OCCURRENCE OF SELECT HEAVY METALS IN GROUNDWATER SOURCES AND POTENTIAL HEALTH RISKS AMONG RESIDENTS IN INFORMAL SETTLEMENTS OF KISUMU EAST COUNTY, KENYA

BY

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DEDICATION

This research project is dedicated to my Husband Nelson, children; Abby, Makena and Ari for your support and encouragement. To my Mother Hellen, my siblings; Faith and Emma for your inspiration and motivation to never give up.

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ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
ADD	Average Daily Dose
As	Arsenic
ANOVA	Analysis of Variance
APHA	American Public Health Association
AS3MT	Methyl-transferase
ASTDR	Agency for Toxic Substances and Disease Registry
AT	Average Time
ATPase	Adenosine Triphosphatase
BW	Bodyweight
Cd	Cadmium
CDI	Chronic daily intake
CH_3 Hg	Methyl mercury
Cs	Concentration
CR	Carcinogenic risk factor
CVDs	Cardiovascular diseases
DALYs	Disability Adjusted Life Years
DMA	Dimethylarsinic
ED	Exposure Dose
EF	Exposure frequency
EMCA	Environmental Management and Coordination Act
FDA	Food and Drug Administration
GPS	Global Positioning System
Hg	Mercury
HI	Hazard index
HQ	Hazard quotient
IARC	International Agency for Research on Cancer
IHME	Institute of Health Metrics and Evaluation

IR	Intake Rate
JECFA	Joint Expert Committee on Food Additives
KEBS	Kenya Bureau of Standards
KIWASCO	Kisumu Water and Sewage Company
Kg	Kilograms
KNBS	Kenya National Bureau of Statistics
L	Litre
LMICs	Low-Middle Income Countries
MAL	Maximum Acceptable Level
mg	Milligrams
MMA	Monomethylarsonic acid
NCDs	Non-communicable Diseases
NACOSTI	National Commission for Science, Technology and Innovation
NRC	National Research Council
Pb	Lead
Ppm	Parts per million
RfD	Reference dose
SAM	S-adenosylmethionine
SF	Slope factor
SSA	Sub-Saharan Africa
THI	Total Health Index
UN	United Nations
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational Scientific Cultural Organization
UNICEF	United Nations Children's Fund
USA	United States of America
USEPA	United States Environmental Protection Agency
WASREB	Water Services Regulatory Board
WHO	World Health Organization
WWAP	World Water Assessment Programme

DEFINITION OF OPERATIONAL TERMS

Maximum Acceptable Level (MAL) is a numerical value expressing the maximum permissible level of a contaminant in water which consumed by individuals from any water source.

Groundwater sources are water access points where water is extracted from the aquifer found beneath the earth. Examples are shallow and deep wells, boreholes and natural springs.

Hand dug well are shallow groundwater sources ranging in depths up to 20 meters and approximately 1.5 meters in diameter.

Shallow wells are groundwater sources that are deeper than 30 meters but lesser than 100meters and have a smaller diameter, approximately 100 to 150 millimeters.

Tube well or borehole is a deep hole that has been driven, bored or drilled, with the purpose of reaching groundwater supplies, depth is usually up to > 100meters.

Informal settlement "are residential areas where; 1) inhabitants have no security of tenure vis-à-vis the land or dwellings they inhabit, with modalities ranging from squatting to informal rental housing, 2) the neighborhoods usually lack, or are cut off from, basic services and city infrastructure and 3) the housing may not comply with current planning and building regulations, and is often situated in geographically and environmentally hazardous areas"(UN Habitat, 2007).

Peri-urban areas (also called urban space, outskirts or the hinterland). It can be described as the landscape interface between town and country, or also as the rural—urban transition zone where urban and rural uses mix and often clash.(UN-Habitat, 2007)

ABSTRACT

Groundwater contamination with heavy metals is a global problem with millions of people at risk. Exposure to even low concentration of heavy metals through long term ingestion of contaminated water is responsible for various non-communicable diseases. In developing countries like Kenya, groundwater supplements water supply due to limited or unreliable piped water in informal settlements. Contamination of groundwater in these settlements due to uncontrolled human activities and infrequent monitoring is a concern considering that Kisumu County is highly reliant on groundwater. In addition, there are limited studies relating to heavy metal contamination, which is a concern with the cognizance of development of non-communicable as a result of exposure to heavy metals in the environment. The study aimed to determine levels of select heavy metals (arsenic, cadmium, lead and mercury) in groundwater sources used for drinking water and the potential health risks from exposure in the informal settlements of Kisumu East County. This was a cross-sectional study among informal settlements of Kisumu where 355 households selected using stratified random sampling technique between 5^{th} and 17^{th} December 2017. `Ethical approval was granted by the KNH/UoN ERC(P352/07/2017) and NACOSTI (P/18/3232/2089A) structured questionnaire captured socio-demographic details, anthropometric measurements and exposure assessment in relation to groundwater use. Groundwater samples were collected from 37 water points in the month of May 2018 and analyzed for levels of heavy. Carcinogenic and non-carcinogenic risk assessment was performed according to the USEPA methodology for both adults and children. Occurrence of heavy metals followed the order; As>Cd>Pb>Hg, and were within WHO and KEBS.limits. Groundwater was used for both drinking and domestic purposes. Prevalence of chronic disease was low at (4% n=50)) with hypertension and diabetes as the main conditions. An increase in age (p=0.001) and gender (p=0.05) were statistically significant factors with presence of chronic disease among the residents using groundwater. Health risk values were within acceptable levels (HQ/HI <1) with a higher value in children compared to adults, making them susceptible to heavy metal exposure. Despite the health risk and results of heavy metals indicating minimal anthropogenic activities in the area, a significant number of households (80%n=257)) did not maintain recommended distance of waste sites to groundwater sources and are therefore a potential source of future groundwater contamination. Regular monitoring of groundwater and strict adherence of pollution policies in the informal settlements can remarkably reduce the risk of ingesting heavy metals.

CHAPTER ONE

INTRODUCTION

1.1 Background of study

Groundwater studies have revealed that these sources are vulnerable to heavy metal contamination (Haileslassie & Gebremedhin, 2015). A phenomenon that has become a global challenge due to the adverse health effects from chronic exposure (Fernández-Luqueño et al., 2013; UNEP, 2013). Other undesirable substances that are of concentration not normally present in water in to the groundwater system include microorganisms, chemicals, waste or sewage rendering the water unfit for its intended use (UNESCO, 2002).

It is estimated that out of the two billion people worldwide relying on aquifers as a drinking water supply, about 75% of Africa's population is dependent on groundwater (UNEP, 2011). About 40 million people in peri-urban and rural sub-Saharan Africa (SSA) use boreholes and wells due to limited access to piped water (MacDonald & Calow, 2009a). According to World Health Organisation (WHO) by 2015 about 663 million people were still lacking improved drinking water sources and were still using groundwater sources such as unprotected wells and springs (WHO and UNICEF, 2015). Cities in developing countries are unable to meet its water demand, impelling slum residents to dig shallow hand dug wells as a source of water (Grönwall, Mulenga, & Mcgranahan, 2010).

Heavy metals are defined as those having a density greater than water, usually of more than 5 g/cm3 (Duffus, 2002) and are non-biodegradable, therefore persist in the environment (Singh et al., 2011). Trace amounts of metals are common in water, and are essential for biological and chemical functions in human cells, these are not harmful to human health and include iron, copper, manganese, selenium and zinc among others (Chitturi et al., 2015). Some of the heavy metals of public health concern that have been reported to contaminate drinking water include arsenic, cadmium, mercury, and lead (WHO, 2008b).

Exposure to chemical contaminants have been associated with non-communicable diseases (NCDs) namely; cardiovascular diseases, chronic respiratory disease, diabetes and cancer (WHO, 2014) and are regarded to as environmental diseases (Sly et al., 2016). These diseases non-linked to environmental toxicants such as heavy metals have often been disregarded in the causation pathways (R. E. Norman et al., 2013a). Heavy metals are harmful to humans because they tend to bio accumulate which means levels increase to dangerous levels in an organism compared to the surrounding environment (Jarup, 2003a). Heavy metals of public health concern are a major source of oxidative stress in the cell and play an important role in the etiology of various human pathologies (Leonard et al., 2004; Nair et al., 2013). Prolonged exposure to low levels therefore, has cumulative health effects on the reproductive, cardiovascular, neurological systems and are responsible for development of various cancers (Gohar & Mohammadi, 2010; Jaishankar et al., 2014a).

Deteriorating water quality is a global issue due to population surge, climate changes, industrialization and agricultural activities which cause changes to the hydrological cycle (Unesco, 2009) (Khatri & Tyagi, 2015a). Developing regions in the world, Africa particularly also has challenges of waste management contributing to the challenge of heavy metal pollution in the ecosystem (Henry et al., 2006; Ziraba et al., 2016). The World Water Assessment Programme (WWAP) reports have shown that chemical contamination from heavy metals and other compounds are as a result of man-made activities like fertilizers or pesticides use, accidental industrial spills, gasoline seepage and landfills run-offs (WWAP, 2006).

The Oxford Business Group in Kenya reported that about 60% of the urban population had no piped water and rely on water vendors or unprotected natural sources where water quality was questionable and the majority of this population lived in informal settlements (Oxford Business Group, 2014).

Groundwater exploitation is an alternative in informal settlements where reliable safe water options are unavailable. In the study area the high water table is prone to contamination from inadequate drainage systems, land run-offs, floods and cross contamination from pit latrines in close proximity (Okotto et al., 2015). Residents in informal settlements using groundwater sources are more likely to be exposed to heavy metals such as arsenic among other metals (Mahmood and Halder, 2011). In addition, children are most vulnerable to heavy metal exposure with increased risk of chronic diseases such as neurodevelopmental conditions (Oyoo-Okoth et al., 2010b). Adults are equally at risk of number of adverse effects such as neurotoxic effects, carcinogenic, and metabolic effects to mention a few (Caito & Aschner, 2015; N. H. Kim et al., 2015; Solenkova et al., 2014; Tokar et al., 2011).

This study determined levels of select heavy metals (arsenic, cadmium, lead and mercury) in groundwater among informal settlements, where studies have mainly been on microbiological contamination, linked to close proximity to sanitation facilities like pit latrines, sewer lines and flooding (Kimani-Murage & Ngindu, 2007a).In addition, focus has been on communicable diseases, with little on environmental risk factors such as heavy metals predisposing residents of the informal settlements to chronic diseases (Etyang et al., 2013).

1.2 Problem Statement

Heavy metals exposure accounts for significant morbidity and mortality due to their adverse health effects. It is estimated that 25 percent of total global burden of disease and 2.94 million deaths is related to environmental factors such as toxic chemicals like metals (Öberg et al., 2010). Lead for example accounts for 3 percent of cerebrovascular disease burden worldwide (WHO, 2010c). Exposure to Arsenic was responsible for 9,100 deaths through contaminated water in Asian regions and 125,000 Disability Adjusted Life Years (DALYs) (Lokuge et al., 2004). Ingesting contaminated water remains a major route of exposure to heavy metals (Kavcar et al., 2009a; Smith et al., 2000).

Developing countries have a challenge in the provision of equitable access to safe water and sanitation services, which is far from reach for the underserved population within informal settlements (Ahaneku & Adeoye, 2014). The resolve to using groundwater is therefore a solution for the rural and urban poor who cannot access piped water (Cherunya et al., 2015a). Despite its reliability and affordability, groundwater is vulnerable to pollution from human activities (Hunter et al., 2010a), industrial disposal of untreated wastes in water sources, over application of agrochemicals (Khan et al., 2013) and improper sewage and disposal services (Farid et al., 2012). This, coupled with limited municipal services in urban slums such and infrequent monitoring of water quality increases the risk of exposure of water to contaminants (Marshall, 2011).

Heavy metal contamination of groundwater in developing regions among the poor is growing. This is evidenced in a number of regions such as; Bangladesh where high arsenic levels and associated adverse effects have been identified (Das et al., 2009), cadmium and lead among other metals have been found to be high in ground waters in the cities (Dixit et al., 2003). In Ghana incidence of high arsenic levels in groundwater has been reported with manifested skin lesions (D. I. Norman et al., 2000). Increased risk to toxic levels of lead and cadmium in hand dug wells and boreholes in Nigeria have been noted (Momodu & Anyakora, 2010).

There is limited research in SSA on groundwater contamination with heavy metals, and the related health conditions in informal settlements. This is despite high levels of metals such as arsenic reported on both surface and ground waters exceeding recommended levels (Fatoki et al, 2013) and increasing prevalence of chronic diseases in African informal settlements (Etyang et al., 2013; Joshi et al., 2014; Olack et al., 2015). Additionally, environmental studies near the study area at Lake Victoria have quantified heavy metal concentrations in surface water sources including arsenic and lead (Makokha et al., 2008; Mireji et al., 2008; Ogola et al., 2002).

Residents in Kisumu peri-urban and informal settlements have been using groundwater as an alternative water source despite its quality (Okotto et al., 2015). The extent of heavy metal contamination and risk it poses to the health of the residents in the study area of Kisumu East County using this water is not known, and it is in this understanding therefore; that the study will be undertaken to attempt to address part of this problem by determining the quality of drinking water from groundwater sources by establishing the concentration levels of heavy metals and potential health risks the residents can encounter due to exposure.

1.3 Justification

Heavy metal contamination of groundwater sources is a threat to the safety and reliability of water sources due to the associated health risks (Fernández-Luqueño et al., 2013). Developing countries are grappling with water quality concerns due to progressive urbanization and industrialization

(Khatri & Tyagi, 2015b). This is in addition to water related diseases which are particularly high in informal settlements due to challenges in access to safe water and sanitation services resulting in use of available vulnerable groundwater sources prone to both chemical and microbiological contaminants (Kimani-Murage & Ngindu, 2007b).

One such place in Kenya with water high morbidity and mortality burden due to water related disease is Kisumu County (Maoulidi, 2011). The area has a high water table and many informal settlements dwellers use groundwater sources such as springs, shallow wells and boreholes as principal water sources despite established municipal water networks (Dickson et al., 2015a; Okotto et al., 2015a). Groundwater is vulnerable to contamination by organic and inorganic contaminants such as nitrates, iron, lead, aluminum and arsenic which have been detected in various surface water sources that act as a recharge for the aquifer in the County (Makokha et al., 2008, 2012; Oyoo-Okoth et al., 2010a). Studies have however not been carried out in groundwater sources in informal settlements to establish the extent of contamination due to uncontrolled human activities and infrequent monitoring.

In addition to behavioral risk factors that have been associated with the development of non-communicable diseases, environmental related risk factors such as heavy metals have been implicated (R. E. Norman et al., 2013b). This has been confirmed by epidemiological and experimental studies that reveal individual exposure to toxic levels of heavy metals such as arsenic, lead, cadmium and others play major role in the growing cardiovascular disease, cancer and neurological disease epidemic (Morais et al., 2012; Tokar et al., 2011).

Given the lack of formal water and sanitation services in most informal settlements, residents are exposed to both biological and chemical contaminants that have potential to cause illnesses (Kyobutungi et al., 2008). Use of unsafe water that is contaminated results in numerous and overlapping health, economic and social impacts that disproportionately impacts these residents. Additionally, economic strain is experienced by the country due to the costs of diagnosis, treatment and loss of man hours, resulting from end-stage complications of chronic conditions (Abegunde & Stanciole, 2006).

This study investigated whether drinking water from groundwater sources contaminated with select heavy metals; arsenic, cadmium, lead and mercury above permissible levels had any potential health risk among informal settlements. The outcome of the study will contribute to understanding the level of heavy metal exposure in groundwater. Government ministries responsible for protection of water resources in the County of Kisumu will be tasked with safeguarding the health of the population by addressing the potential sources of groundwater contamination. The study will also form basis for further research in population health in relation to groundwater studies.

1.4 Research question

Are residents in informal settlements vulnerable to any health risks from consuming contaminated groundwater with heavy metals?

1.5 Objectives

1.5.1 Broad Objective

The main objective was to: Determine levels of select heavy metals (arsenic, cadmium, lead and mercury) in groundwater sources (springs, boreholes and wells) used for drinking, and the potential health risks from exposure among residents in the informal settlements of Kisumu East County.

1.5.2 Specific Objectives

1. To determine levels of select heavy metals in groundwater sources;
2. To compare select heavy metals levels from groundwater sources to Kenya Bureau of Standards and World Health Organization recommended maximum acceptable levels;
3. To determine the population at risk of exposure to select heavy metal in groundwater;
4. To determine the likely health risks due to long term exposure to the select heavy metals investigated.

1.6 Conceptual Framework

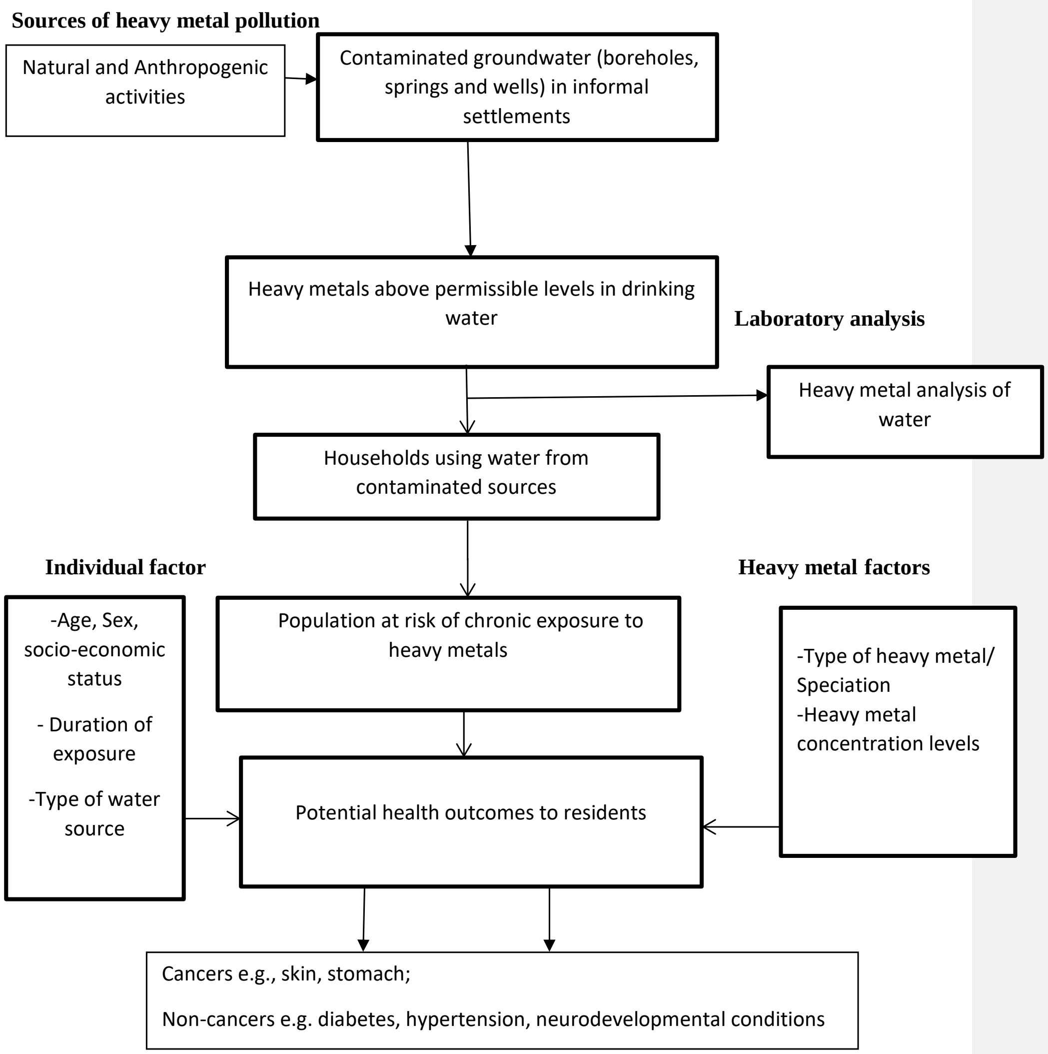

Figure 1: Conceptual framework visualizing potential health outcomes to residents from heavy metals exposure in contaminated groundwater sources.

1.6.1 Conceptual framework of heavy metals exposure from contaminated groundwater

Potential health risks from heavy metal exposure through ingesting contaminated groundwater is influenced by a number of factors. Among these factors are:

a) Individual factors

They include; age, sex , nutritional status and duration of exposure of the household members increases the risk to adverse effects. While the household location, household head income status, and educational level have a bearing on the type of water source household has access to.

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b) Heavy metal factors

Risk of exposure by heavy metals such as arsenic, cadmium, lead and mercury are influenced by; the type of heavy metal, the speciation, the concentration levels of the metals and source of heavy metal pollution.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Globally heavy metal exposure is a public health problem and most of the population is unknowingly exposed (Schwarzenbach et al., 2010). Despite some metals occurring naturally in the environment, they are considered as contaminants when they exceed a certain limit that can cause adverse health effects to exposed individuals (Jaishankar et al., 2014b). In 2004, WHO estimated 4.9 million deaths globally and 86 million Disability Adjusted Life Years (DALYs) were attributable to environmental exposures (Prüss-Ustün et al., 2011).

Heavy metals contaminate water sources through natural processes within the earth (Bradl, 2005) and through human activities from indiscriminate use of metal compounds in fertilizers, pesticides, feed additives, mining and inappropriate industrial and domestic disposal of hazardous waste sites (Armah et al., 2014). These human activities are common in cities where there is poor urban planning, emerging informal settlements and condensed industries all lead to generation and exposure to hazardous wastes in groundwater as a consequence of poor disposal systems (Farid et al., 2012). There is an outspread use of groundwater sources particularly boreholes for domestic use in informal settlements within urban areas (Cronin et al., 2007).

An informal settlement is a residential area lacking one or more of the following; improved water, improved sanitation, sufficient living area, durable housing and secure tenure (UN Habitat, 2007).

It is estimated one billion people live in informal settlements globally (Sachs, 2005), 40 percent of the urban population live in urban informal settlements in SSA (United Nations, 2007) and about 41.4 million of this population use water from wells and boreholes (WHO/UNICEF, 2014). Urban informal settlements and rural areas in Kenya rely largely on groundwater sources largely due to water scarcity from drought, floods, poor management of water supply, forest degradation and a sharp increase in water demand resulting from relatively high population growth (Marshall, 2011). An estimate of 20% was the formalized water supply services coverage in informal slums in Kenya in 2012 (Cherunya et al., 2015b).

Residents in urban informal settlements are exposed to different risk factors concerning non-communicable and communicable diseases due to inequalities in provision of water, sanitation services, housing and also access to quality health care (Anand et al., 2007; Lamba, 1994). Residents in informal settlements using groundwater sources are more likely to be exposed to heavy metals such as arsenic among other metals (Mahmood and Halder, 2011). Children are most vulnerable to heavy metal exposure with increased risk of chronic diseases such as neurodevelopmental conditions (Oyoo-Okoth et al., 2010b). Adults are equally at risk of number of adverse effects such as neurotoxic effects, carcinogenic, and metabolic effects to mention a few (Caito & Aschner, 2015; N. H. Kim et al., 2015; Solenkova et al., 2014; Tokar et al., 2011).

2.2 Groundwater

Groundwater is considered as an attractive option for safe drinking water supply, as it is available in low costs and requires no prior treatment. This is because water is filtrated through the soil and aquifer sediments acting as a natural protection against pathogens (MacDonald & Calow, 2009b). However, there are a wide range of water contaminants apart from pathogens and include chemicals, physical and sensory changes (Ojo, Otieno and Ochieng, 2012). The main classification is microbiological or chemical contaminants, heavy metals within the latter (WWAP, 2006).

Contamination from pathogens has been the focus of water pollution, however emerging contaminants such as persistent organic compounds and heavy metals are of growing concern due to their adverse effects (Richardson & Kimura, 2016). Apart from releasing the heavy metals compounds from natural processes within the earth crust, these compounds polluted the environment from fertilizers or pesticides use, accidental industrial spills, gasoline seepage and landfills run-offs (WWAP, 2006). Contamination from these heavy metals can be from a point source which involves a single source like industrial discharges while non-point source is multiple sources such as landfill run-off and storm water (Kjellstrom et al., 2006).

Industrial pollution through discharge of effluent wastes has been implicated as the major source of water pollution (A. C. C. Ezeabasili et al., 2014). Other sources in urban areas may however be responsible, as a study carried out in the India noted lower levels of heavy metal contamination of groundwater in industrial areas and much higher levels in residential groundwater far from the industries (Mohankumar et al., 2016a). Heavy metal contamination is difficult to treat and even at low concentration levels, it is unsafe for use (Xu & Usher, 2006).

2.3 Select heavy metals

The main threats to human health are from exposure to non-essential heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) which are widely dispersed in the environment (Jarup, 2003b). Exposure to these metals in the human body occur through various modes such as air, food and ingesting contaminated water (Tchounwou et al., 2012a). They have no beneficial effects in humans (Vieira et al., 2011). Adverse human health effects associated with exposure to them depend on the nature and quantity of the metal ingested, effects are diverse and include, but are not limited to, neurotoxic and carcinogenic actions (Castro-González & Méndez-Armenta, 2008; Jomova et al., 2011).

a) Arsenic

Arsenic (As) is a classified as a metalloid that occurs as a natural element found in water, soil and water. It exists in four valence states -3, 0, +3, +5 arsine, elemental arsenic, arsenite and arsenate respectively, depending on the environmental conditions (Henke, 2009). Arsine, elemental arsenic and arsenite is found in varying reducing conditions and arsenate found in oxygenated conditions as the dominant form (WHO, 2001a). In groundwater arsenic exists in two oxidative states that are inorganic forms either arsenite (As +3) or arsenate (As +5). These inorganic forms are considered more toxic, most potent being arsenite (Rai et al., 2011) and are responsible for the arsenic related health effects (Thomas et al., 2001a).

Groundwater sources like wells and boreholes among others are more likely to be contaminated by inorganic arsenic than surface water (WHO, 2012). Arsenic is mobilized into toxicological levels of concern by the natural or anthropogenic activities into groundwater (ASTDR, 2007). Natural processes include weathering reactions, biological activity, geochemical reactions, and volcanic emissions (Mandal & Suzuki, 2002).

Various anthropogenic or man-made activities are equally responsible for arsenic pollution (Garelick et al., 2008a). Main uses of arsenic compounds are in herbicides, fungicides, wood preservatives and cattle and sheep dips (Ravenscroft et al., 2009a). It is also used for glass and as a metal alloy in semiconductors and other electronic devices (Garelick et al., 2008b). Introduction to groundwater is through mining activities, agricultural drains from arsenic based pesticides, disposal and incineration of municipal and industrial wastes (Centeno et al., 2007).

Arsenic concentrations in groundwater varies greatly worldwide and available documented levels in micrograms per litre (μg/L) range from as low as 0.5 μg/L to 5000 μg/L in over 70 countries (Ravenscroft et al., 2009b). However, the provisional permissible level in groundwater is 10 μg/ L up to 50 μg/ L (WHO, 2004). Highest concentrations of arsenic in groundwater due to geological causes are in Chile, China, Argentina, Taiwan, Mexico, Bangladesh and West India (WHO, 2001b). A study in Bangladesh analyzing the arsenic compounds in groundwater noted arsenite as the dominant species (D. Postma et al., 2007).

A review on arsenic in African waters revealed concentrations range between 0.02 and 1760 μg/L, surface water ranged up to 10,000 μg/ L, found in Angola, Kenya, Mali, Zambia (Ahoul et al., 2015). In Africa arsenic contamination of water sources are mainly from anthropogenic sources, documented cases of high arsenic levels in groundwater and soil have been reported in South

Africa, Botswana, Nigeria, Burkina Faso (Fatoki et al, 2013). Ghana which is noted to have high arsenic levels, is from mainly mining activities, geological processes and indiscriminate use of pesticides (Asante & Ntow, 2009). In Nigeria industrial pollution of groundwater sources in the state of Onitsha North and South were attributed to arsenic contamination (A. C. C. Ezeabasili et al., 2014).

Studies in Kenya to determine arsenic levels particularly in Kisumu, reported higher levels in soil samples than water however, high levels but within WHO limits were noted on the shoreline than inshore waters of sampled lake water (Makokha et al., 2012). Whilst the water samples were from tap and surface water, no groundwater sources were sampled in the study. This is despite the fact that groundwater can be contaminated by arsenic by leaching process from soil and surface water interacting with aquifers (Nikolaidis et al., 2004).

According to the National Research Council (NRC) arsenic concentration levels in water is classified in parts per billion (ppb); 1ppb = 1 µg/L where, <50ppb is low, 50-150ppb is moderate and >150ppb is considered high (NRC, 2013). World Health Organization maximum permissible levels of arsenic in drinking water is 10 µg/L, this was after re-evaluated the effects of arsenic on human health from available studies (WHO, 2010a).

b) Cadmium

Cadmium is widely distributed within the earth's crust in sedimentary rocks and marine phosphate. It occurs in ores with other elements commonly in zinc ores and, to a lesser extent with copper and lead ores. In the environment it exists in only one oxidative state +2. In groundwater it can exist in hydrated ions or as ionic complexes with inorganic and organic substances (ATSDR, 2012).

Cadmium is majorly used in manufacturing alkaline batteries as an electrode component, coatings, pigments, plating and as a plastic stabilizer (Jaishankar et al., 2014a). Once cadmium distributed in the environment it remains in the soils and sediments for decades. Industrial and municipal wastes are the main sources of cadmium pollution. Cadmium in drinking water may be from impurities in zinc galvanized water pipes. High levels of cadmium are rarely found in groundwater unless sources are contaminated by industrial wastes from mining, manufacturing and application of phosphate fertilizers, textiles operations, electroplating waste sites and sewage treatment plants (ATSDR, 2012).

The normal concentration of cadmium in natural surface water and groundwater is usually 1 µg/L (ATSDR, 2012). In the USA concentrations of cadmium polluted surface and ground waters have ranged from <1 to 77 µg/L, these levels were due to close proximity to cadmium-emitting industries (ATSDR, 2012). In African waters more research has been on surface water than in groundwater and the studies have been in rural regions than urban areas. High levels of up to 17 µg/L in rivers and dams of a populous rural area of South Africa while in a Nigerian rural settlement high level of 240 µg/L to 360 µg/L were noted (Adekunle et al., 2007; Fatoki & Awofolu, 2004). Probable sources implicated were the geology of the catchment soil, runoffs from agricultural soils that use phosphate fertilizers, leachates from disused nickel-cadmium based batteries and cadmium plated items from the communities that disposed in refuse dumps in the settlements (Fatoki & Awofolu, 2004).

From groundwater studies carried out in urban areas, concentrations of cadmium appear to be high in unprotected sources. One such study in urban area of Zaria City in Nigeria, levels were above permissible levels in open boreholes and wells ranging from 1 to 280 µg/L (Musa et al., 2007). Alluded contamination sources were from natural processes, wells cited indiscriminately without proper geological survey, increased indiscriminately refuse and waste disposal, septic tanks and combustion byproducts from batteries and traffic. According to WHO permissible levels in drinking water is 3 µg/L (WHO, 2011a).

c) Lead

Lead as a metal occurs naturally and is mined from metal ores. It exists in three oxidation states 0, +2 and +4. Lead exists in the environment in the +2 state. It has extensively been used for years in early applications including building materials, pigments for glazing ceramics and pipes for transporting water. The main source of environmental pollution was from emissions to the air from petrol prior to the introduction of unleaded petrol most developed and developing countries over the past two decades, this reduced lead pollution significantly (ATSDR, 2005).

Currently lead pollution is largely from lead compounds still in use which discharge lead in the environment. Lead in drinking water has been found in water delivered through lead pipes or pipes joined with lead (WHO, 2003b). In groundwater lead as a contaminant is mainly from human activities which include pesticides, fertilizers, industries and mining activities, disposal of wastes, industrial wastes into lakes and rivers that interact with aquifer water cycle to ground water (Jaishankar et al., 2014). In the USA the normal range of lead in surface and groundwater is between 5 and 30 µg/L (ATSDR, 2005). Contamination of lead in groundwater can also result from natural processes such as dissolution of lead from soil and earth crust, where it is usually present in a form of carbonate and hydroxide complex, with varying degree of solubility (WHO, 1996).

From a study assessing concentrations of heavy metal an urban area in Nigeria, no lead levels were detected in groundwater sources. A possible explanation being increased distance of groundwater sources from dumpsites and industries can result in minimal contamination (Njar et al., 2012). Lead levels however from Dandora municipal dumpsite in Kenya were documented to be high with levels ranging 50-590 ppm and noted to be a potential source of contamination to nearby water sources (Kimani, 2012). High lead levels ranging 210 to 690 µg/L in various water samples from a river, Lake Victoria and public water systems were found in Kisumu, this was attributed to lead pollution from busy highways with leaded gasoline, upstream pollution of rivers from industries dumping untreated wastewater and lead stearate in plastic pipes a compound that is used as a stabilizer in the manufacture of polyvinyl plastics (Makokha et al., 2008). The permissible levels by WHO in drinking water is 10 µg/L (WHO, 2003b).

d) Mercury

Mercury occurs naturally within the earth's crust. It exits in three forms in the environment; elemental (or metallic), inorganic forms and methyl mercury which is the organic form. At high pressures metallic mercury can turn into mercury vapor (Hg^0) while inorganic mercury combines with other chemical elements to form mercurous mercury (Hg^{+}) or mercuric mercury (Hg^{++}) salts. Organic mercury, also called organometallic results from a covalent bond between mercury and a carbon atom of an organic functional group such as a methyl, ethyl, or phenyl group (ATSDR, 1999a). Methyl mercury (CH_3Hg^{+}) is the most common form of organic mercury to which humans and animals are exposed (Rice et al., 2014).

Inorganic mercury may enter water or soil from natural processes such as volcanic activity, weathering of rocks and as a result of anthropogenic activities such as mining, factories discharging industrial wastes, incineration of municipal garbage that contain mercury like thermometers, electrical switches, or batteries (ATSDR, 1999b; Dong et al., 2012). CH_3Hg^{+} in the environment is predominantly formed by methylation of inorganic mercuric ions discharged from various contaminants by microorganisms present in soil and water. In water it accumulates in fish and bio-accumulates in humans is through fish intake (Hong et al., 2012a).

Mercury in drinking water is in Hg++ form and naturally occurring levels of mercury in groundwater and surface water are less than 0.5 µg/L, higher levels may be found in groundwater from local mineral deposits (WHO, 2005). Increasing mercury levels of up to 5.5 µg/L have been detected in wells in Japan due to volcanic activity. Gold mining areas such as Lake Victoria in Tanzania, Amazon Basin in Brazil and Mindanao Island in the Philippines have polluted both surface and ground waters with mercury (Tsuchiya, 2010). Two studies comparing mercury levels in surface and groundwater sources such as boreholes found higher levels in the former in Nigeria, this was due to surface run-offs (Ada et al., 2012; C. C. Ezeabasili et al., 2015). According to WHO permissible levels in drinking water are 10 µg/L. Few studies in Kenya have detected mercury in water sources above the recommended levels.

Maximum Acceptable levels

In order to protect human health, guidelines for the presence of heavy metals in water have been set by various international organizations regulatory agencies such as European Union Commission, USEPA and WHO. Below is a summary of the Maximum Acceptable Levels (MAL) compiled from literature review stipulated for the heavy metals of interest by World Health Organization (WHO, 2011b) and Kenya Bureau of Standards (WASREB, 2008).

Table 1: Drinking water guidelines of select heavy metals by World Health Organization (WHO) and Kenya Bureau of Standards (KEBS)

Heavy metal	Maximum Acceptable Levels	
	WHO	KEBS
Arsenic	10µg/L	50 µg/L
Cadmium	3 µg/L	5 µg/L
Lead	10 µg/L	50 µg/L
Mercury	1 µg/L	1 µg/L

2.4 Effects of select heavy metal exposure on human health and individuals at risk.

Human exposure to heavy metals is on a rise due to their wide distribution from industrial, domestic, agricultural, technological and medical applications. Potential effects on human health depends on several factors that include dose, route of exposure and chemical species of the metal while the age, gender, genetics and nutritional status of the individuals exposed (Tchounwou et al., 2012b).

Arsenic, cadmium, lead and mercury are among priority metals that are systemic toxicants and are known to cause multiple organ damage even at low levels of exposure. These metals are also classified as known or probable human carcinogens due to their carcinogenic effects (International Agency for Research on Cancer, 2016a; USEPA, 2013).

a) Arsenic

Arsenic is considered to be one of the world's most hazardous chemical contaminant (National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring, 2001). It has more serious health consequences than any other environmental contaminant (Smith A, Steinmaus C, 2007). Due to its adverse multisystem health effects has resulted Food and Drug Agency (FDA) to rank it as a group 1 carcinogen(Food and Drug Administration (FDA), 2010). WHO estimates close to 200 million people are exposed to arsenic levels above the permissible 10 µg/L in drinking water (WHO, 2012). Prolonged and excessive ingestion of arsenic results in arsenicosis which is defined as "chronic health condition arising from prolonged ingestion (not less than 6 months) of arsenic above a safe dose, usually manifested by characteristic skin lesions, with or without involvement of internal organs." (WHO, 2003a)**.**

Exposure, Metabolism and Toxicity

Main sources of exposure to humans is through air and water resulting in acute and chronic effects, inhalation of arsine gas results in acute poisoning (WHO, 2012). The consumption of groundwater with high levels of arsenic or crops irrigated with contaminated water are sources of exposure to humans and a public health concern (UNICEF, 2008). Inorganic arsenic compounds As +3 and As +5 consumed from arsenic contaminated drinking water are absorbed through the gastrointestinal system after which it is transported to the liver (NRC, 2013).

Long-term exposure, ranging 5-20 years from inorganic arsenic in drinking water and food has been known to cause arsenicosis which consists a range of dose-dependent conditions including cancers of the lung, bladder, skin (Martinez et al., 2011) as well as peripheral vascular disease, cardiovascular disease, hematopoietic conditions, diabetes and neuropathy among others (Abdul et al., 2015). The most characteristic effect of chronic arsenic exposure being skin lesions melanosis and hyperkeratosis which are the initial symptoms of exposure to high levels in a minimum of five years (Mazumder, 2001). The skin changes are a precursor of skin cancer among other cancers such as lung and bladder cancers which can occur in 10-20 years of exposure. Other long-term adverse effects are developmental effects, neurotoxicity, diabetes, pulmonary disease and cardiovascular disease. Arsenic exposure has also been associated with poor pregnancy outcomes (WHO, 2016).

Epidemiological studies have been carried out in arsenic contaminated waters of Argentina, Bangladesh, Chile, China linking long-term arsenic exposure to health effects (Rodríguez-Lado et al., 2013a). Studies in Taiwan and Chile have shown ingesting arsenic levels of 800 to 1820 ppb have been associated with a rising prevalence of vascular diseases and cardiovascular mortality (Rosenman K., 2007). Epidemiological data review indicates levels above 150 µg/litre are associated with developing internal cancers (Cantor & Lubin, 2007). There is a strong relative risk of developing cardiovascular disease when exposed to levels >50 µg/litre (Moon et al., 2012). In a cross-sectional study carried out Mongolia, China documented higher prevalence of hypertension in individuals exposed to arsenic levels >50µg/litre (X. Li et al., 2013a).

The poor are more vulnerable to arsenic related diseases, cardiovascular diseases included in this spectrum due to socioeconomic and nutritional limitations in the backdrop of exposure to arsenic from contaminated groundwater sources (Sultana, Hossain and Pervin, 2012). Pregnant women and children are at risk of adverse effects from exposure, a case control study conducted on women of child-bearing age, individuals with malnutrition had more severe effects from arsenic exposure than those of good nutritional status (Milton et al., 2010). Tobacco smokers exposed to arsenic had an increased risk of morbidity and mortality from cardiovascular disease and cancers (C. L. Chen et al., 2010; J. W. Chen et al., 2011). Arsenic exposure in adult life is not only a concern in the development of cardiovascular diseases but also experimental studies have shown a risk of development of the same in the future when there is in utero exposure to a fetus (Srivastava et al., 2007).

b) Cadmium

Cadmium (Cd) is ranked as the 7TH most a toxic metal among other metals (ATSDR, 2012). Its systemic toxic effects mostly targeted in the kidney resulting in renal dysfunction. Severe renal damage and bone destruction has been associated with long term exposure; a syndrome termed 'itai-itai disease identified in women in Japan who consumed contaminated food (rice) and water (World Health Organization, 2010). Due to its carcinogenic effects to the renal and respiratory system the International Agency Research Council (IARC) has categorized it as a group 1 carcinogen (ATSDR, 2012).

Exposure, Metabolism and Toxicity

Exposure is through consumption of contaminated food or water, inhalation through polluted air or occupational exposure in industries. The main route of exposure is inhalation especially from cigarette smoking (WHO, 2011a). Acute toxicity through ingestion causes stomach irritation resulting in abdominal pain, nausea, vomiting and diarrhea. In severe cases due to slow excretion and long term exposure results in accumulation primarily in the kidney causing oxidative damage once it binds to cysteine-rich proteins such as metallothionein, this mechanism is linked to different chronic effects (ATSDR, 2012).

Effects increase with age due to the progressive accumulation of cadmium in the renal cortex (Pan et al., 2010). Females generally absorb larger amounts of cadmium in the gastrointestinal tract than males. Cigarette smoking is a source of cadmium and smokers are more susceptible to cadmium intoxication than non-smokers (Jaishankar et al., 2014a). Epidemiological studies have documented chronic exposure has been associated with developing diabetes, hypertension (Gallagher & Meliker, 2010) and chronic kidney disease (N. H. Kim et al., 2015). Cadmium has carcinogenic effects affecting mainly the lung followed by hematological system, the adrenal glands and the testes (H. S. Kim et al., 2015). Its effects on the fetal development with low birth weight as an outcome, has been studied in case-control studies of exposed mothers with low and high cadmium blood levels (Menai et al., 2012).

c) Lead

Lead (Pb) is a one of the most significant toxins of the heavy metals. Over the years the metal has been known to have its systemic effects manifest in three systems; hematological, renal and the nervous systems. Lead is a metal of public health concern because of the serious irreversible health effects in children affecting the brain and nervous systems (WHO, 2003c). The Institute of Health Metrics and Evaluation (IHME) estimated in the year 2013, lead exposure accounted for 9.3% of the global burden of idiopathic intellectual disability, 4% and 6.6% of the global burden of ischemic heart disease and stroke respectively (Forouzanfar et al., 2015). According to IARC inorganic lead compounds are considered as probable carcinogens (IARC, 2006).

Exposure, Metabolism and Toxicity

The inorganic forms are absorbed through ingestion by food and water, and inhalation**.** Lead distributes in soft tissues and bone once absorbed and interferes with mitochondrial oxidative phosphorylation and sodium, potassium, and calcium ATPase's of the cells.Acute toxicity is related to occupational exposure from manufacturing industries which make use of lead and is uncommon. Chronic toxicity is much more common and occurs at blood lead levels of about 40–60 micrograms per deciliter (μg/dL). It can be much more severe if not treated in time and is characterized by mental retardation, birth defects, psychosis, autism, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, brain damage, kidney damage and may even cause death (ATSDR, 2005).

Children absorb higher concentrations than adults from the source of lead and are thus more vulnerable to exposure. Epidemiological studies have alluded to an association with poor neurodevelopment evidenced by decreased intellectual quotient, progressive deafness, cognitive impairment and behavioral problems (Mason et al., 2014; Mazumdar et al., 2011; Min et al., 2007; S.

K. Park et al., 2010). Calcium and Zinc deficiencies enhance lead absorption and are common in children who are undernourished (Wu et al., 2011). Chronic exposure also results in dysfunction of the kidneys, liver, joints and interferes with hemoglobin synthesis causing anemia (Chandran & Cataldo, 2010; Vij, 2009). Adults have an increased risk of hypertension and subsequently cardiovascular disease (Navas-Acien et al., 2007).

d) Mercury

Mercury (Hg) is a ubiquitous environmental toxin ranked 3^{RD} as the most toxic substance on earth after arsenic and lead metals (ATSDR, 1999b). It produces a wide range of adverse health effects in humans which include the cardiovascular, hematological, pulmonary, renal, immunological, endocrine, reproductive, neurological systems and embryonic development (Jaishankar et al., 2014a). It has profound neurotoxin effects causing brain damage in adults and impaired neurological development in infants and children (WHO, 2013). According to the IARC methyl mercury has potential carcinogenic properties and is thus classified as a possible carcinogen group 2B while metallic and inorganic mercury as not classifiable carcinogens group 3 (International Agency for Research on Cancer, 2016b).

Exposure, metabolism and toxicity

Mercury is highly toxic to humans when consumed, inhaled, lightening creams and amalgam filled teeth (Guzzi & La Porta, 2008a). Exposure to elemental and inorganic mercury occurs to individuals through inhalation of vapors during industrial processes while methyl mercury is of particular concern because it can build up in certain seafood such as fish, shell-fish, swordfish and shark (Morais et al., 2012). Once elemental and metallic mercury are absorbed in the bloodstream, binds on sulfhydryl groups such as glutathione, or metallothionein on red blood cells or is transported suspended in plasma. Mercury undergoes catalase and peroxidase-mediated oxidation in red blood cells and tissues and is transformed into inorganic mercuric mercury (Hg^{++}) and mercurous mercury (Hg^{+}) (ATSDR, 1999b).

Mercury causes the release oxygen radicals that cause cellular damage on the cell membranes (Guzzi & La Porta, 2008b). Acute exposure is usually due to industrial accidents causing nausea, excessive salivation, difficulty in breathing, and blurred vision. Chronic exposure includes memory disturbance, hypertension, vision problems, hallucinations, tremors and personality changes. In infants born to exposed mothers it causes cerebral palsy, mental retardation, peripheral neuropathy and blindness (Bose-O'Reilly et al., 2010; Clarkson & Magos, 2006; J.-D. Park & Zheng, 2012). Excretion of elemental and inorganic mercury is through urine, neurological symptoms can occur when urine mercury concentrations are above 100 µg/L and levels of 800 µg/L or above can be fatal (Ye et al., 2016).

Limited epidemiological studies have documented adverse effects from Hg++ in drinking water as most studies focus on methyl mercury exposure. Organic mercury primarily affects the central nervous system (Hong et al., 2012c). Apart from the known neurological adverse effects of mercury exposure, cardiovascular diseases have been implicated. Chronic exposure causes increased inflammation, oxidative stress, smooth muscle and endothelial dysfunction; resulting in increases vascular resistance this subsequently leads to hypertension, cardiac arrhythmias and myocardial infarction (Houston, 2011).

Exposure to all forms of mercury is nephrotoxic, however Hg++ has the most severe effects (J.-D. Park & Zheng, 2012). Experimental studies on rats with mercury chloride led to glomerular dysfunction, rats with reduced renal mass had more severe effects than ones with normal renal mass. Similarly, individuals with reduced renal function from chronic diseases such as hypertension and diabetes are more susceptible to injury (Orr & Bridges, 2017). Studies on mercury carcinogenicity are inconclusive, renal cancer has been documented in experimental male rats (NRC, 2000). Individuals of special concern to mercury exposure are pregnant or lactating women and children due to the irreversible brain damage and developmental disabilities (ATSDR, 1999b).

2.5 Water challenges and Health in Informal settlements

Informal settlements are a consequence of high rates of urbanization with rural to urban migration of individuals in search of the elusive better education, employment and health (UN-Habitat, 2007). With a dense population, there is limited availability of water and water treatment services coupled with poor sanitation increasing groundwater pollution on available sources (Grönwall, Mulenga, & McGranahan, 2010).

Despite urbanization improving most countries' economies in the world, rapid urbanization has contributed to a rise in a number of health conditions (WHO, 2010b). This is due to poverty, environmental deterioration, and population needs that surpass service capacity. These changes have an implication on the emergence of NCDs (World Health Organization, 2007). Developing countries suffer more than developed countries with a projected 67% of deaths attributable to NCDs by 2020 (Abdesslam Boutayeb, 2005).

Urbanization has been key in contributing to the increased prevalence of CVDs and persons of low socioeconomic status being more likely to suffer from this burden (Di Cesare et al., 2013). Some the cities in world with high rates of urbanization like China, India and Nigeria have been documented increased prevalence of these chronic diseases (Ekezie et al., 2011; Gupta, 2016; Van de Poel et al., 2009). Developing countries in SSA are experiencing a double disease burden of communicable and NCDs, with cardiovascular diseases becoming the leading cause of NCD mortality (Boutayeb, 2006).

Contrary to belief that some chronic diseases such as hypertension are for the affluent alone, a study investigating prevalence of hypertension in a Kenyan informal settlement reported a high prevalence (Joshi et al., 2014). A high prevalence of hypertension with low rates of awareness among urban slum dwellers in a Kenyan informal settlement was documented (van de Vijver et al., 2013a).

Water supply and ultimately the quality is linked to income levels and the household location this is a reflection of inequalities in water and sanitation services between the rich and the poor (UNICEF/WHO, 2011). Majority of these individuals use water without any treatment from contaminated groundwater this predisposes them to illnesses (Zingoni et al., 2005). When heavy metal contaminated water is used for both cooking and drinking this increases the dose of exposure to an individual (Pal et al., 2009). In the USA in the few areas using groundwater, private well owners are responsible for water tests however studies have shown that, those with low levels of education and low levels of income are less likely to have their water tested for contaminants (J. Postma et al., 2011).

From SSA countries utilizing groundwater sources like wells and boreholes, individuals using these sources deemed the water to be safe based on the physical appearance and treatment of water is not a common practice in most households (Kioko & Obiri, 2012; Pavelic et al., 2012). In other regions, individuals perceive improved water sources such as stand pipes with chlorinated water alters the water taste and has an odor resulting to use of groundwater as an alternative (Hunter et al., 2010b). Water treatment options practiced in Africa are boiling, however most chemical contaminants are rarely eliminated, unlike bacterial contaminants (Unicef, 2008). In areas with endemic heavy metal contamination such as India, treatment options include use of chelating agents for ion exchange or remediation. This can be practiced at household or community level (Sarkar et al., 2005).

Chemical water contamination occurs by certain practices in the community through over use of pesticides especially in close proximity to water sources which contaminate soils and result in percolation (Agrawal et al., 2010; Borah et al., 2009). Open sewers, septic leakage and landfills in informal settlements are other potential sources of contamination of groundwater sources (Ede, 2011). An environmental study in Nigeria analyzed arsenic levels in both surface and groundwater sources, industrial pollution, refuse and oil dumps were noted as sources of pollution to rivers and consequently high arsenic levels in boreholes close to the rivers (A. C. C. Ezeabasili et al., 2014).

2.6 Conclusion

Exposure to heavy metals through consuming contaminated water is a public health problem. Based on the literature review, studies have shown that chronic exposure to heavy metals through drinking water are responsible for multiple health effects, particularly NCDs like cancer, cardiovascular diseases, renal disease and neurological conditions. This is of concern as chronic diseases contribute to a high morbidity and mortality burden, in particularly to developing countries where populations suffer a double burden of diseases. Secondly, unlike the infectious conditions chronic diseases are not easily treated and those treatable, the procedures and costs are extremely high.

Groundwater sources are considered a solution to the water supply challenges in informal settlements, due to its readily available and inexpensive nature. However as with poor water quality monitoring and close proximity to the cities with high anthropogenic activities this increases groundwater contamination to high levels of especially heavy metals. Heavy metal contaminated sources in addition to other socioeconomic risk factors among the residents' places this population at risk to chronic diseases. Evidence linking heavy metals contamination of groundwater to various chronic diseases, has been documented in a number of regions of the world (Gallagher & Meliker, 2010; X. Li et al., 2013b; Rodríguez-Lado et al., 2013b).

Low income areas, typically informal settlements where unimproved water sources are used for drinking water and also for irrigation purposes are posed with a double dose of heavy metal exposure. Despite ongoing efforts to address communicable diseases in this population, there is need to recognize heavy metal related chronic diseases as a public health concern. Population awareness to chemical contamination of drinking water sources and other risk factors related to NCDs is wanting and should be integral in the process of mitigating health effects if we are to meet the global targets set to reduce NCDs by 25% by 2025.

Unplanned housing, close proximity to anthropogenic activities, poor waste and disposal systems in informal settlements within cities, increase vulnerability of groundwater to heavy metal contamination. Heavy metal exposure through the drinking pathway among other socioeconomic risk factors places residents in informal settlements at risk of various heavy metal related effects.

CHAPTER THREE

METHODOLOGY

3.1 Study area

The study was carried out in Kisumu East Sub-County, Kisumu County. Kisumu East Sub-County is approximately 9km from Kisumu City. It lies between longitudes 34˚43’ E and 34˚48’ E and latitude 00˚20’ South and 00˚80’ South and covers a total area of 144.9km2. The county borders Aldai Constituency to the North, Nyando to the East, Muhoroni to the North East, Kisumu Town to the West and Lake Victoria to the South. The study area included the settlements of Obunga, Manyatta B, Otonglo, Kogony, Mbeme, Kanyamedha, Kibos and St. Pauls in Kisumu East sub-county, Kisumu County (Figure 2).

The population of Kisumu East by the Kenya National population and Household census of 2009 was 150,124 with a total of 44,290 households. About 60% of the population in Kisumu County live in informal settlement majority of the population is housed in peri-urban and extended area settlements. Housing in informal settlements is congested with most households lacking access to reliable piped water. In areas without piped water, residents use rainwater and groundwater to supplement. Groundwater is obtained through shallow hand-dug wells that ae private owned or through springs which are communal

Geographically the study area lies on a high-water table with tertiary volcanic rocks comprising the geology of the area which is overlain by recent alluvial deposits and soil composed of sands, clays and gravel. The influence of faults, joints and other fractures on groundwater in the study area is two ways. They act as drainage channels of groundwater flow and also as aquifers in the area. Kisumu has two rainy seasons-from March through June, and November through December.

In Kisumu County mixed farming systems predominate; with few farmers cultivating sugarcane and rice for commercial purposes under mono-cropping systems. In the study area, peri-urban settlements practice subsistence farming while in the urban settlements few to no households had farms.

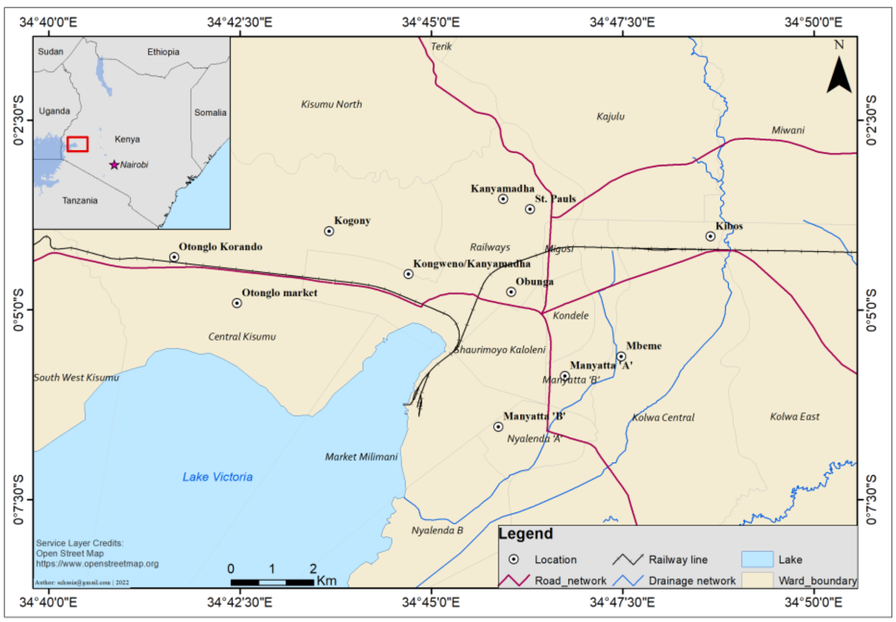

Figure 2: Map of settlements in Kisumu East

3.2 Study Design

This was a cross-sectional study conducted in the months of December 2017 to May 2018 in both urban and peri-urban informal settlements of Kisumu East, Kisumu County. The design was chosen since it was meant to determine prevalence of chronic diseases among residents using groundwater in informal settlements of Kisumu East. The design was ideal so as to carry out a health risk assessment in relation to use of heavy metal contaminated water by residents.

A reconnaissance survey was conducted in 2017 to identify, map and sample groundwater sources in the study area.

3.3 Study Population

The study population was comprised of both households and groundwater sources. Households in the selected informal settlements relied on groundwater sources for drinking and other domestic needs. The settlements in the study were from five sub-locations within Kisumu East. Administratively the settlements were in Kanyakwar, Korando, Kogony, Kolwa West and Central sub-locations. Distribution of households are represented in Table 2 below.

Table 2: Distribution of households in administrative sub-locations of Kisumu East

Sub-location	Households
Kanyakwar	3,553
Kogony	5,164
Korando	1,367
Kolwa west	7,808
Kolwa Central	4,880
Total	**22,772**

(KNBS, 2010).

Peri-uban settlements were characterized by; low population, majority owned residential housing, presence of agricultural activities and majority accessed their water supply from groundwater with few connected to the Kisumu Water and Sanitation Company (KIWASCO) due to poor road network access. Urban settlements were characterized by; Presence of slums with poorly constructed informal housing, communal toilets, poorly managed waste water and solid wastes, fairly high population and overcrowding, rental housing, inadequate and poorly managed piped water supply distribution therefore mainly used groundwater to supplement water needs.

The 37 groundwater sources sampled, receive recharge from Nandi Hills and Mau Hills which are to the east of Kisumu County. The flow is from the highlands in the east downwards to west towards the lower areas to the west of Kisumu County. The sources in the study included wells, boreholes and springs (Table 3).

Table 3: Distribution of groundwater sources against the settlements in the study area

Settlement	Type of groundwater source	No. of sources sampled
Manyatta B	Borehole	1
	Wells	4
St. Pauls	Spring	1
Otonglo	Wells	7
Kanyamedha	Wells	4
	Springs	1
Obunga	Wells	5
	Springs	2
Kibos	Wells	3
	Borehole	1
Kogony	Wells	6
Mbeme	Wells	3
Total		37

3.3.1 Inclusion and Exclusion criteria

Households enrolled in the study consisted a unit where:

i. the household head gave consent for the household members (adults and children) to participate,

ii. the household head was from the area of study and above 18 years of age,

iii. the household was using groundwater as a primary or alternative water source,

iv. household members should have lived in the area for at least one year, because typically risk of chronic toxicity effects to heavy metal occurs months to years of exposure.

Those excluded were:

i. temporary residents in households who used the groundwater source for less than 6 months

ii. non-consenting respondents.

iii. Households not using groundwater.

3.4 Variables

3.4.1 Independent variable

Probable health risk from chronic exposure to groundwater contaminated with select heavy metals

3.4.2 Dependent variables

1. Select heavy metal concentration and speciation.
2. Socio-demographic factors (age, sex, education, income, type of settlement).
3. Average consumption and duration of exposure to contaminated water.
4. Groundwater sources (borehole, shallow well, spring).

3.5 Sampling

3.5.1 Sample size determination

The sample size was determined by the formula for proportions in prevalence studies (Krejcie & Morgan, 1970).

$$n = \frac{Z^2\, p(1-p)}{e^2}$$

Where:

n=desired sample size.

Z²=standard normal deviate at 95% confidence level (1.96)

P= 36 % proportion of the households in informal settlements using groundwater for drinking and domestic use (Okotto et al., 2015a)

e²= margin of error 5%

$$n = \frac{1.96^2 \times 0.36(1-0.36)}{0.05^2}$$

n= 355

3.5.2 Sampling Procedures

Household sampling procedure

The 355 households were selected from urban and peri-urban informal settlements in the study area. Stratified random sampling was used where the five administrative sub-locations formed the strata, where the households were proportionately selected according to the population in the sub-locations (table 4). Households in each sub-location were then selected through simple random sampling method in the eight informal settlements. Only households using groundwater sources were interviewed.

Table 4: Determination of sample size in Kisumu East sub-locations

Sub-location	Determinant	Sample size
Kanyakwar	3553/ 22772 *355	55
Kogony	5164/22772 *355	81
Korando	1367/22772 *355	21
Kolwa west	7808/22772*355	122
Kolwa Central	4880/22772 * 355	76
Total		355

Groundwater sources sampling procedure

The 37 groundwater sources were mapped and included; boreholes, springs, shallow and deep hand dug wells in the study. The selected sources were through convenience sampling from previous reconnaissance in the study area. Most of the sources were communal with few private wells. Table 5 below illustrates the distribution of groundwater sources sampled in both urban and peri-urban with the settlement type and location.

Table 5: Informal settlements and number of groundwater sources sampled in corresponding households in Kisumu East County

Settlement Type	No. Groundwater sources	Settlement Location	Household Sample size
Urban	11	Manyatta B	41
		Obunga	13
Peri-urban	27	Otonglo	32
		Kanyamedha	61
		Kibos	35
		Kogony	62
		St. Pauls	71
		Mbeme	40
Total	**37**		**355**

3.6 Data Collection, Instruments and Methods

Data was collected between 8 am and 4 pm on both weekdays and the weekend by the principal investigator and trained research assistants. To maximize on the response rate households that did not have occupants were revisited on a later time of day or non-eligible head of household was present at the time of interview. The researcher administered a questionnaire to the head of the household and body measurements were taken of all household members. The first and subsequent households were selected from the mapped groundwater sources. All households meeting the inclusion criteria were interview in a systematic house to house method until the allocated households for each settlement were exhausted. Water samples was collected from groundwater sources used by the households.

3.6.1 Household Collection Methods

From the study it was necessary to identify the population in the settlements using the potentially heavy metal contaminated groundwater. A questionnaire was used to collect data capturing the socio-demographic details of the individuals in each household using ground water and their anthropometric measurements (Appendix I). In addition, the questionnaire captured information on type of water source used for drinking and domestic use as an indicator of supply, water treatment methods were indicators of the quality of the drinking-water used in the household. Finally, the exposure assessment to heavy metals through oral ingestion from groundwater sources was obtained by probing household members on duration of groundwater use, frequency and quantity of drinking water. The response rate for participating in the questionnaire was 100%.

3.6.2 Water Collection Methods

Water samples were collected from 37 groundwater sources where respondents reported to have used in the month of May which is within the rainy season of the study area. Sample collection, preservation and storage was followed by approved methods as outlined by Environmental Management and Coordination Act (EMCA). A clean non-sterile 250ml plastic polyethylene used as this was a non-bacteriological study, additionally it was easier to handle the bottles during sample collection and transportation compared to glass bottles. The water samples were drawn using a clean container from the groundwater source. The sample container was rinsed using the same water before filling to the brim. Samples from each source were drawn in duplicate with one container preserved with one drop 10% nitric acid, sealed and labelled. Acidification with nitric acid was necessary to avoid precipitation and keep the metals dissolved. The sample bottles were then stored in ice-packed cooler boxes between 1º C to 4º C and transported the laboratory in Kenya Plant Health Inspectorate Service (KEPHIS) for analysis (Environmental Management and Coordination Act, 1999). During sample collection four physiochemical properties of the water samples were measured and recorded namely; Temperature, PH, Conductivity and turbidity using a portable HydroLab Quanta Multi-parameter water quality meter.

3.7 Data Processing and Analysis

3.7.1 Data analysis

Data from the household questionnaires was coded and checked for completeness prior to entry into excel. The data was then transferred for analysis to Statistical Package for Social Sciences (SPSS) software version 20 for analysis. The Significance level was set at 5%. Descriptive statistics included frequencies, proportions, means, and standard deviations. Tests of association between variables was done using Chi-square and Analysis of Variance (ANOVA) to analyze for differences between and within groups of means.

3.7.2 Laboratory Water Analysis

Heavy metal analysis was processed at KEPHIS in the month of August 2018. The following specific metals species was analyzed As^{+++},Cd^{++} ,$Pb^{++} and\ Hg^{++}$. Preparation and analysis of the samples followed the protocols using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) where series dilutions made from all heavy metal standards and duplicate samples from each sample ran during analysis for data quality purposes as described by (APHA, 2012). Certificate of analysis and quality control reports of all samples analyzed was issued by the Bureau of Standards, Kenya.

3.7.3 Health Risk Assessment

The health risk assessment was conducted following method of estimating the potential health risks from exposure to heavy metals. The assessment was evaluated for both adults and children from all the 355 households for potential health risks. A total of 1316 household members were included in the assessment where the household member’s water intake and anthropometric measurement were captured. This assessment was multi-staged comprising data collection, exposure assessment, toxicity assessment and risk characterization.

a) Exposure assessment: To estimate the daily exposure dosage through ingestion pathway, United States Environmental Protection Agency (USEPA) suggests the average daily dose (ADD) as the exposure metric. The following is a similar representation of daily exposure route modified from USEPA (US EPA, 1992) and adopted in studies assessing the health risk from exposure to heavy metals in drinking water (Kavcar et al., 2009b; Maigari et al., 2016)

$$CDI = \frac{C_s \times IR}{BW}$$

Where the chronic daily intake (CDI) is the average daily dose of each metal through ingestion pathway (mg/kg/day), C_s is the concentration of heavy metal in water (mg/L), IR is the daily intake rate of water (L/day) and BW is the bodyweight (Kg),

b) Risk Assessment: The carcinogenic and non-carcinogenic risks of heavy metals are assessed according to the guidelines in the Risk Assessment Guidance for Superfund of the US Environmental Protection Agency (EPA). According to the categories of heavy metals arsenic and cadmium are grouped as a potential carcinogen risk while lead and mercury have non-carcinogenic risks (USEPA, 2001).

c) Non-Carcinogenic Risk Assessment: Potential non-carcinogenic risks was evaluated by comparing the exposure dose of the chemical contaminants according to water ingestion as the exposure route and with the corresponding reference dose (RfD) giving a resultant hazard quotient (HQ) for each heavy metal.

$$HQ = \frac{\text{CDI}}{RfD}$$

Where RfD was the reference dose of heavy metals in a given condition (mg/kg/day), the reference dose was obtained from USEPA's Integrated Risk Information System guidelines (USEPA, 2013).

d) The hazard index (HI) estimates health risk from more than one contaminant. The THI is the sum of the hazard quotients for all heavy metals. It assumes that the magnitude of the adverse effect will be proportional to the sum of multiple metal exposures (USEPA, 2013).

$$THI = \sum HQ = HQ_{As} + HQ_{Cd} + HQ_{Pb} + HQ_{Hg}$$

Interpretation of the health risk assessment of the heavy metals will be based on the values of HQ and THI. Values less than 1 for HQ or THI means no risk and the greater the values above one, the greater is the risk level of the heavy metals manifesting long term health hazard effects.

e) Carcinogenic Risk Assessment: The carcinogenic risk of chemical contaminants is usually expressed by a carcinogenic risk factor, CR

$$Risk = (ADD \times SF)$$

Where SF is the carcinogenic slope factor (µg/kg/day). The calculated value of CR is the cancer-developing probability of any type of carcinogenic chemicals over a life time exposure for a general population. The slope factor and reference dose will be obtained from similar studies (USEPA, 2013). According to the USEPA's guidelines for acceptable carcinogenic risks, the range of the CR value is from 10−6 to 10−4. If CR < 10-6, cancer risks are considered to be negligible; however, CR > 10−4 cancer risks are considered as unacceptable.

3.8 Minimization of Errors

Four research assistants were trained on data collection techniques to avoid observer bias while administering the questionnaires. The questionnaire was pre-tested in Bandani informal settlement with a convenient sample of individuals in Kisumu North sub-county prior to commencing the actual study. Revisions were made on the questionnaire where questions were unclear to the respondents. Data quality was controlled in the field by the principal investigator randomly checking questionnaires for completeness and personally carrying out the water sample collection. Recommended procedures for water sample collection and storage by EMCA were followed to minimize pre-analytical errors.

3.9 Study assumptions and limitations

Limitations of study included;

i. Generalizing the heavy metal concentrations to regions of the country may be a challenge due to variations in geological aquifer characteristics,
ii. Financial constraints limited having a larger sample size of sampled and ability to conduct a larger study that would determine the seasonal variations of the heavy metal concentrations,
iii. Estimating water intake was subject to recall bias by the respondents during exposure assessment,
iv. Lastly, the hostile reception in the urban settlements resulted in under representation of the area.

The assumption was; the eight informal settlements was an adequate representation of the target population to the entire Kisumu County.

3.10 Ethical Considerations

Study approval was sought from Kenyatta National Hospital/ University of Nairobi Ethics and Research Committee (KHN/UoN ERC) and National Commission for Science, Technology and Innovation (NACOSTI). Administrative consent was sought after proper protocol channels were observed from Kisumu County water and health departments. Participation was voluntarily and written informed consent was obtained from all eligible respondents to take part in the study. Confidentiality was maintained by coding for anonymity in both consent and questionnaire form.

CHAPTER FOUR: RESULTS

4.11 HEAVY METAL CONCENTRATIONS

4.11.1 Concentration levels of heavy metals and recommended levels

Heavy metal concentrations of Arsenic, Cadmium, Lead and Mercury were determined from a sample of 37 mapped ground water sources. The groundwater sources included 30 shallow wells, 5 springs and 2 boreholes. Majority of the groundwater sources were from the peri-urban area (70 (n=26)) while the other (30% (n=11)) were in the urban area. Some of the water sources were protected (73% (n=27)) and others unprotected (27%(n=10)). The order of occurrence of the heavy metals after analysis was as follows Arsenic>Cadmium>Lead>Mercury.

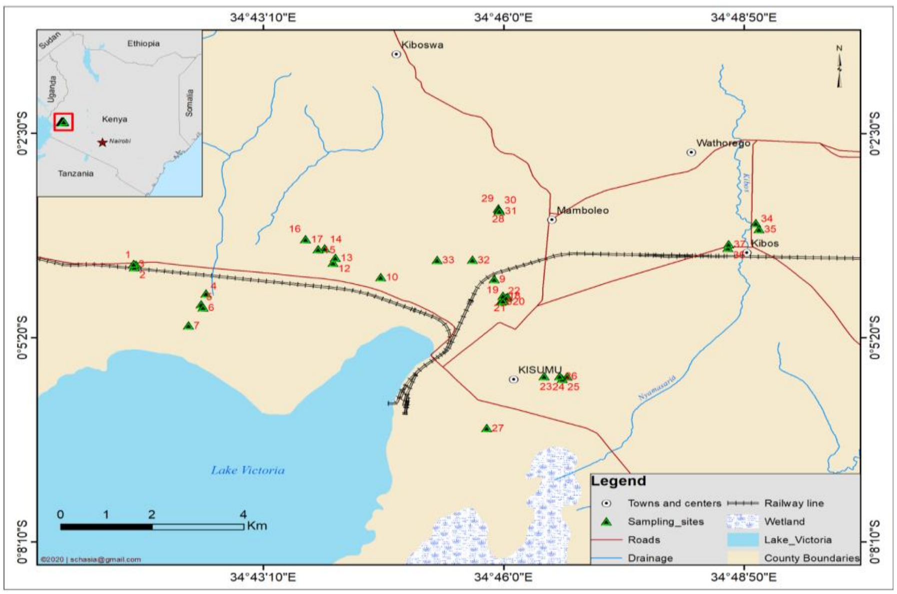

Figure 3: Map of the sampled groundwater sources in the settlements within Kisumu East

The detection frequency for Arsenic (As) was (100% (n=37)) in the ground water sources. The levels ranged from 0.01 to 3.72 µg/L with a mean of 0.27 µg/L, with the highest concentration being3.72 µg/L recorded in a protected borehole (sample 27) and the lowest was 0.01 µg/L from a protected shallow well (sample 22). Detection frequency for Cadmium (Cd) was 97% (n=36), where the levels ranged from 0.01 to 0.12 µg/L with a mean of 0.03 µg/L in the sampled groundwater sources. The highest level was 0.12 µg/L recorded from a spring (sample 11).

On the other hand, the detection frequency for Lead (Pb) was 24% (n=9). The levels were from Below Detection Limit (BDL) to 0.26µg/L with the mean concentration being 0.03µg/L. Lead was detectable in two of the five springs, the highest level being in a shallow well 0.48 µg/L (sample 7)

Mercury (Hg) had the least detection frequency at 14% (n= 5) with concentrations ranging from BDL to 0.48 µg/L, and a mean of 0.02µg/L. Mercury was only detected in shallow wells. The highest levels were detectable in shallow well 0.26µg/L (sample 2). These findings are shown in Table 6 and Appendix V.

Table 6 Mean, S.D and range of heavy metals concentrations by groundwater sources.

		Metal concentration levels µg/L (micrograms/L)	
Groundwater source n=37	**Heavy metal**	**$\bar{x}$ ± SD**	**Range**
Shallow wells			
	Arsenic	0.17±0.16	0.01-0.75
	Cadmium	0.02±0.01	0.01-0.05
	Mercury	0.03±0.07	0-0.26
	Lead	0.02±0.09	0-0.48
Springs			
	Arsenic	0.1±0.09	0.03-0.25
	Cadmium	0.06±0.04	0.03-0.12
	Mercury	-	-
	Lead	0.07±0.14	0-0.32
Borehole			
	Arsenic	2.11±2.28	0.5-3.72
	Cadmium	0.06±0,02	0.04-0.07
	Mercury	-	-
	Lead	0.01±0.01	0-0.02

$\bar{x}$ = Mean, **S. D**=Standard Deviation

All the four heavy metals analysed in the groundwater sources were within WHO and KEBS recommended limits, these findings are summarized in table 7 below.

Table 7: Heavy metal concentrations in sampled ground water sources against WHO and KEBS recommended levels

	Metal concentration levels µg/L (micrograms/L)			
	Arsenic (As)	**Cadmium (Cd)**	**Mercury (Hg)**	**Lead (Pb)**
Mean	0.27	0.03	0.02	0.03
Median	0.13	0.04	0	0
Std. Deviation	0.60	0.02	0.060	0.10
Range	3.71	0.11	0.26	0.48
Minimum	0.01	0.01	0	0
Maximum	3.72	0.12	0.26	0.48
WHO	**10**	**3**	**10**	**1**
KEBS	**50**	**5**	**50**	**1**

(Gorchev & Ozolins, 2011; WASREB, 2008)

4.1~~1~~.2 Physiochemical properties and recommended levels

Physiochemical properties were recorded from all (N=37) the water samples collected. The mean pH level was 6.89 where 84% (n=31) water sources were within range of WHO limit of 6.5-8.5 except 16% (n=6) of the shallow wells water had low pH value ranging 6-6.4. The mean temperature level was 26.85°c where (100%) n=37 of the water source sampled were within range of WHO limit 25-30. Turbidity mean levels were 0.33 NTU where 100% (n=37) of the sampled water sources were within the WHO limit of 5.0 NTU. The mean conductivity levels were 0.66 mS/cm and (100%) n=37 sources were within the WHO recommended level not exceeding 40 mS/cm. These findings are represented in Table 8.

Table 8: Physiochemical properties of groundwater sources sampled against recommended WHO limits

	Temp (°c)	PH	Conductivity (mS/cm)	Turbidity (NTU)

Mean	26.85	6.89	0.66	0.33
Median	26.70	6.72	0.52	0.26
Std. Deviation	1.10	0.58	0.48	0.24
Range	4.30	2.26	2.50	1.25
Minimum	25.10	6.00	0.12	0.06
Maximum	29.40	8.26	2.62	1.31
WHO	**25-30**	**6.5-8.5**	**40**	**5**

(WHO, 2011b)

4.2~~2~~ SOCIO-DEMOGRAPHIC CHARACTERISTICS OF HOUSEHOLD MEMBERS USING GROUNDWATER FOR DRINKING AND DOMESTIC USE.

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The 355 households interviewed had access to both surface water and groundwater. The households were both from urban; 24.2%, (n=86) and peri-urban; 75.8%, (n=269) areas. The households' sociodemographic characteristics, that included water use and water treatment options were captured. The mean duration of stay at the residence was 9.6 years, with a minimum and maximum duration of 1 year and 78 years respectively. The households had a mean size of 4.2 members. Majority of the household heads were 75%, (n=283) males and 25 %, (n=72) were females. From the n=335 households that provided information on total monthly income, 45.9% (n=163) of the households were in the income bracket equal to and above Ksh 8,000 while 54.1% (n=192) were below Ksh 8,000. There was no statistical difference between the amount of income earned in the household and the household settlement location ($\chi 2$=2.050 p-value=0.726).

A total of 1316 household members from the 355 households had their anthropometric measurements, water intake and health status recorded on the questionnaire administered. Among these, 52.8%, (n = 695) were females and 47.2 %, (n=621) were male. The distribution of ages was the minimum age being 1 month old and the maximum was 90years. The mean and median age was 22 years and 21 years respectively. For the vulnerable population; 16.3% (n=208) were children under 5 years, while pregnant/lactating women and the elderly were 4% (n= 52) and 3.4%, (n=44) respectively. From n= 1316 members those asked about their marital status were above 18years. The distribution was as follows 64.7%, n=852 were not married where 41%, n=349 accounted for members under 18years, never married 50.2%, n=428, widowed 6%, n=51, divorced 5%, n=4 separated 2.3%, n=20.Those married accounted for 48%, n=464.

From n=1316 of the household members more than half of the members had none and incomplete education levels 25%, n=150 and 75%, n=559 respectively. Those with complete primary, complete secondary education and college/ university were 20.7%, n=118, 39.2% n=224 and 40.1%, n=229 respectively. Those with none and incomplete education were ≤5years 28% n=208, 6-12 years 29% n=215, 13-24 years 23.4% n=174, 25-59 years 17.3% n=129 and Elderly 2.3% n=19.

Of the 342 individuals with completed primary/secondary education; 55.6%, (n=190) were females and 42.4%, (n=145) were males. Of the n=229 with college/university education, 54.6%, n=125 were males and 45.4%, n=104 were females. There was a statistically significant difference across the various levels of education and the gender of household members ($\chi2$ = 13.42, p value=0.009). This is represented in Table 4 below.

The occupation of n=1316 of household members was as follows: their occupation as follows; Student 32.1% n=423, employed 14% n=184, Self-employed 20.3% n=267, Unemployed 32.4% n=426 and retired 1.2% n=16. The proportion of members in student category were in the age groups of; 6-12, 13-24 and 25-59 was as follows; 43.4% (n=185),51.2% (n=218) and 5.4% (n=20).

The following age groups were in the employed category 13-24, 25-59 and ≥60years was as follows; 8.7% (n=16), 89.1% (n=164) and 1.6% (n=3) respectively. Those self-employed were in age groups 6-12, 13-24,25-59 and ≥60years were as follows 1.1% (n=3), 9% (n=24), 84.3% (n=225) and 35.7% (n=15) respectively. Unemployed members were in age groups <5years, 6-12, 13-24,25-59 and ≥60years were as follows 49% (n=208), 8% (n=34), 19.2% (n=82), 16.2% (n=69) and 10.4% (n=33) respectively. There was a statistically significant difference across categories of occupation and the gender of household members ($\chi 2 = 80.403$, p value<0.000), this is represented in Table 9 below.

Table 9: Sociodemographic characteristic of households using groundwater in Kisumu East

Variable	Values	N (%)	p value (Chi test)
Settlement[1]	Urban	86 (24.2%)	p=0.726 household income
	Peri-urban	269 (75.8%)	
Household head gender[1]	Male	283(75%)	
	Female	72(25%)	
Gender[2]	Male	625(47.2%)	P<0.000* occupation
	Female	691(52.8%)	p=0.009* education
Age[2]	≤5 years	206(15.7%)	
	6 to 12 years	241(18.3%)	
	13 to 24 years	345(26.2%)	
	25 to 59 years	480(36.3%)	
	≥ 60 years	44(3.3%)	
		Mean 21years	
Marital status[2]	Married	464(35.3%)	
	Not married	852(64.7%)	
Education[2]	None	186(14.1%)	
	Incomplete primary/secondary	559(42.5%)	
	Complete primary	118(9%)	
	Complete secondary	224(17%)	
	College/ University	229(17.4%)	
Occupation[2]	Student	423(32.1%)	
	Employed	184(14%)	
	Self employed	267(20.3%)	
	Unemployed	426(32.4%)	
	Retired	16(1.2%)	
Income[1]	Below Kshs. 2000	25(7%)	
	Kshs. ≥2000-5000	70(19.7%)	
	Kshs. >5000-8000	68(19.2%)	
	Kshs. > 8000-11000	71(20%)	
	Above Kshs. 11000	121(34.1%)	

Where; n^1=Number of Households (355), n^2= Number of household members (1316)

4.32 HOUSEHOLD WATER SOURCE, AVAILABILITY, CONSUMPTION AND TREATMENT

Household's water source, its availability, consumption and treatment option in the n=355 households was determined. This was important since the water treatment option, consumption rate influence the level of exposure to heavy metal contaminated water. The key findings are represented in Table 10. The results revealed that groundwater was used by 65.4 %, (n=232) of the households for domestic purposes; with 52.7% (n=187) using it for cooking. Respondents from the 355 households reported to get water for drinking from sources as follows; 67.9% (n=241) piped water, groundwater 26.5% (n=94) and others 5.6% (n=20).

The mean amount of water for domestic use and drinking in a household was 96.3 litres and 13.2 litres respectively whereby, the daily water intake for Children ≤17years and Adults≥18years was 0.92l and 1.51l respectively. On the availability of drinking water sources from the n=355 households; 54.9% (n=195) reported that water was not always available while 45.1% (n=160) reported it was always available. From n=355 about 29.2% (n=104) of the households used surface water consistently for drinking while 70.8% (n=251) of the households relied on groundwater as an alternative drinking water source as follows; shallow wells 63.7% (n=160), springs 26.3% (n=66) and borehole 10% (n=25). From the groundwater sources used for both domestic or drinking purposes, households reported that the sources were protected (73.2% (n=260)) and 26.8% (n=95) were unprotected.

Table 10: Water supply and use from households in Kisumu East

Variable	N(%)

Domestic water source	
Piped water	105(29.7%)
Ground water	232(65.7%)
River/Stream	9(4.5%)
Rain water	4(2.5%)
Local vendors	2(0.8%)
Water tanker	2(0.8%)
Other sources	1(0.3%)
Cooking water source	
Piped water	160(45%)
Ground water	187(52.7%)
Other sources	8(2.3%)
Drinking water	
Piped water	241(67.9%)
Ground water	94(26.5%)
Other source	20(5.6%)
Groundwater drinking source	
Bore hole	25(10%)
Hand dug well	160(5%)
Springs	66(26.3%)
Groundwater source	
Protected	260(73.2%)
Unprotected	95(26.8%)

We sought to establish if the household members were aware if the water they used was tested for contaminants and about (9.9%(n=35)) were aware, (76.2% (n=269)) were unaware and (13.9% (n=49)) unsure. More than half of the households (67.1% (n=237)) treated their water before consumption with the water treatment options are summarized in figure 4 below.

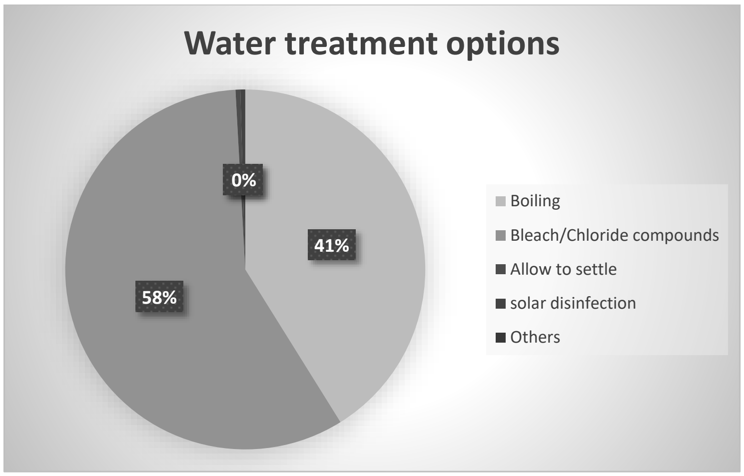

Figure 4: Water treatment options for informal settlements in Kisumu East

There was a statistically significant association between the type of informal settlement and the choice of water source for domestic use by households, choice of drinking water and type of groundwater source as an alternative drinking water source; ($\chi 2$=49.43 p-value $\leq$ 0.000), ($\chi 2$ = 44.11 p-value$\leq$ 0.000) and ($\chi 2$= 26.12 p-value $\leq$ 0.000) respectively as represented in table 11 below.

Table 11: Bivariate analysis of household water choices by type of settlement in Kisumu East

Variable	Values	Peri -urban	Urban	P value(Chi-test)
Domestic water source N=355	Piped water to house,	15(5.6%)	14 (6.3%)	
	Piped water to the yard	41(15.4%)	3(3.5%)	
	Piped standpipe	15(5.6%)	17(19.8%)	**p=≤ 0.000***
	Bore hole	28(10.5%)	17(19.8%)	
	Hand dug well	90(33.7%)	15(17.4%)	
	Springs	68(25.5%)	14(16.3%)	
	River/Stream	5(1.9%)	4(4.7%)	
	Rain water	2(7.0%)	1(1.2%)	
	Local vendors	3(1.1%)	0(0%)	
	Other sources	0(0%)	1(1.2%)	
Drinking water choice N=355	Piped water	186(70.5%)	55(65.6%)	
	Bore hole	2(0.8%)	5(6.0%)	**p=≤ 0.000***
	Hand dug well	19(7.2%)	6(7.1%)	
	Springs	55(20.0%)	7(8.3%)	
	River/Stream	0(0%)	7(8.3%)	
	Rain water	2(8%)	2(2.4%)	
	Other sources	0(0%)	2(2.4%)	
Groundwater drinking source n=251	Bore hole	12(6.0%)	13(25%)	
	Hand dug well	127(63.8%)	33(63.5%)	**p=≤ 0.000***
	Springs	60(30.2%)	6(1.5%)	

4.43 ANTHROPOGENIC ACTIVITIES INFLUENCING HEAVY METAL CONCENTRATIONS.

The identified point and non-point sources of contamination of groundwater sources from anthropogenic activities in the study area were as follows; From the n=355 households a few households had farms and used fertilizers while farming (29% (n=97)) about (90.9 %(n=321)) had a solid waste disposal sites within the compound while 9.1% n=34 had no disposal site.

The following items with a likelihood of having heavy metals compounds were disposed at the waste site within the compound; plastics (48% (n=153)), while metallic items including batteries were (5.3% (n=17)) in the waste disposal sites. The households got rid of the solid waste by burning (93.8 %(n=333)), burying (1.1% (n=6)), leaving in the open (2.3%(n=12)). Probable sources of heavy metals from disposing hazardous items in pit latrines included: sharp/broken items (60% (n=197)), expired fertilizer/chemicals (5% (n=33)), metallic items and batteries (10% (n=14)). The average distances between farms, solid waste sites and pit latrines were measured and the distances were 100metres, 10metres and 30metres respectively to the groundwater sources. Waste disposal sites were not within recommended distances to groundwater sources, where (80% (n=256)) of the households had waste sites at a distance of ≤5m, (15% (n=48)) at a distance of 6m to 9m while (5.2% (n=17)) at a distance of ≥10m. From the households disposing hazardous items in pit latrines, (84% (n= 204)) were distanced ≥ 30m from groundwater sources whereas (16% (n=40)) of the pit latrines were pitched ≤ 30m. Presence of anthropogenic activities and the recommended distances are summarized in table 12,

Table 12: Distribution of heavy metals sources from anthropogenic activities by households and recommended distances to groundwater sources by WHO

Anthropogenic activities	N (%)	X(m)	Recommended distance (m)
Fertilizer/Pesticide Use			
Household farm	42 (12.2%)	100	50
Neighbouring farms	55(16.8%)		
Items disposed at solid waste			
Metallic items and batteries	17(5.3%)	10	50
Plastic items	153(48%)		
Disposal of hazardous items in pit latrines			
Sharp/broken items	197(60%)		
Metallic items and batteries	33(10.2%)	30	15
Expired fertilizer/chemicals	14(3.9%)		

(WHO, 2008a) Where **n**=Number of households, **X**= mean, **m**=metres, % =percentages

Figures 5 to 7 below demonstrate observations made during the study regarding distances between point and non-point sources of heavy metals and groundwater sources.

Figure 5 below is a pictorial representation of an unprotected shallow well that had no lid cover and was in close proximity of less than 50m from a farm.

Figure 5: Groundwater source at high risk of contamination

Figure 6 below is a pictorial representation of a protected shallow well in close proximity by less than 50m from a farm. The well has a lid cover to prevent surface run-off accessing the water.

Figure 6: Groundwater source at minimal risk of contamination

Figure 7 below represents is a protected shallow well next to a pit latrine on the left.

Figure 7: Groundwater source at high risk of contamination

4.43.1 Heavy metal concentrations and associated factors in the study

This section presents the findings of the heavy metal concentrations in relation to the following factors: water source protection. type of groundwater, type of settlement and distance of anthropogenic activities to water source.

There was a statistical difference of the mean arsenic concentrations between protected (n=27) and unprotected (n= 10) water sources (T test=3.007, p value=0.003). Similar findings were noted in mean concentrations of Cadmium (T test=1.983, p value=0.048). There was however, no statistically significant difference in the mean levels between protected and unprotected sources for mercury (T test= 6.78, p value=0.23) and lead metals (T test= -0.938p value=0.349).

The mean concentrations of arsenic and cadmium were not statistically different in the type of settlements; Arsenic (T test=0.399, p value=0.692), cadmium (T test= 0.329, p value=0.744) and lead (T test=0.673, p value=0.606). On the other hand, there was a statistically significant difference between mean levels for mercury in the n= 9 samples between the two settlements; (T test=2.605, p value= 0.013). The detection frequency being higher in the peri-urban settlements.

There was no statistical difference in means for arsenic and lead between the distances from the farm and waste site to groundwater sources (T test=1.86, p value=0.06) and (T test=-2.98 p value=0.43) respectively. Cadmium means levels had a statistical significance between the acceptable distance from the pit latrine to the water sources (T test $p<0.000$). A difference was however observed in the detection of mercury between the acceptable distance from farm to the water source (T test=2.601, p value=0.000).

There was no statistical difference in mean levels between the type of groundwater sources for cadmium ($\chi2$=10.23 p value=0.07), mercury ($\chi2$ = 12.03, p value=0.45) and lead metal ($\chi2$= 6.23, p value=0.06).

Table 13 summarizes the mean levels and the various anthropogenic activities affecting heavy metal concentrations.

Table 13: Multivariable analysis of various factors against mean levels of heavy metals

Variable	Heavy metal concentrations $\bar{x} \pm$ SD (95% CI) Arsenic	Cadmium	Lead	Mercury
<u>Groundwater source</u>				
Shallow well	0.17 ±0.16 (0.01-0.52)	0.03±0.02(-0.05-0.32)	0.02± 0.01(0.02-0.3)	0.03± (-0.02-0.01)
Borehole	2.11 ±1.98 (0.5-3.72)	0.06±0.04(-0.02-0.01)	0.01±0. (0.01-0.1)	BDL(-)
Spring	0.1±0.09 (0.03-0.25)	0.06±0.05 (-0.04-0.08	0.07±0.05 (0.4-0.04)	BDL(-)
<u>Water protection</u>				
Protected	0.19±0.11 **(-0.01-0.06)***	0.03 **(0) ***	0.03±0.02 (-0.01-0)	0.12 (-)
Unprotected	0.15±0.10	0.03	0.04±0.02	0.12
<u>Anthropogenic activities</u>				
Farms &Waste disposal				
<50m	0.18±0.12 (-0-0.6)	0.03±0 (0-0)	BDL (-)	0.02±0 **(0-0)***
≥50m	0.15± 0.9	0.03±0	BDL	0.12±0
Pit latrines				
<15m	0.20±0.10 (-0-0.05)	0.03±0 **(0-0.01)***	BDL (-)	0.12±0 **(0-0)***
≥15m	0.17±0.11	0.03±0	BDL	0.12±0
<u>Settlement</u>				
Urban	**0.30± 0.19** **(-0.49-0.33)**	**0.03± 0.02** **(-0.02-0.01)**	**0.02± 0.07** **(-0.04-0.10)**	**BDL** **(0.01-0.09)***
Peri-urban	**0.22± 0.81**	**0.03± 0.03**	**0.04± 0.12**	**0.04±0.08**

*=Significant Difference, **CI** =95% confidence interval of the difference for T-Test for Equality of means**, BDL** = below detectable levels, $\bar{x}$ = Mean, **S. D**=Standard Deviation, **m**=metres.

4.54 HEALTH STATUS AND HEALTH RISK ASSESSMENT

From the 355 households interviewed a total of (n=1316) household members were recruited for the health risk assessment and their water intake and anthropometric measurements were documented. Majority of the respondents 96% (n=1266) did not experience ailments in the last six months that required them to attend scheduled hospital clinic visits or to be on medication for a similar duration. About 4% (n=50) of the respondents had a chronic disease which included hypertension (52% (n=26)); Diabetes (10% (n=5)); Skin conditions (8% (n=4)). Mental illness and Anaemia which accounted for 4% (n=2) others that were non specified included respiratory illness, joint/back pains accounted for 20% (n=10).

There was a statistically significant difference between the drinking water source and presence of chronic diseases(p=0.001). Children who were 6years and above used groundwater more than those under 5years (p=0.031). There was no statistical difference between the gender and the water source type or presence of chronic disease and type of settlement ($\chi2$=0.004, p value=0.146). The analysis of various variables from socio-demographic characteristics computed against drinking water source is represented on Table 14 below.

Table 14: Bivariate analysis of sociodemographic characteristics against drinking water source among household members in Kisumu East.

Variables /Values N=1316	Surface water	Ground water	P value (Chi-test)
Sex			
• **Male**	435 (48.9%)	190 (44.6%)	p=0.146
• **Female**	455 (51.1%)	236 (55.4%)	
Vulnerable groups			
Under 5years	149(16.7%)	57(13.4%)	
• **>6years**	697(78.3%)	344(80.8%)	**p=0.031***
• **Pregnant/lactating women**	33(3.7%)	17(4.0%)	0.459
• **Elderly>65years**	11(1.3%)	8(2.0%)	0.243
Chronic disease present	24(2.6%)	26(6.4%)	**p=0.001***

From the household members with chronic disease n=50 there was a statistical difference in the presence of chronic diseases between females n=33 than males n=17 ($\chi2$=4.08, p=0.05) and chronic diseases increased with age (p=0.001). The age group with the highest proportion of chronic diseases was 26-64years n=32. These findings are represented on Table 15 below.

Table 15: Bivariate analysis of sociodemographic characteristics against chronic disease status of household members in Kisumu East

Variables N=1316	Chronic disease absent	Chronic disease present	P value (Chi-test)_
Sex			
• **Male**	608(48%)	17(34%)	**p=0.05***
• **Female**	658(52%)	33(66%)	
Settlement			
• **Peri urban**	967(76.4%)	38(76.0%)	
• **Urban**	299(23.6%)	12(34.0%)	p=0.95
Age			
• **≤ 5years**	201(15.9%)	5(10.0%)	
• **6-12years**	237(18.7%)	4(8.0%)	
• **13-25years**	338(26.7%)	7(14.0%)	**p=0.001***
• **26-64years**	448(35.4%)	32(64.0%)	
• **≥ 65years**	42(3.3%)	2 (4.0%)	

4.54.1 Non-carcinogenic health risk analysis

From the results on exposure assessment the chronic daily intake (CDI) which is the average daily dose of each metal through ingestion pathway (mg/kg/day) was calculated using Equation 1 below. The C_s which is the concentration of heavy metal in water (mg/L), IR is the daily intake rate of water (L/day) and BW is the bodyweight (Kg)

1. Average concentration of the 4 metals separately in mg/l from µg/L; As=$2.7*10^{-4}$, Pb=$0.3*10^{-4}$, Cd=$0.2*10^{-4}$ and Hg-=$0.3*10^{-4}$

2. Average weight for Children ≤17 and adults≥18 was 29.39kg and 67.42kg respectively.

3. Average daily water intake for Children ≤17years and Adults≥18years was 0.92l and 1.51l respectively.

Equation 1: $CDI = \frac{C_s \times IR}{BW}$

The potential non-carcinogenic risks as indicated by the hazard quotient (HQ), was evaluated by comparing the exposure dose of the chemical contaminants according and with the corresponding reference dose (RfD as described in Equation 2. Non-carcinogenic risks include hypertension, diabetes, vascular diseases, neurological conditions.

Equation 2: $HQ = \frac{\text{CDI}}{RfD}$

The HQ for both adults and children is as summarized in table 16.

Table 16: Non-carcinogenic health risk assessment through drinking water for the select metals among adults and children of Kisumu East

Heavy metal	RfD (mg/kg/day)*10^{-3}	$CDI_{Adult*10-6}$	$CDI_{Child*10-6}$	HQ_{Adult}	HQ_{Child}
Arsenic	0.3	6.05	8.45	0.020	0.028
Cadmium	1	0.45	6.26	0.001	0.006
Lead	4	0.67	9.39	0.0002	0.0002
Mercury	0.5	0.67	9.39	0.0013	0.0019

The Total Health Index (THI) which is an estimate of the total potential non-carcinogenic health impact caused by exposure to the mixture of the metals in water, was computed using Equation 3 according to the EPA guidelines for health risk assessment (USEPA, 2013). HI values for children and adults were 2.25×10^{-2} and 3.61×10^{-2}, respectively

Equation 3: $THI = \sum HQ = HQ_{As} + HQ_{Cd} + HQ_{Pb} + HQ_{Hg}$

=0.048+0.007+0.0004+0.0032

$$THI = 0.0586$$

$$= 5.86 * 10^{-2}$$

THQ values for metals considered for children and adults' category was in the order As> Cd > Hg > Pb respectively.

4.54.2 Carcinogenic health risk analysis

In this section the probability of cancer risk was evaluated using the CDI and the cancer slope factor (SF) to determine the incremental likelihood of cancer risk (CR) over a life span, resulting from the exposure to a prospective carcinogenic element. According to U.S. EPA Arsenic and cadmium qualify as carcinogenic elements, the cancer slope factor is 1.5 mg/kg-day and 6.1 mg/kg-day for oral exposure respectively. The CR was computed using Equation 4 according to the EPA guidelines for health risk assessment (USEPA, 2013). A summary of the evaluation is represented on Table 17.

Equation 4: $CR = CDI * CS$

Table 17: Carcinogenic health risk assessment through drinking water for select heavy metals among adults and children of Kisumu East

Heavy metal	CSF (mg/kg/day)	CDI_{Adult} $*10^{-}$	CDI_{Child} $*10^{-6}$	CR_{Adult} $*10^{-6}$	CR_{Child} $*10^{-5}$	Total CR $*10^{-5}$
Arsenic	1.5	6.05	8.45	9.08	1.27	2.18
Cadmium	6.1	0.45	6.26	6.26	3.82	4.09

CHAPTER 5

DISCUSSION

5.1: Heavy metals concentration levels in groundwater sources

Generally, levels of arsenic in all 37 samples from the groundwater sources in study were within the normal WHO and KEBS permissible levels. The highest concentration was detected in a protected borehole in a school where farms, waste sites and pit latrines were within the recommended distances to the borehole. Similar findings have been found in boreholes sampled around agricultural and industrial zones of Nairobi (Kiplangat et al., 2021). In the study arsenic levels were within national recommended levels and noted to be lower in the wet season compared to dry season because of the water dilution of the aquifer (Kiplangat et al., 2021). Additionally, the levels could also be low due the volcanic black cotton soil composition that retains water for an extended period of time after the rains thus diluting the metal ions. There was no statistical difference of Arsenic concentrations between urban and peri-urban area. This could be attributed to groundwater sources being in the recommended distance to anthropogenic activities such as agricultural drains from arsenic based pesticides, disposal and incineration of municipal wastes that would be a source of Arsenic. Similar findings of mean differences in urban and peri-urban settlements were statistically insignificant in boreholes and hand dug wells of Wukari area in Nigeria (Oko et al., 2017). In Kenya high levels have been detected in Lake Victoria near gold mining areas (Makokha et al., 2012).

Cadmium mean concentrations were within the normal WHO and national acceptable levels of 3 µg/L and 5 µg/L respectively in the groundwater sources. Similarly, low levels of Cadmium have been reported in boreholes and hand dug wells (AJ Mohamed & M Kitwana, 2018) in Zanzibar. In the study most of the households did not practice indiscriminate refuse and waste disposal, have septic tanks or poor disposal of batteries and which would be sources of cadmium compounds.

The highest level that was within recommended limits was recorded in a protected spring, this finding is similar to a study from shallow groundwater sources peri-urban areas of Kampala City in Uganda (Bakyayita et al., 2019). From the study there was no statistical difference in means from the two settlements. Similar findings of no statistical difference in detecting Cadmium from wells between urban and peri-urban settlements have been reported in Nigeria (Ganiyu et al., 2021). From the study concentrations of cadmium appeared to be detected more in unprotected groundwater sources than protected, similar findings in a study in urban areas of Zaria City in Nigeria, reported concentrations above permissible levels in open boreholes and wells ranging from 1 to 280 μg/L (Musa et al., 2007). Alluded sources were from natural processes, increased indiscriminate effuse and waste disposal, septic tanks and combustion by-products from batteries and traffic.

From the 5 samples detecting lead metal all were within the normal WHO and KEBS permissible level of 1μg/L. Lead levels were detected in 24% (n=9) of the groundwater sources with the mean levels being 0.03±0.09 μg/L was detectable in spring water. The highest levels were detectable in shallow wells. Similar studies of Lead levels within WHO limit have been reported in residential hand dug wells in Nigeria (Elemile et al., 2021) as explained by lack of anthropogenic activities. In the study Lead contamination was at a minimum since use of pesticides and fertilizers in farms by households was not reported. In addition, the groundwater sources were within recommended distance from farms. Other sources of lead metal would be from industrial wastes into lakes and rivers that interact with aquifer water cycle to ground water (Jaishankar et al., 2014a) however in the study area industries were not near groundwater sources.

Mercury was the least detected metal in 14% (n=5) of the samples. The water samples with mercury had levels that were within permissible levels recommended by WHO and KEBS of

10μg/L and 50μg/L respectively. Mercury levels were detected more in unprotected sources compared to protected, similar studies comparing mercury levels in surface and groundwater sources such as boreholes found higher levels in Nigeria, which was attributed to surface run-offs (Ada et al., 2012; C. C. Ezeabasili et al., 2015). Gold mining areas such as Lake Victoria in Tanzania, Amazon Basin in Brazil and Mindanao Island in the Philippines have polluted both surface and ground waters with mercury (Tsuchiya, 2010).

5.1.1: Physiochemical properties in groundwater sources

Water samples drawn from the shallow wells were slightly acidic with a pH ranging from 6 to 6.4 Low pH levels of between 6 and 7 have been shown have been found to facilitate the release rate of heavy metals such as Lead, Cadmium and Iron from the surrounding sediments compared to high pH of between 8 and 10, making the metals more toxic once they dissolve in the water (H. Li et al., 2013).

The temperature in all groundwater sources was within normal levels. Temperature of drinking water is often not of a major concern to consumers as it depends on individual taste and preference. However, it is important to note that high temperatures (30–35˚ c) enhance the release or the availability of heavy metals than in low temperatures (H. Li et al., 2013).

The turbidity (NTU) measures the clarity of water and generally low turbidity levels are recorded from groundwater because of the natural filtration that occurs as the water penetrates through the soil. The mean turbidity in the study was generally low and within WHO guideline limit. Electrical conductivity (EC), which is a measure of the ability of a solution to carry or conduct an electrical current did not also exceed the recommend level. High levels of EC have however been shown to increase heavy metals like cadmium in sediments (Maryam Salim 2013).

5.1.2: Heavy metal concentrations and anthropogenic activities

Anthropogenic activities that produce heavy metals include; environmental pollution from poor waste disposal, excessive use of agrochemicals, lack of proper wastewater drainage and pit latrines. The majority of the households opted to burn their solid waste which could be attributed to the low heavy metal concentrations compared to the option of open dumping which leads to leachate generation that is released to the soil, contaminating groundwater (Ferronato & Torretta, 2019).

Excessive application of fertilizers and pesticides on farms that are in close proximity to ground water sources contribute to heavy metal contamination. Use of agrochemicals among households in this study area was minimal, in addition to the farms being within recommended distance to water source; (average distance 100m), which would also be attributed to the low concentrations of heavy metals. Similar studies have shown that, low levels of Mercury, Arsenic and Cadmium were found in areas where minimal agricultural activities were practiced and no solid waste dump was ruled out as sources of ground water contamination in India (Mohankumar et al., 2016b).

Poor drainage and sewer systems observed in the settlements are a potential source of heavy metal contaminants, but the detection limits were within recommended levels. This in similar to findings by (Obiri-Danso et al., 2009) in peri-urban communities of Ghana and (Nachiyunde et al., 2013) in Zambia where heavy metals were within recommended levels from sampled groundwater sources. This was in the backdrop of populated residential areas with non-functional sewer system, extensive on-site sanitation and dumpsites being in close proximity to groundwater sources.

Majority of the pit latrines in the study area were within the WHO recommended minimum distance of 15m to the water sources sampled for heavy metals. Disposal of batteries, scrap metals and expired fertilizers into the pit latrines was not a common practice by the residents, therefore a possible explanation to. the low levels of heavy metals in the groundwater sources. There is a variation in the recommended distance between the sanitation facilities (septic tanks, latrines and rubbish dumping sites) where (Obiri-Danso et al., 2009) recommended that wells should be sited at least 30 m away in order to minimize groundwater contamination by both chemical and microbiological contaminants.

5.2: Socio-demographic factors

The majority of respondents were from the peri-urban settlements. Respondents who were employed, were self-employed taking up many odd jobs and majority of the households 54% were living slightly below the poverty line which is in keeping with Kisumu county poverty levels at 48% against a national average of 29% (Karanja, 2010). About half of the household members had no complete education with only 18% having completed secondary education. According to (Bakobie et al., 2017) literacy and income levels determine quality of drinking water and decision related to sources of drinking water. The results of education and income levels are similar to studies carried out in other peri-urban areas of Kisumu (Barnes et al., 2018).

A multivariable analysis showed that income and educational status were not statistically significant in explaining the household water choice or the household settlement location. From the study majority of households in the peri-urban setting heavily relied on borehole, springs and hand-dug well as sources of drinking water. Similar findings have been highlighted by (Obiri-Danso et al., 2009) in Kumasi, Ghana where peri-urban communities solely relied on well and borehole water. This was further supported by the Chi-square test, where peri-urban households used groundwater for domestic uses and preferred groundwater as an alternative drinking water source compared to urban households.

From the study 66% households used groundwater for domestic uses and relied on piped water for drinking. However due to unreliability of piped water 54% of the households used groundwater as an alternative source for drinking purposes. The shallow wells were mostly used. Use of the shallow wells could be attributed to ease access, consistency of supply and affordability. This is in accordance with similar studies in Kisumu (Okotto et al., 2015b) where springs were frequently used for drinking and cooking.

The residents in the study area generally had poor knowledge (76%) on the contaminants tested from their drinking water, this may be due to poor knowledge about the toxicity of heavy metals as contaminants in groundwater this corroborated the work of (Azeez et al., 2011) in selected towns in Nigeria. However, studies carried out in Kisumu informal settlements well water consumers were aware of health risks of drinking untreated water due to bacterial contamination (Philip & Stevens, 2013). Despite residents being unaware of the water quality, most (67%) of the households treated drinking water before consumption. Chlorinating and boiling water were the popular methods of making water safe, this is in keeping with other studies in Kisumu of residents using groundwater (Okotto et al., 2015b).

5.3: Health risk assessment

Findings from this study revealed that a significant proportion of respondents had no long-term medical conditions in the last six months. The self- reported non-communicable conditions in the household was about 4%, a low rate which was expected because the region disease burden is mainly due to communicable diseases such as malaria, diarrhoeal diseases, HIV/AIDS among others (Maoulidi, 2011) . Another reason could be the more than half 60% of the household members in the study were below 25 years the median age being 21years, this young age group are less likely to be diagnosed with non-communicable diseases compared to the older age groups.

This is in accordance with (Phillips-Howard et al., 2014) and (Joshi et al., 2014), who revealed a proportionate rise in NCDs among older adults in Kenyan rural and urban slum populations of western Kenya and Kibra respectively.

Hypertension was leading at 52%, which was considerably higher than prevalence reported in various settings in rural Western Kenya ranging from 18.4 to 32.6% (Phillips-Howard et al., 2014). Diabetes was second at 10% which was above the national estimate from 3 to 6% (Meme et al., 2015) (Christensen et al., 2009). The high rates are not a true reflection of the study area due to the small sample size. There is also no available information on the prevalence of chronic conditions in Kisumu County.

Individual factors such as age and sex of the household members contribute to presence of chronic disease. There was a statistical difference in presence of a chronic disease between females and males the results align with other studies confirming women have a higher prevalence of hypertension or Type II diabetes than males (Mkuu Id et al., 2019) in Kenya. Presence of a chronic illness increased with age and the same is reflected in studies demonstrating higher risk of chronic conditions among older age groups (van de Vijver et al., 2013b) (Mkuu Id et al., 2019) in Kenya.

There was a statistically significant difference of those who reported to have a chronic condition and had been consuming groundwater compared to those who did not. Similar findings by (State et al., 2020) in Ogun State, Nigeria among residents using boreholes reported few cases of still births, cancers, skin ailments and stunted growth and this was attributed to groundwater contamination by heavy metals pollution. This hypothesis is further affirmed by self-reported cases of depression and cardiovascular disease after long term exposure to low levels of Arsenic between 2-10 μg/L in drinking water from groundwater source (Zierold et al., 2004) in the United States; type II diabetes (Rafiqul Islam et al., 2012) in Bangladesh.

Exposure assessment exhibited the chronic daily intake was higher in children than in the adults, where children above five were at increased risk of exposure to heavy metals compared to under-five children who consumed drinking water from surface water. Similar studies reported a greater threat of health risks from Cd, Pb and As metals to children and infants in Lagos and Ogun State in Nigeria from various groundwater sources (Ayedun et al., 2015).

According to (U.S. EPA, 2019) HQ and HI greater than unity (HQ/HI >1) implies greater risk level of the heavy metals manifesting long term health hazard effects. From the analysis the HQ and HI values did not exceed the threshold for both adults and children. Therefore, there is a low risk of experiencing non-carcinogenic health effects for both adults and children. The finding is consistent with other studies in Nigeria (Jagaba et al., 2020) and (Muhammad et al., 2011) in Pakistan. The findings were however divergent with studies in Ibadan, Nigeria which indicated possible risk through the oral intake route for heavy metals in the order Cd >Pb. The obtained HQ results were > 1 for Pb and Cd in adult, child, and infant, representing an increased non-carcinogenic health risk (Ganiyu et al., 2021).

The HQ and CDI values for children was greater than adults, this indicates children may be more at risk of non-carcinogenic health effects from heavy metal exposure. The evaluation of cancer risk from exposure to As and Cd in the water samples in this study to residents was within the acceptable U.S. EPA cancer health risk ranges of 1.0×10^{-6} to 1×10^{-4}. The ranges in children being higher compared to adults. Therefore, children may be more at risk of suffering from carcinogenic conditions. This is in contrast to studies in shallow wells in Ibadan, Nigeria which reported CR values for Cd and Pb contamination were higher than the acceptable range of $\leq 1\times10-6$ to $1\times10-4$ for both adults and children (Ganiyu et al., 2021).

5.4: Strengths and weaknesses of the study

The study was not completely a reflection of the urban settlements as few urban households were included in the study due to hostile reception by some respondents resulting from the after effects of the 2017 presidential elections. Information about presence of chronic health condition was self-reported by head of household, this was subject to exclusion if the family members had not disclosed to the household head. Due to financial constraints the number of groundwater sources sampled were few and sampling was carried out in one season hence a complete picture of heavy metal concentrations during the dry season was not possible. Despites these challenges, some of the strengths included having a high response rate and a large household sample size.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1: Conclusion

The aim of the study was to determine whether the residents in the informal settlements were exposed to any health risks from using heavy metal contaminated groundwater. The aquifer being shallow makes it easily accessible and therefore uncontrolled usage of groundwater source particularly wells in the study area. This also makes it vulnerable to contamination from various anthropogenic activities. Despite these considerations, levels of select heavy metals detected were within permissible levels. Likely causes of the low levels of heavy metals include geographic and geochemical reasons; such as the recharge flow of the aquifer, gradient, distance from anthropogenic activities and the season of sample collection. Nevertheless, the low pH levels noted in the shallow wells may impart to rising levels of heavy metals over time.

There was a low prevalence of chronic diseases in the community. The presence of the chronic disease was dependent on self-reporting which could be biased; thus, the rate may be higher from hospital facility non-communicable disease registries. Despite having the presence of chronic disease among groundwater users other risk factors aside from heavy metal exposure should be explored as possible confounders. The overall findings of the study therefore revealed that there are limited concerns of carcinogenic and non-carcinogenic health impacts from the heavy metal contaminants to residents through the cumulative ingestion in the drinking water. However, continuous monitoring is paramount to prevent any eventualities.

This study therefore brings to the fore emphasis on maintaining the water quality from the different groundwater sources within the urban and peri-urban informal settlements of Kisumu. Groundwater sources poses no health risk as far as heavy metal contamination is concerned to residents in the settlements, therefore its utilization can be an option. Nonetheless, strict control of land use (dumping, agricultural activities, pit latrines, etc.) and detailed groundwater monitoring is essential to ensure safe usage of the water resource.

6.2: Recommendations

Based on the outcome of the study the following are the recommendations;

1. The county government through the county water authorities e.g. KIWASCO should continuously monitor heavy metal concentrations of public health concern during routine water quality analysis of groundwater sources exploited for drinking water.

2. Environmental and public health research institutions should carry out further studies in groundwater sources to determine whether there is a difference in heavy metal concentration levels in relation to the wet and dry seasons in the study area.

3. In order to maintain heavy metal concentrations within permissible levels of WHO and KEBS standards, it is recommended that the county government has in place a comprehensive sanitation and waste management plans. This includes proper constructed drainage and sewer systems for the informal settlements in the study area to ensure proper disposal of hazardous waste, thereby preventing contamination of groundwater. The county government of Kisumu in conjunction with the National Environmental Management Authority (NEMA) should monitor high risk pollution sites e.g. factories that are close to groundwater sources to ensure proper effluent disposal management

4. The county government should also ensure regulation and monitoring of the number of groundwater sites accessed by residents. Monitoring entails maintaining minimum safe distance of anthropogenic activities to the nearest groundwater source.

5. At risk population to chronic diseases include those consuming groundwater, children over age of six years and the elderly. It is therefore recommended that public health officials and community health workers need to offer health education at community level through home visits, barazas and in schools. Health education topics should address; water treatment options, dangers of drinking polluted water among these at-risk groups and activities contributing to groundwater contamination with heavy metals. This will in turn address the poor knowledge among the residents on the possibility of heavy metals being contaminants to drinking water.

6. The HQ, CDI and CR values in in the study were within normal ranges. However, it is recommended there is provision of regulatory, monitoring and management of groundwater by the county government in the studied area, especially in the urban informal setting to avoid future development of health risks associated with the use of heavy metal contaminated drinking water.

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APPENDICES

Appendix I: Participant Information And Consent Form(English Version)

Title of Study: **SELECT HEAVY METAL CONCENTRATIONS IN GROUNDWATER SOURCES AND POTENTIAL HEALTH RISKS THROUGH DRINKING PATHWAY AMONG RESIDENTS IN INFORMAL SETTLEMENTS OF KISUMU EAST COUNTY**

Principal Investigator\and institutional affiliation: **GRACE MUTHONI KALUAI**

Introduction:

Good morning /Good afternoon.

My name is ____

I would like to briefly explain to you the purpose of the above study. The purpose of this information is to help you decide whether or not to be a participant in the study. Feel free to ask any questions about the purpose of the research, what happens if you participate in the study, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When we have answered all your questions to your satisfaction, you may decide to be in the study or not. This process is called 'informed consent'. Once you understand and agree to be in the study, I will request you to write your name and sign that you have agreed to participate in this study. You should understand the general principles which apply to all participants in medical research: i) Your decision to participate is entirely voluntary; ii) You may withdraw from the study at any time without necessarily giving a reason for your withdrawal; iii) Refusal to participate in the research will not result in any ill-treatment from the interviewer. We will give you a copy of this form for your records.

May I continue? YES / NO

This study has approval by The Kenyatta National Hospital-University of Nairobi Ethics and Research Committee protocol No. ____________________________

WHAT IS THIS STUDY ABOUT?

This is an interview among households using groundwater as their primary source of drinking water. The purpose of the interview is to determine whether the heavy metal levels in groundwater used as drinking water are at recommended levels and if the people are at risk of exposure in this area. Participants in this research study will be asked questions about the type of groundwater source, frequency of use and duration of use by the household members. Participants will have body measurements of the members in this household taken. Water samples will also be collected from the groundwater sources you use; these will be analyzed for heavy metal concentration levels.

There will be approximately 355 households in this study randomly chosen. We are asking for your consent to consider participating in this study.

WHAT WILL HAPPEN IF YOU DECIDE TO BE IN THIS RESEARCH STUDY?

If you agree to participate in this study, the following things will happen:

You will be interviewed by a trained interviewer in a private area where you feel comfortable answering questions. The interview will last approximately 20 minutes. The interview will cover topics such as groundwater as a source of drinking water and possible sources of groundwater contamination.

After the interview, body measurements such as height and weight will be taken for all members in the household and also water samples from the drinking water source will be collected for analysis for heavy metal concentration levels.

We will ask for a telephone number where we can contact you if necessary. If you agree to provide your contact information, it will be used only by people working for this study and will never be shared with others. The reasons why we may need to contact you include: clarification of some details from the interview and for follow up based on the study findings.

ARE THERE ANY RISKS, HARMS DISCOMFORTS ASSOCIATED WITH THIS STUDY?

Medical research has the potential to introduce psychological, social, emotional and physical risks. Effort should always be put in place to minimize the risks. One potential risk of being in the study is loss of privacy. We will keep everything you tell us as confidential as possible. We will use a code number to identify you in a password-protected computer database and will keep all of our paper records in a locked file cabinet.

If you feel uncomfortable answering questions in the interview or for any reason do not want to respond to any question, you can skip. You have the right to decline to participate in the interview or any questions asked during the interview.

While taking your body measurements no discomfort or pain is expected during the process. However in case of an injury, illness or complications related to this study, contact the study staff right away at the number provided at the end of this document.

ARE THERE ANY BENEFITS BEING IN THIS STUDY?

You may benefit by having your body measurements taken and your drinking water tested for heavy metal concentration levels for free. We will refer you to a hospital for care and support where necessary. Also, the information you provide will help us better understand household water practices and possible sources of contamination by heavy metals of groundwater in the area. This information is a contribution to science and will be beneficial to you and the community as the information will help relevant policy makers to develop interventions if any public health issue is determined.

WILL BEING IN THIS STUDY COST YOU ANYTHING?

You do not need to pay anyone conducting the study money for taking part in this study and conversely no money will be paid to you for taking part in this study.

WHAT IF YOU HAVE QUESTIONS IN FUTURE?

If you have further questions or concerns about participating in this study, please call or send a text message to the study staff at the number provided at the bottom of this page.

For more information about your rights as a research participant you may contact the

Secretary/Chairperson,

Kenyatta National Hospital-University of Nairobi Ethics and Research Committee

Telephone No. 2726300 Ext. 44102

Email: uonknh_erc@uonbi.ac.ke.

WHAT ARE YOUR OTHER CHOICES?

Your decision to participate in research is voluntary. You are free to decline participation in the study and you can withdraw from the study at any time without injustice or loss of any benefits.

CONSENT FORM (STATEMENT OF CONSENT)

Participant's statement

I have read this consent form or had the information read to me. I have had the chance to discuss this research study with a research assistant. I have had my questions answered in a language that I understand. The risks and benefits have been explained to me. I understand that my participation in this study is voluntary and that I may choose to withdraw any time. I freely agree to participate in this research study.

I understand that all efforts will be made to keep information regarding my personal identity confidential.

By signing this consent form, I have not given up any of the legal rights that I have as a participant in a research study.

I agree to participate in this research study: Yes/No

I agree to provide contact information for follow-up: Yes/No

Participant printed name: ____

Participant signature / Thumb stamp ________________________ Date _______________

Researcher's statement

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has willingly and freely given his/her consent.

Researcher's Name: ____________________________________ **Date**: _______________

Signature ____

Role in the study: ___________________________ *[i.e. study staff who explained informed consent form.]*

For more information contact ________________________ at ____________________ from

___________________________ to __________________________

Witness Printed Name (*If witness is necessary, a witness is a person mutually acceptable to both the researcher and participant*)

Name _________________________________ Contact information ____________________

Signature /Thumb stamp:_________________ Date; _________________________________

Appendix II: Participant Information And Consent Form (Dholuo Version)
WECHE MAG BETIE NONRO KOD YIE MAR DONJO E PUONJRUOK

Nying nuonjruok: <u>YIERO CHUMBE MAPEK MIYUDIE PI MAWUOK E BWO LOWO TOGI CHANRUOK MAGI KELO E NGIMA DHANO BANG MODHO PIGNI NE JODAK MA KISUMU WUOK CHIENG (EAST)</u>

Jatim nonro mogirore/ togi kar somo mowuoke: <u>GRACE MUTHONI KALUAI</u>

Chakruok:

Oyawore/Amosou.

Nyinya en____

Daher mar leroni gima omiyo watimo nonro man malo no. Waminyi wachegi mando okonyi ichopie paro mar betie/ donjoe nonro ni kata ooyo. Yie ibed thuolo mar penjo, penjo moro amora kuom nonro ni, kidonjie, chandruok man tiere, konyruok manyalo yudo, adieri mara togi wach moro amora maok angeyo ler mare. Kawase duoko penjo gi duto to inyalo yiero betie nonro ni kata ooyo, chenroni iluongo ni "ler mar yie mari". Ka isewinjo wechengi maler kendo iyie betie nonro ni to abiro kwayi, mondo indik nyingi kaeto iket lweti manyiso ni iyie gi nonro ni. En ratiro mari mondo iwinjimaler chenro duto mibiro tiyo godo kod joma oyie mar oyiebetie nonro ni mar thieth: i) Yie mar betie nonroni en chiwruok mari ii) Inyalo wuok e nonro ni asaya maok inyiso gima omiyo iii) Tamruok betie nonro ok nyal miyi chandruok moro amora kod jartim nonro. Wabiro miyi kopi fom ni mondo ikan.

Anyalo dhi nyime? Ayie/ooyo

Nonro ni opuodhi kod thieth ma Kenyatta (Kenyatta National Hospital)- Balariany ma Nairobi (University of Nairobi) matimo nonroni.

Namba mar joma timo nonro ni____

ANG'OMA NONRO NI WUOYOE

Nonro ni itimo ne joma tiyo kod pi mawuok e bwo lowo kaka mar modho. Nonro ni itimo mondo wange ka chumbe mapek mayudore e bwo lowo owinjore gi ngima dhano e pi modho kata ka ngima mar dhano nitiere kamarach e aluorani. Joma nitie nonro ni ibiro penji kama pi magimodho wuoke, kaka itiyo kode to gi thuolo mane mitiyogo godo kod gi joma odak e aluora no. Joma obetie nonro ni ibiro pimo pek margi. Pi mawuok e bwo lowo bende ibiro tuom mondo timnengi nonro mar ng'eyo ka chumbe mapek nitiere.

Wabiro bedo kod jodak maromo mia adek gi biero abiriyo gachiel (355) e nonro ni, moyie maok ochan. Wapenjo ka iyie mondo ibetie nonro ni.

ANG'OMA BIRO TIMORE KA ABAETIE NONRO NI?

Ka iyie mar betie nonro ni to magi e gik mabiro timore.

Ibiro penji penjo gi jatim nonro molony e kama opondo mondo iyud thuolo mar duoko penjogi. Penjogi biro kawo dakika piero ariyo. Penjo gi biro wuok kuom pi modho mawuok e bwo lowo togi yore ma pi nyalo bedo mochido.

Bang timo nonro ni, ibiro pim dend joma odak, kaluwore gi bor margi, pek margi kachiel gi kawo pi mondo tim nonro kadipo ni gin kod chumbe mapek mayudore e bwo lowo.

Wabiro kwayi namba mari mar simo, ma wanyalo tudore godo kodi sama owinjore. Ka imiyowa namba mari mar simo to ibiro mana tiyo kode kod jok matie nonroni kende, to kendo ok wabi miye ngata angata. Wanyalo duaroo tudore kodi nikech: wanyalo duaro ler mamoko e weche mag nonro kachiel gi luwo nonro kachiel gi luwo nonro ni bang yudo duoko mang nonro ni.

BENDE NITIERE CHANDRUOK, HINYRUOK MANYALO KELO WINJO MARACH KALUWORE GI NONRO NI?

Nonro ni kaluwore gi weche mag thieth nyalo kelo paruok, mirima kata chandruok mag del. Chenro makare nyaka keti mondo oduok kit chandruok gi chien. Chandruok maduong mar betie nonro ni en wito bedo kar kendi. Wabiro rito gik moko duto minyisowa maling ling kaka nyalore. Wabiro tiyo kod namba mar yagoi mondik piny mar bui marwa (password) kendo weche duto mondik piny wabiro loro ma ng'ato ok nyal yawo kata choopoe.

Kaok in thuolo mar duoko penjo e nonro ni kata ka in kod gima omiyo ok inyal duoko penjo gi, to inyalo weyo maok iduoko kata inyalo kadho penjono.

En ratiro mari mar tamruok betie nonro ni kata duoko penjo moro amora sama itimoe nonroni.

Sama ibiro pim dendi, ok ibi winjo marach kata onge rem moro amora e chenro ni. Makmama kadipo ni iyudo hinyruok, tuo kata bedo gi pek moro kaluwore gi nonro ni to inyalo tudori kodwa e namba marwa machiwo e giko mar ndiko ni.

BENDE NITIERE OHALA E NONRO NI?

Ohala minyalo yudo en ni ibiro pim dendi kachiel gi chumbe mapek manyudore e pi modho. Magi wabiro timo nono maonge chudo. Wabiro ori e od thieth mondo iyud rit makare kata kony mowinjore. Weche mawa yudo kuom joma odak biro konyowa kaluwore gi weche mag pi modho kachiel gi chumbe mayudore e bwo lowo e gwengno. Weche mawa yudo e nonro ni biro konyo e siyans to kendo en ohala kata konyruokne in kachiel gi joma odak kanyo, nikech wechegi biro konyo jo n'gand rieko duaro yore mag kelo kony kaluwore gi ngima mag jopiny.

BENDE BETIE NONRO NI DWARO CHUDO?

Ok onego ichul ngato gimoro amora matima nonro ni kuom betie to kendo onge pesa moro amora mibiro chuli kuom betie nonro ni.

ANG'OMA INYALO TIMO KA IN KOD PENJO E NDALO MABIRO?

Ka in kod penjo mamoko kata gimoro machadi kuom betie nonro ni yie mondo itudri kodwa kata ior ote machuok ne jotim nonro e namba momiyi no e giko ndiko ni. Kiduaro weche mathoth kuom ratiro mari mar betie nonro ni, to iyie itudri gi:

Jagoro/Jakom

Kenyatta National Hospital-University of Nairobi Ethics and Research Committee

Telephone No. 2726300 Ext. 44102

Email: uonknh_erc@uonbi.ac.ke.

ERE YIERO MAGI MAMOKO?

Yie mari mar betie nonro ni en yiero mari. In kod thuolo mar tamruok betie nonro ni kendo inyalo wuokie sa nasaya maonge rach moro kata wito ohala moro amora.

FOM MAR YIE MARI (NDIKO MAR YIE)

Wach mar jabetie nonro:

Asesomo weche duto kata yudo kata yudo weche mosomna. Aseyudo thuolo mar loso e nonro ni gi jakony mar nonroni. Penjo mane an godo osedukoki e dhok mawinjo. Chandruok kata ohala mar nonroni oselerna. Betie nonroni en yiero mara kendo anyalo wuok sa asaya. Ayie mondo abetie nonro ni.

Osenyisa ni okang duto ibiro kawo mondo weche machiwo ibiro kan maling ling.

Kuom keto koka (lweta) e form ni, ok onyiso ni aweyo ratiro mara kuom betie nonro ni.

Ayie mondo abetie nonro ni: Ayie/ooyo

Ayie mar chiwo tudruok mara minyalo tiyo godo bange: Ayie/ooyo.

Nying jabetie nonro____

Lwet jabatie nonro____

Wach jatim nonro:

An ma nyinga ni piny ka, aselero weche duro mowinjore kalurowe gi nonroni ne jabetie nonro ni manyingeni malono kendo an kod yie ni owinjo weche duto kapok oyie betie nonro ni.

Nying jatim nonro______________________________Tarik ________________________

Keto lwedo ____

Gima ibiro timo e nonro ni ____

(kaka olerni e fom mari yie gi jatim nonro)

Kiduaro ngeyo weche mamoko to tudrok en __________________________________

Kama irome ________________ kachakore saa _____________ nyaka saa ___________

Nying janeno(mana kowinjore, janeno en ngama oyie godo gi jatim nonroni togi jabetie nonro)

Nying janeno __________________________ tudruok mare _______________________

Keto lwedo ____________________________ Tarik ______________________________

Appendix III: Household Questionnaire

Questionnaire Number…..

Identification

1. Name of Informal settlement…………………………………………
2. Sub-location of household……………………………………………..
3. Location of household…………………………………………………
4. Household Code (e.g. M001)…………………………………………………

Date and Time of visit 1…………………………*Result……………………
Date and Time of visit 2…………………………*Result……………………
Date and Time of Visit 3…………………………*Result…………………….
Date and Time of Final visit……………………..*Result……………………..
*Complete(C) or Incomplete (I)

Part A

Socio-demographic, anthropometric measurements and water consumption details

The household head and household members will be the respondents in this section. Anthropometric measurements will be taken from all household members and information on their water consumption documented.

1. In total how many members are in this household……………..?
2. How much is the average monthly total net income in this household Ksh………………..?

		Coding
a)	Below Ksh 2000	1
b)	Ksh 2500-5000	2
c)	Ksh 5500-8000	3
d)	Ksh 8500-1100	4
e)	Above 11500	5

Household Member code	Residence 4.	Relationship 5.	Sex 6.	Age 7.	Education level 8.	Occupation 9.	Marital status 10.	Special groups 11&12.		Measurements 13&14.		Frequency of water intake 15.	Health status 16.
Please identify persons of permanent residency of this household *(Code e.g. E0001)*	**For how long has the household member lived in this household?** *Should be in years*	**What is your relationship to Head of Household** *1.Head* *2. Spouse* *3. Daughter/Son* *4. Mother/Father* *5. Brother/Sister* *6. Grandchild* *7. Nephew/Niece* *8. In-law* *9. Grandparent* *10.Other Relative* *11. Non relative*	**What is the sex of the household member?** *1. Male* *2. Female*	**What is the age of the household member?** *0 for those <1year otherwise record actual age in years lived*	**What is the highest level of education for household members >3years of age?** *1. None* *2. Incomplete primary* *3. Complete primary* *4. Incomplete secondary* *5. Complete secondary* *6. College/University*	**What is the occupation of the household member?** *. Student* *2. Employed* *3. Self Employed* *4. Not Employed* *5. Retired* *6. Other*	**What is the marital status of the household member?** *1. Never married* *2. Married* *3. Widowed* *4. Divorced* *5. Separated*	**Indicate the household member code for all children under age 6**	**Indicate the household code for members who are pregnant/lactating women**	**What is the household member weight?** *Body weight in kilograms*	**What is the household member's height?** *Height in centimeters*	**What was your water intake yesterday?** *Intake in mls* *250mls =1glass*	**Do you have any chronic condition that requires you to attend clinic or be on long-term medication?** *1.Hypertension* *2.Diabetes* *3. Mental illness* *4.Cancer* *5.Skin condition* *6.Anaemia* *7. Other*

Part B

This section will capture information on the household drinking water source and possible sources of heavy metal contamination. The section will be answered by the individual who is usually responsible for water collection.

Particulars of this respondent are from Part A of the questionnaire (Indicate the household member code)……………

Has a water sample from the water source been taken for heavy metal analysis (indicate Ref number) Y/N …………………

	Water source	Coding
1.	In this household what is your main source of water for domestic uses _____________?	
2.	What is the main source of drinking water for members of your household (If it varies by season, ask about the current time)? a. Borehole b. Hand dug well c. Springs	 1 2 3
3.	(Observe) Is the source protected or unprotected a. Protected (P) b. Unprotected (UP)	 1 2
4.	How long have you been using this water source?	…………..years.
5.	Is water always available from this source? a. Yes b. No	 1 2
6.	If No, what is your other alternative water source? a. KIWASCO-municipal b. Surface water-(river, lake, pond, dam, stream) c. Rainwater d. Borehole e. Hand dug well f. Springs g. Bottled water	 1 2 3 4 5 6 7
7.	If yes, how many litres of water did your household access from the water source yesterday?	………… L

	1jerrican =20Litres	
8.	Approximately, how many litres of drinking water did your household use yesterday? 1jerrican =20Litres	…………L
9.	Are you aware if the main source of water has ever been tested for contaminants? a. Yes b. No c. Do not know	 1 2 3
10.	If Yes, when was the last time it was tested (date) _____________?	
11.	Do you treat your water in any way to make it safe for drinking? a. Yes b. No	 1 2
12.	If yes, how do you make your water safe, before drinking it? a. Boiling b. Chlorination c. Allowing to settle d. Filtration e. Solar disinfection f. Other________________________(specify)	 1 2 3 4 5
C	**Possible point and non-point sources of contamination**	
13.	Do you practice any farming with fertilizers a. Yes b. No (Comment) Distance of garden/farm to water source …………..metres	 1 2
14.	Do any of your neighbors practice any farming with fertilizers? a. Yes b. No (Comment) Distance of the farm to water source_____metres	 1 2
15.	Do you have a waste disposal site a. Yes b. No	 1 2
16.	What do you dispose in this site? a. Organic kitchen waste vegetables, fruits b. Paper, cardboard paper c. Cotton clothes	 1 2 3

	d. Woolen clothes e. Metal cans, tin, aluminium, batteries f. Plastics g. Others(specify)________________________	4 5 6
17.	How to you get rid of the household solid waste? a. Burn b. Bury c. Leave it in the open d. Use of waste collection services e. Others_______________(specify) (Observe) distance of waste site to the water source………………….metres.	 1 2 3 4 5
18.	Which of these materials do you dispose of in your pit latrine? a) Expired Medicines b) Paper c) Wood d) Expired Fertilizers/Chemicals e) Metal f) Batteries g) Others _____________(specify) (Observe) distance of the pit latrine to the water source_______________metres.	 1 2 3 4 5

Appendix VI: KNH-UoN ERC approval letter

UNIVERSITY OF NAIROBI
COLLEGE OF HEALTH SCIENCES
P O BOX 19676 Code 00202
Telegrams: varsity
Tel:(254-020) 2726300 Ext 44355

KENYATTA NATIONAL HOSPITAL APPROVED
11 DEC 2017
KNH/UoN-ERC
P.O. Box 20723-00202 NRB.

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Ref: KNH-ERC/A/371

11th December, 2017

Dr. Grace Muthoni Kalual
Reg. No.H57/81027/2015
School of Public Health
College of Health Sciences
University of Nairobi

Dear Dr. Kalual

RESEARCH PROPOSAL – SELECT HEAVY METAL CONCENTRATIONS IN GROUNDWATER SOURCES AND POTENTIAL HEALTH RISKS THROUGH DRINKING PATHWAY AMONG RESIDENTS IN INFORMAL SETTLEMENTS OF KISUMU EAST COUNTY (P352/07/2017)

This is to inform you that the KNH- UoN Ethics & Research Committee (KNH- UoN ERC) has reviewed and **approved** your above proposal. The approval period is from 11th December 2017- 10th December 2018.

This approval is subject to compliance with the following requirements:

a) Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
b) All changes (amendments, deviations, violations etc.) are submitted for review and approval by KNH-UoN ERC before implementation.
c) Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH- UoN ERC within 72 hours.
d) Death and life threatening problems and serious adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the KNH-UoN ERC within 72 hours of notification.
e) Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. (*Attach a comprehensive progress report to support the renewal*).
f) Submission of an *executive summary* report within 90 days upon completion of the study. This information will form part of the data base that will be consulted in future when processing related research studies so as to minimize chances of study duplication and/ or plagiarism.

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Yours sincerely,

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Appendix V: List of sampled groundwater sources with heavy metal concentrations

Water Sample ID	Source	Metal concentration levels µg/L (micrograms/L)			
		Arsenic	Cadmium	Mercury	Lead
1(A)/(B)	Shallow well	0.75	0.05	0.16	BDL
2(A)/(B)	Shallow well	0.31	0.03	0.26	BDL
3(A)/(B)	Shallow well	0.16	0.01	0.18	BDL
4(A)/(B)	Shallow well	0.15	0.04	0.11	BDL
5(A)/(B)	Shallow well	0.29	0.04	0.11	0.04
6(A)/(B)	Shallow well	0.22	0.04	BDL	BDL
7(A)/(B)	Shallow well	0.13	0.05	BDL	0.48
8(A)/(B)	Spring	0.07	0.04	BDL	0.05
9(A)/(B)	Shallow well	0.16	0.05	BDL	0.02
10(A)/(B)	Spring	0.05	0.04	BDL	BDL
11(A)/(B)	Spring	0.1	0.12	BDL	0.32
12(A)/(B)	Spring	0.03	0.03	BDL	BDL
13(A)/(B)	Shallow well	0.06	0.04	BDL	BDL
14(A)/(B)	Shallow well	0.06	0.02	BDL	0.03
15(A)/(B)	Shallow well	0.04	0.01	BDL	0.13
16(A)/(B)	Shallow well	0.23	0.02	BDL	BDL
17(A)/(B)	Shallow well	0.08	0.04	BDL	BDL

18(A)/(B)	Shallow well	0.16	BDL	BDL	BDL
19(A)/(B)	Shallow well	0.1	0.04	BDL	BDL
20(A)/(B)	Shallow well	0.1	0.02	BDL	BDL
21(A)/(B)	Shallow well	0.04	0.04	BDL	BDL
22(A)/(B)	Shallow well	0.01	0.03	BDL	BDL
23(A)/(B)	Shallow well	0.22	0.05	BDL	BDL
24(A)/(B)	Shallow well	0.52	0.03	BDL	BDL
25(A)/(B)	Spring	0.25	0.05	BDL	BDL
26(A)/(B)	Shallow well	0.13	0.01	BDL	BDL
27(A)/(B)	Borehole	3.72	0.04	BDL	BDL
28(A)/(B)	Shallow well	0.04	0.01	BDL	BDL
29(A)/(B)	Shallow well	0.06	0.01	BDL	BDL
30(A)/(B)	Shallow well	0.07	0.04	BDL	0.01
31(A)/(B)	Shallow well	0.09	0.01	BDL	BDL
32(A)/(B)	Shallow well	0.06	0.01	BDL	BDL
33(A)/(B)	Shallow well	0.13	0.02	BDL	BDL
34(A)/(B)	Borehole	0.5	0.07	BDL	0.02
35(A)/(B)	Shallow well	0.22	0.03	BDL	BDL
36(A)/(B)	Shallow well	0.38	0.02	BDL	BDL
37(A)/(B)	Shallow well	0.19	0.01	BDL	BDL

Appendix VI: Turnitin report

OCCURRENCE OF SELECT HEAVY METALS IN GROUNDWATER SOURCES AND POTENTIAL HEALTH RISKS AMONG RESIDENTS IN INFORMAL SETTLEMENTS OF KISUMU EAST COUNTY, KENYA

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