HEALTH RISK ASSESSMENT OF NITRATE CONTAMINATION IN GROUNDWATER IN URBAN INFORMAL SETTLEMENTS IN KISUMU, KENYA

BY

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DEDICATION

First and foremost, I am grateful to God for wisdom, insight and provision. This research project is dedicated to my husband, children, parents and siblings for all their support and encouragement, inspiration and motivation to never give up.

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ABBREVIATIONS

ADI: Acceptable Daily Intake.

APHA: American Public Health Association.

CDI: Chronic Daily Intake.

EPA: Environmental Protection Agency.

ERC: Ethics and Research Committee.

FAO: Food Agriculture Organization.

HQ: Hazard Quotient.

IARC: International Agency for Research on Cancer.

KDHS: Kenya Demographic and Health Survey.

KEBS: Kenya Bureau of Standards.

KNBS: Kenya National Bureau of Statistics.

KNH: Kenyatta National Hospital.

LMIC: Low- and Middle-Income Countries.

MDGs: Millennium Development Goals.

N: Nitrogen.

NACOSTI: National Commission for Science, Technology and Innovation.

NCD: Non-Communicable Diseases.

NO_2 : Nitrite.

NO_3 : Nitrate.

PPM: Parts Per Million.

RBS: Random Blood Sugar.

RfD: Reference Dose.

RFID: Radiofrequency Identification.

SDGs: Sustainable Development Goals.

SSA: Sub Saharan Africa.

UN: United Nations.

UoN: University of Nairobi.

UV: Ultraviolet.

VIS: Visual Spectrophotometry.

WASH: Water, Sanitation and Hygiene.

WHO: World Health Organization.

DEFINITION OF OPERATIONAL TERMS

Acceptable daily intake: Estimated amount of a substance to which an individual can be exposed to daily without significant health risk.

Hand dug well: Holes dug in the ground and excavated below the groundwater table. They usually have a depth of 10 to 30 feet and a diameter of approximately 0.8 meters.

Improved sanitation facility: Sanitation facility that hygienically separates human waste from human contact. This includes those with sewer connections, septic system connections, pour-flush latrines, VIP latrines and pit latrines with a slab.

Improved water source: This refers to piped water, protected wells, protected springs, borehole water, collected rainwater and bottled water.

Informal settlement: Residential areas where the inhabitants do not have any legal claim to the housing or the land. Housing is usually not in compliance with planning and building regulations. These neighbourhoods lack basic services and infrastructure.

Maximum contaminant level: Highest level of a contaminant that is allowed in drinking water. If this level is surpassed consumers of this water are at risk of negative health effects.

Parts per million: Concentration equivalent to one milligram per litre or per kilogram (mg/L or mg/kg).

Protected well: Wells that have well shaft lined with various materials (stone, brick or tile) to prevent collapse and reduce vulnerability of water to contamination.

Well head: The part of the well visible above the ground. It offers protection from surface runoff.

ABSTRACT

Background

Groundwater is increasingly being used as a primary source of water for domestic use in low- and middle-income countries worldwide. This water is vulnerable to nitrate contamination due to a variety of factors, the most significant of which are excessive nitrogen-based fertilizer use and widespread onsite sanitation (use of pit latrines). Increase of nitrate concentration in groundwater has become a global concern in recent years. Prolonged nitrate exposure can cause a number of non-communicable diseases.

Objective

The objective of this study was to determine the nitrate concentration in various groundwater sources (wells and springs) and to calculate the health risk of exposure among residents as an indicator of public health impact.

Methods

This was a cross sectional study on informal settlements in urban and peri urban areas of Kisumu County. The study was conducted in urban and peri urban informal settlements within Kisumu County. Groundwater sources were identified using the snowball method while households were selected using simple random sampling. A structured questionnaire was used to collect data among heads of households. Water samples were analysed to determine their nitrate levels. The chronic daily intake (CDI) and hazard quotient (HQ) were used to assess human health risk.

Results

Nitrate levels in 26.6% (n=45) of the groundwater sources were above the WHO recommended cut-off. Prevalence of diabetes and hypertension was 4% (n=299) and 19% (n=299) within this community. The chronic daily index was 0.189 mg/kg/day while the hazard index was 0.118.

Conclusion

The presence of nitrate in groundwater was contributed by pit latrines and use of fertilizers in the urban and peri-urban settlements respectively. Since the hazard index is less than one, the population is currently at low risk of disease.

Recommendation

The management of groundwater in the area and the implementation of preventive measures to stop further pollution will benefit from the study's findings because doing so is essential for long-term sustainability.

CHAPTER 1. INTRODUCTION

1.1 Background

Access to safe water is a basic human need. Clean water is required for human health and well-being. The sixth Sustainable Development Goal (SDG) was established to ensure availability of safe water and sustainable management of water sources globally (United Nations, 2016). Water insecurity is a concern that is growing globally, especially in developing countries (Grönwall *et al*., 2018). Several factors contribute to this situation, one major factor being rapid urbanization. The rapid increase in population density within the urban areas is exerting great pressure on water provision systems (Arfanuzzaman & Atiq-Rahman, 2017). The extension of the piped water network is occurring at a much slower pace than the population's expansion, and this is more marked in the informal settlements. The urban poor are then forced to meet their needs through self-supply using groundwater, as it is readily accessible, reliable and more resilient to climate change (Lapworth *et al*., 2017).

Groundwater, which is the main source of drinking water among the fast-growing urban population in developing countries, is at great risk of contamination as a result of human activities (United States Environmental Protection Agency (US EPA), 2002). Low- and middle-income countries like Kenya have a challenge in providing adequate and safe water to its population, thus compelling its people to resort to using groundwater (Saana *et al*., 2016). This water is accessed mainly from naturally occurring springs and hand dug wells. Most of these water sources are not protected hence they are vulnerable to contamination (Odiere *et al*., 2011).

Nitrate is a widespread groundwater pollutant because it is persistent in soil and highly soluble in water (Templeton *et al*., 2015). Presence of nitrate is one of the indicators that is used to assess the impact of on-site sanitation on groundwater quality (Shivendra & Ramaraju, 2015). A review of groundwater hydrochemistry in 272 regions worldwide assessed nitrate levels in multiple groundwater sources in various countries. The results showed that Africa and Asia were the continents with the highest number of groundwater sites whose nitrate levels were above the regulatory cut-off, while Europe and America had the least number (Abascal *et al*., 2022). In Africa, nitrate has been identified as a major groundwater pollutant, and this is related mainly to on-site sanitation and poor waste management (Ouedraogo & Vanclooster, 2016). On-site sanitation is a major contributor because of the rise of overcrowded urban settlements that lack centralized sewerage systems (Rasolofonirina *et al*., 2015). Studies done in South Africa (Masindi & Foteinis, 2021), Tanzania (Pantaleo *et al*., 2018), Cameroon (Kringel *et al*., 2016), Madagascar (Ramaroson *et al*., 2020; Rasolofonirina *et al*., 2015), Côte d'Ivoire (Georges-Eblin *et al*., 2019) among other African countries all reveal a worrying trend of rising nitrate levels. These studies were mainly conducted in low-income urban settlements while a few were carried out in peri urban farming areas.

Within Kenya, presence of nitrates has been documented in both surface and groundwater in Eldoret (Khazenzi *et al*., 2014) and around Mombasa (Mwaguni *et al*., 2017). Nitrate has also been identified in samples of water obtained from River Molo and its tributaries (Chebet *et al*., 2020) but at levels below the recommended cut-off. Previous studies in Kisumu also show a deterioration in groundwater quality because of the rapidly growing urban population that has led to an increasing demand on water and sanitation services (Nyilitya *et al*., 2020; Okotto-Okotto *et al*., 2015).

Long term consumption of contaminated water poses adverse health effects. The regulatory limit of 50 ppm for total nitrate in water was established to protect infants from developing methaemoglobinaemia, which is an acute condition. It occurs when ingested nitrates are converted into nitrites, which then oxidize the ferrous iron in haemoglobin into ferric form; and this form has reduced oxygen carrying capacity (Denshaw-Burke *et al*., 2015). Since this level protects infants, it is assumed to be protective across all age groups in the population. Further research is required to determine if this level is adequate to protect against other acute diseases, or chronic diseases in the case of long-term exposure (Ward *et al*., 2018). Some studies have shown positive effects of low levels of dietary nitrate. Once converted into nitrous oxide after ingestion, it has a cardio-protective effect and is beneficial in regulating blood pressure (Parvizishad *et al*., 2017). Overall, these epidemiological studies have are limited in their ability to accurately estimate the true effects of long-term exposure on an individual level (Org-Schullehner *et al*., 2018).

The aim of this study was to establish nitrate levels in various groundwater sources and conduct a health risk assessment among residents dwelling in urban informal settlements within Kisumu County. This population is heavily dependent on groundwater due to lack of clean and safe piped water supply. The groundwater is vulnerable to contamination because of the rising use of pit latrines in an area with a high water table. Focus on these residents is because evidence has shown that people from the lower socioeconomic category generally have poorer health. Evidence shows that NCDs are following a gradient of higher risk in people categorised in the lower socioeconomic group (Marmot & Bell, 2019).

1.2 Problem statement

Nitrate is an inorganic compound that exists naturally in the environment as a by-product of degraded organic matter. Although nitrates are inert compounds, concern about their level arises due to the potential to convert into nitrite form under anaerobic conditions after ingestion, a process known as nitrosation. This is the form which is responsible for the hazardous effects (Ward *et al*, 2018) .

Normal groundwater values of nitrate range between 4-9 parts per million (ppm) (Cronin *et al*., 2007). Human activities have altered the nitrogen cycle dramatically, leading to steady accumulation of nitrate in groundwater aquifers (Ward *et al*., 2005). Nitrates are the most common chemical contaminants in groundwater (Ward *et al*., 2005), with sources of pollution being either point or non-point. Point sources are industrial emissions and wastewater that are improperly disposed. Non-point sources are agricultural and urban runoffs (Jadhav *et al*., 2013).

Excessive loading of nitrates into groundwater mainly occurs due to influence of human activities through two main pathways: sanitation and agriculture (Yu *et al*., 2020). High demand for food worldwide has led to increased use of nitrogen-based fertilizers. Availability of nitrogen compounds in the environment is also increased by poor sanitation practices noted in urban informal settlements. Industrialization also contributes to contamination of water when the waste material is disposed of in an improper and indiscriminate manner (Saana. *et al*, 2016).

High nitrate levels are a global public health concern (Rahmati *et al*., 2015) because of the association with adverse effects on both human and environmental health. Excess nitrate in water bodies leads to eutrophication (overstimulation of growth of algae) which in turn leads to poor growth of aquatic life. This is particularly important in Kisumu because Lake Victoria has experienced eutrophication which has led to negative changes in the lake ecosystem.

Residents in the urban and peri-urban informal settlements of Kisumu have been relying on groundwater as the main source of supply with little regard to quality. Previous water quality studies in Kisumu and Ahero (Nyilitya, 2020) show significantly high nitrate concentration above the WHO threshold. Ingestion of nitrate compounds has been linked to several health problems in human beings, including methaemoglobinaemia in infants, various types of cancers, adverse reproductive outcomes including birth defects and spontaneous abortion, thyroid gland hypertrophy, hypertension and diabetes. These toxic effects are more severe in vulnerable groups such as infants, pregnant women and the elderly, as well as those with compromised immune systems (Campbell. *et al*, 2015).

1.3 Justification

Non communicable diseases (NCDs) are a challenge to development, especially in developing countries. They were responsible for 63% of deaths in low- and middle-income countries in 2008 (WHO, 2015) . In prevention of these diseases, the focus tends to be on lifestyle modification. There is limited research describing environmental factors as causative agents of disease, therefore, their full contribution is not yet known (Norman. *et al*, 2013).

Increase in non-communicable diseases is now parallel to communicable diseases, leading to a double burden of disease in developing countries (Boutayeb, 2006). In the year 2015, 31% of deaths in adults were caused by non-communicable diseases, with 51% of these adults being below 70 years of age. Between 2003 and 2010, 37% percent of deaths in individuals 15years of age and above in western Kenya were attributed to non-communicable diseases (Phillips-Howard *et al*., 2014). The four leading causes of NCD related deaths are cardiovascular diseases, cancer, chronic respiratory conditions and diabetes (WHO, 2015), some of which have been associated with long term nitrate ingestion.

According to Townsend et al in 2003, human activities have led to increased nitrogen availability in the atmosphere. The full scope of interconnections between these changes in the nitrogen cycle and human health are yet to be fully understood (Townsend *et al*., 2003). It is critical to conduct an analysis of both acute and chronic human and environmental health effects resulting from nitrate abundance, as nitrate may be one of the various factors acting as causative agents of disease. Nitrate contamination of groundwater occurs through various pathways, including use of nitrogen based fertilizer, widespread use of pit latrines, improper waste disposal and industrialization.

Urban water users prefer groundwater over piped water due to its lower cost, with little attention paid to the water quality (Okotto. *et al*, 2015). At least 30% of the urban poor rely on groundwater which is supplied through communal wells, boreholes, public taps, and water vendors (Molle & Closas, 2016). A previous study of six informal settlements in Kisumu town showed that 25% of slum dwellers mainly used groundwater for drinking while 49% use it for cooking (Okotto *et al*., 2015). There are few studies in sub–Saharan Africa analysing groundwater quality, and even fewer that include analysis of the impact of pit latrines on groundwater (Graham & Polizzotto, 2013).

1.4 Research questions

a. What are the commonly used groundwater sources in urban informal settlements of Kisumu County, Kenya?
b. What are the concentrations of nitrate in these groundwater sources?
c. What are the distances between these water points and the nearest pit latrines?
d. Is there a health risk of developing non communicable diseases in the population secondary to chronic exposure to nitrate?
e. What is the prevalence of chronic diseases in the urban informal settlements of Kisumu County, Kenya?

1.5 Aims and Objectives

The aim of this study was to determine the levels of groundwater nitrate and assess the potential health risk among the residents secondary to long term exposure at this level. This was achieved through the following specific objectives:

1. To identify the commonly used groundwater sources in urban informal settlements of Kisumu County, Kenya
2. To determine the nitrate levels in the commonly used groundwater sources identified;
3. To determine the distance between these water points and the nearest sanitation facilities;
4. To conduct a health risk assessment of non-communicable diseases related to nitrate exposure in the resident population;
5. To estimate prevalence of non-communicable diseases related to nitrate exposure in these urban informal settlements , specifically diabetes and hypertension.

2. CHAPTER TWO: LITERATURE REVIEW

Water is precious and essential for human survival. Global trends show decreased availability and increasing demand of water. Provision of safe water has always been a major part of global health improvement initiatives, as evidenced by the elements of primary health care (PHC), Millennium Development Goals (MDGs) and now Sustainable Development Goals (SDGs) (United Nations, 2016). Groundwater is the centrepiece of all these initiatives. Unsafe water is the most important negative influence on the general health and wellbeing of populations, especially in developing countries, as it is responsible for up to a tenth of the global disease burden (Campbell *et al*., 2015). Great efforts are being made to increase quantity of water, with little attention being paid to quality (Chindah & Ordinioha, 2016).

Within recent decades, low- and middle-income countries have become rapidly urbanized leading to the development of megacities (Ahmed *et al*., 2016). About 40 million people in sub–Saharan Africa (SSA) reside in urban areas (Lapworth *et al*., 2017) and this number continues to grow day by day. Urbanization has been accompanied by rise of informal settlements, and this has been accompanied by increased demand for water and sanitation (WASH) services. Residents in informal settlements have turned to using groundwater and pit latrines to meet their WASH needs. This has led to compromise in groundwater quality, and many water quality studies confirm presence of several contaminants in groundwater. Nitrate is one common chemical contaminant present in groundwater, and long-term consumption of nitrate has been shown to put human beings at risk of developing chronic diseases such as diabetes, hypertension, and various forms of cancer among others.

2.1 Use of groundwater in urban informal settlements

Groundwater is the primary source of water to at least half of the world's population (Li *et al*., 2021), and this is accessed through hand dug wells, boreholes, and springs. Rapid population growth in urban areas increases demand on water distribution services, a demand which has not been met by the local bodies in charge of water provision. Delivery of water is a service influenced by many factors, including economic, social, and political factors (Ocholla *et al*., 2022). Piped water networks in urban areas are focused on the suburbs with little extension into the slums (Mitlin *et al*., 2019), partly because slum development is mainly unplanned and disorganized making it difficult for the relevant authorities to plan for extension. This situation is worse in SSA where most of its cities have the lowest proportion of piped water (Satterthwaite *et al*., 2020).

Therefore, water access options in slum areas are limited to installing a private well or purchasing water from vendors (Urfanisa *et al*., 2022). One main source of piped water within Kisumu is from Lake Victoria. This option is mostly unaffordable to majority of slum residents, as the suppliers must grapple with the added cost of water treatment, a situation resulting from pollution of the water (Nyilitya *et al*., 2020). The trend in urban slums is therefore moving towards groundwater use. In India, half of the urban residents rely on groundwater, most of which is accessed privately without planning and monitoring by the local authorities (Shah *et al*., 2015). Slum residents choose to access groundwater because it is cheaper (Foster *et al*., 2020), and this is mainly through shallow hand dug wells because the cost of construction is minimal (Nyilitya *et al*., 2020). This continuous access puts groundwater sources at risk of over-abstraction. A study on the influence of socioeconomic state on choice of water source found that well water users tended to be from the poorer wealth quintiles (Okotto *et al*., 2015).

2.2 Groundwater quality in urban informal settlements

In many urban informal settlements, piped water is either intermittent or non-existent, leading consumers to supplement their water supply through hand dug wells which tend to be shallow and unprotected; and are therefore easily contaminated by human, animal and industrial waste products (Okotto *et al*., 2015). Unprotected water sources may become contaminated by surface runoff after heavy rains (in the absence of a well head), or during abstraction of water using contaminated buckets and ropes (Okotto-Okotto *et al*., 2015).

On site sanitation in the form of pit latrines is the preferred and affordable solution to lack of centralized sewerage systems in informal settlements (Kimani-Murage & Ngindu, 2007; Sinharoy *et al.*, 2019). However, housing in slum areas is also unplanned leading to overcrowding, which then limits the distance between the latrines and wells (Herman & Ombok, 2017; Kimani-Murage & Ngindu, 2007). This close proximity further allows migration of biological and chemical contaminants from the latrines into well water. Nitrates and chloride are a by-product of faecal matter degradation, and these will leach into the ground (Shukla & Saxena, 2020), and subsequently, into groundwater. WHO recommends an ideal distance of 30 meters between latrines and wells, although a minimum of 15 meters is still acceptable (WHO, 2018). A positive correlation between depth of wells as well as distance to sanitation facilities has been noted in some studies; meaning, the shallower the well or the closer it is to a sanitation facility, the higher the level of nitrate in water (Rasolofonirina *et al*., 2015).

Compromise of groundwater quality occurs due to a combination of factors: poorly constructed pit latrines, sandy soils that lead to easy collapse of latrines and a shallow aquifer that is prone to contamination (Lapworth *et al*., 2017). Pit latrines are generally discouraged as the method of sanitation in areas with a high water table, due to the ability of nutrients to leach from the pit into the surrounding soil and consequently groundwater. When circumstances dictate otherwise, WHO recommends the pit latrines should be at least two meters above the water table in areas where mainly groundwater is used for drinking purposes to avoid contamination (Orner *et al*., 2019).

Urban agriculture is the other main pathway of nitrate contamination into groundwater. Nitrogen based fertilizers are the main stay of modern agriculture and up to 15% of derived nitrogen can persist in soil for three decades (Sebilo *et al*., 2013). In the long term, up to 12% of derived nitrogen compounds leach into the groundwater or runoff from topsoil into surface water (Sebilo *et al*., 2013).

2.3 Nitrates and non-communicable diseases

Nitrates are classified as water borne inorganic chemical compounds and are the most common chemical contaminants worldwide (Yu *et al*., 2020). The potential danger of nitrates to human health has been observed since 1945, when it was associated with methaemoglobinaemia, an acute but potentially fatal condition in infants.

According to Townsend *et al* in 2003, the full impact of these changes in the nitrogen cycle on human health is not fully understood. Nitrogen affects human health both negatively and positively (Mcnally *et al*., 2016; Townsend et al., 2003). Negative consequences may be direct or indirect. Direct consequences are diseases that develop after consumption of contaminated water. Indirect consequences occur through ecologic feedback to disease. For example, there is a positive correlation between concentrations of inorganic nitrate in surface water and abundance of larvae of the mosquito species Anopheles, Culex and Aedes (Townsend *et al*., 2003). Therefore, elevated nitrate levels may promote breeding of the vector and increase incidence and prevalence of vector borne diseases like malaria.

According to Ward, there are several mechanisms through which nitrates can cause effects on human health (Ward *et al*., 2018). The first mechanism occurs after ingestion where oral and gastric normal flora convert nitrate into nitrite which then competes with oxygen in binding haemoglobin, thereby reducing the oxygen carrying capacity of red cells (Gumanova *et al*., 2017). The second mechanism is through nitrosation, where nitrites combine with amines and amides to form potent carcinogens and teratogens (Ma *et al*., 2018). At high doses, nitrate competes with thyroid uptake of iodine, leading to hypertrophic changes (Ward *et al.,* 2010; Ward *et al*.,2018).

Chronic diseases are quickly evolving to become the largest cause of death worldwide (Anderson & Durstine, 2019). Leading chronic diseases include cancer, diabetes, cardiovascular disease, and chronic respiratory disease. These were responsible for 39 million deaths worldwide in the year 2016 (Anderson & Durstine, 2019). Long term ingestion of nitrates has shown to have effects on blood pressure and blood sugar regulation, development of cancer, thyroid gland function, respiratory conditions and reproductive outcomes (Bahadoran *et al*., 2016; Hezel *et al*., 2015; Lundberg *et al*., 2018; Ma *et al*., 2018; Mcnally *et al*., 2016; Ward *et al*., 2018). These diseases are a result of complex interaction between amount of nitrate ingested, ingestion of precursors and cofactors of nitrosation and presence of medical conditions that increase nitrosation. Effects on livestock and the environment have also been noted. It is important to conduct nitrate risk analysis in high-exposure areas.

2.3.1 Cancer

Once ingested, nitrates are converted to nitrites through a process of gastric nitrosation. These nitrites react with secondary amines to produce nitrosamines (Ward, 2009). Data from the International Agency on Research of Cancer (IARC) support a role for N-nitroso compounds in causing tumours (IARC, 2010), although epidemiologic studies relating cancer to nitrate intake have reported inconsistent findings. Therefore, ingested nitrates and nitrites have been classified under group 2A, that is, probably carcinogenic to humans under conditions that result in nitrosation (IARC, 2010). The main source of human exposure to nitrate is through water and vegetables but the nitrate form found in vegetables is less likely to result in endogenous formation of N-nitroso compounds (IARC, 2010) possibly due to the presence of inhibitors of nitrosation for example dietary antioxidants like vitamin C and E.

Studies show evidence of association between nitrate in drinking water and various forms of cancer, the association being most significant with gastric and bladder cancers (Picetti *et al*., 2022). In central India, ingestion of nitrate levels above 45 ppm was associated with increased risk of gastrointestinal tumours (Taneja *et al*., 2017) whereas an inverse relationship between nitrate ingestion and gastric cancer was reported elsewhere (Xie *et al*., 2016) meaning that ingestion of high nitrate is actually gastro protective. Long term exposure to nitrate levels above 25 ppm is associated with increased risk for colon cancer (van Grinsven *et al*., 2010). The higher the level of nitrate in drinking water, the higher the risk of colorectal cancer (Schullehner *et al*., 2018). A case control study in Italy and Spain also found an association between colorectal cancer and drinking water nitrate (Espejo-Herrera *et al*., 2016), with a stronger association in subjects who ingested other forms of dietary nitrate. A positive association has been observed between bladder cancer and nitrate concentration in drinking water, with risk being higher in concentrations above the 95th

percentile as compared to the lowest quartile (Hughes Barry *et al*., 2020). Ward points out that most studies relating cancer and nitrates have been ecologic in design, with the rest being case control and cohort in design.

2.3.2 Hypertension

Several clinical trials have shown that nitrate can affect blood pressure. Oral nitrate ingestion has now been consistently observed and reported to reduce both systolic and diastolic blood pressure (Ahluwalia *et al*., 2016). This occurs through the vasodilative effects of nitric oxide, a compound resulting from reduction of ingested inorganic nitrate in the nitrate-nitrite-nitric oxide pathway (Kapil *et al*., 2020).

Early investigations suggested that nitrate had no beneficial effects on blood pressure. Administration of potassium nitrate caused an increase in blood pressure (Gilchrist *et al*., 2011), but further investigation has demonstrated that this effect is transient . A study was conducted to assess the effect of increased drinking water nitrate on blood pressure of school going children. This study concluded that effects of sodium and nitrate on blood pressure appear to be additive yet independent of each other (Pomeranz *et al*., 2000), where the mean systolic blood pressure was highest in the groups ingesting the most nitrate.

Hypertension is a chronic disease with multifactorial origin and is characterized by persistently elevated blood pressure. Recent evidence shows that nitrate may have cardioprotective and antihypertensive effects. Nitrate rich diets have been shown to effectively reduce baseline blood pressure and improve vascular function within 150 minutes through vasodilatation (Jonvik *et al*., 2016). However, these beneficial effects have been observed in hypertensive patients who are drug naïve, while nitrate supplementation seems ineffective in hypertensive patients who have commenced an antihypertensive drug regimen (Broxterman *et al*., 2019). Long term consumption of up to three years has not been associated with increased risk of hypertension despite the level of consumption (Golzarand *et al*., 2016). Overall, current research shows that dietary supplementation of nitrate is beneficial in lowering blood pressure.

2.3.3 Diabetes

Diabetes mellitus is an NCD characterised by hyperglycaemia. Existing literature is exhaustive in pointing out modifiable and non-modifiable risk factors as causative agents of diabetes. The contribution of contaminated groundwater is often overlooked or sidelined when discussing aetiology of diabetes. Groundwater contamination is emerging as a possible predisposing risk factor to diabetes mellitus. Some studies have suggested that the geographical distribution of diabetes is related to groundwater contaminants, therefore it is important to study the links between the two (Osayomi, 2021).

Nitrosamines lead to generation of free radicals which are directly toxic to pancreatic beta cells, leading to apoptosis and development of insulin dependent diabetes mellitus (Longnecker & Daniels, 2001). An increased risk of type 1 diabetes mellitus has been observed in some studies with very high nitrate levels (Bahadoran *et al*., 2016) but evidence from multiple studies is conflicting, and further research is required for clarification. Increased risk of developing type 1 diabetes has been reported after consumption of nitrate above 40 ppm has been reported in a study done in Colorado, America (Bahadoran *et al*., 2016) but the same results were not reported in similar studies conducted in Scotland and central England (Parvizishad *et al*., 2017). High blood nitrate levels have been associated with a 1.7-fold increase in risk of developing type 2 diabetes (Gumanova *et al*., 2017). However, recent research in patients with pre-existing type 2 diabetes demonstrates that ingested nitrate, once converted to nitric oxide, attenuates hyperglycaemia, reduces insulin resistance, and improves hyperlipidaemic states (Lundberg *et al*., 2018) . Male offspring are more susceptible to developing the disease if exposed to *N*-nitroso compounds during the early stages of pregnancy (Bodin *et al*., 2015).

3. CHAPTER THREE: METHODOLOGY

3.1 Study design

This study adopted a descriptive cross-sectional design.

3.2 Study area

The study was conducted in Kibos, Obunga and Nyalenda "A" settlements located in Kisumu, which is county number 42 (KLRC, 2023) . It has an approximate area of 2,407 km^2 , a total population of 1,031,485 and a population density of 402.5 (KNBS, 2012). Administratively, all these settlements are in Kisumu East Location, Winam sublocation. Kibos is in East Kolwa ward, Obunga is in Kisumu East ward, while Nyalenda "A" is in West Kolwa ward (Maoulidi, 2010). Nyalenda A and Obunga are urban informal settlements, while Kibos is a peri-urban settlement with an abundance of agricultural practice. Below is a pictorial representation of the informal settlements in Kisumu County (figure 1)

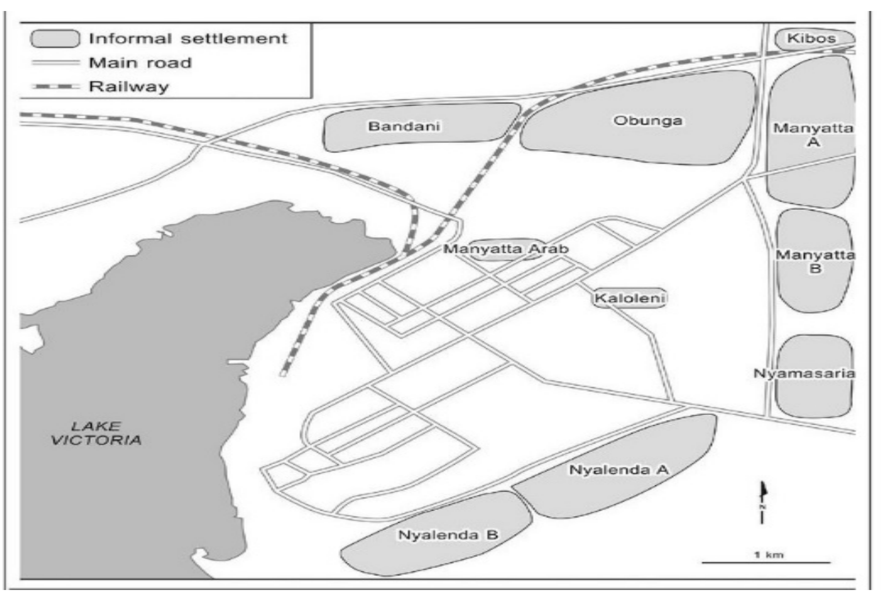

Figure 1: map showing informal settlements in Kisumu County.

Source: adapted from Pamoja Trust, 2005

The county is located in the western border of Kenya. It lies within longitudes 33º 20'E and 35º 20'E and latitudes 0º 20'South and 0º 50'South (KNBS, 2015). It has nine informal settlements, and this is where at least 60% of the urban population resides (Maoulidi, 2012; Simiyu *et al*., 2019). In 2013, the total population living in informal settlements was estimated to be 179,424 people with about 91% of these residents residing in urban areas while the rest reside in peri-urban areas (Kenya National Bureau of Statistics, 2013). The area has a high water table (Simiyu *et al*., 2017) which puts groundwater under constant threat of contamination from pit latrines.

3.3 Variables

The outcome variable was the risk of development of disease, referred to as hazard index (HI) or hazard quotient (HQ). Human health risk assessment was calculated from the chronic daily index (CDI) and oral reference dose (RfD) and reported as high (>1) or low (≤1).

The predictor variables included the concentration of nitrogen compounds in groundwater, socio-demographic factors of the respondents (age and sex), water intake rate and length of stay within the area as shown in the table below. These variables directly influence the outcome variable: nitric oxide (a product of nitrate reduction) increases significantly with age in women but not in men (Tokumitsu *et al*., 2000), water intake rate determines the amount of exposure thereby determining risk, and length of stay defines chronicity and increases risk.

These variables were measured as continuous, nominal or discrete as shown in the table below (table 1):

Table 1: Predictor variables and their measurement

Predictor variable	Type	Unit of measurement
Age	Continuous	Years
Sex	Nominal	Male or female
Water intake rate	Continuous	Liters per day
Length of stay	Continuous	Years
Nitrate concentration in water	Discrete	Parts per million

3.4 Study population

There were two study populations: various groundwater sources (wells and springs) and heads of households. The preferred head of household was female as it was assumed that the female head of household would be more aware of the household water sources and use. In households where there was no female head, the male head was interviewed.

3.5 Sampling

Mapping of groundwater sources was done between 14/05/18 and 18/05/18 using a GPS machine Garmine Trex 10™. The snowball method was employed, where residents were used to identify existing groundwater sources. Each water source was mapped based on these referrals, until all the sources were exhausted. Out of the 82 wells and springs that were mapped, 45 were selected for sampling; and this calculation was done using the Yamane formula (Kasiulevičius *et al*., 2006).

Household data was collected from a total of 299 households. This figure was obtained through calculation using the formula for calculating sample size in cross sectional studies (Charan & Biswas, 2013). The calculation was based on data obtained from the 2009 Kenya Population and Housing Census (Kenya National Bureau of Statistics, 2010). The sampling frame consisted of the households in the three informal settlements. The sampling unit was the individual household. The 299 households where questionnaires were administered were selected through simple random sampling.

The distribution of groundwater sources and households was done proportionate to the size of the informal settlement; and was based on the following calculation as shown in the table below (table 2):

Table 2: Distribution of groundwater sources and households among the informal settlements in Kisumu County

Settlement	No. of wells and springs mapped	No. of wells and springs sampled	No. of existing households	No. of households sampled
Kibos	19	19/82 × 45 = 10	2,168	2168/13791 × 299 = 48
Obunga	18	18/82 × 45 = 10	3,553	3553/13791 × 299 = 77
Nyalenda "A"	45	45/82 × 45 =25	8,070	8070/13791 × 299 = 174
Total	**82**	**45**	**13,791**	**299**

3.6 Data collection

Data was collected over a period of 6 days, between 11/03/19 and 16/03/19. Pretesting of questionnaires was done in Kodiaga settlement. This is an urban informal settlement and was selected for pre-testing because it was an accurate representation of the target locations where the study was later carried out. Data collection was done from two populations: households and groundwater sources.

3.6.1 Collection of water samples

Water was collected in clean, single use, plastic (high density polyethylene) containers which had a volume of 500ml. These bottles were first rinsed with water from the groundwater source, and emptied before sample collection was done.

The types of groundwater sources that were sampled were springs (protected or unprotected) and wells. Sub-surface water sampling was done at a depth of 20 - 30 cm for unprotected wells. In the case of protected springs and pumps, water was collected at the point of discharge. In the case of wells, the buckets that the residents usually used for abstraction of water were the same ones used for sample collection (Bartram *et al*., 1996). All samples were filtered using Whatman™ filter paper size 1 micron before analysis to avoid suspended material interfering with spectrophotometry. Afterwards, two drops of dilute sulphuric acid were added into each sample for purposes of sample preservation. The bottles were then labelled with a unique identification code and immediately stored in a cooler box with ice packs.

Once the target number of water samples had been collected, they were transported in the cooler box and stored in a refrigerator at 2°C - 6°C awaiting laboratory analysis. The entire collection procedure was done according to American Public Health Association (APHA, 1999) guidelines on the standard methods for the examination of water and wastewater.

3.6.2 Household data collection

Questionnaires and observation checklists were used to collect data from 299 households. In each settlement, a starting point was identified at the boundary. Using a local guide, researchers were guided from one household to another in a linear fashion, as much as the settlement's layout would allow. In each household, the head of the household was interviewed.

3.7 Data analysis

3.7.1 Analysis of household data

Data was sorted and then checked for completeness and consistency. Questionnaires were checked daily for completeness and consistency, and any forms with missing data were kept aside for a repeat visit. Verification was conducted to identify errors.

Data was initially entered into a Microsoft Excel spreadsheet. The validated dataset was then transferred to International Business Machines Corporation - Statistical Package for the Social Sciences (IBM - SPSS®) version 22.0. For descriptive data, analysis was done, and data was displayed as tables and graphs.

The normality of the distribution of data was done using Skewness test, and data was found to be non-normally distributed. Mann-Whitney U test and Point-Biserial correlation calculators were used to determine the existence of a significant statistical relationships between the observed nitrate concentration and independent variables; namely presence or absence of protection of the water sources and distance from sanitation facilities. Values of $p<0.05$ were considered statistically significant.

3.7.2 Analysis of water samples

Analysis was done within a week of collection at the Department of Geology, University of Nairobi. This was done using a DR6000™ Ultra Violet (UV) Visible Spectrum (VIS) spectrophotometer without radiofrequency identification (RFID) technology. Samples were first brought to room temperature at the time of analysis to increase accuracy.

The cadmium reduction method was used. For purposes of accuracy and reliability, the machine was first calibrated using a pre-manufactured standard solution. Afterwards, a standard concentration of cadmium was introduced into each sample. Cadmium reduced the nitrate in the samples to nitrite. A further reaction between the nitrite and sulphuric acid resulted in a change of colour, from clear to red. The wavelength of this colour change was measured by the spectrophotometer. Each sample was analysed individually with results being recorded in a spreadsheet.

Using this method, the machine had a precision (95% confidence interval) of 0.35 – 0.45 ppm for nitrate-nitrogen (NO_3-N), a sensitivity of 0.003 ppm and a minimum detection limit of 0.01ppm for the same.

3.8 Health Risk Assessment

3.8.1 Exposure assessment

Acceptable daily intake (ADI) is the amount of chemical that can be ingested daily by a human being without subsequent hazardous effects (EPA, OEI, SOR, 2012). ADI was set as 0 – 3.7 mg/kg body weight for nitrate and 0 – 0.07 mg/kg body weight for nitrite (US EPA, 2015)

Chronic daily intake (CDI) is an estimate of the level of chemical that all subgroups of the population can be exposed to daily for a chronic period of time without hazardous effects. It is expressed as mg/kg/day. CDI was calculated as follows (Wu & Sun, 2016):

$$CDI = \frac{conc \times IR \times EF \times ED}{BW \times AT}$$

Where:

Conc. = nitrate concentration in water expressed in ppm

IR = intake rate of water which has been standardized by WHO to 2L/day for adults (Rausand, 2011) and 1L/day for children (Moya, 2008).

EF = exposure frequency for chronic duration expressed as 365 days/year

ED = standardized to 6 years for children and 30 years for adults (EPA, 2005)

BW = body weight which has been standardized by WHO to 70kg for adults (EPA, 1989) and 15kg for children (Zheng *et al*., 2010)

AT = average time expressed in days (age × EF)

3.8.2 Effects assessment

Oral reference dose (RfD) is the estimated level of chemical where daily exposure at this level is unlikely to produce hazardous health effects in humans (EPA, OEI, SOR, 2012). A RfD of 1.6 mg/kg/day was used (US EPA, 2015).

3.8.3 Risk characterization

The hazard quotient (HQ) is ratio of the potential exposure to a substance and the level at which no adverse effects are expected (US EPA, 2011). This was calculated to determine the overall potential for non-carcinogenic health effects of exposure to nitrate.

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

A value of less than or equal to one shows that the risk of adverse effects is minimal (HQ≤1). HQs greater than 1 show that the risk of adverse effects is present but the increase in risk is not necessarily linear to the dose of exposure (HQ >1). Therefore, the higher the HQ, the higher the health risk.

3.9 Ethical considerations

Ethical approval was obtained from the Kenyatta National Hospital (KNH) – University of Nairobi (UON) Ethics and Research Committee (ERC) protocol Number P448/06/2018 (appendix IV). Further approval was also sought from the National Commission for Science, Technology, and Innovation (NACOSTI) permit number: NACOSTI/P/18/3232/14903 (appendix V). County administration approval was obtained from both Nairobi and Kisumu counties. Informed written consent was sought and obtained from all participants prior to data collection. To maintain confidentiality, participants’ names were omitted from the data collection forms.

4. CHAPTER FOUR: RESULTS

4.1 Socio-Demographic characteristics of respondents using groundwater for domestic use.

Respondents from 299 households were selected through simple random sampling to be interviewed. These households had access to groundwater for drinking and domestic use. The households were located in both urban and peri-urban informal settlements. Of the households interviewed, 83.9% (n=299) were located in urban settlements, while 16.1% (n=299) were in peri-urban settlements.

The length of stay in their current residence was assessed and about 52% (n=299)) of the respondents reported to have been residents for 1-5 years, about 21% (n=299) of the respondents reported 6-10 years of residence, whereas about 25% (n=299) of the respondents reported eleven or more years of residence. Of the household heads interviewed, 241 were female (81.6%) and 58 were male (19.4%). The age of the respondents ranged between 18 years and 87 years with a mean and median age of 33 and 28 years respectively. This is summarized in table 3.

Table 3: Socio-demographic data of the residents using groundwater in urban and peri-urban informal settlements in Kisumu County (n = 299)

Variable		Frequency	Percentage (%)
Type of settlement	Urban	251	83.9
	Peri-urban	48	16.1
Sex of respondents	Male	54	19.4
	Female	241	80.6
Length of stay	1-5 years	158	52.8
	6-10 years	65	21.7
	>10 years	76	25.4
Age	18-25 years	105	35.1
	26-59 years	170	56.8
	≥60 years	24	8.1

4.2 Groundwater sources in the study area

Within the study area, respondents were asked to identify the commonly used groundwater sources. A total of 90 groundwater sources were identified using the snowball method; and 45 of these were selected for water sampling. Out of these, 35 were hand dug wells (77.8%) while ten were springs. The presence of protection of groundwater was assessed, that is, the presence of a non-porous wall lining as well as an intact and fitting lid. Out of the 45 sampled sources, 22 (48.8%) were found to be protected. Below are examples of a protected versus an unprotected well (figure 2 and 3).

Figure 2: A protected hand dug well with intact well head and well cover.

Figure 3: An unprotected hand dug well.

Pit latrines were the main mode of sanitation used in the study area. To avoid contamination of groundwater by faecal matter, a minimum distance of 15 metres is recommended between groundwater sources and sanitation facilities (Usman & Aliyu, 2020). Only 13 out of 45 (28.8%) groundwater sources met this recommendation, meaning that the wells were dug too close to pit latrines. None of the wells was located more than 30 metres from a pit latrine. Below is a pictorial presentation of a well adjacent to a pit latrine (figure 4).

Figure 4: A hand dug well situated adjacent to a pit latrine. The water is under great threat of contamination.

Below is a summary of the physical characteristics of the wells and springs sampled in the study area (table 4).

Table 4: Physical characteristics of groundwater sources in urban and peri urban informal settlements in Kisumu County (n = 45)

Variable		Frequency	Percentage
Type of groundwater source	Wells	35	77.8
	Springs	10	22.2
Presence/Absence of protection	Protected	22	48.8
	Unprotected	23	51.2
Distance from nearest sanitation facility	< 15 meters	32	71.2
	15 – 30 meters	13	28.8

4.3 Nitrate levels in groundwater

A total of 45 groundwater sources were sampled. Groundwater analysis revealed high variability of nitrate levels. The highest nitrate level was 27.1 ppm while the lowest was 0.2 ppm. The mean±standard deviation (SD) nitrate level in this study was 6.618 ± 6.782 ppm while the variance was 45.991. The presence of nitrates was thought to be contributed to mainly by sanitation practices, with a minor contribution from agricultural practices (Nyilitya, 2020). Twelve out of 45 water samples (26.6%) were found to have nitrate levels exceeding the recommended cut-off of 10 ppm and were therefore not recommended for drinking purposes. A summary of the nitrate concentration in the various wells and springs sampled is shown in table 5 below.

Table 5: Nitrate concentration in groundwater sources in urban and peri urban informal settlements in Kisumu County (n = 45)

Source number	Nitrate level (ppm)	Type of source
W1	0.2	Well
W2	4.3	Well
W3	8.8	Well
W4	27.1	Spring
W5	11.3	Well
W6	4.3	Well
W7	5.0	Well
W8	0.3	Well
W9	9.9	Well
W10	5.4	Spring
W11	14.6	Well
W12	5.6	Well
W13	0.8	Spring
W14	0.3	Well
W15	1.2	Well
W16	0.4	Well
W17	2.6	Well
W18	5.5	Spring
W19	0.3	Well
W20	6.2	Spring
W21	1.6	Well
W22	12.3	Well

W23	14.7	Well
W24	0.3	Spring
W25	13.1	Well
W26	0.4	Well
W27	7.5	Well
W28	0.6	Well
W29	2.3	Well
W30	13.1	Spring
W31	8.1	Well
W32	1.7	Well
W33	0.3	Well
W34	15.7	Well
W35	1.9	Well
W36	17.1	Well
W37	0.6	Spring
W38	4.2	Well
W39	3.3	Well
W40	3.7	Spring
W41	0.5	Well
W42	19.7	Well
W43	15.9	Well
W44	3.9	Spring
W45	21.4	Well

The significance of the relationship between the nitrate levels, and distance was assessed (the distance between the pit latrines and dug wells). The result of the chi square test was chi square =

0.1205 and p-value = 0.72853. This value is not significant at $p<0.05$, meaning there is no relationship between the two variables. This is summarised in table 6.

Table 6: Association between nitrate levels in groundwater and distance from sanitation facilities (n = 45)

	Nitrate level <10ppm	**Nitrate level >10ppm**	**Total**
Distance <15m	23	9	32
Distance >15m	10	3	13
Total	33	12	45

$x^2 = 0.1205$ p-value = 0.72853

4.4 Health risk assessment

The non-carcinogenic health risk due to exposure to nitrate was calculated as chronic daily intake (CDI) and hazard index (HI). The CDI obtained in this study ranged between 0.189 - 0.774 with a mean±standard deviation (SD) of 0.189±0.192. The HI calculated was 0.003 – 0.484 with a mean±SD of 0.118±0.119.

4.5 Prevalence of non-communicable diseases

Data was collected on history of non-communicable diseases amongst the members of each household. The diseases of interest were diabetes, hypertension, and any form of cancer. Generally, prevalence of NCDs was very low, with over 80% of the individuals having no history of NCDs. Of those with a positive history, hypertension was the most prevalent and cancer was the least prevalent disease. A summary of the history of non-communicable diseases among the respondents is shown in the table below (table 7):

Table 7: History of non-communicable diseases in urban and peri urban informal settlements in Kisumu county (n=299)

Number of respondents	299
• **Male**	54
• **Female**	241
History of NCD	
• **Diabetes**	18 (5.9%)
• **Hypertension**	26 (8.7%)
• **Cancer**	2 (0.6%)
• **No history of NCD**	263(84.8%)

Blood pressure and random blood sugar measurement was done for all consenting individuals who were above 18 years of age. For random blood sugar, the cut-off was set at 11.1mmol/L (American Diabetes Association, 2018). For blood pressure, elevated values were defined as high normal (systolic pressure of 135-139 mmHg or diastolic pressure of 85-89 mmHg) or hypertension (systolic pressure of >139mmHg or diastolic pressure of >89mmHg) (Ministry of Health, 2018). Recorded values were an average of two readings taken five minutes apart. Within this population, the prevalence of diabetes was at 4%, while the prevalence of hypertension was slightly higher at 19.9%.

Table 8: Prevalence of non-communicable diseases in urban and peri urban informal settlements in Kisumu county (n=299)

Non communicable disease	Prevalence
Diabetes	
• Elevated RBS	12 (4%)
• Normal RBS	287 (96%)
Hypertension	
• High normal blood pressure	17 (5.9%)
• Hypertension	42 (13.9%)
• Normal blood pressure	240 (80.2%)

It was noted that during questioning, the number of respondents with a positive history of diabetes was 5.9%, while the prevalence upon measurement was 4%. This disparity may have been caused by respondents being on treatment and achieving glycaemic control. The proportion of respondents with a positive history of hypertension was 8.7%, while the prevalence upon measurement was 19%. A possible explanation is that these respondents may have been asymptomatic and therefore unaware of development of the disease.

5. CHAPTER FIVE: DISCUSSION

Water is a valued resource with multiple uses including industrial, agricultural, and domestic purposes. Adequate supply of safe drinking water has been recognised worldwide as a basic human need. Groundwater plays a very important role in the development and management of water resources. Globally, groundwater is extensively exploited due to increased demand of water which is a result of rapid population growth. Groundwater is a major source of fresh water, and it is a particularly important resource in arid and semiarid areas where surface water is scarce.

Safe and renewable supply of groundwater is a crucial driver of sustainable development in any nation. Groundwater is the main alternative in informal settlements where reliable and safe water options are not available (Roy *et al*., 2016). Groundwater sources are under threat of contamination from various anthropogenic activities resulting from urbanization, agriculture, mining, industrial activities and environmental changes (Li *et al*., 2021; Yu *et al*., 2020). Multiple contaminants are emerging, and these pose a threat to human health and environment. Concern about environmental related disease is on the rise, with WHO reporting that a quarter of mortalities have resulted from environmental risk factors (Radfard *et al*., 2019).

The main objective in this study was to determine the nitrate levels in the various groundwater sources in the study area, and to assess if residents who consumed this water were at long term risk of developing chronic diseases. The study area has a high water table; therefore, the water is prone to contamination. Residents in informal settlements who are using groundwater from various sources are exposed to contaminants and are therefore at increased risk of chronic diseases.

5.1 Groundwater sources in informal settlements

The urban population is expected to double in number by the year 2050 (The World Bank, 2023) and the bulk of this growth will occur in informal settlements. The highest percentage of growth in urban areas is predicted to occur in Africa (Havik, 2012). The speed and scale of urbanization is accompanied by challenges in availability of basic needs, with provision of clean and safe water being one of these needs. All governments should strive to provide access to clean water and sanitation facilities to all populations. Urban informal settlements lack adequate access to piped water, and this deficit is more marked in informal settlements (Kiptum & Ndambuki, 2012). This contributes to the poor state of health observed in this population.

Globally, about 2.5 billion people rely on groundwater for daily use (Grönwall & Danert, 2020). Nine percent (9%) of the world's freshwater sources are available in Africa (Havik, 2012). People living in urban informal settlements are heavily reliant on groundwater as their main source of water for domestic use. In SSA, about 54% of the urban population receives safe piped water, while those in informal settlements remain either un-serviced or under-serviced by water provision companies (Ocholla *et al*., 2022).

Piped water supply in slum areas tends to be characterised by intermittent supply and poor quality of water (Urfanisa *et al*., 2022). Slum residents seek water supply from surface and groundwater sources, or unregulated small-scale vendors (Sinharoy *et al*., 2019). Groundwater is the preferred source because it is readily accessible and available (Lapworth *et al*., 2017), but it is vulnerable to contamination. Regulatory bodies that manage urban groundwater reserves rarely exist in most countries, and this lack of governance leaves groundwater vulnerable to over-exploitation.

In this study area, groundwater was accessed either through shallow hand dug wells, or springs which were community owned. Wells are constructed through human effort while springs are naturally occurring. A total of 90 groundwater sources were identified by residents as commonly used, and 45 of these were selected for water sampling; 35 hand dug wells and ten springs. The sanitary features of the water sources were observed. These included presence of a well cover, presence and state of wall lining, and presence of any waste material around the well. A total of 23 of the wells and springs observed were constructed without adequate protection (51.2%, n=45), because use of protection would increase construction costs in an already strained socioeconomic setting. The effects of lack of protective mechanisms were noted, as six wells and springs were visibly turbid while two wells contained some dead animal bodies.

5.2: Nitrate levels in groundwater

Quality of drinking water is of great importance because it relates directly to human health. About 80% of diseases in the tropics results from water contamination (Ochieng *et al*., 2011). Groundwater contamination is the addition of undesirable substances to groundwater, and this is a result of human activities. It is a global problem which has significant impact on human health. Contaminants are broadly classified as chemical, biological and radioactive. Chemical contamination is a common theme that has been reported in groundwater quality studies over the past three decades (Li *et al*., 2021). Contaminants in groundwater are colourless and odourless, and in addition, the negative impacts on human health are chronic (Tirkey *et al*., 2017).

Nitrate is a common inorganic chemical groundwater pollutant due to its highly soluble nature. It is a critical ion that influences groundwater quality, and its presence, especially in high levels, is evidence that poor sanitation impacts groundwater (Shivendra & Ramaraju, 2015) . Nitrate occurs naturally in the environment as a by-product of degradation of organic matter and easily leaches into groundwater. Organic and inorganic nitrogen is usually converted to ammonia, and then oxidized into nitrite and nitrate. Nitrate in soil is usually taken up by plants during growth. However, excess nitrate readily leaches into groundwater where it persists for long periods of time due to the anaerobic conditions underground.

In urban environments, several factors have been considered as contributing to a marked increase of nitrate levels in groundwater; these include industrial activities, use of pit latrines for sanitation purposes and use of nitrogen based fertilizers in agriculture (Zendehbad *et al*., 2022). In recent decades, nitrate has attracted considerable attention because of high concentrations being detected in drinking water. Nitrate contamination of groundwater is a common problem across Africa that has been demonstrated in studies across several countries such as Cameroon (Ouedraogo & Vanclooster, 2016) , Tanzania (Pantaleo *et al*., 2018) and South Africa (Esterhuizen *et al*., 2015; Kringel *et al*., 2016) among others. Degradation of groundwater quality in Kisumu has been documented in previous studies (Cronin *et al*., 2007; Nyilitya *et al*., 2020) continues to be a cause of concern.

The mean±standard deviation of nitrate level obtained in this study was 6.618 ± 6.782 ppm, and this was within acceptable levels. Drinking water with levels of nitrate at or below 10 ppm is considered safe for all age groups (KNBS, 2012; World Health Organization, 2016). Based on the overall vulnerability of the groundwater sources, the mean nitrate level was surprisingly low. This may have resulted from sample collection being done during the dry season. During the dry season, nitrate tends to accumulate in soil. Once the rainy season begins, there is a rise in the water table and increased mobilization of nitrate into groundwater.

A wide range of nitrate levels was observed between the different water sources, with the highest being 27.1 ppm and the lowest being 0.2 ppm. The presence of nitrate was probably mainly caused by leaching from pit latrine contents. Human waste is the main input into pit latrines, and this waste contributes to both chemical and microbiological contaminants. The extent to which pit latrine waste contaminates water is dependent on environmental conditions of the geographical area, such as depth of water table and type of soil and other geological factors.

Nitrate contamination was also caused by fertilizer use as an aid for agriculture (Nyilitya, 2020). A few of the wells were located within farms, and this was noted especially in the peri-urban settlements. These results are fairly comparable to previous water quality studies conducted within the area (Nyilitya et al., 2020; Okotto-Okotto et al., 2015). In 2014, a study that followed up wells over a period of more than 10 years found that the mean nitrate level reduced over time, but a wide range of nitrate levels was observed between the different wells (Okotto-Okotto et al., 2015). Regular monitoring of nitrate levels is essential to safeguard against elevation to toxic levels.

5.3: Distance between groundwater sources and sanitation facilities

With the global increase in urbanization, informal settlements are a growing challenge in urban and peri urban areas. Since the year 2000, the urban population has grown by six million people annually, with 90% of this growth occurring in developing countries (Sinharoy *et al*., 2019; WHO & UN-HABITAT, 2010). Slum residents depend on pit latrines and groundwater to meet their sanitation and water needs, as these needs are not being met by the local municipal bodies. Simple pit latrines were chosen mainly because of cost and ease of construction.

Housing structures in the study area were mainly unplanned, and this resulted in poor environmental planning as evidenced by the paucity of piped water networks and sewerage systems. The residents resorted to digging shallow wells to access drinking water, while others accessed nearby springs. These water sources were found to be closely situated to pit latrines, and in addition to this, the level of protection of the well also reduced the risk of contamination of water. Approximately half of the wells (51.2% n=45) were observed to have inadequate protection, and six of these water sources were observed to contain visibly turbid water.

A study by Kimani- Murage & Ngindu reported that slums are marked by overcrowding, and this limited the distance between the wells and the pit latrines (Kimani-Murage & Ngindu, 2007). Overcrowding is a result of rapid population growth that does not allow for proper planning and construction of housing and installation of public utilities (Dupont *et al*., 2016). Use of pit latrines further increase the risk of nitrate contamination. The risk of groundwater contamination with nitrates could be higher, especially in this study area where the water table is high. Although it is difficult to give a general rule suitable for all soil types, commonly used guidelines dictate that a well should be at least 15 meters away from a pit latrine and two meters above the water table (Ahaneku & Adeoye, 2014). The WHO recommends that the ideal distance between sanitation facilities and groundwater sources should be 30 meters, but where this is not possible, 15 meters is acceptable as the minimum distance (WHO, 2018). This requirement was met by 28.8% (n=45) of the wells sampled. The shortest distance observed between a well and a pit latrine was 1.08m. This means that the wells and latrines are very closely spaced, therefore well water is under great threat of contamination.

5.4: Health risk assessment

Health risk assessment is a systematic approach to assessing potential health effects resulting from exposure to contaminants. It is helpful in understanding the probability of harmful impact on human health as a result of exposure to a contaminant. The non-carcinogenic health risk was calculated using the human health risk assessment (HHRA) model, as recommended by the USEPA (USEPA - U.S, 2005) .

The primary route of exposure to nitrate is through ingestion. Nitrate can be consumed through contaminated drinking water or food. Nitrate is greatly concentrated in many types of vegetables and can be found in lower concentrations in processed meat products and fruit. Other routes of exposure include dermal exposure through application of topical drugs, and inhalation route (Rahman *et al*., 2021). This study focused on exposure through drinking water. Infants below the age of four months and pregnant women are the population groups that are at the greatest risk of adverse health effects from nitrate exposure (ATSDR, 2017).

The chronic daily intake (CDI) is the average range of nitrate levels that the residents are exposed to daily through drinking groundwater. The CDI was calculated from the concentration of nitrate present in water sampled, duration of exposure to nitrate, standardized water intake rates and body weight. In this study, the CDI was 0.189 - 0.774 mg/kg/day. The oral reference dose (RfD) is the maximum acceptable oral dose of a contaminant, such that there should be no adverse effects noted even after a lifetime of exposure below this dose. A standardized RfD value of 1.6 mg/kg/day was used for nitrate.

Non carcinogenic health risk was expressed as the hazard index (HQ), and it is calculated from the CDI and the RfD. Based on USEPA guidelines, a HQ of less than or equal to one ($HQ \leq 1$) is ideal (US EPA, 2015).The HQ calculated in this study was 0.003 – 0.484. Since all these values were less than one, they indicated that the risk of adverse effects of nitrate ingestion to the population is currently low. The effect of unsewered sanitation has been demonstrated by rising nitrate concentration in groundwater elsewhere in Kenya. This study closely compares to a study conducted in urban informal settlements in Nyali and Diani-Chale (Mwaguni *et al*., 2017). Risks to human health secondary to nitrate exposure has been studied in various parts of the world, including India, China, Malaysia and Romania (Alif & Shaharuddin, 2014; Feng *et al*., 2020; Irina *et al*., 2014; Norkhadijah *et al*., 2013; Nur et al., 2017; Suvarna *et al*., 2020; Wagh *et al*., 2020; Yu *et al*., 2020). In Malaysia, low nitrate levels, and consequently low hazard index was reported despite the study being conducted in a high intensity agricultural area (Nur *et al*., 2017) and this was attributed to the study being conducted before the rainy season. A similar study conducted in India went a step further to compare nitrate levels in groundwater before and after the rainy season (Wagh *et al*., 2020) and higher levels were reported after the rainy season. Heavy rainfall leads to leaching of nitrate through soil and into water thus increasing subsurface nitrate levels. In China, assessment was carried out comparing level of health risk between two study areas (Feng *et al*., 2020) and the groundwater sources in the northern location were found to have higher nitrate levels and therefore posed a greater risk to human health. This was because the northern region is more agriculturally intensive as compared to the south.

5.5: Prevalence of non-communicable diseases

Nitrate is a metabolite of nitric oxide and is an important regulator whose role in human health remains controversial. Long term exposure to dietary nitrate has been linked to the development of non-communicable diseases (NCDs). A study investigating the relationship between fasting blood nitrate levels and presence of NCDs found that the prevalence of chronic diseases, namely diabetes mellitus and coronary artery disease, began to increase significantly among subjects with serum nitrate levels above 53.6 µm (3.33 ppm) (Gumanova *et al*., 2017). More recently, dietary inorganic nitrate is gradually being identified as having potential therapeutic effects against obesity, diabetes mellitus and hypertension; although the mechanisms of action are complex and therefore not fully understood (Mcnally *et al*., 2016). Overall, studies that have been conducted assessing chronic diseases as outcomes of nitrate exposure are very few in number and thus do not allow firm conclusions about risk (Ward *et al*., 2018). The role of nitrate as a friend or foe is yet to be fully understood, therefore any potential benefits to human health cannot yet be harnessed.

Chronic ingestion of nitrate has long been associated with development of NCDs, such as diabetes, hypertension and various types of cancer (Gumanova *et al*., 2017; Hughes-Barry et al., 2020; Jones *et al*., 2016; Ward, 2009; Ward *et al*., 2005, 2010, 2018). Of note, boiling the water before drinking does not reduce the risk of developing these diseases (Chebet *et al*., 2020). The mechanism of action is thought to be related to conversion of ingested nitrate to nitrosamine compounds, although it has been observed that the human body also forms nitrosamine compounds endogenously; as a by-product of biochemical cell reactions. Some animal studies show results that are contrary to the findings in human studies, by demonstrating that animals show improved insulin sensitivity and greater insulin secretion (Li *et al*., 2016), and improvements in endothelial function and consequently blood pressure (Bondonno *et al*., 2023). Other analysis has also shown reduced weight gain when type 2 diabetic individuals were treated with inorganic nitrate (Bondonno *et al*., 2023; Golzarand *et al*., 2016). In Spain and Italy, a case-control study was conducted and found that participants with daily nitrate intake greater than 10ppm in water had higher odds of colorectal cancer than those whose daily intake was less than 5ppm (Espejo-Herrera *et al*., 2016).

The self-reported prevalence of diabetes and hypertension was low, at 5.9% and 8.7% respectively in the study area. The mean and median age of respondents was 28 and 33 years respectively. This age is much lower than the age when non communicable diseases are likely to be diagnosed. Prevalence of NCDs is higher in the older population.

The prevalence of diabetes and hypertension was found not to vary much from the national, regional and global values. In this study, the prevalence of diabetes was at 4%. These results are not a true reflection of the actual prevalence in the study area because of a small sample size; as well as the limitation of not being able to carry out repeat measurements to ascertain the participant's true physiological state. It is well documented that a participant's blood pressure and blood sugar results are affected by factors such as time of day, emotional state and length of time post prandial. According to the International diabetes Federation, the prevalence of diabetes in Africa was 3.9% while the national prevalence in Kenya was 2.2% (IDF, 2019). These values are lower than the global prevalence of 9.3% (Saeedi et al., 2019). The prevalence of hypertension in this study was 19.9%. In Kenya, the national prevalence of hypertension stands at 24% (Ondimu *et al*., 2019), a figure which is similar to a global prevalence of 26% (Alexander *et al*., 2019).

5.6: Limitations of the study

Due to financial constraints, sampling of water sources was carried out during one season (the dry season), and therefore does not give a complete picture of the seasonal variation of nitrate levels in groundwater.

Due to limited time, serial blood pressure and blood sugar measurements could not be carried out. This was therefore not a true picture of the participant's physiological state. Blood pressure measurements were taken twice and an average of the same used in the study.

The study was not a complete reflection of all the urban settlements in the study area, since the study was carried out only in three of the settlements.

Some hostility was encountered during data collection from the residents which slowed down the process. Despite these challenges, an adequate sample size was achieved by extending the daily length of time for data collection.

CONCLUSION

Groundwater contamination is a global problem, but its nature and influencing factors vary between different countries, climatic regions and geological features. The countries that are most affected are those undergoing rapid economic development. These issues should be addressed using a wide range of measures, techniques, and policies. Occurrence of nitrate in groundwater is a serious problem that results mainly from anthropogenic nitrogen pollution and natural nitrate accumulation.

The aim of the study was to determine whether the residents in the informal settlements were exposed to any health risks after drinking groundwater contaminated with nitrate. The water table in the study area is shallow and this makes it easily to access groundwater from wells and springs. This also makes the water vulnerable to contamination from various anthropogenic activities. Despite these considerations, mean level of nitrate detected was within permissible levels. The nitrate concentration ranged from 0.2 to 27.1 ppm, with 26.6% of the sampled sources exceeded the WHO recommended cut-off value of 10 mg/L. The presence of nitrate in groundwater is possibly due to current sanitation and agricultural practices.

There prevalence of non-communicable diseases in the community was 4% for diabetes and 19.9% for hypertension. Other risk factors aside from nitrate exposure should be explored as possible confounders. The non-carcinogenic health risk to the residents is below one, therefore the population is currently not at risk of developing NCDs, but this situation may change over time, as the groundwater sources remain vulnerable to contamination.

This study emphasizes on the importance of maintaining the water quality from the different groundwater sources within the urban and peri-urban informal settlements of Kisumu.

Groundwater sources currently pose a low health risk as far as nitrate contamination is concerned to the residents in the study area. Nonetheless, creating awareness on groundwater contamination and frequent monitoring is essential to protect the resource.

RECOMMENDATIONS

1. Follow up studies of these water sources by environmental and public health institutions is recommended, particularly studies that compare seasonal variation of nitrate and studies that attempt to identify the links between nitrate and non-communicable diseases. This will prevent development of future health risks from consumption of contaminated groundwater.
2. The county government should regulate and monitor the construction and number of groundwater sites accessed by residents. Monitoring will ensure high quality of construction is adhered to and minimum safe distance from pit latrines is maintained. Regular water quality analysis should also be carried out.
3. Policy makers should create awareness about the importance of water quality among the residents in the area. Health education offered by community health workers/volunteers at a community level will increase the residents' level of knowledge on the dangers of contaminated groundwater.
4. The county government of Kisumu should put in place comprehensive sanitation and waste management plans within the informal settlements to ensure proper waste disposal and therefore prevent groundwater contamination.

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APPENDICES

Appendix I: Participant Information and Consent Form(English)

TITLE OF STUDY: Health effects resulting from nitrate exposure through drinking water in urban slums in Kisumu, Kenya

PRINCIPAL INVESTIGATOR AND INSTITUTIONAL AFFILIATION: Elver Mwara/ University of Nairobi

CO-INVESTIGATORS AND INSTITUTIONAL AFFILIATION: AFRIWATSAN

INTRODUCTION

Good morning/afternoon,

I would like to tell you about a study being conducted by the above listed researchers. The purpose of this consent form is to give you the information you will need 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 about the research or this form 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 sign your name on this form.

You should understand the general principles which apply to all participants in a 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 affect the services you are entitled to in this health facility or other facilities. 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?

The researchers listed above are interviewing individuals who consume groundwater. Participants in this research study will be asked questions about their water sources and consumption rates. Participants will also have the choice to undergo test such as random blood sugar and blood pressure measurement.

There will be approximately ____________ participants 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 30 minutes. The interview will cover topics such as water source, intake rate, duration of residency and presence of non-communicable

diseases.

After the interview has finished, blood pressure and random blood sugar measurements will be carried out. Blood pressure measurement is painless, while blood sugar measurement involves drawing a drop of blood from the tip of your finger. A sample of water will be collected from the source for further testing.

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 reason why we may need to contact you is dissemination of feedback once the study is complete.

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. However, no system of protecting your confidentiality can be absolutely secure, so it is still possible that someone could find out you were in this study and could find out information about you.

Also, answering questions in the interview may be uncomfortable for you. If there are any questions you do not want to answer, you can skip them. You have the right to refuse the interview or any questions asked during the interview.

You may feel some discomfort when the medical tests are carried out. The tests will be carried out by the principal investigator and within the household. Each member of the household will undergo the tests individually and privately. In case of an injury, illness or complications related to this study, contact the study staff right away on the following number: 0722 403 986

ARE THERE ANY BENEFITS BEING IN THIS STUDY?

You may benefit by receiving free blood sugar and blood pressure testing. We will refer you to a hospital for care and support where necessary. The information you provide will help us better understand the disease patterns in this area and is a contribution to science. Also, you will benefit from the knowledge of the quality of your drinking water.

WILL BEING IN THIS STUDY COST YOU ANYTHING?

This study is of no cost to you.

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.

The study staff will pay you back for your charges to these numbers if the call is for study-related communication.

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 study counsellor. 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 ______________

Appendix II: Participant Information and Consent Form (Luo)

WECHE MAG BETIE NONRO KOD YIE MAR DONJO E PUONJRUOK

Chakruok

Oyawore/Amosou.

Daher mar nyisiler mar nonro ma itimogijononromawaseleronimalokaemagin Elver Mwara e bwo loo Mbalariany mar Nairobi gi AFRIWATSAN. Gimaomiyowamiyi form ni mar yie kata dagibedoachiel mar jomanienonroni en mondomiyithuolo mar somogigoduto ma onegoingemondoiyierksdiherbedoachiel mar jogo kata dagibedoachiel mar jo nonrogi.

Bed thuolo mar penjo, penjomoroamora ma inyalobedogodo kaka gi ma omiyo watim ononroni, Ango ma timore kai bedo achiel kwomjo maoyoie timonon roni, rach mane kata ber mane manyalobetie, Dwol ma in godo kaka ngamao chiwore, kata gi moro amora machiel omadih erpenjo kwom nonroni kata kwom form ni ma ok iwinj e yomaler.

Bang kawaseduokopenjo ma ingodote, inyaloyie kata da gi bedo achiel kwomjo maoch iwore mondoo timnonroni. Mae en yor kwa yimondo imi wathuolo mar bedokodi e nonroni. Kaisewinjolerne ma iyiebedo e nonroni, Abiro dwaroni mondo indi knwa nyingi kendo igolwe domari e form ni.

Kawokang mar bedo e nonro-ni en kwomchiwruok nono. Inyaloweyobedo e nonrosaa moro amora ma ok iwachogimaomiyoiwuok e nonro. Kaitamoribedo e nonro-ni, ok bi chachothieth ma iosebedokaiyudo e od thiethmakae kata e od thiethmoko . Bende wabiromiyi copy mar form nimondoinbendeibedgimari ma inyalokano.

Wanyalodhimabele? Ee / Ooyo.

Nonro-niopwodhgiodthiethmaduong mar Kenyatta National Hospital- gi

Mbalariany mar University of Nairobi Ethics and gi Research Committee protocol No.

NONRO –NI EN MAR ANGO?

Nonro ma oseler nwama lokae penjo ji ma tiyogipii ma okuny. Jo mani enonro- ni ibiro penj penjo machalo kaka kama git womepii ma git iyo good kodkar rom mar pii ma gitiyogodo. Bende gi biro bedo githuolo mar yiero dwaro pi motuo mar pressure gitwo mar sukari.

ANG'O MABIRO TIMORE KA IYIE BEDO ACHIEL KWOM JOMA ITIMONEGI NONRO NI?

Kaiyie bedo achiel kwojo ma itimo nego nonro-ni, magi e gik ma birotimore:

Ibiro penji penj ogijal no ma olony e yoo mar timo nonro kama oumore ma ni thuologo ma

Inyalodwoko penjo. Penjo biro kaothuolo mar dakika piero adek (30). Bende pejo ma ibiro penji biro mulo penjo kaka ama igloo pii, Rom mar pii ma itiyo godo, Higni ma ise dak kamaidke no

Kod kabende niti eretwo chewa landore.

BENDE NITIERE RACH MORO AMORA, HINYRUOK KATA BEDO GI KIAWA MORO AMORA MA OTUDORE GI NONRO-NI?

Achiel kwom richo manya lobe doe en mana koso bedo gi siri. Wabiro pando gimoro amora ma Iwacho nwakae kaka wanyalo mondo kik dugiwuo goko. Bende wabiro tiyo kod Cod namba mari ma wanyalonge yogodo e computa man kod password kama wakano e ripode ma wayudo, wabiro keto form mari e droo ma iloro.

Bende dwoko penjo e interview nyalo bedo matekni. Kaniti penjo ma okdi herd woko to inyalokalogi. In gidhwolo mar dagibedo e nonro ni kata dwok openjo ma openj.

BENDE NITIERE BER MA ANYALO YUDO KWOM BEDO ACHIEL KWOM JOMA OTIMNEGI E NONRO-NI.

Ee enitiere, Inyalo yudo thuolo mar pimotwo mar sukari kod pressure nono, Wabiroori e Odth ieth mondo mi iyudthiethgirit ma idwaro kama nyalor. Ler ma ibiro miyowa biro Konyo wang'eyo kaka two chegin itiere kendo landore e alwora kaebende en yo mar medoparo/ rieko e science.

BENDE BEDO E NONRO-NI BIRO MIYI GARAMA MORO AMORA?

Ooyo, ok ibi bedo gigarama moro amora.

TO KA IN GI PENJO BANGE?

Ka in kod penjo moro amora kata wach moro amora kwom bedo achiel kwomjo maoti mne ginonro-ni, inyakogoyo-nwasimo kata oro nwabaru wamachchwok ne jotich mag nonro-ni e namba ma ochiw e bwo form ni.

Mondo mi inge matutthwolo/ dwol ma ingodo kaka jalno ma ochiwore bedo achiel kwomjo mait imone ginonroni, inyalogocho ne Jagoro / Jakom Kenyatta National Hospital-University of Nairobi Ethics and Research Committee No mar Ong'wryamo en 2726300 Ext. 44102 emailuonknh_erc@uonbi.ac.ke.

YIERO MARI MOKO GIN ANG'O?

Mondo mi ibed achiel kwomjogo ma itimone ginonro-ni en kwomdhwolomari e yorchiwruok. In thwolomondo mi itamribedoachielkwomjononro-ni kata inyalo weyo dhinyi meg ipenj ogisamoro amora maongela loyutomoro amora ma otudor eginonro-ni.

FORM MMAR PUODHRUOK KOD YIE BEDO E NONRO-NI.

Asomo form mar puodh ruok katao somna ma awinjo lerne. Ayudo thuolo mar twak giwinjo ler mar nonro ni gija chung nenonro-ni, Penjo na bende odwoki tee e dhok ma winjo kendo Lalkata bermany alobeti ebendeo lerna duto te.

Awinjoler mar nibedo naachiel kwomjogo ma itimo ne ginonroni en kwon yie kodc hiwruo kmara kendo anyalowe yobedo e nonro-nisaamor oamora. Ayie kwomchiw ruok mar bedo achiel kwoomjo maiti mone ginonro-ni. Kendo ange yo niibiro timmate kmondo weche ma awacho kata lerna obedm opondo.

Wach mar jabetienonro. Aseso mowecheduto kata yudo kata yudo weche mosomna. Aseyudothuolo mar loso e

Nonro nigijakony mar nonroni. Penjo mane angodoosedukoki e dhokmawinjo. Chandruok kata ohala mar nonronioselerna. Betienonroni en yieromara kendo anyalowuoksaasaya.

Ayie mondo abeti enonroni.

Ose nyi sani okang duto ibiro kawomondo weche machiwo ibiro kanmaling ling.

Kuomketokoka (lweta) e form ni, ok onyisoniaweyoratiromarakuombetienonroni.

Ayie mondo abeti enonroni: Ayie/ooyo

Ayie mar chiwo tudruo kmaraminya lotiyo godobange: Ayie/ooyo.

Nyingjabetienonro____

Lwetjabatienonro____

Appendix III: Household Questionnaire

Questionnaire Number…..

Identification

1. Name of Informal settlement

2. Ward of household

3. Household Code

4. Length of residency years

The respondent for the next section is the head of household.

Water sources and uses

1. In total how many members are in this household?

2. Ages of all household members to be indicated in years

3. What is the main source of drinking water in this household (indicate name of source)?

Classify water source (borehole = 1, spring = 2, well = 3,)

4. Is the source protected or unprotected? (researcher to observe and indicate)

(protected = 1, unprotected = 2)

5. How long have you been using this water source (number of years)?

6. How many containers of water do you collect in a day? (researcher to view the containers and indicate capacity in litres)

7. How many containers of water are used for drinking in a day? (researcher to view the containers and indicate capacity in litres)

8. Are you aware if your water source is tested for contaminants?

(yes = 1, no = 2, don’t know = 3)

9. a) Do you treat your water before drinking?

(yes = 1, no = 2)

b) If yes, what method of treatment do you use?

(boiling = 1, other = 2)

Identification of sources of nitrate contamination

1. Do you practice farming (or neighbours in the case of a communal dwelling)?

(yes = 1, no = 2)

2. What type of toilet/sanitation facility is used in this homestead? (researcher to physically view the sanitation facility and note)

(pit latrine = 1, open defecation = 2, flush toilet with septic tank= 3)

Data on non-communicable diseases

Have you or any member in this household ever been diagnosed or treated for any of the following conditions (diabetes, hypertension, cancer)?

Data on presence non communicable diseases

Disease	Present (P)/Absent (A)	Year of diagnosis (if present)	Under management (Y/N)
Diabetes			
Hypertension			
Cancer			

Blood pressure measurement to be done for any household member above the age of 13 years. If the member is below the recommended age, indicate not applicable. Random blood sugar measurement to be done for all household members. These tests will be conducted by the principal investigator. They will be conducted within the household, where each member will be examined individually.

Data on selected vital statistics

Member number	Age (years)	Random blood sugar (mmol/L)	Blood pressure (mmHg)
1			
2			
3			
4			
5			

Checklist for inspection of selected water points

1. Type of water point

(spring = 1, hand dug well = 2, borehole = 3, other = 4)

2. Is the water point protected?

(yes = 1, no = 2)

3. Presence or absence of agricultural activities around water point.

(present = 1, absent = 2)

4. Distance of nearest sanitation facility from water point in metres. (investigator to measure distance between water point and sanitation facility)

5. Type of sanitation facility.

(open pit = 1, pit without slab = 2, pit with slab = 3)

6. Is the pit latrine lined? (investigator to inquire from respondent as well as physically assess the latrine for presence of lining. Lining is use of materials such as brick, wood, concrete or stone on the inside of the pit. Lining may be partial or full)

(yes = 1, no = 2)

Appendix IV: KNH-UoN ERC approval letter

[redacted]

KENYATTA NATIONAL HOSPITAL
APPROVED
16 NOV 2018
KNH/UoN-ERC
P. O. BOX 20723 - 00202 NAIROBI

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

KNH-UON ERC
Email: uonknh_erc@uonbi.ac.ke
Website: http://www.erc.uonbi.ac.ke
Facebook: https://www.facebook.com/uonknh.erc
Twitter: @UONKNH_ERC https://twitter.com/UONKNH_ERC

KENYATTA NATIONAL HOSPITAL
P O BOX 20723 Code 00202
Tel: 726300-9
Fax: 725272
Telegrams: MEDSUP, Nairobi

Ref: KNH-ERC/A/416

16th November 2018

Dr. Elver Mbabazi Mwara
Reg. No.H57/88173/2016
School of Public Health
College of Health Sciences
University of Nairobi

Dear Dr. Mwara

RESEARCH PROPOSAL – HEALTH RISK ASSESSMENT OF NITRATE CONTAMINATION IN GROUNDWATER: A CASE STUDY OF URBAN INFORMAL SETTLEMENTS IN KISUMU, KENYA (P448/06/2018)

This is to inform you that the KNH- UoN Ethics & Research Committee (KNH- UoN ERC) has reviewed and **approved** your above research proposal. The approval period is 16th November 2018 – 15th November 2019.

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) 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.
d) 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.
e) Clearance for export of biological specimens must be obtained from KNH- UoN ERC for each batch of shipment.
f) 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*).
g) 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.

For more details consult the KNH- UoN ERC website **http://www.erc.uonbi.ac.ke**

Protect to discover

[redacted]

Yours sincerely,

PROF. M.L. CHINDIA
SECRETARY, KNH-UoN ERC

c.c. The Principal, College of Health Sciences, UoN
The Director, CS, KNH
The Chairperson, KNH-UoN ERC
The Assistant Director, Health Information, KNH
The Director, School of Public Health, UON
Supervisors: Dr. Richard Ayah, Prof. Mutuku A. Mwanthi

Protect to discover

Appendix V: NACOSTI Approval for the AFRIWATSAN project

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone: 020 400 7000,
0713 788787,0735404245
Fax: +254-20-318245,318249
Email: dg@nacosti.go.ke
Website: www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/18/3232/20891**

Date: **19th January, 2018**

Prof. Daniel Ochieng Olago
University of Nairobi
P.O. Box 30197-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"AFRIWATSAN - Sustaining low cost urban water supply and sanitation systems in Africa,"*** I am pleased to inform you that you have been authorized to undertake research in **Kisumu County** for the period ending **19th January, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Kisumu County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

GP Kalerwa

GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kisumu County.

The County Director of Education
Kisumu County.

CONDITIONS

1. You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit.
2. Government Officer will not be interviewed without prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2) hard copies and one (1) soft copy of your final report.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

REPUBLIC OF KENYA

NACOSTI

National Commission for Science, Technology and Innovation

RESEACH CLEARANCE PERMIT

Serial No.A 12285

CONDITIONS: see back page

THIS IS TO CERTIFY THAT:
PROF. DANIEL OCHIENG OLAGO
of UNIVERSITY OF NAIROBI, 0-100
nairobi,has been permitted to conduct
research in *Kisumu County*

on the topic: *SUSTAINING URBAN LOW-COST WATER SUPPLIES AND SANITATION SYSTEMS IN AFRICA*

for the period ending:
7th December,2017

Permit No : NACOSTI/P/16/3232/14543
Date Of Issue : 8th December,2016
Fee Recieved :Ksh 10000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix Vi: Turnitin report

HEALTH RISK ASSESSMENT OF NITRATE CONTAMINATION IN GROUNDWATER IN URBAN INFORMAL SETTLEMENTS IN KISUMU, KENYA

ORIGINALITY REPORT

13%	5%	12%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Jamaludin. "HEALTH RISK ASSESSMENT OF NITRATE EXPOSURE IN WELL WATER OF RESIDENTS IN INTENSIVE AGRICULTURE AREA", American Journal of Applied Sciences, 2013 Publication	<1%
2	www.tandfonline.com Internet Source	<1%
3	bmcpublichealth.biomedcentral.com Internet Source	<1%
4	Rolf Nieder, Dinesh K. Benbi, Franz X. Reichl. "Soil Components and Human Health", Springer Science and Business Media LLC, 2018 Publication	<1%
5	makir.mak.ac.ug Internet Source	<1%
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