ASSESSMENT OF OCCUPATIONAL EXPOSURES TO LEAD AMONG ARTISANS WORKING IN THE INFORMAL AUTOMOBILE SECTOR IN NAKURU TOWN, KENYA

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EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted wholly or in part for an award of any degree or diploma in this or any other learning institution known to me.

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DEDICATION

This work is dedicated to my family members, Parents; Rose Odongo and Leonard Odongo, Wife Ruth Anyango Owino and my lovely daughters and son; Dishan Anne Owino, Rachael Amondi Owino, Naomi Rose Owino and Evan Mark Owino for their inspiration and unwavering support throughout the study period.

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ABSTRACT

Lead is a common toxic heavy metal with unique physical and chemical properties that make it suitable for a variety of applications in automobile industry. The artisans in the informal automobile industry are involved in diverse occupational tasks such as spray painting and welding that predispose them to health risks associated with lead exposures. Their work presents risks of inhalation, dermal absorption or ingestion of lead particles. The objective of this study was to evaluate occupational exposures to lead and associated health risks among the artisans. A comparative cross-sectional study was conducted and data collected using structured questionnaire, observational checklist and laboratory analysis. In the study, 115 purposively sampled participants participated. Stratified and proportionately sampled 55 artisans were recruited from 10 workshops and 60 college students as the non-exposed comparative group. Flame Atomic Absorption Spectrophotometry (FAAS) was used to analyze lead concentrations in blood (n=30) and scalp hair (n=30) samples. Task-based airborne lead samples were analysed using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) in accordance with NIOSH 7300 standard method. Serum Alanine aminotransferase (ALT) activity and estimated glomerular filtration rate (eGFR) measurements were conducted using Reflotron biochemical auto-analyzer. Data was analysed using descriptive statistics, regression analysis, ANOVA, Chi-square, t-test and Prevalence Ratios (PR) calculated. Results showed that there was statistically significant differences in mean airborne lead exposure levels in the different occupational tasks ($F (4, 15) = 10.087$, $p=0.000$). A high statistically significant mean blood lead (BPb) level was recorded among artisans compared to students ($p=0.001$). The mean BPb exceeded the WHO biological exposure index (BEI) of concern for adults ($p=0.049$). There was a positive correlation between task based airborne lead exposure levels with BPb levels ($r=0.68$, $p=0.001$). The artisans had a statistically significant decrease in eGFR compared to the students ($p = 0.000$). However, the mean eGFR values were within the normal reference value (>90 $mL/min/1.73m^2$). In conclusion, the artisans were occupationally exposed to lead and task based airborne lead was a statistically significant predictor of blood lead levels ($p = 0.001$). Key recommendations are to institute intervention measures at the industry to curb lead health risks and possible chronic health effects, review the legislative framework on occupational safety and health for the sector and put surveillance system that integrates lead screening and testing among the study participants.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometry
ACGIH®	American Conference of Governmental Industrial Hygienists
ALT	Alanine Aminotransferase
ATSDR	Agency for Toxic Substances and Disease Registry
BPb	Blood Lead Level
CDC	US Centre for Disease Control and Prevention
CKD	Chronic Kidney Disease
CKD-EPI	Chronic Kidney Disease Epidemiology Collaboration
DNA	Deoxyribonucleic Acid
DOSHS	Directorate of Occupational Safety and Health Services
eGFR	Estimated glomerular filtration rate
EMCA	Environmental Management and Coordination Act
EPA	Environmental Protection Agency
EPZ	Export Promotion Zones
ERBS	Rotary Bell Spray
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GCHP	Global Conference on Health Promotion
GDP	Gross Domestic Product
GOK	Government of Kenya
HVLP	High Volume Low Pressure
IARC	International Agency for Research on Cancer
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy
IHME	Institute for Health Metrics and Evaluation
ILO	International Labour Organization
IPCS	International Programme on Chemical Safety
KAM	Kenya Association of Manufacturers
KDHS	Kenya Demographic and Health Survey
KEMRI	Kenya Medical Research Institute
KENAS	Kenya Accreditation Service

KES	Kenyan Shillings
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KIRDI	Kenya Industrial Research and Development Institute
KITP	Kenya Industrial Transformation Programme
KNBS	Kenya National Bureau of Statistics
MCN	Municipal Council of Nakuru
MDRD	Modification of Diet in Renal Disease Study
MSDS	Material Safety Data Sheet
MSEs	Micro and Small sized Enterprises
NACOSTI	National Commission for Science, Technology and Innovation
NAWASSCO	Nakuru Water and Sanitation Services Company Limited
NCDs	Non-communicable diseases
NEDPS	National Export Development and Promotion Strategy
NHANES	National Health and Nutrition Examination Survey
NTP	National Trade Policy
OSHA	Occupational Safety and Health Administration
OSH	Occupational Safety and Health
PCEA	Presbyterian Church of East Africa
PKC	Protein kinase C
PPE	Personal Protective Equipments
ROS	Reactive Oxygen Species
SEZ	Special Economic Zones
TCR	T-Cell Receptor
TCR-mf	T-cell receptor mutation frequencies
USEPA	USA Environmental Protection Agency
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNCHS	United Nations Centre for Human Settlements
VSMC	Vascular Smooth Muscle Cells
VOC	Volatile organic compound
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background information

Heavy metal pollution has increased sharply since 1900 and causes major environmental and occupational health problems worldwide (Baslar *et al*., 2009). The metals pose serious problems and risks to human health and environment because unlike organic pollutants, they do not degrade naturally and as a result they easily bioaccumulate (Smejkalova, Mikanova and Boruvka, 2003). In small quantities, certain heavy metals are nutritionally essential for human health and are referred to as trace elements (e.g. Iron, Manganese and Zinc). However, they become toxic when not metabolized by the body and accumulate in the soft tissues (Hu, 2002). The metals may enter the human body through food, water, air or absorption through the skin when they are exposed to humans in industrial settings. Lead as a heavy metal is ubiquitous and has special characteristics such as resistance to corrosion and low melting point that has made it to be widely used in industries (Flora, Gupta and Tiwari, 2012). This has led to increased lead pollution, distribution and accumulation in the environment and in biological systems. Among these industries, lead has widely been used in automobiles and paint-manufacturing industries.

As a cumulative toxicant, lead presents multiple symptoms including neurological disturbances, haematological effects, gastrointestinal, cardiovascular and renal effects (WHO, 2010a). In men, effects of lead on the reproductive system include increased number of abnormal sperm and a decreased sperm count. Moreover, evidence shows that long-term occupational exposure to lead may result in cancer (IARC, 2006). Acute exposures to lead may cause gastrointestinal disturbances (anorexia, nausea and vomiting, abdominal pain), hepatic and renal damage, hypertension and neurological effects (malaise, drowsiness and encephalopathy) that may result to convulsions and death (ATSDR, 2007). Lead is found at low levels in soil and rocks, air and water mainly as sulphide galena (IARC, 2006). The widespread occurrence of this metal in the environment is largely as a result of anthropogenic activities such as informal recycling of industrial products (UNEP, 2010).

Occupational diseases such as lead intoxication are diseases associated with a particular occupation or workplace. They occur as a result of physical, chemical, social, biological and psychological hazards present at workplace. Though preventable, the diseases can result because of poor working conditions and practices. Protecting workers against work-related diseases therefore should be of great concern to the government and the public. This can be achieved through an appropriate occupational safety and health system (Alli, 2008). "Occupational safety and health (OSH) is the science of the anticipation, recognition, evaluation and control of hazards arising in or from the workplace that could impair the health and well-being of workers, taking into account the possible impact on the surrounding communities and the general environment."(Alli, 2008). For this to be achieved and to put focus on preventive health, occupational safety and health system must be established. The developments in occupational safety and health over the years have focused on improving work conditions as well as promoting the provision of health services to workers so as to assure their safety and health. However, despite the risks involved in informal sector, informal workers in most African countries are not protected by occupational health and safety services (Laura, 2015).

In order to institute and enhance these services at the informal sector, more research to generate reliable data in the area of occupational health hazards is needed. Accessibility to occupational health services among the working population approximates 100% in developed countries but the coverage is generally lower in developing countries particularly in the informal sector (Rantanen and Lavicoli, 2013). Kenya as a developing nation has high proportion of workers at the informal sector, currently standing at 83% (KNBS, 2018). This population may also have low accessibility to occupational safety and health services.

In Kenya, the informal sector refers to a section of the economy that includes all occupations which are not recognized as ordinary income sources, and on which taxes i.e Pay As you Earn (PAYE) are not usually paid. The sector is also referred to as "jua kali", which literally means hot sun in Swahili and majorly operates at subsistence level. The name stems from the fact that the workers in the informal sector work under open air, indicating the severe conditions under which the micro-entrepreneurs work. Surviving on relatively low income and providing cheap goods and services, the work is labour intensive (Orwa, 2007). The sector includes a number of professions including automobile repair artisans, hawkers, carpenters and market vendors, the study focused on automobile repair artisans. There is a tremendous increase in the activities and involvement of Kenyan population in the sector. This may be attributed to an increased population growth and high rate of unemployment especially among the youth. According to the Kenya economic survey 2018 report, the sector employed over 80% of the Kenyan working population (KNBS, 2018).

This number may also represent the majority of Kenyans who are exposed to unpredictable poor working conditions. These conditions may comprise poor work practices, irregular income plans, poor labour protection, unsecured social protection and security. These conditions make this group of the population vulnerable to occupational exposures to hazards such as lead intoxication.

There are few studies that exist on the magnitude and health effects of occupational exposures to lead in Kenya, and particularly in the informal automobile repair establishments where workers have greater risk of exposure to occupational lead. The sector lacks engineering control measures and appropriate protective devices are often unavailable. Majority of these enterprises are unregistered and are not inspected workplaces thus unlikely to have an occupational health and safety system. Exposures to lead are usually characterized by subtle, non-specific symptoms that frequently contribute to misdiagnosis of intoxication (ATSDR, 2007). The onset of symptoms depends on whether the intoxication was acute or chronic. Common manifestations are an irreversible reduction in neurocognitive potential, decreased attention span and increased aggressiveness (Garfunkel, Kaczorowski and Christy, 2007). In most developed countries, stricter controls and prevention measures have reduced environmental and occupational exposures to lead, however exposure continues to be an issue in the developing countries (IARC, 2006). Significant human suffering related to occupational exposures often results in substantial financial loss due to the burden on health and social security systems, which can negatively influence production and the national economy (Ahmed, Ayanaand Engidawork, 2008).

Evaluation and biomonitoring of human health risks from occupational exposure has been conducted in the past through measurements of pollutants in biological materials such as blood, plasma, serum, urine, hair and fingernails. Measuring the concentration of lead in blood is most widely used in epidemiological studies because the levels can be associated with clinical effects (Barbosa *et al*., 2005). This study aimed at investigating occupational exposure to lead among the informal sector automobile repair artisans and associated human health risks through the evaluation of task based airborne lead, human blood, and scalp hair lead concentrations.

1.2 Statement of the problem

Occupational exposures to lead in most developing countries, Kenya included is inadequately regulated and monitored. Lead exposure is a risk factor for non-communicable diseases because it primarily affects the peripheral and central nervous systems, renal function, hepatic, haematopoietic and reproductive systems. Kenya is experiencing an epidemiological evolution in its disease burden from infectious to non-communicable conditions. Non-communicable diseases (NCDs) account for over 50% of total hospital admissions in Kenya. For example, it is approximated that 4 million Kenyans have Chronic Kidney Disease (CKD) and globally, approximately 5–10 million people die annually from CKD (WHO, 2018). Lead is a nephrotoxin and thus can result to CKD (Luyckx *et al*., 2017). Occupational exposures to lead may be one of the causes of increased non-communicable diseases particularly among the informal automobile artisans. Moreover, WHO has identified lead as one of ten chemicals of major public health concern that need action by member states to protect the health of workers (WHO, 2010b). The socio-economic and physical environment in the informal automobile repair workshops confers poor protection to the artisans from the risks of occupational exposures. The informal sector automobile repair artisans are involved in activities that include; spray painting, soldering, welding and other repairing tasks that expose them to gradual health risks from lead exposure. With a rapidly increasing human population in Nakuru town, particularly after the 2007/2008 post-election violence, the number of artisans in the informal sector has tremendously increased. This is also as a result of lack of formal employment among the youth. Kenya has prioritized manufacturing in its economic agenda (KAM, 2018), which has resulted to an increase in motor vehicle assembly. This coupled with increased second hand motor vehicle importation, has resulted to increased work force in the sector, probably reflecting the population at risk of lead intoxication. Empirical studies are necessary to assess occupational lead exposures and associated health risks among the informal automobile repair artisans. The use of biomarkers may fill important gaps in the path from exposure to human health risks. This therefore calls for empirical scientific studies in order to come up with practical actionable measures to prevent and minimize lead intoxication in such workplaces.

1.3 Objectives

1.3.1 Broad objective

The overall objective of this study was to contribute to the knowledge and evidence on occupational lead exposures and possible health risks at the informal automobile repairs industry through occupational and human lead exposure assessments.

1.3.2 Specific objectives

(i) To determine work safety conditions and practices at the sampled informal sector automobile repair workshops that can contribute to occupational lead exposures.

(ii) To determine task based personal airborne lead exposure levels at the sampled informal sector automobile repair workshops and compare them with the Occupational Safety and Health Administration (OSHA) permissible exposure limit.

(iii) To determine blood lead levels of the automobile repair artisans and compare them with those of non-artisan students and the recommended biological exposure index (BEI) of concern in adults.

(iv) To determine the lead levels in scalp hair of the sampled informal sector automobile repair artisans and compare them with those of the non-artisan students.

(v) To determine estimated glomerular filtration rate (eGFR) of the sampled informal sector automobile repair artisans and compare them with those of the non-artisan students.

(vi) To determine serum Alanine Aminotransferase (ALT) activity of the sampled informal sector automobile repair artisans and compare them with those of the non-artisan students.

1.4 Research question

(i) What are the work safety conditions and practices that can contribute to occupational lead exposures at the sampled informal sector automobile repair workshops?

1.5 Research hypotheses

(i) There are no statistically significant differences in task based personal airborne lead exposure levels at the selected informal automobile repair workshops, and as compared to Occupational Safety and Health Administration (OSHA) permissible exposure limit.

(ii) There are no statistically significant differences in blood lead levels among the sampled informal automobile repair artisans with those of the non-artisan students, and as compared to the biological exposure index (BEI).

(iii) There are no statistically significant differences in scalp hairs lead levels among the sampled informal automobile repair artisans with those of the non-artisan students.

(iv) There are no statistically significant differences in the estimated glomerular filtration rate (eGFR) among the sampled informal automobile repair artisans with those of the non-artisan students.

(v) There are no statistically significant differences in the serum Alanine aminotransferase (ALT) activity among the sampled informal automobile repair artisans with those of the non-artisan students.

1.6 Justification of the study

Occupational exposure to lead continues to be a challenge in most developing nations including Kenya. The international action plan for preventing lead intoxication provided guidelines towards achieving an environment free of lead (UNEP, 2010). Recommended initial steps of action included, assessing the problem through data collection on occupational health and safety and environmental contamination, raising public awareness on dangers of lead, among other measures. Due to increased unemployment rate in Kenya, there is proliferation of informal sector automobile repair workshops that may be using leaded industrial products thus increased risks of occupational lead exposures and related health risks. Kenya's informal sector has been growing rapidly. The sector accounted for 83.4 per cent of total employment in the year 2017, and in the same year automobile repair sub-sector, recorded tremendous growth due to the monthly increase in the number of vehicle imports (KNBS, 2018). Currently manufacturing including motor vehicle assembly is one of the Kenya Government economic growth priority areas. This gives an indication of rising work force to address the expected automobile repair needs and the number of Kenya's population that may be at risk of such occupational exposures.

Non-communicable diseases (NCDs) account for 27% of the total deaths and over 50% of total hospital admissions in Kenya (WHO, 2014). These non-communicable diseases e.g. CKD and hypertension may result from occupational exposures to lead. Reduction of deaths from non-communicable diseases by one-third by 2030 is a key target for the sustainable development goals (SDGs). Moreover, the SDG environmental health key target (3.9) is to substantially reduce the number of deaths and illnesses from hazardous chemicals and air contaminants. While the key SDG target on occupational health (8.8) is to protect labour rights and promote safe and secure work environments of all workers. Countries have set priorities among the seventeen SDGs according to their needs and conditions. The SDGs can be achieved by addressing health as a critical determinant of sustainable development. Kenya has set health as a priority area under the social pillar in its vision 2030. In addition, the 9th Global Conference on Health Promotion (GCHP) declared that health is a requirement for the sustainable development goals (WHO, 2017). Health promotion for example, through risk assessments offers means to achieve the SDGs by advancing healthy public and work environment and creating health awareness.

Such strategies and actions have the potential to make a significant impact on the burden of chronic diseases that may result from chronic occupational exposures. The approach towards allocation of resources and priority areas in healthcare provision, need to be established and guided by scientific data. Hazards need to be identified, quantified, and the choice of chemical materials and their use patterns must be modified to minimize health risks. Human biomonitoring data in public health risk assessment can be of significance in establishing relationships between a specific chemical exposure and a specific human health risk. With the Kenyan government declaring manufacturing as a top priority investment area, Kenya is geared towards transiting to an industrial economy with little effort to prevention and control of occupational health hazards particularly at the informal sector. This therefore calls for empirical research to institute measures to combat occupational exposure to industrial chemicals such as lead.

1.7 Scope of the study

The study area was Nakuru town covering both Nakuru East and West sub counties. The informal sector automobile repair workshops with at least one of the following activities being undertaken were sampled; radiator repairs, lead-acid battery repairs, spray painting, welding or soldering, and general motor vehicle mechanics. The artisans recruited from the workshops were those who had worked in the environment for at least one year. Socio-economic and other demographic data that may influence work practices and work safety conditions were documented. Task based personal inhalable airborne lead exposure levels in the workshops were measured to assess the occupational lead contamination. Human blood and scalp hair samples were used as biomarkers of lead exposure. Students from Medical Training College were the comparative non-artisan group. This is because they were not working at the automobile repair workshops and thus least likely to be occupationally exposed to lead in the workshops.

1.8 Limitations and assumptions of the study

The following were the limitations and assumptions of the study:-

(i) The study did not look at diet intake and food habits that may influence the blood lead (BPb) levels and the associated health risks. Long-term recall of dietary habits may be less reliable. This was controlled by use of the non-artisan comparative group to assess the general population lead exposure levels and by calculating Prevalence Odds Ratio (POR) and Prevalence Ratio (PR) to determine the risk of occupational lead exposures.

(ii) Cultural beliefs on obtaining blood and hair samples among the study population made potential participants initially reluctant to participate. To overcome this, the purpose and benefits of the study was thoroughly explained to the participants and thereafter approved consent obtained prior to participation. In addition, ethical approval was obtained from Egerton University Ethics committee, NACOSTI and Ministry of Health Nakuru County.

(iii) The measurement of blood lead levels at a single point in time may not have been a representative of the total blood lead body burden. This was controlled by assessing the scalp hair and task based air lead levels that were also indicators of lead exposure levels.

(iv) Potential environmental sources of lead exposures were not assessed. The blood lead levels of the non-artisan comparative group were assessed to give an estimation of non-occupational exposures to lead in the general population.

(v) The study did not assess the clinical outcomes of lead exposure among the study population. However, it assessed possible liver and kidney damage through biochemical indicators to establish possible adverse pathological health outcome.

(vi) For the purpose of this study, it was assumed that any open or partially closed work area where automobile repairs were being undertaken was an informal automobile workshop.

(vii) Another assumption was that the sampled respondents truthfully answered the questions during the interview and that the sample was a representative of the study population.

1.9 Definition of terms and operationalization of variables

Airborne lead exposure limit was the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 50 µg/m^3.

Associated health risks: were the pathological risks assessed by analyzing the serum Alanine Aminotransferase (ALT) activity and estimated glomerular filtration rate (eGFR).

Automobile artisans: are the informally trained craft workers and apprentice dealing with motor driven engine or vehicle repairs.

Breathing zone was defined as the zone within a 30cm (or 10 inches) radius of worker's nose and mouth.

Biomarkers were the tissues, fluids and the biochemical indices used to measure lead concentrations, and to examine its health effects i.e. Blood, scalp hair, serum ALT activity and estimated glomerular filtration rate.

Elevated blood lead level was blood lead concentrations ≥20µg/dl recommended Biological Exposure Index (BEI) of concern for adults.

Hazard the inherent potential to cause damage to the health of the study population.

Health risk was defned as a factor that raises the probability of adverse health outcomes.

Informalautomobile sector was that which encompassed automobile repair mechanics enterprises that are generally not licensed for regulation.

"Jua Kali" sector is a name given to the informal sector in Kenya, small scale workshops where people work under harsh conditions and are not regulated.

Lead exposure the amount of occupational lead agent that reaches an individual study participant.

Non-artisan students were considered as the comparative group, comprised of sampled students who were not working at the informal automobile repair workshops.

Occupational disease disease known, under prescribed conditions, to arise out of exposure to substances or dangerous conditions in workplace processes, or occupations.

Occupational hazards were considered as the presence of conditions and materials in the work environment of automobile artisans that can adversely affect their health.

Occupational lead exposure is exposure to lead that is because of work activity or the occupational task.

Personal work behaviour behaviours at the worksites that could contribute to ingestion of lead particle i.e eating and smoking at the worksite.

Walkthrough evaluation walking through the automobile repair workshops and observing the work processes, practices and conditions.

Work practices: the routine procedures employed by the artisans during motor vehicle repair and maintenance activities.

Work safety conditions: health and safety circumstances within the automobile workshop environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Lead is a toxic metal and has no known useful function in the human body. Its widespread use has resulted in extensive environmental contamination, human exposure and significant public health problems in many parts of the world. Despite the ban on the use of leaded petrol in most countries, lead is still used in many industrial products such as lead-acid batteries, pigments, solder and paints, most of which are in the automobile industry. As a result of continued use of lead in most of these industrial products, lead intoxication has remained a global public health problem. Globally, there are an estimated 674,000 deaths annually attributed to lead exposures, including many from cardiovascular diseases (Lim *et al*., 2012). The Institute for Health Metrics and Evaluation (IHME) estimated that in 2016 lead exposure accounted for 540,000 deaths and 13.9 million years of healthy life lost (disability-adjusted life years (DALYs) worldwide due to long-term effects on health. The highest burden was in low- and middle-income countries (IHME, 2017). Progress in reducing human exposures to lead has been achieved over the last decades, but exposure is still pervasive, especially in low- to-middle-income countries where it continues to be a major occupational hazard (Meyer, McGeehin and Falk, 2003). Concerted efforts have been made to reduce lead intoxication with the WHO identifying lead as one of the ten chemicals of major public health concern that need action by member states to protect the health of workers (WHO, 2010a).

2.2 Informal sector and automobile industry in Kenya

Many countries particularly developing nations including Kenya, have witnessed the growth of the informal sector economy partly due to high population growth and limited employment opportunities in the formal sectors of the economy. The informal sector, generally known as the Jua Kali Sector, in Kenya comprises all small-scale activities that are unregulated and uses simple technologies in service provision (KNBS, 2017). The sector is characterized by crafts-artisans, small-scale trading and entrepreneurial activities, which are not registered and do not comply with various regulations, minimal capital investment, and job insecurity (KNBS, 2018). Over the years, the sector has expanded to include some manufacturing activities.

Kenya has the highest unemployment rate in the East African Community (EAC), which is particularly high among the urban youths (KIPPRA, 2017). This has resulted to a remarkable growth in the informal sector that offers alternative avenues for gainful employment. According to the 2018 economic survey report published by the Kenya National Bureau of Statistics (KNBS), the informal sector accounted for 83.4 per cent of the total employment in 2017 (KNBS, 2018). Over 60% of those working in the sector are youth and women, aged between 18–35 years (KNBS, 2018). Informal employment tends to be of lower quality than formal employment in terms of work conditions, salary and employment incentives. Therefore, majority of Kenyans particularly the youth work in a sector that may negatively affect the quality of their lives. This underscores the need for promotion of occupational safety and health services in the sector.

The Kenya Economic Survey report of 2017 indicated that the informal sector was the largest contributor to employment for the manufacturing sector. The sector grew by 2.7% in 2016 and by 0.2% in 2017 (KNBS, 2018). The automobile repair sub-sector also recorded tremendous growth in the same review period with increasing number of monthly vehicle imports. Motor vehicles sales recorded a growth rate of 12.1% in December 2017, and generally, Kenya has an annual average motor vehicles sales growth rate of 4.1 % (KNBS, 2018). These growth rates may result in the need for more work forces to address the repair needs in the sector. As manufacturing activities, motor vehicle assembly and imports increase, the demand for automobile repair activities and the population of repair artisans will equally increase. Motor vehicle assembly is on the rise because of the new economic incentives by the government. Some international automotive manufacturers such as Volkswagen and Japan's Toyota are currently operating and have committed to increase production in Kenya (KAM, 2018).

The growth in this sector is further expected to increase with the current government initiatives to achieve a robust economic growth. The government has identified manufacturing as one of its big four-agenda and has set targets for growth and employment creation in the sector. Through the Kenya Industrial Transformation Programme (KITP), the government aspires to grow the shares of manufacturing sector from 9.2% to 15% by the year 2022 (KAM, 2018). In addition, under Vision 2030, the country has a dream to develop a diversified and competitive manufacturing sector. To achieve this, the government has drafted a number of policies aimed at supporting the manufacturing sector to make Kenya an industrialized country. These policy documents include the Export Promotion Zones (EPZ)

Act, 1990; Kenya's Vision 2030; Kenya Industrial Transformation Programme (KITP); National Trade Policy (NTP); National Export Development and Promotion Strategy (NEDPS) and Special Economic Zones (SEZ) Act, 2015 among others (KAM, 2018). These developments will not only enhance the growth of the automobile repair industry but also result in an equal workforce population growth at the informal sector. Studies have shown that employees in the informal, small and medium enterprises are more vulnerable to work related hazards, health risks and illnesses (ILO, 2005).

2.3 Workplace conditions and practices as determinants of occupational health and safety

In this study, a work safety condition was defined as health and safety circumstances within the automobile repair workshop relevant to lead exposure. Workshop safety and health comprise of activities and practices that help to reduce or prevent occupational accidents, biological and chemical exposures. Some major concerns on the environmental conditions in the automobile workshops may include good housekeeping, ventilation, lighting, drainage, water and sanitation facilities (Alli, 2008).Ventilation is especially significant in air exposure studies and in automobile repair workshops due to fumes and dust that may be generated during repair activities, and if the workshops are enclosed. It helps to provide fresh air for breathing and prevents inhalation of contaminants by the occupants. According to Kenya Occupational Safety and Health Act, 2007 a clean workplace is vital for ensuring the health and safety of the workers. Safe and clean environment is necessary to prevent workplace accidents and exposure to chemicals through ingestion and inhalation. Therefore, regular cleaning of workplaces, equipment and devices should be carried out to ensure an adequate level of workplace hygiene (GOK, 2007).

The environmental condition under which the worker operates is a key component of health and safety practices in an automobile repair workshop. Most informal automobile repair workshops are characterized by poor environmental conditions and operate under an open air. Suplido and Ong (2000), in their study on lead exposure among small-scale automobile radiator mechanics, in Manila, observed that the workshops were completely open. Studies have shown that the informal automobile repair workshops are not usually located in designated areas and work is done inside or outside the workshops, e.g. on roadsides and with inadequate safety (Apreko *et al*., 2015). Osei-Boateng and Ampratwum (2011) reported that most informal sector workers in Ghana operate under trees or open spaces in temporary sheds that is reminiscent in Kenya. Majority of the workshops have good ventilation and lighting but are untidy and lack toilets and other sanitary facilities (Apreko *et al*., 2015). Besides, provision and accessibility of adequate and suitable washing facilities, sufficient and suitable sanitary conveniences for occupants in workplaces should be provided, maintained and kept clean (GOK, 2007). Overcrowding in workplaces particularly where there is use of equipment and machines and in the presence of other health hazards e.g. air contaminants, may increase the risks of accidents and work related diseases. The Kenya-OSH Act 2007, under general provisions stipulates that an occupier shall ensure that the workplace shall not be so overcrowded as to cause risk of injury to the health of the worker. All these measures when appropriately instituted in a work place can minimize occupational lead exposures to the automobile repair artisans.

The goal of Occupational Safety and Health (OSH) is to prevent and minimize occupational illnesses. Workplace environment is key in combating such illnesses and as such, evaluation of workplace environmental conditions is essential. The evaluation process entails identification of hazards in the work environment and assessing the risk of injury or illness from the hazards (Tadesse and Admassu, 2006). Factors to be considered include physical, chemicals and biological hazards, working space, and equipment among others. Safe work environments not only save expenditure associated with occupational illnesses and deaths but also promote physical, mental and social well-being of workers (Tadesse and Admassu, 2006). The unstructured nature of the informal automobile repair sector makes it challenging to be regulated. Moreover, the workers in the sector are either ignorant about their workplace safety issues or cannot afford protective equipment that can protect them from adverse environmental and occupational hazardous conditions (Osei-Boateng and Ampratwum, 2011).

Automobile workshops can be dangerous work sites due to numerous hazards, which may be in the form of dust, fumes, solvent vapour, cuts etc. Ametepeh *et al*. (2013) in their study on occupational health hazards and safety of the informal sector in the Sekondi-Takoradi metropolitan area in Ghana, indicated that informal sector workers were exposed to chemical hazards such as smoke, dust and fumes, physical hazards; noise, fire, dirty environment; ergonomic hazards including poor working posture; psychosocial hazards such as stress and violence. Effect of these hazards on humans can be acute or chronic illnesses, and death.

To protect workers from exposure to occupational hazards, work practices, administrative and engineering controls as well as personal protective equipment are usually considered as per the principles of hazards control (Alli, 2008). The hazard control measures should be implemented in a hierarchical manner with priority given to controlling the hazard from the source. These entails; elimination of risk from the work environment, which is of the highest priority, substitution of materials, equipment or processes with less hazardous ones when risks cannot be eliminated, engineering control focusing on isolating and protecting people from hazards; Administrative control that targets the workers through education, training, and work rotations to minimize exposure to hazards.

Finally use of Personal protective equipment (PPE), which is the lowest in the control hierarchy (Alli, 2008). The high priority control measures are rarely implemented at the informal work place environment partly due to inadequate resources, poor technical capacity and ignorance of occupational safety and health (OSH) standards (ILO, 2005). Moreover, the sector suffers from poor or lack of OSH regulations and services. Engineering controls such as use of local exhaust ventilation, which removes the fumes and gases at their source, is an effective method that is rarely used. This can be provided by a partial enclosure, such as a ventilated workbench, or by hoods positioned close to the source (OSHA, 2013).

Respirators can also be used to control exposure to fumes and gases. Administrative controls such as the use of Material Safety Data Sheet (MSDS) and product labels, which provide information on product composition, usage, warnings on hazards and first aid interventions, are not used in such enterprises. Product labels are generally not read, probably because of lack of knowledge on the health and safety implications of hazards associated with the use of the products (Adei *et al*., 2011). Substitution methods can prevent hazardous exposures e.g. the use of lead–free solder in welding can help reduce lead exposures. Training on safe work practices, safe use of equipment and processes are part of preventive measures that can be instituted to curb occupational health hazards. Moreover, precautionary measures such as routine air monitoring and medical examination of workers can help reduce overall effects of the workplace hazards. Part XI of Kenya-OSH Act, 2007 recommends that workers receive periodic medical examinations and in cases of illnesses that may arise due to the nature of work processes and conditions.

Studies have shown that workers in informal enterprises are prone to occupational hazards and risks (Rongo *et al*., 2004; Sambo *et al*., 2012). Artisans at the automobile repair workshops should use the necessary PPEs to prevent these hazards and their adverse health effects (Rongo *et al*., 2004). Personal protective equipment (PPEs) are used to shield or isolate individuals from physical, chemical, and biological hazards that may present at the work places. The successful applications of such PPEs depend on the appropriate use, knowledge and willingness of the workers to use them. They should be selected carefully in order to effectively protect the workers from the occupational hazards (OSHA, 2013). PPEs such as protective clothing, respirators, hearing and eye protective devices may be helpful. However, they should always be used along with safe work practices and engineering controls to achieve the best results. Protective clothing that should be worn while undertaking automobile repair activities includes gloves, head cap, apron, face shield, coveralls, safety glasses, and helmets. Earplugs or earmuffs should be worn for hearing protection during noisy operations such as grinding and welding.

Several other studies have reported that workers at the informal automobile repair workshops rarely use PPEs. Okwabi, Agyemang and Nyanor (2016) in their study on assessment of informal sector garages; workers' safety awareness in Accra, Ghana established that only 12%of the respondents used PPEs and all the respondents had not received any training on personal safety and use of PPEs that can help them gain knowledge and skills on potential hazards at the workshops. In another study at an informal spray-painting workshop, only 0.7%of respondents always used the appropriate personal protective equipment such as apron, nose mask, goggles, and safety boots to prevent occupational exposures to hazards such as inhaling toxic vapours and mist during paint spraying (Adei *et al*., 2011). Rongo *et al*. (2004) also recorded that workers in small-scale industry in Dar es Salaam-Tanzania, were exposed to a variety of work-related hazards but were not using protective equipment. Further, Sambo *et al*. (2012) in their study on determinants of occupational health hazards among roadside automobile mechanics in Zaria, North Western Nigeria, reported high level of awareness on occupational health hazards but low usage of protective device among respondents.

The informal sector employs over 80% of the Kenyan working population (KNBS, 2018). This number may therefore also represent the number of workers who are exposed to unstable working conditions that include unsecured environment, social and labour protection. Therefore, workshop safety and health practice measures for informal sector industries is very important to prevent and or reduce occupational illnesses. It is essential that studies be conducted on work conditions and practices in the informal automobile repair sector in order to develop health and social protection policies. In addition, there is lack of information regarding standard practices associated with artisans in the sector. These workers, by the nature of their work, are exposed to several health risks resulting from repair work activities. This study will enhance awareness and contribute towards the development of health and safety measures and awareness programs that relate to automobile repair artisans.

2.4 Informal sector automobile repair processes

Duties that may directly or indirectly contribute to occupational lead exposures include spray painting, sanding, welding and soldering, grinding and cutting automotive body parts, lead acid battery repairs, radiator repairs among others. The current study focused on general mechanics, spray painting, welding, lead acid battery repairs, and radiator repairs.

2.4.1 Radiator repairs

Exposures to dust and leaded fumes at radiator repair workshops may put workers at risk to lead intoxication. Studies have reported that radiator repair workers have increased risk to lead exposure, for example, a survey on lead exposure in radiator repair workers in Washington state, reported that radiator repair workers had elevated (60 μg/dl) blood lead levels compared to other worker population (Whittaker, 2003). Another study in Manila, Philippines among automobile radiator mechanic concluded that radiator repair activities increased the body burden of lead, however the increase was not significantly different from the unexposed population (Suplido and Ong, 2000). The process of radiator repairs consists of cleaning and examining for leaks, and covering the leaks using leaded solders. The workers were probably exposed to lead fumes and dust during soldering. Nunez *et al*. (1993), in their study on lead exposure among automobile radiator repair workers in New York, reported that the radiator repair activities entailed, cleaning with caustic soda solution, testing for leaks, disassembling by melting solder joints, and replacing the radiator cores. These processes expose the workers to lead fumes and dusts that may accumulate on the radiators during vehicle operations. Exposures to lead in such enterprises can be controlled through proper installation and use of ventilation system that extracts the polluted air from the breathing zone or by proper use of PPEs. Hoods or booths that withdraw air from the back of the enclosures can be installed at the workstations or workbenches (Whittaker, 2003).

2.4.2 Spray painting

Automobile body repairs normally require re-painting after panel beating and other body works. In most small-scale automobile repair workshops, conventional solvent-based paint is used because of technical and economic reasons (Hsu *et al*. 2018). The painting is essential to give an attractive appearance to the vehicles and to protect the body against corrosion and weathering. Lead exposure may occur when lead dust or fumes are inhaled during spray painting with lead-based paint. Studies have shown that workers who use solvent-based automotive paints are at high risk of lead exposure (Hsu *et al*., 2018). Water based paints are environmental "friendly", but pose challenges in their use. Their application usually takes longer period, and the use of 2-butoxethanol that is readily absorbed through the skin as an ingredient, poses serious occupational dermal exposures (Kezic *et al.,* 2002). Automobile repainting process entails; stripping or removal of old paint and rust, sanding and application of filler paste where necessary to fill the pits and achieve a smooth surface, undercoat, auto-refinishing and clear varnish paints are then applied successively through spray painting. Drying of the coating can be achieved by heating to cure in spray painting booths (Kezic *et al.,* 2002). Ideally, several coats of auto refinishing and clear varnish should be applied, though this is not done at the informal automobile repair workshops probably because of workload and cost implications. Equipment that can be used for spray painting includes; spray guns, High Volume Low Pressure (HVLP) sprayers and Rotary Bell Spray (ERBS). Spray guns are cheaper and affordable to the informal workers and thus generally used in small-scale industries.

2.4.3 Welding and soldering

Welding is primarily the means of repairing metal products that is often used in joining automobile body components in repair workshops (Devarasiddappa, 2014). Welding joins pieces of metal by the use of heat and pressure while soldering, involve the use of a filler metal or alloy that has a lower melting point than the metal pieces to be joined (Devarasiddappa, 2014). Manual metal arc welding (MMAW) is the widely used technology in most welding processes. In this technology, high heat from an electric arc is used to melt and fuse the metal at the joint between the two parts (Balkhyour and Goknil, 2010). Other welding processes involve the use of oxy-acetylene torch. Fumes arise in welding processes through vaporization of the core metal and flux components of the electrode. The vaporized metals react with air, and produce metal oxides that condense and form fumes (Balkhyour and Goknil, 2010).

The constituents of the welding fumes may include lead oxides and particles among other heavy metal components. The composition of the fumes depend on the base metal being welded, filler materials or electrodes in use, coatings covering the electrode or on base metal, and operating conditions (temperature and current) (Balkhyour and Goknil, 2010). Other tasks such as grinding and cutting create dust that may contain lead. During such processes, condensed vaporized metal particles may be inhaled (OSHA, 2013). Adhering to OSHA standards that cover many aspects of welding work, including welding in confined spaces, welding safety, handling of compressed gases, ventilation, use of protective equipment and worker training may control and minimize most of the occupational health effects that may result from welding repair processes (OSHA, 2013).

2.4.4 Lead acid battery repairs

A lead-acid battery is made up of several components enclosed within a casing, which include positive and negative terminals made of lead, positive and negative plates kept apart by plate separators that allow free movement of the ions in the electrolyte solution. The positive plates are grids made of lead or lead alloy coated with porous metallic lead paste, and the negative plates are lead grids coated with lead dioxide paste (UNEP, 2003). The manufacturing, recycling and repairs of lead-acid batteries are practised worldwide in both formal and informal establishments (UNEP, 2003). Small-scale battery repair involves recharging, changing of the battery case, or replacement of battery terminals (Suplido and Ong, 2000). Workers may be exposed to lead particle, dust and fumes that are generated during such processes.

2.4.5 General mechanics

An automotive workshop is generally a place where vehicle maintenance services are done including engine overhaul. General mechanics deal with replacement and adjustment of components of motor vehicles, inspection, diagnosing, and servicing. Maintenance generally keeps the motor vehicle in good running condition. These maintenance services may include transmission oil and lubrication services, engine tune-ups and reconditioning. If suitable and sufficient occupational health and safety precautionary measures such as personal protection, personal hygiene, ventilation, and housekeeping are not practised, workers can be exposed to hazardous chemicals through these maintenance services.

2.5 Toxicokinetics of Lead

Factors that determine lead toxicity to an exposed individual are mainly; dose and duration of exposure, route of entry, personal hygiene, age and diet (ATSDR, 1997). The age of an individual influences the body metabolic rate and thus the toxicokinetics and health effects of lead. Children have a higher respiratory frequency and higher metabolic rate than adults, thus can absorb higher percentage of inhaled and ingested lead than adults (ATSDR, 2010). Nutrition and diet also influences lead toxicokinetics. For example, low dietary intake of Calcium, Iron deficiency, Zinc and ingestion on an empty stomach enhances absorption of lead in the gastrointestinal tract (Goyer, 1996). Studies have shown that among adults, ingestion of lead during a period of fasting results in greater absorption than if lead were ingested with food. Rabinowitz *et al.* (1980) reported that among adult male study participants, lead ingested without food was 35% absorbed, whereas tracer amounts of lead ingested with food were 8.2% absorbed. Other studies have reported that besides total food intake, percent dietary fat also influences absorption of lead in the gastrointestinal tract and thus susceptibility to lead toxicity (Mahaffey, 1981).

Increased duration of exposure may result to chronic exposure while route of exposure may influence the bioavailablity and the ultimate human health effects**.** Lead can be absorbed through the gastrointestinal tract, respiratory system, and the skin. Absorption via the respiratory tract is highly efficient, with almost all inhaled lead being absorbed into the body (ATSDR, 2010). An adult human being is able to absorb approximately 95% of inhaled lead dust deposited in the lungs (Karri, Saper and Kales, 2008). Inhalation could be the dominant exposure route in an occupational setting such as automobile repair workshops. The gastrointestinal tract is less efficient, with only approximately 10–15% of the ingested lead being absorbed into the bloodstream (Karri, Saper and Kales, 2008). The absorption of lead from the gastrointestinal tract primarily takes place in the duodenum and depends on the chemical form ingested and nutritional factors (Goyer, 1996).

Dermal exposure may be significant in an occupational setting but not in the general population. Inorganic lead is not efficiently absorbed through the skin but organic lead compounds such as those used in petrol are well absorbed through this route (EPA, 1990). Once absorbed, lead is bound to erythrocytes, distributed and stored in other body compartments such as soft tissue and the bone. Bone stores over 95% of the total body lead content where the half-life of lead is approximately 10 years. However, the concentration of lead in blood changes rapidly with exposuresand has a half-life of 25-28 days (ATSDR, 2007). Consequently, blood lead concentrations largely reflect current lead exposure while lead in the bones reflects total body lead burden since it serves as the major lead repository in the body.

Inorganic lead is not metabolized but forms reversible complexes with amino acids and non-protein thiols conjugated to glutathione and excreted primarily in the urine, and lesser amounts through sweat, hairs and nails (Kosnett, 2001). In individials with high bone lead burden, release from the skeleton may elevate blood lead concentration for years after exposure ceases and pathological high bone turnover states such as hyperthyroidism may result in lead intoxication (Kosnett, 2001). Organic Lead is biotransformed in the liver through cytochrome p-450 enzymes mediated oxidative dealkylation to highly neurotoxic metabolites or completely oxidized to inorganic lead (ATSDR, 2007). The biochemical basis for the multiple toxic effects of lead is its ability to form complexes with ligands such as sulphate, carboxylic and the imidazole groups of proteins and interact with the function of enzymes, signal systems and membranes (ATSDR, 2007).

The clinical diagnosis of lead intoxication can be difficult when there is no clear history of exposure because poisoned individuals can be asymptomatic. At acute intoxication, clinical symptoms become more obvious with abdominal pain, clumsiness and headache as the most common symptoms (Needleman *et al.*, 1990). Such symptoms were recorded in a study done at Owino Uhuru, a slum area in Mombasa city Kenya, adjacent to a lead battery-recycling factory providing scientific evidence of lead poisoning among the residents in the informal settlement. The department of public health ascertained the poisoning through medical diagnosis of three children whose blood lead levels measured as high as 23 μg/dl, 17 μg/dl and 12 μg/dl (Okeyo and Wangila, 2012). In addition to occupational medical histroy, laboratory investigations are the only reliable way to diagnose lead-exposed individuals and therefore play a vital role in the assessment of occupational lead exposures.

2.6 Mechanism of lead pathogenesis

Suggested mechanisms for lead toxicity at molecular level entail essential biochemical processes involving both enzyme actions and reactive oxygen species (ROS) metabolites. Lead exposures result to harmful effects on the reproductive, central nervous, hematopoietic, and renal systems, primarily through oxidative stress. Studies using experimental animals that have investigated mechanisms of lead-induced disease pathogenesis have identified several causative factors that include oxidative stress, nitric oxide (NO) deficiency, and alteration of cellular Ca^{2+} transport and intracellular distribution (Vaziri *et al*., 2008).These harmful changes play a significant role in disease pathogenesis (Flora *et al*., 2012). Oxidative stress plays a crucial role in the pathogenesis of many acute and chronic illnesses, including hypertension and cardiovascular diseases (Vaziri and Iturbe, 2006).

Reactive oxygen species (ROS), such as superoxide (O^{2-}) and hydrogen peroxide (H_2O_2), are usually generated during oxygen metabolism and are safely controlled in the body by the antioxidant defense mechanisms. However, various pathophysiological conditions result in increased production of ROS and sometimes impaired antioxidant enzyme mechanisms, which in turn results to oxidative stress. In the presence of oxidative stress, uncontrolled ROS causes tissue damage and dysfunction by denaturing functional and structural molecules, and through activation of transcription factors and signal transduction pathways (Vaziri *et al*., 2008). Lead can promote Reactive Oxygen Species production and oxidative stress by participating in Fenton- and Haber-Weiss reactions, which result in formation of highly toxic hydroxyl radical (•OH), ($H_2O_2 + e^- \rightarrow \bullet OH + OH^-$). Studies have shown that accumulation of H_2O_2 in animals with lead-induced hypertension can facilitate •OH production and thereby, promote oxidative stress and tissue damage (Ding *et al*., 2001). In a study by Vaziri *et al*. (2008), exposure to lead caused oxidative stress in the kidney and cardiovascular tissues in vivo and in endothelial cells and vascular smooth muscle cells (VSMC) in vitro. The study by Vaziri and Iturbe (2006) established the vital role of oxidative stress in the pathogenesis of lead induced endothelial dysfunction and hypertension in experimental animals.

By inducing oxidative stress through increased Reactive Oxygen Species production, lead causes functional nitrogen oxide (NO) deficiency that is partly due to inactivation by Reactive Oxygen Species (Vaziri and Iturbe, 2006). Reactive oxygen species also forms peroxynitrite ($ONOO^-$), a highly cytotoxic reactive nitrogen species through inactivation reaction of NO ($NO + 2O^{\bullet} \rightarrow ONOO^-$). Both NO deficiency and peroxynitrite ($ONOO^-$) can contribute to the adverse harmful cardiovascular, renal, and neurological effects of lead exposure (Vaziri *et al*., 2008). Antioxidant enzymes such as catalase and glutathione peroxidase are responsible for the reduction of H_2O_2 and other ROS in the cells e.g. by converting H_2O_2 to water ($H_2O_2 \rightarrow H_2O+O_2$). Lead inhibits antioxidant enzymes, such as catalase, glutathione peroxidase and superoxide dismutase (Gurer and Ercal, 2000). Consequently, low tissue levels of antioxidant enzymes due to severe oxidative stress can result in accumulation of H_2O_2. Hydrogen peroxide is not only a substrate for the production of a highly reactive hydroxyl (•OH) free radical that can cause oxidative injury but also serves as a cellular growth signal contributing to inflammation of cells (Vaziri *et al*., 2008).

Other molecular biochemical processes for lead toxicity include the ability of lead to mimic or inhibit the actions of calcium and binding to sulfhydryl and carboxyl groups of proteins (ATSDR, 2017). As a result, this interferes with various calcium-dependent cellular functions and enhanced toxicity to multiple enzyme systems (Dapul *et al*., 2014). Oxidative stress can promote inflammation and apoptosis by activating nuclear factor$_{\text{-K}}$B (NF$_{\text{-K}}$B) activator, which is the general transcription factor for numerous pro-inflammatory cytokines, chemokines, and adhesion molecules (Vaziri and Iturbe, 2006). For example, Protein kinase C (PKC) that is involved in many cellular functions, such as cell growth, vascular contraction, blood flow, and permeability is activated by oxidative stress. Studies have shown that lead exposures increase Protein kinase C activity. Hwang *et al*. (2002), concluded that lead induced vasoconstriction is partly mediated by PKC activation after finding an elevated erythrocyte PKC activity in a group of lead-exposed Korean workers. Occupational exposures to lead may therefore contribute to lead pathogenesis through these mechanisms.

Consequently, the lead toxic mechanisms can be exhibited in various organ systems as follows; in hematopoiesis, lead inhibits the enzyme delta-aminolevulinic acid dehydratase and prevents incorporation of iron into the protoporphyrin molecule via the enzyme ferrochelatase resulting in anemia (Dapul *et al*., 2014). In the liver, lead interferes with cytochrome P450 enzymes (Dapul *et al*., 2014). Cytochrome P450 prevents liver damage by biotransforming potentially toxic compounds including environmental toxicants (Vaziri and Iturbe, 2006). Lead therefore interferes with the normal liver functions and impairs the detoxification of environmental toxicants. Perhaps, because the cytochrome P450 enzymes are the major hemoproteins contained in the liver, inhibition of heme biosynthesis could also influence their function (Lowry *et al*., 2006) thus possibly exacerbating liver damage and dysfunction. Chronic exposure to high blood lead concentrations is also a risk factor to lead nephropathy. Data reviewed by Ekong *et al*. (2006) indicate that lead contributes to nephrotoxicity, even at blood lead levels below 5µg/dl. Studies have also shown that chronic, high lead exposure levels are likely cause of renal pathology with increased risk factor for Chronic Kidney Disease (CKD).In cardiovascular system, chronic low-level lead exposure have been reported to result in marked hypertension coupled with increased production of ROS and decreased urinary nitric oxide (NO) excretion (Vaziri *et al*., 1997).

2.7 Health effects of lead in humans

The principal toxic effects of lead occur in the liver, kidney, hematopoietic and central nervous system. More often, indivduals exposed to low lead levels are asymptomatic, however, with increased chronic exposures, symptoms may develop due to multiple organ dysfunction. These symptoms may be manifested as follows;

2.7.1 Renal effects

The kidney is the major route of lead excretion. Lead exposure can result in impairment of proximal tubular function, manifested by decreased estimated glomerular filtration rate (eGFR), proteinuria, enzymuria, impaired tubular transport, and histopathological damage (ATSDR, 2019). Even at blood lead level lower than 10µg/dl, lead intoxication can result in proximal tubular function impairment (Loghman-Adham, 1997). Studies suggest that low-level exposures to lead are a risk factor for chronic kidney disease (CKD) (Yu *et al*., 2004; Ekong *et al*., 2006). For example, a four-year prospective longitudinal study in China on environmental exposure to lead and progression of chronic renal diseases concluded that low-level environmental lead exposure is associated with accelerated deterioration of chronic renal insufficiency, which becomes more evident after long-term follow-up (Yu *et al.*,2004). Estimation of glomerular filtration rate (eGFR) is the most common method for clinically assessing kidney function in epidemiological studies. High blood lead levels were associated with low and reduced eGFR among USA adults study participants (Spector *et al*., 2011). In another cross-sectional study on tubular and glomerular kidney effects among Swedish women, higher blood lead levels were associated with lower serum cystatin C-based eGFR (Åkesson *et al*., 2005). Estimation of glomerular filtration rate (eGFR) was used in this study to assess kidney function among the study population and therefore as an associated occupational lead exposure health effect index.

2.7.2 Hepatic effects

The liver is a critical organ that is involved in detoxification and excretion of metabolic products in the body. Occupational exposure to lead has been associated with abnormal liver function. For example, occupational exposure to lead was associated with significant liver dysfunction in a study conducted among mechanics and petrol attendants in Nigeria (Onyeneke and Omokaro, 2016). Lead interferes with the function of enzymes and essential cations (Ca^{2+}) in cells throughout the body (ATSDR, 2007). In the hepatic system, exposure to lead possibly causes and increases serum or plasma liver enzymes, enlarged liver, and increased thickness of gall bladder wall (ATSDR, 2019). The liver enzymes are markers of hepatocytes damage. As a response to hepatocytes injury they can leak into the circulation and hence their serum activity is a reflection of the physiological state of the liver. In a study conducted on biochemical effects of lead exposure and toxicity on battery manufacturing workers of Western Maharashtra (India), Kshirsagar *et al*. (2015) reported a significant increase in serum levels of serum Alanine aminotransferase (ALT) and serum alkaline phosphatase enzymes in workers compared to control subjects. Alteration of liver function tests were statistically significant but within the normal range.

Serum ALT activity has been regarded as a reliable and sensitive marker that may be useful as a screening test for early detection of asymptomatic liver disease (Kim *et al*., 2008). In disease conditions that cause hepatocellular damage, serum ALT levels rises and can be used to identify an ongoing liver disease process. A study in Scandinavia of patients with mild to moderate elevations of serum aminotransferase levels for at least six months showed that liver disease was common among the patients (Mathiesen *et al*., 1999). Liver enlargement associated with increased proliferation of hepatocytes may occur as a result of exposures to lead. In a study in Poland among 145 workers occupationally exposed to lead was found to cause liver enlargement and to activate inflammatory reactions in employees compared to the control subjects (Kasperczyk *et al*., 2013)**.** Serum ALT activity was used in this study as an indicator of probable liver damage and thus as an associated occupational lead exposure health effect index.

2.7.3 Hematological effects

At high blood lead levels (>70µg/dl) acute hemolysis may occur and anemia may develop (ATSDR, 2010). Anaemia is one of the most characteristic symptoms that indicate high and chronic exposure to lead due to inhibition of a number of enzymes that are involved in haem-synthesis (Morita *et al.,* 1997). The inhibition of delta-aminolevulinic acid dehydratase (δ-ALAD) activity, an enzyme in heme biosynthetic pathway leads to decreased blood hemoglobin and anemia, decreased activity of other erythrocyte enzymes, and altered plasma erythropoietin (EPO) levels (ATSDR, 2019). The decrease in delta-aminolevulinic acid dehydratase (ALAD) activitycauses an increase in delta-aminolevulinic acid (δ-ALA) in plasma and consequently increased excretion in the urine (Sakai and Morita, 1996). Delta-aminolevulinic acid in urine (δ-ALA) has been recommended as a measure of lead hematopoiesis effect and can be used as a surrogate marker of blood lead (Higashikawa *et al.,* 2000). In the study conducted among lead workers of smelting plant in Veles Macedonia, significantly higher blood lead (BPb) levels and significantly lower delta-aminolevulinic acid dehydratase (ALAD) activity was recorded among the workers than in the controls (Stoleski *et al.,* 2008) indicating effects of lead on hematopoiesis. Similarly, workers in lead acid battery repair in Addis Ababa, Ethiopia, indicated a significant high urinary aminolevulinic acid levels in lead exposed group (16 µg/ ml ± 2.0) compared to the non-exposed group (7 µg/ml ± 1.0) ($p < 0.001$) (Ahmed *et al.*, 2008).

2.7.4 Neurological effects

Lead poisoning in adults may result to decreased cognitive function including attention, memory, and learning; altered neuromotor and neurosensory function; altered mood and behavior; and decreased peripheral nerve conduction velocity (ATSDR, 2019). Acute lead exposures can cause acute symptoms, such as hyperirritability, ataxia, convulsions, coma, and death. The most serious and irreversible effects of lead exposure occur in the central nervous system where it can distort enzymes and structural proteins, and affect neuronal signaling by competing with cerebellar phosphokinase C (Markov and Goldstein, 1988). Lower blood lead levels (>10 µg/dl) have been associated with the development of behavioral changes and neurocognitive decline (Baghurst *et al*., 1992; Mendelsohn *et al*., 1998). Other studies have reported death because of lead poisoning e.g. a study in Dakar Senegal on mass lead intoxication from an informal lead acid battery recycling reported deaths and blood lead concentrations ranging from 39.8 µg/dl to 613.9 µg/dl among the affected persons.

2.7.5 Carcinogenic effects

Lead exposures cause increased risk of cancer, including cancer of the respiratory tract, intestinal tract, and larynx, and glioma (ATSDR, 2019). Studies have shown that lead and its conjugated compounds are suspected genotoxic agents affecting the integrity of chromosomes (IARC, 2006). García-Lestón *et al.* (2012) in a study to evaluate the genotoxic effects of occupational lead exposure in a population of 148 workers in Portugal showed a significant increase in T-Cell Receptor (TCR) mutation frequency (TCR-Mf) and primary DNA damage in lead exposed workers. However, several studies on lead exposed workers have provided inconclusive evidence on lead induced carcinogenicity (Steenland and Boffetta, 2000).

2.7.6 Immunological effects

Epidemiological and clinical studies have suggested that chronic exposures to lead may cause deficiencies in the normal functioning of the immune system (Skoczyńska *et al*., 2002). The exposures are characterized by autoimmunity, inflammation, and sensitization, modification of humoral and cell-mediated immune systems, and decreased resistance to diseases (ATSDR, 2019). Significant increases in the number of leukocytes were observed in humans exposed to lead compared to the control group in a study in Poland (Kasperczyk *et al*., 2013). Lead may also regulate immunological responses at various stages, altering inflammatory reactions, including the number of circulating natural killer (NK) cells, T and B-lymphocytes (Dietert and Piepenbrink, 2006). Besides, lead exposures may modify humoral and cellular immunological responses that are linked to the occurrence of allergic, neoplastic and inflammatory diseases (Ercal *et al*., 2000).

2.7.7 Cardiovascular effects

Exposures to lead may result to increase in systolic and diastolic blood pressure, increased risk of hypertension, atherosclerosis, altered cardiac conduction, increased risk of heart disease, and increased mortality due to cardiovascular disease (ATSDR, 2019). The toxic effect of lead may also cause hypertension and kidney failure by impairing the function of the proximal convoluted tubules (Rubin and Strayer, 2008). A study conducted to assess adverse effects in workers exposed to inorganic lead at a smelting plant in Veles city, Macedonia, recorded high prevalence of lung disease symptoms in lead workers than in controls, though the difference was not significant (20 % vs. 6.6 %)

(Stoleski *et al.,* 2008). Lead exposures have also been linked to the development of hypertension among workers in diverse industrial plants in Kenya (Were *et al*., 2014).

Other effects of exposures to lead can be observed in the reproductive and gastrointestinal systems. Reproductive studies in males have shown effects such as low sperm counts, alterations in semen quality, decreased fertility, histopathological damage to the testes, and possible altered serum concentrations of reproductive hormones (ATSDR, 2019). In females, lead intoxication may result to possible alterations in serum concentrations of reproductive hormones, decreased fertility, spontaneous abortion, preterm birth, and decreased age at the onset of menopause (ATSDR, 2019). Gastrointestinal effects of lead poisoning include vomiting, anorexia, constipation, and abdominal pain (ATSDR, 2019). Because of such significant human health effects of lead exposure, there is need for evaluation and monitoring of lead levels both in the environment and in individuals to determine the level of exposure. The current study assessed the possibility of liver and kidney lead induced damage among the study population.

2.8 Biomarkers of lead exposure in humans

The use of biomarkers has become an essential and widely employed tool in risk assessment and understanding health effects (Ikeda *et al.,* 2000). Lead concentrations in biological tissues and fluids can be used as biomarkers of lead exposure. Central and peripheral nervous system, bone marrow, kidney and digestive system are critical organs where the first biological effects can be observed in lead exposure (ASTDR, 2007). The decreased enzyme activity or the amounts of altered intermediates in the biochemical pathways and other adverse effects in such critical organs can be used as biomarkers of its effects (Sakai, 2000). Human blood and scalp hair samples were used in this study as biomarkers of exposure and estimated glomerular filtration rate (eGFR) and serum Alanine aminotransferase (ALT) activity to assess the associated health risks.

2.8.1 Lead in blood

Measurement of blood lead concentration largely reflects current lead exposure, since lead in blood has a half-life of 25 to 28 days. Blood lead (BPb) is the most reliable regularly used indicator to assess lead exposure since over 95% is bound to erythrocytes (ATSDR, 2007). Moreover, it is a presentative of soft tissue lead and has the best ability to discriminate between individuals with different mean concentrations (Sommar *et al.,* 2014).

The erythrocytes behave as a depository for lead therefore might result to some disturbances in erythrocyte metabolism such as delta–aminolevulinic acid dehydratase (ALAD) activity (Morita *et al.,* 1997). Decreased ALAD activity can be used as a biomarker of effect to lead exposure. Lead in plasma and urine that are generally regarded as a reflection of recent exposure, increases exponentially with an increase in whole blood lead (Sakai, 2000). There is a dynamic equilibrium between plasma and whole blood lead (Smith *et al.,* 2002).Lead in plasma is considered to be the most significant measure of toxicologically available lead because it strongly represents the fraction of lead in circulation that is readily exchanged with peripheral target tissues such as brain, kidney, and skeleton (Smith *et al.,* 2002). In Sweden, it was recently established that whole blood lead was logarithmically associated with urinary lead with a standardized regression coefficients of 0.29 in a study among lead workers (Sommar *et al.,* 2014).

Studies in epidemiology have indicated that subclinical effects of lead with common manifestations such as irreversible reduction in neurocognitive potential, decreased attention span and increased aggressiveness occur at a low blood lead concentrations (Garfunkel *et al.,* 2007). These effects may occur at blood lead levels currently designated as being below the Centers for Disease Control and Prevention (CDC) lead level of concern (10 μg /dl). Very high blood lead levels (≥70 μg/dl) are rare and can result in coma and death. Many studies have used whole blood as a biomarker for occupational lead exposures. A comparative study on lead exposure among five distinct occupational groups in Jordan, reported significantly higher mean blood lead concentration in taxi drivers and auto-mechanics compared to other groups (Gharaibeh *et al.,* 2014). In another study in Irbid, Jordan, blood lead distinctively identified and linked higher BPb to certain occupations such as metal casters (41.6 μg/dl) and radiator repairers (32.8 μg/dl) compared to non-exposed University students (5.7 μg/dl) (Hunaiti and Soud, 2000).

2.8.2 Lead in hair

Hair as a biomarker, is noninvasively and easily collected, can easily be stored and transported to the laboratory for analysis (Schuhmacher *et al.,* 1991) thus has been widely used in heavy metals exposure risk assessments. World Health Organization (WHO) and United States Environmental Protection Agency (US EPA) have recommended scalp hair analyses as a method for determination of heavy metal levels such as lead in humans (Morton *et al.,* 2002). Heavy metals e.g. lead and other contaminants from circulating blood and other body fluids are stored and incorporated in a growing hair follicle (Ahmed and Elmubarak, 1990). It is estimated that the concentration of heavy metals in scalp hair of healthy individuals may be 10-50 times higher than in blood (Cheng *et al.,* 1996). Such heavy metals in scalp hair may reflect long-term exposures.

Although hair analysis may be able to answer some specific questions about environmental and occupational exposures, currently there is insufficient epidemiological data to support predictions of health effects related with specific concentration of lead in scalp hair (Harkins and Susten, 2003). Besides, there is lack of correlation between concentrations of heavy metals in hair and other target organs such as the liver and the kidney (Seidel *et al.*, 2001). However, studies using hair as a biomarker of lead indicate significant differences between exposed and non- exposed persons. For example, a study conducted in Lithuania using scalp hair indicated higher mean lead levels among the exposed ceramic workers (7.6µg/g, 95% CI (6.5-8.7) than the non-exposed (3.2µg/g, 95% CI (2.8-3.6) (Strumylaite *et al.,* 2004). Similarly, a comparable study in Nigeria reported increased levels of lead in adults scalp hair of the sampled population attributable to occupational exposures in the cities of Ibadan and Ilorin (Adekola *et al.,* 2004).

2.9 Occupational exposures to lead

Most adults are susceptible to lead exposures at their workplaces and globally, high lead exposures have been reported in developing countries than in the developed nations (Kaiser *et al*., 2001). The high lead exposures may be due to occupational exposures because in the developing countries, generally, air quality monitoring is limited and there are inadequate enforcement and regulation of occupational lead exposures particularly at the informal automobile repair enterprises. The assessment of occupational exposures to lead among different occupations is important because lead exposures can result to an increased mortality rates for instance, Schober *et al.* (2006) in their National Health and Nutrition Examination Survey (NHANES II) reported an increased relative risk of mortality at increased blood lead levels. Occupational exposures to lead can take place in many industries including automobile industry, during the application and removal, grinding, welding and cutting of materials painted with protective lead-containing paints (Fewtrell *et al.,* 2003).

The occurrence of lead in the environment has decreased greatly in recent decades because of elimination of most leaded gasoline. However, occupational exposures continue mainly via leaded industrial products (IARC, 2006) and in adults, occupational exposure have been identified as the main cause of lead intoxication (Needleman, 2004). Metallic lead is used in batteries, cables, solders and steel products, electronic equipment and circuit boards while inorganic lead pigments are used in paints, plastics, glass and rubber products (Patrick, 2006). Numerous activities involving handling of such leaded industrial products such as panel beating, metal cutting, spray painting, welding and motor vehicle mechanics are carried out within the informal sector automobile workshops. Most of the spray painting is done within an enclosed environment sometimes in painting booths which may compromise sufficient ventilation.

Lead is one of the largest environmental and occupational health problems in terms of numbers of people exposed and public health burden (Pokras and Kneeland, 2008). A study conducted among automobile mechanics in Nnewi, Nigeria, showed that occupational exposure to lead significantly increased blood lead in exposed subjects compared to the non-exposed (Dioka *et al*., 2004). Similarly, a study among lead exposed production workers in Kenya recorded a mean BPb levels ±SD of 59.5 ±10.1 µg/dl among the exposed compared to 41.6±7.6 µg/dl among office workers (Were *et al.*, 2012). Another study conducted in Nairobi Kenya on environmental and occupational exposure to lead recorded a startling levels of lead exposure, 15% of the entire sample had BPb above 15 µg/dl (Njoroge *et al.*, 2008).

Other recent study conducted among battery repair workers occupationally exposed to lead in Lagos, Nigeria reported that majority had BPb between 20µg/dl and 40µg/dl (Ogbenna *et al.,* 2017). In the USA, evaluations of the distribution of blood lead levels among healthy adult population is normally done during National Health and Nutrition Examination Surveys (NHANES) through the National Institute for Occupational Safety and Health's Adult Blood Lead Epidemiology and Surveillance Program (ABLES). Accordingly, as Kenya gears towards an industrial economy, such baseline surveys should be carried to establish the population index for blood lead exposures. However, this might not be achieved through the Kenya Directorate of Occupational Health and Safety due to lack of or inadequate capacity in terms of personnel and other resources. Studies such as the current study can provide the much needed information to fill this gap. The study sought to explore the informal automobile repair industry and its connection with lead exposures by examining the possible sources of lead exposure and pathological health effects among the artisans.

2.10 Legal and policy framework on Lead exposures in Kenya

Kenya has comprehensive laws, policies and regulations on environment and occupational safety and health of workers though there are inadequate provisions on lead as a specific chemical pollutant. Moreover, there are inadequate human and environmental protection measures due to lack of or poor enforcement on the existing legislations. The Kenya constitution (2010) for example, has a section on environmental policy development e.g the entitlement to a clean and healthy environment in article 42, enshrined in the Bill of Rights. The constitution also under article 70 deals with enforcement of these environmental rights. By including environmental considerations in the constitition, the government acknowledges the significance of the environment to human health.

The primary environmental legislation in Kenya is the Environmental Management and Coordination Act of 1999 (EMCA,1999) which also acknowledges the right to a clean and healthy environment and the duty to safeguard and enhance the environment. Part VII of the Act on environmental audit and monitoring is relevant to this study. Section (78) on air quality requires the establishment by the enforcement authority of criteria and procedures for the measurement of air quality. The enforcement authority to recommend or set ambient air quality standards, occupational air quality standards, emission standards for various sources, and establish criteria and guidelines for air pollution control for both mobile and stationary sources. Section (86) stipulates that the standards and enforcement authority shall, recommend measures necessary to identify materials and processes that are dangerous to human health and the environment, and prescribe standards for waste, their classification and analysis. Relevant subsidiary legislations have been enacted to support EMCA 1999. They include Environmental Management and coordination (Air quality standards) regulations of 2007 and Environmental Management and coordination (controlled substances) regulations of 2007 which provide for occupational air quality management. The EMCA 1999 Act and the subsidiary legislations indirectly deals with exposures to lead and thus their enforcement may help in curbing occupational lead exposures.

In addition, the first schedule under the factories and other places of work Act, (cap. 514) provides the occupational exposure limits – control limits (OEL-CL) for lead as 150 $\mu g/m^3$. This value is three times the world health organization permissible exposure limit (PEL) and the American Conference of Governmental Industrial Hygienists (ACGIH®) recommended exposure limit of $50 \mu g/m^3$ in air. The provisions of the factories and other places of work Act are rarely enforced in most of the informal sector enterprises. Moreover, with new scientific evidence on health effects of various occupational chemical hazards such as lead, the occupational exposure limits (OEL) standards in Kenya need periodical reviews to address emerging occupational health diseases and their diverse sources in order to match the international regulatory standards.

The Ministry of Labour and Social Services, has a key function in the management of occupational health and safety. The Directorate of Occupational Safety and Health Services (DOSHS) specifically perform this role for the Ministry. In order to effectively manage the occupational health and safety services, the government enacted the Occupational Safety and Health Act, 2007, which provides guidance, rules and regulations on health and safety management. Some of the legislative requirements considerable to this study are found in the following sections: - Part II under general duties, which specifies the duties of the employer and employee in ensuring safety, health and welfare at work of all persons working in an enterprise.

The employer is required to provide information, instruction, training and supervision to ensure the safety and health at work of every person employed, carry out appropriate risk assessments in relation to the safety and health of persons employed and adopt preventive and protective measures among others. While the employee, is required to ensure his own safety and health and that of other persons who may be affected by his acts or omissions at the workplace among others. Part VI of the Act gives regulations on general provisions on health, which include cleanliness, ventilation, overcrowding, drainage and sanitary provisions. Part X concerns welfare in the workplaces. Provision of easily accessible washing and safe drinking water is required at the enterprises among others. While Part XI of the Act, give guidelines concerning workplaces with hazardous exposures, provision of personal protective equipment and medical surveillance (GOK, 2007).

Other provisions under the Act, applies to safety and health of all workers and is intended to regulateoccupational exposures to hazardous substances. Under the second schedule in the Act, lead and its compounds are listed as a prescribed occupational hazards. This entails the use or handling of or exposure to fumes, dust or vapour of lead or a compound of lead, or substance containing lead at the work places. Noteworthy that lead exposures at the informal sector are not adequately addressed in the Act. These legislations and regulations are deficient and as such additional specific regulations may be necessary to deal with lead contamination and management in order to achieve the international action plan for preventing lead intoxication. Furthermore, because Kenya is transiting to an industrial economy, there is need to enhance the existing legislative framework on occupational exposure to chemical hazards such as lead whose application is extensive in most manufacturing industries.

2.11 Research gaps

Majority of studies on occupational exposures to lead have been undertaken in the formal sector, particularly at the lead acid battery enterprises. In Kenya, such studies are minimal and the existing in the literature, were conducted at the formal sector industry among the lead acid battery workers, while some have focused on environmental lead exposures. The current study is unique in that, an assessment of occupational exposures to lead was conducted at the informal automobile repairs sector, an industry that is rapidly growing with minimal provision of occupational safety and health services. Compared to other studies, the current study used multiple biomarkers. Task based personal airborne lead exposures evaluated the exposures at the source giving an overview of the most likely tasks that were risks to lead exposures. Blood and hair samples were used to assess the artisans' individual exposures.

The variables were thereafter, correlated to ascertain the trends in exposure levels among the study participants. Most studies have used pooled samples in examining these relationships e.g. pooled mean ambient air samples and blood lead concentrations. However, in this study, the personal airborne samples, blood and hair samples were collected simultaneously hence individualized to give better interpretation of the results. Subsequently, the study used serum Alanine Aminotransferase (ALT) activity and estimated glomerular filtration rate (eGFR) as biomarkers of effects to examine lead induced hepatic and renal effects respectively. The study therefore assessed and traced lead exposure from a single occupational source to its probable hepatic and renal pathological effects. These made the current study to be unique compared to other studies in the literature. Given the occupational challenges characterized with an increasing unemployment in Kenya, the study would make a significant contribution to the knowledge and evidence on occupational lead exposures. The study would fill the gap and research needs as suggested by the international action plan for preventing lead intoxication (UNEP, 2010) and the relevant Sustainable Development Goals (SDGs) key targets. From literature review and based on each study objective, the following are some of related studies and their contribution that helped to conceptualize this study (Table 2.1).

Table 2.1: Research gaps

S/No	Author(s) and year of publication	Focus of the study	Current study concept or research gap
1	Were *et al*., (2012)	Study was conducted at the formal sector in lead acid battery recycling and manufacturing plants in Nairobi, Kenya. Study was on ambient air and blood lead levels.	The current study examined the correlation between task based personal airborne and blood lead levels. It was undertaken at the informal automobile repair enterprises in Nakuru, Kenya.
2	Ibiebele, D. D. (1994)	Assessed chronic exposure of acid-lead battery factory workers to lead by determining blood lead levels among 20 workers and relating the values to lead in air values. The study was conducted in a formal enterprise in Ghana.	Current study used task based personal airborne samples as opposed to ambient air samples. Study was among the informal automobile repair artisans from five distinct occupations.
3	Goldberg *et al*., (1997)	The study applied a task-based approach to assess lead exposure among structural steel iron workers engaged in bridge rehabilitation project.	A part from airborne lead assessment, the current study, assessed blood and hair lead exposures and examined correlations between the variables.

5	Strumylaite *et al*., (2004)	Study was performed to estimate if human hair can be used in assessing environmental and occupational exposures to metals in epidemiological surveys.	In addition to hair samples, the current study used blood and airborne lead exposure levels, which were correlated. The study helped to conceptualize the current study in using hair samples as a biological indicator of lead exposure.
6	Ahmad *et al*., (2018)	The study assessed lead exposure among automobile technicians in, Pakistan using biological samples (blood, hair, nails). The study population included exposed automobile technicians (n = 50) and a control group (n = 50).	Other than the biomarkers; blood and hair, the current study assessed pathological lead exposure effects through eGFR, and ALT indices. It also assessed the occupational tasks contributing to the exposures.
7	Ashraph *et al*., (2013)	The study analyzed the effects of lead exposures on hemoglobin levels and kidney function among the informal workers in Mombasa, Kenya.	In addition to kidney function, the current study examined hepatic pathological effects of occupational exposures to lead among the study population. It also assessed the sources of occupational exposures to lead through task based airborne lead exposure measurements.
8	Dioka *et al*., 2004	The study assessed liver and renal functions in artisans occupationally exposed to lead in	In addition to assessing liver and renal effects of exposures to lead. The current study assessed the sources and other determinants of the occupational lead exposures such as

		mechanics in Nigeria. The study used the following biochemical markers: electrolytes urea, uric acid, creatinine, zinc and blood lead, as well as serum AST and alkaline phosphatase.	personal hygiene and behaviours among the study population.
10	Obeng-Gyasi *et al*.,(2018)	The study was a across sectional study of the general population that investigated the effects of lead exposure by analyzing AST, ALT, ALP, GGT, and total bilirubin clinical markers. The study used the National Health and Nutrition Examination Survey (NHANES) 2007–2008 and 2009–2010 datasets.	The current study was specific to informal automobile repair artisans and used corresponding individual blood lead, ALT levels and eGFR to examine the relationship between effects and exposure levels, as opposed to using grouped exposure data sets. Primary data was used as opposed to secondary data.
11	Rodrigues *et al*., (2009)	Assessed personal air and personal behaviors (washing, smoking) and work site conditions as potential determinants of blood lead levels	The study helped the current study to conceptualize on personal hygiene, work behaviour and work site conditions as possible determinants of occupational lead exposures among the study population.

		among painters in New England.	
12	Rongo *et al*.,(2004)	The was a descriptive study to assess occupational exposures and perceived health risks of workers in the informal sector enterprises in Dar es Salaam, Tanzania	The study helped conceptualize the current study on the aspect of work safety conditions and practices at the automobile repairs workshops that can contribute to occupational lead exposures.
13	Apreko *et al*., (2015)	The study was a descriptive study conducted to evaluate knowledge regarding clean and safe working environment among informal automotive artisans in Ghana.	The current study assessed work place environment and practices that may contribute to occupational lead exposures. These were further examined in relation to the exposures and health risk indices.

2.12 Conceptual Framework

The conceptual framework shows the relationship of variables determining lead exposure among the informal sector automobile artisans (Figure 2.1). The independent variables include the specific kind of work (occupational task) the artisans are engaged in, the work processes, use of personal protective equipment (PPE), and demographic characteristics for example, level of education and age. These determines the breathing zone airborne lead levels, blood lead levels and lead concentrations in scalp hair as the dependent variable. Estimated glomerular filtration rate (eGFR) and serum Alanine aminotransferase (ALT) activity were biochemical indicators of associated health risks to occupational lead exposures. These variables were assessed and their relationships examined in the study.

The intervening variables in the study entailed food and diet intake, environmental exposure (for example piped water), personal hygiene and habits, and exposure to other chemicals like polycyclic aromatic hydrocarbons that may influence toxicological interactions and bring synergistic or antagonistic effects. Lead is ubiquitous and other environmental sources for instance, contaminated water may influence blood lead exposure levels. The physiological characteristics of individual artisans could influence lead toxicokinetics hence influence their blood lead (BPb) levels. Personal hygiene e.g. hand washing before eating may influence amount of lead ingested and thus exposure levels. The total food intakes and diet may greatly influence the lead toxicokinetics for example, low dietary intake of Calcium, Iron deficiency, Zinc and ingestion on an empty stomach (fasting or starvation) enhances absorption of lead in the gastrointestinal tract. The route of exposure (ingestion, dermal, oral or inhalation) may influence the dose of exposure e.g. minimal amount will reach the circulatory system through the dermal route but about 95% of inhaled lead dusts deposited in the lungs goes into the blood stream. Some of the intervening variables were controlled by screening and excluding the participant, for example, those with chronic illnesses were excluded in the study. Other data on these intervening variables were collected and analyzed in the study.

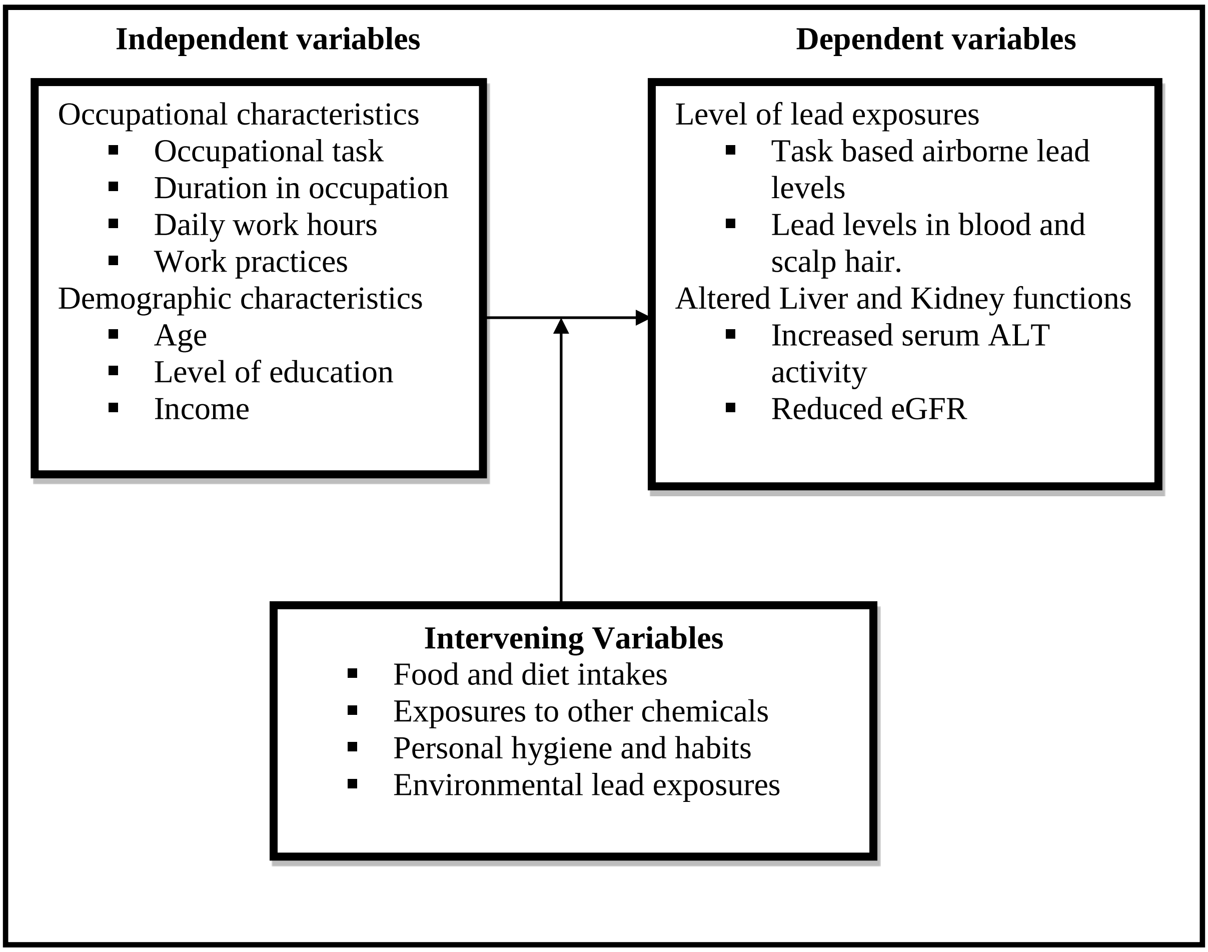

Figure 2.1: Conceptual framework

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

The study was conducted in Nakuru town (0° 18' 11.1564" S and 36° 4' 48.0900" E.) which is located 160 kilometres northwest of Nairobi city along the Kenya-Uganda highway (Figure 2). Nakuru town is the headquarters of Nakuru County and the fourth largest town in Kenya after Nairobi, Kisumu and Mombasa. It is situated at an altitude of 1850 m above sea level between the Menengai Crater to the north and Lake Nakuru national park to the south (Foeken and Owuor, 2000). It is a semi-arid region and due to its location on the floor of the Rift Valley with its volcanic soils, the town is usually engulfed with dust during the dry season. The total area of the town is about 292 km^2 of which the lake covers 44 km^2 (Foeken and Owuor, 2000). The town is located within two sub counties (Nakuru West and Nakuru East). Nakuru town West having two administrative divisions (Kaptembwo and Viwanda) with six locations and Nakuru town East has also two administrative divisions (Lake View, Menengai) with five locations and is divided into five administrative locations: Lanet, Afraha, Kaptembwo, Baharini and Barut (GOK, 2017).

3.1.2 Population

In the 2014 Kenya Demographic and Health Survey (KDHS), Nakuru County had a population of 1,603,325 with 875,980 being urban. Nakuru town is the headquarters of Nakuru County with the major urban population in the County. It is a cosmopolitan town with diverse ethnic groups. The population has been growing at the rate of 5.6% per annum higher than the national annual growth rate. From a population of 38,181 in 1962, the population reached 163,927 in 1989 and 289,385 in 1999 and 473,288 in 2009 population and housing census report (Kenya National Bureau of Statistics, 2010). It is one of the fastest growing towns in Africa (UN-HABITAT, 2010), and continues to experience a population influx attributed to external migration from other towns. Similar to major towns in Kenya, the town is experiencing growth in the informal sector due to lack of formal employment particularly among the youth. The informal sector in Kenya grew by 6% in 2015 according to the Kenya National Bureau of Statistics (KNBS) economic survey 2016.

3.1.3 Health services

Under the 2010 Kenya constitution, health function has been devolved to the County government with distinct functions being assigned to the National and County governments. The County governments are responsible for County health services, waste disposal and promotion of primary health care among others. Despite a life expectancy that is higher than the national average (Kenya National Bureau of Statistics, 2010), the town is still facing many health challenges. The challenges may be as result of its tremendous growth associated with its status as one of the major administrative and commercial town in Kenya. A study done on the social determinants of health in Nakuru town by Muchukuri *et al.* (2009) identified unemployment, poor waste management, and unhealthy environments as areas of concern relevant for reducing the health inequalities.

3.1.4 Economic activities

Nakuru's economy is largely reliant on its vast agricultural neighborhood with increased small-scale agricultural activities within the urban area. The town has a vibrant economy based on sectors such as commerce, manufacturing, service and tourism, agriculture and informal trade industry (KNBS, 2018). Automobile and spare parts trade and informal sector enterprises are among the leading forms of business within the Central Business District (CBD) (KNBS, 2018). The informal sector automobile enterprises are common in the town due to increasing lack of formal employment. The automobile repair workshops are indiscriminately constructed within the town with majority being in the industrial area in Nakuru East Sub County.

The workshops in the town with the following cadre of automobile artisans: radiator repairers, lead-acid battery maintenance and repair, spray painters, welders, general auto-mechanics were considered as study sites. These workshops were located within the Municipality in both Nakuru West and Nakuru East sub counties, they included from 001 – 010, Farhad, Ngish, KIE Ugenya, Buck Ambrose, Buck Jack, Mamboz, Buena, ASK Mwash, ASK Sammy, and Pondamali garage, the 11th site being the Medical Training College where the comparison group (students) were sampled (Figure 1).

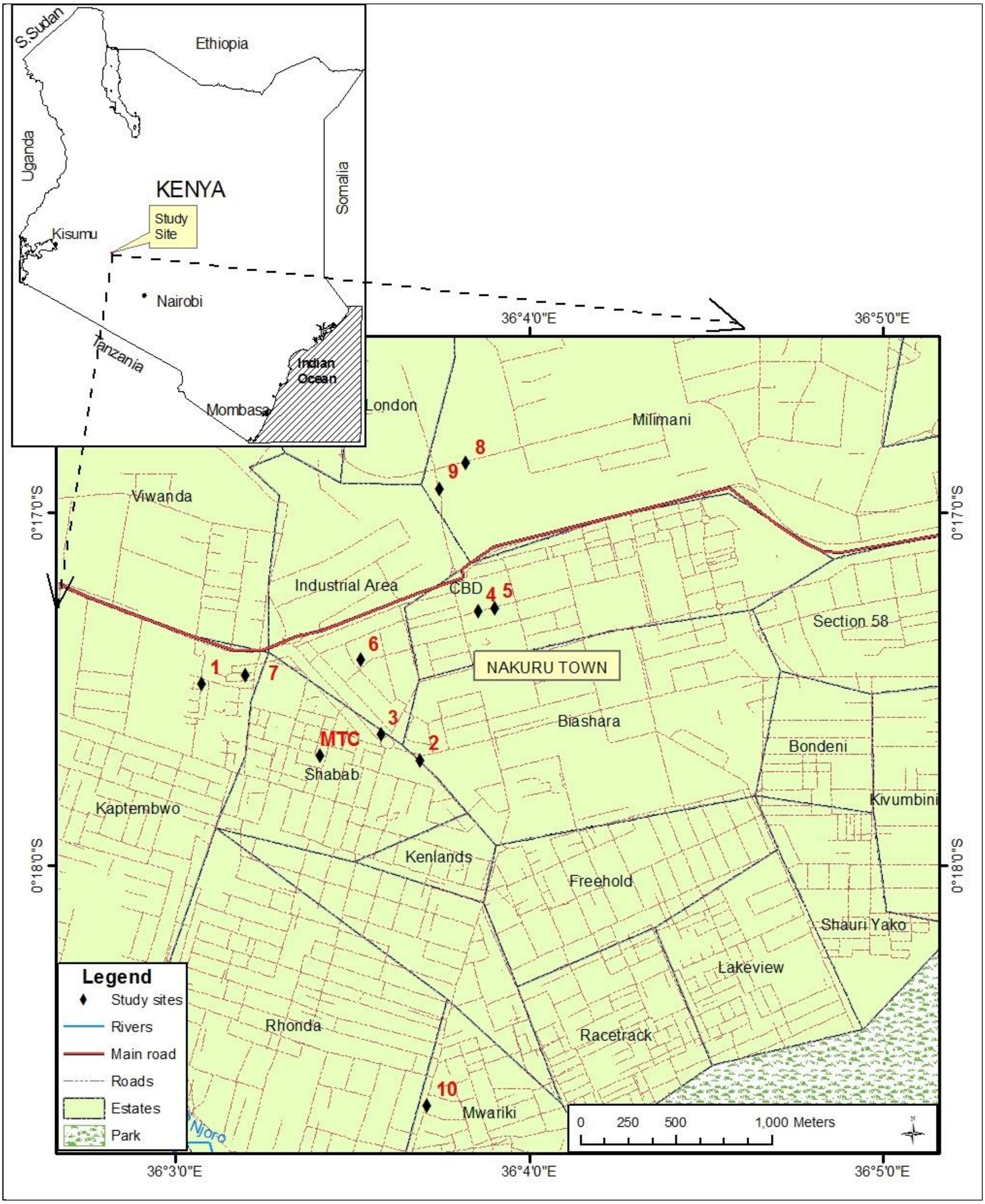

Figure 3.1: Map of Nakuru town showing the study sites

Source: Survey of Kenya Maps

3.2 Research design

A comparative cross-sectional study was conducted at purposively sampled informal sector automobile repair workshops (n=10) for the artisans and P.C.E.A Medical Training College located in the vicinity for the comparative group (students). The artisans were considered as the occupationally exposed populations while the students occupationally non-exposed. Socio-demographic information was obtained from the artisans and the students. Thereafter the collected task based airborne samples, blood and hair samples were analyzed for lead in the laboratory by the various outlined procedures. The results were compared among the artisans in various occupational tasks and between the artisans and the comparative group to assess the occupational exposures to lead and associated health risks. Structured questionnaires (Appendices 1 and 2) and observations using checklist (Appendix 3) were used in data collection.

3.3Study subjects

Since most of the informal automobile repair workshops are not regulated, a preliminary survey was conducted to collect primary data on the population of the target groups and to determine the study sites. Workshops with the following occupational tasks were considered for sampling:-

(i) Spray painting: some of the paints may contain lead
(ii) Welding: involves soldering with leaded products
(iii) Radiator repairing: lead alloys are used in radiator repairs
(iv) Lead-acid battery maintenance and repair: both the positive and negative battery plates contain lead
(v) General motor vehicle mechanics: involved in engineering and lead is used in auto manufacturing

3.4 Sampling and sample size

The ten sampled workshops had a working population of 108 artisans and 50.9% participated in the study. Non-participants either were not present on the day of sample collection or declined to participate. A sample size of 115 study participants was used in the study i.e. n=55 for automobile artisans and n=60 for the students who were matched with the artisans based on sex and age category. Five artisans consented to give both hair and blood samples thus 55 artisans were recruited instead of 60. Thirty blood samples and thirty hair samples were collected separately from both the artisans and the students. The artisans were proportionately sampled based on the artisans' population in each workshop and different occupational tasks (Appendix 5). Strata were identified as per different occupational tasks within the workshop. In each stratum participants were randomly selected at work, briefed on the proposed research, those willing, and consented to participate in the study were recruited.

The 60 non-artisan participants were recruited by targeting and randomly selecting the students who were in their 2nd, 3rd and 4th year of study and were in the college on the day of sampling. After briefing them on the proposed research, those who consented and met the inclusion criteria through the information obtained from the filled structured questionnaire (Appendix 2) were recruited. All the participants were aged 18 years and above. The artisans and the students with at least one-year duration at the workshop and in college respectively, with no reported history of chronic illnesses such as kidney and liver diseases, cancer, diabetes and hypertension were recruited.

3.5 Data collection and analyses

3.5.1 Questionnaire and checklist

Some data were obtained by use of pretested structured questionnaire (Appendices 1 & 2) while others through checklist (Appendix 3), walkthrough evaluation and observations at the workshops. Information concerning physical layout and general conditions at the workshops was collected. The questionnaire was administered during face-to-face interviews. Data on socio- economic status, personal characteristics and perceived health status were collected from both the artisans and the students. Specific data for the artisans on duration of occupation, type or nature of work and practices, use of personal protective equipment (PPE) and other relevant factors (Appendices 1& 2) that might influence work related lead exposures were also obtained. Trained research assistants aided in data collection.

3.5.2 Blood and hair sample collection

Standard precautions were applied during collection, transport and storage of blood samples (Cornelis, *et al*, 1996). The blood samples were collected with the assistance of a qualified Medical Laboratory Technician (Phlebotomist) registered by the Kenya Medical Laboratory Technicians and Technologist Board (KMLTTB).Sixty blood samples were collected (n=30 for artisans and n=30 for the students). An 8ml (4ml in two separate vacutainer tubes) venous whole blood sample from each study participant was collected using a 21-gauge vacutainer needle and holder into a navy blue top heparinized vacutainer tube (for lead analysis) and redtop vacutainer tube (for determination of serum ALT activity and eGFR). Samples for lead analysis were preserved at 4°C until processing while samples for the determination of serum ALT activity and eGFR were separated by centrifugation at 3000 rpm for 5 min (samples not immediately analyzed were stored at 4°C).

Scalp hair samples (shavings) were collected with the assistance of barbers working at different barbershops within the vicinity of the sampled population. Sixty scalp hair samples were collected (n=30 for artisans and n=30 for the students). The hair samples were put in specimen labeled envelops and stored under room temperature. Only the hairs with natural colour from the study participants were collected and chemically treated hairs were not sampled. All used disposable field sample collection equipment and materials were taken to Nakuru County referral hospital for proper disposal.

Plate 3.1: Blood and hair samples collection

3.5.3 Blood sample preparation for lead analyses

National Institute for Occupational Safety and Health (NIOSH 8003) standard method was adopted(Smallwood, 1994).A3ml blood sample was digested using 6 mL aqua regia (HNO_3/H_2SO_4: 5:2v/v) solution and oxidation completed by 10 mL conc. hydrogen peroxide, thereafter pH of the solution adjusted to 2.3 using Conc. Ammonia solution. Lead was chelated by 1 mL 4% Ammonium pyrrolidine dithiocarbamate (APDC). The solution was then extracted with 10 mL of pure methyl-isobutyl ketone (MIBK) and the organic supernatant separated into screw-capped polypropylene specimen containers. Working standard solutions were prepared and treated using the same method as blood samples.

3.5.4 Hair sample preparation for lead analyses

The hair samples were digested using wet acid digestion with Nitric acid and hydrogen peroxide as described by Gaza *et al.* (2017). The hair samples were soaked and washed with acetone and subsequently rinsed with distilled–deionized water to remove the exogenous contaminants. As observed by Samanta *et al.* (2004), the washing method does not result in any loss of the heavy metals. The washed samples in labeled petri dishes were oven dried at 60 °C to a constant weight of 0.5 g. The samples transferred to a 50 ml Erlenmeyer flask and 10 ml of Conc. Nitric acid (69%) added at room temperature. Under a fume chamber, the samples were digested on a hot plate at 40 °C to accelerate the digestion. The Nitric acid was added until dense white fumes appeared marking the end of the digestion process. The digest was allowed to completely cool to room temperature and 2 mL hydrogen peroxide added to complete the oxidation. The digest were then transferred to 50 mL volumetric flask and diluted to volume with nitric acid.

Plate 3.2: Blood and hair samples preparation

3.5.5 Lead analysis using Flame Atomic Absorption Spectrophotometer

Hair and Blood lead analyses were conducted at Nakuru Water and Sanitation Services Company limited (NAWASSCO) laboratories, Nakuru. The lead (Pb) concentrations in both the prepared blood and hair samples were analyzed using thermo electron (S) series Flame Atomic Absorption Spectrophotometer (FAAS) at a wavelength of 283.3nm. After optimizing the various instrument parameters, the samples were analyzed in triplicate and instrument drift controlled by running standards after analyzing 10 samples as described by (ATSDR 2007).

Plate 3.3: Thermo electron (S) series FAAS, for lead analyses

3.5.6Determination of estimated glomerular filtration rate (eGFR)

Serum creatinine was measured using Reflotron Assay method by Roche Diagnostics Ltd, United Kingdom (fully automated biochemical analyzer) at SCANLAB medical centre laboratory Nakuru. The principle of the test was based on the method described by Peake and Whiting (2006). The Reflotron analyzer is an in vitro diagnostic device, which quantitatively determines clinical chemistry parameters on whole blood, plasma or serum samples using test reagent strips and the results show concordance with the wet chemistry methods (Ahmad *et al.*, 2011).

Creatinine values obtained were converted into estimated glomerular filtration rates (eGFR) using the eGFR calculator based on Modification of Diet in Renal Disease study (MDRD) equation and Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) Creatinine Equation (2009) for estimation of glomerular filtration rate (GFR) as recommended by the USA National Kidney Foundation (Levey *et al.*, 2007).

3.5.7 Determination of serum Alanine aminotransferase (ALT) activity

The analyses were conducted at SCANLAB medical centre laboratory Nakuru. Serum ALT activity was determined using fully automated biochemical analyzer i.e. Reflotron Assay method by Roche Diagnostics Ltd, United Kingdom. The principle being that ALT catalyzes the transamination reaction in which, α-ketoglutarate and Alanine are converted to pyruvate and glutamate. The pyruvate product in turn becomes a substrate for lactate dehydrogenase (LDH) in the indicator reaction in which NADH is oxidized to NAD^+. The decrease in the optical density of NADH measured photometrically (at 340nm) is directly proportional to the pyruvate concentration and thus to the ALT activity (Kasperczyk *et al.*, 2013). The enzyme activity was expressed in IU/l.

Plate 3.4: Reflotron analyzer for determination of serum ALT and creatinine for eGFR

3.5.8 Personal task based air samples collection

A task-based sampling strategy was used to collect personal airborne lead samples from the representative artisans. Twenty breathing zone air samples (collected in duplicate) were collected from the ten sampled automobile repair workshops (Appendix 6). Air samples were collected for 2 hours (excluding any rest period) by personal air sampling near the breathing zone. The samples were collected at a constant flow rate of 2.5 L/min using portable low-volume personal air sample pumps (SKC, AirChek sampler Model 224-52) equipped with rechargeable batteries. Pre-weighed standard 37 mm sample cassettes holders with mixed cellulose ester membrane filters (0.8 μm pore size) and attached to Tygon tubing were connected to the sample pump. The pumps were worn on the waist for the duration of the sampling period and the sample cassette mounted on the collar in the breathing zone of each participant (Were *et al.*, 2012). The sampling pumps were calibrated with a primary standard flow meter (Mesa Labs Bios-Defender 510) prior to the survey and re-checked after completion of the survey. The calculated pre and post-calibrations flow rates differed by 2%, which was within the recommended accuracy limit of not more than 5%. Total suspended inhalable particulates were sampled in accordance with the National Institute for Occupational Safety and Health (NIOSH 0600) method (Clere, 1994). The cassettes-loaded membrane filters with inhalable particulates were sealed with stoppers and transported to analytical laboratories for analyses.

Plate 3.5: Task based airborne sample collection for radiator repairs and spray painting

3.5.9 Airborne lead analyses

The airborne lead analyses were conducted at SGS Kenya Limited laboratories Mombasa. The analyses were done using inductively coupled plasma atomic emission spectroscopy (ICP-AES-720 series) at 283.3nm wavelength, NIOSH method 7300 (NIOSH, 1994). The principle being that, Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) uses inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element. Atomic emission spectroscopy (AES) uses the intensity of the light emitted from a flame, plasma or spark at a particular wavelength to determine the quantity of an element in a sample. The wavelength of the atomic spectral line gives the identity of the element.

Plate 3.6: ICP-AES-720 series used in airborne lead analysis

3.6 Quality control and Assurance

Both the SGS Kenya Company Limited and NAWASSCO laboratories are accredited by Kenya Accreditation Service (KENAS) and ISO/IEC 17025:2005 certified. SCANLAB Medical Centre Laboratories are accredited by the Kenya Medical Laboratory Technicians and Technologist Board (KMLTTB) as per the MLTT Act 10 of 1999. All the relevant analytical procedures and protocols at the laboratories were therefore, adhered to. The spectrophotometer was calibrated following the manufacturer's instructions. The method was validated for linearity and the calibration curves had a correlation coefficient in the range of R^2 = 0.965–0.995. The working standards were analysed for every 10 samples and recoveries checked using spiked sample solutions. The mean percentage recovery was 94.25% and the relative standard deviation (RSD) for the interday precision was 3.09%. Externally sourced quality control check (QCC) sample was used to assure the reliability and accuracy of the laboratory analytical procedures. Laboratory control check samples (LCC) were also used to assure that the results produced were within acceptable limits for precision and accuracy.

All plastic tubes, bottles, flasks and pipettes were soaked, acid-washed with 2% (v/v) nitric acid for 24 hours, and thoroughly rinsed with deionized water. The reliability of the research questionnaire and checklist was ascertained by conducting a pilot study at informal sector automobile workshops at Njoro town 20 Km away from the study location. Thirty research questionnaires and checklist were administered for this purpose and thereafter corrected and adjusted accordingly. The University Ethics committee approved the questionnaire and the checklist. The samples collections and laboratory analyses as reported were conducted using accepted standard procedures and supervised by the University supervisors.

3.7 Ethical Considerations

The study was approved by Egerton University research Ethics committee (Appendix 27), National Commission for Science, Technology and Innovation (NACOSTI/P/17/10144/19789) (Appendix 28), Ministry of Health Nakuru County (Appendix 29), and from the Ministry of Interior & Coordination of National Government-Nakuru county commissioner (Appendix 30). In addition, the study subjects voluntarily participated in the research study following their informed consent (Appendix 4). Confidentiality of information was assured and the study conducted in accordance with the World Medical Association Helsinki Protocols of 2013, which stipulate appropriate ethical considerations for studies that involve human samples.

3.8 Data Analyses

Data collected were analysed using statistical package for social sciences (SPSS) version 22 and p-values ≤ 0.05 considered statistically significant. Descriptive statistics were used and results presented in frequencies, percentages and means. The analysis of variance (ANOVA) statistical tests were used to conduct multiple comparisons of the differences in lead exposures among artisans, tasks and across workshops. Where ANOVA test showed statistical significant differences, Posthoc Tukey HSD comparison test was done to identify the actual variables being tested that differed. Linear regressions to evaluate the contributions and correlations of airborne lead levels, age, duration of work, and daily work hours on blood lead exposure levels. As well as, blood lead concentrations on serum ALT activity and eGFR. Chi-square (χ^2) tests were performed to test for statistical significance of association between BPb exposures levels among artisans performing different tasks, with different levels of education and monthly income. Student's t-test to compare the mean concentrations of blood lead levels, hair lead levels, estimated glomerular filtration rate (eGFR) and serum ALT activity among artisans and the non-artisan students. Finally, Prevalence Odds Ratio (POR) and Prevalence Ratio (PR) were calculated to estimate the risk of high blood and hair lead levels among the study participants.

Table 3.1: Data analyses summary table

S/no	Research question and hypotheses	Independent Variables	Dependent Variables	Data Analysis
1	What are the work safety conditions and practices that can contribute to occupational lead exposures at the sampled informal sector automobile repair workshops?	Occupational task, Duration of exposure, Age and sex, Level of education, Use of PPE	Hair lead levels, BPb levels Airborne lead levels	Descriptive statistics
2	There are no statistically significant differences in task based personal airborne lead exposure levels at the selected informal automobile repair workshops, and as compared to Occupational Safety and Health Administration (OSHA) permissible exposure limit.	Occupational task, Age and sex, Level of education, Use of PPE	Task based airborne lead levels	Descriptive statistics ANOVA , t-test Regression analysis
3	There are no statistically significant differences in blood lead levels among the sampled informal automobile repair artisans with those of the non-artisan students, and as compared to the biological exposure index (BEI).	Occupational task, Duration of exposure, Age and sex, Level of education, Use of PPE	Blood lead levels	Descriptive statistics t-test, ANOVA Chi-square, Regression analysis, Prevalence Ratio (PR)

4	There are no statistically significant differences in scalp hairs lead levels among the sampled informal automobile repair artisans with those of the non-artisan students.	Occupational task, Duration of exposure, Age and gender, Level of education, Use of PPE	Hair lead levels	Descriptive statistics t-test, ANOVA Chi-square, Regression analysis, Prevalence Ratio (PR)
5	There are no statistically significant differences in the serum Alanine aminotransferase (ALT) activity among the sampled informal automobile repair artisans with those of the non-artisan students.	Occupational task, Duration of exposure Age and gender, Level of education	Serum ALT activity	Descriptive statistics Pearson's correlation Regression analysis,
6	There are no statistically significant differences in the estimated glomerular filtration rate (eGFR) among the sampled informal automobile repair artisans with those of the non-artisan students.	Occupational task, Duration of exposure, Age and gender, Level of education	Estimated glomerular filtration rate (eGFR)	Descriptive statistics Pearson's correlation Regression analysis,

CHAPTER FOUR

RESULTS AND DISCUSSION

The current study was carried out among the informal automobile repair artisans with the aim of assessing occupational exposures to lead and associated health risks particularly, liver and kidney damage by evaluating the liver enzyme serum Alanine aminotransferase (ALT) activity and kidney estimated glomerular filtration rate (eGFR). In this chapter, the results have been presented and the relationships of the various variables discussed.

4.1 Socio-demographic characteristics of study population

From the ten workshops, fifty-five automobile repair artisans (50.9%) gave consent to and participated in the study (Appendix 5). Majority of the study participants were youth with their age ranging from 18 to 27 years (Figure 4.1). This supports the fact that the informal sector offers a major proportion of employment opportunities for the Kenyan youth (Zepeda *et al.*, 2013; Afande *et al.*, 2015). The mean age among the artisans was 26 years ± 1.01 SE while the non-artisan participants were college students with mean age of 23 years ± 0.3 SE. Notably, the age was more dispersed among the artisans because apprentices were included in the study. Many young people (78.7% of workers between the ages of 15-29), work in the informal sector with limited social protection and exposed to significant work related hazards (ILO, 2017). All the study participants were males. This indicates that females are rarely engaged in automobile repairs work in Kenya and could constitute very low proportion where present. Coupled with severe work conditions at the informal sector, automobile repairs are labour intensive. This possibly justifies why young and energetic males dominate the sector.

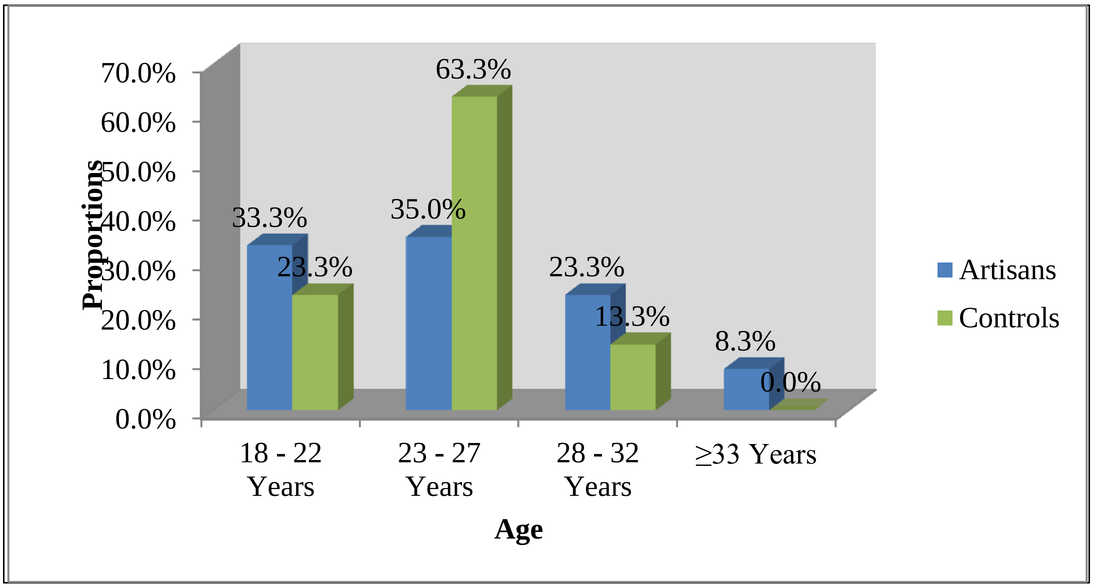

Figure 4.1: Age distribution among the study participants

Artisans who have been on the occupation for at least 1 year were considered for the study. The average duration on the occupation was 6 years ± 0.9 SE. More than half of the artisans (52.7%) had been on the occupation for <5 years and 9.1% ≥13years (Figure 4.2).The finding supports the fact that most artisans were young and probably inexperienced. It is noteworthy that duration of exposure to toxicants or chemical hazards influences toxicity and health effects (ATSDR, 2007).Although theblood lead concentrations decreases rapidly with decreased exposure, prolonged duration of exposure may result to chronic exposures and significant health effects to the artisans.

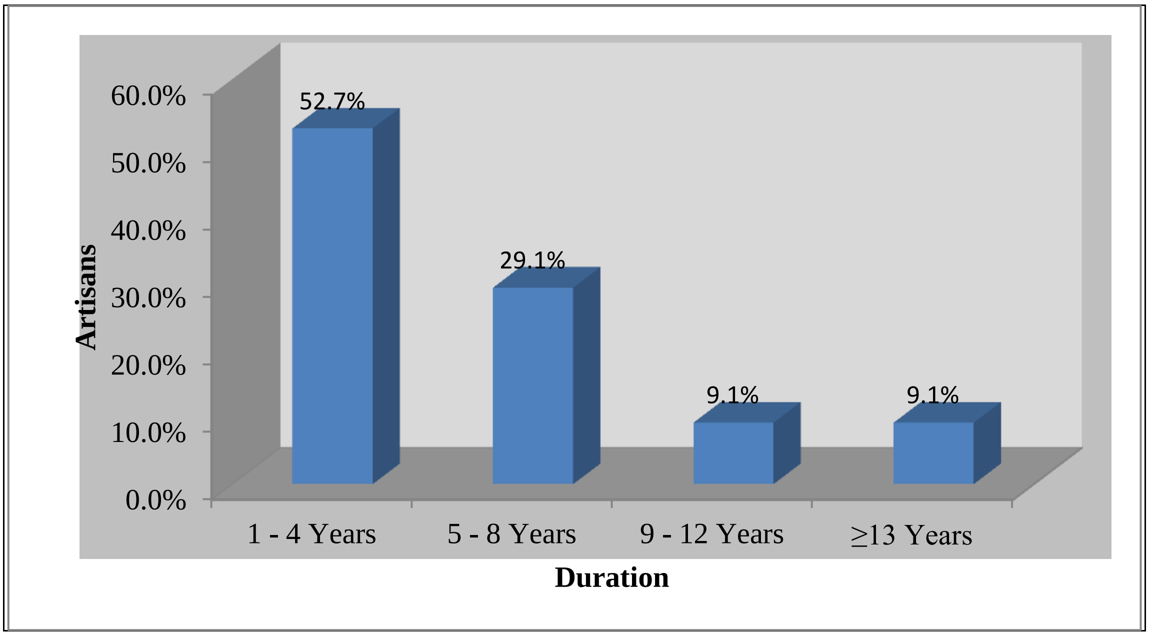

Figure 4.2: Duration on the occupation among the artisans

Majority of the artisans (60%) earned an average monthly income of KES 5,000 -KES 10,000 and 3.6% earned KES>20,000 (Figure 4.3). This is probably the situation in Kenya at the informal sector since the Kenya economic survey reported an average minimum wage of KES 7,284 in 2016 and KES 8,595 in 2017 (KNBS, 2018). These levels of income portend low socio-economic protection towards occupational exposures and other occupational health risks among the artisans. The finding corroborates a study on understanding the drivers of the youth labour market in Kenya, which reported that young people work in the informal sector under low income with little or no social protection (Escudero and Mourelo, 2014). The vulnerability of the youth to work under such conditions with minimum wage is exacerbated by youth unemployment rate that is currently approximately three times higher than that of adults (ILO, 2018). A study on challenges and consequences of urban youth unemployment in Nairobi reported that about 55% of Kenyans' urban population lives in poverty in slum settlements (Muiya, 2014). With such low average monthly income, the artisans may lack adequate daily food intake, which can exacerbate the effects of the occupational exposure to lead. Hunger and malnourishment may increase lead toxicity, studies have shown that ingestion of lead on an empty stomach (during fasting or starvation) enhances its absorption in the gastrointestinal tract (Goyer, 1996).

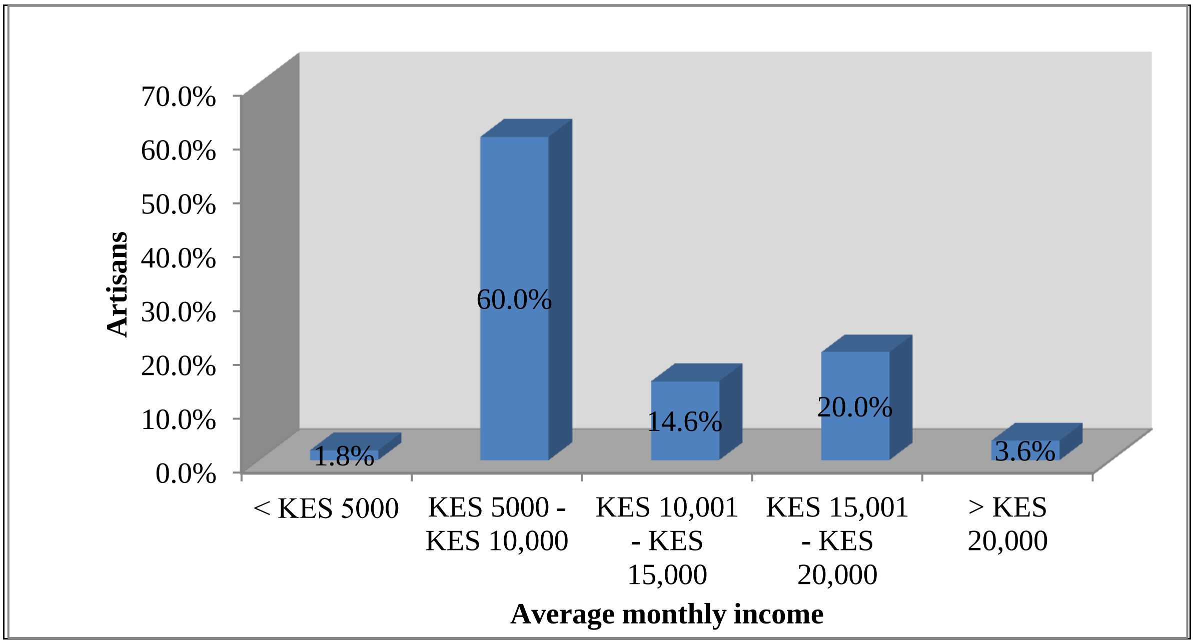

Figure 4.3: Average monthly income of the artisans

Notable in the study that the occupation was not a preserve for the uneducated, 7.3% and 41.8% of the artisans had respectively attained tertiary and secondary education. However, a significant proportion (49.1%) of all the respondents had basic primary education whereas the remaining proportion (1.8%) had no formal education (Figure 4.4). Studies have shown that people with higher levels of education are less often engaged in informal employment, while workers with low levels of education tend to remain in the same employment notwithstanding difficult working conditions (ILO, 2017). This could best explain the observed composition among the study population. The informal sector is characterized by underemployment as reported by the KNBS (2018) in the Kenya economic survey 2017. The 7.4% of the artisans who had attained tertiary education could experience this in the course of their work. A study by Odhiambo and Manda (2003) on urban poverty and labour force participation in Kenya, reported that children from informal settlement drop out of school at an early age to seek employment in the informal sector due to poverty. This could explain the high percentage of artisans with basic primary education.

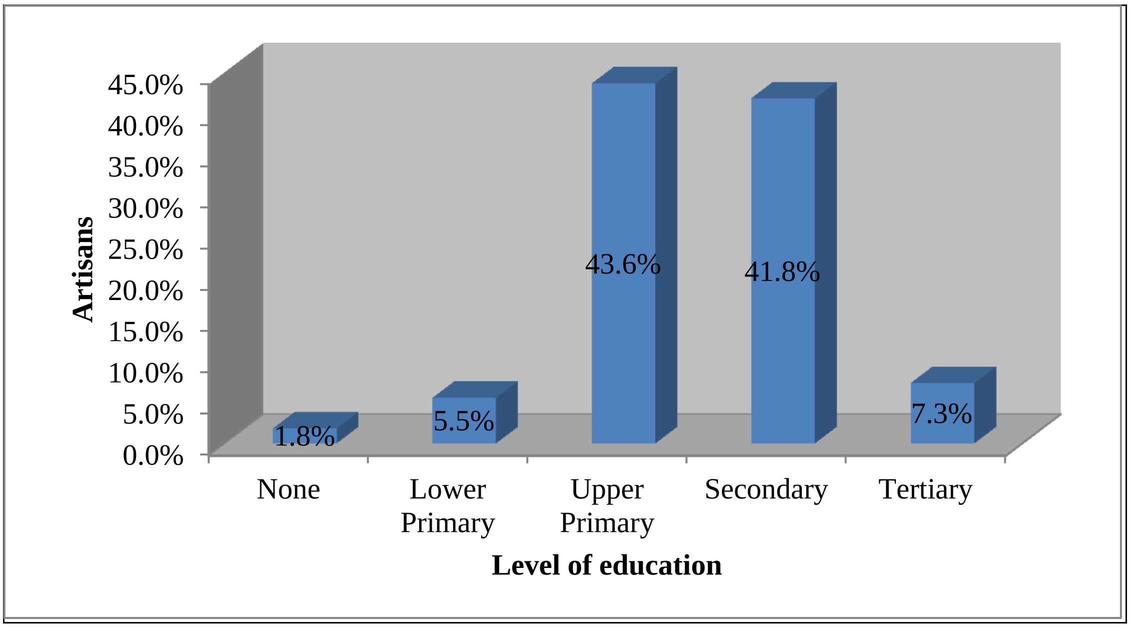

Figure 4.4: Level of education among the artisans

The observed trend is also a reflection of the uptake for free primary and secondary education policy in Kenya. Although there is free primary and secondary education, enrolment declines progressively e.g. under tertiary training due to numerous reasons, including exorbitant costs and persistent poverty levels (Maronga *et al.,* 2015). However, currently the Kenyan government has enhanced Vocational Education and Training (TVET) through rapid enrolment in tertiary institutions like Youth Polytechnics, Technical Training

Institutes, and National Industrial Vocational Centres through increased accessibility to grants and other funding that is likely to change future trends. Zepeda *et al.* (2013) in their report on Kenya's youth employment challenge, reported high unemployment rate among tertiary educated youth and indicated increased unemployment among the youth aged 18-to-25-year old. This among other factors like requisite knowledge and skills for formal employment, could have driven the automobile artisans who have attained tertiary education to work at the informal sector automobile industry. Nonetheless, the government must be keen on how to tap the tacit knowledge and skills that this sector is endowed with and probably consider accreditation of such apprenticeship training. It must also endeavor to equip this group of youth with necessary entrepreneurship skills for the economy to realize full potential benefits from this industry.

4.2 Occupational activities and processes at the workshops

In this study, work practices were the routine procedures employed by the artisans during automobile repair and maintenance activities that could contribute to lead exposures. An understanding of occupational activities and processes gives insight into detection of hazards relevant to lead exposures in the workshops. Such knowledge may guide in forecasting possible incidents and work related diseases that are likely to afflict the artisans. The information, may then guide in setting up specific preventive and control measures for the prevention of occupational diseases among the automobile artisans. The workshops dealt with all types of automobile services, from body works to overhauling the engine. Almost every occupational task performed by the artisans in automobile repair workshops puts them at risk of a variety of hazardous materials, chemicals toxicants and heavy metals (Barlet, 2013).

The current study identified five occupational tasks; general mechanics, spray painting, welding, lead acid battery repairs, and radiator repairs. These occupational tasks were proportionately sampled across the ten workshops (Appendix 5).Spray painting was the most widespread occupational activity while lead acid battery repairs the least. Among the artisans who participated, 32.7% and 5.5% of them were respectively engaged in spray painting and lead acid battery repairs. Probably as a result of the advent and increasing use of maintenance-free lead acid batteries by motorists, there has been a tremendous downward trend in the use of rechargeable lead-acid batteries. It was noted through walkthrough surveys and personal interviews that the sampled occupational tasks directly or indirectly contributed to occupational lead exposures as described in (Table 4.1) below.

Table 4.1: Occupations that predispose artisans to lead exposures

S/No	Activity	Occupational tasks	Predisposing risks
1	Spray painting	Spray painting was conducted after body surface preparation, which entailed carrying out sanding to remove the old paint or rust, grinding, buffering and priming. Conventional solvent-based paint and a spray gun were used in this operation.	Use of a spray gun created over-sprays, which potentially contain toxic particles of paint pigments and vapor fumes.
2	Welding and soldering	Was majorly done during repairs to body panels, frames and in straightening bent body parts. Metal cutting was also done during this operation, and an oxyacetylene gas used.	Potentially leaded welding fumes and gases could probably result from the base material being welded, coatings and paints on the metal.
3	Radiator repairs	The artisans first drained the coolant (antifreeze agent). The work consisted of cleaning the radiators in a tank containing caustic soda solution (NaOH), inspecting the surface for weak points, testing for leaking areas, and then sealing the detected leaking joints by soldering. Soldering was done using an acetylene gas to seal the detected leaking joints.	Radiator dust and soldering fumes from electrode and filler metal contained lead.

4	Lead acid battery repairs	Repairs or reconditioning involved recharging, changing of electrolyte, or replacement of battery cells and terminals (cathode and anode plates). Soldering was also done to connect the terminals when rebuilding cells.	Exposure to dried lead oxide and sulfide paste occurred during manual disassembly and segregation of battery components. Leaded fumes were emitted during soldering.
5	General mechanics	General mechanical maintenance services and repairs were done to keep the motor vehicle in a good running condition. It entailed decarburizing engine parts by physically scraping off carbon deposits from the various engine components.	Dust particles from cleaning and decarburizing engine parts, and ignition spark plugs could contain lead particles.

Most of occupational chemical hazards such as lead arise from inhalation of the chemical agents in the form of dusts, vapours, gases and fumes or by ingestion and dermal contact. Prior to spray painting, motor vehicle body repair artisans perform numerous activities on body surface preparation including surface sanding, grinding, paint-removal or rust-removal, application of adhesives and body fillers (Enander *et al.*, 2004). Health hazards associated with spray painting come from paint ingredients such as solvents, pigments, and other additives that impart special characteristics to the paint. Most of chrome pigments and primers in solvent paints contain lead (Hsu *et al*., 2018). Spray painting causes aerosolization, oversprays and subsequent inhalation of the paint constituents. Besides, surface preparation processes generate hazardous dust. Welding on the other hand, requires that the material melt or fuse through heating which generates fumes that might be leaded depending on the material being welded and the electrodes (Balkhyour and Goknil, 2010). While soldering, involve the use of a filler metals, which in most cases contain lead (Devarasiddappa, 2014). The welding process involved the use of oxy-acetylene torch. During the process, vaporized metals react with air, and produce metal oxides that condense and form fumes that may contain lead oxides and particles.

Radiator repairs consist of cleaning and examining for leaks, and covering the leaks using solders or filler metals. These processes expose the workers to lead fumes and dusts that may accumulate on the radiators during vehicle operations (Nunez *et al*., 1993). Several components of lead acid battery are leaded including the positive and negative plates. Replacement of these terminals during repairs exposes the artisans to lead dust and fumes thus is a high-risk process to lead intoxication (Suplido and Ong, 2000). General mechanics involves replacement and adjustment of engine components including spark plugs and decarburization. These processes generate dust that can be inhaled or ingested through hand to mouth contacts. Nevertheless, automobile repair and maintenance has been identified as a high-risk occupation for lead exposures (NIOSH, 2017a).

4.3 Work safety practices and personal behaviours at the automobile repair workshops

Workshop safety and health comprise of activities, practices and behaviours, which help to prevent or reduce work related illnesses. The study examined work safety practices and personal behaviours that may contribute to occupational lead exposures among the artisans. Several predisposing factors could arise at the workshops mainly through improper work practices e.g. inadequate use or lack of personal protective equipment (PPEs), lack of engineering and administrative control measures. These were assessed through interviews and walkthrough evaluations using questionnaire and checklist. The probable pathways of occupational exposures to lead were dermal absorption, inhalation and ingestion of dust and fumes containing lead. These could be prevented and controlled through appropriate safe work practices e.g. by proper use of personal protective equipment.

4.3.1 Use of personal protective equipment and other control measures

Part II of the Occupational Safety and Health Act, 2007 under general functions, section 12(b) and 13(c) requires that at all times the workers shall use appropriate safe systems of work, preventive and control measures, and where not feasible, use suitable personal protective appliances and clothing in preventing risks to safety and health (GOK, 2007). Personal protective devices are designed to protect the user's body from hazards. They reduce worker exposure to chemical hazards and particulate matter by providing a physical barrier (Yeung *et al*., 2002; Alli, 2008).Only 3.6% used eye goggles, face shield in welding and 1.8 per cent mouth, or nose masks majorly in spray-painting (Table 4.2). Majority (78.2%) used overalls or aprons purposely to prevent dirt while none of the artisans used hand gloves. Among the artisans, 16.45% did not use any form of personal protective equipment and none used full complement of the required personal protective equipment. Gloves when worn while performing occupational tasks such as grinding and sanding could significantly decrease the risk of ingesting lead dusts since they protect the hands from dusts (EPA, 2013). Besides, mouth and nose mask could prevent inhalation of toxic vapours and mist, however, overalls and face shields had little or no protection to occupational lead exposures as regards the tasks that were being undertaken. Face shields protects the eye against injury while overalls primarily against dirty clothing.

The findings were consistent with those of Sambo *et al*. (2012) who reported that the mostly used personal protective equipment among automobile mechanics in Zaria, Nigeria were overall at 69%. Other studies have also shown that workers at the informal automobile repair workshops rarely use personal protective equipment. Use of personal protective equipment among study participants was only 27% in a study conducted by Monney *et al*. (2014a) on occupational health and safety practices among vehicle repair artisans in Ghana. Similarly, Rongo *et al*. (2004) in their study on occupational exposures and health problems in small-scale industry in Dar es Salaam-Tanzania, recorded that workers were exposed to a variety of work-related hazards but were not using protective equipment. In this study therefore, the use of appropriate personal protective equipment (PPEs) was poor and consequently the artisans were not fully protected from inhaling and ingesting paints, fumes and dust generated in most of their activities.

Table 4.2: Percentage use of protective equipment among artisans

	Occupational tasks					
Type of PPE	Radiator repairs	Lead acid battery repairs	Spray painting	Welding soldering	General mechanics	Totals (n=55)
Overalls/aprons	7.3%	3.6%	27.3%	20.0%	20.0%	78.2%
Mouth/Nose mask	0.0%	0.0%	1.8 %	0.0%	0.0%	1.8 %
Hand gloves	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Eye goggles or face shields	0.0%	0.0%	0.0%	3.6 %	0.0%	3.6 %
Did not use any form of PPE	3.6 %	1.8 %	3.6 %	5.5 %	1.8 %	16.4 %

Further data analyses using chi-square test of independence showed that there was neither a statistically significant association between the artisans' level of education and use of PPEs, ($\chi^2(12) = 3.74$, $p=0.98$) (Appendix 7) nor was there a significant association between their monthly income and PPE use ($\chi^2(12) = 10.18$, $p=0.60$) (Appendix 8). Suggesting that despite of the hazards at the workshops, poor use of PPEs was not influenced by the two factors, which could imply that the artisans were either ignorant or negligent about the health implications of their work. Osei-Boateng and Ampratwum (2011) in their study of informal sector in Ghana, reported that workers were either unaware of safety and health issues or could not afford the personal protective equipment. Some of the artisans could be seen welding and handling used engine oils, grease and paints without hand gloves and perhaps oblivious of the hazard exposures and health implications (Plate 4.1). The oils and paints may contain lead and its compounds, which can be absorbed through the skin. Enander *et al.* (2004) established that automobile repair technicians were at a risk of lead exposure above the Occupational Safety and Health Administration (OSHA) regulatory limits, mainly when there is inadequate use of proper personal protective equipment and proper ventilation.

Plate 4.1: Artisans working without using any protective device

Personal protective equipment such as protective clothing, hearing and eye protective devices may be helpful in controlling the workplace hazards. However, in order to achieve the best results, they should be used along with other safe work practices, administrative and engineering control measures. Engineering controls such as use of local exhaust ventilation, which removes dust, fumes and gases at their source, is an effective method that can be utilized in overcrowded workshops. These can be achieved using a partial enclosure, such as a ventilated workbench, or by hoods positioned close to the source (OSHA, 2013). The workers in such environments can also use air-purifying respirators that filter out air pollutants thereby reducing exposures to lead fumes and dust. Noteworthy, from the study that none of the workshops applied any engineering control measure for example, there was no use of any mechanical ventilation or respirator to control fumes and vapours; neither was spray-painting conducted in booths equipped with an appropriate exhaust system (Appendix 9). This was in breach of the Occupational Safety and Health Act 2007,part IX, section 89 (1) that requires every workplace where dust and fumes are given off by a work process to provide and maintain exhaust appliances, as near as possible to the source of the impurity to prevent any ill health effects.

Administrative control measures to control the hazards were equally not applied at the workshops. None of the workshops had caution labels and signage for warning of hazards, and neither was hazardous substances that may cause harm by inhalation, ingestion, and skin absorption identified and documented at the workshops (Appendix 9). This was also in contravention with the Occupational Safety and Health Act, 2007, part IX on chemical safety, section 86 (1), which stipulates that all chemicals to be clearly labeled at the workplace in order to indicate their identity and be easily understood by the users. Studies have reported that hazard prevention and control measures are rarely implemented at the informal work places partly due to inadequate resources, poor technical capacity and ignorance of occupational safety and health (OSH) standards and services (ILO, 2005). The open-air nature of the workshops may not make engineering interventions appropriate and therefore use of appropriate personal protective devices should be encouraged. Studies have shown that proper use of personal protective equipment(PPE) together with other measures like general hygiene may decrease occupational exposure to lead (Pogăcean and Pop, 2015).

4.3.2 Personal behaviours at the worksites among the artisans

Other than inadequate use of personal protective equipment, other factors that could predispose the artisans to occupational lead exposures may result from their personal behaviours. Part II of the Occupational Safety and Health Act, 2007, under general duties, section 12(a) and 13(a) require workers to take all necessary precautions to ensure their own safety and health at the workplace (GOK, 2007). Hand washing practices, cigarette smoking and eating at the worksite were considered as personal behaviours that might influence occupational lead exposures to the artisans. These behaviours would probably result to ingestion of lead particles and dust among the study population. Studies have shown that human exposure to lead through hand-to-mouth mechanism has a significant contribution to increased blood lead level (Rodrigues *et al.*, 2009).

In this study, 92.7% of the artisans reported to be eating (which entailed chew gums, fruits and cooked foods) at the work sites (Table 4.3).The finding was consistent with a study in Philippines by Suplido and Ong (2000), where some small-scale mechanics were reported to eat within their worksites. This contravened Occupational Safety and Health Act, 2007**,** Part XI under special provisions on health, safety and welfare, section (100), which stipulates that no person shall be permitted to take food or drink in workplaces where poisonous substances are used that give rise to dust or fumes (GOK, 2007). The finding suggests that nearly all artisans are at risk of ingesting poisonous substances at the workplace. Eating at the work sites may be exacerbated by the fact that none of the workshops had eateries and restrooms (Table 4.4).The artisans reported that food vendors supply them with foodstuffs in the worksites and that some retailers operate informal eateries in the neighborhood that cater for their needs for food supplies and meals during working hours. This contravened Part X, section (94) of the Occupational Safety and Health Act that calls for the provision and maintenance of suitable eating and resting facilities for workers (GOK, 2007).

Less than half, (20%) of the artisans reported to be smoking cigarette at the work sites (Table 4.3). The finding was predictable since studies have shown that workers with low socio-economic status are likely to smoke cigarette compared to those with higher socio-economic status (Barbeau *et al*., 2004). Furthermore, exposures to dust and chemical hazards at workplace have been significantly associated with increased probability of cigarette smoking (Chin *et al*., 2012). This is plausible because cigarette smoking could increase hand to mouth transfer and thereby ingestion of lead particles and dust. The smoking habit at the worksites among the artisans is of particular concern since they are also occupationally exposed to fuel exhaust fumes and dust that might increase disease risks associated with smoking (Oliver *et al*., 2001).

A comparative study of lead exposures in industrial 'hot spots' in Jordan and Israel reported that increased hand to mouth activities at workplace environments such as eating and cigarette smoking were associated with significant high blood lead levels (Nsheiwat *et al.,* 2010). Eating and cigarette smoking while at work suggests lack of understanding among the artisans of the ill health effect associated with their occupational tasks and such behaviours. Chi square test of independence revealed that education level was statistically significantly inversely associated with eating habits among the artisans ($\chi^2(4) = 13.7$, $p = 0.008$)(Appendix 10). Artisans with low education levels reported higher frequency of eating at the worksites than those with higher levels of education. However, the association between education level and cigarette smoking was statistically insignificant (χ^2 (4) =0.86, p= 0.93).

Table 4.3: Percentage frequency of personal behaviours among the artisans

Study variable (n=55)	Frequency (n)	Percentage (%)
Cigarette smoking at worksites (hand to mouth activity)	Yes (11)	20.0
	No (44)	80.0
Eating at worksites (hand to mouth activity)	Yes (51)	92.7
	No (4)	7.3
Hand washing before any hand to mouth activity (before eating at the worksites)	Yes (26)	47.3
	No (29)	52.7

Notwithstanding the apparent risk of not washing their hands, 52.7% of the artisans reported not to be washing their hands before eating at the worksites. This suggests lack of an understanding of the likely effects of such behaviours that perhaps would increase the risk of ingesting lead particles and dust. Consistent finding was reported by Rongo *et al*. (2004) in their cross sectional survey of the small-scale industry in Dar es Salaam-Tanzania, where 36.7% of the study respondents indicated to be washing their hands but not all the time. Hand washing practices may play a significant role in reducing occupational health risks. Far *et al*. (1993) in their study of evaluating the significance of mouth and hand contamination for lead absorption in lead-acid battery workers in Singapore, reported that an implementation of hand washing and mouth-rinsing program resulted to a decrease in blood lead levels among the workers. This is an indication that hand to mouth activities may be important risk factors to occupational lead exposures.

Hand washing particularly with soap is recognized as an effective way to remove dirt from the hands, which decreases the risk of health hazards (Curtis and Cairncross, 2003). Adequate hand washing involves washing both hands with soap under running water (Monney *et al*., 2014b). On the contrary, this was not the practice among the artisans who reported to be washing their hands before eating. These behaviours exhibited poor personal hygiene. Without proper adequate hand washing, dust that contains lead may be ingested during these incidents of hand to mouth contacts. Studies have recorded that lead intake by ingestion as a result of contaminated hands had a significant effect on lead absorption in a group of workers from a car battery factory (Hwang *et al.*, 2002). While other studies have demonstrated that practicing improved personal hygiene among other control measures could decrease occupational exposures to lead (Virji *et al*., 2008a).

4.4 Training and awareness on occupational safety and health practices

In this study, 92.7% of the artisans had not received any kind of training on occupational safety and health and the same percentage were not aware of any occupational safety and health regulation governing the workplace (Figure4.5). Moreover, 69.1% of the artisans were not aware of any chemical hazard in their workplace that could cause them ill health (Figure 4.5). A similar study on assessment of informal sector garages; workers' safety awareness in Ghana by Okwabi *et al*. (2016), reported that no respondents had received any training on personal safety and use of personal protective equipment. This implies that occupational safety and health services are inadequate at the informal sector. Chi square test of independence showed a statistically significant association between training on occupational safety & health and education level, (χ^2 (4) = 29.70, p=0.00) (Appendix 11), and so was the association between awareness on occupational safety & health and education level, (χ^2 (4) = 29.70, p=0.00).

Training and awareness on occupational safety and health was positively influenced by education. Artisans who reported to have been trained on occupational safety & health were aware of the OSH regulations and had higher levels of education compared to those who reported to have not been trained. However, awareness on hazardous chemical substances at the worksites was statistically insignificantly associated with the level of education (χ^2 (4) = 5.4, p=0.25). This could be true since chemical safety requires a deeper understanding of the safety practices and as such might not be within the scope of the curriculum standards likely to be taught at the level of the artisans. Studies have shown that workers with higher levels of education have a better understanding of health and safety issues, and are more likely to be compliant with safety measures and thus less likely to suffer ill health than those with lower levels of education (Ayim and Salminen, 2010).

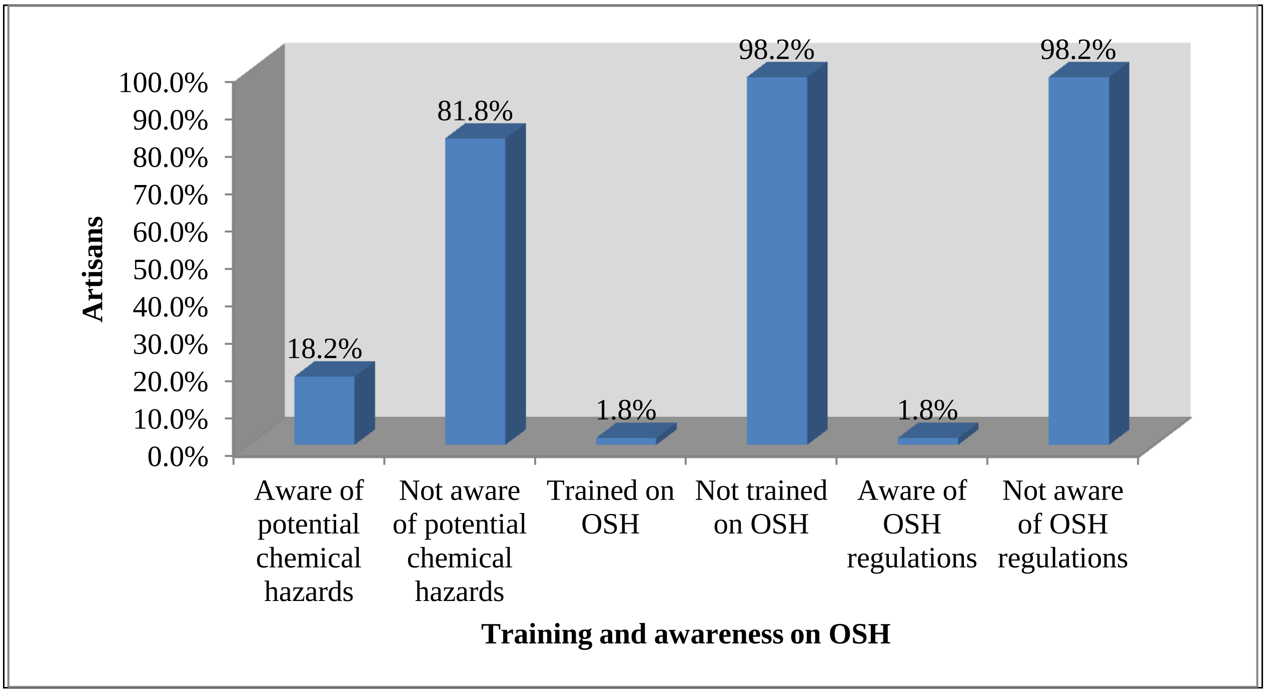

Figure 4.5: Training and awareness on OSH practices and regulations

Appreciating hazards and using the available protective measures and devices at the workplace is essential for the prevention and control of the hazards. Studies have shown that training on occupational safety and health as a control measure reduces occupational exposures to lead (Colligan and Cohen, 2004).The reported inadequate use of personal protective equipment may also be attributed to lack of training and awareness on occupational safety and health. In addition, on lack of awareness on chemical hazards in the workplace that may contribute to occupational illnesses. Conversely, Chi square test of independence showed statistically insignificant association between training on occupational safety and health and use of personal protective equipment (PPEs) among the artisans, (χ^2 (3) = 6.13, p=0.12) (Appendix 12). Moreover, there was no association between awareness on chemical hazards and the use of personal protective equipment among the artisans, (χ^2 (3) = 0.82, p=0.84) (Appendix13).

There seemed to be a gap between training, awareness and use of personal protective equipment among the artisans. The results were contrary to the expectation since the artisans who were aware of the likely chemical hazards in the workplace could be motivated to use the PPEs for personal protection. However, the results were similar to that of a study by Sabitu *et al*. (2009) on the awareness of occupational hazards and utilization of safety measures among welders in Kaduna, Nigeria, who reported high level of awareness on occupational hazards but low utilization of protective measures. Sambo *et al*. (2012) recorded similar findings in their study on determinants of occupational health hazards among roadside automobile mechanics in Zaria, Nigeria, in which they reported high level of awareness and low usage of personal protective devices.

Nearly all the artisans gained knowledge and skills informally through apprenticeship without formal technical training where safety precautions and safe work practices are taught. This was in contravention to the Occupational Safety and Health Act 2007, Part XI on health, safety and welfare, which spells out that apprentices engaged in a hazardous work process or work condition should be adequately supervised and protected against the occupational hazards. Health and safety culture at any work place requires finances, time and concerted effort among the employees and the employers, the informal automobile repair workshops is no exception for them to achieve safe work place environment. The artisans need to be properly trained and motivated towards occupational safety and health services. The experienced artisans should integrate basic occupational health and safety practices for example, use of personal protective equipment during the apprenticeship trainings. This might afterwards instill a safety and health culture that would enhance the utilization of such services. Such initiatives would require collaboration between the artisans and relevant stakeholders such as Directorate of Occupational Safety and Health Services (DOSHS) and the county government.

The study demonstrated that there was low awareness and training on occupational safety and health services among the artisans. Part III of the Occupational Safety and Health Act, 2007, under administration, section 23(c) and (d) mandates DOSHS to promote occupational safety and health in all workplaces and in the community to encourage safety and health culture, and conduct training for enterprises and self-employed persons (GOK, 2007). This presents a good opportunity for such collaborative efforts since the artisans were more enthusiastic to participate in such training programs.

4.5 Work site conditions and characteristics

The work environment is essential for workers' safety and health. Key concerns on the environmental conditions in an automobile repair workshop may entail good housekeeping, ventilation, drainage, and sanitation facilities. Good housekeeping means cleanliness and ambient working environment. Walkthrough surveys and face-to-face interviews were conducted in the ten sampled automobile repair workshops in order to assess the worksite conditions that could predispose the artisans to occupational lead exposures. All the ten workshops (100%) were small-scale open-air repair workshops indiscriminately established and scattered in the study locality (Figure 3.1). The ten workshops had a population of 108 artisans with the smallest having 3 employees and the largest 19 (Appendix 5). Most studies have reported that the automobile repair workshops operate in an open environment (Rongo *et al*., 2004; Apreko *et al*., 2015).

The surrounding cleanliness was inadequate in 90% of the workshops, which also had combustible scrap, debris and solid wastes not collected and stored safely. Only one workshop, which had three artisans and dealt with only radiators repair was relatively clean with scraps and debris removed from the worksite (Table 4.4). Sambo *et al*. (2012) had similar findings in their study on determinants of occupational health hazards among roadside automobile mechanics in Zaria, Nigeria. Their study reported that 65.5% of the garages had inadequate cleanliness. According to Occupational Safety and Health Act, 2007, a clean and tidy workplace is essential to ensure the health and safety of the workers. Regular cleaning of workplaces should be carried to ensure an adequate level of workplace hygiene. Additionally, Part IX of the Act requires that suitable system be developed for the safe collection and disposal of chemical wastes, and empty containers of chemicals to avoid the risks to safety and health of employees and the environment. All the workshops (100%) had no suitable system in place to regularly and promptly remove empty used chemical containers and wastes at the worksites.

Part VI of the Occupational Health and Safety Act, 2007 on general health provisions, section 48 (2), describes an adequate workplace as of sufficient size for work to be carried out with ease and shall further have the necessary free space. In addition, having regard to the nature of the work, an adequate amount of air for each employee, the minimum permissible being $10m^3$ per person. With the exception of the workshop with the three employees, all the other workshops (90%, n=9) were crowded with motor vehicles and scrap metals (Table 4.4) thus lacking the necessary free space as described by the OSH Act, 2007. This was not expected given that the workshops were open-air worksites. Sambo *et al*.(2012) in their study in Nigeria also reported inadequate workspace (71%) at the studied automobile workshops. The general health provisions of the Act require workplaces not to be overcrowded while work is in progress in order to prevent risk of injury to the health of the workers.

More than a half (60%) of the workshops had no form of sanitation facility (Table 4.4). The artisans reported to rely on neighbouring toilets for sanitary convenience. Less than a half (40%) of the workshops had washrooms or toilets and among them one had a pit latrine which was dilapidated and unhygienic (Plate 4.2). These washrooms had no separate provisions for females and males, however noted that the males dominated the occupation. The results were coherent with those of Apreko *et al*. (2015) who in their study on safe work environment in local automotive garage in Ghana, reported that the garages had no formal suitable toilet facility. The finding contradicts Occupational Safety and Health Act, 2007 part VI requirements, which stipulate that every workplace shall have sufficient and suitable sanitary facility, and where both sexes are present, separate facilities, shall be provided. The finding is not only a health risk to the artisans but also to the other surrounding business facilities, residents and the environment.

Table 4.4: Status of worksite conditions

Study variable	Responses (N=10) (Percentage) Yes (%, n)	No (%, n)
Generally open air workshop	(100, n=10)	(n=0)
Are all worksites clean and orderly?	(10, n=1)	(90, n=9)
Is combustible scrap, debris and waste stored safely and removed from the worksite promptly?	(10, n=1)	(90, n=9)
Are washrooms/toilets available and kept clean	(40, n=4)	(60, n=6)
Is water provided for drinking and washing	(30, n=3)	(70, n=7)
Are eateries and restrooms available and kept clean	(n=0)	(100, n=10)
Are the working space adequate and easily accessible	(10, n=1)	(90, n=9)

The study also found out that only 30% of the workshops had access to water supply for drinking and washing, one among them had a car wash (Table 4.4). This implied that the artisans could not conveniently wash their hands that could improve their personal hygiene. This may have contributed to the reported poor hand washing hygiene practices among the study population. The finding was corroborated by those of Rongo *et al.*(2004), who reported lack of washing facilities in a similar study on small-scale automobile workshops in Dar es salaam, Tanzania. Conversely, Suplido and Ong (2000) reported that all the studied workplaces had running water for hand washing in their study on lead exposure among small-scale automobile radiator mechanics in Manila, Philippines.

Occupational Safety and Health Act 2007 Part X, requires workplaces to have easily accessible safe drinking water and adequate suitable washing facilities for employees. Water is necessary in maintaining high personal hygiene and general cleanliness, which are essential in prevention and control of occupational exposures in such workplaces. Exacerbating the plight of these artisans are the adverse weather conditions such as rain and excessive heat, under which they work because of inadequate provision of shelter. These could have other negative health implications. Rains for example, could result to stagnant water in the worksites thereby breeding sites for disease vectors. This together with poor sanitation may result to spread of other diseases such as cholera. Exposure to heat coupled with physically demanding work has also been reported to cause reproductive problems mainly in men, by reducing sperm counts, and may cause skin cancer as a result of penetrating ultraviolet radiations on the surface skin (Fartasch *et al*., 2012).The workshops therefore, offered little or no environmental and socio-economic protection to the artisans.

Plate 4.2: Pit latrine at one of the automobile workshops

4.6 Personal task-based airborne lead exposure levels

In order to assess the airborne lead exposure levels in the workshops, a total of 20 tasked- based personal air samples (two samples from each workshop) were collected from the ten workshops and airborne lead levels determined(Appendix 6).The task-based personal sampling strategy permitted direct measurement of occupational tasks that contributed to the artisans' exposure levels. Table (4.5), lists the mean and the standard error (as ± SE) of the measured values for the respective occupational tasks. The individual measured airborne lead (PbA) exposure values ranged from 1.15 to 86.19µg/m^3 minimum and maximum values respectively. The arithmetic mean PbA level ± SE exposures varied from 76.11±10.18µg/m^3

lead for lead acid battery repairs to 4.29±0.25µg/m^3 for radiator repairs. Notable in each task that there was a large standard error (SE) probably reflecting the fact that there were no standard materials and work procedures for respective tasks in the workshops.

Lead acid battery repairs recorded a higher mean task-based airborne lead exposure levels compared to the other occupational tasks. This was probably because the task directly involved leaded battery components e.g. the electrodes that were potential sources of lead fumes and lead oxide particles. Studies have recorded high airborne lead levels in lead acid battery repairs and recycling activities. For example, Ibiebele (1994) recorded high mean airborne lead in a study on air lead levels in battery recycling factory in West Indies, and Ravichandran *et al.* (2005) also reported high airborne lead levels in their study on environmental monitoring in a lead acid battery repair plants in India. These are indications that the occupation is a high risk for lead exposures.

Spray painting and welding exhibited relatively high mean PbA exposure levels of 21.72±4.83µg/m^3 and 19.81±7.33µg/m^3 respectively. The overspray in spray painting could contain lead particles of paint pigments, lead dusts, and in some cases vapor fumes. Noteworthy, that the artisans were using solvent-based paints that could be having high lead content. A study by Virji *et al*. (2009b) on task-based lead exposures among small-scale bridge painters in Massachusetts recorded high personal inhalable lead exposures. This corroborates the findings that spray painting could be a high-risk task for occupational lead exposures among the artisans. Furthermore, the conventional spray guns used at the workshops are characterized by high amount of overspray and auto-refinishing paint thus likely to increase lead exposures. Welding on the other hand, have potentially leaded welding fumes and gases, which could result from the base material being welded or the filler metal,coatings and paints on the metals.Radiator repairs had potential lead exposures during soldering through lead fumes, and lead dusts that accumulate in radiator parts. While decarburizing engine components and replacing dirty air and fuel filters and plugs could potentially expose the artisans to lead dusts in general automobile mechanics tasks. The findings suggest that the occupational tasks had an influence on the airborne lead exposure levels and thus significant pollution from occupational lead exposures at the workshops.

Table 4.5: Tasked-based airborne lead exposure levels

Occupational task	Number of samples (n)	Mean Airborne lead conc. (S.E) µg/m^3	Range		
			Minimum	Maximum	
Radiator repairs	2	4.29 (0.25)	4.04	4.54	ANOVA
Lead acid battery repairs	2	76.11(10.81)	65.30	86.91	F (4,15)= 10.09
Spray painting	6	21.72 (4.83)	8.65	43.71	*p*=0.000
Welding	6	19.81 (7.33)	1.15	48.29	
General mechanics	4	10.25 (2.57)	3.40	15.48	
Total	20	22.55 (5.05)	1.15	86.91	

Accordingly, analysis of variance statistical test showed a statistically significant difference in task based airborne lead exposure levels in different occupational tasks ($F_{(4, 15)}$ =10.087, p=0.000) (Table 4.5). Goldberg *et al*. (1997) reported consistent findings in their study on assessing lead exposure among bridge rehabilitation workers in New York. The task-specific data showed significant differences in exposure levels among different tasks. This indicates the usefulness of task-based exposure data, which may be used for the development of workers protection intervention programs. Posthoc comparisons using Tukey HSD test showed significant differences in mean airborne lead exposure levels between lead acid battery repairs and the other tasks. However, among the other tasks the differences were statistically insignificant (Table 4.6). This signifies that lead acid battery repairs could be the leading source of occupational exposures to lead among the study population.

Table 4.6: Multiple comparison of PbA exposure levels across the tasks using Tukey HSD test

(I) Occupational activity	(J) Occupational activity	Mean Difference (I-J)	Std. Error	P value	95% CI Lower Bound	95% CI Upper Bound
Radiator repairs	Lead acid battery repairs	-71.815*	13.226	0.001	-112.655	-30.975
	Spray painting	-17.432	10.799	0.511	-50.777	15.914
	Welding	-15.522	10.799	0.615	-48.867	17.824
	General mechanics	-5.955	11.454	0.984	-41.323	29.413
Lead acid battery repairs	Radiator repairs	71.815*	13.226	0.001	30.975	112.655
	Spray painting	54.383*	10.799	0.001	21.038	87.729
	Welding	56.293*	10.799	0.001	22.948	89.639
	General mechanics	65.860*	11.454	0.000	30.492	101.228
Spray painting	Radiator repairs	17.432	10.799	0.511	-15.914	50.777
	Lead acid battery repairs	-54.383*	10.799	0.001	-87.729	-21.038
	P-value > 0.05 with all the other tasks					
Welding	Radiator repairs	15.522	10.799	0.615	-17.824	48.867
	Lead acid battery repairs	-56.293*	10.799	0.001	-89.639	-22.948
	P-value > 0.05 with all the other tasks					
General mechanics	Radiator repairs	5.955	11.454	0.984	-29.413	41.323
	Lead acid battery repairs	-65.860*	11.454	0.000	-101.228	-30.492
	P-value > 0.05 with all the other tasks					

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

4.6.1 Comparison of airborne lead exposures (PbA) with the Permissible Exposure Limit (PEL)

Only lead acid battery repair mean PbA exposure levels exceeded the WHO 50µg/$m^3$8-hr time-weighted average (TWA) permissible exposure limit (PEL) (OSHA, 2013). Consistent results were reported by Were *et al.* (2012) in their study on assessment of airborne lead levels in recycling battery plants in Nairobi, which recorded values exceeding OSHA permissible exposure limit. However, the overall average airborne lead level in the workshops was significantly lower (22.55 µg/m^3 ± 5.05 SE) than the PEL value. Notably the workshops were open air thus greater dilution of the airborne lead concentration could be achieved in such environment. Even though the airborne lead PEL value is 50µg/m^3, exposure levels ≥30µg/m^3 is the recommended action level where periodic biomonitoring is required (CDC, 2012). Therefore, considering all the airborne lead measurements, 25% exceeded the action level and among them were43.71µg/m^3 and 48.29µg/m^3 for spray painting and welding activities respectively. This implies that periodic biomonitoring is necessary among the study population.

Contrary to the permissible exposure limits (PEL), the Kenya factories and other places of work Act, (cap. 514), hazardous substances regulation, 2007 provides for the occupational exposure limits–control limits (OEL-CL) for lead as 0.15 mg/m^3 (150µg/m^3). This is three times the OSHA permissible exposure limit (PEL) and as such should be considered for review. Studies have shown that any lead exposure that is likely to cause an increase in blood lead levels regardless of airborne lead levels is considered significant (Holland and Cawthon, 2016). For example, a dose–response relationship study of occupational lead exposure and health effects in China by Wu *et al*. (2016) reported airborne lead concentrations associated with lead poisoning as 20µg/m^3 and 10µg/m^3 for occupational exposure to lead dust and lead fumes, respectively. Other than the high occupational lead exposure limits of 150µg/m^3 set by Kenya under the factories and other places of work Act, (cap. 514), the provisions of the Act are rarely enforced in the informal sector enterprises and as a result, such hazards are neither prevented nor controlled in such enterprises.

As Kenya focuses and transits to industrial economy, there is need for enforcement of occupational health and safety regulations, review and enforcement of applicable policiesin the rapidly growing informal automobile sector. More stringent regulations and policies regarding chemical exposures such as lead, biomonitoring, and medical removal from the workplace of affected workers should be developed. Exposures from individual occupational tasks may contribute to the overall ambient airborne lead within the workshop and environmental pollution. ANOVA statistical test showed no statistically significant difference on airborne lead levels across the workshops, ($F (10, 9) = 1.07$, $p = 0.45$). This was probably true because there were no observed differences in the work techniques, practices and conditions across the workshops e.g. a spray gun was used to apply auto-finishing paint across all the workshops.

4.7 Blood lead levels (BPb) of the study population

Measuring the concentration of lead in blood is the primary tool accepted for screening, diagnostic and epidemiological studies for lead exposures (WHO, 2011). This is because studies have shown that blood lead can be linked with clinical effects (ATSDR, 2007; Betts, 2012). In this study, high blood lead levels was defined as ≥20 µg/dl current biological exposure index (BEI) of concern for adults recommended by the American Conference of Governmental Industrial Hygienists ACGIH® (NIOSH, 2017b). A total of 30 samples were collected proportionately among the five sampled occupational strata, across the ten workshops (Appendix, 4).

4.7.1Artisans' blood lead levels (BPb)

The mean blood lead (BPb) level of the artisans was 25.36µg/dl ± 2.62SE, with a minimum value of 0.04µg/dl and maximum 61.37µg/dl (range, 61.33µg/dl) (Table4.7). Noteworthy that the blood lead levels were more dispersed due to diverse occupational tasks with different lead exposure levels. The highest mean BPb level was recorded in lead acid battery repair artisans (47.85±13.53µg/dl) followed by welders and spray painters, whereas the lowest (9.07±8.26µg/dl) among radiator repairs artisans. High blood lead levels among lead acid battery repairs were probable because of direct contamination with dust and fumes generated in handling leaded electrodes and lead oxides in the batteries. Suplido and Ong (2000) reported consistent results in their study on lead exposure among small-scale battery and radiator mechanics in Philippines. They reported mean blood lead level that was significantly higher for battery workers (54.23 mg/dl) compared to other workers. Other reviewed studies have also recorded high blood lead exposure levels among lead acid battery workers (Gottesfeld and Pokhrel, 2011). The observed low blood lead levels among radiator repairs probably was as a result of their low workload, since they reported minimal frequency of work (repair activities) comparable to other occupational tasks at the time of the study.

However, similar studies have reported relatively high blood lead levels among radiator repairs, for example a study by Nunez *et al*. (1993) on lead exposure among automobile radiator repair workers in New York, reported a relatively high mean blood lead levels of (25µg/dl).

Table 4.7: Blood lead concentrations of artisans per occupational task

Occupational task	Number of samples (n)	Mean Blood lead conc. (S.E) µg/dl	Range		
			Minimum	Maximum	
Radiator repairs	3	9.07 (8.28)	0.04	25.60	ANOVA
Lead acid battery repairs	2	47.85 (13.53)	34.32	61.37	F(4,25)= 4.52
Spray painting	9	26.62 (4.76)	5.74	46.18	
Welding	8	31.40 (3.81)	18.88	52.10	*p*=0.007
General mechanics	8	18.40 (2.04)	10.36	27.69	
Total	30	25.36 (2.62)	0.04	61.37	

Accordingly, there was a statistically significant difference in BPb levels among the artisans in different occupational tasks, (F (4, 25) =4.52, p=0.007) (Table 4.7). The finding was inconsistent to the findings of a study conducted to assess lead exposure among automobile technicians in Pakistan, where specific occupational tasks performed by the technicians did not influence the BPb levels (Ahmad *et al*., 2018).The magnitude and the work processes in each occupational task were distinct. Among the tasks that exceeded 20µg/dl threshold included those with welding and spray painting activities. This signified that such tasks were likely to have greater risks of occupational exposures to lead than the others. Welding or soldering for example requires that the material melt or fuse through heating which generates leaded fumes depending on the material being welded (NIOSH, 2017a). Moreover, artisans carry out surface sanding and grinding activities prior to spray painting (Enander *et al*., 2004). Possibly, during these occupational activities, fumes and dust that might contain lead is inhaled or ingested. Posthoc analysis using Tukey HSD test showed that the mean BPb levels were statistically significantly higher ($p<0.05$) in lead acid battery repairs and maintenance compared to the other occupational tasks (Table 4.8).

Table 4.8: Multiple comparison of BPb exposure levels across the tasks using Tukey HSD test

(I) Occupational activity	(J) Occupational activity	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Radiator repairs	Lead acid battery repairs	-38.77500*	10.735	0.011	-70.302	-7.248
	Spray painting	-17.552	7.840	0.199	-40.577	5.472
	Welding	-22.328	7.961	0.066	-45.709	1.054
	General mechanics	-9.335	7.961	0.767	-32.716	14.046
Lead acid battery repairs	Radiator repairs	38.77500*	10.735	0.011	7.248	70.302
	Spray painting	21.223	9.193	0.175	-5.776	48.221
	Welding	16.448	9.297	0.413	-10.856	43.751
	General mechanics	29.44000*	9.297	0.030	2.137	56.744
Spray painting	P-value > 0.05 with all the other tasks					
Welding	*P*-value > 0.05 with all the other tasks					
General mechanics	Radiator repairs	9.335	7.961	0.767	-14.046	32.716
	Lead acid battery repairs	-29.44000*	9.297	0.030	-56.744	-2.137
	Spray painting	-8.217	5.714	0.610	-24.999	8.565
	Welding	-12.993	5.880	0.209	-30.261	4.276

*. The mean difference is significant at the 0.05 level

Even though all the workshops were open-air workshops, further analysis of variance, showed a statistically significant difference in blood lead levels among the artisans across the different automobile repair workshops, (F (9, 20) = 7.52, *p*= 0.000). This could be attributed to the different occupational activities that were being undertaken at the workshops. This was also plausible because there could be other sources and pathways of lead exposure within the workshops. Posthoc comparisons using Tukey HSD test indicated statistically significant differences in mean blood lead levels across eight workshops. However, in two workshops (006 and 010) the differences were statistically insignificant (Table 4.9).The findings implied that the blood lead levels could be associated with specific occupational tasks since the worksite conditions were similar.

Table 4.9: Multiple comparison of artisans' BPb levels across workshops using Tukey test

(I) Workshop	(J) Workshop	Mean Difference (I-J)	Std. Error	P value	95% CI Lower Bound	95% CI Upper Bound
001	002	40.895*	8.245	0.002	11.700	70.090
	003	30.450*	7.140	0.011	5.166	55.734
		P-value > 0.05 with all the other workshops				
002	001	-40.895	8.245	0.002	-70.090	-11.700
	004	-31.799*	6.898	0.005	-56.225	-7.373
	007	-46.152*	7.526	0.000	-72.803	-19.500
	008	-29.808*	7.526	0.021	-56.460	-3.157
		P-value > 0.05 with all the other workshops				
003	001	-30.450	7.140	0.011	-55.734	-5.166
	004	-21.354*	5.531	0.026	-40.939	-1.769
	007	-35.707*	6.297	0.001	-58.005	-13.409
		P-value > 0.05 with all the other workshops				
004	002	31.799*	6.898	0.005	7.373	56.225
	003	21.354*	5.531	0.026	1.769	40.939
		P-value > 0.05 with all the other workshops				
005	007	-29.429*	6.297	0.004	-51.727	-7.131
		P-value > 0.05 with all the other workshops				
006		P-value > 0.05 with all the other workshops				
007	002	46.152*	7.526	0.000	19.500	72.803
	003	35.707*	6.297	0.001	13.409	58.005
	005	29.429*	6.297	0.004	7.131	51.727
	009	27.192*	7.526	0.043	0.540	53.843
		P-value > 0.05 with all the other workshops				
008	002	29.808*	7.526	0.021	3.157	56.460
		P-value > 0.05 with all the other workshops				
009	007	-27.192*	7.526	0.043	-53.843	-0.540
		P-value > 0.05 with all the other workshops				
010		P-value > 0.05 with all the other workshops				

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

4.7.2 Relations of individual characteristics with blood lead levels among the artisans

The observed significant differences in blood lead levels of the artisans in different occupational tasks and across the different workshops could also be as a result of their individual characteristics and personal work behaviours, which may influence the blood lead levels. The following possible determinant factors were examined in the study to ascertain the relationships.

The artisans' mean blood lead levels were compared by age. ANOVA statistical test results showed no statistically significant difference in blood lead levels with the age of the artisans ($F(3, 26) = 0.20$, $p=0.896$) (Figure 4.6, Appendix14). Consistent findings have been reported by similar studies e.g. no correlation was found between prevalence of high BPb and age in an epidemiological study of lead exposure among lead workers in West Turkey (Tozun *et al*., 2009). The finding was also similar to a study by Tripathi *et al.* (2001) in their study of atmospheric and blood lead as indicators of vehicular traffic and other emission sources in Mumbai, India. Occupational exposures may be intermittent and acute thus the observed association of blood lead exposure levels with age. However, artisans whose ages were ≥33 years had mean blood lead level of 28.64±4.57µg/dl, slightly higher than artisans whose ages were <33 years (Figure 4.6, Appendix, 14).Suggesting that older artisans had mean blood lead levels slightly higher than younger artisans.

This signifies that an increase in age could possibly influence blood lead concentrations since lead is able to accumulate in other tissues such as bone, which later can contribute to blood lead concentrations through bone resorption (ATSDR, 2007). Other Studies in the literature have shown that environmental exposures to lead increase blood lead levels with increase in age. Lead levels in adults increased with increasing age in a study conducted to assess trace element levels and its association with age in Canada (Clark *et al.,* 2007). Apostoli *et al.* (2002) in their study on blood lead reference values: the results of an Italian polycentric, also reported that age significantly influenced blood lead levels. These are plausible because there could be gradual accumulation of lead in body tissues through environmental exposures.

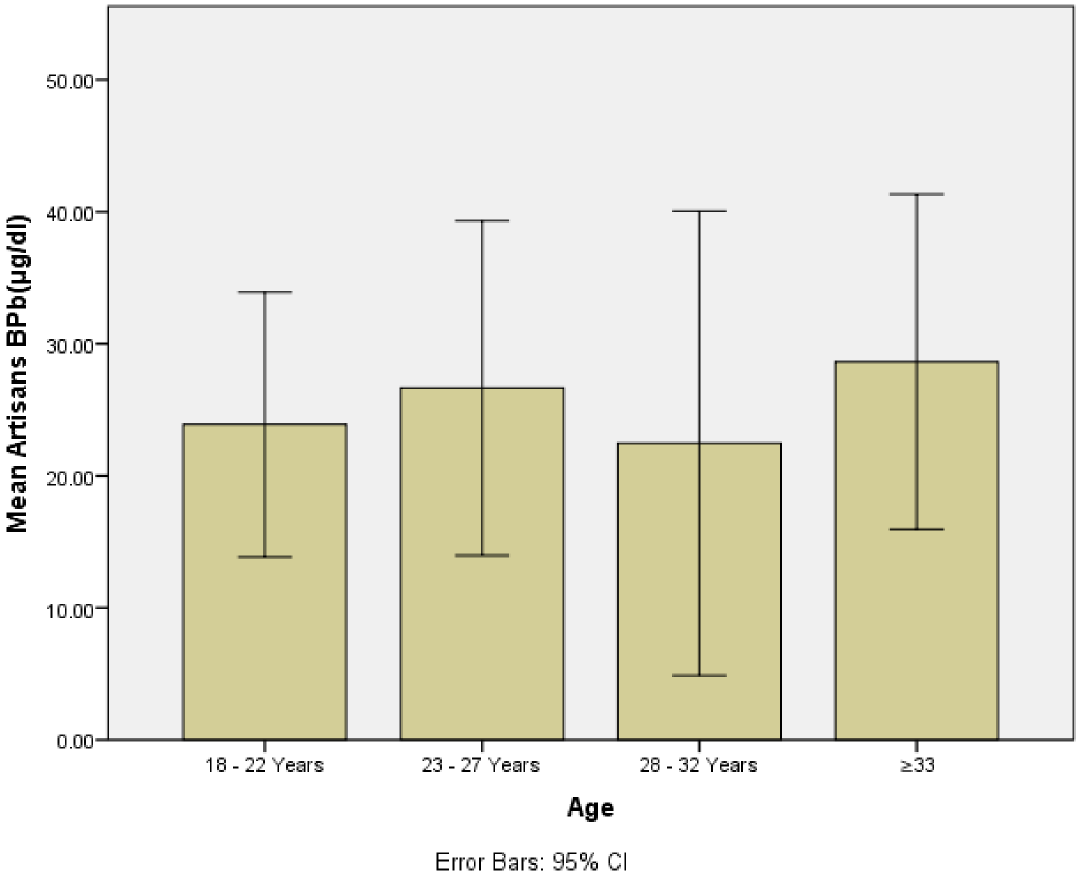

Figure 4.6: Artisans blood lead levels among different age groups

Duration of exposure is equally important because lead accumulates in target organs over time and this could have an effect on the dose-response relationship (Wu *et al.*, 2016). Notable that not all of the lead absorbed in the body are eliminated and therefore continued exposure may result in accumulation of lead in body tissues particularly the bones (ATSDR, 2007). However, the artisans' mean blood lead levels were not significantly different with the durations in the occupation ($F (3, 26) = 2.40$, p=0.091) (Table 4.10). Correspondingly, Saliu *et al.* (2015) found that duration on the occupation was not significantly associated with high blood lead levels in a comparative study conducted to assess blood lead levels of automobile technicians in Lagos, Nigeria. Acute occupational lead exposures and environmental exposures might cause the artisans to accumulate high amount of lead in a shorter period hence the insignificant relationship.

Table 4.10: Artisans' blood lead levels with different durations in the occupation

Duration in the occupation	Mean BPb conc. (S.E) µg/dl	Range		
		Minimum	Maximum	
1 - 3 Years (n=14)	27.09 (4.09)	5.74	61.37	ANOVA
4 - 6 Years (n=10)	27.11 (3.85)	12.23	52.10	$F(3,26)= 2.40$
7 - 9 Years (n=2)	0.81 (0.77)	0.04	1.57	
≥10 Years (n=4)	27.24 (4.78)	19.77	41.00	$p=0.091$

It is important to note that the relationship between blood lead levels, age and duration of exposure can further be complicated by conditions such as bone resorption, which may occur at an advancing age thereby influencing an increased blood lead levels among the older artisans. A steady state between resorption and elimination may be achieved at some point because continuous occupational exposure does not occur throughout the working life or the age cycle e.g. while not at work. Further analysis of variance showed that blood lead levels increased with increase in daily work hours, but this was also not significant ($F (2, 27) =1.54$, $p=0.233$) (Figure 4.7, Appendix 15). The observed increase in blood lead levels with increasing daily work hours though not significant, is plausible because lead in blood measures current exposures since blood lead concentration changes rapidly with exposures and has a short half-life of 28 to 30 days (ATSDR, 2007).

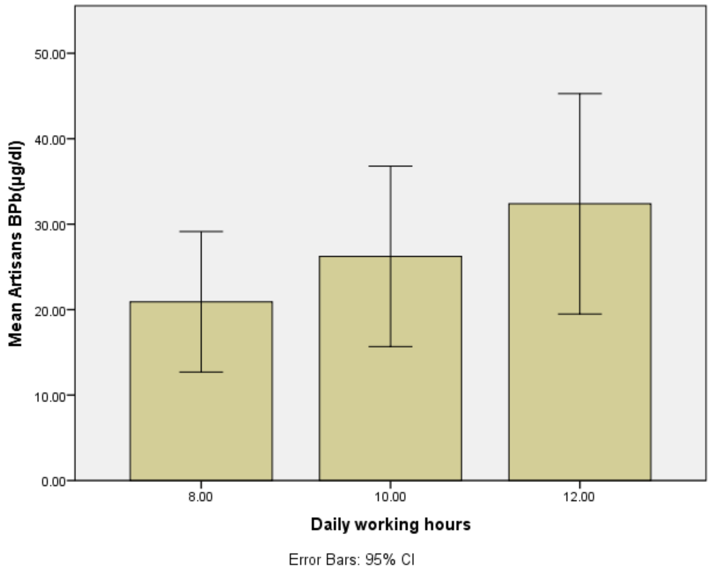

Figure 4.7: Artisans' blood lead levels across different daily working hours

These findings suggest that the same risk factors apply for the observed BPb levels among the artisans regardless of age, duration on the occupation and daily work hours. The variables could however reflect potential differences among the artisans in lead toxicokinetics i.e. distribution, metabolism and storage.

4.7.3 Relationship between personal work behaviour and blood lead levels among the artisans

Hand to mouth activities may influence blood lead levels since lead particles and dust may be ingested in such contacts. The study assessed cigarette smoking, eating at the worksites, and hand washing practices particularly washing of hands before eating among the artisans as some of the personal work behaviours that may influence the artisans' blood lead levels. The blood lead levels were stratified into <20 μg/dl and ≥20 μg/dl and chi-square test of independence performed to examine these relationships.

Cigarette smoking could contribute to the elevated blood lead levels among the artisans. A larger proportion (13.33%) of artisans who reported smoking recorded high blood lead levels (Table4.11). However, chi-square test of independence showed no statistical significant relationship between the blood lead levels with cigarette smoking, (χ^2 (1) =0.0, p=1.0) (Table, 4.11). Conversely, a longitudinal study conducted in Taiwan among battery workers reported that frequent smoking at work was statistically significantly (p= 0.001) associated with high blood lead concentrations (Chuang *et al*., 1999). Smoking could possibly increase hand to mouth contacts and thereby ingestion of lead particles and dust. Other studies have recorded contradictory findings on the relationship between cigarette smoking and blood lead concentrations. Some studies have demonstrated that cigarette smoking or secondary exposure to cigarette smoke contributes to elevated blood lead levels (Mannino *et al*., 2005) while others disapproving this relationship (Suna *et al*., 1991). Cigarette smoking as a health behaviour has been reported to have a significant impact on health inequalities (Barbeau *et al*., 2004). This is probably because it contains high contents of both organic and inorganic toxicants e.g. it has been reported that one of the most abundant redox inactive heavy metal in cigarette smoke is lead (Sebiawu *et al.,* 2014).

Table 4.11: Distribution of artisans' BPb levels by cigarette smoking at work cross-tabulation

			Artisans BPb levels		
			≥20 μg/dl	<20 μg/dl	Total
Smoking at work	Smokers	Count (n)	4	2	6
		% Proportion	13.33	6.67	20.0
	Non smokers	Count (n)	16	8	24
		% Proportion	53.33	26.67	80.0
Total		Count (n)	20	10	30
		% Proportion	66.66	33.34	100.0

p=1.0

Similarly eating at the worksites by the artisans was not associated with the observed blood lead levels (χ^2 (1) =0.27, *p*=0.61) (Table4.12). However, a remarkable 63.33% of the artisans that reported eating at the worksites had high blood lead levels. The finding was consistent to a study conducted to examine the relationship of blood lead levels with personal hygiene habits in lead battery workers in Taiwan, where eating food at work was not associated (*p*= 0.069) with blood lead concentrations (Chuang *et al.*,1999). The reported 47.3% hand washing before eating among the artisans perhaps may influence this finding.

Table 4.12: Distribution of artisans' BPb levels by eating at worksite cross-tabulation

			Artisans BPb levels		
			≥20 μg/dl	<20 μg/dl	Total
Eating at worksites	Eat at worksite	Count (n)	19	9	28
		% Proportion	63.33	30.0	93.33
	Do not eat at worksite	Count (n)	1	1	2
		% Proportion	3.33	3.33	6.67
Total		Count (n)	20	10	30
		% Proportion	66.67	33.33	100.0

p= 0.61

In Table (4.13), 20% of the artisans who did not wash their hands before eating hand high blood lead levels (≥20 μg/dl). However, hand washing before eating was also not significantly associated with the blood lead levels, (χ^2 (1) =0.34, *p*=0.56) (Table 4.13). On the contrary, a study by Rodrigues *et al.* (2009) on personal exposure, and behaviour as determinants of blood lead among bridge painters in New England, reported that workers with low personal hygiene had significantly (p = 0.02) higher blood lead levels than workers with high personal hygiene. Besides, workers with higher levels of surface lead on their hands had higher blood lead levels in a study conducted by Askin and Volkmann (1997) in U.S.A. Hand washing before eating signifies some level of personal hygiene among the artisans. Lead particles and dust on the surface of the hands could be washed away thereby reducing the possibility of lead ingestion through hand to mouth transfer.

Table 4.13:Distribution of artisans' BPb levels by Hand washing before eating or smoking cross-tabulation

			Artisans BPb levels		
			≥20 μg/dl	<20 μg/dl	Total
Hand washing before eating or smoking	Wash hands before eating or smoking	Count	14	8	22
		% Proportion	46.66	26.67	73.33
	Do not wash hands before eating or smoking	Count	6	2	8
		% Proportion	20.0	6.67	26.67
Total		Count	20	10	30
		% Proportion	66.67	33.33	100.0
p=0.56					

4.7.4 Association of education and income with blood lead levels among the artisans

Education and income are indicators of socioeconomic status in a society, which in turn are related to resources and susceptibilities that may affect occupational health and safety. Studies have shown that low socioeconomic status (i.e. poverty or lack of education) is associated with high blood lead levels (Kim *et al.,* 2018). Socioeconomic inequality is possible contributor to nutritional deficiencies, resulting in increased vulnerability to lead poisoning (Kordas *et al.,* 2007). The possible associations of levels of education and income with blood lead levels were therefore examined in the study.

In order to perform chi square test of independence to examine the relationship between the artisans' blood lead (BPb) levels and their levels of education, the blood lead levels were stratified into <20 μg/dl and ≥20 μg/dl. Table (4.14), shows the percentage distribution of low and elevated blood lead levels among the artisans by their levels of education. Chi-square test of independence showed no significant relationship between blood lead levels with the levels of education, ($\chi^2(4)$ =1.75, p=0.78) (Table 4.14).This was consistent with an epidemiological study conducted among lead workers in west Turkey that reported education as insignificant risk factor for high blood lead levels, (p> 0.05) (Tozun *et al*., 2009). However, the level of education was reported to be significantly and inversely related to blood lead concentrations in a study conducted among lead battery workers in Taiwan (Chuang *et al*., 1999).

Knowledge and skills attained through education may affect a person's cognitive functioning, make them more receptive and more able to access information on occupational health and safety and seek for appropriate health and safety services (Galobardes *et al.,* 2006). In the current study therefore, it was expected that higher levels of education would influence the safety and health behaviours of the artisans and probably their blood lead levels e.g. by knowing probable sources of occupational exposures to lead, the artisans would take appropriate health and safety measures. On the contrary, the results were an indication of ignorance among the artisans.

Table 4.14: Distribution of artisans' BPb levels by level of education cross-tabulation

Variable (Level of Education)			Artisans BPb levels category		
			≥20 μg/dl	<20 μg/dl	Total
	None	Count (n)	1	0	1
		% Proportion	3.33	0	3.33
	Lower Primary	Count (n)	1	0	1
		% Proportion	3.33	0	3.33
	Upper Primary	Count (n)	8	3	11
		% Proportion	26.67	10.0	36.67
	Secondary	Count (n)	8	6	14
		% Proportion	26.67	20.0	46.67
	Tertiary	Count (n)	2	1	3
		% Proportion	6.67	3.33	10.0
Total		Count (n)	20	10	30
		% Proportion	66.67	33.33	100.0
	p=0.78				

Moreover, analysis of variance test showed no statistically significant difference in blood lead levels with average monthly income of the artisans ($F(3, 26) = 2.01$, $p=0.137$) (Table 4.15).Income indirectly affects health and safety, it is a socioeconomic indicator that directly measures material resource components and services that enhances the health and safety work conditions (Galobardes *et al.,* 2006). Low income implies low purchasing power and thus probable inability to purchase food e.g. lunch at workplace among the artisans. Poor nutrition resulting from low income may increase an individual's susceptibility to lead exposures and effects.

Studies have shown that lack of food and low concentration of micronutrients in the diet induces a high degree of absorption and retention of lead (Shahar *et al.,* 2005; Kordas *et al.,* 2007). It was expected that increased income would change the socio-economic status of the artisans and probably have an impact on work safety measures for instance,. the ability to afford and use appropriate personal protective devices and in turn, reduce the occupational lead exposure levels. Conversely, the finding suggests equal risks of occupational lead exposures irrespective of income. As earlier reported (Figure 4.3), the artisans survive on meager and unpredictable income, which could contribute to the observed results. Generally, these findings on the relationship between the artisans' blood lead levels and the monthly income and the level of education support the fact that the informal occupational environment offers poor socio-economic and inadequate work safety to all the artisans.

Table 4.15: Artisans' blood lead levels with different average monthly income

Average monthly income	Number of samples (n)	Mean BPb conc. (S.E) µg/dl	Range Minimum	Maximum	
KES 5000 - KES 10,000	13	29.27(4.35)	5.74	61.37	ANOVA
KES 10,001 - KES 15,000	10	22.24(3.52)	0.04	41.00	$F(3,26)= 2.01$
KES 15,001 - KES 20,000	5	29.21(5.99)	12.23	46.18	$p=0.137$
> KES 20,000	2	5.97(4.40)	1.57	10.36	

4.7.5Comparison of blood lead levels of the artisans with the biological exposure index (BEI)

The mean blood lead (BPb) levels of the artisans (25.08±3.48µg/dl) exceeded the 20µg/dl biological exposure index (BEI)of concern for adults recommended by American Conference of Governmental Industrial Hygienists (ACGIH®), the difference was statistically significant(t (29) =2.05, *p*=0.049). A large proportion (66.7%) of the artisans exceeded this reference value (Table 4.16). This implies that the occupation could endanger the health of the artisans through long-term lead effects and as such, medical surveillance is necessary. A consistent finding of high blood lead levels in automobile mechanics (p-value< 0.001) was recorded by a study in Nnewi, South-East Nigeria (Ibeh *et al*., 2016).

Even though the mean blood lead levels for the artisans were compared with the biological exposure index (BEI) of 20µg/dl, epidemiological studies on occupational lead exposures, including those by the American Academy of Pediatrics (AAP), have indicated health effects at lower blood lead levels (Betts, 2012; AAP, 2016).Adverse health effects such as neurocognitive defects have been recorded in adults at blood lead levels <5µg/dl (CDC, 2012). Results from USA National Health and Nutrition Examination Survey (NHANES III) mortality study have shown adverse health effects at low to moderate BPb levels in the range <5–9 µg/dl (Schober *et al*., 2006). The American College of Occupational and Environmental Medicine (ACOEM) recommends that workers be immediately removed from the exposure if blood lead level is 30µg/dl or be removed if repeated within four weeks blood lead measurements are ≥20 µg/dl (Holland and Cawthon, 2016). Approximately, 27% of the artisans had blood lead levels exceeding this action level and as such should be removed from such work environment.

4.7.6 Comparison of blood lead levels of artisans and the non-artisan students

The mean blood lead level of the students was 14.17 µg/dl±1.74SE, with a minimum value of 0.11 µg/dl and maximum 30.91 µg/dl (range of 30.80 µg/dl). It was noted that the mean BPb level of the students was significantly below the 20 µg/dl biological exposure index (BEI). Since lead is ubiquitous, the observed blood lead levels among the students might have been because of environmental sources such as water and agricultural food produce among others. The students were from a medical training college situated in the urban neighborhood of the informal automobile repair workshops. Therefore, most likely, vehicular emissions and other sources of lead pollutants might as well have contributed to the observed blood lead levels among the students. Studies have shown that urban setting where there is probably a high rate of environmental pollution records higher blood lead levels compared with rural areas for example, Njoroge *et al.* (2008) reported higher prevalence rate of environmental lead exposure to the general public in Nairobi compared with Olkalou a rural setting.

Both the students and the informal automobile repair artisans were exposed to lead but the mean BPb levels ± SE for the artisans(25.4 ± 2.6 µg/dl) were higher and more dispersed compared to that of students (14.17 ± 1.7 µg/dl). Paired sample t-test recorded a statistically significant higher mean blood lead levels for the artisans at 95% confidence interval, (t (29) =3.65, p=0.001) (Table 4.16). This could indicate the likelihood of occupational exposures among the artisans since the students were not most likely to be occupationally exposed. The findings corroborate others in the literature; for example, a study conducted in Jordan, reported significantly higher mean lead blood concentration in auto-mechanics compared to other participants (Gharaibeh *et al*., 2014). Similarly, Ashraph *et al.* (2013) recorded elevated BPb levels among the exposed groups compared to the non-exposed groups in their study among informal sector workers in Mombasa, Kenya.

Furthermore, bivariate analysis showed that age was statistically significantly correlated with blood lead levels among the students, (Pearson's correlation coefficient, (r) (30) = 0.41, p= 0.024) but statistically insignificant among the artisans, (r (30) = 0.16, p= 0.388). The finding was possibly due to occupational exposures where there is a likelihood of acute exposures among the artisans compared to the students. Perhaps this could be the correlation that would distinguish between occupational and environmental lead exposures. The positive association between age and blood lead levels among the students unlike among the artisans seems to be coherent because gradual exposures to environmental lead can cause a gradual increase in blood lead levels.

Table 4.16: Paired sample t test for artisans and control subjects blood lead levels

	Mean	Std. Error Mean	95% Confidence Interval of the Difference		t	df	P value
			Lower	Upper			
Artisans BPb(µg/dl) - Students BPb levels (µg/dl)	11.189	3.068	4.914	17.464	3.65	29	0.001

4.7.7 Prevalence Ratio of high blood lead levels among the study participants

In order to calculate the Prevalence Ratio (PR) and measure the associations of high blood lead levels among the study populations, a 2x2 contingency table was constructed (Table 21). While the majority of the artisans (66.7%) had BPb levels ≥20 µg/dl reference value, 33.3% of the students had blood lead levels ≥20 µg/dl. Chi-square test of independence established that there was a statistical significant difference in the proportion of artisans with blood lead levels ≥20 µg/dl compared to the students (χ^2 (1) = 6.67, *p*=0.01) (Table 4.17).

Table 4.17: Distribution of blood lead levels among study participants cross-tabulation

Study participants		Blood lead Levels ≥20µg/dl	Blood lead Levels <20µg/dl	Total
Artisans	Count (n)	20	10	30
	% Proportion	66.7	33.3	100.0
Students	Count (n)	10	20	30
	% Proportion	33.3	66.7	100.0

Using the calculated prevalence in Table (4.17), Prevalence Odds Ratio (POR) was calculated to measure high blood lead (≥20 µg/dl) as a chronic health risk and Prevalence Ratio (PR) to measure acute health risk among the study population (Table 4.18) (Alexander *et al*., 2014).

Prevalence Odds Ratio (POR) = $\frac{ad}{bc} = \frac{20 \text{ x } 20}{10 \text{ x } 10} = 4$

Prevalence Ratio (PR) = Prevalence of high BPb levels among artisans divide by

Prevalence of high BPb levels among students

$$= \frac{66.7}{33.3} = 2$$

The artisans were at a higher risk of having high blood lead levels (≥20 µg/dl) with (POR) 4.0, 95% Confidence Interval (CI) 1.37-11.70) compared to the students. The Prevalence Ratio (PR) of 2.0 at 95% Confidence Interval (CI) 1.14–3.52) signified that the prevalence of blood lead levels greater than 20 µg/dl is twice as higher in artisans than among the college students who were considered occupationally unexposed. Therefore, the high blood lead levels greater than 20 µg/dl was positively associated with occupational exposures to lead. This finding portends a risk to gradual chronic lead exposure among the artisans that could negatively affect their health. Studies have demonstrated that blood lead measurements may serve as a basis for identifying populations at risk of lead intoxication (Barbosa *et al*., 2005).

Table 4.18: Prevalence Ratio of high BPb levels among study participants

		95% Confidence Interval	
	Value	Lower	Upper
POR for study participants (Artisans/ Students)	4.00	1.37	11.70
PR for BPb Levels = ≥20µg/dl	2.00	1.14	3.52
PR for BPb Levels = <20ug/dl	0.50	0.28	0.88

4.7.8Correlation between airborne (PbA) and blood lead (BPb) exposure levels

The twenty simultaneously collected blood and air samples were used for comparison. Airborne lead exposure levels data were matched with blood lead data with respect to the artisans and workshops (Appendix 16).After assessing that the key assumptions of linear regression; normality, homoscedasticity, and absence of multicollinearity were met. Subsequently, the study investigated the possibility of a statistical relationship between airborne and blood lead exposure levels, using linear regression models. Figure 4.8, depicts a positive significant relationship between the two variables (Pearson's correlation coefficient, r=0.68, *p*=0.001). Task based airborne lead concentrations could explain 46.3% of the variation in blood lead levels (R^2=0.463).

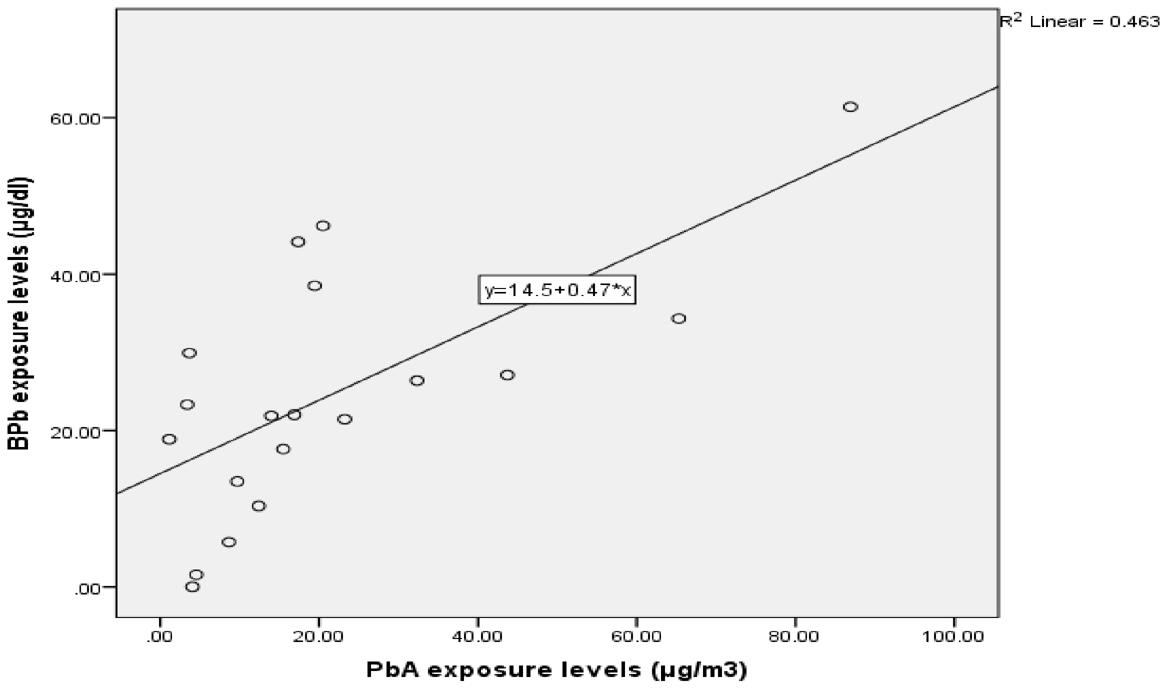

Figure 4.8: Correlation between airborne and blood lead exposures levels

4.7.8.1 Simple linear regression model

The simple linear regression model with the estimated equation; BPb levels (y) = 14.504 + 0.469β_1, where β_1 is the airborne lead level, significantly explained the influence of airborne lead exposure to the blood lead levels (R^2 = 0.463, F (1, 18) =15.49, p=0.001) (Appendix 17). For every 1µg/m^3 increase in PbA exposure, the artisans' blood lead level was predicted to increase by 0.469 µg/dl. Based on the model, and using the reported average task based airborne exposure concentration of 22.55 µg/m^3, the predicted BPb level will be 25.08 µg/dl, which was the reference mean blood lead concentration (25.08 µg/dl) thus supporting the model.

The obtained significant correlation gave the impression that the blood lead values were majorly determined by the air lead concentrations. However, exposure to lead in air is not causal to blood lead concentrations. When airborne lead aerosols are inhaled, particles are deposited in the lung and lead enters the blood stream, though the retention time in blood depends on how much already lead is in the system (Tripathi *et al*., 2001). The finding is corroborated with other studies in the literature; De Medinilla and Espigares (1991) reported a relatively close correlation of (r = 0.8, p = 0.01) based on the measurements obtained for 20 workers using personal air samples in their study in Spain. Rodrigues *et al.* (2009) also reported that air lead was a statistically significant predictor of blood lead in their study on personal exposure and work site conditions as determinants of blood lead among bridge painters in New England.

Moreover, Bierkens *et al.* (2011) in their study on predicting blood lead levels from current and past environmental data in Europe concluded that airborne lead remains the best predictor of blood lead levels in the population. However, contrasting findings have also been reported in the literature. Ulenbelt *et al.* (1990) in a study based on data from ten workers in a battery factory in India, reported a non-significant correlation of ($r = 0.42$, $p=0.11$), the study however, observed that the workers used airstream helmets in case of increased external lead loads. In another study in Singapore of 25 workers in a battery factory using personal air samples, Far *et al.* (1993) established statistically non significant correlations on two sampling occasions ($r = 0.12$, $p=0.58$) and ($r = 0.13$, $p=0.54$). It is notable that hygienic behaviour, use of PPEs and other engineering controls could affect the PbA-BPb relations. Noteworthy in this study, no artisan in all the workshops were using appropriate personal protective device such as respirators that could influence the airborne lead personal samples.

Based on the simple linear regression equation model, the WHO 50 µg/m^3 airborne lead PEL value would predict a value of 37.95 µg/dl blood lead exposure levels. This value exceeds 30µg/dl, which is the recommended value for medical removal from the exposure by the American College of Occupational and Environmental Medicine (ACOEM) (Holland and Cawthon, 2016). Consequently, this suggests that the 50µg/m^3 PEL value is not clinically protective. A dose–response relationship study of occupational lead exposure and health effects in China by Wu *et al.* (2016) reported airborne lead concentrations associated with lead poisoning as 20µg/m^3 and 10µg/m^3 for occupational exposure to lead dust and lead fumes, respectively. With this model, these values (20µg/m^{3}and 10µg/m^3) will respectively predict BPb exposure levels of 23.88µg/dl and 19.19µg/dl, which are relatively above and below the ACGIH® 20µg/dl biological exposure index of concern. The study is thus in agreement with the study by Wu *et al.* (2016) that their values should be considered as significant levels of concern for such work places since lead dust and fumes were the potential forms of lead exposure in the study.

Permissible exposure limit (PEL) value of 50µg/m^3 is unlikely to be safe and effective at the studied work sites because it would give a marked increased BPb levels among the artisans. Considering the USA-OSHA action airborne lead level value of ≥30µg/m^3 required for periodic workplace biomonitoring (CDC, 2012), the simple linear regression equation model would predict 28.57µg/dl BPb exposure level. This value is relatively close to 30µg/dl recommended for medical removal from exposure. The model therefore, fits the studied occupational environment. Following current reports that lower concentrations of blood lead may cause adverse health effects such as neurocognitive effects in adults at BPb levels <5µg/dl (CDC, 2012). Precise modelling of PbA-BPb relations, at air lead levels below the 50µg/m^3 conventional standard is of significance. Through these findings, possible lowering of the PEL value and associated BPb concentrations may be considered. Probably through further research, PEL values for specific occupational tasks in automobile industry can be established.

4.7.8.2 Multiple linear regression model

In order to modify for possible confounding factors, multiple linear regressions were performed to analyze the influence of the studied personal characteristics (age, duration of work and daily work hours) on levels of lead in blood. The multiple linear regression model obtained significantly explained the blood lead exposure levels, (R^2 = 0.599, F (4, 15) = 5.599, *p*=0.006) (Appendix 18). Therefore, the contributions of these variables to the observed BPb levels were assessed through the following estimated regression equation:

BPb levels (y) = $0.493\beta_1 + 0.646\ \beta_2 + 3.134\ \beta_3 - 0.548\ \beta_4 - 5.268$

Where: β_1 = airborne lead, β_2 = duration of work, β_3=, daily work hours, β_4=, age of artisan.

Except for airborne lead exposures, the other variables were not significantly correlated with the observed blood lead levels as summarized in (Table 4.19). The finding was consistent with the earlier reported ANOVA statistical test results, which recorded statistically insignificant differences in blood lead exposure levels with these characteristics. Remarkably, one year increase in age reduced the BPb level by -0.548 µg/dl (*p*=0.53) while an hourly increase in daily work hours increased the BPb level by 3.134 µg/dl (*p*=0.07), however, these were insignificant as indicated by the respective p-values. Based on this multiple linear regression equation model and using the reported average values of the predictor variables, the predicted BPb level would be 25.07 µg/dl, which is close to the reference mean BPb concentration of 25.08 µg/dl thus supporting the model.

Table 4.19: Variables contributions to BPb levels in multiple linear regressions

Variables	Unstandardized Coefficients Beta (β) value	Std. Error	t-value	P-value
(Constant)	-5.268	22.214	-0.237	0.816
Airborne lead levels	0.493	0.114	4.336	0.001
Duration of work	0.646	0.781	0.827	0.421
Daily work hours	3.134	1.609	1.948	0.070
Age of artisan	-0.548	0.852	-0.643	0.530

Based on this modified estimated multiple regression equation, a predicted blood lead level for an 18 years old artisan exposed to the WHO 50 µg/m^3 (PEL) value of airborne lead for 1year duration of employment and working 8hrs a day would be 35.24µg/dl. A value that is comparatively higher than 30 µg/dl recommended for medical removal from exposure by the American College of Occupational and Environmental Medicine (ACOEM). Notably, the simple linear regression equation model predicted a value of 37.95 µg/dl BPb exposure level with the Permissible Exposure Limit (PEL) value. The difference in these values therefore, could be attributed to these factors.

The 2nd schedule of Kenya Occupational Safety and Health Act (GOK, 2007), considers lead and its compounds as hazardous chemical occupational agents whose exposure should be prevented or controlled at work places. It considers workers to be protected when handling exposure to fumes, dust or vapour of lead or a compound of lead, or substance containing lead at the work places. However, this standard is intended for formal work sites and is rarely enforced at the informal enterprises. In addition, the Kenya factories and other places of work Act, (cap. 514), hazardous substances 2007 regulation, provides for the occupational exposure limits–control limits (OEL-CL) for lead as 0.15 mg/m^3 (150 µg/m^3). This is three times that of WHO permissible exposure limit value of 50 µg/m^3.

Using the estimated simple regression equation with the OEL-CL, the predicted BPb concentration would be 84.85 µg/dl, which could be clinically fatal among the artisans. These findings, therefore, calls for an immediate action and review of the legislative framework of occupational lead exposures in such workplaces in Kenya. Lead and its compounds are extensively used in manufacturing industries. Consequently, as the country focuses and transits to industrial economy, there is need to establish a framework for review and enforcement of occupational health and safety regulations, and other applicable policies in the rapidly growing informal automobile enterprises.Such measures will contribute towards achieving the international action plan for preventing lead intoxication (UNEP, 2010).

4.8 Hair lead (HPb) exposures levels of the study population

The use of scalp hair as a biological indicator to assess metal body burden of workers or as an index of long-term exposure has been widely used (Mehra and Juneja, 2003). The presence of lead in scalp hair may indicate occupational exposures and unlike blood, scalp hair could probably reflect cumulative lead exposure among the artisans. Lead levels of concern have not been established for human scalp hair and insufficient data is available to predict a health effect from hair lead (HPb) levels. Therefore, HPb measurements cannot be treated as the only indicator of lead body burden hence the determination of blood lead is key for reliable exposure assessment (Furman and Laleli, 2000; Harkins and Susten, 2003). In this study, both scalp hair and blood were used.

4.8.1 Artisans' hair lead (HPb) levels

The mean hair lead (HPb) level of the artisans was 15.29 mg/kg ± 2.01SE, with a minimum value of 0.59 mg/kg and maximum 35.36 mg/kg (range 34.77 mg/kg) (Table 4.20). Relatively high mean HPb levels were recorded among spray painters and welders compared to the other occupational tasks. Higher HPb levels among the artisans involved in spray painting was because of probable use of lead-based paints. Notable in the study that high amount of inhalable overspray was generated and exposed to the artisans during spray painting when using a spray gun. The finding was consistent with the earlier reported findings on airborne and blood lead levels, suggesting that the two tasks could be of high risk to occupational lead exposures at the informal automobile repair workshops. However, there was no statistically significant difference in HPb exposure levels among the artisans in different occupational tasks, ($F (4, 25) = 1.51$, $p=0.23$) (Table 4.20). This was consistent with the results of Ahmad *et al.* (2018) in their study of assessing lead exposures among automobile technicians in Pakistan. Using human scalp hair among other biomarkers, they reported that specific tasks performed by the workers did not influence the average levels of lead exposures.

The finding in the current study was probable because unlike blood lead concentrations, hair lead reflects cumulative lead exposure and may be only appropriate for long-term exposure biomonitoring (Harkins and Susten, 2003).The finding and the reported HPb levels suggest that a longitudinal study may be necessary in order to ascertain the influence of automobile repair occupational tasks when using hair lead levels as a biological indicator. On the other hand, there was a statistically significant difference in HPb exposure levels among the artisans across the workshops, (F (9, 20) = 3.57, p=0.009) (Appendix 19). This was possible because generally, the workshops would have diverse sources of lead exposures. Posthoc test using Tukey HSD showed differences in only two workshops (001 and 002) while all the other workshops recorded insignificant differences. This supports the fact that the worksites had similar occupational characteristics and that the observed differences across the workshops could be due to other factors including environmental sources.

Table 4.20: Hair lead (HPb) concentrations of artisans per occupational task

Occupational task	Number of samples (n)	Mean Hair lead conc. (S.E) mg/kg	Range		
			Minimum	Maximum	
Radiator repairs	3	10.30(5.63)	0.59	20.09	ANOVA
Lead acid battery repairs	2	3.73(3.08)	0.65	6.80	$F(4,25)$ =1.51,
Spray painting	9	19.26(3.45)	4.26	34.27	p=0.23
Welding	8	19.02(4.26)	3.98	35.36	
General mechanics	8	11.88(3.69)	2.04	27.81	
Total	30	15.29(2.01)	0.59	35.36	

4.8.2 Relations of age and hair lead levels among the artisans

Hair lead levels are expected to accumulate with age. Seemingly, older artisans had relatively higher hair lead levels compared to the younger artisans. However, the increase in hair lead levels with age was not statistically significant (Figure 4.9).While this finding was dissimilar to that of Shan and Ikram (2012) in their study in Pakistan, it was consistent with those reported by Adekola *et al*. (2004) in their comparative study of age and heavy metals in human hair in Nigeria. It was notable that some artisans joined the industry at a younger age while others at a relatively elderly age thus could influence the findings. Some of the younger artisans who joined the industry at an early age had higher hair lead exposure levels than their older counterparts.

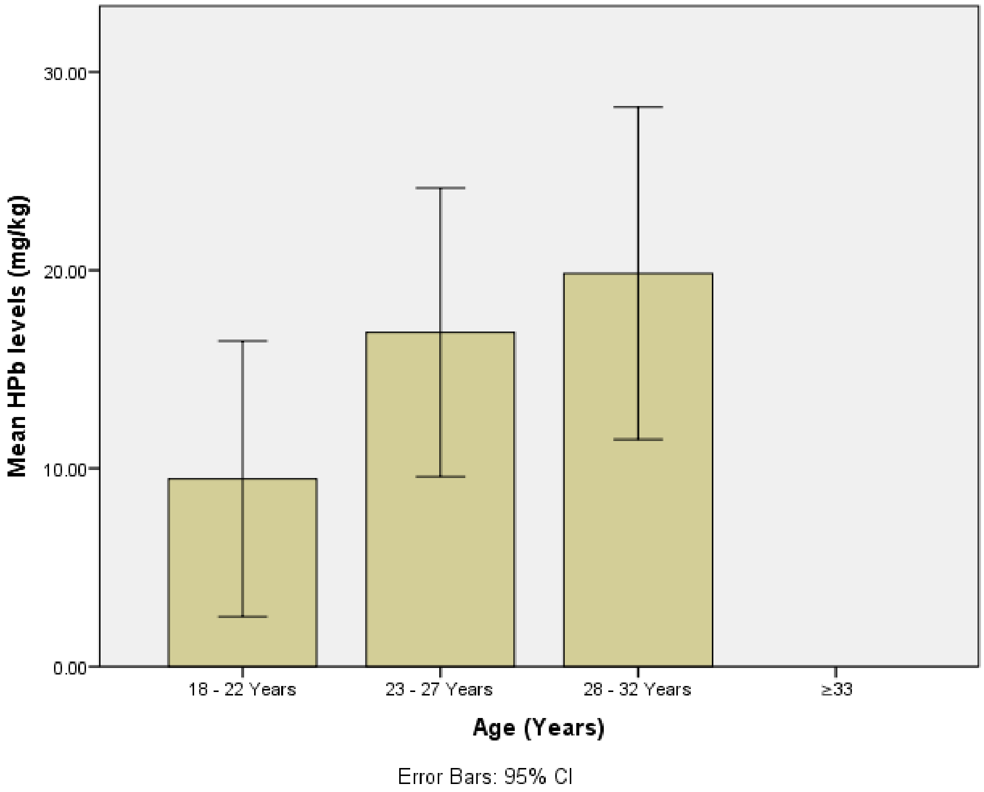

Figure 4.9: Hair lead (HPb) concentrations of artisans with age

Further Analysis of variance of the artisans' hair lead levels with duration at the occupation and daily work hours showed statistically insignificant differences (Appendices, 20 and 21).

4.8.3Comparison of hair lead levels for artisans and non-artisan students

The mean scalp hair lead (HPb) level for the students (occupationally unexposed) was 8.05 mg/kg ± 1.21S.E with a minimum value of 0.05 mg/kg and maximum 26.28 mg/kg. The artisans had higher and more dispersed HPb levels (15.29 mg/kg ± 2.01SE) compared to the students, which may indicate occupational exposures. Paired sample t-test showed a statistically significant higher mean scalp hair lead levels among the artisans at 95% confidence interval, (t (29) = 3.17, p =0.004) (Table 4.21). This was corroborated by the results of the blood lead levels among the artisans, which suggests occupational exposures among the artisans. The results were consistent with most studies reported in the literature e.g. significantly elevated scalp hair lead levels were recorded among automobile technicians (23.6 ± 11.2 mg/kg) compared to the control groups (4.8±3.4 mg/kg) in a study conducted in Pakistan to assess lead exposure among automobile technicians (Ahmad *et al.*, 2018).

Mehra and Juneja (2004) also reported that occupationally exposed auto mechanics had significant high hair lead (HPb) levels (52.68 ± 6.66 μg/g) compared to the control subjects (8.28 ± 6.87μg/g) in their biomonitoring study in India.

Table 4.21: Paired samples test for hair lead levels among study participants

Hair lead levels		Mean	Std. Error Mean	95% Confidence Interval of the Difference		P value
				Lower	Upper	
Pair 1	HPb levels (mg/kg) - HPb levels (mg/kg)	7.248	2.284	2.577	11.920	0.004

4.8.4Prevalence Ratio of high hair lead levels among the study participants

High hair lead level was defined as ≥20 mg/Kg in order to calculate the risk estimate. The study reported Prevalence Odds Ratio (POR) of 4.3, 95% Confidence Interval (CI) 1.20 - 15.61) and a statistically significant Prevalence Ratio (PR) of 3.0, 95% Confidence Interval (CI) 1.09 - 8.25) (Tables 4.22 and 4.23). Prevalence Odds Ratio (POR) = $\frac{\text{ad}}{\text{bc}} = \frac{12 \text{ x } 26}{18 \text{ x } 4} = 4.3$

Prevalence Ratio (PR) = Prevalence of high HPb levels among artisans (exposed) divide by

Prevalence of high HPb levels among students (Alexander *et al*., 2014).

$= \frac{40}{13.3} = 3.0$

The results implied a higher prevalence of hair lead levels ≥20 mg/Kg among the artisans compared to the students. Occupational exposure to lead therefore was positively associated with high hair lead levels. This finding was consistent with those earlier reported on blood lead exposure levels. Studies have demonstrated that data provided by human hair analysis may serve as a basis for identifying population groups at risk (for example, workers) or subjects living in polluted environments (Bencko, 1995).

Table 4.22: Prevalence Ratio of high HPb levels among study participants

	Value	95% Confidence Interval Lower	Upper
POR for study participants (Artisans/ Students)	4.33	1.203	15.605
PR for HPb levels = ≥20 mg/kg	3.00	1.090	8.254
PR for HPb levels = <20 mg/kg	0.692	0.501	0.957

Additionally, majority of the artisans (40%) had hair lead levels ≥20 mg/Kg reference level while 13.3% of the comparative group had hair lead levels ≥20 mg/Kg. Chi-square test of independence showed that there was a statistical significant difference in the proportion of artisans with blood lead levels ≥20 µg/dl compared to the students (χ^2 (1) = 5.46, *p*=0.02) (Table 4.23).

Table 4.23: Distribution of hair lead levels among study participants cross-tabulation

Study participants		Hair lead levels ≥20 mg/kg	<20 mg/kg	Total
Artisans	Count (n)	12	18	30
	% Proportion	40.0	60.0	100.0
Students	Count (n)	4	26	30
	% Proportion	13.3%	86.7%	100.0%

4.8.5Correlation between hair lead (HPb) and blood lead (BPb) exposure levels

To examine this relationship, blood and hair lead concentrations were matched per workshop and as per the occupational tasks since the two samples were obtained from different study participants but within the same workshops. Figure 4.10, shows that in each task the hair lead levels were higher than blood lead levels probably reflecting long-term exposures. Noteworthy that due to the slow growth rate, lead (Pb) concentrations in human hair reflects long-term exposures, whereas blood lead levels are more indicative of recent, short-term exposures (Gil *et al.*, 2011). Studies have shown that hair metal content may provide better estimation of long-term exposure risks of the general population as compared to the blood levels (Foo *et al.*, 1993). Concentrations in hair may be up to 10 times higher than the levels found in blood (Cespón-Romero and Yebra-Biurrun, 2007). This was reflected in the current study (Figure 4.10).

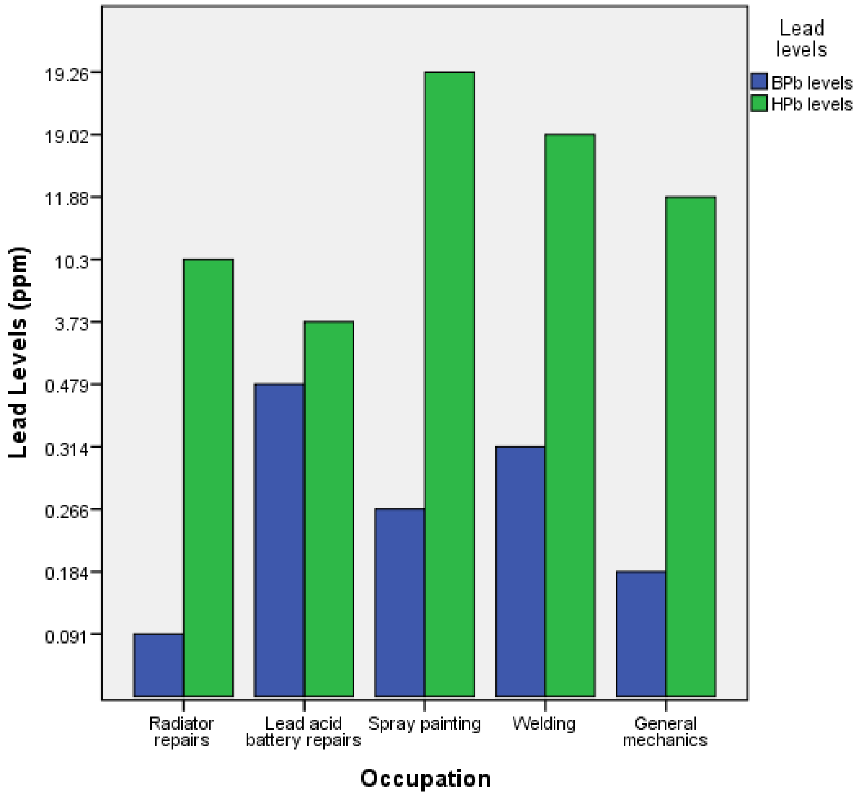

Figure 4.10: Artisans' BPb and HPb levels per occupational task

Hair lead levels and blood lead levels within the workshops showed a strong significant correlation, (Pearson correlation coefficient, (r) = 0.83, p= 0.003). In each task, relatively higher blood lead levels corresponded with higher hair lead levels (Figure 4.10). Trace elements and other toxicants from the environment are steadily incorporated and excreted in hair over time. Human hair is a vehicle of excretion of substances from the body including heavy metals (Bader *et al.*, 1999). Circulating metal cations can bind to the sulphur of the keratin protein present in the hair matrix (Bencko, 1995). Due to the binding, the metals concentrations in human hair should theoretically correlate with the blood concentration (Leotsinidis and Kondakis, 1990). In a similar study, significant concentrations of lead were found in scalp hair among occupationally exposed persons in Romania and regression analysis showed an exponential accumulation of the lead content in hair concomitantly with the increase of the values in blood (Niculescu *et al.*, 1983).

It was generally notable that both blood and hair lead concentrations were higher among the automobile repair artisans compared to the control subjects, suggesting that the observed high exposure levels were as a result of occupational exposures. However in the current study, neither a significant correlation was found between age and HPb levels among the artisans (r= 0.17, p=0.357) nor among the control subjects (r= -0.21, p=0.265). This is possibly true because the pharmacokinetics of lead in human scalp hair is not well understood (Harkins and Susten, 2003). Nevertheless, the results of this study can be used for further studies on the lead body burden of the study population.

4.9 Estimated glomerular filtration rate (eGFR) of the study population

In this study, estimated glomerular filtration rate (eGFR) was used to assess the kidney function of the participants. Estimated glomerular filtration rate (eGFR) is the mostly used method to clinically assess kidney function for epidemiologic studies. It evaluates the excretory function of the kidney and is regarded as the standard measure to assess renal function (Jin *et al.,* 2008, Spector *et al.,* 2011). A decline in eGFR precedes the onset of kidney failure or damage, therefore, a persistently reduced eGFR is a diagnostic criterion for chronic kidney disease (CKD). The USA National Kidney Foundation for chronic kidney disease (CKD) uses the following guidelines based on eGFR measurements, eGFR exceeding 90 mL/min/1.73m^2 as normal kidney function; eGFR of 60 to 89 is mildly decreased; an eGFR of 30 to 59 as moderately decreased and may signify “renal insufficiency”; an eGFR of 15 to 29 mL/min/1.73m^2 is considered severely decreased; and an eGFR of less than 15 is considered kidney failure (Levey *et al.,* 2003).

4.9.1 Estimated glomerular filtration rate for the artisans

The mean estimated glomerular filtration rate for the artisans (n=30) was 128.37 mL/min/1.73m^2 ± 4.37 SE, with a minimum value of 89 mL/min/1.73m^2 and a maximum of 186 mL/min/1.73m^2 with (Appendix 16). The lowest eGFR was recorded among the artisans involved in welding, implying a decreased renal function among them compared to the other artisans. However, all the occupational tasks recorded artisans with normal kidney function as per the United States National Kidney Foundation guidelines for chronic kidney disease based on eGFR(>90 mL/min/1.73m^2). Consequently, there was no statistically significant difference in eGFR among the artisans in different occupational tasks (F (4, 25) =0.54, p=0.71) (Figure 4.11, Appendix 22). This was consistent with the findings of a study in Nnewi Metropolis Nigeria by Amah *et al*. (2014) on evaluation of nephrotoxic effect of lead exposure among automobile repairers, who reported no statistically significant difference (p>0.05) in blood lead levels among different categories of automobile repairers.

The results were also consistent with other studies in the literature, which have shown and argued that occupational exposures to lead is not a significant cause of renal insufficiency or reduced kidney function. Evans *et al*. (2010) in their study on occupational lead exposures and severe CKD: a population-based case-control and prospective observational cohort study in Sweden found no evidence on the role of occupational lead exposures in the cause or progression of chronic kidney disease (CKD). In addition, Evans and Elinder (2011) in their study review on chronic renal failure from lead, argued that kidney do not show early symptoms of lead exposures. However, studies have shown that pathological late stage lead induced nephropathy is characterized by weakening and dilation of the glomeruli tubules (IPCS, 1995).

Other authors have suggested that parameters that are used to detect renal effects of occupational exposures to lead such as estimated glomerular filtration rate indicate effects after lead nephropathy has reached an irreversible phase that may lead to renal insufficiency (Odigie *et al*., 2004). Nonetheless, other studies on renal effects of environmental and occupational exposure to lead have associated chronic lead exposure of ≤20 µg/dl with reduced eGFR (Loghman-Adham, 1997). The findings in this study therefore, do not rule out a gradual lead nephropathy that may result to renal insufficiency if the artisans continue to be exposed at such work environment.

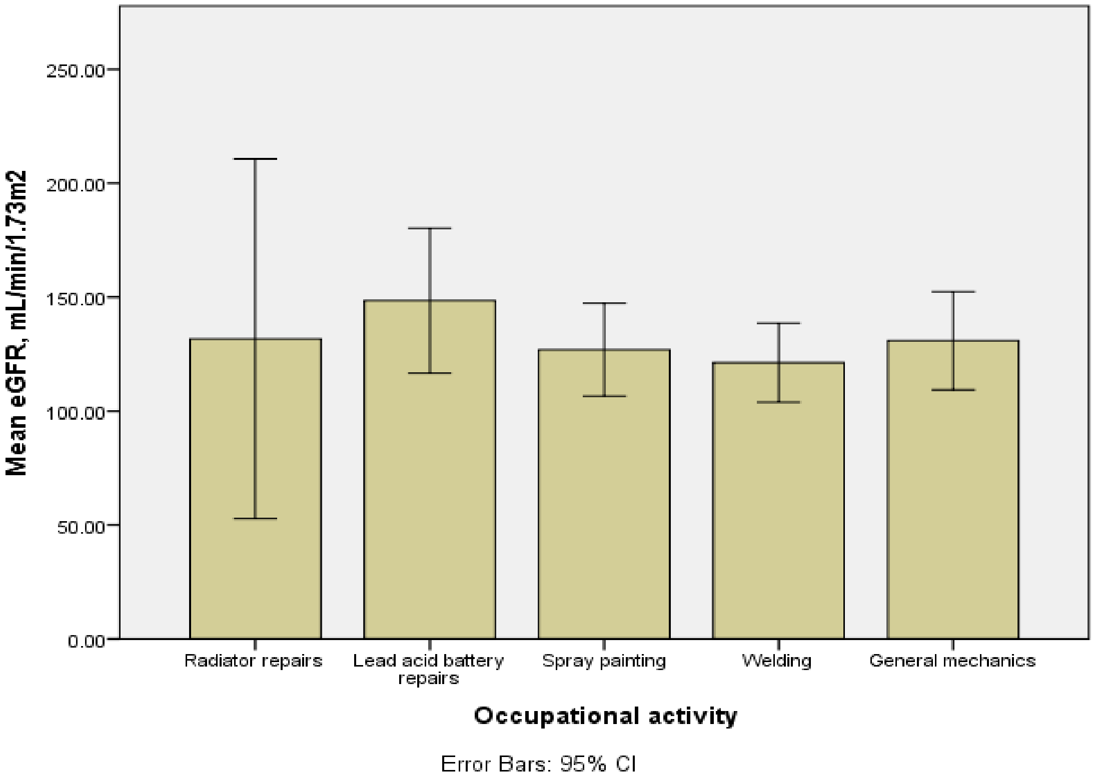

Figure 4.11: Artisans' estimated glomerular filtration rate per occupational task

4.9.2 Association between estimated glomerular filtration rates with age of the artisans

Estimated glomerular filtration rate may be influenced by a number of factors including existence of an underlying disease like cardiovascular disease, age and diet among others. Generally, in a normal population, it is believed that estimated glomerular filtration rate declines with age at an average rate of 1 ml per year after the age of about 30 years (Morrissey and Yango, 2006). This study recorded no significant difference in estimated glomerular filtration rate with age among the artisans ($F (3, 26) = 2.64$, $p = 0.071$), (Figure 4.12, Appendix 23). The finding was similar to that of Bowling *et al*. (2011) who showed that reduced estimated glomerular filtration rate was not associated with age among their study participants in USA.

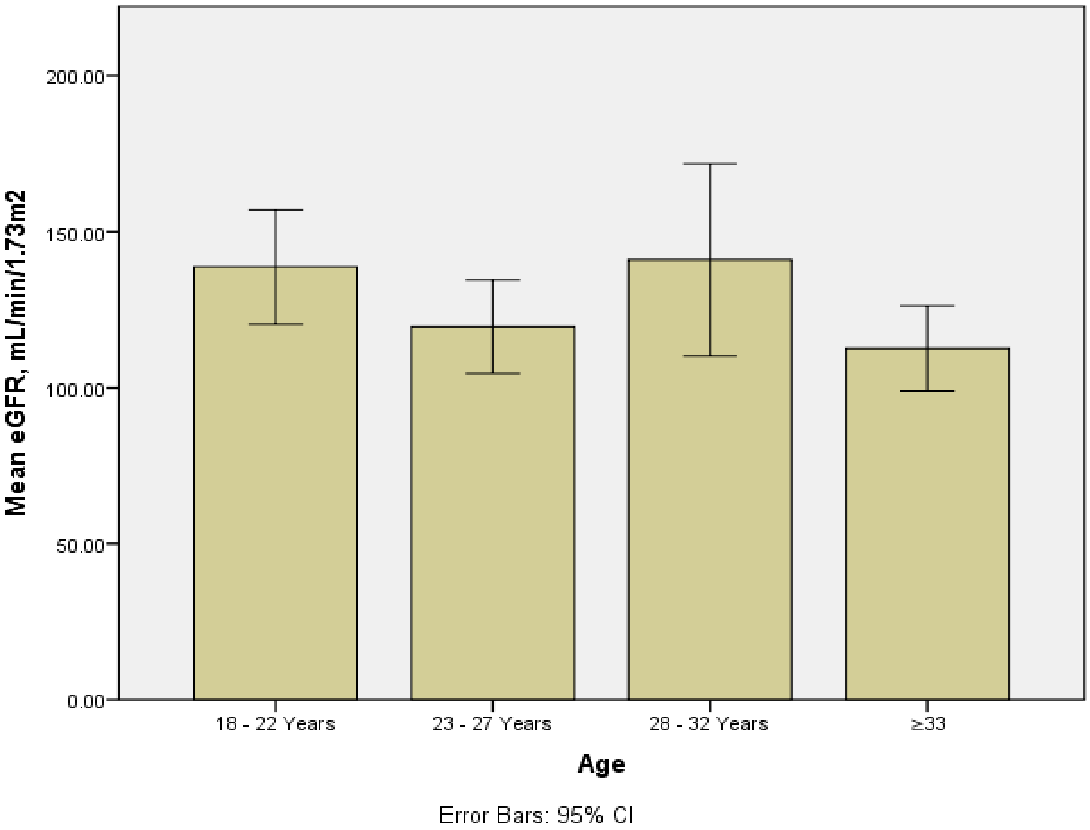

Figure 4.12: Artisans' estimated glomerular filtration rate with age

4.9.3Estimated glomerular filtration rate (eGFR) for the non-artisan students

The students recorded an average estimated glomerular filtration rate of 152.93 mL/min/1.73m^2 ± 3.91SE, with a minimum value of 106 mL/min/1.73m^2 and a maximum of 193 mL/min/1.73m^2 (Appendix 24). All of which were within the normal reference value (>90 mL/min/1.73m^2). The estimated glomerular filtration rate showed a statistically significant decrease with increasing age among the students, (F (2, 27) = 6.32, p=0.006) (Figure4.13, Appendix 24). Subsequently simple linear regression showed an inversely significant relationship between the eGFR and age among the control subjects (Pearson's correlation coefficient, (r) = -0.62, p=0.000).

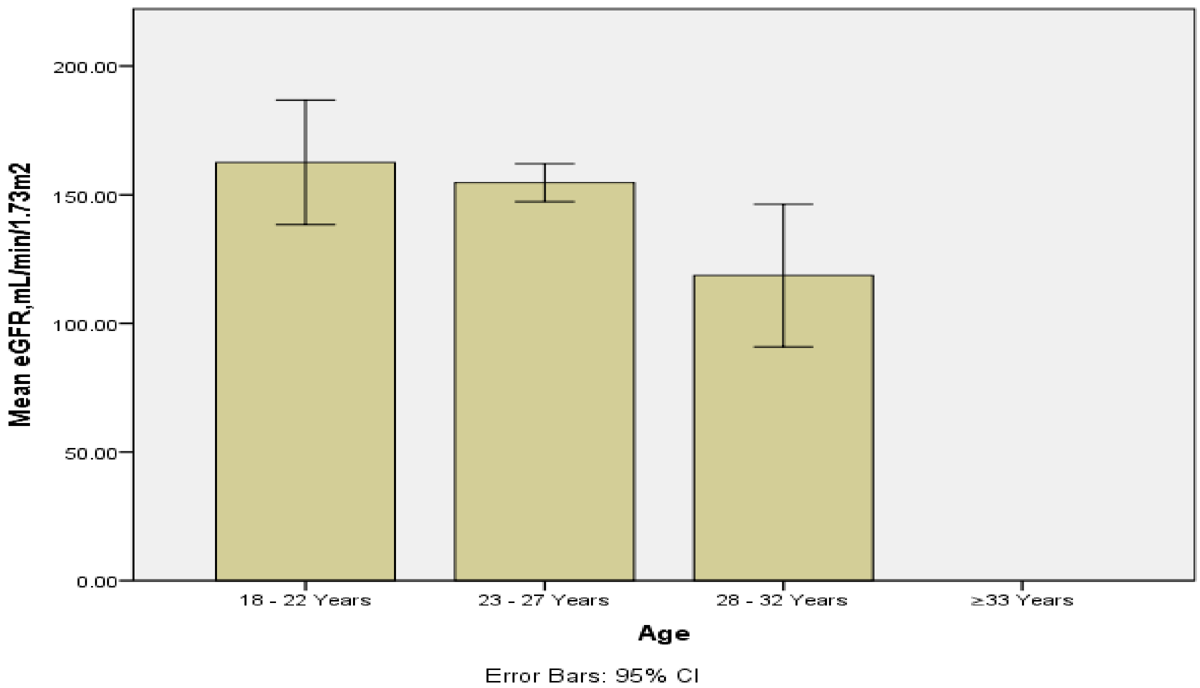

Figure 4.13: Estimated glomerular filtration rate by age for students

The estimated regression equation; eGFR (y) = 267.92 - $5.16\beta_{1,}$ where β_1 is the age of the student, significantly explained the influence of age on the eGFR (R^2 = 0.38, F (1, 28) =17.25, *p*=0.000). For every 1-year age increase, estimated glomerular filtration rate decreased by 5.16mL/min/1.73m^2 (Table 28). This probably reflects that estimated glomerular filtration rate decreases with age in a normal population (i.e. the students) as also recorded by Morrissey and Yango (2006).

Table 4.24: Regression of Age Vs eGFR for the artisans Coefficients

Model		Unstandardised Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		B	Std. Error	Beta	t	P value	Lower bound	Upper Bound
1	(Constant)	267.918	27.862		9.616	0.000	210.846	324.99
	Age (raw)	-5.164	1.243	-.617	-4.153	0.000	-7.711	-2.617

a. Dependent Variable: eGFR

4.9.4 Comparison of estimated glomerular filtration rate for artisans and non-artisan students

The artisans had a decreased and more dispersed eGFR (128.37 mL/min/1.73m^2 ± 4.37 SE) compared to the students (152.93 mL/min/1.73m^2 ± 3.91SE). Paired sample t-test showed a statistically significant decreased estimated glomerular filtration rate among the artisans at 95% confidence interval, (t (29) = -4.49, *p* =0.000) (Table4.25).Ashraph *et al*. (2012) recorded similar findings in their study on health effects of occupational lead exposure among "Jua Kali" workers in Mombasa, Kenya. They reported low estimated glomerular filtration rate among the exposed workers than the non exposed. The findings suggest that the kidney function among the artisans could be gradually deteriorating and this may be because of occupational lead exposures. Among the artisans, 96.6% had a normal eGFR i.e. > 90mL/min/1.73m^2 reference value and only 3.33% had mild decreased eGFR of 89 mL/min/1.73m^2.Two artisans (6.67%) recorded relatively reduced eGFR of 91 and 94 mL/min/1.73. However, none of the students recorded a decreased estimated glomerular filtration rate compared to the normal reference value.

Studies on renal effects of environmental and occupational exposure to lead have associated lead exposure with reduced eGFR (Yu *et al.*, 2004). A study by Amah *et al*. (2014) in Nnewi Metropolis Nigeria on evaluation of nephrotoxic effect of lead exposure among automobile repairers reported a significant increase in the mean serum concentration of serum creatinine among the automobile repairers compared to the control subjects (*p*<0.05). Therefore, the relatively reduced eGFR among the artisans probably was because of their occupational tasks.

Table 4.25: Paired samples test for estimated eGFR among study participants

Estimated glomerular filtration rate		Mean	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	P value
Pair 1	eGFR for Artisans, mL/min/1.73m2 – eGFR Students, mL/min/1.73m2	-24.57	5.47	-35.76	-13.38	-4.49	29	0.000

In order to assess the distribution and associations of reduced estimated glomerular filtration rate among the study participants, a 2x2 contingency table was constructed (Table 4.26). Only 3.3% of the artisans had recorded a reduced estimated glomerular filtration rate (<90 mL/min/1.73m^2). None of the students recorded a reduced estimated glomerular filtration rate. Chi-square test of independence showed that there was no statistically significant difference in the proportion of artisans with reduced estimated glomerular filtration rate (<90 mL/min/1.73m^2) compared to the students, (χ^2 (1) = 1.02, p=0.31), therefore, the occupation was not associated with reduced estimated glomerular filtration rate. This was consistent with the earlier reported finding of statistically insignificant difference in estimated glomerular filtration rate among the artisans in different occupational tasks (Figure 4.11).

Table 4.26: Distribution of eGFR among study participants cross-tabulation

Study participants			eGFR (categorized) <90 mL/min/1.73m2	≥90 mL/min/1.73m2
	Artisans	Count (n)	1	29
		% Proportion	3.3%	96.7%
	Students	Count (n)	0	30
		% Proportion	0.0%	100.0%

4.9.5 Correlation between eGFR and blood lead (BPb) exposure levels

Simple linear regression test showed no significant association between blood lead concentrations with estimated glomerular filtration rate among the artisans, (Pearson correlation coefficient (r) 0.04, p=0.83). This suggests that the observed blood lead levels among the artisans could not be associated with the observed eGFR values. The finding was corroborated with other studies in the literature, e.g. a study conducted on the effects of lead exposure among battery workers in Addis Ababa Ethiopia showed no significant correlation between occupational lead exposure and kidney function (Ahmed *et al.*, 2008). However in the current study, it was observed that there was a statistically significant inverse association between blood lead levels and estimated glomerular filtration rate among the students with a Pearson correlation coefficient of (r = -0.62, p=0.000). Notably, relatively higher blood lead levels were significantly associated with lower estimated glomerular filtration rate among the students. This was consistent with other studies among non-lead exposed populations for example, Pollack *et al.* (2015) recorded a decrease in eGFR with increased blood lead among premenopausal women in a prospective cohort study in Maryland USA. Fadrowski *et al*. (2010) in their prospective study among U.S. Aadolescents also reported a consistent association of high blood lead levels with low estimated glomerular filtration. Besides, a weak insignificant linear relationship between blood lead and eGFR with spearman's correlation coefficient of 0.272 for the exposed subjects and -0.113 for the non exposed $p>0.05$ were reported in a related study in Mombasa (Ashraph *et al.*, 2012).

Greater health risk of chronic nephropathy has been recorded in occupations with workers having BPb>60 µg/dl (Kshirsagar *et al.,* 2015). Amah *et al.* (2014) in their in Nnewi Metropolis, Nigeria concluded that the reported high blood lead levels among the automobile repairers may be responsible for the recorded elevated renal biomarkers which may ultimately result to their renal damage. In the current study, the mean blood lead of the artisans was 25.4±14.3 µg/dl thus perhaps unlikely to cause a significant detectable impact on the estimated glomerular filtration rate. Longitudinal studies have shown that high blood lead levels are associated with lower estimated glomerular filtration rate and impaired renal function (Muntner *et al.,* 2003). Therefore, probably longitudinal studies would better explain the correlation of blood lead concentrations with estimated glomerular filtration rate among the study population.

4.10 Serum Alanine aminotransferase (ALT) activity among the study population

Lead induced liver damage can be assessed indirectly through analyzing the activity of the liver enzymes released in the blood from damaged liver cells and the concentrations of other metabolites excreted by the hepatocytes into the blood for instance bilirubin (Kasperczyk *et al.,* 2013). Serum aminotransferases e.g. Alanine aminotransferase (ALT) are such enzymes. They are commonly referred to as "liver enzymes," because they are abundantly present within hepatocytes where they catalyze the transfer of amino groups during amino acid metabolism. In this study, serum ALT activity was measured to evaluate hepatocellular damage among the informal sector automobile repair artisans. Serum ALT activity has been regarded as a reliable and sensitive marker of liver damage. It is generally elevated in disease status that causes hepatocellular damage thus can effectively identify an ongoing liver disease progression (Kim *et al.,* 2008).Serum ALT levels greater than the upper limit of the normal (ULN) range (45 IU/L) suggest a potentially active liver disease process (Lee *et al.,* 2008).

4.10.1 Serum Alanine Aminotransferase activity for the artisans

The mean serum ALT activity for the artisans (n=30) was 18.50 IU/L ± 1.63 SE, with a minimum value of 9.77 IU/L and maximum value 51.0 IU/L (Table 4.27).The highest mean serum ALT activity was recorded among spray painters, suggesting a probable progression of liver damage among them compared to the other artisans. Notable, that the artisan with 51.0 IU/L serum ALT activity was engaged in spray painting. However, all the mean values of serum ALT activity in all the occupational tasks were within the normal range i.e. <45 IU/L reference value. Moreover, there was no statistically significant difference in serum ALT activity among the artisans in different occupational tasks (F (4, 25) =1.38, p=0.27) (Table 4.27). Similar findings were reported by Bhagwat *et al*. (2008) in their study on occupational lead exposures and liver function among workers involved in manufacturing and recycling of lead batteries around Kolhapur (Maharashtra)-India. They recorded no effects on liver functions at considerably high blood lead levels in the range of 25.8 – 78 µg/dl. Although, the findings were in contrast to a study by Kapaki *et al*. (1998) in Athens, Greece, who reported significantly increased serum ALT activity among workers occupationally exposed to lead. The findings could be probable due to comparably low blood lead levels in the study compared to earlier studies that had linked lead exposures to hepatocellular damage.

Table 4.27: Artisans' serum ALT activity per occupational task

Occupational activity	Number of samples (n)	Mean serum ALT activity (S.E) IU/L	Range		
			Minimum	Maximum	
Radiator repairs	3	17.67(4.77)	12.80	27.20	ANOVA
Lead acid battery repairs	2	18.80(5.10)	13.70	23.90	F (4,25)= 1.38, *p*=0.27
Spray painting	9	23.83(4.30)	11.80	51.00	
Welding	8	16.83(2.16)	11.10	30.10	
General mechanics	8	14.40(1.39)	9.77	21.60	
Total	30	18.50(1.63)	9.77	51.00	

4.10.2 Association between serum ALT activity with age of the artisans

Serum ALT activity has been reported to be influenced by a number of factors such as age, gender and time of the day for example, for time within a given day, the activity is reported to be greater in the afternoon than early morning, and with increased activity at an old age (Prati *et al.*, 2002; Ruhl *et al.*, 2013). The study recorded no significant difference in serum ALT activity with age among the artisans ($F (3, 26) = 2.02$, $p= 0.14$), (Figure 4.14, Appendix 25). Since the artisans were of diverse ages, this suggests that age did not influence their serum ALT activity. Further simple linear regression analyses showed that age was not correlated with the observed serum ALT activity (Pearson's correlation coefficient, (r) = 0.27, p=0.07). The results were in contrast with those reported by Lee *et al*. (2001) in their 4 years follow up study in Britain that recorded an inverse correlation between age and serum ALT activity. Other factors such as body mass index (BMI) and triglyceride levels, which have been shown to influence serum ALT activity (Salvaggio *et al.*, 1991), could have influenced these findings. Therefore, this study may not rule out the influence of age on serum ALT activity and probably a longitudinal study considering all these factors may better explain the association.

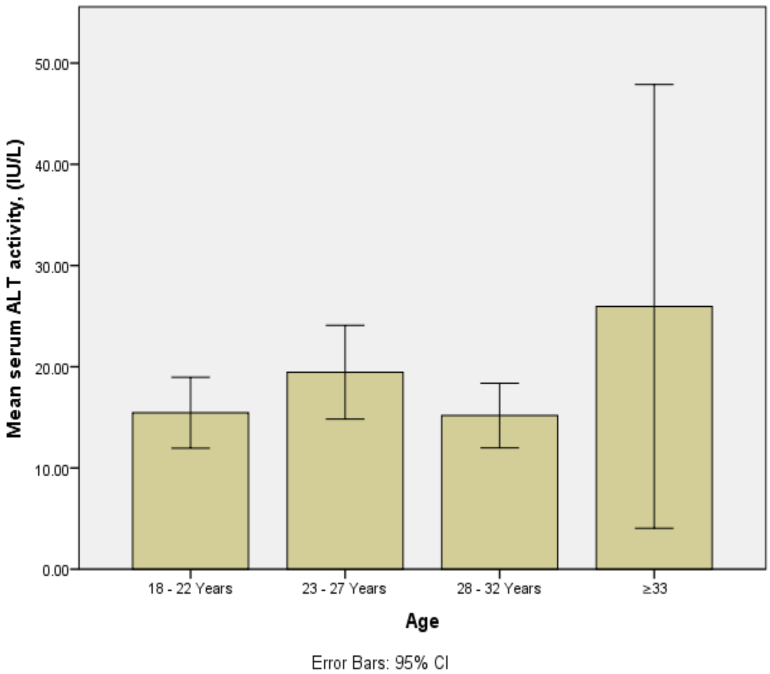

Figure 4.14: Artisans' serum ALT activity with age

4.10.3 Serum Alanine Aminotransferase (ALT) activity of the non-artisan students

The students recorded mean serum ALT activity of 21.34 IU/L± 2.85 SE, with a minimum value of 8.52 IU/L and a maximum of 76.40 IU/L (Appendix 26). It was notable, that two students recorded serum ALT activity greater than 45 IU/L reference value. This could be due to other factors such as body mass index (BMI), which have been reported to influence serum ALT activity (Salvaggio *et al.*, 1991). However, all the mean serum ALT activity values across the age groups were within the normal reference value (<45 IU/L). Further analysis of variance showed no statistically significant change in serum ALT activity with age among the students, ($F (2, 27) = 0.81$, p=0.045) (Figure 4.15, Appendix 26). More than half (66.7%) of the students were in the same age bracket of 23 to 27 years, this could have therefore influenced the findings.

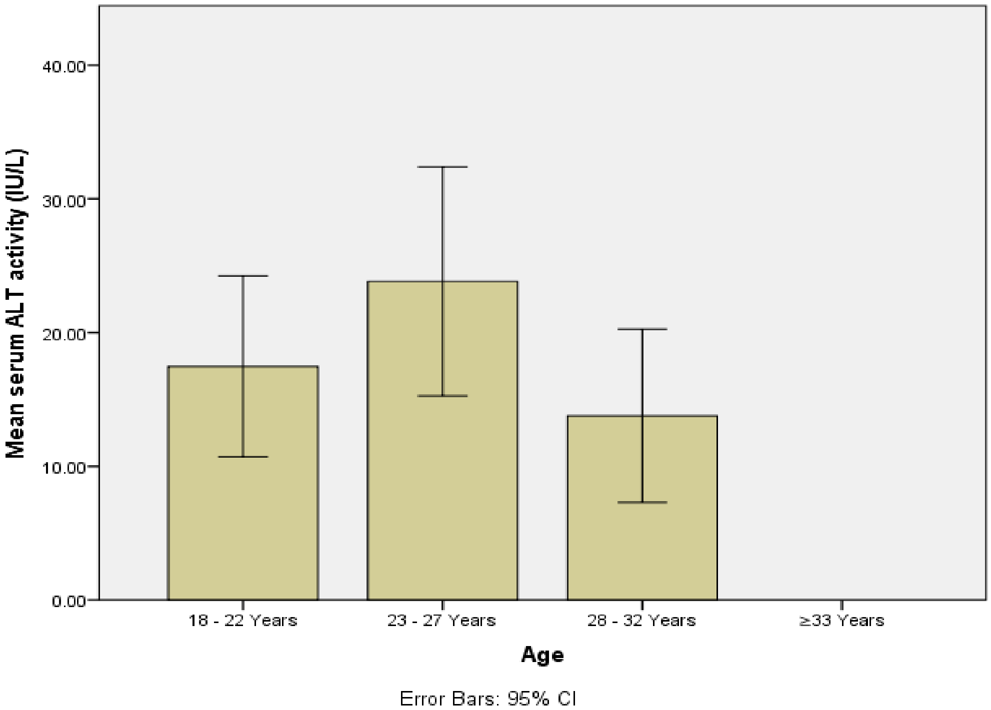

Figure 4.15: Serum ALT activity by age of the students

4.10.4 Comparison of serum ALT activity for artisans and non-artisan students

The artisans had a lower mean serum ALT activity of 18.50 IU/L ± 1.63 SE compared to the students (21.34 IU/L ± 2.85 SE). Nonetheless, paired sample t-test showed statistically insignificant difference in mean serum ALT activity between the artisans and the comparative group at 95% confidence interval, ($t (29) = 0.86$, p =0.40) (Table 4.28). The observed mean values of serum ALT activity for both the artisans and the students were within the normal range (<45 IU/L). The results were inconsistent with most studies in the literature e.g. a study conducted to evaluate effects of automobile workshop on the health status of auto-mechanics in Pakistan, recorded increased concentrations of serum ALT activity (104.4 ± 49.46 IU/L) in workers compared to the non-exposed subjects (Khan *et al.*, 2010). Another divergent study by Onyeneke *et al.* (2016) in Nigeria, recorded an elevated serum ALT activity among different groups occupationally exposed to lead compared to non-exposed groups. The results therefore, suggest that there was no evidence of lead induced liver damage among the informal sector automobile repair artisans.

Table 4.28: Paired samples test for serum ALT activity among study participants

Serum ALT activity		Mean	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	P value
Pair 1	serum ALT activity for students, IU/L - serum ALT activity for artisans, IU/L	2.85	3.33	-3.93	9.62	0.86	0.39

High serum ALT activity was defined as >45 IU/Lin order to assess associations and calculate the Prevalence Ratio (PR) of serum ALT activity among the study participants (Table 4.29). Statistically insignificant Prevalence Ratio (PR) of 0.5, 95% Confidence Interval (CI) 0.05-5.22) was calculated (Table 4.29).

Prevalence Ratio (PR) = Prevalence of high serum ALT activity among artisans (exposed) divide by prevalence of high serum ALT activity among students= $\frac{3.3}{6.7}$ = 0.5

Suggesting that occupational exposure to lead was not a risk factor to the observed serum ALT activity among the artisans. Additionally, only 3.3% of the artisan and 6.7% of the students had serum ALT activity >45 IU/L. Thereby, chi-square test of independence showed that there was no statistically significant difference in the proportion of artisans with elevated serum ALT activity (>45 IU/L) compared to the students, (χ^2 (1) = 0.35, *p*=0.55) (Table 4.29). The finding was consistent with the earlier reported ANOVA results indicating no statistically significant difference in serum ALT activity among the artisans in different occupational tasks (Table 4.27).

Table 4.29: Distribution of serum ALT activity among study participants cross-tabulation

		Serum ALT activity (categorized)		
Study participants		>45 IU/L	<45 IU/L	Total
Artisans	Count (n)	1	29	30
	% Proportion	3.3%	96.7%	100.0%
Students	Count (n)	2	28	30
	% Proportion	6.7%	93.3%	100.0%

4.10.5Correlation between serum ALT activity and blood lead (BPb) exposure levels

Simple linear regression analyses showed no association of blood lead concentrations with serum ALT activity among the artisans, (Pearson correlation coefficient (r) = 0.244, p=0.097) (Table 4.30). This suggests that the serum ALT activity could not be associated with the observed blood lead levels among the artisans. Consistent findings have been reported in the literature by Kasperczyk *et al*. (2013) in their study on the function of the liver and bile duct in humans exposed to lead in Poland, they reported no association between blood lead and serum ALT activity. Furthermore, it was observed in the current study that there was no association between blood lead levels and serum ALT activity among the students, (Pearson correlation coefficient (r)= -0.027, *p*=0.444). However, other authors have reported higher serum ALT activity among lead exposed workers than non-exposed groups (Chang *et al*., 2013).

Another study conducted in the United States have also shown that occupational exposures to lead played a significant role in initiating and promoting adverse hepatobiliary clinical outcomes (Obeng-Gyasi *et al*., 2018). Probably, in order to ascertain the impact of lead exposure among such study population, longitudinal studies are necessary and other indices of liver dysfunction can be considered. Serum ALT activity coupled with such indices e.g. the concentrations of bilirubin in the liver and other metabolic products excreted by hepatocytes in the blood can better ascertain the findings in this study.

Table 4.30: Correlation between serum ALT activity and BPb levels of the artisans

		Serum ALT activity, (IU/L)	Artisans BPb(µg/dl)
Pearson Correlation	Serum ALT activity, (IU/L)	1.000	0.244
	Artisans BPb(µg/dl)	0.244	1.000
Sig. (1-tailed)	Serum ALT activity, (IU/L)	.	0.097
	Artisans BPb(µg/dl)	0.097	.
N	Serum ALT activity, (IU/L)	30	30
	Artisans BPb(µg/dl)	30	30

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The informal automobile repair artisans were occupationally exposed to lead as evident by the various investigated occupational and human exposure indices. The following conclusions were drawn based on the research objectives.

(i) The following were the likely safety conditions and practices that could contribute to occupational exposures to lead among the study population:-

a) Poor personal behaviours such as eating at the worksites and not washing hands before eating.

b) Poor work practices such as poor and inadequate use of appropriate personal protective equipment (PPEs), lack of administrative and engineering control measures.

c) Inadequate or lack of training and awareness on occupational safety and health practices among the artisans.

d) Poor environmental work conditions particularly dirty overcrowded worksites and lack of access to water supply for drinking and washing.

(ii) There was a statistically significant difference in task based airborne lead exposure levels in different occupational tasks. However, the overall average airborne lead level in the workshops was significantly lower than the Occupational Safety and Health Administration (OSHA) permissible exposure limit.

(iii) The artisans had a statistically significant higher blood lead levels compared to the non-artisan students. In addition, artisans' mean blood lead levels significantly exceeded the 20µg/dl biological exposure index (BEI) of concern for adults.

(iv) The artisans had a statistically significant higher scalp hair lead (HPb) levels compared to the non-artisan students.

(v) The artisans had a statistically significant decreased estimated glomerular filtration rate compared the non-artisan students. Inasmuch as the alterations in eGFR were within the normal range (>90 mL/min/1.73m^2), because of the significant decrease compared to the comparative group, the study does not rule out a gradual lead nephropathy that may result to renal insufficiency.

(vi) There was no statistically significant difference in mean serum ALT activity of the artisans and the non-artisan students, indicating that there was no evidence of lead induced liver damage among the artisans.

5.2 Recommendation

Occupational exposures often results in substantial financial losses due to the burden on health, which can negatively influence production and the overall economy. The findings of this study provided preliminary evidence and baseline data that informal sector automobile repair artisans are at risk of occupational exposures to lead. Therefore, the following are recommended.

5.2.1 Recommendations for the artisans

(i) Experienced artisans or the supervisors to integrate into the apprenticeship training the proper use of personal protective equipment and other occupational hazard control measures.

(ii) Artisans to reduce vulnerability to exposures by proper and consistent use of interventions such as personal protective equipment and safe work procedures.

(iii) General cleanliness at the workshops to be maintained in order to avoid dusts and fumes in the overcrowded worksites.

(iv) Employers and self-employed artisans to seek periodic medical screening and regular checkup. This will create health awareness and enhance proper work practices among the artisans.

5.2.2 Recommendations for the government and other relevant agencies

(i) Lead screening and testing should be integrated in public health surveillance systems. This will curb the possible adverse chronic health effects that can be experienced among workers in such occupations.

(ii) Almost all the provisions of Occupational Safety and Health Act 2007 were breached. This calls for action by the Directorate of Occupational Safety and Health Services (DOSHS). Other than regulatory, DOSHS is mandated to enhance awareness and training among the working community. The findings present a good opportunity for collaborative efforts since the artisans were more enthusiastic to participate in such training programs.

(iii) As the country focuses and gears towards industrial economy, it is necessary to enhance occupational health and safety monitoring and intervention programmes at the informal sector automobile industry in order to reduce occupational health risks associated with lead exposures.

(iv) The Kenya factories and other places of work Act, (cap. 514), hazardous substances 2007 regulation, provides for the occupational exposure limits–control limits (OEL-CL) for lead as 150 μg/m^3, which is three times that of WHO permissible exposure limit of 50 μg/m^3 and as such should be reviewed to conform with international standards.

(v) There is also need to review the legislative framework and enforcement of occupational health and safety regulations, and other applicable policies in the rapidly growing informal automobile enterprises. Such measures will contribute towards achieving the international action plan for preventing lead intoxication.

5.2.3 Recommendations for further research studies

The research study established other issues that could not be tackled due to the limitations in the study. The areas that are recommended for future research include, but not limited to the following:

(i) Intervention studies to explore strategies, the efficiency and the best possible measures such as use of personal protective equipment, proper personal hygiene, and engineering control measures in preventing and controlling occupational exposures to lead in such work environment.

(ii) Longitudinal studies particularly on pathological and clinical human health effects of occupational lead exposures among the study populations.

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APPENDICES

Appendix 1: Questionnaire for the Artisans

This questionnaire seeks to assess risk factors for occupational exposure to lead. Please assist by completing the questionnaire as accurately as possible.

Participant ID:	
SECTION A: BACKGROUND INFORMATION	
	CODE
1. Residential area of the respondent Estate………………………………………….. Sub-location……………………………………. Location………………………………………… Workshop/Garage……………………………….	
2. Sex ▪ Male ▪ Female	[1] [2]
3. Age of Respondent	
4. Level of education ▪ No formal Education ▪ Lower primary ▪ Upper primary ▪ Secondary ▪ Tertiary	[1] [2] [3] [4] [5]
5. On average, what is your income per month? ▪ < KES 5000 ▪ KES 5000 - KES 10,000 ▪ KES 10,001 - KES 15,000 ▪ KES 15,001 - KES 20,000 ▪ > KES 20,000	[1] [2] [3] [4] [5]
6. Are you currently on any medication? ▪ Yes [1] ▪ No [2] If yes, explain.	[1] [2]
7. Do you have any of the following chronic illness?	

▪ Kidney disease ▪ Liver disease ▪ Cancer ▪ Diabetes ▪ Hypertension ▪ None Others specify.	
SECTION B: OCCUPATIONAL HEALTH & SAFETY ASSESSMENT	
8. How long have you worked at the automobile workshop? (in Years)	
9. What kind of work activity/task are you engaged in? ▪ Radiator repairs ▪ Lead-acid battery repairs ▪ Spray Painting ▪ Welding /Soldering ▪ General mechanics	 [1] [2] [3] [4] [5]
10. How many hours(average) do you work per day at the workshop?	
11. Do you smoke cigarette at the worksite? ▪ Yes ▪ No	 [1] [2]
12. Do you take alcohol at worksite? ▪ Yes ▪ No	 [1] [2]
13. Do you eat any kind of food (e.g. chew gums, fruits and cooked foods) at the worksite? ▪ Yes ▪ No	 [1] [2]
14. If 11 and 13 are yes, do you wash your hands before eating or smoking? ▪ Yes ▪ No	 [1] [2]

15. Do you use personal protective devices at work? Yes ▪ Overalls/aprons ▪ Mouth/Nose mask ▪ Hand gloves ▪ Eye goggles or face shields ▪ None Others (specify)	 [1] [2] [3] [4] [5]
16. Are you aware of potential chemical hazards stored or used at the workshops ▪ Yes ▪ No	 [1] [2]
17. Have you had any training on occupational Safety & Health? ▪ Yes ▪ No If yes, who trained you	 [1] [2]
18. Do you know of any environmental or occupational Safety& Health rules and regulations for your work place? ▪ Yes ▪ No If yes give an example	 [1] [2]

Appendix 2: Questionnaire for the students

This questionnaire seeks to assess risk factors for occupational exposures to lead. Please assist by completing the questionnaire as accurately as possible.

Participant ID:	
SECTION A: BACKGROUND INFORMATION	
	CODE
1. Residential area of the respondent Estate (at Nakuru)……………………………………….. Sub-county (at Nakuru)……………………………………. Home County……………………………………………….	
2. Sex ▪ Male ▪ Female	 [1] [2]
3. Age of Respondent	
4. Year of study ▪ 1st Year ▪ 2nd Year ▪ 3rd Year ▪ 4th Year	 [1] [2] [3] [4]
SECTION B: INCLUSION CRETERIA ASSESSMENT	
5. How long have been at the college (in years)	
6. Are you engaged or have been engaged in any work activity within the informal automobile workshops? ▪ Yes ▪ No If yes, explain.	 [1] [2]
7. How many hours on an average do you spend at the college	
8. Are you currently on any medication? ▪ Yes ▪ No If yes, explain.	 [1] [2]
9. Do you have any of the following chronic illness? ▪ Kidney disease ▪ Liver disease ▪ Cancer ▪ Diabetes ▪ Hypertension	

▪ None Others (specify)	
10. Do you smoke cigarettes? ▪ Yes ▪ No	[1] [2]
11. Do you drink alcohol? ▪ Yes ▪ No	[1] [2]
12. Do you chemically treat your hairs ▪ Yes ▪ No If yes, explain	 [1] [2]

Appendix 3: Observation checklist

Name of workshop:		**Yes (1)**	**No (2)**
	Variable (Engineering or administrative controls measures)		
1	Is the workshop generally an open air		
2	Is adequate working space provided		
4	Are all worksites clean and orderly?		
5	Is combustible scrap, debris and waste stored safely and removed from the worksite promptly?		
6	Are washrooms/toilets available and kept clean		
7	Is water provided for drinking and washing		
8	Are the working space adequate and easily accessible		
9	Are eateries and restrooms available and kept clean		
10	Are employees instructed on proper first aid and other emergency procedures		
11	Are caution labels and signs (signage) used for warning		
12	Are hazardous substances identified which may cause harm by inhalation, ingestion, skin absorption or contact?		
13	Are portable fire extinguishers provided		
14	Is employee exposure to fumes and vapours controlled by mechanical ventilation, use of respirators, or other means		
15	Are spray-painting operations done in spray booths equipped with an appropriate exhaust system		

Appendix 4: Informed consent form

My name is ***Mr. Alfred Owino Odongo***, a PhD student at Egerton University conducting a study on,

An assessment of occupational exposure to lead among the informal sector automobile artisans in Nakuru town

You are invited to participate in the research study. The research study will screen levels of occupational exposure to lead, increase awareness and identify probable health risks to occupational exposure to lead among the automobile artisans. The information generated from the study will be shared by the Ministry of health, Directorate of occupational health and safety to assist in policy reviews besides recommendations for further research areas.

Procedures to be followed

Participation in this study will require that I have one on one interview and collect blood and hair samples where applicable.

The venipuncture site of each of the participants will be disinfected with 95% ethanol. 8ml venous whole blood sample from each study subject will be drawn in a disposable syringe and transferred to a navy blue top heparinized vacutainer tube; Medical hand gloves for each participant will also be provided. Hair samples shavings from the head (from 'Kinyozi' barber) will be collected from the participants and put in individual specimen labeled envelop.

The laboratory analysis will be done at NAWASCO Nakuru and SCANLAB Nakuru Laboratories.

Participation in the study is voluntary and the samples will not be used for any other tests.

Risks and discomforts

There are no known physical risks associated with this research to the participants, however, collection of the samples and some of the questions you will be asked are private and may make you uncomfortable.

Potential benefits

Participants will benefit by knowing their environmental/occupational and human health status regarding Lead exposure. They will be advised on appropriate prevention and treatment measures if found with significant exposure levels and related health effects.

Besides, the researchers will identify health risks related to occupational lead exposure among this group of workers.

Protection of confidentiality

We will do everything we can to protect your privacy. Your identity will not be revealed in any publication resulting from this study. The interviews will be conducted in private settings. Your name will not be recorded on the questionnaire or on the samples. The samples will be properly disposed after laboratory tests.

Voluntary participation

Your participation in this research study is voluntary. You may choose not to participate and you may withdraw your consent to participate at any time. You will not be penalized in any way should you decide not to participate or to withdraw from this study.

Contact information

If you have any questions or concerns about this study or if any problems arise, please contact Dr. Wilkister N.Moturi on 0721-566802 or Dr. Meshack Obonyo on 0721-214032 or Egerton University research ethics committee on dvcre@egerton.ac.ke Tel 051-2217808.

Please tick to indicate you consent to the following (Participant)

1. I have read, or have been read to me in a language that I understand, and I understand the Participant study Information.	Yes ☐	No ☐
2. I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time.	Yes ☐	No ☐
3. I consent to the research staff collecting and processing my information, including information about my health and collected blood and hair samples.	Yes ☐	No ☐
4. If I decide to withdraw from the study, I agree that the information collected about me up to the point when I withdraw may continue to be processed.	Yes ☐	No ☐

Declaration by participant:

I hereby consent to take part in this study.

Participant's special ID:

Signature:	Date:

Declaration by researcher:

I believe that the participant understands the study and has given informed consent to participate.

Researcher's name:

Signature:	Date:

Appendix 5: Artisans proportionate sample size based on occupational tasks per workshop

Occupational Task		Radiator Repairs		Lead acid battery Repairs		Spray Painting		Welding		General Mechanics		Target Artisans sample size	Totals Artisans sampled
Garage Code	Artisans total popu. per garage	Actual popu.	Sampled	Actual popu.	Sampled	Actual popu.	Sampled	Actual popu.	Sampled	Actual popu.	Sampled		
001	8	NIL	NIL	NIL	NIL	3	1	4	2	1	NIL	4	3
002	3	3	2	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	2	2
003	15	4	2	NIL	NIL	5	3	2	1	4	2	8	8
004	19	2	1	2	1	7	3	4	2	4	2	11	9
005	16	NIL	NIL	NIL	NIL	6	3	4	2	6	3	9	8
006	8	NIL	NIL	NIL	NIL	3	2	3	2	2	1	4	5
007	12	NIL	NIL	NIL	NIL	7	3	5	2	NIL	NIL	7	5
008	9	2	1	2	1	3	2	2	1	NIL	NIL	5	5
009	7	NIL	NIL	NIL	NIL	NIL	NIL	2	1	5	3	4	4
010	11	NIL	NIL	2	1	2	1	5	3	2	1	6	6
Totals	108		6		3		18		16		12	60	55
NOTE: 5 Artisans gave both Hair and blood samples thus 55 participants;i.e (001 (1 artisan), 004 (2 artisans), 005 (1 artisan), 007 (1 artisan).													

Appendix 6: Blood, Hair and Airborne sample size per workshop

Workshop Code	Total Artisans population at the workshops (Study population)	Blood samples collected	Hair samples collected	Total samples (Blood and Hair) collected	Task based airborne samples
001	8	2	1	3	2
002	3	1	1	2	2
003	15	5	3	8	2
004	19	5	6	11	2
005	16	4	6	10	2
006	8	2	3	5	2
007	12	3	2	5	2
008	9	3	3	6	2
009	7	2	2	4	2
010	11	3	3	6	2
Totals	108	30	30	60	20

Appendix 7: Distribution of level of education and use of PPEs cross-tabulation

Level of education		Use of PPE: Use dust mask	Use overall/ aprons	Use goggles or face shields	Do not use PPE	Total
None	Count	0	1	0	0	1
	Expected Count	0.0	0.8	0.0	0.2	1.0
Lower Primary	Count	0	3	0	0	3
	Expected Count	0.1	2.3	0.1	0.5	3.0
Upper Primary	Count	0	20	1	3	24
	Expected Count	0.4	18.8	0.9	3.9	24.0
Secondary	Count	1	16	1	5	23
	Expected Count	0.4	18.0	0.8	3.8	23.0
Tertiary	Count	0	3	0	1	4
	Expected Count	0.1	3.1	0.1	0.7	4.0
Total	Count	1	43	2	9	55
	Expected Count	1.0	43.0	2.0	9.0	55.0

$x^2(12) = 3.74$, $p=0.98$

Appendix 8: Distribution of average monthly income and use of PPE cross-tabulation

Average monthly income		Use dust mask	Use overall/aprons	Use goggles or face shields	Do not use PPE	Total
		Use of PPE				
< KES 5000	Count	0	1	0	0	1
	Expected Count	0.0	0.8	0.0	0.2	1.0
KES 5000 - KES 10,000	Count	1	26	0	6	33
	Expected Count	0.6	25.8	1.2	5.4	33.0
KES 10,001 - KES 15,000	Count	0	8	2	1	11
	Expected Count	0.2	8.6	.4	1.8	11.0
KES 15,001 - KES 20,000	Count	0	6	0	2	8
	Expected Count	0.1	6.3	0.3	1.3	8.0
> KES 20,000	Count	0	2	0	0	2
	Expected Count	0.0	1.6	0.1	0.3	2.0
Total	Count	1	43	2	9	55
	Expected Count	1.0	43.0	2.0	9.0	55.0

x^2 (12) =10.18, *p*=0.60.

Appendix 9: Use of engineering or administrative control measures in the workshops

Engineering or administrative control (N=10 workshops)	Radiator repairs	Lead acid battery repairs	Spray painting	Welding soldering	General mechanics
Is employee exposure to fumes controlled by mechanical ventilation, use of respirators, or other means	0.0%	0.0%	0.0%	0.0%	0.0%
Are spray-painting operations done in spray rooms or booths equipped with an appropriate exhaust system	N/A	N/A	0.0%	N/A	N/A
Are caution labels and signs (signage) used for warning	0.0%	0.0%	0.0%	0.0%	0.0%
Are hazardous substances identified which may cause harm by inhalation, ingestion, skin absorption or contact?	0.0%	0.0%	0.0%	0.0%	0.0%

Key: N/A, not applicable

Appendix 10: Distribution of level of education and eating at work cross-tabulation

Level of Education			Eating at worksites: Eat at worksite	Eating at worksites: Do not eat at worksite	Total
	None	Count	0	1	1
		Expected Count	0.9	0.1	1.0
	Lower Primary	Count	3	0	3
		Expected Count	2.8	0.2	3.0
	Upper Primary	Count	23	1	24
		Expected Count	22.3	1.7	24.0
	Secondary	Count	21	2	23
		Expected Count	21.3	1.7	23.0
	Tertiary	Count	4	0	4
		Expected Count	3.7	0.3	4.0
Total		Count	51	4	55
		Expected Count	51.0	4.0	55.0

$x^2(4) = 13.7$, $p = 0.008$

Appendix 11: Distribution of education levels and training on occupational safety and health cross-tabulation

Level of Education			Training on OSH: Trained on OSH	Not trained on OSH	Total
	None	Count	0	1	1
		Expected Count	0.1	0.9	1.0
	Lower Primary	Count	0	3	3
		Expected Count	0.2	2.8	3.0
	Upper Primary	Count	0	24	24
		Expected Count	1.7	22.3	24.0
	Secondary	Count	1	22	23
		Expected Count	1.7	21.3	23.0
	Tertiary	Count	3	1	4
		Expected Count	0.3	3.7	4.0
Total		Count	4	51	55
		Expected Count	4.0	51.0	55.0

$x^2(4) = 29.70$, p=0.00

Appendix 12: Training on occupational safety & health and use of PPEs cross-tabulation

Use of PPE			Training on OSH: Trained on OSH	Training on OSH: Not trained on OSH	Total
	Use dust mask	Count	0	1	1
		Expected Count	0.1	0.9	1.0
	Use overall/aprons	Count	2	41	43
		Expected Count	3.1	39.9	43.0
	Use goggles or face shields	Count	1	1	2
		Expected Count	0.1	1.9	2.0
	Do not use PPE	Count	1	8	9
		Expected Count	0.7	8.3	9.0
Total		Count	4	51	55
		Expected Count	4.0	51.0	55.0

$x^2(3) = 6.13$, p=0.12

Appendix 13: Awareness of chemical hazards and use of PPE cross-tabulation

Use of PPEs			Awareness of chemical Hazards: Aware of potential chemical hazards	Awareness of chemical Hazards: Not aware of potential chemical hazards	Total
	Use dust mask	Count	0	1	1
		Expected Count	0.3	0.7	1.0
	Use overall/aprons	Count	13	30	43
		Expected Count	13.3	29.7	43.0
	Use goggles or face shields	Count	1	1	2
		Expected Count	0.6	1.4	2.0
	Do not use PPE	Count	3	6	9
		Expected Count	2.8	6.2	9.0
Total		Count	17	38	55
		Expected Count	17.0	38.0	55.0

$x^2(3) = 0.82$, $p=0.84$

Appendix 14: Artisans blood lead levels among different age groups

Age	Mean BPb conc. (S.E) µg/dl	Range: Minimum	Range: Maximum	
Age (years)				ANOVA
18 - 22 (n=10)	23.89(4.44)	5.74	46.18	F(3,26)=
23 - 27 (n=10)	26.65 (5.61)	1.57	61.37	0.199
28 - 32 (n=5)	22.47 (6.34)	0.04	37.22	p=0.896
≥33 (n=5)	28.64 (4.57)	19.77	41.00	

Appendix 15: Artisans' blood lead levels across different daily working hours

Daily working hours	Mean BPb conc. (S.E) µg/dl	Range Minimum	Range Maximum	
8 hours (n=13)	20.92 (3.77)	0.04	44.11	ANOVA
10 hours (n=10)	26.23 (4.67)	10.36	61.37	$F(2,27)=$
12 hours (n=7)	32.38 (5.27)	13.50	52.10	1.54 p=0.233

Appendix16: Task based airborne lead (PbA) and Blood lead (BPb) levels matched samples

S/No	Artisan Study ID	Occupational task	Airborne lead levels (PbA)µg/m^3	Blood lead levels (BPb) µg/dl
1	Pb 25/16	Spray Painting	20.49	46.18
2	Pb 26/16	Spray Painting	43.71	27.10
3	Pb 09/16	Spray Painting	17.37	44.11
4	Pb 19/16	Welding/soldering	1.15	21.44
5	Pb 22/16	Spray Painting	16.89	22.03
6	Pb 06/16	Spray Painting	23.22	18.88
7	Pb 03/16	Welding/soldering	48.29	37.22
8	Pb 37/17	Spray painting	8.65	5.74
9	Pb 20/16	Lead acid repairs	86.91	61.37
10	Pb 35/17	Welding/soldering	13.99	21.89
11	Pb 07/16	Welding/soldering	3.67	29.91
12	Pb 10/16	Welding/soldering	32.33	26.39
13	Pb 05/16	Radiator repairs	4.04	0.04
14	Pb 23/16	Radiator repairs	4.54	1.57
15	Pb 13/16	General mechanics	9.7	13.50
16	Pb 12/16	Welding/soldering	19.44	38.50
17	Pb 04/16	General mechanics	15.48	17.64
18	Pb 11/16	General mechanics	3.4	23.31
19	Pb 32/16	General mechanics	12.4	10.36
20	Pb 33/16	Lead acid repairs	65.3	34.32

Appendix 17: Simple linear regression model summary for airborne and blood lead levels

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	P value
1	0.680[a]	0.463	.433	11.72019	0.463	15.491	1	18	0.001

a. Predictors: (Constant), Airborne Lead levels

Appendix 18: Multiple linear regression model summary for airborne and blood lead levels

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	P value
1	0.774[a]	0.599	0.492	11.091	0.599	5.599	4	15	0.006

a. Predictors: (Constant), Age (raw), Airborne lead levels, Daily working hours, Duration in the occupation (raw)

b. Dependent Variable: Artisans BPb(raw)

Appendix 19: Hair lead levels among the artisans across the workshops

Workshop codes	Number of samples (n)	Mean Hair lead conc. (S.E) mg/kg	Std. Error	Range		
				Minimum	Maximum	
001	2	31.88(3.48)	3.48000	28.40	35.36	ANOVA
002	2	2.35(1.76)	1.75500	0.59	4.10	F (9, 20) =
003	3	6.75(2.44)	2.44377	2.04	10.23	3.57, *p*=0.009
004	5	14.39(5.36)	5.36451	2.12	28.38	
005	5	18.72(3.92)	3.92301	4.65	27.81	
006	3	22.12(1.80)	1.80477	19.73	25.66	
007	2	31.37(2.91)	2.90500	28.46	34.27	
008	3	6.52(4.19)	4.19323	0.65	14.64	
009	2	7.81(3.35)	3.35000	4.46	11.16	
010	3	13.44(6.34)	6.33745	6.80	26.11	
Total	30	15.29(2.01)	2.01488	0.59	35.36	

Appendix 20: Artisans' Hair lead levels with different durations in the occupation

Duration in the occupation	Mean HPb conc. (S.E) (mg/kg)	Range		
		Minimum	Maximum	
1 - 3 Years (n= 21)	13.83 (2.37)	0.59	34.27	ANOVA
4 - 6 Years (n= 5)	24.25 (5.23)	4.46	35.36	F(2,27)=2.21
7 - 9 Years (= 4)	11.76 (3.40)	4.65	20.98	*p*=0.130
Total n= 30)	15.29 (2.01)	0.59	35.36	

Appendix 21: Artisans' Hair lead levels with different working hours

Daily work hours	Mean HPb conc. (S.E) (mg/kg)	Range Minimum	maximum	
8.00 (n=10)	14.84 (3.83)	2.12	35.36	ANOVA
10.00 (n=11)	17.63 (3.35)	0.65	34.27	$F(2,27)=0.44$
12.00 (n=9)	12.94 (3.45)	0.59	28.40	$p=0.647$
Total (n=30)	15.30 (2.01)	0.59	35.36	

Appendix 22: Artisans' estimated glomerular filtration rate per occupational task

Occupational task	Number of samples (n)	Mean eGFR (S.E) mL/min/1.73m^2	Range Minimum	Maximum	
Radiator repairs	3	131.67(18.35)	109.00	168.00	ANOVA
Lead acid battery repairs	2	148.50 (2.50)	146.00	151.00	$F (4,25)= 0.54$,
Spray painting	9	126.89(8.84)	89.00	186.00	$P=0.71$
Welding	8	121.25(7.32)	100.00	161.00	
General mechanics	8	130.88(9.11)	91.00	157.00	
Total	30	128.37(4.37)	89.00	186.00	

Appendix 23: Artisans' estimated glomerular filtration rate with age

Age	Number of samples (n)	Mean eGFR (S.E) mL/min/1.73m^2	Range Minimum	Maximum	
18 - 22 Years	10	138.70(8.07)	91.00	186.00	ANOVA
23 - 27 Years	10	119.60(6.62)	89.00	153.00	$F (3,26)= 2.64$,
28 - 32 Years	5	141.00(11.09)	110.00	168.00	$P=0.071$
≥33	5	112.60(4.92)	100.00	130.00	
Total	30	128.37(4.37)	89.00	186.00	

Appendix 24: Estimated glomerular filtration rate by age for the students

Age groups	Number of samples (n)	Mean eGFR (S.E) mL/min/1.73m^2	Range Minimum	Maximum	
18 - 22 Years	7	162.57 (9.90)	120.00	193.00	ANOVA
23 - 27 Years	20	154.70(3.51)	126.00	182.00	F (2,27)= 6.32,
28 - 32 Years	3	118.67(6.43)	106.00	127.00	P=0.006
Total	30	152.93(3.91)	106.00	193.00	

Appendix 25: Artisans' serum ALT activity with age

Age groups	Number of samples (n)	Mean serum ALT activity (S.E) IU/L	Range Minimum	Maximum	
18 - 22 Years	10	15.47(1.55)	9.77	25.50	ANOVA
23 - 27 Years	10	19.46(2.04)	11.80	30.10	F (3,26)= 2.02, *p*=0.14
28 - 32 Years	5	15.18(1.15)	12.80	18.10	
≥33	5	25.96(7.90)	11.10	51.00	
Total	30	18.50(1.63)	9.77	51.00	

Appendix 26: Serum ALT activity by age for the students

Age group	Number of samples (n)	Mean serum ALT activity (S.E) IU/L	Range Minimum	Maximum	
18 - 22 Years	7	17.47(2.77)	8.52	27.50	ANOVA
23 - 27 Years	20	23.83(4.09)	10.80	76.40	F (2,27)=
28 - 32 Years	3	13.76(1.51)	11.70	16.70	0.81,
Total	30	21.34(2.85)	8.52	76.40	P=0.455