Plastic Manufacturing Industry in Zimbabwe. *Journal of Scientific Research & Reports* ***4*(1),** 21-27, 2015.

Piercy, J.E., Embleton, T. & Sutherland, L. (1977). Review of noise propagation in the atmosphere, *JASA 61*(6), 1403-1418.

Product Data. Predictor LimA Software Suite Types 7810. The Intuitive Solution for Environmental Noise Calculation and Mapping. http://www.bruel.hu/doksik/bp1602combined.pdfhttp://www.bruel.hu/doksik/bp1602combined.pdf.

Raed, S., Al-Naemi, T. & Abdal, A. (2012). Noise Induced Oxidative Stress And Hearing Loss In Electrical Generator Workers. *Duhok Med J , 6*(2), 10-20.

Republic of Kenya, (2005). *Legal Notice No. 25, the Factories and other places of work* (Noise Prevention and Control), Nairobi: RoK.

Republic of Kenya. (2009). *Statistical Abstract 2009. Kenya National Bureau of Statistics.* Nairobi: Government Printer.

Republic of Turkey, Ministry of Environment. (1986). *Turkey organization standards, noise exposure regulation.* Turkey: MoE.

Ronoh, E. K. (2010). *Thin layer drying characteristics of Amaranth grains in a natural convection Solar tent dryer*. Unpublished MSC thesis, Juja: Jomo Kenyatta University of Agriculture and Technology.

Sarndal, C.E., Swenson, B., & Wretman, J. (2003). Model Assisted Survey Sampling. Pp 9-12

Stat Trek, Teach yourself statistics. Retrieved from: http://stattrek.com/statstics/dictionary.aspx?definition=coefficient_of_determination

Scott, M., & Delbert, S. (2006). Longitudinal and cross-sectional data collection and analysis in the study of crime and delinquency. Institute of Behavioral Science and Department of Sociology, University of Colorado., Boulder. *Justice Quarterly*, *7*, 11-55.

Stephensons, J. (2003). Research Contract – Noise Mapping Industrial Sources. Acoustic Technology. Department for Environment, Food and Rural Affairs. Final Report. Technical Report No: AT 5414/2 Rev 1

Stoter, J. (1999). Noise Prediction Models and Geographic Information Systems, a sound combination. Presented at SIRC 99 – The 11th Annual Colloquium of the Spatial Information Research Centre University of Otago, Dunedin, New Zealand December 13-15th 1999

Stone, D., & Ellis, J. (2006). *Evaluation of Means of Small Samples. The t-test*. New Zealand: Pretice hall.

Svebak, S. (1982). The effect of task difficulty and threat of aversive electric shock upon tonic physiological changes. *Biological Psychology*, *14*, 113-128.

Taylor, D. (1999). Introduction to Research Methods. Retrieved from: http://www.austin.org.au/Assets/Files/2014%20Session%201%20-%20Research%20Design.pdf.

Togrul, T., & Pehlivan, D. (2003). Modeling of drying kinetics of single apricot. *Journal of Food Engineering. 58*(1), 23-32.

Tsai K.T., Lin M.D., & Chen Y.H. (2009). Noise mapping in urban environments: A Taiwan study. *Appl. Acoust.* ***70*****(7),** 964,.

Uluko, H., Kanali, C.L., Mailutha, J.T. & Shitanda, D. (2006). A finite element model for the analysis of temperature and moisture distribution in a solar grain dryer. *The Kenya Journal of Mechanical Engineering,* **2(1),** 47–56, Nairobi: Fimen Publishers.

UNSD, (2016). *United Nations Statics Division*, UN: UNSD.

USEPA, United States Environmental Protection Agency. (1973). *Public health and welfare criteria for noise.* Washington DC: USEPA.

United States Department of Labour. (1983). *Occupational Safety and Health Adminstration* United States: United States Department of Labour.

Veltma, T.A. & Gaillard, A.W. (1996). Physiological Indices of Workload in a simulated flight task. *Biological Psychology*, ***42,*** 323-342

Veltman, J.A. & Gulfed, A.W. (1993). Indices of mental workload in a complex task environment. *Neuro psychobiology*, (28),73-75.

Veltman, J.A. & Gaillard, A.W. (1998). Physiological workload reactions to increasing levels of task difficulty. *Ergonomics, 41*, 656-669.

Verbeek, J.H. A.M., van Dijk,F.J., & De Vries, F.F. (1986). Non-auditory effects of noise in industry: III. Secondary analysis of a national survey. *International Archives of Occupational and Environmental Health, 58*, 333-335.

Vos, P., Beuving, M. & Verheijen. (2005). Harmonised Accurate and Reliable Methods for the EU Directive on the Assessment and Management of Environmental Noise. Final Technical Report. HAR7TR041213AEAT03.doc. Retrieved from: http://doutoramento.schiu.com/referencias/outras/Harmonised%20Accurate%20and%20Reliable%20Methods%20for%20the%20EU%20Directive.pdf.

Welden, E.C., & Pietrasanta, A.C. (1961). *Community and Industrial noise.* Apha eighty-ninth annual meeting vol. 51, No. 9. A.J.P.H., Michigan: Detroit.

WHO, (1947*). Constitution of the World Health Organization: Principles. Health is a state of* *complete physical, mental and social well-being and not merely the absence of disease or infirmity*. Geneva: World Health Organization.

WHO. (1997). *Health and Environment in sustainable Development*, Geneva WHO: Retrieved from:http://www.who.int/environmental-information/information-resources/ htmdocs/execsum.htm. Accessed on 5/02/2014.

WHO. (1999). *Guidelines values for community noise in specific Environment*, Geneva: World Health Organization.

WHO. (2001). *Occupational and community noise, (Fact Sheet No. 258),* Geneva: World Health Organization.

WHO, (2003). *World Health Report 2003 − shaping the future*. Geneva: World Health Organization.

WHO, (2004). *Protection of the Human Environment. Occupational noise. Assessing the burden of disease from work-related hearing impairment at national and local levels*. Geneva: World Health Organization.

Yahaya, M., Chukwufumnanya, R.O., & Odunola, E.A. (2012). Assessment of Noise Levels Generated in Some Feed Mills in Ibadan, Nigeria. *Science Journal of Environmental Engineering & Management*, ***104*****(5),** 104.

APPENDICES

Appendix 1: Letter of Introduction

We, the Jomo Kenyatta University of Agriculture and Technology (JKUAT) are undertaking an environmental safety survey aimed at evaluating the extent and effects of excessive environmental sounds in Nairobi city. Towards this end, we would like you to help us gather some information by way of filling this short questionnaire. It should take not more than 10 minutes of your time.

All responses you give us will be confidential and will not be connected in any way to yourself or your organization and the Information gained will only be used for academic purposes.

Please note that this exercise is purely voluntary and you do not have to provide your personal details. However, the information gained from you will be highly appreciated.

If you wish to proceed with the questionnaire kindly sign below and proceed to the next page. Thanks for your time.

Sign______________________________________Date________________________

Notes:

____
____
____
____

Appendix 2: Questionnaire

SECTION 1: Demographic Information

1. Which department do you work for?
2. What is your role in this company? Please tick.

   I. Executives and senior managers [ ]
   II. Middle level managers / Supervisors / Team leaders [ ]
   III. Technician [ ]
   IV. Machine operator [ ]
   V. Support/Subordinate Staff [ ]

3. Gender: Male [ ] Female [ ]
4. Age Bracket:

   Below 20 [ ] 21-30 [ ] 31 – 40 [ ] 41 – 50 [ ] Over 50 [ ]

5. Marital status

   Married [ ] Single [ ]

6. Highest education level

   Primary School [ ] Secondary School [ ] Diploma [ ] First Degree [ ]

   Master's Degree [ ] PhD [ ]

7. For how long have you been employed in the company (in years)?

   1 – 5 [ ] 6 – 10 [ ] 11 – 15 [ ] over 20 [ ]

SECTION 2 Noise Pollution in the Industry

8. How would you rate the noise generated by this organization

Very Mild [ ] Mild [ ] Moderate [ ] Severe [ ]

9. How many hours in a day are you exposed to noise?

Less than 2hrs [ ] 2-5hr [ ] 5-8hr [ ] over 8hr [ ]

10. How many days in a week do you work in the same place?

Less than 1 day [ ] 1-3 days [ ] 3-5 days [ ] Over 5 days [ ]

11. How often do you change your work station (shift)?

Weekly [ ] Monthly [ ] Yearly [ ] Never [ ]

12. Has exposure to industrial noise affected you in any way?

Yes [ ] No [ ]

13. If the answer to above question is yes, how have you been affected?

Sleeplessness [ ] Headaches [ ] Hearing loss [ ] Anger [ ]

Other [ ] Explain

14. It is difficult to communicate with my neighbour when the noise is on.

Strongly agree [ ] Agree [ ] Uncertain [ ] Disagree [ ] Strongly Disagree [ ]

15. I have no problem concentrating on my work when the machines are on.

Strongly agree [ ] Agree [ ] Uncertain [ ] Disagree [ ] Strongly Disagree [ ]

16. Do you use hearing protective equipment?

Yes [ ] No [ ]

17. If the answer to the question above is “no”, why don’t you use protectors?

N/A [ ] Not available [ ] Not Comfortable [ ] Equipment Expensive [ ]

Not aware I need the equipment [ ] No reason [ ]

18. If the answer to question above is “**yes”**, for how long do you use protectors in a day?

Less than 5 hr[ ] 6 hrs [ ] 7 hrs [ ] 8 hrs [ ]

19. What would you say is the general state of the workers in this organization with regard to noise?

Completely Satisfied [ ] Very Satisfied [ ] Somewhat Satisfied [ ]

Somewhat Dissatisfied [ ]Very Dissatisfied [ ] Completely Dissatisfied [ ]

SECTION 3(a): Noise Assessment in the Organization

20. How often does your business go through environmental audit or occupation health and safety audit?

Always [ ] Very Often [ ] Fairly Often [ ] Sometimes [ ] Almost Never [ ] Never [ ]

21. When is the last time you carried out a noise level assessment in this organization?

I don't know [ ] Less than 2 yrs ago [ ] Less than 5 yrs ago [ ] Never [ ]

22. How often have you heard complaints on noise in this organization?

Always [ ] Very Often [ ] Fairly Often [ ] Sometimes [ ] Almost Never [ ]

SECTION 3(b): Noise Control Programme

23. How often do you rotate work stations (Shifts)?

Always [ ] Very Often [ ] Fairly Often [ ] Sometimes [ ] Almost Never [ ]

24. Do your workers use ear protectors?

Yes [ ] No [ ]

25. If the answer is yes, how often do you monitor on the use of ear protectors?

Always [ ] Very Often [ ] Fairly Often [ ] Sometimes [ ] Almost Never [ ]

26. Workers in this organization have regularly been trained on noise

Definitely True [ ] True [ ] Don't Know [ ] False [ ] Definitely False [ ]

27. What measures are provided to safeguard workers from excessive noise exposures?

End. Thank you very much for your time.