CHILD EXPOSURE TO LEAD IN THE VICINITIES OF INFORMAL USED LEAD-ACID BATTERY RECYCLING OPERATIONS IN NAIROBI SLUMS, KENYA

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

I dedicate this important work to the children in the studied communities; and my beloved mum, Alice Abigail Ondayo for her love and support in my entire life.

ABSTRACT

Lead exposure from informal used lead-acid battery (ULAB) recycling operations is a serious environmental health concern. Research shows that young children living in the vicinities of these operations have elevated blood lead levels and fatalities have also been reported. From January 2015 to August 2015, the study investigated child exposure to lead in the vicinities of informal ULAB recycling operations in Nairobi slums, Kenya. This was in consideration of activity patterns of children under seven years that influenced exposure levels through house dust and soil. Top soil (N = 232) and floor dust (N = 322) samples were collected from dwelling units (N = 120) and preparatory schools (N = 44) and analyzed using inductively coupled plasma-optical emission spectrometer (ICP-OES) at the Mines and Geological Department Laboratory in the Ministry of Mining, Nairobi. From the lead levels in soil and house dust obtained, child blood lead levels were subsequently predicted using the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK), Windows version. Results indicated high indoor and outdoor lead contamination in studied areas. Lead loadings in all the floor dust samples (100%) from Dandora, Kariobangi and Mukuru slums exceeded the US EPA guidance value for lead on floors with a range of 65.2 – 58,194µg/ft^2. Control floor dust samples recorded lower lead loadings as compared to the values recorded in Dandora, Kariobangi and Mukuru slums. 70.7% of the soil samples collected from waste dumps, industrial sites, residential areas, playgrounds and preparatory schools in Dandora, Kariobangi and Mukuru recorded lead concentrations that exceeded the respective US EPA guidance values for lead in soils. Lead concentration in all (100% of) the control soil samples were below the respective US EPA guidance values. From the IEUBKwin predictions, nearly 99.9% of children ≤ 7 years old living near informal ULAB recycling operations in Dandora, Kariobangi and Mukuru slums, were at risk of being lead poisoned with predicted blood lead levels above the CDC reference value for blood lead. 99.9% of exposed children living in Dandora, Kariobangi and Mukuru slums are likely to have blood lead levels above 20 µg/dL, 19 µg/dL and 34 µg/dL respectively. The study established that Dandora, Kariobangi and Mukuru slums face vast environmental health challenges, with many children at risk of lead poisoning due to the rapid unprecedented growth of informal ULAB recycling. The soil and house dust results demonstrate the need for coordinated efforts towards decreasing lead emissions from informal battery recycling in Nairobi slums and to remediate existing soils particularly around battery workplaces and dumpsites. Child blood lead levels should be clinically tested and appropriate intervention measures taken.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic absorption spectrophotometer
ATSDR	Agency for Toxic Substances and Disease Registry
BLLs	Blood Lead Levels
CDC	United States Centers for Disease Control and Prevention
US EPA	United States Environmental Protection Agency
HUD	United States Department of Housing and Urban Development
ICP-OES	Inductively Coupled Plasma- Optical Emission Spectrometer
IEUBKwin	Integrated Exposure Uptake Biokinetic Model for Lead in Children,Windows version
IQ	Intelligence Quotient
LAB	Lead-acid battery
NEMA	National Environment Management Authority
OK	Occupational Knowledge International
PbB	Lead in Blood
PbD	Lead in Dust
PbS	Lead in Soil
ULAB	Used lead-acid battery
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
WHO	World Health Organization

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CHAPTER ONE

INTRODUCTION

1.1 Background

Exposure to lead (Pb) remains a serious environmental health concern, particularly for young children in developing countries (Fewtrell *et al.*, 2004; WHO, 2014). It contributes to nearly one million cases of intellectual disability in children annually (Lim *et al.*, 2012). Exposure refers to a child's contact with lead, for example when; lead contaminated soil is eaten or when lead contaminated dust-laden fingers or objects are put into the mouth by a child. Exposure to lead can be assessed either directly by measuring lead levels in human samples such as blood or indirectly from environmental data (WHO, 2010). Lead is highly toxic and is considered one of the most hazardous chemicals on earth (ATSDR, 2006). It exists naturally as an element on the earth’s crust in low quantities (Wu *et al.*, 2004). Anthropogenic activities are known to contribute most of the lead in the environment, particularly in Africa (Nriagu, 1988; Banza *et al.*, 2009). After phasing out leaded petrol, the major sources of lead include; use of leaded paint, manufacture and recycling of lead-acid batteries, production of plastic and rubber, and incineration of wastes (WHO, 2010; Swaddiwudhipong *et al.*, 2014). In this study, it was assumed that soil and dust are the major routes of lead exposure to children below seven years. Other sources of environmental lead contamination such as historical use of leaded petrol spray painting, panel beating, metal cutting and welding as well as motor vehicle mechanics are not included in this study (Kimani, 2005). Children in the studied areas drink piped water supplied by the Nairobi Water and Sewerage Company. Vegetables, fruits and other foods are bought from areas outside Nairobi.

Over the years, production of lead-acid batteries, commonly referred to as car batteries, is the largest use of lead (ATSDR, 2007). These rechargeable batteries are made of lead plates, acids, other suspended and dissolved metals and minerals such as arsenic, antimony, tin and calcium. However, the lead accounts for about 70% of the total battery weight (Dell & Rand, 2001). Lead-acid batteries are used primarily in vehicles for starting, lighting, and ignition purposes; and to store energy in photovoltaic solar installations and telecommunication systems. After numerous cycles of recharging, the lead plates eventually deteriorate thus the battery loses its ability to store energy for any period of time (Chanjaroen, 2008; Chen & Finlow, 2009). Once the lead acid battery ceases to be functional, it is unusable and deemed a used lead-acid battery (ULAB). Under the Basel Convention, ULAB is classified as a hazardous waste for safe recycling as well as final disposal (UNEP, 2002).

Over 50% of the world's ULAB is reported to be recycled by informal recyclers in the developing world (Blacksmith Institute, 2007, 2011). Usually, the recycling is conducted in densely populated urban residential areas, where workers are paid little. In addition, environmental and occupational health regulations lack or are unenforced. The lead recovery in these operations is usually less resulting into more lead contaminated wastes (Dasgupta *et al.*, 1998; Cobbing & Divecha, 2005; UNEP, 2005; Gottesfeld & Pokhrel, 2011). All the processes involved in informal ULAB recycling such as breaking of used batteries, removal of lead plates, crushing, screening, dry mixing and melting down generate loads of airborne lead dust. Lead-laden fly ash particulates are also emitted during open burning of ULAB. Solid and liquid wastes from these processes are dumped in the open in surrounding areas (Hay & Noonan, 2001; Chen *et al.*, 2009; Zhang, 2013). In retrospect, informal ULAB recycling operations result in increased environmental lead contamination and human exposure to lead in nearby areas (Paoliello & DeCapitani, 2005; Zheng *et al.*, 2008; Gottesfeld & Pokhrel, 2011).

Despite the hazardous nature of informal ULAB recycling operations, people still indulge in similar activities due to lack of awareness on the dangers of lead combined with a lack of viable economic alternatives (Hua *et al.*, 2005; Haefliger *et al.*, 2009; Swaddiwudhipong *et al.*, 2014).

Children under the age of seven years are the most exposed via ingestion of lead-contaminated soil and dust. This age group has special vulnerabilities to the toxic effects of lead on their bodies (Kaul & Mukerjee, 1999; Rasmussen *et al.*, 2001; US EPA, 2002, 2008a; Falk, 2003; Gould, 2009; Bell *et al.*, 2010). This is because of their behavioral, physiological and developmental characteristics. Children have different behavior from adults including crawling and playing on the waste slag, handling soil, rocks and dirt containing lead, bringing objects covered with lead dust back into the home, greater frequency of hand-to-mouth contact and pica behavior (Duggan & Inskip 1985; Kranz *et al.*, 2004; Gulson *et al.*, 2013). Secondly, gastrointestinal absorption of lead is higher in children's bodies than in adults (Amitai *et al.*, 1987; Mushak, 1991; Bellinger, 2004; Swaddiwudhipong *et al.*, 2013). Thirdly, lead can permanently and severely interferes with growth, differentiation and developmental processes of vital organs and systems in a child's body (ATSDR, 2006; Wu *et al*., 2008; WHO, 2014).

1.2 Health Effects of Lead on Exposed Children

Child exposure to lead can result in severe irreversible health effects even at low exposure levels (Surkan *et al.*, 2007; Bellinger, 2011; Swaddiwudhipong *et al.*, 2014). Lead affects the central nervous system, the brain, the blood tissue, the kidneys and the skeleton (Mielke & Zahran, 2012; Chakrabarty *et al.*, 2014). Moderate blood lead exposures between 5 to 40 μg/dL during early childhood have been linked to region-specific reductions in adult grey matter volume (Cecil *et al.*, 2008). Early childhood exposure to lead can alter gene expression and increase the risk of disease and death later in life. This reduces the quality life years in individual children (Lim *et al.*, 2012; Mazumdar *et al.*, 2012).

Symptoms of acute exposure to lead include loss of appetite, delirium, convulsions, coma, vomiting and possibly death (ASTDR, 1999; CDC, 2000; Wu *et al*., 2003; ATSDR, 2007; Rossi, 2008; WHO, 2010). This was the case in Dakar, Senegal, where at least eighteen children living within the vicinity of informal used lead-acid battery (ULAB) recycling operations died from lead poisoning (Jones *et al*., 2011).

In most cases, exposure to low amounts of lead over extended periods of time also known as chronic exposure is a much more common and widely reported problem. However, it is usually asymptomatic. Effects include; reproductive problems, abdominal pain, chest pain, frequent headaches, constipation and appetite loss. Cognitive and behavioral problems include; loss of memory, reduced concentration span, insomnia, mood swings, aggressiveness, hypertension and irritability (Lanphear *et al.*, 2002; WHO, 2010; Chakrabarty *et al.*, 2014). Children with blood lead concentrations between 2 µg/dl and 120 µg/dL can suffer IQ loss, shorter attention span, learning disabilities, behavioral problems, retardation, hearing and visual problems or impaired motor skills (Bellinger, 1992; Wang *et al*., 2002, 2008; US EPA, 2006; Zhang *et al.*, 2013). A study by Wu *et al.* (2003) revealed retarded sexual maturation among girls exposed to lead in the US. At blood lead levels above 45µg/dl, the exposed is at a high risk of encephalopathy and chelation therapy should be administered (CDC, 2013).

A research by Prüss-Üstün and Corvalán (2006) revealed evidence of reduced intelligence quotient (IQ) in children exposed to lead. Another study found that 189,725 children in 7 countries (Bangladesh, India, Indonesia, Kazakhstan, Pakistan, Phillipines and Thailand) had diminished IQ due to exposure to lead (Caravanos *et al*, 2012). Lead is highly toxic to children even at low exposure levels. Miranda *et al* (2007) reported that blood lead levels as low as 2 µg/dL can lower a child's performance in elementary school, and can have a continued long-term impact on the child's work performance later in life.

Furthermore, unborn children can be lead poisoned when pregnant women become exposed to lead. This can result in premature births, smaller babies, decreased mental ability in the infant, learning difficulties, and reduced growth (Vimpani *et al.*, 1985;

Levallois *et al.*, 1991; Brown *et al*., 2010; Dooyema *et al.*, 2010). Vinceti *et al.*, (2001) reported cardiovascular defects, oral clefts and musculoskeletal anomalies due to lead exposure to unborn children during pregnancy period.

In Africa, studies on metal contamination and associated human exposures still remain limited (Nriagu, 1997a, 1997b; Were *et al*., 2009; Banza *et al*., 2009; Oyoo-Okoth *et al*., 2013a). Though widely under-reported in most urban areas in Kenya, informal ULAB recycling is one of the most significant sources of lead release into the environment. Currently, there is limited data on exposure to lead and lead contamination from informal ULAB operations to guide decision making and form basis for further research. The study therefore set out to investigate child exposure to lead in the vicinities of informal ULAB recycling activities in selected slums in Nairobi City, Kenya. The study determined the levels of lead in soil and interior dust near ULAB recycling activities and then predicted blood lead levels in children living near these operations in Dandora, Kariobangi and Mukuru slums using the Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children. This study focused on children under seven 7 years of age.

1.3 Problem Statement and Justification

Research shows that informal ULAB recycling operations create lead contaminated sites and are sources of high lead exposure to children living nearby (Safi *et al.*, 2006; OK, 2012; van der Kuijp *et al.*, 2013). Children are the most exposed and at risk of permanent adverse toxic effects of lead, particularly effects on brain development, kidneys, the blood system, the nervous system and the skeleton (ATSDR, 2007; Cecil *et al.*, 2008;

Mazumdar, *et al.*, 2012; Chakrabarty *et al.*, 2014). Childhood exposure to lead is known to alter gene expression and increase risk of disease and death later in life and thus reduce quality life years (WHO, 2010). Recent researches reveal that there is no safe level of child lead exposure as young children can still suffer profound irreversible health effects at very low levels of lead exposure (CDC, 2013) Thus, there is urgent need to identify and assess the sources and levels of lead. This will help in developing appropriate measures to eliminate/reduce childhood lead exposure in order to protect our current populations and future generations (CDC, 2012).

There are several informal used lead-acid battery recycling operations in the densely-populated slum areas such as Mukuru, Dandora and Kariobangi in Nairobi City. In these areas children constitute over 50% of the total population (KNBS, 2014). The children are continuously exposed to indoor and outdoor lead as a result of unregulated informal ULAB recycling operations within their environments. This puts them at a great risk of lead poisoning. Currently in Kenya, no efforts have been put in place to curb the situation. This is mainly due to limited information and scientific data on the current situation of the informal ULAB recycling sector and the extent of environmental and human exposure to lead arising from the sector’s activities, and limited resources.

Previous studies in Kenya assessed occupational exposure to lead in the formal sectors and found significant levels of lead in human (blood, hair, nails) and environmental (soil, air and water) samples. For instance, Were *et al.* (2014) determined blood pressure and occupational lead exposure levels among production workers in diverse industrial plants, including lead-acid battery recycling plants in Kenya. A similar study was also carried out on air and blood lead levels in the formal lead acid battery recycling and manufacturing plants in Kenya (Were *et al*., 2012). Another study by Kimani (2005) revealed blood lead levels of 0-10µg/dl among children aged 0-10 years in Nairobi. The blood lead levels observed were attributed to the use of leaded petrol, spray painting, panel beating, metal cutting and welding as well as motor vehicle mechanics (Kimani, 2005).

This research therefore aimed at assessing child exposure to lead from informal ULAB recycling operations in Dandora, Kariobangi and Mukuru slums in Nairobi in an effort to mitigate childhood lead exposure. The study illustrated the vast public health risks posed by the informal ULAB recycling sector in Kenya. It determined lead levels in soil and house dust. The study also predicted pediatric blood lead levels from the soil and house dust lead levels obtained using the Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children. It therefore provides valuable information which should be used by policy makers and relevant stakeholders to protect the children and the wider society from the risks associated with ULAB recycling in Kenya.

1.4 Research Objectives

The study was guided by general and specific objectives.

1.4.1 General Objectives

The overall objective of the study was to investigate child exposure to lead in the vicinities of informal used lead-acid battery recycling operations in Nairobi slums, Kenya.

1.4.2 Specific Objectives;

The study was guided by the following specific objectives;

1. To determine the levels of lead in floor dust in dwelling units and preparatory schools in the vicinities of informal ULAB recycling operations in Nairobi.
2. To determine the concentration of lead in soil in residential areas, preparatory schools, children's playgrounds and dumpsites in the vicinities of informal ULAB recycling activities and, workplaces.
3. To predict blood lead levels in children under seven years living within the study area using the Integrated Exposure Uptake Biokinetic Model for lead in children, Windows Version.

1.5 Research Hypotheses

1. Lead concentrations in soils and lead loadings in indoor floor dust in study areas are above the recommended the respective US EPA limits for lead in soil and floor dust.
2. Predicted pediatric blood lead levels in the study areas are above the Centers for Disease Control and Prevention recommended limit of 5ug/dl in children.

1.6 Significance of the Study

The information gathered in this study will provide baseline scientific data, on the extent of environmental and children's exposures to lead as a result of informal ULAB recycling activities in selected slums of Nairobi. This will assist in the formulation and implementation of appropriate nationwide policies and frameworks aimed at eliminating lead exposures from informal ULAB industry and other sources. Consequently, it will contribute to national and global initiatives to reduce exposure to lead. Furthermore, the study findings and recommendations will guide decision-making on sustainable cost effective interventions to be undertaken in the study areas and other parts of the country with similar environmental health concerns.

1.7 Scope and Limitations of the Study

The study investigated child exposure to lead in the vicinities of used lead-acid battery recycling operations in Dandora, Kariobangi and Mukuru slums in Nairobi, Kenya. These three areas are also representative of several other areas where similar informal ULAB recycling operations are undertaken. Control samples were obtained from Ruiru, situated about 22 km from Nairobi's Central Business District. The control had no known point sources of lead. Soil and indoor floor dust were sampled and analyzed for lead (Pb). Pediatric blood lead levels were not clinically tested due to limited resources, including cultural and ethical issues. Instead, they were predicted from soil and house dust lead levels obtained using the Integrated Exposure Uptake Biokinetic Model for Lead in Children, Windows Version (IEUBKwin). The soil and indoor floor dust samples collected were representative enough to satisfy the objectives of the study.

In this study, it was assumed that soil and dust are the major routes of lead exposure to children below seven years.

CHAPTER TWO

LITERATURE REVIEW

2.1 Lead Contamination near Informal ULAB Recycling Activities

Informal ULAB recycling is a significant source of environmental lead contamination especially in developing countries (Mohammed *et al.*, 1996; WHO, 2010; Blacksmith Institute, 2011). On average, typical lead-acid batteries for vehicles contain 7.94 kg lead and 5.68 liters of sulfuric acid and last up to six years (Dell & Rand, 2001). In developing countries, poor manufacturing quality and tropical climates reduce the batteries' life cycle resulting into more frequent recycling (Zhang, 2013). According to Blacksmith Institute's (2011) technical report on Lead Poisoning and Car Batteries, over 50 percent of the world's used lead-acid batteries are recycled by the informal sector in developing countries. In most cases, such operations are carried out using crude technologies in homes, backyard units or on the road sides with no safety and environmental controls.

The recycling process mainly involves breaking of used batteries, removal of lead plates, crushing, screening, dry mixing, acidic and alkaline baths, melting down and acid bleaching to recover secondary lead (UNEP, 2002; Van der Kuijp *et al.*, 2013). These activities release critical amounts of lead-dust, and gaseous lead into local soils, air and waterways which find their way into the human system. Worse still, critical amounts of fly ash particulates laden with lead are usually emitted during open burning (Chen *et al.*, 2009; Were *et al*, 2012). Most recyclers use the waste/used oil re-refining units which use the acid-clay process. The used motor oil is usually burned in inadequately equipped installations to produce heat for smelting. This process emits large quantities of heavy metal particles, mainly lead. All these processes involved in informal ULAB recycling result in increased lead exposure to humans and the environment in nearby areas (Hay & Noonan, 2001; Gottesfeld & Pokhrel, 2011; Zhang, 2013).

Several studies that have been carried out in areas near informal ULAB recycling operations reveal elevated levels of lead in soil, water, dust and pediatric blood which exceed regulatory limits. After reviewing published studies on environmental contamination Paoliello and DeCapitani (2005) established that, after banning leaded gasoline and closing lead mining and primary smelting plants in Brazil, hundreds of small battery recycling plants still caused local contamination. A Middle Eastern study found blood lead levels exceeding 10 mg/dL among 17.2% of young children in Gaza, 2.2% in Israel, less than 1% young children in Jordan, and 5.2% in West Bank. All of the children in Gaza with blood lead levels >10 mg/dL lived near local small smelters and engaged in secondary recycling, smelting, and battery manufacture (Safi *et al*., 2006).

In a case study of Lead Poisoning, typically blood levels higher than 10 ug/dL were recorded among people living near backyard smelters and shops where lead acid batteries were repaired (Falk, 2003). A study carried out in Lianjiang River near a Chinese informal ULAB recycling village revealed lead levels that were 2,400 times higher than World Health Organization Guidelines for Drinking Water (BAN, 2002). In Dakar, Senegal, homes and soils were found to contain critical amounts of lead (indoors: up to 14 000 mg/kg; outdoors: up to 302 000 mg/kg). In the same study, about 950 residents were lead poisoned as a result of informal used lead–acid battery recycling with minimal environmental controls. Inhalation and ingestion of lead-contaminated soil dust were reportedly the major exposure pathways (Haefliger *et al.*, 2009).

It is evident that informal ULAB recycling activities are extremely hazardous and pose serious environmental and health risks. However, due to poverty, high rates of unemployment and ignorance, people still depend on similar harmful activities as their only source of livelihood. As a result, there is continued extensive environmental degradation and mass human exposure to lead, particularly children (Gottesfeld & Pokhrel, 2011; Galadima *et al.*, 2012). In Kenya, researchers have assessed occupational exposure to lead in the formal battery recycling sector (Were *et al.*, 2012, 2014). Another study found blood lead levels between 0-10µg/dl among children aged 0-10 years in Nairobi. The sources of exposure included the use of leaded petrol, spray painting, panel beating, metal cutting and welding as well as motor vehicle mechanics (Kimani, 2005). However, studies on the informal battery recycling sector are limited.

2.2 Child Exposure to Lead through Dust and Soil

Over the decades, studies have shown that informal ULAB recycling operations create lead contaminated sites and are sources of high dose lead exposure for children living nearby (Koplan *et al.*, 1977; Kawai *et al.*, 1983; Matte *et al.*, 1991; Paoliello & DeCapitani, 2005; Ye & Wong, 2006; Safi *et al.*, 2006; Haefliger *et al.*, 2009; OK, 2012; van der Kuijp *et al.*, 2013; WHO, 2014). In children, lead intake is influenced by age, behavioral and biological characteristics of the child and, the bioavailability of lead in the source material (Wigle *et al.*, 2007). Young children are closer to the ground and exhibit the greatest hand-to mouth activity and pica behavior. While playing indoors or outdoors, they crawl and play on lead-contaminated playgrounds and floors, eat with dusty hands, put lead-contaminated objects, such as toys or dust-laden fingers into their mouths and also eat non-food items such as contaminated soils exposing them more to lead (Lanphear *et al.*, 2002; US EPA, 2002; Kranz *et al.*, 2004; Chen *et al.*, 2012). According to a report, a typical one to six-year old child ingests between 100-400 milligrams of soil and house dust every twenty four hours. Children who engage in pica are therefore more exposed (US EPA, 2008a). Ingestion of lead-contaminated soil and house dust is thus the major pathway of exposure to lead in children (Sayre *et al.*, 1974; Lanphear *et al.*, 1995; Lanphear *et al.*, 1998; Gottesfeld & Pokhrel, 2011; Galadima *et al.*, 2012; Levallois *et al.*, 2014).

Ingested lead is absorbed into the child's body via the gastrointestinal tract. In a child's body, gastrointestinal absorption of ingested lead is enhanced up to 70% compared to 10% in similarly exposed adults (Bellinger, 2004; Chakrabarty *et al.*, 2014). Furthermore, the ongoing developments of vital organs in young children are more vulnerable to irreversible severe damage by lead (WHO, 2010; CDC, 2013). Usually, childhood exposure to lead occurs up to seven years of age and is maximum at two years. Children in this age category are thus the most exposed, vulnerable and at risk for serious morbidity and death resulting from lead poisoning (Falk, 2003; Gould, 2009; CDC, 2012).

The general population can also get exposed to lead via soil and dust. However, the rate of intake is much lower compared to children. Inhalation is the major exposure pathway to lead in adults. Infants and young children are usually more exposed than adults to environmental toxicants because of their behavior, diet, and metabolic and physiologic characteristics. They take in more air, water, and food per unit body weight per day than adults; they eat relatively larger amounts of certain foods that may contain pollutants and; have age-dependent differences in the absorption, distribution, metabolism and excretion of chemical residues (NAS, 1993; Rasmussen et al. 2001; Wigle *et al.*, 2007; Dooyema *et al.*, 2010; Bell *et al.*, 2010; Galadima *et al*., 2012).

Studies carried out; in Senegal, Asia, Thailand, Ghana, India, China and several other parts of the world reveal the hazards and fatalities posed by informal ULAB recycling operations to nearby residents, particularly, children (BAN, 2002; Fork H, 2003; Haefliger *et al.*, 2009; Caravanos *et al.*, 2012; Aboh *et al.*, 2013; Van der Kuijp *et al.*, 2013; Swaddiwudhipong *et al.*, 2013; 2014). According to Kumar (2008) lead-contaminated house dust was found to pose serious health hazards to children in Delhi, India. The dust lead levels exceeded US EPA limit of 40 micrograms of lead in dust per square foot on floors and 250 micrograms of lead in dust per square foot on interior window sills. Elevated blood lead-levels in children living near ULAB recycling operations were reported in Dakar, Senegal. The blood lead levels ranged between 32.5–613.9 µg/dl with ingestion of lead contaminated soil and dust being the major route of exposure to lead (Haefliger *et al*, 2009; Jones *et al.*, 2011).

2.3 Relationships between Lead in Soil, House Dust and Children's Blood Lead Levels

Over the years, studies have shown that levels of lead in house dust and soil are both strongly linked to children's blood lead levels (Lewandowski & Forslund, 1994; Lanphear *et al.*, 1996, 1998, 2005; Mielke *et al.*, 2007; Dixon *et al.*, 2009; Gaitens, *et al.*, 2009; Richardson *et al.*, 2011). Levallois *et al.* (2014) found that house dust lead contributes to a significant increase in blood lead levels in exposed young children aged between 1-5 years (Levallois *et al.*, 2014). Basing on this knowledge, various predictive models have been developed to assess child exposure. With good data on lead levels in environmental media such as soil and house dust, the models can be used to predict blood lead levels in children living in a given area (Sayre *et al.*, 1974; Charney *et al.*, 1983; Duggan & Inskip, 1985; Weitzman *et al.*, 1993; White *et al.*, 1998; Syracuse Research Corporation, 2007; Aboh *et al.*, 2013). An example of such models is the Integrated Exposure Uptake Biokinetic Model for Lead in Children-Windows version (IEUBKwin).

2.3.1 Integrated Exposure Uptake Biokinetic Model for Lead in Children

The Integrated Exposure Uptake Biokinetic Model for Lead in Children—Windows version (IEUBKwin) has been widely used to predict blood lead concentrations in young children exposed to lead. The model mathematically and statistically links environmental lead exposure to blood lead concentrations for a population of children between ages 0-7 years (IEUBK Guidance Manual, U.S. EPA, 1994; US EPA, 2002; Syracuse Research Corporation, 2007).

In the past few decades, IEUBKwin has been used to estimate pediatric blood levels in several countries including Ghana and the USA (HUD, 2004; Aboh *et al*, 2013). The model uses exposure, uptake, biokinetic, and probability distribution to estimate blood lead levels in children exposed to lead contaminated media. The geometric mean blood lead is predicted from available information about the child's or children's exposure to lead such as soil and dust data (White *et al.*, 1998; Christa *et al.*, 2006).

The amount of lead in residential dust is quantified by lead loading and lead concentration. Lead loading is the concentration of lead per unit area measured in micrograms per square meter ($\mu g/m^2$) or micrograms per square foot ($\mu g/f^2$). Dust loading refers to the amount of dust per unit area measured in grams per square meter (g/m^2) or grams per square foot (g/ft^2). Lead concentration refers to the mass concentration of lead per mass of dust, typically reported as micrograms per gram (μg/g or ppm). The IEUBK model uses lead concentration data as the metric to represent the extent and magnitude of lead in residential dust at a site. Dust lead concentration is calculated from lead loading (L_{Pb}) and dust loading (L_D) (US EPA, 2008b). From this distribution, the model estimates the risk (probability) that a child or a population of children will have their blood lead concentrations exceed a certain limit (O'Flaherty, 1998; Hogan *et al.*; 1998; Syracuse Research Corporation, 2007). A research by Lewandowski and Forslund (1994) shows that IEUBKwin's predictions are comparable with actual blood lead values. Figure 2.1 summarizes the spread of lead from informal ULAB recycling operations through various migration routes to soil and dust in children's environments. When children ingest the lead-contaminated soil and dust, lead subsequently enters the gastro-intestinal tract and finally the blood through biokinetic components.

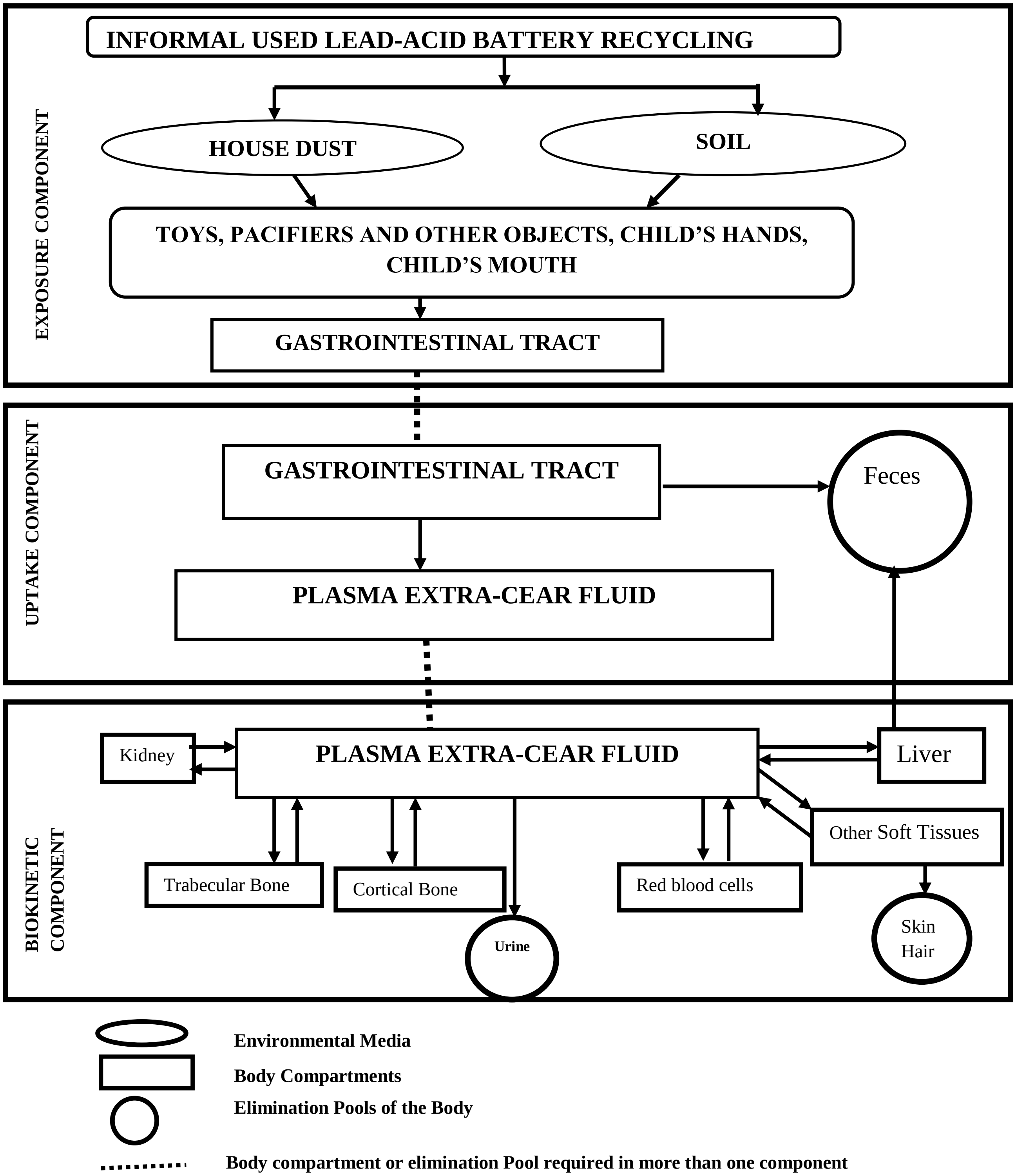


Figure 2.1: Conceptual Framework (Hodgson, 2004; US EPA, 2002)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The study was undertaken to determine child exposure to lead in the vicinities of informal ULAB recycling activities. The field activities and related investigations started in January 2015 and ended in August 2015. The research design was a cross-sectional study in Dandora, Kariobangi and Mukuru slums where informal ULAB recycling operations were carried out. The study involved collection of soil and floor dust samples from children's environments. The levels of lead in the soil and floor dust samples were determined. From the soil and house dust lead levels obtained, child blood lead levels were predicted using IEUBKwin in an effort to link the health risk posed to children under seven years by informal ULAB recycling activities.

3.2 Study Area

Nairobi is the capital city of Kenya with a human population of over four million (KNBS, 2014). The study area selection was purposive and was based on presence of informal ULAB recycling activities that were suspected to be potential sources of childhood exposure to lead (Pb). All sites that were studied were within the residential area with several human activities that included informal used lead-acid battery recycling. The areas chosen for the study were; Dandora, Kariobangi and Mukuru slums in Nairobi, Kenya as shown in Figure 3.1.

Figure 3.1 is a map showing the study area.

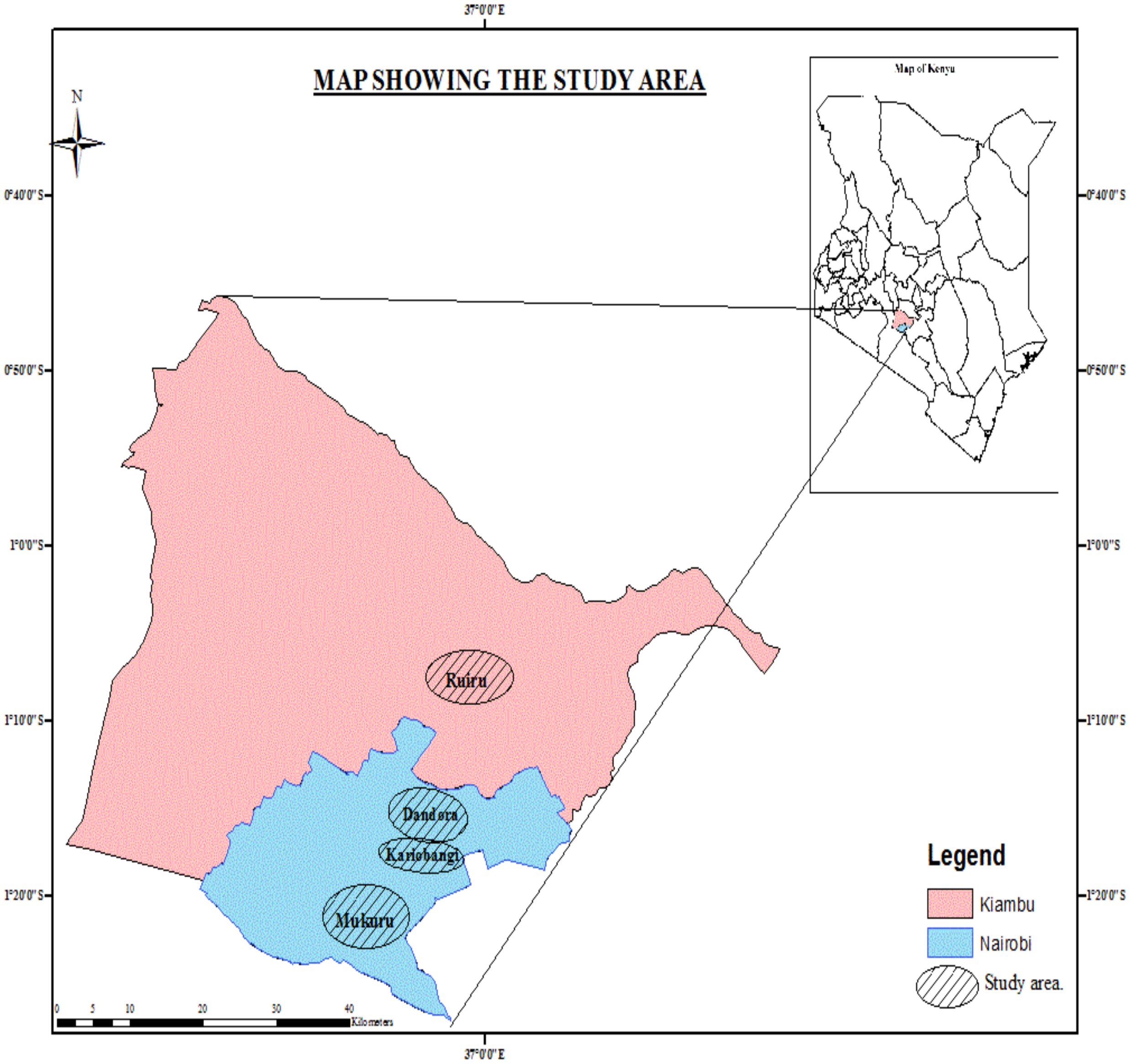


Figure 3.1: Map Showing the Study Area

Dandora is located in Embakasi division, about 8 km from Nairobi's Central Business District. It is divided into five phases and is the home of Nairobi's principal dumpsite. Kariobangi is a low-income residential area in northeastern Nairobi, Kenya situated along the Outer Ring Road. It is located approximately 15 Km from Nairobi City Centre and covers about 20 square kilometers of land. It is generally flat with a few slopes in bridges along rivers. It has a human population of about 1,910,000 (KNBS, 2014). Nairobi River crosses Dandora, and Kariobangi. Mukuru slum borders Nairobi's industrial area and has over 70,000 residents (KNBS, 2014). The area is generally flat and windy. There is little or on infrastructure, in most parts of Mukuru slums. The houses in Mukuru slums were mainly dirty dwellings. River Ngong, a tributary of Nairobi River passes the area.

Over 50% of the dwellers in Dandora, Kariobangi amd Mukuru slums are children (KNBS, 2014). Dandora, Kariobangi and Mukuru slums are served by several schools, churches, market centers, road side kiosks and commercial centers, and health facilities. The three areas are among the most densely populated slums in Nairobi with high unemployment and crime rates.

A control site was chosen in Ruiru in the neighbouring Kiambu County (Figure 3.1). Ruiru is located about 22 kilometers from Nairobi City along the Thika superhighway. The area had similar, industrial and traffic activities like Dandora, Kariobangi and Mukuru slums but with no known point sources of lead. It did not have informal ULAB recycling operations during the study period. The area was estimated to have about 20,000 residents (KNBS, 2013). River Ruiru crosses the area and is a source of water for irrigation.

3.3 Sampling Sites and Procedures

Sampling points were selected at random using random numbers, based on children’s activity patterns. Indoor floor dust sampling points were selected as follows; where children lived (dwelling units) and where children below seven years spent most of their time learning (preparatory schools). Dwelling units were deemed eligible if children between 0 to 84 months of age resided there. Dwelling units and preparatory schools were excluded if they were painted to avoid the confounding effect of lead in paint. Most of the dwelling units in the areas were single-roomed.

Soil sampling points were selected in children’s environments defined as 1) industrial sites where informal ULAB recycling was carried out 2) waste dumps where waste from the informal ULAB recyclers was disposed, 3) residential areas where young children resided, 4) play grounds where young children spent most of their time playing and 5) Preparatory schools where infants and children spent most of their time during the day while under care and learning.

Similarly, control floor dust sampling points in dwelling units and preparatory schools were randomly selected in rural Ruiru, which is located in Kiambu County about 22 km from Nairobi City (Figure 3.1). Control soil sampling points were randomly selected in residential areas, preparatory schools, playgrounds, waste dumps and industrial sites. During the study period, there were no informal ULAB recycling operations or other known point sources of lead into the environment in the control (Ruiru). Field observations were also made and photographs taken.

3.4 Sample Collection and Preparation

3.4.1 House Dust Sample Collection and Preparation

The dust wipe method described by the U.S. Department of Housing and Urban Development (HUD) was followed during collection and preparation of house dust samples (HUD, 2012). This method determines lead loadings on surfaces, allows for comparisons and samples the surface that most likely is the source of children's exposure to lead laden dust. Thus, the lead levels obtained can suitably be used in the model to predict child blood lead levels (HUD, 2012; Gulson *et al*., 2013).

With informed consent, the midpoint or largest area in the room was selected for floor dust sampling unless the child had a specific play area in the room, in this case the play area was considered. A one square foot plastic quadrant was carefully placed on the sampling area on the floor without disturbing the dust. The outside edges of the template were taped to the floor to keep it from moving while wiping. Using preweighed moist wipes (Cussons baby wipes, UK), dust samples were collected from the surface covered by the template. The samples were transferred into clean pre- preweighed Ziploc polythene bags, and then subsequently labeled. A total of ninety (N = 90) were collected from dwelling units in Dandora, Kariobangi and Mukuru slums. One hundred and fifty five (N = 155) floor dust samples were collected from preparatory schools in Dandora, Kariobangi and Mukuru slums (HUD, 2012).

Using the same standard procedures, 78 floor dust samples were collected from dwelling units and preparatory schools in the control area (Ruiru). All the 322 indoor floor dust samples were taken to the Mines and Geological Department Laboratory in the Ministry of Mining in Nairobi. Each dust sample was weighed together with the wipes and Ziploc polyethene bags. For each sample, total weight of dust collected (dust loading) was determined by the difference between the weight of the wipe and the polyethene bag, and recorded prior to chemical digestion.

3.4.2 Soil Sample Collection and Preparation

Using clean plastic shovel, two hundred and thirty two (N = 232) triplicate top soil samples were collected 0-2.5 cm deep from residential areas, preparatory schools, playgrounds, industrial area and waste dumps. Each soil sample was subsequently kept in a separate pre-cleaned Ziploc polythene bag, labeled, and then taken to the Mines and Geological Department Laboratory in the Ministry of Mining. The soil sample was then oven-dried at 40ºC to a constant weight, crushed, and homogenized prior to chemical digestion.

3.5 Sample Digestion

3.5.1 House Dust Sample Digestion

After homogenizing each house dust sample, a 2.5 g representative was weighed using an electronic analytical balance (Kern & Sohn, GMbH, Germany) and placed into 50 mL glass beaker then 20 mL de-ionized water added and the sample placed in the fume extraction hood. Next, 20 mL of 69% concentrated nitric acid was added. After 8 hours, 2 mL of 37% concentrated hydrochloric acid and 3 mL of 30% hydrogen peroxide were added and the contents allowed to react for approximately 5 min, then heated on hot plate to 180°C-200°C for 5 min. The temperature was maintained for 10 min then the beaker contents allowed to cool. On cooling, the beaker contents were filtered, diluted with de-ionized water and brought up to volume in a 50 mL volumetric flask prior to analysis. This is a typical digestion process to release lead from the dust wipe matrix and the soil matrix.

3.5.2 Soil Sample Digestion

For each soil sample, 0.5 g was weighed and placed into an inert polymeric microwave digestion vessel (Multiwave 3000, Anton Paar GmbH, Germany). The vessels were placed in the fume hood then 5.0 mL of double distilled water, 9.0 mL of concentrated nitric acid (65%), 1.0 mL of concentrated hydrochloric acid (30%), and 2.0 mL hydrogen peroxide (30%) were added. Double distilled water was added to improve mineral solubility and prevent temperature spikes due to exothermic reactions. In order to allow gases to escape, each sample was allowed to react for approximately 5 min prior to sealing. The vessels were then placed on the rotor and placed in the microwave and heated between 180°C and 210°C for 5.5 min, then maintained at the same temperature for another 15 min. After cooling, the vessel contents were filtered and diluted with double distilled water to a volume of 100 mL in a volumetric flask prior to analysis

3.6 Sample Analysis

3.6.1 Preparation of Stock and Working Solutions of Lead

Stock solution of lead (Pb) was prepared by dissolving 1.0 g of lead in 20.0 ml of 1:1 nitric acid and then diluting to 1.0 L to give 1000 ppm of lead. A working solution of 100 ppm was prepared by pipetting 10.0 ml from 1000 ppm stock solution into 100 mL volumetric flask then made to the mark using distilled water. Standard solutions of 0.5 ppm 1.0 ppm 5.0 ppm, 10.0 ppm, 20.0 ppm and 40.0 ppm were prepared by pipetting 0.5 mL, 1.0 mL, 5.0 mL, 10.0 mL, 20.0 mL and 40.0 mL respectively, of the working solution into 100 mL volumetric flask then made to the mark using deionized water. The standards were used to calibrate the inductively coupled plasma optical emission spectrometer (ICP-OES) using standard procedure (HUD, 2012; US EPA, 2008b). The calibration curve that was obtained is given in Appendix 1.

3.6.2. Analysis of Lead

The concentration of lead in the digested soil (N=232) and floor dust (N=322) samples was determined using the inductively coupled plasma-optical emission spectrometer (Spectro Arcos ICP Model Arcos FHS12, Germany). The lowest detection limit of the ICP-MS was 0.0594 ppm. For each sample analyzed, the readings were expressed in milligrams lead per liter (mg/L). Lead concentration in parts per million (ppm) in each sample was calculated as follows;

Pb (ppm) = [Reading (mg/l)*dilution (ml)] / weight of the sample (g)……………..**Equation 1**

Lead concentration in soil was expressed as milligrams of lead per kilogram of soil (mg/kg) whereas lead loading in house dust was expressed in micrograms lead per square foot (µg/ft^2).

3.7 Estimation of Child Blood Lead Levels

From the measured floor dust lead loadings and soil lead concentrations, IEUBKwin Version 1.1 Build 11 (Syracuse Research Corporation, North Syracuse, New York) was used to predict BLLs in children age ≤ 7 years (Syracuse Research Corporation, 2007). IEUBKwin has been widely used to predict blood lead concentrations in young children exposed to lead. The model mathematically and statistically links environmental lead exposure to blood lead concentrations for one child or a population of children between ages 0-7 years. The model uses exposure, uptake, biokinetic, and probability distribution to estimate blood lead levels in children exposed to lead contaminated media. The geometric mean blood lead is predicted from available information about the child's or children's exposure to lead such as soil and dust data (US EPA, 2002; Syracuse Research Corporation, 2007)

The amount of lead in residential dust is quantified by lead loading (measured in micrograms per square meter ($\mu g/m^2$) or micrograms per square foot ($\mu g/ft^2$), and lead concentration measured in micrograms per gram (µg/g or ppm). Dust lead concentration is calculated from lead loading (L_{Pb}) and dust loading (L_D) as follows;

Dust lead concentration = Lead loading (L_{Pb}) / Dust loading (L_D)..………… **Equation 2**

From this distribution, the model estimates the risk (probability) that a particular child or a population of children will have their blood lead concentrations exceed the Centers for Disease Control and Prevention reference values for lead in blood (Syracuse Research Corporation, 2007). For this study, the model assumed that soil and dust are the only major means by which children come in contact with lead. Therefore, all other lead pathways (maternal, air, water and diet) values were set to zero and only inputted dust and soil values. The default soil ingestion value was set as 500 mg/day for the dusty, dirt environments studied.

Currently, there are no reference levels for pediatric blood lead or house dust lead in Kenya. Therefore, 10 µg/dL and 5 µg/dL were used for comparison, while 40 $\mu g/ft^2$ was used as a reference value for house dust lead loading on floors (US EPA, 2001; CDC, 2002; CDC, 2012). US EPA guidance values of 400 mg/kg lead in soils in residential areas, schools and playgrounds, and 1,200 mg/kg lead in waste dumps and industrial soils were used (US EPA 2011a).

3.8 Quality Control and Assurance

Detailed standard procedures for collection, transport, and storage of samples were followed. Analytical grade chemicals (Sigma Aldrich Co, Germany) were used throughout the analyses. Deionized water was used throughout the analytical procedures.

Floor dust field blanks were prepared following similar procedure for collection of floor dust. Lead concentrations in the floor dust field blanks ranged from not detected level to 2.1 $\mu g/ft^2$. Laboratory wipe sample blanks were also prepared and digested. Lead was not detected in any of the laboratory blank wipe samples.

Reagent blanks were similarly digested and analyzed with the samples. Lead was not detected in any of the reagent blanks.

Certified Reference Materials (CRM) for soils (Institute for Reference Materials and Measurement (IRM) and INTER 2000, France) were weighed and digested together with soil samples. Lead concentration in the CRM certificate was 64 mg/kg, while lead levels in the CRM digests ranged from 63.4 mg/kg – 64.0 mg/kg, equivalent to 98.98-99.97% recoveries of the certified concentration.

An inter-laboratory comparison of the lead levels in six randomly selected samples each of soil and house dust was conducted at the Kenya Industrial Research and Development Institute (KIRDI) and Kenya Plant Health Inspectorate services (KEPHIS) Analytical Chemistry Laboratories in Nairobi using similar procedures. Lead was detected using AAS (calibration curve shown in Figure 2) and GFAAS (calibration curve shown in Figure 3) in KIRDI and KEPHIS respectively. Correlation coefficient between the sets of soil and house dust lead levels was 0.94 and 0.99 respectively. The study results were therefore deemed reliable.

3.9 Statistical Methods

Statistical analyses were performed, using Minitab version 17.0 (Minitab Inc.) The Ryan Joiner test was used to test the normal/log-normal distribution of the data for soil and floor dust lead values in the areas studied. All the data was log-transformed. The geometric means (GMs) and medians for soil and house dust were calculated. Comparison of lead concentrations in house dust in different sampling sites was done using One-way ANOVA. All the levels of statistical significance were set at $p<0.05$, unless otherwise stated.

The Integrated Exposure Uptake Biokinetic Model for Lead in Children—Windows Version 1.1 Build 11 was then used to predict blood lead levels in children ≤ 7 years of age living in the study areas (IEUBK Guidance Manual, US EPA, 1994; O'Flaherty, 1998; Hogan *et al.*, 1998; US EPA, 2002; Christa *et al.*, 2006; Syracuse Research Corporation, 2007; Aboh *et al.*, 2013). The IEUBKwin was also used to generate the geometric mean blood lead levels. The percentage of children with blood levels exceeding 10 µg/dl (CDC, 2002) and 5 µg/dl (CDC, 2012) was determined in each area (Syracuse Research Corporation, 2007).

CHAPTER FOUR

RESULTS

This chapter presents the results of floor dust lead loadings and soil lead concentrations in environments where children under seven years spend most of their time in close proximity to informal ULAB recycling operations. Lead loadings results for the two hundred and forty four (N = 244) floor dust samples from dwelling units and preparatory schools in the study areas (Dandora, Kariobangi and Mukuru) and those of the control (Ruiru) (N = 78) are presented in Tables 4.1 and 4.2.

Lead concentrations determined in the one hundred and seventy four (N = 174) soil samples from waste dumps, industrial sites, residential areas, playgrounds and preparatory schools in the study areas (Dandora, Kariobangi and Mukuru) and the fifty eight (N = 58) soil samples from the control (Ruiru) are presented in Tables 4.3 and 4.4. From the floor dust lead loadings and soil lead concentrations obtained, child blood lead levels were predicted as presented in Table 4.5.

4.1 Lead Loadings in Floor Dust.

Lead was detected in all (100%) the floor dust samples. Mean floor dust lead loading values were elevated with significant ($p<0.05$) variations among the areas. The mean floor dust lead loadings were highest in in Kariobangi, followed by Mukuru slums then Dandora. Individual indoor floor dust samples from Kariobangi recorded as high lead loadings as 58,194 µg/ft^2 (about 6% lead) as compared to the US EPA guidance value of 40 µg/ft^2. The control recorded lower mean lead loadings compared to the study case areas as presented in Table 4.1.

Table 4.1: Lead loadings (µg/ft^2) in Floors in Dwelling Units and Preparatory Schools in the Study Areas.

Study Area	Dwelling units			Preparatory schools		
	N	G. Mean ± SD	Median	N	G. Mean ± SD	Median
Dandora	30	7495.1 ±1.8^d	7094.0	44	1749.0 ±1.57^d	1617.3
Kariobangi	30	9358.1 ±2.31^e	7390.9	56	2300.8 ±2.51^d	2016.3
Mukuru	30	8892.8 ±1.74^e	8839.7	55	1828.0 ±2.18^d	2050.8
Ruiru (Control)	30	63.7 ±1.61^a	75.3	48	46.3 ±2.65^a	59.4
F value		451.5			257.8	
P value		<0.0001			<0.0001	

*Geometric Mean lead loading values that do not share a superscript letter are significantly different. ^{a}G.Mean, Geometric mean; ^{b}SD, Standard deviation; ^{c}N, Number of samples.

The mean lead loading values recorded in each area (Dandora, Kariobangi, Mukuru and Ruiru) varied significantly ($p<0.05$) between sampling sites (households and preparatory schools). Floor dust from dwelling units contained significantly higher lead loadings than floor dust from the preparatory schools in Dandora, Kariobangi and Mukuru slums ($p<0.05$). This was not the case in the control (Ruiru) where the difference was not significant ($p>0.05$).

The percentage distribution of lead loadings in the floor dust samples collected in Dandora, Kariobangi, Mukuru slums and the control (Ruiru) are presented in Table 4.2.

Each floor dust lead loading measurement from dwelling units and preparatory schools in Dandora, Kariobangi and Mukuru slums exceeded the US EPA guidance value of 40 μg/ft^2. In contrast, only 76.7% and 68.8%, respectively, of floor dust loadings from dwelling units and preparatory schools in the control area exceeded the US EPA guidance value (Table 4.2).

Table 4.2: Percentage Distribution of Floor Lead Loadings in the Study Areas

Study Area	Sampling Sites	n	N	Percentage (%)of Floor Lead Loading Measurements		
				≤10 μg/ft^2	>10≤40 μg/ft^2	>40 μg/ft^2
Dandora	Dwelling units	30	30	0.0	0.0	100.0
	Preparatory Schools	10	44	0.0	0.0	100.0
Kariobangi	Dwelling units	30	30	0.0	0.00	100.0
	Preparatory Schools	13	56	0.0	0.0	100.0
Mukuru	Dwelling units	30	30	0.0	0.0	100.0
	Preparatory Schools	12	55	0.0	0.0	100.0
Total		**125**	**244**	**0.0**	**0.0**	**100.0**
Ruiru (Control)	Dwelling units	30	30	0.0	20.0	80.0
	Preparatory Schools	9	48	14.6	16.7	68.8
Total		**39**	**78**	**8.9**	**17.9**	**73.1**

[a]**N**, Number of Samples; [b]**n**, Number of Sampling Sites; [c]40 μg/ft^2, US EPA guidance value for lead loading indoor floor dust (US EPA, 2001).

4.2 Lead Concentrations in Soil in Study Areas

Soils in Dandora, Kariobangi and Mukuru slums were found to have high lead concentrations as given in Table 4.3.

Table 4.3: Lead Concentrations in Soil Samples by Site and Location.

Study Area		**Soil Lead Concentration (mg/kg)**				
		Waste dumps	Industrial sites	Residential areas	Playgrounds	Preparatory schools
Dandora	G. Mean ± SD	1891.3 ± 1.0^{a}	1933.9 ± 1.0^{a}	472.2 ± 1.1^{fg}	400.7 ± 1.0^{ghi}	339.1 ± 1.3^{hi}
	Median	1883.0	1922.0	463.6	398.7	331.9
	N	9	9	18	9	13
Kariobangi	G. Mean ± SD	1665.4 ± 1.0^{b}	1670.7 ± 1.15^{b}	391.9 ± 1.2^{ghi}	357.1 ± 1.1^{ghi}	440.5 ± 1.9^{f}
	Median	1631.1	1654.0	395.4	349.3	380.0
	N	9	9	18	9	13
Mukuru	G. Mean ± SD	6922.9 ± 1.1^{c}	4714.9 ± 1.1^{d}	758.9 ± 1.1 ^{e}	477.8 ± 1.1^{fgh}	319.4 ± 1.3^{i}
	Median	7097.0	4433.0	773.2	449.0	345.2
	N	9	9	18	9	13
Ruiru (Control)	G. Mean ± SD	58.8 ± 1.0^{j}	56.61 ± 1.1^{j}	21.45 ± 1.3 ^{j}	32.14 ± 1.6^{j}	55.0 ± 1.4^{j}
	Median	57.9	55.4	19.6	23.9	51.6
	N	9	9	18	9	13
F value		231.6	345.4	97.3	57.8	126.6
p value		<0.001	<0.001	0.004	0.0046	<0.001

*Geometric means that do not share a superscript letter are significantly different; ^{a}G. Mean, geometric mean; ^{b}D, Standard deviation; ^{c}N, Number of samples.

Significant (*$p<0.05$*) variations were observed in lead concentrations among the areas (Dandora, Kariobangi, Mukuru and Ruiru). The geometric mean soil lead concentrations recorded were highest in Mukuru slums followed by Dandora then Kariobangi. Waste dump and industrial soils in Dandora, Kariobangi and Mukuru slums were found to have a high geometric mean lead concentration (2,630.5 mg/kg).The lead concentrations in the waste dump and industrial soils were elevated and ranged between 1,589.0 mg/kg and 7,108.0 mg/kg as compared to the US EPA guideline of 1,200 mg/kg for lead in waste dumps and industrial soils (Table 4.3) (US EPA, 2011a). The study also established that outdoor soils in preparatory schools, residences and playgrounds near informal ULAB recycling activities in Dandora, Kariobangi and Mukuru had a high geometric mean lead concentration of 437.1 mg/kg as compared to the US EPA guidance value of 400 mg/kg for lead in soils in residential, playground and school areas, with a range of 214.0 mg/kg to 1,870.8 mg/kg (Table 4.3).

ANOVA analysis carried out revealed significant ($p<0.05$) variations in the mean soil lead concentrations among the sites that included waste dumps, industrial, residential, playgrounds and preparatory schools (Table 4.3). Though obvious, waste dumps and industrial soils recorded the highest lead concentrations in all the areas. The control had a lower mean lead concentration compared to the study case areas (Dandora, Kariobangi and Mukuru).

The percentage distribution of soil lead concentration measurements for Dandora, Kariobangi, Mukuru slums and Ruiru are presented in Table 4.4.

Table 4.4: Percentage Distribution of Soil Lead Concentrations in the Study Areas

Study Area	**Sampling Sites**	**N**	**Percentage (%) of Soil Lead Concentration Measurements (mg/kg)**			
			≤40	**>40≤100**	**≤1, 200**	**>1, 200**
Dandora	Waste dumps	9	0.0	0.0	0.0	100.0
	Industrial sites	9	0.0	0.0	0.0	100.0
Kariobangi	Waste dumps	9	0.0	0.0	0.0	100.0
	Industrial sites	9	0.0	0.0	0.0	100.0
Mukuru	Waste dumps	9	0.0	0.0	0.0	100.0
	Industrial sites	9	0.0	0.0	0.0	100.0
Total		**54**	**0.0**	**0.0**	**0.0**	**100.0**
Ruiru (Control)	Waste dumps	9	0.0	100.0	0.0	0.0
	Industrial sites	9	0.0	100.0	0.0	0.0
Total		**18**	**0.0**	**100.0**	**0.0**	**0.0**
			≤40	**>40≤100**	**≤400**	**>400**
Dandora	Residential areas	18	0.0	0.0	0.0	100.0
	Playgrounds	9	0.0	0.0	66.7	33.3
	Preparatory schools	13	0.0	0.0	84.6	15.4
Kariobangi	Residential areas	18	0.0	0.0	61.1	38.9
	Playgrounds	9	0.0	0.0	77.8	22.2
	Prep. schools	13	0.0	0.0	61.5	38.5
Mukuru	Residential	18	0.0	0.0	0.0	100.0
	Playgrounds	9	0.0	0.0	0.0	100.0
	Prep. schools	13	0.0	0.0	61.5	38.5
Total		**120**	**0.0**	**0.0**	**42.5**	**57.5**
Ruiru (Control)	Residential	18	100.0	0.0	0.0	0.0
	Playgrounds	9	66.7	33.3	0.0	0.0
	Prep. schools	13	15.4	84.6	0.0	0.0
Total		**40**	**65**	**35**	**0.0**	**0.0**

[a] **N**, Number of Samples; [b]1,200 mg/kg, US EPA guidance value for lead concentration in waste dump and industrial soils; [c]400 mg/kg, US EPA guidance value for lead concentration in schools, playgrounds and residential soils (US EPA, 2011a).

Lead concentrations in 57.5% (69 out 120) of the soil samples from residential, playgrounds and preparatory schools in Dandora, Kariobangi and Mukuru slums exceeded the 400 mg/kg standard. All (100%) control soil samples recorded low lead concentrations that were below the recommended values. Each waste dump and industrial soil lead concentration measurement from Dandora, Kariobangi and Mukuru slums exceeded the US EPA guidance value (Table 4.4).

4.3 Predicted Blood Lead Levels in Children

Table 4.5 gives the predicted blood lead levels in children ≤ 7 years old in the study areas.

Table 4.5: Predicted Blood Lead Levels in Children ≤ 7 Years Old in the Study Areas.

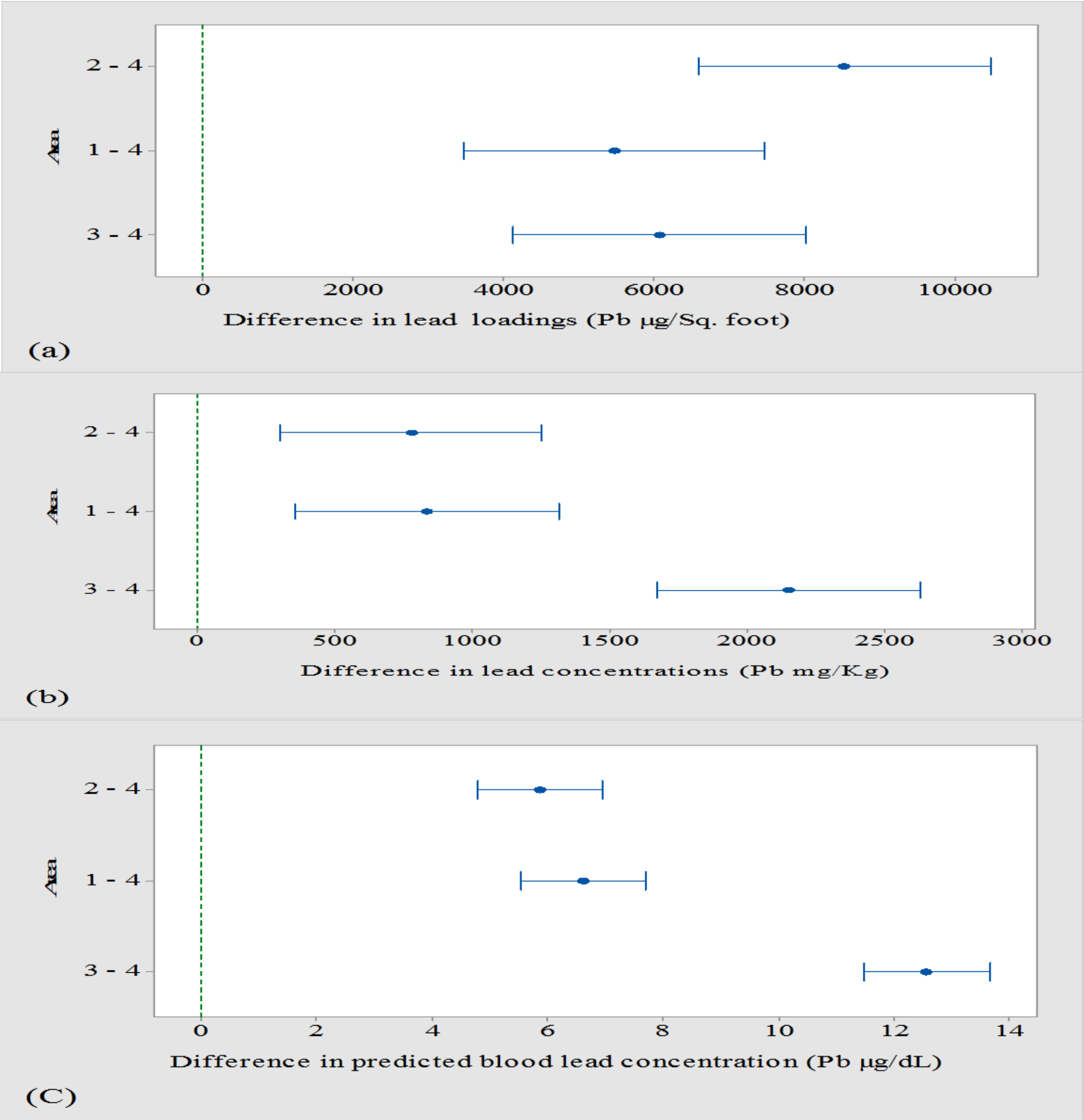
Age (Years)	Dandora	Kariobangi	Mukuru	Ruiru
0.5-1	27.3	25.5	44.1	2.3
1-2	25.1	23.3	40.5	1.9
2-3	22.7	21.1	37.1	1.6
3-4	22.3	20.7	36.8	1.5
4-5	22.1	20.4	36.7	1.5
5-6	21.4	19.7	36.0	1.4
6-7	20.3	18.7	34.4	1.3
GM	22.4	20.8	37.0	1.6
% exceedance (10 µg/dl cut off)	95.7	94.0	99.7	0.0
% exceedance (5 µg/dl cut off)	99.9	99.9	99.9	0.8

[a]IEUBKwin was used to predict the BLLs (US EPA, 2002; Syracuse Research Corporation, 2007); [b]10 µg/dL (CDC, 2002) and 5 µg/dL (CDC, 2012) were used as the cut off/reference for child BLLs; [c]GM – Geometric mean blood lead level in children; [*]Geometric standard deviation = 1.60. **Child soil ingestion rate = 500 mg/day (Syracuse Research Corporation, 2007).

99.9% of children in Dandora, Kariobangi and Mukuru slums were predicted to have elevated mean blood lead levels that exceeded the CDC reference value of 5 µg/dL for lead in blood (CDC, 2012). The predicted child blood lead levels varied significantly among the areas and age-groups ($p<0.05$). Children living near informal ULAB recycling activities in Mukuru slums were predicted to have the highest geometric mean blood lead level followed by those living in Dandora, Kariobangi and Ruiru consecutively. Accordingly, children living in the control (Ruiru) were predicted to have a low mean blood lead level below the CDC recommended value (Table 4.5).

Using CDC (2002) 10µg/dL as the cut-off blood lead level in the model, about 95.7%, 94.0%, and 99.7% of children under seven years living near informal ULAB recycling operations in Dandora, Kariobangi and Mukuru, respectively, were likely to have elevated blood lead levels that exceeded 10 µg/dL. On the other hand, when CDC (2012) limit of 5µg/dl for lead in blood was used as the cut off in the IEUBKwin, the percentage exceedance in the areas were found to increase to 99.9% in Dandora, Kariobangi and Mukuru slums, and 0.8% in Ruiru. It was found that children below four years were at risk of being lead poisoned with blood lead levels above 34 µg/dL in Mukuru, above 22 µg/dL and above 20 µg/dL in Dandora and Kariobangi respectively (Table 4.5).

The levels of lead in soil and house dust and, the predicted child blood lead levels in Dandora, Kariobangi and Mukuru were compared to those recorded in the control (Ruiru) as presented in Figure 4.1.



KEY: Area 1, Kariobangi, Area 2, Dandora; Area 3, Mukuru; Area 4, Control (Ruiru)

Figure 4.1: Comparisons of Levels of Lead in the Study Case Areas and the Levels in the Control Area.

Fisher multiple comparisons with control revealed differences in the levels of soil lead concentrations, house dust lead loadings and predicted pediatric blood lead levels between the control (Ruiru) and all the other study areas as presented graphically in

Figure 4.1. The means of floor dust lead loadings recorded in Dandora, Kariobangi and Mukuru were significantly ($p<0.05$) higher than those found in the control (Ruiru) in all the dwelling units and preparatory schools studied (Figure 4.1(a)). Similarly, the mean lead concentrations in soils in Dandora, Kariobangi and Mukuru were significantly ($p<0.05$) higher than those obtained in Ruiru (Figure 4.1(b)).

Furthermore, predicted blood lead levels in children living near informal ULAB recycling activities in Dandora, Kariobangi and Mukuru were all higher than the levels found in those living in the control (Ruiru) (Figure 4.1 (c)). The differences were significant ($p<0.05$). We hypothesize that the differences represented the impact of informal ULAB recycling operations. However, other sources of environmental lead contamination such as historical use of leaded petrol, spray painting, panel beating, metal cutting and welding as well as motor vehicle mechanics may have also contributed to the elevated lead levels recorded in the study (Kimani, 2005).

CHAPTER FIVE

DISCUSSION

Previous studies have reported elevated levels of environmental lead and related human health risks in the vicinities of informal ULAB recycling operations (Koplan *et al*., 1977; Kawai *et al*., 1983; Matte *et al*., 1991; Paoliello & DeCapitani, 2005; Ye & Wong, 2006; Safi *et al*., 2006; Haefliger *et al*., 2009; Jones *et al*., 2011; OK, 2012; van der Kuijp *et* al., 201; WHO, 2014). In this study, significantly ($p<0.05$) high levels of lead were also found in soil and house dust in the vicinities of informal ULAB recycling operations in Dandora, Kariobangi and Mukuru, where the lead levels exceeded the US EPA (2001, 2011a) guidance values for lead in soil and interior floor dust. From the established high lead levels in soil and house dust in the studied areas, the predicted child blood levels were also high and exceeded the CDC (2012) 5 µg/dl reference value for lead in blood. These findings indicate serious public health risks posed to children under seven years living in the vicinities of informal ULAB recycling activities. The findings are important in assisting carefully focused interventions.

One of the uncertainties of this study was how to determine the actual amount of the ingested lead that is absorbed into the child’s gastrointestinal tract and subsequently, interacted with body cells, organs and systems. This quantity of lead is referred to by Mielke and Reagan (1998), Huang *et al*. (2015) and Syracuse Research Corporation (2007) as the delivered dose, bioaccessible lead or bioavailable lead, respectively. According to Mielke and Reagan (1998), basing on the measurable amount of lead to determine delivered dose, makes informal lead-acid battery recycling the greatest hazard.

However, determination of delivered dose of lead for house dust and soil is a challenge since there is no feasible way to directly and accurately find what the child consumes or the true exposure concentration. As established in this study, coupling the total lead with bioaccessible lead is more reliable for determining lead exposure and pathways in children than using only total lead (Pb) (Li *et al*., 2014; Huang *et al*., 2015). In the uptake component, IEUBKwin modeled the process by which ingested lead is transferred to the child's blood plasma (bioavailable lead). By using the IEUBK model in this study, different bioavailabilities of lead from different soils and house dust were appropriately addressed. The model allowed for a partial saturation of absorption at high levels of lead intake (Syracuse Research Corporation, 2007).

5.1 Lead Levels in House Dust and Soil

5.1.1 Lead Loadings in House Dust

Lead loading values found in the study areas showed significantly ($p<0.05$) higher indoor lead contamination in preparatory schools as well as dwelling units where children below seven years spend most of their time compared to the control (Table 4.1). Lead loadings in 100% of floor dust samples (N = 244) collected from dwelling units and preparatory schools in Dandora, Kariobangi and Mukuru exceeded the US EPA (2001) guidance value of 40 µg/ft^2 for lead in interior floor dust (Table 4.2). The samples had a higher mean lead loading value of 7, 074.0 µg/ft^2 compared to the mean value of 55 µg/ft^2 recorded in the control (Ruiru). Lead loading values in dwelling units and preparatory schools in Dandora, Kariobangi and Mukuru slums ranged from 65.0 µg/ft^2 to 58,194 µg/ft^2 compared to the range of 4.31 µg/ft^2 to 342.22 µg/ft^2 found in the control (Ruiru).

The high lead loading values found in Dandora, Kariobangi and Mukuru could be attributed to the fact that the dwelling units and preparatory schools were located in the vicinities of informal ULAB recycling operations. The activities were observed as shown in plate 5.1, where informal ULAB recycling processes were carried out in close proximity to preparatory schools in a residential area in Dandora.

Plate 5.1: Informal ULAB Recycling Industrial Site near a Preparatory School in a Residential Area in Dandora (Source: Author, 2015).

In addition, lead accounts for about 70% of the total weight of a typical ULAB. The crude methods that are used in informal ULAB recycling processes were reported to release high levels of lead to the surrounding environs and also result in large amounts of lead-containing wastes which were dumped in the open (Zhang, 2013). It was also observed (Plate 5.1) that the crude methods used in the ULAB recycling released white fumes containing lead that were blown by the prevailing wind. These processes also emitted large amounts of lead dust which settled in surrounding areas and buildings. The lead contaminated soils could become airborne when disturbed and blown by wind, then deposited in nearby dwelling units and schools causing indoor contamination. Family members can also "carry home" lead-contaminated soil dust from outside when they enter the house without removing their shoes. Studies by Mohammed et al. (1996), Haefliger *et al*. (2009) and Jones *et al*. (2011) also found that informal ULAB recycling is a significant source of indoor lead contamination. The higher mean lead loading values found in Dandora, Kariobangi and Mukuru than those recorded in the control established the fact that lead loading depended on the source of lead and the amount of dust. This study is in agreement with the United States Department of Housing and Urban Development, HUD (2012) that also reported correlations between lead loading, the source of lead and the amount of dust.

Most of the floors in dwelling units and preparatory schools studied were dirty with walls constructed using broken iron sheets which had several openings that may have allowed in lead–containing dust both during the day and at night. The floor surfaces had also crevices onto which lead containing dust could have embedded. It was found that wet cleaning of dirty floors was difficult, the residents therefore practiced dry-sweeping of the floors with the children in their vicinities. All these combinations of activities generated large amounts of dust that was observed. This therefore explains the significantly ($P<0.005$) high levels of lead in the dust in all the dwelling units and preparatory schools that exceeded the US EPA (2001) guidance value of 40µg/ft^2 for lead in floor dust.

The large amounts of lead-containing dust that was measured easily came into contact with the children's toys, hands, pacifiers and several other objects which they put into their mouth during their regular hand-to-mouth activity and pica behavior. Due to their undeveloped unhygienic behavior, the children were found eating using their dusty hands. They further crawled and played on the lead-contaminated floors in the dwelling units and preparatory schools and ingested more lead. Similar studies by Lanphear *et al.* (2002), US EPA, (2002), Kranz *et al.* (2004) and Chen *et al.*, 2012) also reported children ingesting more lead in contaminated environments. Furthermore, young children in the slums investigated were found to spend several hours indoors which made them to be constantly exposed to the lead-contaminated floor dust. A related study by US EPA (2008a) reported that every twenty four hours, a typical one to six year old American child ingests between 100-400 milligrams of soil and house dust with the highest ingestion rate at the age of two years. Consequently, with the dusty environments studied the dust ingestion rate among children who lived near the informal ULAB activities could be higher.

The study environments posed serious public health risks to the children who are usually the most exposed and vulnerable to the severe impacts of lead, due to their behavior, diet and, metabolic and physiologic characteristics. According to WHO (2010) and Lim *et al.* (2012), lead exposure contributes to about 1 000,000 cases of intellectual disability in children every year. It was further found that children below seven years in this study spent several hours in the dusty, lead-contaminated and poorly-ventilated dwelling units and preparatory schools investigated. This therefore suggests that indoor lead contamination could have a higher impact on children compared to outdoor dust. This study is consistent with studies by Lanphear *et al.* (1995, 1996, 1998), Kumar (2008), Dixon *et al.* (2009) and Haefliger *et al.* (2009) which also revealed that lead-contaminated house dust has significant impact on the health of infants and young children.

Even though there were no informal ULAB recycling activities in the control (Ruiru) during the study period, control floor dust samples recorded an elevated mean lead loading value that exceeded the US EPA (2001) guidance value of 40 $\mu g/ft^2$ for lead in interior floor dust (Tables 4.1 and 4.2). This could be attributed to the fact that lead particles from the informal ULAB recycling operations were readily transported by air and wind resulting into contamination in other far places including the control (Ruiru). The International Finance Corporation (2007) and McCartor and Becker (2010) also reported that water, air, wind, humans and animals are important transport agents for toxic pollutants such as lead resulting into contamination several kilometers away from the contaminant's source.

5.1.2 Soil Lead Concentrations

The elevated lead concentrations found in the study revealed significant ($p<0.05$) outdoor lead contamination in soils (waste dumps, industrial sites, residential areas, playgrounds and preparatory schools) that were frequently accessed by children below seven years in Dandora, Kariobangi and Mukuru. Accordingly, the control area (Ruiru) that had no known point source of lead contamination had low levels of lead in soils (Tables 4.3 and 4.4).

All the soil samples (100%) from waste dumps and industrial sites in Dandora, Kariobangi and Mukuru slums were found to have a high mean lead concentration (3,137.00 ± 278 mg/kg) that exceeded the US EPA (2011a) guidance value of 1200 mg/kg for lead in waste dumps and industrial soils. In these areas, lead concentrations in waste dumps and industrial soils ranged between 1,589.00 mg/kg and 7,108.00 mg/kg. In contrast, all the soil samples (100%) from waste dumps and industrial areas in the control recorded a low mean lead concentration of 56.75 ± 0.55 mg/kg which was below the US EPA (2011a) guidance value of 1200 mg/kg for lead in waste dumps and industrial soils. Lead values in the control ranged from 51.88 mg/kg to 59.37 mg/kg.

It was found that the soil samples from residential areas, playgrounds and preparatory schools in Dandora, Kariobangi and Mukuru slums had an elevated mean lead concentration of 471.3 ± 19.9 mg/kg that exceeded the US EPA (2011a) guidance value of 400 mg/kg for lead in soils in residential, playground and school areas. Lead concentrations recorded in the three areas varied from 214.0 mg/kg to 1,870.8 mg/kg. 57.5% (69 out 120) of the samples had lead concentrations that exceeded the recommended values. On the contrary, all the soil samples (100%) from residential areas, playgrounds and preparatory schools in the control (Ruiru) recorded a low mean lead concentration of 35.65 ± 3.26 mg/kg that was lower than the guidance values, where individual lead values ranged from 15.81 mg/kg to 88.08 mg/kg. The high lead concentrations recorded in Dandora, Kariobangi and Mukuru in this study could be attributed to the uncontrolled informal used lead-acid battery recycling processes which were being carried out within residential areas, near preparatory schools and children's play grounds with no environmental and human exposure controls. There was generation of substantial amount of white fumes in the areas (Plates 5.1 – 5.2).

Plate 5.2: Informal ULAB Recycling Industrial Site near Preparatory Schools in Kariobangi (Source: Author, 2015)

The processes involved in informal ULAB recycling activities that included breaking of used batteries, removal of lead plates, crushing, screening, dry mixing, open burning and melting down generated large amounts of lead-containing dust and fumes that were seen in the areas. Considerable amounts of dust containing lead settled on surrounding soils, which was also observed in Plates 5.1 – 5.3.

Plate 5.3: An Informal ULAB collection point within an industrial site in Mukuru slums (Source: Author, 2015)

Similar to the findings of this study, Blacksmith Institute (2007), Chen *et al.* (2009) and Zhang, (2013) also reported that typical informal ULAB recycling operations in developing countries are usually conducted in residential places with no pollution controls. In retrospect, all the activities involved in informal ULAB recycling operations in Dandora, Kariobangi and Mukuru resulted in elevated levels of lead in the outdoor soils investigated. Findings of this research concur with studies by Haefliger *et al.* (2009), Gottesfeld and Pokhrel, (2011), and Jones *et al.* (2011) which also reported contaminated soils in vicinities of unregulated informal ULAB recycling activities.

Besides, the crude methods used in informal ULAB recycling processes are inefficient. Thus, the lead recovered in these operations is usually less (UNEP, 2005; Gottesfeld & Pokhrel, 2011). As a result, the informal ULAB recycling processes in Dandora, Kariobangi and Mukuru generated large amounts of wastes. The slag had high lead-containing impurities and was dumped in the open near preparatory schools and children's playgrounds within residential areas as observed in Plate 5.4.

Plate 5.4: Informal ULAB Recycling Waste Dumps near Preparatory Schools and Children's Playgrounds within a Residential Area in Kariobangi (Source: Author, 2015).

The waste dumps were therefore major sources of lead exposure. Children under seven years living in the vicinities of the waste dumps played and crawled on the contaminated soils of the toxic waste dumps as observed in Plates 5.4 and 5.5.

Plate 5.5: Contaminated Playground near Waste Dumps in Dandora (Source: Author, 2015).

The children further handled the waste slag and the contaminated soils using their bare hands, put lead-contaminated objects (dust-laden fingers, toys and pacifiers) in their mouths, and ate the lead-contaminated soils as observed in Plates 5.4 and 5.5. It was also found that the children brought objects covered with lead soil dust back into their homes. The children living near the investigated informal ULAB recycling operations in Dandora, Kariobangi and Mukuru were therefore frequently exposed to significant amounts of lead through ingestion of lead-contaminated soils in their environments (residential areas, playgrounds, preparatory schools, waste dumps and industrial sites) while playing. Thus, they were greatly impacted. This is consistent with a study by Mielke *et al*. (2007) which also reported that sensitivity of the children to lead is strongly linked to their distinct behavior during play. This study is in agreement with similar studies by Duggan and Inskip (1985), Kranz *et al*. (2004) and Gulson *et al*. (2013) which also found that children below seven years ingested large amounts of lead in outdoor soils due to their behavioral characteristics.

Besides, due to the enhanced gastrointestinal absorption in a child's body, most (about 70%) of the ingested lead is absorbed and becomes bioavailable as reported by Amitai *et al*. (1987), Mushak (1991), Bellinger (2004), Li *et al*. (2012), Swaddiwudhipong *et al*. (2013) and Huang *et al.* (2015) . Once in the child's body, lead permanently and severely interferes with growth, differentiation and developmental processes of vital organs and systems such as the brain, blood tissue, kidneys and the skeleton in a child's body and may lead to death. The three aspects discussed; behavioral, metabolic and physiological characteristics of young children make them the most exposed and susceptible to the harmful effects of lead (ATSDR, 2006; Wu *et al*., 2008; WHO, 2014).

The lead-contaminated soils investigated in Dandora, Kariobangi and Mukuru therefore posed great health risks to children living nearby. Through constant ingestion of the highly contaminated soils and soil dust, the health of children living near the informal ULAB recycling operations was negatively impacted as established by the predicted blood lead levels in this study. This study is consistent with studies by Hefliger *et al.*

(2009), Jones *et al.* (2011), OK, (2012) and van der Kuijp *et al.* (2013) which also reported elevated levels of lead in soils in vicinities of informal ULAB recycling operations as a serious health hazard to young children living nearby who get exposed to the lead when they frequently ingest the contaminated soils.

5.2 Predicted Child Blood Lead Levels

Previous researches have reported relationships between the levels of lead in environmental media and human samples. For instance, studies by Charney *et al.* (1980), Lewandowski and Forslund (1994), Lanphear *et al.* (1998, 2005), Gaitens, *et al.* (2009), Richardson *et al.* (2011), Aboh *et al.* (2013) and Levallois *et al.*, 2014) found correlation of soil and house dust lead to blood lead in support of pica and hand-to-mouth route of lead ingestion in children below seven years. In this study, house dust lead loadings and lead concentrations in soils in children's environments were used to predict child blood lead levels using the IEUBKwin. A study by Lewandowski and Forslund (1994) showed that IEUBKwin's predicted levels are comparable with actual blood lead levels.

From the study results (Table 4.5), children below seven years living within the vicinities of informal used lead-acid battery recycling activities in Dandora, Kariobangi and Mukuru were at a great risk of lead poisoning with elevated predicted geometric mean blood lead levels of 22.4 µg/dL, 20.8 µg/dL and 37.0 µg/dL respectively, which exceeded the CDC (2012) reference value of 5 µg/dL for lead in blood. The highest predicted mean blood lead level was recorded in Mukuru, followed by Dandora, and then Kariobangi. On the contrary, children living in the control (Ruiru) were predicted to have a low mean blood lead level of 1.6 µg/dL, which was below the CDC (2012) reference value of 5 µg/dL for lead in blood. The predicted pediatric blood lead results found in this study concur with the results of similar studies in China, Puerto Rico, Senegal and Ghana where children living near informal ULAB recycling activities were found to have elevated blood lead levels (Haefliger *et al.*, 2009; Jones *et al*., 2011; García *et al.*, 2012; Aboh *et al.*, 2013; van der Kuijp *et al*., 2013).

In Puerto Rico, 11 out of 68 (16%) children below seven years had blood lead levels ≥10 µg/dL, and 28 out of 68 children (41%) had blood lead levels ranging from 5–9 µg/dL (García *et al.*, 2014). These values are consistent with the findings of predicted child blood levels in this study. In Dakar, Senegal, at least 18 children died of lead poisoning. The mean blood lead concentrations were 138.0 ± 60.4 µg/dL with a range of 59.1 µg/dL and 345.4 µg/dL for the 32 siblings of deceased children and, 114.3 ± 132.5 µg/dl with a range of 39.8 µg/dL and 613.9 µg/dL for the 18 children who were unrelated to the deceased children (Haefliger *et al.*, 2009; Jones *et al.*, 2011). Compared to these studies, lead levels in soil, dust and predicted children's blood lead levels in this study were lower. This could be due to the differences in the intensities of informal ULAB activities between areas.

According to the United States Centers for Disease Control and Prevention, CDC (2012), the current reference blood lead level at which public health remedies should be initiated is 5 µg/dL. When 5 µg/dL was used as the cut-off blood lead level in the IEUBKwin in this study, the percentage of children that were considered to be at risk of lead poisoning in each area increased (Table 4.5). Blood lead levels (levels less than 10 µg/dL) previously considered to be safe are now causing severe irreversible health effects in children (CDC, 2013; WHO, 2014). The effects include; damage to the developing brain, the nervous, the immune, reproductive and cardiovascular systems (WHO, 2010). According to a report by CDC (2012), low blood lead levels from as low as 2 µg/dl to 10 µg/dL can cause neurological damage in children (CDC, 2012).

Children under the age of seven years are the most exposed via ingestion of lead-contaminated soils and dusts (Kaul & Mukerjee, 1999; Rasmussen *et al.*, 2001; US EPA, 2002, 2008a; Falk, 2003; Gould, 2009; Bell *et al.*, 2010). This was also established in this study. Children have special vulnerabilities to lead due to the ongoing vital developmental processes in their bodies (Cecil *et al.*, 2008; Mazumdar, *et al.*, 2012; Lim *et al.*, 2012). Costs associated with childhood exposure to lead are very huge and include reduced work performance, behavioral and psychosocial loss, and losses in intellectual capacity among others. These have negative impacts on individuals, society and the entire economy of the country (Landrigan et al., 2002; UNEP, 2010; Caravanos et al., 2012; Trasande & Attina, 2013). Preventive approaches are therefore recommended to minimize and finally eliminate lead exposure in children. Various sources of lead should also be identified and controlled to reduce and/or eliminate exposures (CDC, 2013).

The study established the contribution of informal ULAB recycling activities to the elevated soil lead concentrations, house dust lead loadings and predicted pediatric blood lead levels in Dandora, Kariobangi and Mukuru (Figure 4.1). Fisher multiple comparisons with control performed simultaneously at 87.65% and 95% confidence levels revealed differences in the levels of lead in soil, house dust and predicted pediatric blood lead levels between the control (Ruiru) and the cases studied (Dandora, Kariobangi and Mukuru). The lead levels found in soil and house dust and, predicted pediatric blood lead levels in the cases studied were significantly ($p<0.05$) higher than those in the control even though the control and the cases studied were located in similar environments with similar industrial and traffic activity. We hypothesize that the differences in the lead levels could be primarily be attributed to the unregulated informal ULAB recycling operations in Dandora, Kariobangi and Mukuru that resulted into the high levels of lead in house dust, outdoor soils and the elevated predicted child blood lead values. This study established the public health risk posed on children by the informal ULAB recycling activities in Dandora, Kariobangi and Mukuru slums and is necessary in guiding interventions.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study investigated child exposure to lead in the vicinities of informal ULAB recycling operations in selected slums in Nairobi, Kenya. Based on study findings, the following conclusions are drawn;

1. Outdoor soil and interior house dust in children's environments in the studied areas were contaminated with lead with values that exceeded the US EPA (2001, 2011a) regulatory limits for lead in soils and house dust. Thus, hypothesis one was accepted.

2. The IEUBKwin model for predicting blood lead concentrations of age-specific children showed very high probability of blood lead levels exceeding the recommended limit of 5ug/dl (CDC, 2012) in children living near informal ULAB recycling activities in Dandora, Kariobangi and Mukuru. Hypothesis two was thus accepted.

From the Fisher's multiple comparisons with control results, Informal ULAB recycling activities are the most likely primary contributors of the high lead levels in outdoor soil and interior house dust in the studied areas. This study provides baseline data of the child lead exposure levels in informal battery recycling sector in Kenya. We believe that the lead exposures measured in this study are representative of the lead exposures in similar and related setups in Kenya. In conclusion, Nairobi slums and other slum areas in the entire Kenya face significant environmental health challenges with many children currently at risk of lead poisoning due to the unprecedented growth of informal used lead-acid battery recycling.

6.2. RECOMMENDATIONS

6.2.1. Recommendation from this Study

The study indicated the vast public health risks posed by the informal ULAB recycling sector in Kenya by predicting pediatric blood lead levels from soil and dust lead levels using the Integrated Exposure Uptake Biokinetic (IEUBK) model for lead in Children. The results of this study will be shared with the relevant authorities to serve as a basis for developing remediation plans and policies on lead exposures from informal ULAB recycling. The study therefore outlines specific recommendations as follows;

1. Constructing educational institutions and residential houses away from informal ULAB recycling activities.
2. Creating public awareness on child exposure to lead, the risks posed and, the need for proper handling and recycling of used lead-acid batteries.
3. Disseminating of research findings about child exposure to lead.
4. Child exposure to lead should be prevented by the following;

    i. Regularly wet-mopping floors and other housing unit components.
    ii. Regularly washing children’s hands, pacifiers and toys.
    iii. Covering bare soils with mulch, wood chips or by planting grass.

   iv. Encouraging children and other adults to take off shoes when entering the house to avoid bringing lead-contaminated soil dust in from outside.
   v. Preventing children from playing in contaminated soil, especially near the waste dumps and informal ULAB industrial sites where lead is present.
   vi. Improving children's environments, particularly the housing structures and ventilation in dwelling units and preparatory schools in the studied areas in order to reduce exposure to lead via interior dust.
   vii. Encouraging children to regularly wash their hands before eating.

5. Creating and enforcing policies and regulations on proper ULAB handling and recycling.
6. Jointly coordinating actions to decrease lead emissions from informal ULAB recycling in Nairobi slums and to remediate existing soils particularly around battery workplaces and dump sites.
7. Due to inadequate technical and financial capacities, there is need for collaboration with international organizations such as International Lead Management Center Inc. (ILMC) and Pure Earth and, conventions to introduce environmentally sound ULAB collection and recovery networks and technology to eliminate environmental lead contamination and human exposure, remediate existing soils particularly around battery workplaces and dumpsites and, to administer appropriate treatment to the exposed children.

6.2.2. Recommendation for Further Research

1. Actual blood lead levels of exposed children should be clinically tested.
2. Studies should be conducted to investigate the role of wind and all other meteorological parameters in spreading lead from informal ULAB recycling operations in order to determine the possible extent of contamination. Whereas the soil lead levels in the control were very low, it had high levels of lead in house dust which could be explained by the strong prevailing winds that need to be further investigated.
3. Frequent nationwide studies should be conducted to assess lead levels and related health impacts as a result of informal used lead-acid battery activities.
4. Adequate funding and institutional support is fundamental in order to successfully achieve the above recommendations.

REFERENCES

Aboh, I.J.K., Sampson, M.A., Nyaab, L.A., Caravanos, J., Ofusu, F.G., Kuranchie-Mensah, H. (2013). Assessing Levels of Lead Contamination in Soil and Predicting Pediatric Blood Lead levels in Tema, Ghana. *Journal of Health and Pollution*. 3, 5.

ATSDR (Agency for Toxic Substances and Disease Registry). (2006). *Lead*. Chemical Agent Briefing Scheme. Atlanta, U.S.A.

ATSDR (Agency for Toxic Substances and Disease Registry). (2007). Toxicological profile for lead. Accessed May 10, 2015 from http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=96&tid=22.

Amitai, Y., et al. (1987). Hazards of 'deleading' homes of children with lead poisoning. *American Journal of Diseases of Children,* 141, 758–760.

Banza, C.L.N., Nawrot, T.S., Haufroid, V., Decree, S., De Putter, T., Smolders, E., Kabyla, B.I., Luboya, O.N., Ilunga, A.N., Mutombo, A.M., Nemery, B. (2009). High human exposure to cobalt and other metals in Katanga, a mining area of the Democratic Republic of Congo. *Environ. Res.* 109, 45–752.

BAN and SVTC (Basel Action Network and Silicon Valley Toxics Coalition). (2002), *Exporting Harm – The High-Tech Trashing of Asia*, Retrieved: 01 July 2015.

BAN (Basel Action Network) 2002.The Basel Ban and Batteries: A Teaching Case. Accessed from http://www.commercialdiplomacy.org/case_study/case_batteries.htm on January 12, 2015.

Bell, T., Campbell, S., Liverman, D.G.E., Allison, D. and Sylvester, P. (2010). Environmental and potential human health legacies of non-industrial sources of lead in a Canadian urban landscape: The case study of St. John's, Newfoundland. *Int. Geol. Rev.*, 52(7-8), 771-800.

Bellinger, D.C. (2011). The protein toxicities of lead: New chapters in a familiar story. *Int J Environ Res Public Health* 8, 2593-628.

Bellinger, D.C. 2004. Lead. *Pediatrics*, 113(suppl 4), 1016–1022.

Bellinger, D.C., Stiles, K.M. and Needleman, H.L. (1992). Low-level lead exposure, intelligence and academic achievement: A long-term follow-up study. *Pediatrics*, 90,855-861.

Blacksmith Institute (2007). The world's worst polluted places. New York. Accessed on June 30 2014 from (http://www.blacksmithinstitute.org/wwpp2007/finalReport2007.pdf

Blacksmith Institute (2011). Lead Poisoning and Car Batteries Project. New York. Accessed May 2015 from http://www.blacksmithinstitute.org

Brown, M.J., McWeeney, G., Kim, R., Tahirukaj, A., Bulat, P., Syla, S., et al. (2010). Lead Poisoning among Internally Displaced Roma, Ashkali and Egyptian children in the United Nations-Administered Province of Kosovo. *Eur J Public Health*, 20(3), 288–292.

Caravanos, J.A., Chatham-Stephens, K., Ericson, B., Landrigan, J.P. and Fuller, R. (2012). The burden of disease from pediatric lead exposure at hazardous waste sites in 7 Asian Countries. *Environmental Research*, 120, 119-125. doi:10.1016/j.envres.2012.06.006

Cecil, K. M., Brubaker, C. J., Adler, C. M., Dietrich, K. N., Altaye, M., Egelhoff, J. C., Wessel, S., Elangovan, I., Hornung, R., Jarvis, K. and Lanphear, B. P. (2008). Decreased Brain Volume in Adults with Childhood Lead Exposure. *Plos Medicine*, 5, 741-750.

CDC (Centers for Disease Control and Prevention) (2013). Blood Levels in Children Aged 1-5 Years – United States, 1999-2010, Morbidity and Mortality. *Weekly Report*. 62, 245-248.

CDC (Centers for Disease Control and Prevention) (2002). Managing Elevated Blood Lead Levels among Young Children: Recommendations from the Advisory Committee on Childhood lead Poisoning Prevention. Atlanta, GA.

CDC (Centers for Disease Control and Prevention) (2005). Preventing Lead Poisoning in Young Children: A statement by the Centers for Disease Control and Prevention.

CDC (Centers for Disease Control and Prevention) (2012). Low level lead exposure harms children: A Renewed Call for Primary Prevention. Advisory Committee on Childhood Lead Poisoning Prevention. Accessed on April 26, 2015 from http://www.cdc.gov/nceh/lead/acclpp/final_document_030712.pdf

Chakrabarty, J. K., Imon, R., Samin, H. (2014) Molecular interaction behind the toxicity of lead contamination. *Universal Journal of Pharmacy,* 03(02), 6-19

Chanjaroen, C. (2008). *Zinc Gains on Speculation Lower Prices Will Force Mine Closures.*

Charney, E., Kessler, B., Farfel, M., Jackson, D. (1983) Childhood lead poisoning: A controlled trial of the effect of dust-control measures on blood lead levels. *N Engl J Med*, 309, 1089–1093

Charney, E., Sayre, J., Coulter, M. (1980) Increased lead absorption in inner city children: Where does the lead come from? *Pediatrics*. 65, 226-231.

Chen H.Y, Li A.J, Finlow D.E (2009). The lead and lead-acid battery industries during 2002 and 2007 in China. *J Power Sources,* 191, 22–27.

Chen L., Xu Z., Liu M., Huang Y., Fan R., Su Y., Hu G., Peng X., Peng X. (2012). Lead exposure assessment from study near a lead-acid battery factory in China. *Sci Total Environ* 429, 191-198.

Christa C., Patrick B., Marc van S., Jean-Claude van der A. (2006). Use of the IEUBK Model for Determination of Exposure Routes in View of Site Remediation. Human and Ecological Risk Assessment. *An International Journal, Volume* 12, Issue 5, 963 – 982.

Cobbing, M. and Divecha, S. (2005). *The Myth of Automobile Battery Recycling*, Greenpeace. Retrieved: 2 March 2014.

Dasgupta, S., Lucas, R.E.B., Wheeler, D. (1998) Small Plants, Pollution and Poverty: New Evidence from Brazil and Mexico, DECRG; Infrastructure Environment Group, World Banks.

Dell, R.M. & Rand, D.A.J. (2001) *Understanding Batteries*. The Royal Society of Chemistry, Cambridge, UK.

Dixon, S.L., Gaitens, J.M., Jacobs, D.E., Strauss, W., Nagaraja, J., Pivetz, T., et al. (2009). Exposure of U.S. Children to Residential Dust Lead, 1999–2004: II. The Contribution of Lead-Contaminated Dust to Children's Blood Lead Levels. *Environmental Health Perspectives* 117, 468–474.

Dooyema, C.A., Neri, A., Lo Y., Durant, J., Dargan, P.I., Swarthout, T., Biya, O., Gidado, S.O., Haladu, S., Sani-Gwarzo, N., Nguku, P.M., Akpan, H., Idris, S., Bashir, A. M., Brown, J.M. (2010). Outbreak of Fatal Childhood Lead Poisoning Related to Artisanal Gold Mining in Northwestern Nigeria. *Environmental Health Perspect*ives 120, 601–607 Available from http://dx.doi.org/10.1289/ehp.1103965

Duggan, M.J., Inskip, M.J. (1985) Childhood exposure to lead in surface dust and soil: A community health problem. *Public Health Rev*, 13, 1-54.

Falk, H (2003). International Environmental Health for the Pediatrician: Case Study of Lead Poisoning. *Pediatrics,* 112(1 Pt 2), 259–264.

Fewtrell, L.J., Prüss-Ustün, A., Landrigan, P., Ayuso-Mateos, J.L. (2004). Estimating the global burden of disease of mild mental retardation and cardiovascular diseases from environmental lead exposure. *Environ Res* 94, 120–133.

Gaitens, J. M., Dixon, S. L., Jacobs, D. E., Nagaraja, J., Strauss, W., Wilson, J. W. and Ashley, P. J. (2009). Exposure of US Children to Residential Dust Lead, 1999-2004: I. Housing and Demographic Factors, *Environmental Health Perspectives.* 117, 461-467.

Galadima, A., and Garba, Z.N. (2012). Heavy metals pollution in Nigeria: Causes and consequences. *Elixir Pollution,* 45, 7917-7922 available at; www.elixirjournal.org

García, B.R., Rullán, M.J., O'Neill, M., Garrison, G., Santella, D., Maddaloni, M.M., Evangelista, P., Cirillo, A., Huerta-Montanez, G., Caldwell, K., Dignam, T., and Brown, M.J. (2012). Take-Home Lead Exposure among Children with Relatives Employed at a Battery Recycling Facility. *Morbidity and Mortality Weekly Report*, 61(47), 967-970.

Gottesfeld, P. and Pokhrel, A.K. (2011) Review: Lead Exposure in Battery Manufacturing and Recycling in Developing Countries and Among Children in Nearby Communities. Occupational Knowledge *International. Journal of Occupational and Environmental Hygiene*, California. 8, 520–532.

Gould, E. (2009). Childhood lead poisoning: Conservative estimates of the social and economic benefits of lead hazard control. *Environmental Health Perspectives*; 117,1162–7:10.1289/ehp.0800408.

Gulson, B., Anderson, P. and Taylor, A. (2013). Surface Dust Wipes are the Best Predictors of Blood Leads in Young Children with Elevated Blood Lead Levels, *Environmental Research.* 126, 171-178.

Haefliger, P., Mathieu-Nolf, M., Lociciro, S., Ndiaye, C., Coly, M., Diouf, A., Faye A., Sow, A., Tempowski, J., Pronczuk, J., Filipe, A., Bertollini, R., Neira, M (2009).Mass lead intoxication from informal used lead-acid battery recycling in Dakar, Senegal. *Environ Health Perspectives*, 117, 1535–1540.

Hay, J.E. and Noonan, M. (2001). Anticipating the Environmental Effects of Technology, Overview of lead recycling. United Nations Environment Programme, Division of Technology, Industry, and Economics.

Hodgson, E. (2004). A Textbook of Modern Toxicology (3rd ed.). New Jersey, John Wiley & Sons, Inc.

Hogan, K., Marcus, A., Smith, R., White, P. (1998) Integrated Exposure Uptake Biokinetic Model for Lead in Children: empirical comparisons with epidemiologic data. *Environmental Health Perspectives*, 106 Suppl 6, 1557-67. Accessed 2015 January 5 from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1533426/pdf/envhper00541-0291.pdf

Hua, L., Yang, W.H., Liu, X.Z., Huang, H.K., and Xie, G.X., Chin, J. (2005). Child Health Care, 14, 304.

Huang, L., Ma, Q.L., Chen, K., and Juhasz, L.A. (2015) Childhood Lead Exposure in an Industrial Town in China: Coupling Stable Isotope Ratios with Bioaccessible Lead. *Environ. Sci. Technol*, 49, 5080−5087

HUD (U.S. Department of Housing and Urban Development) (2012). Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing.

IFC (International Finance Corporation) (2007). Environmental, Health, and Safety Guidelines: Base Metal Smelting and Refining. World Bank Group. Available at http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_SmeltingandRefining/$FILE/Final+-+Smelting+and+Refining.pdf. (Accessed October 10, 2015)

Jones, D.E., Diop, A., Block, M., Smith-Jones, A., Smith-Jones, A. (2011). Assessment and Remediation of Lead Contamination in Senegal. *Journal of Health and Pollution.* 1(2).

Kaul, B., and Mukerjee, H. (1999). Elevated blood , lead and erythrocyte protoporphyrin levels of children near a battery-recycling plant in Haina, Dominican Republic. *Int. J. Occup. Environ. Health*, 5(4), 307–312.

Kawai, M., Toriumi, H., Katagiri,Y., Maruyama,Y.(1983). Home lead work as a potential source of lead exposure for children, *Int. Arch. Occup. Environ. Health,* 53, 37–46.

Kimani, N. G. (2005). Blood lead levels in Kenya: A case study for children and adolescents in selected areas of Nairobi and Olkalou, Nyandarua District. Kenyatta University, Nairobi, Kenya and UNEP.

KNBS (Kenya National Bureau of Statistics) (2013). Population and Housing. Retrieved from www.knbs.or.ke

KNBS (Kenya National Bureau of Statistics) (2014). Population and Housing. Retrieved from www.knbs.or.ke

Koplan, J.P., Wells, A.V., Diggory, H.G., Baker,E.L., Liddle,J. (1977). Lead absorption in a community of potters in Barbados, *Int. J. Epidemiol*. 6, 225–229.

Kranz, B.D., Simon, D.L. and Leonardi, B.G. (2004). The behavior and routes of lead exposure in pre-grasping infants. *Journal of Exposure Analysis and Environmental Epidemiology*, 14, 300-311.

Kumar, A. (2008). Dusty Toxics: A study on lead in household dust in Delhi. *Toxics Link*, Chennai, India.

Landrigan, P.J., Schechter, C.B., Lipton, J.M., Fahs, M.C., Schwartz, J. (2002) Environmental pollutants and disease in American children: estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. *Environmental Health Perspectives*. 110 (7), 721–728.

Lanphear, B. P., Hornung, R., Ho, M., Howard, C. R., Eberly, S. and Knauf, K. (2002). Environmental Lead Exposure during Early Childhood, *Journal of Pediatrics*, 140, 40-47.

Lanphear, B.P., Dietrich, K., Auinger, P., Cox, C. (2000). Cognitive deficits associated with blood lead concentrations <10 microgram/dL in US children and adolescents. *Public Health Rep*, 115(6), 521-529.

Lanphear, B.P., Hornung, R., Khoury, J., Yolton, K., Baghurstl, P., Bellinger, D.C.et al. (2005) Low-level environmental lead exposure and children's intellectual function: An international pooled analysis. Environ *Health Perspect*; 113, 894–9.

Lanphear, B.P., M. Emond, D.E. Jacobs, M. Weitzman, M. Tanner, N.L. Winter, B. Yakir, and S. Eberly. (1995). A side-by-side comparison of dust collection methods for sampling lead-contaminated house dust. *Environmental Research*. 68, 114-123.

Lanphear, B.P., Matte, T.D., Rogers, J., Clickner, R.P., Dietz, B., Bornschein, R.L., Succop, P., Mahaffey, K.R., Dixon, S., Galke, W., Rabinowitz, M., Farfel, M., Rohde, C., Schwartz, J., Ashley, P. and Jacobs, D.E. (1998). The contribution of lead-contaminated house dust and residential soil to children's blood lead levels: A pooled analysis of 12 epidemiologic studies. *Environ Res*; 79, 51–68.

Lanphear, B.P., Weitzman, M., Winter, N.L., Eberly, S., Yakir, B., Tanner, M., Emond, M., and Matte, T. (1996). Lead-contaminated house dust and urban children's blood lead levels. *American Journal of Public Healt,* 86, 1416-1421.

Levallois, P., Lavoie, M., Goulet, L., Nantel, A.J. and Gingras, S. (1991). Blood lead levels in children and pregnant women living near a lead-reclamation plant. *Canadian Medical Association Journal,* 144, 877-885.

Levallois, P., St-Laurent, J., Gauvin, D., Courteau, M., Pre´ vost, M., Campagna, C., Lemieux, F, Nour, S., D'Amour, M. and Rasmussen, P.E. (2014). The impact of drinking water, indoor dust and paint on blood lead levels of children aged 1–5 years in Montre´al, Que´bec, Canada. *Journal of Exposure Science and Environmental Epidemiology,* 24, 185–191

Lewandowski, T.A., Forslund, B.L.(1994) Comparison of IEUBK model predictions and actual blood lead values at a former battery recycling site. *Environmental Geochemistry and Health*, 16, 3-4.

Li, H. B., Cui, X. Y., Li, K., Li, J., Juhasz, A. L. and Ma, L. Q. (2014). Assessment of in vitro lead bioaccessibility in house dust and its relationship to in vivo lead relative bioavailability. Environ. *Sci. Technol*. 48, 8548−8555.

Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H. et al (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010. *Lancet,* 380, 2224–60.

Matte, T.D., Figueroa, J.P., Ostrowski, S., Burr, G., Jackson-Hunt, L., Baker, E.L. (1991). Lead exposure from conventional and cottage lead smelting in Jamaica. *Arch. Environ. Contam. Toxicol*, 21, 65–71.

Mazumdar, M., Xia, W. M., Hofmann, O., Gregas, M., Sui, S. H., Hide, W., Yang, T., Needleman, H. L. and Bellinger, D. C. (2012). Prenatal Lead Levels, Plasma Amyloid Beta Levels, and Gene Expression in Young Adulthood, *Environmental Health Perspectives,* 120, 702-707.

McCartor, A. and Becker, D. (2010). Blacksmith Institute's world's worst pollution problems report. Top Six Toxic Threats. New York, Blacksmith Institute. Accessed on August 15, 2014 from http://www.worstpolluted.org/files/FileUpload/ files/2010/WWPP-2010-Report-Web.pdf

Mielke, H. W. and Reagan, P. L. (1998). Soil is an important pathway of human lead exposure. *Environmental Health Perspectives*, 1(106), 217- 229.

Mielke, H. W. and Zahran, S. (2012). The Urban Rise and Fall of Air Lead (Pb) and the Latent Surge and Retreat of Societal Violence, *Environment International.* 43, 48-55.

Mielke, H.W., Gonzales, C.R, Powell, E., Jartun, M. and Mielke, P.W. (2007). Nonlinear association between soil lead and blood lead of children in metropolitan New Orleans. *Sci Total Environ* 388, 43–53.

Miranda, M. L., Kim, D., Galeano, M. A. O., Paul, C. J., Hull, A. P. and Morgan, S. P. (2007). The Relationship between Early Childhood Blood Lead Levels and Performance on End-of-Grade Tests. *Environmental Health Perspectives.* 115, 1242-1247.

Mohammed, T., Chang Yen, I., Bekele, I. (1996). Lead Pollution in East Trinidad Resulting from Lead Recycling and Smelting Activities. *Environmental Geochemistry and Health*, 18, 123-128.

Mushak, P. (1991). Gastrointestinal absorption of lead in children and adults: Overview of biological and biophysico-chemical aspects; (Proceedings of the Symposium on the Bioavailability and Dietary Exposure of Lead. *SEGH Monograph Series*, 3, 87-104.

National Research Council, Committee on Measuring Lead in Critical Populations (1993). *Measuring lead exposure in infants, children, and other sensitive populations*. National Academy Press, Washington, DC. Accessed on April 20, 2015 from http://www.nap.edu/openbook.php?record_id=2232&page=215

Nriagu J., Jinabhai, C.C., Naidoo, R., Coutsoudis, A. (1997a). Lead poisoning of children in Africa, II Kwazulu/Natal, South Africa. *Science of the Total Environment*, 197, 1–11.

Nriagu J., Oleru N.T, Cudjoe C., Chine A. (1997b). Lead poisoning of children in Africa, III Kaduna, Nigeria. *Science of the Total Environment*, 197

Nriagu, J. and Pacyna, J. (1988). Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature* 333, 134-139.

Nriagu, J.O. (1992). Toxic metal pollution in Africa. *Science of the Total Environment*, 121, 1-37.

O'Flaherty E.J. (1998). A Physiologically based Kinetic Model for Lead in Children and Adults. *Environ Health Perspectives.*

Occupational Knowledge International (OK): 2012. Summary of Mass lead Poisoning Incidents. San Francisco, CA.*OK International*.

Oyoo-Okoth, E., Admiraal, W., Osano, O., Manguya-Lusega, D., Ngure, V., Kraak, M.H.S., Chepkirui-Boit, V., Makwalie, J. (2013a) Contribution of soil, water and food consumption to metal exposure of children from geological enriched environments in the coastal zone of Lake Victoria, Kenya. *International Journal of Hygiene and Environmental Health*, 216, 8–16.

Paoliello, M.M.B., DeCapitani, E.M., (2005). Environmental contamination and human exposure to lead in Brazil, Review. *Environmental Contamination and Toxicology*, 184, 59–96.

Prüss-Üstün, A. and Corvalán, C. (2006). Preventing Disease Through Healthy Environments: Towards an Estimate of the Environmental Burden of Disease.

Rasmussen, P.E., Subramanian, K.S., Jessiman, B.J. (2001). A multi-level profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. *The Science of the Total Environment*, 267, 125-140

Richardson, E., Pigott, W., Craig, C., Lawson, M., and Mackie, C. (2011). North Hamilton Child Blood Lead Study Public Health Report. Hamilton Public Health Services, Hamilton, Ontario. Accessed Feb.2015 from http://www.hamilton.ca/NR/rdonlyres/453D1F95-87EE-47D2-87AB-025498737337/0/Sep26EDRMS_n216098_v1_BOH11030_Child_Blood_Lead_Prevalence_Stud.pdf

Rossi, E. (2008). Low Level Environmental Lead Exposure: A Continuing Challenge. *Clin Biochemist.,* 29(2), 63-70.

Safi, J., Fischbein, A., El Haj, S., Sansour, R., Jaghabir, M., Hashish, M.A., Suleiman, H., Safi, N., Abu-Hamda, A., Witt, J.K., Platkov, E., Reingold, S., Alayyan, A., Berman, T., Bercovitch, M., Choudhri, Y., Richter, E.D. (2006). Childhood lead exposure in the Palestinian Authority, Israel, and Jordan: results from the Middle Eastern Regional Cooperation Project, 1996–2000, *Environmental Health Perspectives*, 114, 917–922.

Sayre, J.W., Charney, E., Vostal, J., Pless, I.B. (1974). House and hand dust as a potential source of childhood lead exposure. *AJDC* 127, 167-170.

Surkan, P.J., et al. (2007). Neuropsychological function in children with blood lead levels <10 micrograms/dL. *Neurotoxicology,* 28, 1170–1177.

Swaddiwudhipong, W., Kavinum, S., Papwijitsil, R., Tontiwattanasap, W., Khunyotying, W., Umpan, J., Boonthum, R., Kaewnate Y., Boonmee, S., Thongchub, W. and Rodsung, T. (2014). Personal and environmental risk factors significantly associated with elevated blood lead levels in rural Thai children. Thailand, 45(6).

Swaddiwudhipong, W., Tontiwattanasap, W., Khunyotying, W., Sanreun, C. (2013). Blood lead levels among rural Thai children exposed to lead-acid batteries from solar energy conversion systems. *Southeast Asian J Trop Med,* 44, 1079–87.

Syracuse Research Corporation. (2007) User's guide for the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) windows. United States Environmental Protection Agency.

Trasande L, Attina TM. Economic Costs of Childhood Lead Exposure in Low- and Middle-Income Countries, Environmental Health Perspectives. 2013: 121, 1097-1102.

U.S. EPA (U.S. Environmental Protection Agency) (2011a). Brownfields and Urban Agriculture: Interim Guidelines for Safe Gardening Practices. Region5:Chicago,IL.EPA560/s-11/001. Accessed March 10, 2014 from http://www.epa.gov/swerosps/bf/urbanag/pdf/bf_urban_ag.pdf

U.S. EPA (U.S. Environmental Protection Agency) (2008a). Child-Specific Exposure Factors Handbook (Final Report).

U.S. EPA (U.S. Environmental Protection Agency) (2002). User's Guide for the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) Windows Version–32 Bit Version. *EPA–K–01–005*.Office of Solid Waste and Emergency Response Washington, DC.

U.S. EPA (United States Environmental Protection Agency) (2001). Lead; Identification of Dangerous Levels of Lead; Final Rule. 40CFR745. Fed Reg 66:6763–6765. Accessed December 3, 2014 from https://www.environmentaleducation.com/content/docs/Final%20Rule%20ID%20of%20Dangerous%20Levels%20of%20Lead.pdf

U.S. EPA (Environmental Protection Agency) (1994). Technical Support Document: Parameters and Equations used in the Integrated Exposure Uptake Biokinetic Model for Lead in Children. Solid Waste and Emergency Response.

U.S. EPA (Environmental Protection Agency) (2008b). Guidance for the Sampling and Analysis of Lead in Indoor Residential Dust for Use in the Integrated Exposure Uptake Biokinetic (IEUBK) Model. Superfund Remediation and Technology Innovation Accessed January 2015 from http://epa.gov/superfund/lead/products/dust_sampling_guidance_final.pdf

U.S. EPA (Environmental Protection Agency) (1994) Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children. Office of Emergency and Remedial Response. Washington DC. NTIS PB 93-963510.

UNEP (United Nations Environment Programme) (2005a). E-waste, the Hidden Side of IT Equipment Manufacture and Use.

UNEP (United Nations Environment Programme) 2002.New Basel Guidelines to Improve Recycling of Old Batteries, UNEP News Release 22/05/2002/40.

UNEP (United Nations Environment Programme) (2010). Final review of scientific information on lead –Version of December 2010. Chemicals Branch, DTIE.

van der Kuijp, T.J., Huang, L. and Cherry, C.R. (2013). Health hazards of China's lead-acid battery industry: a review of its market drivers, production processes, and health impacts. *Environmental Health*, 12, 61.

Vimpani, G. et al. (1985). The Port Pirie Study: A Prospective Study of Pregnancy Outcome and Early Childhood Growth and Development in a Lead-exposed Community – Protocol and Status Report. *Environmental Research*, 38(1), 19–23.

Vinceti, M., Rovesti, S., Bergomi, M., Calzolari, E., Candela, S., Campagna, A., Milan, M. and Vivoli, G. (2001) 'Risk of birth defects in a population exposed to environmental lead pollution'. *The Science of the Total Environment* 278: 23-30

Wang, C.L., Chuang, H.Y., Ho, C.K., Yang, C.Y., Tsai, J.L., Wu, T.S. and Wu, T.N. (2002). Relationship between Blood Lead Concentrations and Learning Achievement among Primary School Children in Taiwan. *Environ. Res.*, 89, 12–18.

Wang, H.-L., Chen, X.-T., Yang, B., Ma, F.-L., Tang, M.-L., Hao, M.-G. and Ruan, D.-Y. (2008). Case-control Study of Blood Lead Levels and Attention Deficit Hyperactivity Disorder in Chinese Children. *Environmental Health Perspectives*, 116(10), 1401–1406.

Weitzman, M., Ashengrau, A., Bellinger, D. et al. (1993). Lead-contaminated Soil Abatement and Urban Children's Blood Lead. *JAMA*, 269, 1647-54.

Were, F.H., Moturi, M.C., Gottesfeld, P., Wafula, G.A., Kamau, G.N., Shiundu, P.M. (2014). Lead Exposure and Blood Pressure among Workers in Diverse Industrial Plants in Kenya, *Journal of Occupational and Environmental Hygiene*, 11:11, 706-715, DOI: 10.1080/15459624.2014.908258 Accessed on Apri 30, 2015 from; http://dx.doi.org/10.1080/15459624.2014.908258

Were, F.H., Kamau, G.N., Shiundu, P.M, Wafula, G.A. and Moturi, C.M. (2012). Air and Blood Lead Levels in Lead Acid Battery Recycling and Manufacturing Plants in Kenya, *Journal of Occupational and Environmental Hygiene*, 9:5, 340-344. Available at http://dx.doi.org/10.1080/15459624.2012.673458 (Accessed May 2, 2015).

Were, F.H., Njue, W.M., Murungi, J and Wanjau, R. (2009). Comparison of Some Essential and Heavy Metals in the Toenails and Fingernails of School-Age Children in Kenya, *Bull. Chem. Soc. Ethiop*, 23(1), 117-122. ISSN 1011-3924 Available at http://www.ajol.info/index.php/bcse/article/view/21308 (Accessed January 12, 2015).

White, P., Van Leeuwen, P., Davis, B., Maddaloni, M., Hogan, K., Marcus, A., and Elias R. (1998). U.S. Environmental Protection Agency. The Conceptual Structure of the Integrated Exposure Uptake Biokinetic Model for Lead in Children. *Environmental Health Perspectives*, 106 (Suppl. 6), 1513.

Wigle, D.T., Arbuckle, T.E., Walker, M., Wade, M.G., Liu, S., & Krewski, D. (2007). Environmental Hazards: Evidence for Effects on Child Health, *Journal of Toxicology and Environmental Health, Part B: Critical Reviews*, 10, 1-2,3-39 Accessed March 1, 2014 from http://dx.doi.org/10.1080/10937400601034563.

WHO (World Health Organization) (2010). Childhood Lead Poisoning. World Health Organization Document Production Services, ISBN 978 92 4 150033 3.

WHO (World Health Organization) (2014). Chemicals of Public Health Concern and their management in the African Region.

Wu, J., Basha, M.R., Brock, B., Coz, D.P., Cardozo-Pelaez, F., McPherson, C.A., Harry, J., Rice, D.C., Maloney, B., Chen, D., Lahiri, D.K. and Zawia, N.H. (2008). Alzheimer's disease (AD)-like pathology in aged monkeys after infantile exposure to environmental metal lead (Pb): Evidence for a developmental origin and environmental link for AD. *J. Neurosci*., 28, 3–9.

Wu, T., Buck, G.M. and Mendola, P. (2003). Blood lead levels and sexual maturation in U.S. girls: the Third National Health and Nutrition Examination Survey, 1988–1994. *Environtal Health Perspectives*, **111**, 737–741.

Ye, X. and Wong, O. (2006) Lead exposure, lead poisoning, and lead regulatory standards in China, 1990–2005. *Regul Toxicol Pharmacol*, **46**,157–162.

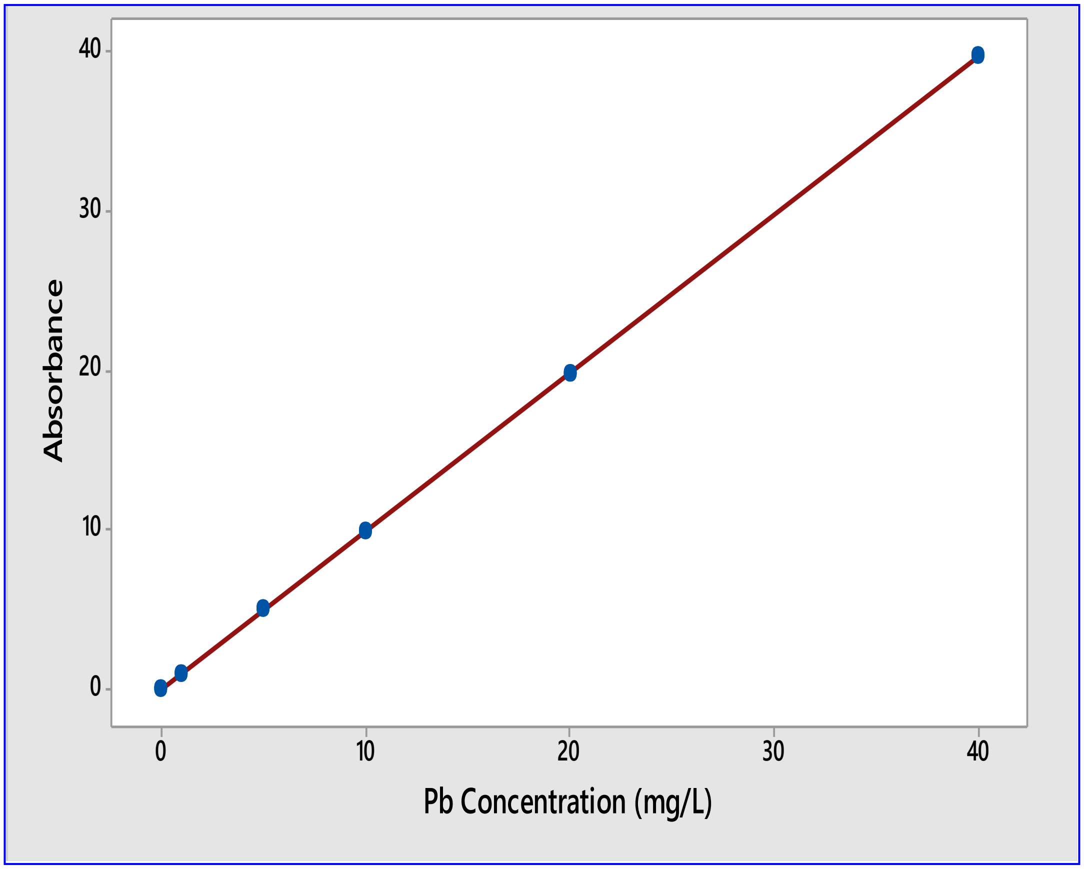
Zhang, N., Baker, H.W., Tufts, M., Raymond, R.E., Salihu, H., Elliott, M.R. (2013). Early childhood lead exposure and academic achievement: Evidence from Detroit public schools, 2008–2010. *Am J Public Health* **113**, e72–7.

Zhang, Q. (2013) Technical Report: The Current Status on the Recycling of Lead-acid Batteries in China. *International Journal of Electrochemical Science*, **8**, 6457 – 6466.

APPENDICES

Appendix I shows the calibration curve generated by the inductively coupled plasma optical emission spectrometer (ICP-OES) during analysis of lead in the soil and house dust sample digests at Mines and Geological Laboratory, as discussed in Chapter 3.

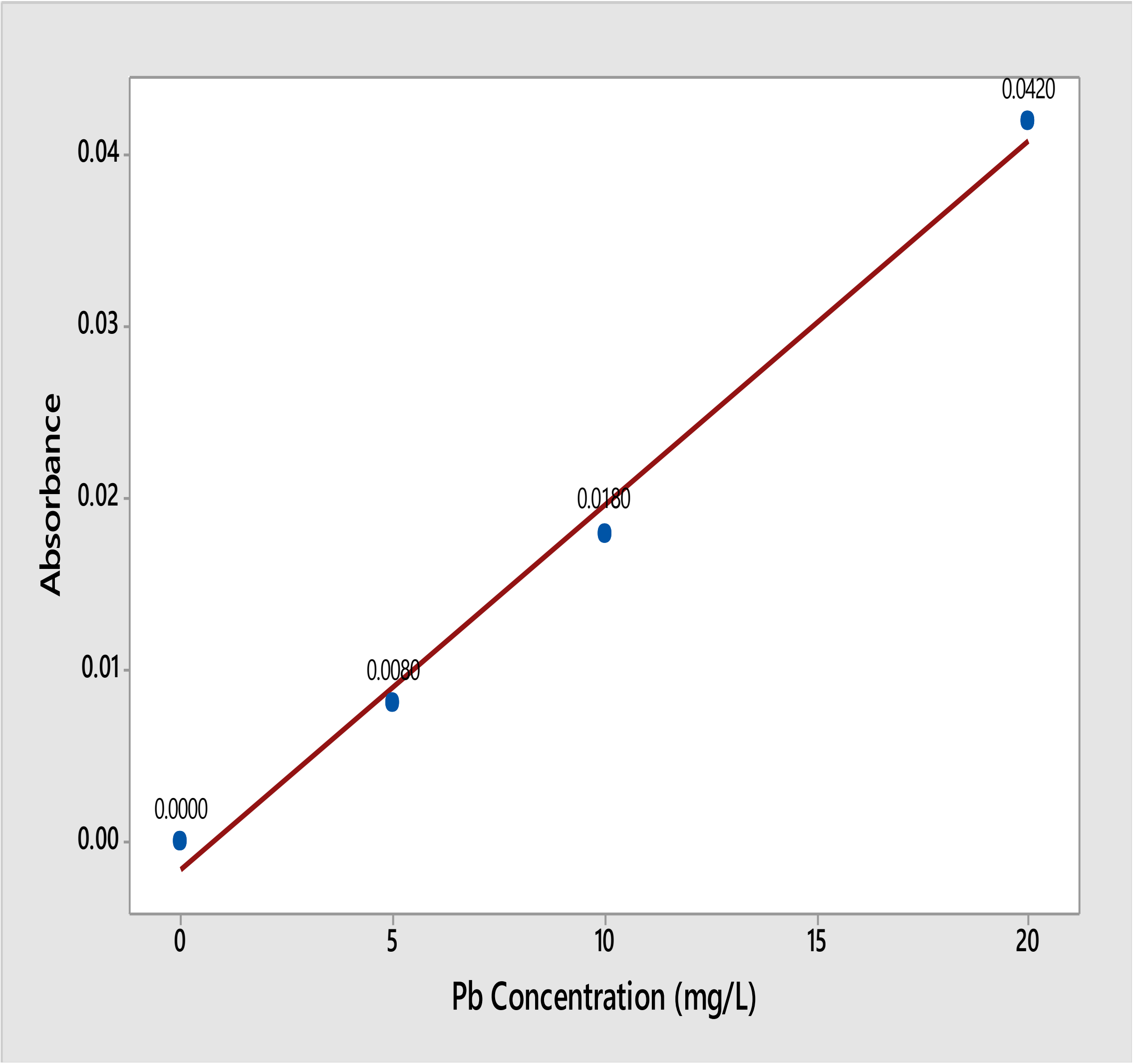
Appendix I: Calibration curve for the Inductively Coupled Plasma-Optical Emission Spectrometer



Regression Equation: Absorbance = -0.03600 + (0.9935*Concentration); $\mathbf{r}^2 = 0.9995$

Appendix II shows the calibration curve generated by the atomic absorption spectrometer (AAS) during the analysis of lead in soil and house dust sample digests, as discussed in Chapter 3.

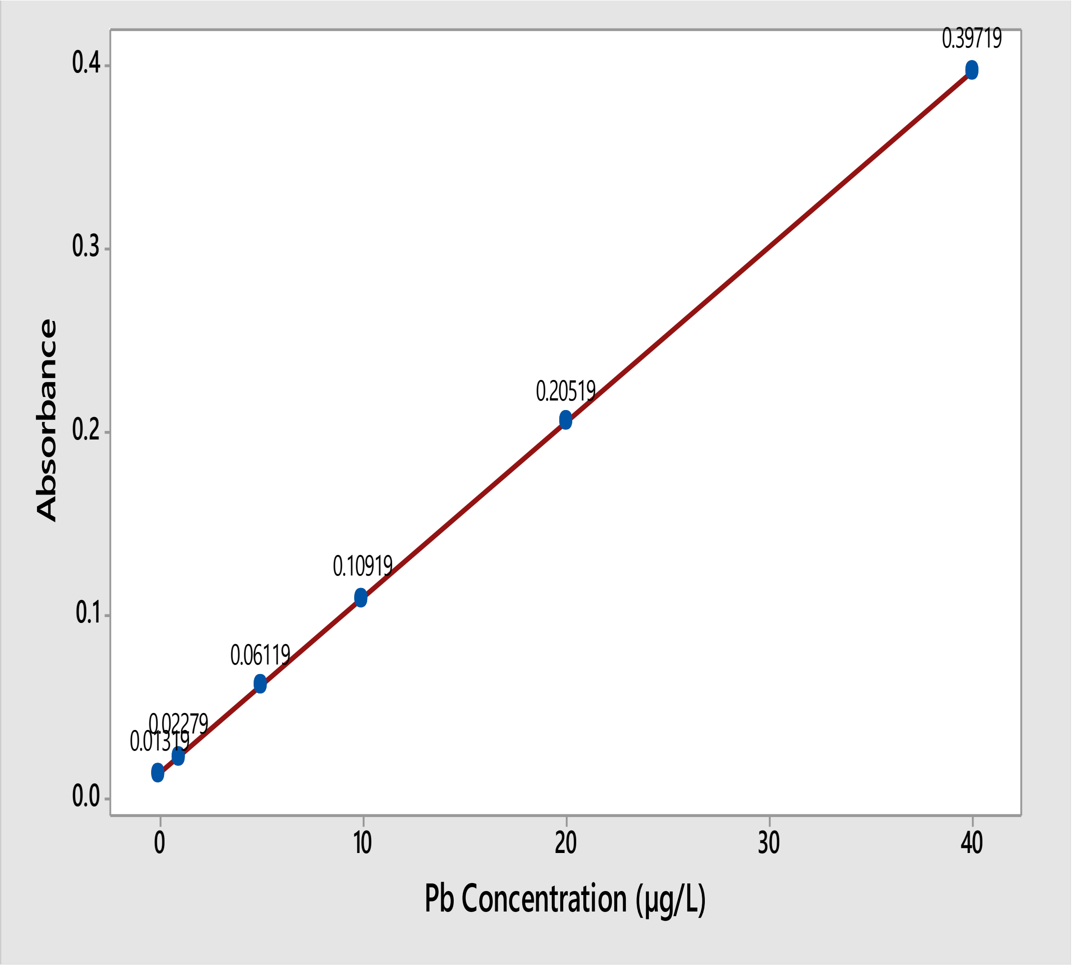
Appendix II: Calibration Curve for the Atomic Absorption Spectrometer (AAS): Mines and Geological Laboratory.



Regression equation; Absorbance = -0.002 + 0.002*Concentration; $\mathbf{r}^2$= 0.9924

Appendix III shows the calibration curve generated by the Graphite Furnace Atomic Absorption Spectrometer (GFAAS) during the analysis of lead in soil and house dust samples at KEPHIS laboratories, as discussed in Chapter 3.

Appendix III: Calibration curve for the Graphite Furnace Atomic Absorption Spectrometer at KEPHIS laboratory.



Regression equation: Absorbance = (0.009600*Concentration) + 0.01319; $\mathbf{r}^2 = 0.9983$

The input metrics of lead levels in soil and house dust used in the IEUBKwin are presented in Appendix 4 below.

Appendix IV: Summary of Standardized Input Metrics used in the IEUBKwin Model for Lead in Children

Area	**PbS (mg/kg)**	**Dust Loading (g/M^2)**		**Lead Loading ($\mu g/M^2$)**		**Concentration (ug/g)**
		Dwelling units	Preparatory schools	Dwelling units	Preparatory schools	
Dandora	1158.3	191.2	76.7	80,647.3	18,819.2	333.6
Kariobangi	1032.3	301.1	96.6	100,069.3	24,748	295.3
Mukuru	3168.8	200.6	92.5	95,686.5	19,669.3	344.8
Ruiru	47.0	35.1	39.4	685.4	498.3	16.1

PbS – lead in soil; Dust loading (L_D) is the amount of dust per unit area; Lead loading (L_{Pb}) is the concentration of lead per unit area; Concentration is the mass concentration of lead per mass of dust; Dust lead concentration (CD) is calculated from lead loading (LPb) and dust loading (LD) as; CD = L_{Pb}/L_D (US EPA, 2008b).