EFFECT OF HUMAN ACTIVITIES ON GROUNDWATER QUALITY IN RURAL AND PERI-URBAN AREAS: A CASE OF KANDUYI SUB-COUNTY, BUNGOMA COUNTY, KENYA

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A research project submitted in partial fulfillment of the requirement for the award of degree of Master of Science in Water Resources Engineering to the department of Civil and structural Engineering of Masinde Muliro University of Science and Technology

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DECLARATION

This research project is my original work and has not been presented for award of any certificate, diploma or degree in any other college or university.

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CWR/G/01-53145/2018

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a thesis entitled **'Effects of human activities on quality of Groundwater in Rural and Peri-Urban areas: A case of Kanduyi, Bungoma County.**

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DEDICATION

I dedicate this work to the Almighty God and my family, who have never stopped believing in me and supporting me.

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Thank you and May the Almighty God bless you all abundantly.

ACRONYMS

GPS	Global Positioning System
KEBS	Kenya Bureau of Standards
SPSS	Statistical Package for Social Sciences
SSA	Sub Saharan Africa
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WHO	World Health Organization
WQI	Water Quality Index

ABSTRACT

Human activities and land use changes stand as the primary drivers of groundwater pollution, a consequence of growth in population, urban expansion, and heightened demand for farming and the escalated application of chemicals to enhance agricultural yields in response to growing food needs. These endeavors exert adverse impacts on groundwater quality. The central goal of the research was to analyze the influence of human activities on groundwater quality in rural and peri-urban areas of Kanduyi, Bungoma County. This main objective was realized through the pursuit of the subsequent specific aims: evaluating the sanitary-related risk factors contributing to the deterioration of water quality in wells and springs within Kanduyi, Bungoma County; ascertaining the physicochemical and bacteriological attributes of water from the existing wells and springs in the area; and assessing the water quality index for wells and springs in the seven wards of Kanduyi sub-county, Bungoma county. Total of 89 wells and 10 springs were selected by simple random technique through randomization principle to avoid biasness. Human activities neighboring water sources were investigated using structured questionnaires administered via the online mWater application. These questionnaires were completed during field visits and subsequently subjected to analysis. The study scrutinized the sanitary conditions of eighty-nine wells (89) and ten springs (10), gauging their susceptibility to contamination in connection with human activities and potential risk elements. This process involved assessment and categorization of risk levels. Moreover, samples from these sources were gathered and subjected to testing in a water laboratory, evaluating seven physicochemical parameters (pH, turbidity, electrical conductivity, total dissolved solids, nitrates, sulphates, and phosphates) as well as two bacteriological parameters (total coliform counts and E. coli presence). The results of physicochemical parameters were utilized to establish a Water Quality Index for each source. The findings demonstrated that the examined waters contained phosphates and nitrates at levels ranging from 0.39 to 24 mg/l and 1 to 51 mg/l, respectively, significantly exceeding both the recommended thresholds set by Kenya Bureau standards and the drinking water quality standards stipulated by the World Health Organization. Furthermore, inadequate drainage (58%) emerged as a potential contamination risk factor through runoff. The study employed Weighted Arithmetic Mean concept to calculate Water Quality Index and found that 6% of the wells and 50% of the springs in the study area exhibited CWQI values falling between 38 and 50, categorizing them as 'good.' Conversely, a majority of the wells (58%) exhibited Water Quality Index values ranging from 103 to 458, rendering them unsuitable for consumption because according to categorization or rating scale, any CWQI values >100 are deemed to be unfit for consumption. This state of quality is attributed to revelation that most of the wells were found to have contamination risk factors such as proximity to sanitation facilities, inadequate well covers, poor modes of solid waste disposal, carrying out farming and washing clothes from near the wells and springs. The research recommends that public health authorities in the County, along with other stakeholders, ought to heighten awareness regarding the necessity of utilizing government-approved disposal sites for solid waste. Stringent control over farming activities and washing practices near water sources should be implemented to mitigate contamination. Additionally, the study recommends that pertinent water authorities formulate groundwater management policies to guide and regulate the construction, siting, and periodic quality monitoring of these sources

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CHAPTER ONE

INTRODUCTION

1.1.Background

Water, as the most indispensable natural resource, holds vital importance. Especially in developing nations, the access to clean and safe water is a pressing concern. The severe impact of polluted water on human health is evidenced by the staggering six million deaths attributed to waterborne illnesses like diarrhea (Ghebremichael, 2004). These circumstances necessitate substantial investment in water treatment chemicals by developing countries. The quality of water in rivers is heavily influenced by human activities altering the land use within watersheds, leading to potential degradation (Machiwa and Ngoye, 2004). Land use encompasses diverse anthropogenic activities undertaken for economic, residential, recreational, conservation, and governmental purposes, closely intertwined with the evolution of human society. Historical land use patterns have shaped local and global environments, influencing present and future development trajectories (Craun, 2003; Elumalai, 2020).

Water quality is inherently multifaceted, measured by physical, chemical, and biological parameters for various uses like drinking, industry, agriculture, recreation, and habitat preservation (Giri and Qiu, 2016). However, this quality varies significantly due to geological, topographical, temporal, weather-related, and contaminant source differences (Giri and Qiu, 2016). Modifications in land cover and management practices, whether natural or human-induced, substantially impact hydrological systems, ultimately affecting runoff and water quality (Bai et al., 2010).

Transformation of land use transpires during urbanization, industrialization, agriculture, and other developmental activities. Such shifts can dramatically alter watershed surface characteristics, influencing both the quantity and quality of surface runoff. Consequently, the interplay between land use and water quality indicators becomes crucial in understanding the impact of land use changes by human activities on water quality (Tu, 2011).

Groundwater, a pivotal freshwater resource, serves as a vital source for domestic, agricultural, and industrial purposes, supplying a third of the global population's drinking water needs (International Association of Hydrogeologists, 2020). However, threats posed by urbanization, agriculture, industry, and climate change jeopardize groundwater quality. A wide array of contaminants, including toxic metals, hydrocarbons, organic compounds, pesticides, nanoparticles, and emerging pollutants, pose risks to both human health and ecological balance (Li, 2017).

Groundwater contamination refers to the introduction of undesirable substances through human activities, rendering the resource unsafe for use (Government of Canada, 2017). Unlike surface water contamination, groundwater pollution is elusive and challenging to remediate due to its subterranean location and lengthy residence times (Green, 2011; Wang, 2020). These contaminants are often invisible and odorless, leading to chronic health impacts that are challenging to detect (Chakraborti et al., 2015). The natural cleansing processes for contaminated groundwater can span decades or even centuries, aggravating the consequences (Su, 2020).

The roster of contaminants detected in groundwater continues to grow, broadly classified into chemical, biological, and radioactive types stemming from both natural and human sources (Elumalai, 2020). Natural sources, such as seawater, brackish water, and poor-quality surface waters, can become significant pollution contributors if human activities disrupt natural balances, exemplified by saltwater intrusion from aquifer depletion or hazardous chemical leaching from excessive irrigation (Su, 2020; Wang, 2020; Li, 2008).

Several global studies underscore the link between human activities use and water quality, demonstrating the significant correlation between these variables (Baker, 2003; Buck, 2004; Li, 2008). This research employs diverse methodologies to unveil the distressing influence of diffuse pollution on groundwater quality. Similarly, investigations by Rodrigues et al. (2018) establish that areas with high anthropogenic and economic activity exhibit elevated water pollutant levels, while pristine areas like natural forests coincide with better water quality. The provision of safe water and sanitation is still a challenge in most parts of the world including Kenya., According to the impact report No. 15 that coverage and drinking water quality stood at 62% and 95% respectively against universal access by 2030 (WASREB Impact Report, 2023) which implies that over 38% of the Kenya population do not have access to clean water sources. This study aims to establish a connection between human activities and groundwater contamination in Kanduyi, while also developing a water quality index value for the area. In 2019 report, Kenya National Housing and Bureau of Statistics also reported the same indicating that 35.9% and 22.1% of the population in the study area rely on springs and wells respectively as their sources of water (KNBS, 2019).

1.2.Statement of the problem

The Kenyan Constitution of 2010 and the Water Act of 2016 provide assurances for the provision of sufficient and safe water to the citizens of Kenya (Constitution of Kenya, 2010). However, the combination of drought and the impacts of climate change has led to the gradual depletion of surface water sources, which have historically been relied upon. As a result, groundwater sources have emerged as a viable alternative to bridge the widening gap in water demand (UNEP, 2010).

In Bungoma County, the daily water demand is 58,500 cubic meters, yet the regulated urban water sources only supply 20,550 cubic meters per day. Boreholes and rural schemes contribute 6,970 cubic meters per day and 1,164 cubic meters per day respectively. This leaves a deficit of 29,866 cubic meters per day that is sourced from unregulated wells and springs, which are known to have poor water quality. It has been reported that merely 25.8% of Bungoma County's residents have access to safe drinking water from regulated sources. This falls below the global average of 69% and the African average of 73%. It's even lower than Kenya's national coverage of 57%. The Kenya National Housing and Bureau of Statistics (2019) similarly indicated that in the study area, 35.9% and 22.1% of the population rely on springs and wells respectively as their water sources (KNBS, 2019). Moreover, the surface water sources in the county are beset by issues of industrial pollution and sedimentation, prompting most residents to turn to groundwater sources as a more affordable option (Bungoma CIDP, 2018).

These reports collectively reveal that a significant portion of the county's population, particularly in rural and peri-urban areas depend on springs and wells whose quality has never been ascertained. It’s therefore evident that currently a larger part of the county population remains outside the regulated sources especially in rural and peri-urban areas of which its quality has been questionable. The socio-economical assessment report, 2015 by Korean International Cooperation Agency for Bungoma county showed that 52.4% of the reported cases of ailment due to waterborne related diseases. However, despite being an alternative water source for a substantial population, these wells and springs are vulnerable to contamination from both natural and human-induced activities, affecting their physicochemical and bacteriological quality.

Therefore, its evident that the population particularly those in rural and peri-urban areas who relies of groundwater are at risk and this calls for a scientific based approach to establish the effects of human activities on existing wells and springs for the purpose of sustainable resource management through policies and enhanced strategies.

1.3. Research objective

The main objective of the study was to determine the effect of human activities on quality of groundwater sources in areas of Kanduyi sub-county, Bungoma county.

1.3.1 Specific objectives

1 To evaluate the sanitary risk factors that contribute to groundwater quality variations in Kanduyi sub-county, Bungoma County.

2. To determine the physio-chemical and bacteriological characteristics of groundwater quality in Kanduyi sub-county, Bungoma county.

3. To evaluate the Water Quality Index for wells and springs in Kanduyi sub-county, Bungoma County.

1.3.2 Research questions

1. What are the sanitary risk factors that contribute to groundwater variations in Kanduyi sub-county, Bungoma County?
2. What are the physio-chemical and bacteriological characteristics of groundwater quality in Kanduyi sub-county, Bungoma County.?

3. What is the Water Quality Index for wells and springs in Kanduyi sub-county, Bungoma County?

1.4.Significance of the study

The study holds paramount importance as it brings out the relationships between human activities, sanitary risk factors, and the quality of water sourced from wells and springs. This research undertaking stands as a pivotal step towards comprehending the extent to which human activities might be contributing to the reported cases of ailments related to water contamination.

The study will provide scientific-based data that will be used in water resources management.

Furthermore, the implications of this study resonate well beyond its immediate findings. Its contribution to the scholarly arena (academic advancement) of waste management and ground water abstraction is invaluable. By adding a new layer of understanding to these fields, the research augments the academic discourse, enriching the body of knowledge and serving as a catalyst for further exploration. As a wellspring of information, the study not only meets the needs of current researchers but also serves as a well of inspiration for future investigation and further studies.,

1.5. Scope of the study

The study's focus was confined to assessing the impact of human activities on groundwater quality within the rural and peri-urban areas of Kanduyi, situated in Bungoma County. Consequently, the study's findings cannot be extrapolated for broader application. Due to financial limitations, the data collected during fieldwork for water quality examination was restricted to wells and springs, without encompassing other groundwater sources such as boreholes. Moreover, the analysis of the collected samples was restricted to a select few drinking water quality parameters which were P^H, Turbidity TDS, Electro-conductivity, Phosphates, Sulphates, Nitrates, Total and E-coli.

1.6 Limitations of study

The limitations that affected the research were primarily related to methodological and research design constraints, which had the potential to compromise the validity of the results. One significant challenge was the limited access to historical data for groundwater sources, which hindered our ability to assess changes in water quality over time. The incorporation of historical data could have significantly enhanced the validity of the results by providing a baseline for comparison. Moreover, inadequate funding and resources during the research project constrained the scope and depth of the study. This limitation resulted in a smaller sample size and in ability to utilize advanced laboratory to carry out analytical tests for the study.

CHAPTER TWO
LITREATURE REVIEW

2.0. Introduction

Groundwater constitutes more than 90% of the available freshwater on Earth (UNEP 2008). It holds significant natural value and is of considerable economic importance (Zhou, 2015). Globally, groundwater serves as a primary source for nearly half of the world's drinking water supply (WWAP, 2009) and plays a crucial role in agricultural irrigation, accounting for over 40% of global water consumption (Siebert, 2010). Remarkably, groundwater extraction is the most substantial among all raw materials, reaching a withdrawal rate of approximately 980 km3/yr. Nevertheless, for a considerable period, groundwater remained overlooked, evading attention. Furthermore, the degradation of groundwater systems to alarming levels often takes longer than the decision-making timeframes of societies, even if recognized. Consequently, despite its paramount importance, groundwater remains relatively marginalized in the realm of water resources management. However, this neglect is undergoing a transformation. Groundwater utilization has overtaken surface water in numerous regions, a trend that is expected to escalate due to advancements in drilling and pumping technologies (UNEP 2008).

2.1. Groundwater resources in Africa

In Sub-Saharan Africa (SSA), groundwater has emerged as a favored water source in numerous urban centers to cater to the escalating demands of burgeoning populations. For instance, in cities like Lusaka, boreholes contribute to a significant 55% of the water supplied by public utilities (Foster, 2017). Furthermore, it is approximated that approximately 100 million individuals in small towns and villages across SSA rely on groundwater and alternative sources for their drinking water and domestic needs (Pavelic P. 2012), with residents of impoverished urban areas resorting to self-owned wells. Unfortunately, these sources are susceptible to contamination from diverse origins, encompassing factors like pit latrines, storm water runoff, and other forms of unhygienic waste management (Tillett, 2013).

A study undertaken by Nyenje (2013) in Kampala unveiled substantial nutrient pollution within groundwater, particularly in shallow aquifers situated beneath pit latrines. Similarly, a comparable investigation conducted in Zambia documented contamination, including the presence of 'emerging contaminants.' This study identified insect repellent (diethyltoluamide) concentrations of up to 1.8 mg/l in groundwater obtained from shallow wells in low-cost housing zones. This contamination was linked to deficient sanitation infrastructure, inadequate waste disposal measures, and insufficient well protection (Sorensen, 2014).

In Vihiga County, only 16.8% of residents have access to piped water, while the remainder rely on point sources like wells and springs. Furthermore, the county lacked a sewerage system, so residents had to make do with improvised systems like pit latrines and septic tanks (CIDP, 2018).

In the context of Kenya, the results are consistent. In a study conducted by Wright et al. (2013) in the peri-urban region of Kisumu, it was shown that groundwater samples collected in close proximity to pit latrines exhibited elevated levels of thermo-tolerant coliform counts and NO_3 concentrations exceeding the World Health Organization's recommended limit of 10 Mg-N/l. The proximity of latrine construction to water sources heightens the potential for water contamination.

Kanda et al., (2023) studied the water quality of dug wells in the Sabatia sub-County of Vihiga County, which is near pit latrines. The physiochemical and bacterial makeups of water were studied after collecting samples from 48 drilled wells. Water from a number of dug-wells was examined, and some of the physiochemical parameters were outside of acceptable ranges for human consumption. Total coliforms and fecal coliforms were found in the water, indicating contamination by bacteria. The pit latrines and lack of sanitation around the dug-wells may explain the high fecal coliform values found in the water samples. These bacteriological markers raised concerns that drinking the water as-is could be dangerous. In comparison to the other six areas, the water quality index is greater in Chavakali, North Maragoli, and Busali. Significant bacterial variation in water samples was not detected at distances greater than 30 meters.

2.2. Groundwater vulnerability

Groundwater Vulnerability pertains to the relative ease with which a contaminant, such as a pesticide, introduced on or near the land surface, can migrate to the target aquifer under specified agronomic practices, pesticide characteristics, and hydrogeological sensitivities.

Groundwater vulnerability hinges on the premise that the physical environment inherently shields groundwater from human-induced impacts, particularly the intrusion of contaminants into the subsurface environment. It denotes the likelihood or propensity of contaminants to infiltrate the groundwater system after being introduced at the surface. This concept is rooted in the fundamental notion that certain land areas are more susceptible to groundwater contamination than others (Buck, 2004). Groundwater vulnerability is concerned solely with the hydrogeological framework and natural factors that influence the behavior of various pollutant types, shaped by their interactions and chemical properties (Tu, 2011). This concept is a relative, dimensionless attribute, challenging direct measurement, and it does not encompass the propagation and attenuation of pollutants. Generally, two types of vulnerability assessments are recognized: one addressing specific vulnerability, tied to a particular contaminant, contaminant category, or human activity; and the other addressing intrinsic vulnerability, which doesn't consider the attributes and behavior of specific pollutants and encompasses all sources of pollution (Craun, 2003).

The susceptibility of groundwater to microbial contamination poses a substantial public health threat to communities reliant on private or unregulated wells as their primary drinking water source. Over the course of time, there have been several instances of waterborne sickness outbreaks and episodes of contamination that have been associated with unregulated water systems (Craun, 2003; DeSimone LA, 2009; Yoder J, 2008). Environmental health programs frequently include inspections and testing of private wells as part of the permitting process. However, it is important to note that issues and illnesses related to these systems constitute a substantial component of the water safety initiatives undertaken by these programs. Due to financial limitations, numerous environmental health permitting programs are expected to reduce their provision of services related to private wells. The Centers for Disease Control and Prevention's Environmental Health Specialists Network (EHS-Net) Water Program has created a groundwater vulnerability assessment tool called Land-use Hydrology and Topography (LHT) with the aim of enhancing local environmental health initiatives. The technique was implemented in 18 counties in Georgia with the objective of assessing the efficacy of the approach in identifying uncontrolled wells for priority intervention (Baloch MA, 2011). This discourse presents an argument advocating for the implementation of a groundwater vulnerability mapping approach in order to efficiently prioritize intervention initiatives aimed at safeguarding private or individual wells that are highly prone to pollution.

2.2.1 Ground water pollution

The concept of groundwater resource pollution hazard pertains to the likelihood that groundwater within an aquifer will become contaminated, surpassing the established guideline value for drinking water quality (Bai et al., 2010). Hazards encompass activities and developments that pose a threat to groundwater integrity (Ghebremichael, 2004). Generally, the hazard is assumed to initiate at the ground surface, involving the potential release of contaminants. The risk associated with groundwater contamination takes into account the potential consequences of a contamination event (Zhou, 2015). This circumstance has spurred researchers to devise techniques for assessing potential risks to groundwater resources, manifested in the concept of "groundwater vulnerability," which found its origins in the 1960s (Vrba, 1994).

The realm of man-made pollutants capable of contaminating water sources is extensive. Based on their origins, two distinct categories of sources are recognized: point and spread. Prominent point sources encompass a range of notable entities such as industrial facilities, metropolitan regions, agricultural establishments, manure storage facilities, and landfills. Identifying and managing point sources is often considered to be a more straightforward task in comparison to diffuse (non-point) sources. Diffuse sources encompass several mechanisms, such as the leaching of nitrates and pesticides into surface and groundwater as a result of precipitation, soil penetration, and runoff originating from agricultural areas. According to Farwell (2003), these dispersed sources have a significant role in causing considerable variations in water contamination levels over a period of time.

(Farwell, 2003) asserts that beyond the division of contaminant sources into point and non-point categories, two types of water contamination are acknowledged: (1) Emergency contamination (single incidents) often with immediate catastrophic consequences, leading to fish and aquatic life mortality, along with significant damage; (2) Long-term contamination, characterized by persistent organic pollution that exerts an overall adverse impact on the aquatic environment and disrupts the food chain for aquatic life, potentially leading to the absence of certain fish species in affected river zones.

Sasakova (2014) observes that numerous infectious diseases affecting both animals and humans are waterborne. These diseases spread through the ingestion of water contaminated with pathogenic bacteria, viruses, and parasites (protozoa, parasite eggs) present in human or animal feces. The survival of these agents in water varies based on multiple factors. The monitoring of water source safety involves assessing parameters indicative of pollution stemming from sewage, animal waste, waste storage, animal manure, artificial fertilizers, and other sources (Sasakova, 2014, Fridrich, 2014).

In rural regions of emerging countries like Kenya, shallow (hand-dug) wells are commonly managed by individuals or owners who lack the technical knowledge and expertise required for safe operation and maintenance. Groundwater resources face risks from the proximity of pit latrines and inadequately constructed and managed septic tanks, particularly when these facilities are located in close proximity to wells (Kanda, Odiero, Lutta, & Ong'or, 2018).

However, despite the existing research, a noticeable gap persists in comprehensively addressing the combined influence of inadequate technical knowledge and poorly managed sanitation facilities on the contamination of groundwater resources, particularly in areas with limited resources and technical expertise. This research gap underscores the need for targeted studies that delve into the specific mechanisms and consequences of such contamination events in order to develop effective interventions and strategies for safeguarding groundwater and public health in vulnerable areas. Groundwater denotes water originating from the percolation and infiltration of precipitation through the soil layers, amassing beneath the Earth's surface in a porous stratum commonly known as the aquifer. It constitutes an integral component of the hydrologic cycle, with the volume and quality of water retained in the aquifer influenced by factors such as geological composition, precipitation levels, terrain features, surface cover, and the environmental state (Salami, 2012). Upon the infiltration of precipitation into a landfill, it interacts with decomposed waste, resulting in the extraction of water-soluble substances and the formation of a liquid byproduct known as leachate (Salami, 2012). This leachate then seeps and percolates into groundwater aquifers, thereby contributing to the contamination of groundwater resources.

2.3. Sanitary Risk Factors

Groundwater pollution takes place when pollutants are released into the ground and travel to aquifers. Groundwater contamination is mainly caused by the release of contaminants either through point or non-point sources through human activities or natural causes **(**USGS, 2023**)**.

2.3.1 Modes of waste disposal

Waste management has recently become a prominent concern for key stakeholders in both developed and developing nations. The global growth in population has led to an escalation in waste production, owing to increased consumption patterns and technological advancements (Asase, 2009). It is crucial to evaluate the complete service chain of trash generation and disposal in order to protect the environment. According to the World Health Organization and UNICEF (2010), over 2.6 billion people do not have access to better sanitation facilities. better sanitation refers to the availability of water-based toilets that are connected to sewers, septic systems, or pit latrines, as well as the presence of simple or vented upgraded pit latrines. According to previous studies (Albonico et al., 2008; Cairncross et al., 2010), the implementation of enhanced sanitation infrastructure can effectively alleviate the problem of groundwater contamination.

Sustainable Development Goal 6, as outlined in the SDG framework, encompasses a range of targets. These targets include the attainment of universal access to appropriate and fair sanitation facilities, the reduction of open defecation practices, the improvement of water quality through the mitigation of pollution, the reduction of hazardous substance emissions, the halving of untreated wastewater proportions, and the eradication of improper waste disposal (UN SUMMIT, 2023). In both rural and urban settings, a considerable number of households choose to utilize either improved or unimproved pit latrines as their primary sanitation solution, mostly driven by factors such as affordability and accessibility (Cairn cross, [year]). Enhanced sanitation can be achieved through the utilization of improved pit latrines. These latrines are designed with a pit, which can be circular, rectangular, or square in shape,that is excavated into the ground. To ensure proper containment, a concrete slab or floor is installed over the pit, containing a designated hole for excreta disposal. This cost-effective approach offers an upgraded solution for sanitation needs. In contrast, unimproved pit latrines do not possess these slabs or platforms. The increased reliance on pit latrines and groundwater resources, particularly in low-income nations, has raised concerns regarding the potential health impacts stemming from microbiological and chemical groundwater contamination linked to pit latrine use (Jain, 2011).

Pit latrines commonly do not possess a physical partition, such as concrete, that separates the accumulated excrement from the surrounding soil and/or groundwater (van Ryneveld and

Fourie, 1997). This characteristic allows contaminants from pit latrine excreta to percolate into the groundwater, posing a threat to human health by contaminating well water. This scenario underscores the pressing need to address the associated risks and potential health consequences, thus emphasizing the significance of comprehensive strategies and interventions to safeguard both groundwater quality and public health in regions where pit latrines are a common sanitation option

2.3.2 Well design factors

The building of onsite sanitation systems (OSS) has been found to have a significant impact on the quality of groundwater. It has been observed that the pollution of wells can occur due to inadequate design and/or construction of the wells (Macdonald D, Ahmed KM, Islam MS, Lawrence A, Khandker ZZ 2004). The coexistence of shallow wells and pit latrines in close proximity gives rise to a situation wherein the transport of contaminants is facilitated (Okotto et al., 2015). The design of sanitary facilities is believed to be influenced by geological elements, including geology and soils, topography, and patterns of flood risks (Douglas et al., 2008). The presence of a shallow water table in certain areas poses significant construction issues and imposes limitations on the depth of pit latrines (Douglas et al., 2008). The contamination of groundwater sources might occur as a result of inadequate maintenance of the space between pit latrines. According to Van Ryneveld and Fourie (2003), pit latrines lack a physical barrier, such as concrete, that separates the stored excreta from the surrounding soil and/or groundwater.

2.3.3 Human activities

As stated by Almasri (2007), the significance of groundwater in supporting human life and facilitating various activities is unquestionable. Nevertheless, this resource is confronted with potential hazards stemming from excessive utilization and the deterioration of water quality. The challenges to groundwater, encompassing both its quantity and quality, are being exacerbated by climatic shifts, alterations in land use, and the expansion of human population. The agriculture industry has been identified as the primary source of nitrogen pollution in groundwater. According to Almasri (2007), the solubility and rapid mobility of nitrate make it prone to leaching from the unsaturated zone. The principal source of leached nitrates that infiltrate groundwater is the widespread application of fertilizers, particularly when used as a diffuse source. Furthermore, it has been shown that point sources, such as septic tank breaches and malfunctioning sewage systems, play a significant role in the contamination of groundwater with nitrates (MacQuarrie, 2001).

According to van Grinsven (2010), the nitrogen cycle has been significantly disrupted by human activities, leading to increased emissions of nitrate into the environment. This occurrence has resulted in significant deterioration of water quality, decline in biodiversity, and intensification of eutrophication. The pollution of groundwater has the potential to result in a variety of negative consequences. These include the compromise of drinking water quality, reduction in the availability of water resources, deterioration of surface water systems, escalation of cleanup expenses, dependence on alternative water sources, and the possibility of health-related problems (van Grinsven, 2010). Indeed, it is expected that alterations in climatic patterns and anthropogenic activities will have an effect on the quality of groundwater. This can be attributed mostly to the impacts of recharge processes and land use practices on groundwater systems (Green, 2011). The possibility for modification of shallow aquifer susceptibility due to climate change is evident in studies conducted by Pointer (2005), Siebert (2010), and Toews (2009). Additionally, Li and Merchant (2013) have shown that changes in land use can potentially have an impact on groundwater vulnerability. It is important to identify the probable sources of pollution and implement preventative actions in order to protect the sources. According to the study conducted by Daniel, King, and Ferrero in 2020, it was found that... The objective of this study is to gather data on the sanitary risk features in the vicinity of wells and springs, and subsequently assess them by considering potential sources of contamination, mechanisms of transmission, and protective measures.

2.4 Groundwater quality characteristics.

2.4.1 Physio-chemical characteristics

Research has demonstrated the significant role that physio chemical properties of water play in safeguarding the fragile ecosystems it sustains (Kumar and Puri, 2012). The presence of organic and inorganic chemicals, whether suspended or dissolved, can influence the physicochemical parameters employed to assess water quality (Ugwa and Wakawa, 2012). This existing research has facilitated a comprehensive understanding of water quality status and its linkage to pollution levels in aquatic environments. These parameters, encompassing both organic and inorganic aspects, integrate the physical and chemical factors. Elevated values of these factors, as indicated by WHO and other water quality monitoring authorities, can have adverse implications for end users' health and environmental well-being. Parameters encompassed in this study include color, odor, turbidity, temperature, total dissolved solids (TDS), pH, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), salinity, alkalinity, acidity, hardness, nitrates, heavy metals, total suspended solids (TSS), and total solids.

Among these, turbidity, indicating water cloudiness, varies across different water sources. Water with silt and clay appears more turbid than clear spring water. Turbidity is influenced by elements like fine particles of organic and inorganic matter, plankton, and soluble organic compounds, which scatter and absorb light (EPA, 2001; Gerba et al., 2009). Factors like soil erosion, urban runoff, and industrial wastes contribute to increased turbidity in surface water. Elevated turbidity levels can raise water temperatures, decrease light penetration, hinder photosynthesis and dissolved oxygen production, impair water clarity, add aesthetic displeasure, and escalate water treatment expenses. For effective chlorination during treatment, a turbidity level of 1 NTU or less is recommended (WHO, 2011).

The pH of water, reflecting its acid-base activity, is crucial for assessing the solubility and biological interactions of chemical components like nutrients and heavy metals. Pollution can disrupt pH levels, rendering water more acidic or basic. The pH of water is also affected by detergent use and algal growth. A pH value below 4 is detrimental to aquatic life, while neutral pH stands at 7.0, although natural sources can deviate from this due to environmental factors. Plant decomposition and carbon dioxide dissolution generate carbonic acid, altering water pH (Gupta et al., 2009). Factors like agricultural runoff, limestone presence in riverbeds, and biomass decomposition influence pH fluctuations.

While the existing research delves into these aspects, there remains a research gap regarding a comprehensive assessment of the implications of physicochemical parameters, particularly turbidity and pH, on groundwater quality. This study aims to bridge this gap by investigating these factors in relation to groundwater quality.

2.4.2 Bacteriological characteristics of groundwater

Groundwater contamination stems from a variety of factors, encompassing the water table depth, soil characteristics, and wastewater quality (Hussain et al., 2001). Moreover, groundwater quality can be influenced by residential, municipal, commercial, industrial, and agricultural operations. A pivotal aspect of drinking water adequacy is its bacteriological quality. The presence of numerous coliforms in water indicates a higher likelihood of the presence of other pathogenic bacteria or microorganisms. Bacteriological quality is assessed by detecting total coliforms and fecal coliforms, including Escherichia coli (E. coli). The density of bacterial populations in drinking water is indicated by total germ count (Levallois, 2003). Notably, E. coli serves as a prominent indicator of fecal contamination (Edberg et al., 2000). Both total coliforms and E. coli are utilized as indicators to gauge pollution levels and water quality.

Uncontrolled bacteria in water pose serious threats to human and animal health when consumed untreated. Bacteria are primary culprits behind numerous waterborne diseases, such as typhoid fever, diarrhea, and cholera. Some bacteria function as indicator organisms, signifying water contamination (Izah and Ineyougha, 2015). A positive identification of total coliforms, fecal coliforms, or fecal Streptococcus signals potential fecal material contamination. Bacteria, particularly Escherichia coli, infiltrate potable water from sources like malfunctioning septic tank systems, improperly designed or constructed septic systems, as well as municipal sludge and sewage. Furthermore, both faecal and total coliforms may also exist in certain soils due to environmental fecal matter exposure through human activities (Enetimi Idah Seiyaboh and Felix Okponanabofa Youkparigha, 2018; Sylvester Chibueze, 2018).

2.5 Water quality index

The Water Quality Index (WQI) constitutes a crucial tool for assessing water quality in urban, rural, and industrial settings. The WQI is defined as an index that captures the composite impact of various water quality parameters considered for its calculation (Janardhana Raju, 2009). These parameters encompass both bacteriological and physio-chemical aspects.

The method was initially developed by Horton in 1965 to assess water quality. It utilizes the 10 most frequently used water characteristics. Over the course of time, several specialists have made adjustments to the methodology, leading to the development of indices that utilize varied quantities and categories of water quality parameters. The allocation of weights to each parameter is determined by their respective standards, indicating the relative importance and impact of each parameter on the index. According to Tyagi (2013), the standard technique for calculating the Water Quality Index (WQI) consists of three main steps: parameter selection, development of a quality function for each parameter, and aggregation using a mathematical equation.

The index provides a singular numerical representation of the comprehensive water quality at a particular site and moment, encompassing many water characteristics. This index facilitates the comparison of several sampling sites, thereby condensing complex data into simply understandable and relevant information. The water quality categorization system employed in the Water Quality Index (WQI) serves to indicate the appropriateness of water for human consumption. The index produces a solitary output value that is obtained by considering multiple characteristics. This value conveys significant information on the quality of water, hence enabling comprehension by individuals without expertise in the subject (Chowdhury, 2012).

In nations with limited resources, the attainment of accessible and sustainable water resources presents notable difficulties. The current investigation employs the weighted arithmetic Water Quality Index (WQI) approach as a means of conveying water quality data to professionals in the field of Water and Sanitation Hygiene. One benefit of employing this methodology is its ability to minimize the number of factors needed for evaluating water quality in relation to certain objectives (Tyagi, 2013).

2.6 Conceptual Framework

The conceptual framework was constructed based on the principles of cause and effect. The dependent variables in this study pertain to the observed outcomes or consequences of pollutants, while the independent variables refer to the identified inputs or factors that contribute to these outcomes. Moderating variables, which are variables that have an impact on the relationship between the variables under investigation,. These variables are believed to exert an influence on the behavior of the subjects being investigated and are assumed to have an effect on the dependent variable. Figure 2.1 presents the conceptual framework for this study in which the independent variables were mapped to dependent variables and intervening variables.

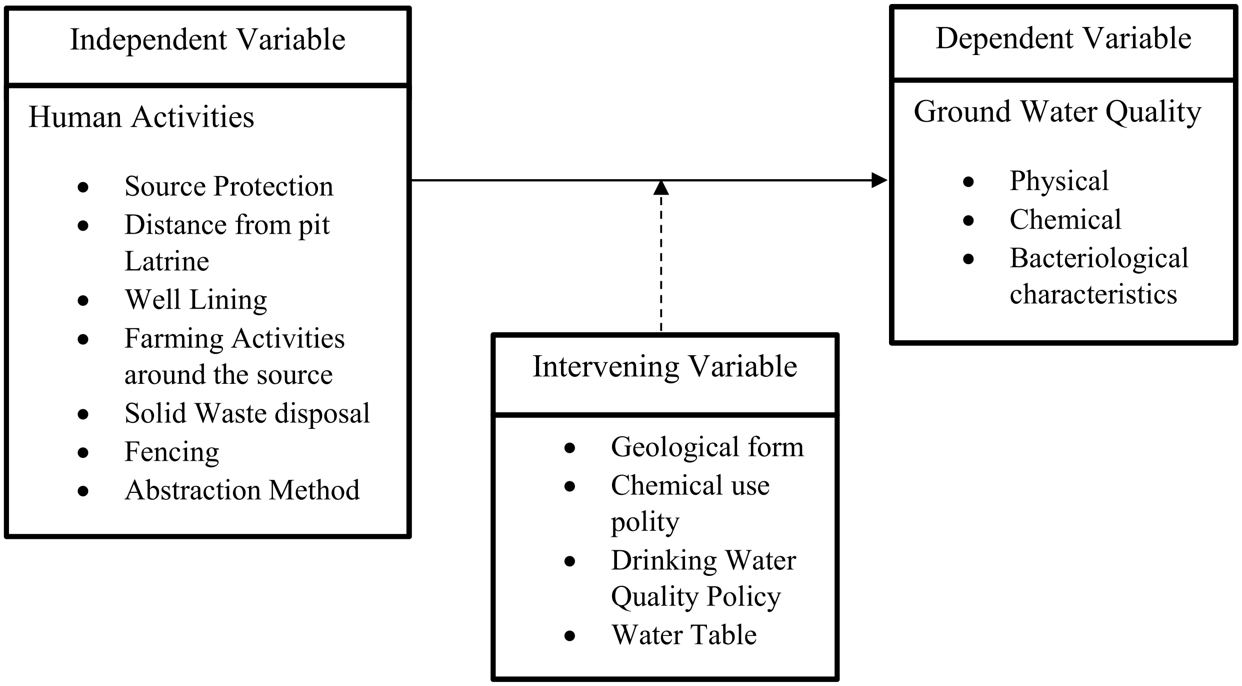

Figure 2. 1: Conceptual framework.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the materials and methods used in this research. The chapter begins by describing the study area, discusses research design and population sampling and further points out the research instruments deployed in the study as well as the questionnaires used. The data collection approaches adopted are presented and finally data analysis is discussed.

3.2 Study Area

3.2.1 Location

The study focused on Kanduyi Sub-County which is one of the seven sub-counties of larger Bungoma County. The area coverage is approximately 318.8 square kilometers and lies between latitude 0.566700^{00}-and longitude 34.566700^{00} (Figure 3.1). Bungoma town is the main urban centres within the study area. Kanduyi sub-county has a population of about 341,605 people who comprises of several tribes. Kanduyi sub-county is divided into seven wards (KNBS 2019)

The study was conducted in seven selected administrative wards of which some are rural, urban and peri-urban. Four wards that include: Bukembe West, Bukembe East, West Sang'alo and East Sang'alo are in rural set up , while the rest three wards that's Marakaru/Tuuti, Musikoma and Khalaba are within peri-urban areas of Bungoma town. Most of the groundwater that is accessed by the local community is within between 40m-50m of the surface because its expensive and not affordable.

The geographical locations of the identified sources as per the GPS system were presented in Figure 3.1.

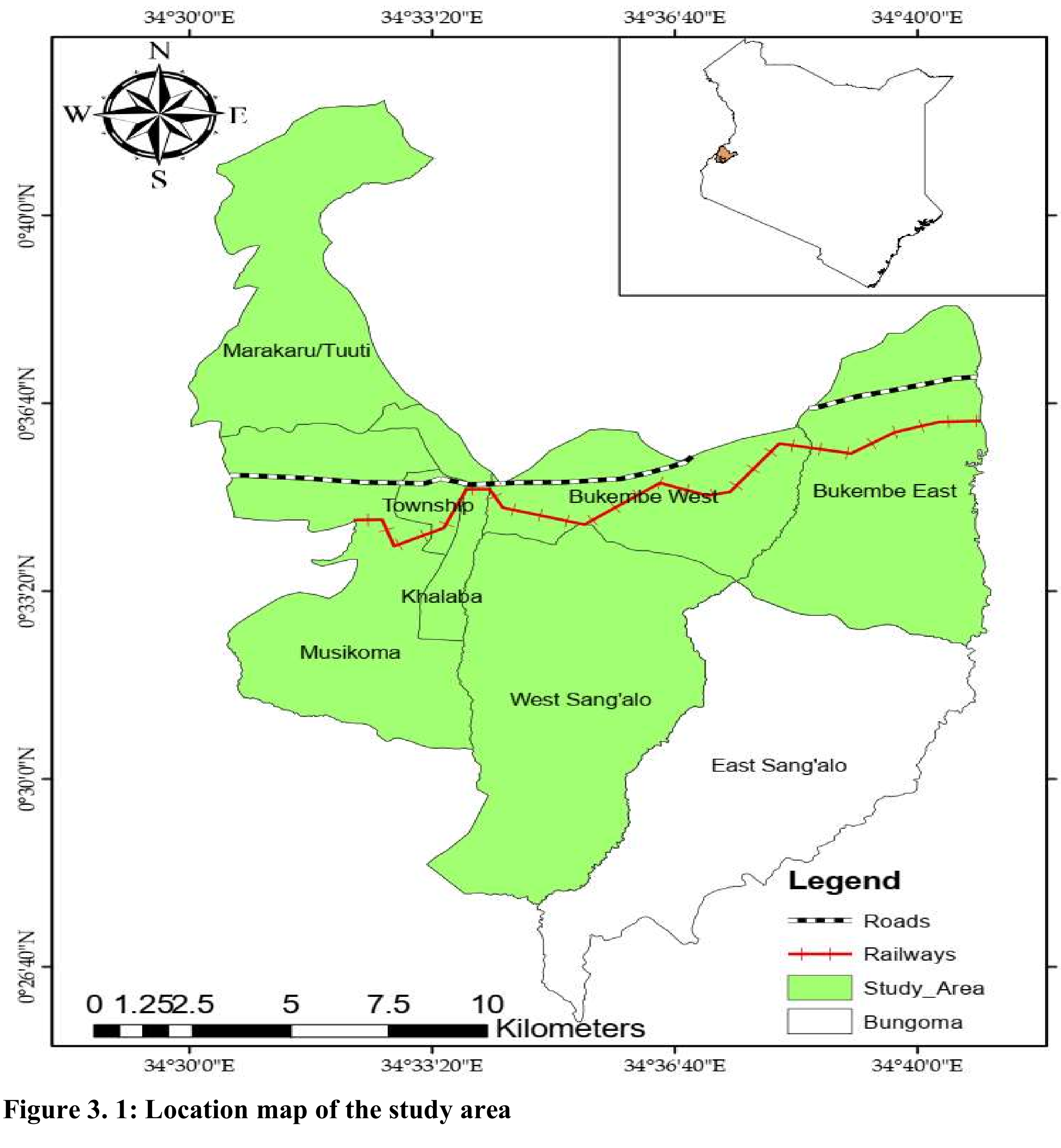

Figure 3. 1: Location map of the study area

(Source: Researcher 2023)

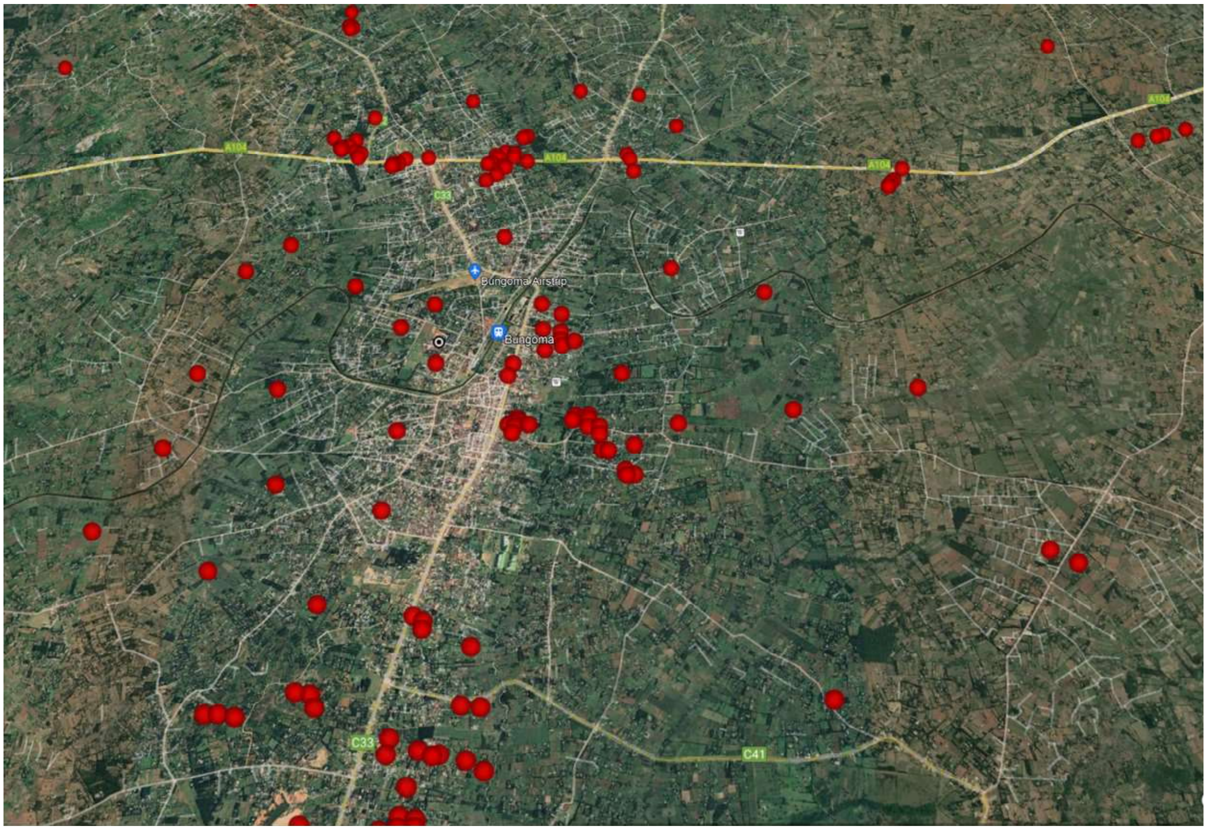

Figure 3. 2: Sampling location for the study area

3.2.2 Topography

The county exhibits effective drainage patterns as a result of its rugged geography. The drainage pattern has a radial configuration on the upper slopes, transitioning to a parallel arrangement on the mid-slopes. Nevertheless, the drainage infrastructure has deficiencies. Stormwater flows unrestricted, transporting substantial amounts of sediment downstream. Water erosion is the predominant mode of erosion within the region. The elevation of the County varies, with the highest point being Mount Elgon at an altitude of 4,321 meters, while the lowest point is situated at approximately 1,200 meters above sea level.

The average altitude of the county ranges from over 424m to 1200 above sea level.

3.2.3 Climate

The region undergoes two distinct periods of precipitation, namely the long rainy season spanning from March to July, and the short rainy season occurring from August to October. The county experiences a range of yearly rainfall, with the lowest recorded at 400mm and the highest at 1000mm. The annual temperature exhibits a range of 0°C to 32°C, which can be attributed to variations in altitude. Notably, the summit of Mt. Elgon experiences temperatures slightly below freezing, specifically below 0°C. The mean wind velocity is recorded as 6.1 kilometers per hour.

3.4. Research Design

The research study adopted analytical design to gather data from the field and analyze using scientific techniques and laboratory. The selection of the well sites was randomly applying the principle of randomization in order to minimize biasness.

The potential sanitary risk factors that could have impact on groundwater quality were evaluated, then physio-chemical and bacteriological characteristics of the samples from these sources were also analyzed where averagely twelve (12) number samples and one (1) sample of water were taken in each ward for wells and springs respectively. The Howard's method that has widely been used in other studies was employed (Omara et al, 2019). That embraces the use of questionnaires and observation guide or checklist to determine the sanitary risk factors around the water sources. However, the analytical design involved sampling of water from the identified sources and laboratory analysis for physio-chemical and bacteriological parameters.

3.5 Target Population and Sampling Frame

This section describes the methodology used to determine the size of the study sample from which data were obtained. Additionally, the paper elucidates the sampling methodologies employed for the purpose of selecting elements to be incorporated as subjects inside the study sample. According to Mugenda & Mugenda (2003), the target population is defined as the complete group that a researcher is interested in or the group from whom the researcher aims to draw conclusions.

A sample size refers to a subset of the entire population that is selected in order to provide a representation of the overall characteristics and perspectives of the target group (Kothari, 2004). The sample size should be chosen in a manner that ensures it is representative of the population under study, allowing for the generalization of research findings. In order to ensure statistical validity of the findings, the necessary sample size was determined based on the characteristics of the target population. This excerpt exemplifies a viable specimen or a representative subset of a populace, utilized to ascertain the attributes of the entire population (Frankel & Wallen, 2008).

The sample size for the study was determined by a statistical formula and selected by randomization using random sampling to minimize biasness. 5% level of significance (Margin Error) was adopted in the study.

$$\boldsymbol{n} = \frac{\boldsymbol{N}}{\mathbf{1}+\boldsymbol{N}(\boldsymbol{e})^{\mathbf{2}}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \text{ Equation (3.1)}$$

Where;

n – sample size

N – Population size

e – Level of significance

The simple random sampling technique was employed to determine the number of wells and Springs to be assessed.

Table 3. 1: Population Sampling Size.

Region		Estimated Target Population	Sample Size
Wells	N	115	89
	n	89	
Water Springs	N	11	10
	n	10	

i.e. in this case for :

Hand Dug Wells , $\mathbf{n} = \frac{115}{1+(0.05)2} = 89$

Thus the sample size for wells in the study area was 89 while that of water springs were 10.

3.6 Research Instruments

The study obtained primary and secondary data on the ground and through a literature review, respectively. These were essential in giving the study's foundation and results. Questionnaires containing closed and open-ended questions, field observations, measurements, and checklists were used to collect primary data. Queries were designed to capture all aspects of human activity, hygienic conditions, and risk considerations surrounding the sources. Once questionnaires were produced, their reliability was evaluated and they were reinforced. The tool was improved, and the questions were added to the mWater collect API (Application Programming Interface), which enables online data collecting using a smart phone. The tool's built-in GPS system was utilized to capture (x, y) coordinate data. Tapes were utilized to monitor well depths and distances between the well and existing pit latrines, as well as other potential contamination risk factors.

ArcGIS software was used for mapping. Secondary information was gathered through document checks and report compilations.

3.7 Reliability and Validity of Research Tools.

According to Chava and Davi (1996), Reliability is a gauge of the degree to which the research instruments yield reliable results or facts after repetitive trials. This study ascertained the accuracy and consistency of the research instruments before they were used using data collected from piloting. Split half method was adopted in this study to test the reliability of the questionnaire. It measured the degree to which all parts of the test contributed equally to what was being measured. This was done by comparing the outcome of one half of a test with the outcomes from the other half. To ensure trustworthiness in qualitative research the researcher paid attention to data coding. The Cronbach's alpha is widely regarded as the most often used reliability coefficient in academic research. It is employed to assess the internal consistency of a test by examining the interrelationships among all test items and their collective coherence with the overall test data. Cronbach's alpha ($\bar{\alpha}$) is a statistical measure that assesses the degree to which a collection of items may be regarded as assessing a singular underlying construct. The value of 0.7, which is commonly recommended, was utilized as a threshold for determining the reliability of the data. According to Cronbach (1951), a test's reliability increases as its coefficient becomes greater.

The research questionnaires yielded a Cronbach Alpha coefficient of 0.77. This finding suggests that the instruments used in the study had a high level of reliability. Based on the results of the reliability test, it was hypothesized that the scales employed in this study are reliable for measuring the constructs.

The validity is the correctness and meaningfulness of inferences which are based on the research results. Mugenda and Mugenda (2003) refer to validity as the level to which results got actually represents the phenomenon under study. The pilot test was carried out to test the reliability of the questionnaire and to identify problems in data collection that could probably affect the survey.

Questionnaire pre testing was carried out where 10% of sample space from selected sites were piloted. The aim was to gauge time of completion and deficiencies.

Necessary corrections were done to increase validity of the instruments to be used in data collection.

3.8 Data Collection

Both primary and secondary data were used in the study. Primary data came from respondents from the field across the five categories. Probing was done to encourage the respondents to respond more. Data collection took an average of over two weeks. Secondary data was collected from Department of water, Bungoma county.

3.8.1 Sanitary Risk Assessment

3.8.1.1. Accessing mwater Portal:

The collection of sanitary risk factors began with fieldwork. The researcher used their smartphones to access the Mwater portal through a web browser at http://portal.mwater.co. To initiate this process, an Mwater account was created. This app was founded by Annie Feighery, EdD (2012)

3.8.1.2. Uploading Checklists and Questionnaires

In preparation for data collection, specific checklists and structured questionnaires were designed to capture various attributes of sanitary conditions pertaining to selected wells and springs. These materials were then downloaded onto the mWater app in the smartphones.

3.8.1.3. Deployment for Data Collection

With the checklists and questionnaires in hand, the deployment phase commenced. The enumerators visited a total of eighty-nine wells and ten springs that had been earmarked for study. These locations were spread across the study area.

3.8.1.4. Assessing Sanitary Risk Factors

The data collection process involved assessing several sanitary risk factors within the vicinity of the wells. These factors included farming activities, the presence of existing sanitation facilities, methods of solid waste disposal, techniques for water abstraction from the wells, and a physical inspection of the protective structures around the wells and springs.

3.8.1.5. Measurement of Distances

For accurate assessment, the distances between the wells and nearby human activities or sanitary risk factors (such as pit latrines and solid waste dumpsites) were physically measured using measuring tapes.

3.8.1.6. GPS Mapping

The Mwater app incorporated Global Positioning System (GPS) technology, which was utilized to map the geographical coordinates of the randomly selected wells. These wells were located across seven different wards.

3.8.1.7. Data Saving and Analysis

The collected data were saved within the Mwater app and subsequently downloaded to a computer. This step allowed for data cleaning and in-depth analysis of the sanitary risk factors associated with the proximity of the wells and springs.

3.8.2 Physio-chemical and Bacteriological Sampling

Samples were picked in the month of April 2022, in all the selected wells and springs. The collection completely adhered to the sampling parameters outlined in by Kebs and (WHO, 1996). Standards for drinking water quality. There were used 1-liter capacity, clean glass bottles with caps. The sample bottles were cleaned with a nitric acid solution and rinsed completely with clean water to eliminate the acid. The bottles were then filled with sample water, carefully shaken, and emptied. Following multiple repetitions of the same technique, the final sample was taken. The sample bottle stoppers were carefully secured, and each bottle was appropriately labeled with the source name, sampling date, and time. For identification purposes prior to transit. Each source yielded two samples; one for physical and chemical testing, and the other for bacteriological testing with measures against contamination. The bacterial analysis samples were obtained in a 100ml glass sample

3.8.3 Water Quality Index

Water Quality Index (WQI) values were computed using the measured physio-chemical parameter results of pH, Turbidity, EC, TDS, Sulphates, Nitrates and phosphates in order to effectively evaluate pollution levels for each water source (wells and springs). The study employed the Weighted Arithmetic Mean concept created by Horton (1965), Brown et al. (1970), and Cude (2001) for ten measures of water quality.

$$\mathbf{WQI} = \frac{\sum(\,WnXQn)}{\sum(\,Wn)}$$

Step 1 Assigning of weights to the parameters according to their importance in the overall water quality with maximum value of five and the minimum of one. A higher weight was assigned to the most significant parameters and letter weight attached to the lesser parameter . Where the following steps were used to calculate the Index

Step 2 To calculate the quality rating (**Qn** $= \frac{Vn-Vi}{Vs-Vi} x100$

Where: **Qn**- Is the sub-index of the nth parameter

Vn- Is the actual value or concentration of parameter in a water sample

Vi- The ideal value of the parameter (0) for all parameters except for PH which is 7

Vs- Is the standard value for the parameter.

Step 3: To find Relative weight of the parameter (**Wn):** Wn-K/Vs where K is the proportionality constant such that

$$\mathbf{K} = \frac{1}{\sum(\,1/Sn)}$$

Step 4 : To calculate Water Quality Index ,

$$\textbf{WQI} = \frac{\sum (WnXQn)}{\sum (Wn)}$$

3.9 Data Analysis

3.9.1 Sanitary Risk Factors analysis and categorization

After fieldwork the questionnaires and checklists were checked and cleaned. The results were then analyzed based on the existence or absence of sanitary risk conditions, such as well liner, well cover, solid waste disposal near the well, abstraction method, and source location in relation to the position of the pit latrines.

One point was awarded for a response of Yes (Y), which indicated the presence of risk in the area. However, the answer No (N) suggested that no risk was identified in the area, and hence no points were granted. The ultimate sanitary risk score for each source (wells and springs) was determined by summing all the affirmative responses. The percentages were then computed by applying the formula;

$$\text{Risk\%} = \frac{\text{No. of answered Yes risk questions}}{\text{Total No of risk questions}} \times 100 \text{-----------------------------} (3.7)$$

The study utilized the risk scorecard developed by other researchers, in which 81-100% indicated a Very High risk, 51-80% a High risk, 31-50 a Medium risk, 1-30% a Low risk, and 0% no danger (Lukubye & Andama, (2017), Omara et al, 2017).

The second stage involved the construction of aggregate variable and creation of cleaned data sets that were imported to Statistical Packages for Social Science (SPSS) for analysis which generated forms of tables, charts as means / percentages and correlations.

3.9.2 Physio-chemical and Bacteriological analysis

Water quality parameters were collected and tested on site and in the laboratory according to WHO, 1996 and Kebs guidelines for drinking water quality. Turbidity was one of the physical and chemical factors assessed. TDS, nitrates, and phosphates. Total and Feacal coliforms (E-Coli) were analyzed using the plate count method in accordance with Egbueri (2019) protocols at a water laboratory. The physio-chemical parameters PH and Turbidity were measured on-site using a PH Meter (Merck KGa, Germany) and a Turbidimeter 2100Q (Hach, Switzerland) respectively. TDS, Nitrates, and Phosphates were also analyzed in a water laboratory using conventional equipment HACH Pocket pro TDS LR (Hack business, USA

The data underwent coding and was afterwards imported into Excel spreadsheets. Prior to conducting any analysis, thorough error checking and correction procedures were implemented. The statistical analysis was conducted using SPSS version 21, with a significance level of 95%. The water quality parameters were subjected to statistical analysis using Anova and T-test at a significance level of 95% ($p<0.05$) to compare them with the drinking water quality requirements set by the World Health Organization. A simple regression analysis was employed to ascertain the impact of human activities on water quality. The findings were displayed in tabular and graphical formats, thereafter analyzed and conclusions were derived in accordance with the study inquiries and objectives.

3.9.3 Water Quality Index (WQI)

The Calculated Water Quality Index (CWQI) values from the selected wells and springs were analyzed and compared with the rating scale of Weighted Arithmetic Mean as indicated in table 3.7

The Index ranks water quality into categories from excellent to poor depending on the score. The lower the value of WQI, the better the water quality as an indicator of the low level concentration of the contaminants.

Table 3. 2: WQI Levels

	WQI Levels	Rating Values	Description
1	0-25	Excellent	The preservation of water quality is ensured by a state of minimal risk, characterized by conditions that closely resemble those found in natural environments.
2	25-50	Good	The protection of water quality is generally effective, with only minimal levels of hazard observed. Instances where water conditions deviate from natural or optimal levels are infrequent.
3	51-75	Poor	The quality of water is frequently compromised as conditions often deviate from the desired values.
4	76-100	Very Poor	The purity of water is regularly jeopardized, resulting in deviations from its natural state.
5	>100	Unfit for consumption	The water quality is currently at risk due to the presence of unacceptable levels.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Introduction

This chapter presents the findings of the survey as set out in research methodology. The study findings are presented to establish the effects of human activities on wells and springs water sources.

The results are discussed under the three objectives. The first objective discussed in this chapter was to assess the sanitary risk factors. The study focused on human activities within the proximity of the wells and springs. This include farming and cloth washing, modes of solid waste disposal, type of sanitation facilities, water abstraction methods etc.

The second objective discussed in this chapter focused on sampling and testing water in a laboratory to establish their physio-chemical and bacteriological characteristics of the individual selected wells and springs. The results were then compared with Kenya Bureau of standards guidelines.

The third objective was to use the physio-chemical results to develop a Water Quality Index for the wells and springs in the study area. This was the followed by developing a spatial distribution map in the seven wards of Kanduyi.

4.2. Sanitary risk factors observed less than 30m close to wells and springs

The purpose of the study was to determine the human activities and sanitary risk factors within the proximity of selected wells and springs as shown below

4.2.1. Farming and cloth washing activities.

The study sought to establish the human activities that were less than 30metres away from the well. The figure 4.1 shows some of the activities observed that include cultivation, animal grazing and cloth washing activities near the well.

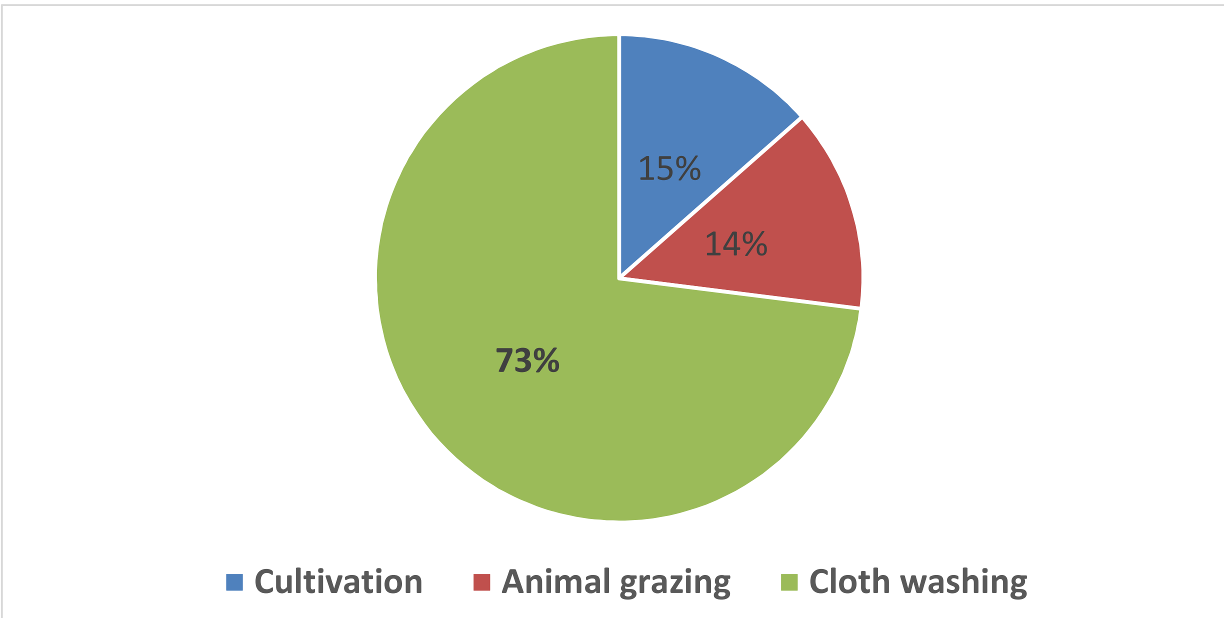

Figure 4. 1: Main human activities

The results suggest that there are three main human activities occurring near the wells: cloth washing, animal grazing, and cultivation. The percentages associated with each activity provide insights into the potential effects of these activities on groundwater quality.

The high percentage of cloth washing of 73% activity were observed to be at less than the recommended 30m away from the source indicates that a significant portion of the local population engages in this practice. Cloth washing typically involves using water combined with detergents or soaps to clean clothes. This can introduce chemicals and contaminants from detergents into the groundwater system. Common pollutants from detergents include phosphates and surfactants. Over time, the repeated use of detergents for cloth washing can lead to the accumulation of these pollutants in the soil, which can then percolate down into the groundwater.

The results showed that 14% of the selected wells were found to have animal grazing less than 30m from the wells which have several implications for groundwater quality. The waste products of grazing animals contain organic matter, nutrients, and potentially pathogens. If these wastes are not managed properly, they can infiltrate the soil and affect the quality of groundwater. Organic matter can lead to increased microbial activity in the soil, potentially affecting groundwater quality through the leaching of organic compounds. Nutrients like nitrogen and phosphorus from animal waste can also contribute to groundwater pollution, particularly if the soil's natural filtration capacity is exceeded. In most regions, livestock farming is developing at a higher rate than crop production. Animal husbandry is connected with substantial waste generation, particularly manure, which has severe effects on the quality of groundwater (FAO, 2006). Veterinary medicines (antibiotics, vaccinations, and growth stimulants) have given rise to a new class of agricultural pollutants, which migrate from farms through water to ecosystems and drinking-water sources. Moreover, zoonotic waterborne diseases are a big problem (WHO, 2012).

It was further found that 13% of the visited wells had cultivation activities observed less than 30m from the wells. This involves activities related to growing crops and can impact groundwater quality in various ways. The use of fertilizers, pesticides, and herbicides in agriculture can lead to the leaching of these chemicals into the groundwater. Nitrate, a common component of fertilizers, is particularly concerning due to its potential to contaminate groundwater and pose health risks. Pesticides and herbicides used for pest and weed control can also find their way into groundwater through runoff or infiltration. Many studies have established a causal relationship between agricultural practices and groundwater nitrate levels (Dunn et al., 2005; Liu et al., 2005; Hansen et al., 2012). When it comes to non-point sources of nitrate in groundwater, fertilizers are often cited as the biggest culprit (Almasri et. al., 2007). Nitrate pollution in the groundwater is caused by numerous point sources, such as septic tanks and malfunctioning sewage systems (MacQuarrie et al., 2001). Poor drinking water quality, the loss of a drinking water supply, the degradation of surface water systems, increased expenses for remediation or the need to find new sources of water, and even health problems are all possible outcomes of polluted ground water (van Grinsven et al., 2010).

Due to the use of land for agriculture, water may get contaminated with various toxins (Hooda et al. 2000; Lovell and Sullivan 2006). With the widespread use of pesticides in agriculture, the presence of pesticides in water supplies is a problem for water-quality evaluation. Pesticides are a class of toxic substances that provide a potential threat to human health (Ayranci and Hoda 2005).

4.2.2. Modes of solid Waste Disposal

The study aimed to assess the modes of solid waste disposal within the vicinity of water wells and springs. The objective was to understand the potential sanitary risks posed by these disposal practices to the quality of water in these sources. The results depicted in Figure 4.2 provide crucial insights into the various methods employed for waste management in relation to water wells and their potential implications

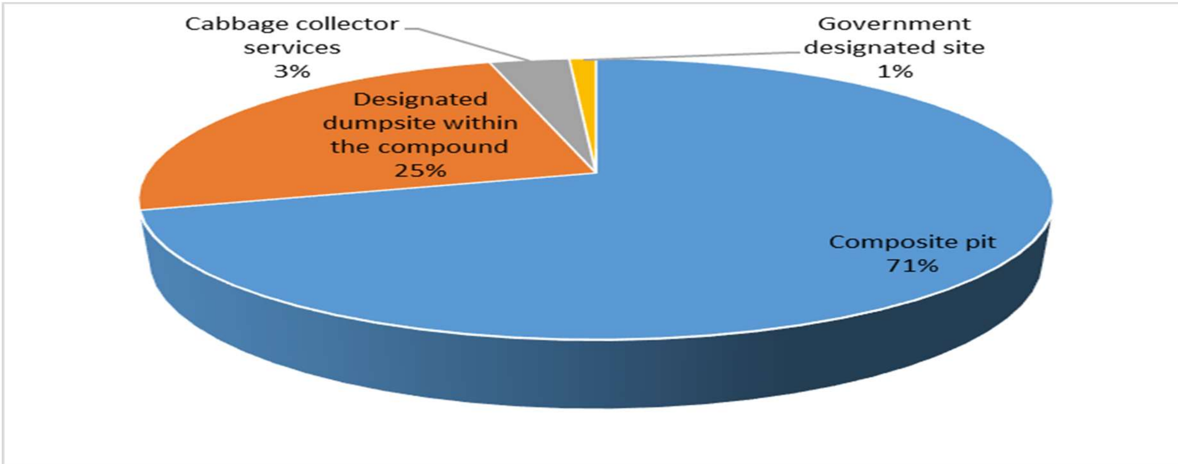

Figure 4. 2: Modes of solid Waste Disposal

The results presented in Figure 4.2 shed light on the different practices of waste management in relation to water wells, highlighting potential sanitary risk factors.

The results indicated that 71% of the visited sites employed composite pits as the primary mode of waste disposal near water wells. Composite pits involve the accumulation of household waste in designated areas. This prevalent practice poses a substantial risk to water quality, as waste materials may seep into the ground, potentially contaminating groundwater sources.

The 25% of the sites utilized designated waste disposal sites within the compounds. While this method may provide some containment, its proximity to water wells still carries a risk of leachate percolating into the ground and affecting water quality.

However, 3% of well sites opted for cabbage collector services. While this might imply a more organized waste collection, it's important to note that the impact on water quality depends on the disposal practices adopted by the collector. Surprisingly, only 1% of the sites were reported to be utilizing government-approved dumping sites. This practice is likely associated with the peri-urban setup of the township ward. Although this method seems safer for water quality, its low adoption suggests challenges related to accessibility, awareness, or logistics.

The findings from Figure 4.2 further reveal significant insights into the modes of solid waste disposal practices near water wells and their potential impact on water quality. The dominance of composite pits and the limited utilization of government-approved dumping sites indicate that there are significant sanitary risk factors that may contribute to groundwater corruption. To safeguard the quality of water in wells and springs, it's imperative to raise awareness about proper waste disposal methods and encourage the adoption of safer practices that minimize the risk of contamination. Inadequate and unsatisfactory management of solid waste poses a substantial risk to water quality, primarily due to the leaching of organic compounds such as nitrates and sulphates. Taylor and Allen (2006) emphasized that, in the context of assessing the situation, landfills are predominantly associated with groundwater pollution stemming from liquids generated by waste. Nevertheless, any site where waste is accumulated, processed, and stored, even for brief periods, has the potential to act as a source of contamination for groundwater

4.2.3 Abstraction methods of water from the sources

The study sought to determine the abstraction methods of water from sources. The results are indicated below

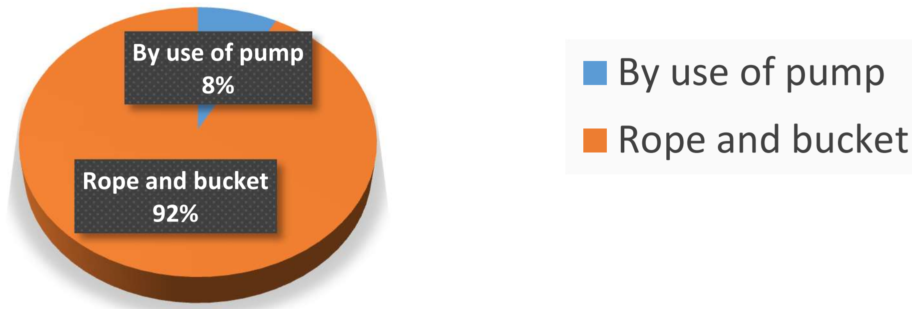

Figure 4. 3: Abstraction methods of water from the sources

Figure 4.3 shows the results of methods used for water abstraction. The information suggests that among the selected wells, the method of water abstraction from wells is predominantly done using a "rope and bucket," accounting for 92.1% of cases. In contrast, only a minority, 7.9%, employed the use of "pulleys" for water abstraction. This finding aligns with a study conducted in Eldoret by Mbaka, Mwangi, and Kiptum (2017 , which similarly discovered that the majority of individuals drew water from wells using the "rope and bucket" method. This common practice of using a rope and bucket for drawing water from wells is noted to have potential implications for water contamination,

The implication here is that the "rope and bucket" method might have greater potential for introducing contaminants into the water source compared to the use of "pulleys." The ease of access and simplicity of the "rope and bucket" approach might make it more prevalent, but it could also expose the water to various sources of contamination. The "pulleys" method might be less prone to contamination as it involves less direct contact with the water source.

4.2.4 Assessment of well protection covers

The study sought to evaluate the source of protection of wells under study. Figure 4.4 shows the wells that had covers and those that didn't have.

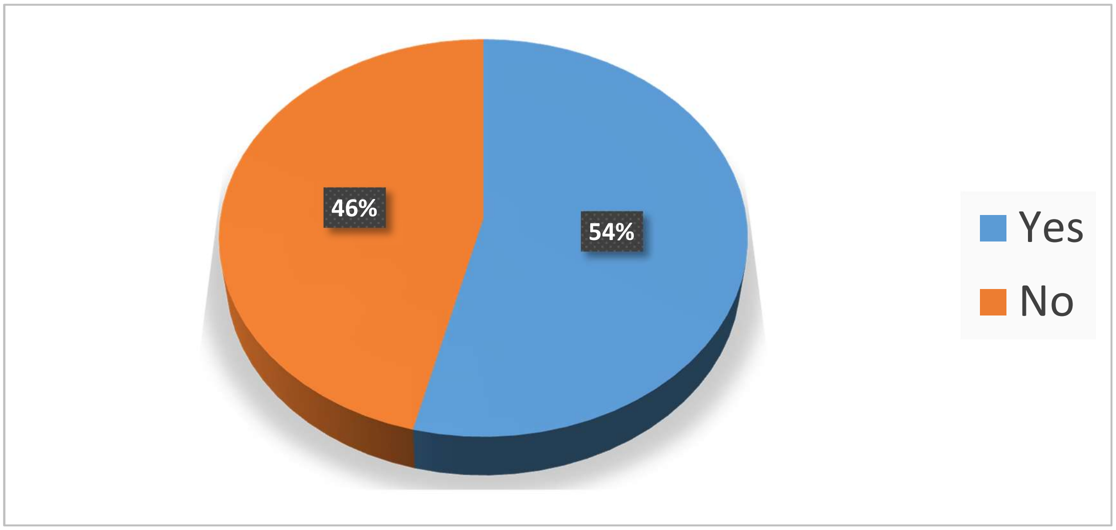

Figure 4. 4: Assessment of well protection covers

The study revealed that a substantial portion of the wells, specifically 46%, lacked proper covers. This deficiency was observed in forty-one wells, primarily located in rural areas. In contrast, 53.9% of the wells were equipped with covers, with a mix of wooden and metallic lids, which were deemed sufficient for protecting the wells.

The absence of covers on a considerable number of wells is a concerning issue, as it renders these wells vulnerable to contamination from surface runoff. This risk is particularly evident when wells are positioned downhill from on-site sanitation facilities. In these scenarios, rainwater runoff can carry pollutants and contaminants from the surroundings directly into the wells, thus affecting the quality of the groundwater.

Further analysis of the uncovered wells revealed that 38% of them exceeded the permissible limits for nitrate concentration. This excess nitrate presence suggests a significant contribution to the deterioration of water quality. The likely cause of this contamination is the runoff from rainfall, which carries nitrate-containing substances from the environment and deposits them into the unprotected wells.

In conclusion, the study sheds light on the detrimental effects of human activities on groundwater quality. The prevalence of uncovered wells, particularly in rural areas, highlights the need for improved sanitation practices and protective measures to prevent surface runoff contamination. The elevated nitrate levels in uncovered wells underscore the direct link between the absence of well covers and groundwater quality degradation.

4.2.5 The assessment of conditions of concrete apron around the well

The study sought to assess the conditions of the concrete apron around the water wells and springs. The objective was to understand the potential sanitary risks posed by their conditions to quality of water in these sources. Figure 4.5 shows the conditions.

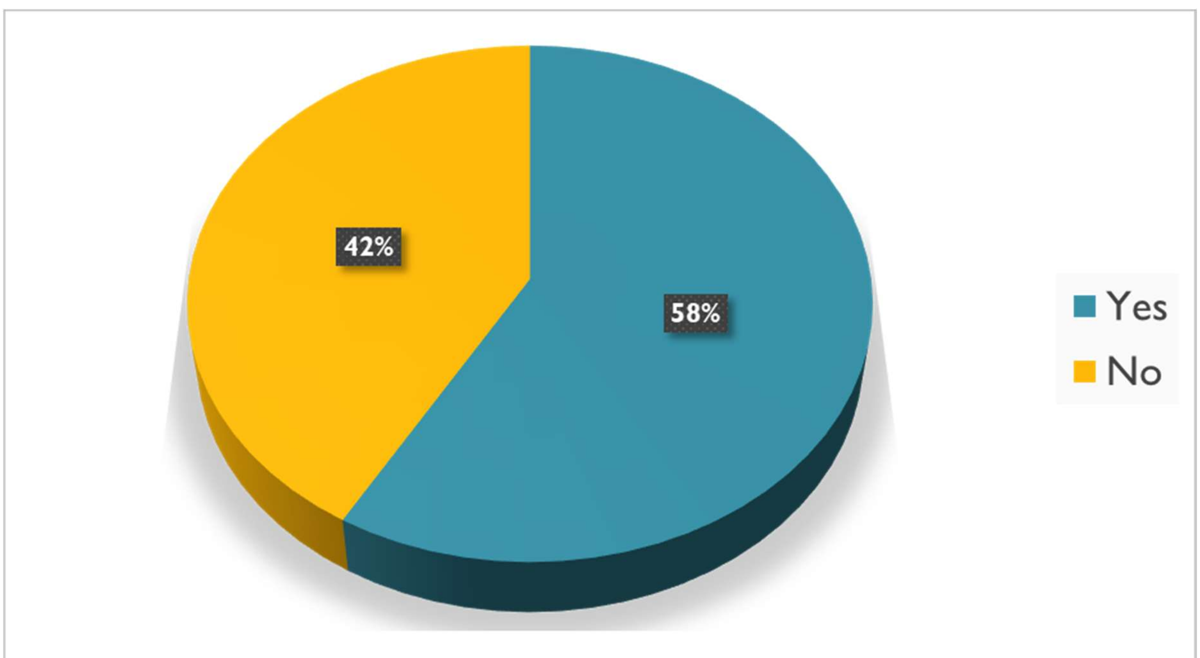

Figure 4. 5: Showing the Concrete floor<1.5m wide around the well

The study aimed to investigate the connection between sanitary conditions, specifically the presence of a concrete floor within a distance less than 1.5 meters around wells, and its impact on water quality in both wells and springs. The results of the assessment provide valuable insights into how different sanitary factors can influence the protection of water sources from contamination.

The evaluation of the sanitary conditions of the concrete floor around the wells revealed interesting findings as indicated in Figure 4.5 that out of the total 89 wells assessed: 37 wells, accounting for 42% of the total, lacked a concrete floor within the specified distance, potentially allowing runoff water to percolate into the well.

On the other hand, 52 wells, representing 58% of the total, featured an intact concrete floor, particularly prevalent in peri-urban wards.

These results underscore the significance of proper sanitary measures in preserving water quality in wells and springs. The absence of a concrete floor around a considerable portion of the wells presents a clear vulnerability to contamination. Without this protective barrier, runoff water, which often carries pollutants and contaminants from the surrounding area, can easily seep into the well, leading to a decline in water quality.

In contrast, the presence of an intact concrete floor around wells, especially in peri-urban areas, demonstrates a proactive approach to maintaining water quality. This preventive measure acts as a barrier that impedes the infiltration of runoff water and potential contaminants, safeguarding the well water from degradation.

Overall, the findings of this study emphasize the essential role of sanitary factors, specifically the presence of a concrete floor, in influencing the quality of water in wells and springs.

4.2.6 Assessment of the sanitation facilities within the proximity of wells

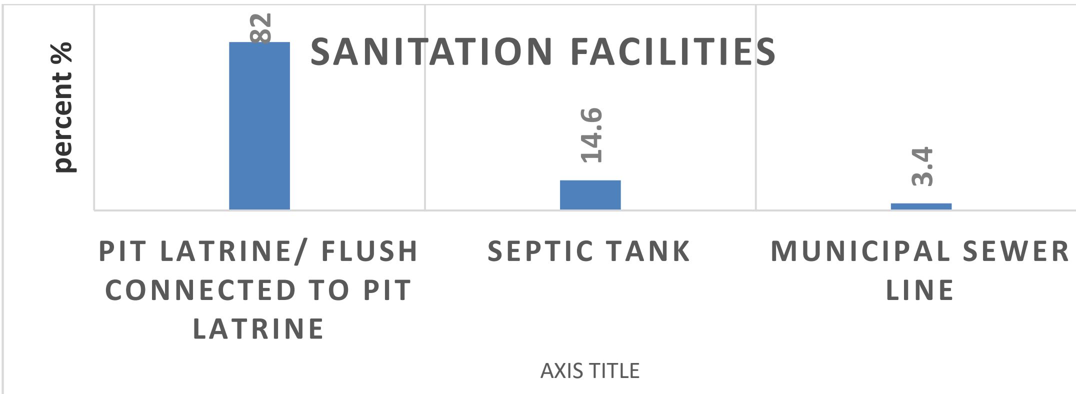

Figure 4. 6: showing different types of sanitation facilities

The findings from the assessment shed light on the relationship between sanitary conditions and water quality in wells and springs. The data revealed the presence of various sanitation facilities in proximity to these water sources, and this has implications for their overall quality. According to the assessment results in Figure 4.6 it indicated that a significant proportion, specifically 82%, of the visited sites had pit latrines located in close proximity to wells and springs. This indicates that a substantial number of water sources are at risk of potential contamination from the waste generated by pit latrines.

Around 14.6% of the sites, which were primarily situated in peri-urban wards, had septic tanks nearby. This indicates a relatively higher level of sanitation infrastructure in these areas compared to others. A small minority, constituting only 3.4%, were utilizing sewer lines for their sanitation needs. This suggests a more advanced level of sanitation infrastructure but is relatively rare, potentially due to its limited availability.

The high prevalence of pit latrines in close proximity to wells and springs raises concerns about water quality. Pit latrines can contribute to groundwater contamination, as waste and pathogens can leach into the ground and reach the water sources. In study area the presence of high density of pit latrines close to wells increases the risk of contamination through leachate this was also observed in Cameroon by Viban et al (2021).

This increases the concentration of nitrates and Coliforms. The survey also revealed that a considerable number of people living on relatively tiny plots, where they had established groundwater sources and sanitation facilities. The findings are in accordance with those of previous researchers (Pujari et al., 2007, 2012; Jangam et al., 2015), who found that a rising population has increased the strain on groundwater resources, leading to a reduction in quality brought on by both human and geogenic factors.

The presence of septic tanks in peri-urban wards is a positive sign as these systems are designed to manage and contain waste better than pit latrines. However, improper septic tank maintenance can still pose risks to groundwater quality. Several authors have discussed the effects of septic tanks on groundwater quality evaluations (NEERI 2005; Pujari et al. 2007, 2012; Lu et al. 2008; Jangam et al. 2015). Pujari et al. (2007) found a greater concentration of nitrate and bacteria in groundwater near On-site sanitation systems, indicating a negative impact on groundwater quality. Large areas of India are heavily contaminated with groundwater due to the improper disposal of household waste. On-site sewage treatment systems pose a danger to the long-term health of groundwater. The importance of this phenomenon increases when geological circumstances make it easier for poisons to migrate. When the groundwater table is low, the situation is dire.

The utilization of sewer lines is a favorable sanitation practice, as it minimizes direct contamination of groundwater. However, its limited adoption could be due to factors such as infrastructure availability and cost.

The assessment underscores the close connection between sanitary factors and the quality of water in wells and springs. The prevalence of pit latrines near these water sources raises concerns about potential contamination, while the presence of septic tanks and sewer lines indicates better sanitation practices.

4.2.7. Distance from the well to the existing sanitation facility

The study aimed to analyze the distances between potential contaminant sources and water wells or springs. The findings presented in Table 4.7 offer valuable insights into the spatial proximity of potential contaminant sources to water sources and the resulting impact on water quality.

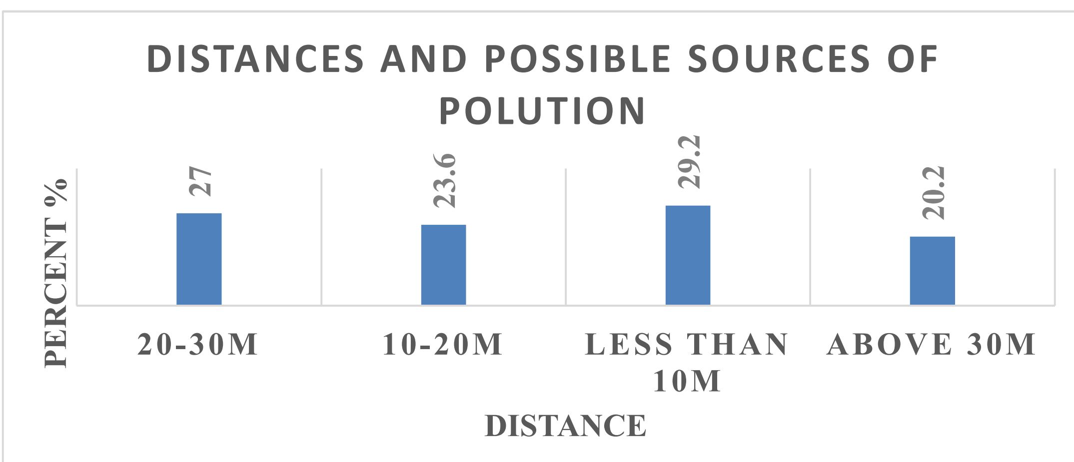

Figure 4. 7: Results of distance of pollution source against well locations

The distances were categorized into two ranges: those above 30 meters and those 30 meters or below. These distances are critical as they determine the potential exposure of water sources to pollutants such as animal waste, landfills, and trash, as well as the proximity of pit latrines, which are recognized as potential sources of contamination.

The results presented in Figure 4.7 showed the following insights: Above 30m Distances: A noteworthy observation is that only 20.2% of the sites were situated at distances exceeding 30 meters from the water source. This implies that a relatively small proportion of the studied sites are potentially less exposed to direct contamination from pollutant sources, suggesting a potentially lower risk of water quality degradation.

30m and Below Distances: In contrast, the majority of the sites fell within the range of 30 meters or below from the water sources. These close proximities increase the likelihood of contamination from various sources, including animal waste, landfills, trash, and the immediate presence of pit latrines. This heightened exposure within the 30-meter radius significantly elevates the risk of water contamination.

Pit Latrine Proximity: Importantly, in areas where the majority of wells were located, the presence of pit latrines further compounded the risk of contamination. These pit latrines are potential sources of pollutants that can easily infiltrate groundwater, especially when located within close proximity to water sources.

The findings demonstrate that majority of studied wells were situated within less than 30-meter range from pollutant sources, posing a significant threat to water quality. The presence of pit latrines in areas with numerous wells adds to this risk. This results is consistent with the study carried out in Kisii county where 80% of pit latrines were found to be at less than

30m close to the wells (Misati, at el, 2017). In the neighborhood Kisumu, Opisa at el (2012) found similar scenario where 64% of the wells were located less than 30m from the pit latrines.

This correlation table appears to show the Pearson correlation coefficients between different variables related to water quality. Pearson correlation coefficient measures the strength and direction of the linear relationship between two variables**.**

Table 4. 1: Correlation between distances from wells to existing pit latrine and nine selected water quality parameters.

		Distance of pollution source in m to the well	**Turbidity**	**PH**	**TDS**	**E.C**	**Sulphates**	**Phosphate**	**Nitrates**	**Total Coliforms**
Distance of pollution source in m to the well	**Pearson Correlation**	1								
Turbidity	Pearson Correlation	.033	1							
PH	Pearson Correlation	.005	.242	1						
TDS	Pearson Correlation	-.150	-.071	.199	1					
E.C	Pearson Correlation	-.178	-.095	.191	.945	1				
Salinity	Pearson Correlation	-.129	.544	-.091	.038	.000				
Sulphates	Pearson Correlation	-.096	.258	.121	-.047	-.080	1			
Phosphate	Pearson Correlation	.034	.228	-.162	.024	.004	.397	1		
Nitrates	Pearson Correlation	-.017	.419	.133	-.047	-.045	.487	.300	1	
Total Coliforms	Pearson Correlation	-.093	.127	.116	.016	.017	-.076	-.042	.143	1
Feacal Coliforms	Pearson Correlation	-.087	.167	.204	.040	.045	-.027	-.018	.160	.884

The correlations in Table 4.1 provides insights into how different water quality parameters relate to each other and their potential relationship with the distance to a pollution source.

Turbidity which is a measure of water clarity. It has a very weak positive correlation (0.033) with the distance to the pollution source. This suggests that there is a slight tendency for turbidity to increase as the distance to the pollution source increases, but the relationship is not strong.

pH is a measure of the acidity/basicity of water. It has a very weak positive correlation (0.005) with the distance to the pollution source. The correlation with pH is also weak (0.242), suggesting a slight positive relationship between pH and turbidity.

The Total Dissolved Solids is a measure of the concentration of dissolved solids in water. It has a negative correlation (-0.150) with the distance to the pollution source, indicating that as the distance increases, TDS tends to decrease slightly. TDS also has weak correlations with other variables.

The Electrical conductivity (EC) is a measure of water's ability to conduct an electric current. It has a negative correlation with the distance to the pollution source (-0.178). Additionally, it has a strong positive correlation (0.945) with "Sulphates", suggesting a potential close relationship between these two variables.

The Salinity has negative correlations with the distance to the pollution source and with other variables like pH and turbidity. It has a strong positive correlation (0.544) with "Turbidity" and weaker correlations with other variables.

The Sulphate concentration has a negative correlation (-0.096) with the distance to the pollution source. It also has weak positive correlations with variables like turbidity and pH. Interestingly, it has a relatively strong positive correlation (0.258) with "Turbidity".

Phosphate has a weak positive correlation (0.034) with the distance to the pollution source. It also has weak negative correlations with variables like TDS and pH. It has a stronger positive correlation (0.397) with "E.C".

The Nitrates have a weak negative correlation (-0.017) with the distance to the pollution source. They have a moderate positive correlation (0.419) with variables like "Turbidity" and a relatively strong positive correlation (0.487) with "E.C".

Total coliform counts had weak negative correlations with the distance to the pollution source and other variables. The strongest correlation (0.143) is with "Salinity".

Feacal Coliforms: Similar to total coliforms, Feacal coliforms have weak negative correlations with the distance to the pollution source and other variables. They have a relatively strong positive correlation (0.884) with "Total Coliforms".

In summary, the correlation table provides insights into how different water quality parameters relate to each other and their potential relationship with the distance to a pollution source. However, it's important to note that correlation does not imply causation, and further analysis is needed to draw meaningful conclusions about the relationships observed here.

4.2.8. Risk Assessment and categorization for Wells and Springs

4.2.8.1. Wells

The study sought to establish a Risk Assessment Scorecards for wells. The findings from the assessment of sanitary risk factors on water quality from the Risk Assessment for Wells provide valuable insights into the potential risks associated with various wells in different wards. The classification was based on the percentage of risk questions answered "Yes" or potential questions, categorized as High, Medium, or Very High Risk. The distribution of risk levels across the wards highlights the varying degrees of potential threats to water quality.

Musikoma Ward:

Three wells (3, 7, 12) were identified as having very high risk levels.

Two wells (9, 10) were classified as medium risk.

Khalaba Ward: One well (15) was categorized as very high risk, while the remaining wells were at medium risk.

Bukembe East Ward: Two wells (31, 34) were labeled as low risk.

The rest of the wells in this ward exhibited high and medium risks.

West Sang'alo Ward: Only one well (45) showed a low risk classification.

The other wells demonstrated medium and high risks.

Township Ward: Well number 57 was identified as having a very high risk.

The remaining wells were mostly high and medium risk.

Bukembe West Ward: Two wells (66, 76) were designated as very high risk.

Consistent Patterns: Four wards (Musikoma, Khalaba, Township, Bukembe West) recorded very high risk levels, primarily attributed to human activities.

West Sang'alo and Bukembe East wards had some wells with low risk, suggesting comparatively better sanitary conditions.

Average Mean Values: The wells across all seven wards displayed average mean values ranging from 58.60% to 68.15%, indicating a consistent pattern of high risk across the study area. The results from this study align with the findings of a previous assessment by Moses Kiwanuka et al. (2022) in Kampala's urban slums, which observed similar patterns of risk associated with water quality from springs.

Overall, the findings highlight the critical importance of assessing sanitary risk factors to ensure water quality in wells. The presence of high and very high-risk wells, particularly in certain wards, underscores the need for targeted interventions to improve sanitation practices and mitigate potential contamination sources.

4.2.8.2. Springs.

Table 4. 2: Risk classifications of the springs in relation to potential risk factors

Sample source	Risk Score	Risk Classification
Spring 1	53	High Risk
Spring 2	60	High Risk
Spring 3	86	Very High Risk
Spring 4	47	Medium Risk
Spring 5	40	Medium Risk
Spring 6	66	High Risk
Spring 7	40	Medium Risk
Spring 8	60	High Risk
Spring 9	73	High Risk
Spring 10	66	High Risk

The study assessment included several human activities and sanitary conditions of the springs. The parameters were weighted according to their ratings, and the weights were multiplied to obtain risk indices that were then used to classify the parameters into four risk classes: Low Risk, Medium Risk, High Risk, and Extremely High Risk.

Each spring's risk assessment score was listed in Table 4.3. The seven springs were at risk of faecal pollution. On the scorecard, the accumulated values ranged from Moderate to Very High. Spring No. 3 scored between 81% and 100%, suggesting a very high danger. Whereas spring 1,2,6,8,9, and 10 indicated a high risk of 51 to 80 percent.

Since ancient times, people have migrated closer to spring water supplies since it is thought that spring water is of high quality. Nevertheless, this belief has changed as a result of population expansion. This has led to an increase in human activity near the springs, resulting in pollution. Testing for Feacal coliforms parameter, for example, may indicate a potential hazard of contamination since pathogens like E. coli bacteria may come from leakage of animal and human wastes maybe from on-site sanitation facilities (Ashun, 2014).

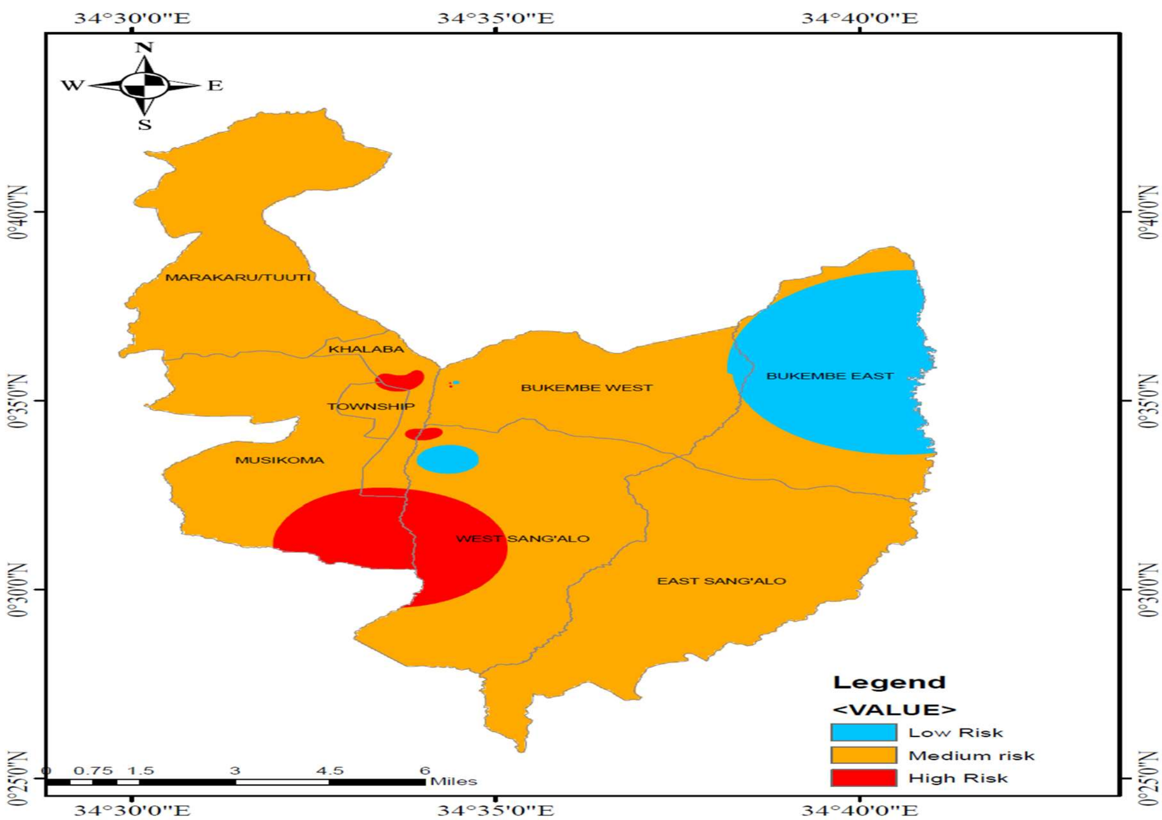

Figure 4. 8: Spatial risk cauterization map for Wells and springs in Kanduyi

Source: Researcher, 2023.

The results of the risk assessment were utilized to categorize distinct wards within the mapped area into different risk zones, employing geospatial methodologies. These risk zones essentially delineate varying degrees of susceptibility to groundwater sources, spanning from minimal to substantial. The wells characterized by few risk-contributing factors were designated as low-risk zones. Conversely, regions characterized by elevated concentrations of contaminants, coupled with a higher count of human risk-contributing factors, were designated as high-risk zones.

For instance, as depicted in Figure 4.9, the spatial representation of the study area revealed that Bukembe East ward exhibited a low-risk classification. This results can be attributed to the predominantly rural nature of the area, where larger land plots lead to fewer risk-contributing factors in proximity to existing wells and springs. Five other wards, namely Khalaba, Musikoma, Bukembe West, and East Sang'alo, were categorized as medium-risk zones. This classification can also be attributed to these wards rural set up as well as the research found that even in peri-urban areas, most wells exhibited proper lid covers and intact sanitary components within their small plots.

However, the investigation further unveiled that West Sang'alo ward was classified as a high-risk zone. This classification arose due to the pronounced intensity of human activities and settlements in the area. These activities significantly impacted groundwater quality and contributed to the elevated risk level associated with this region.

In summary, the study's risk mapping analysis used geospatial techniques to classify different areas into distinct groundwater quality risk zones. These zones ranged from low to high risk, with the classification being influenced by contaminant levels and the presence of various risk-contributing factors. The specific categorizations of different wards were informed by factors such as rural versus peri-urban settings, land use patterns, and the extent of human activities and settlements impacting groundwater quality.

4.3. Physio-Chemical and Bacteriological Water Quality

The study results for physio-chemical and bacteriological characteristics of the water in the seven (7) wards of Kanduyi sub-county were subjected to statistical analysis and compared with Kenya Bureau of standard (Kebs) guidelines. The results were presented in (Table 4.5) shown below.

Table 4. 3: Statistics of the parameters analyzed and comparison with KEBS guidelines for wells and springs.

Sampling Sites		Turbidity	pH	TDS	E.C	Salinity	Sulphates	Phosphate	Nitrates	Total Coliforms	E-Coli
		NTU	UCC	Mg/l	uCM	Mg/l	Mg/l	Mg/l	Mg/l	Cfu/100ml	Cfu/100ml
Musikoma Ward	**Average**	6.3	6.9	113.2	229.7	15.3	5.6	7.4	8.8	11.1	3.9
	Min	2	6.4	63	126	4	1	4.4	2.4	0	0
	Max	14	8.2	210	421	33	19	10.3	19.1	40	12.4
	SD	3.5	0.5	34.7	70.9	7.2	5.3	2.0	5.0	13.2	4.1
	N	13	13	13	13	13	13	13	13	13	13
Khalaba Ward	**average**	8.8	6.8	128.9	240.1	18.1	12.2	8.2	7.2	5.1	0
	Min	1	4.5	75	145	0.4	1	2.1	2.4	0	0
	Max	21	9.4	245	434	51.4	47	20.4	19.04	21	7
	SD	6.3	1.2	49.9	73.4	13.5	13.7	5.1	4.8	6.6	0
	N	14	14	14	14	14	13	14	14	14	14
Bukembe East Ward	**average**	12.8	6.4	84.2	176.8	21.0	15.5	6.4	13.6	4.7	2.3
	Min	4	5.2	35	71	0.7	0.1	0.39	3.4	0	0
	Max	64	6.8	188	377	103.4	52	18.13	51	13	6
	SD	15.8	0.4	43.6	84.3	29.9	17.1	6.6	13.9	5.4	2.6
	N	13	13	13	13	13	13	13	13	12	12
West Sang'alo Ward	**average**	4.0	7.6	179.8	336.3	5.9	5.7	3.6	7.5	5.5	2.9
	Min	1.1	7.13	69	121	3.5	1	0.77	3	0	0
	Max	7.8	11.1	450	721	11.7	11	8.6	13	21	9
	SD	1.8	1.1	125.3	224.4	2.7	3.3	2.5	2.8	5.7	3.1
	N	12	12	12	12	12	12	12	12	12	12
	average	8.5	7.1	183.5	393.5	10.9	8.3	4.3	6.1	4.9	0

	Min	2	6	71	143	2	0.3	1.5	1	0	0
Township Ward	**Max**	24	9.2	372	746	23.6	21	9.69	11.4	13	8
	SD	5.5	0.9	109.3	240.7	7.5	6.6	2.3	3.0	5.1	2.5
	N	14	14	14	14	14	14	14	14	14	14
	average	8.9	7.3	75.1	149.3	8.3	11.9	4.0	8.5	8.0	3.3
	Min	2	6.1	43	83	0.4	1.8	1.01	2.5	0	0
Bukembe West	**Max**	33	13	152	302	19.2	45.6	11.3	12.6	54	14
	SD	8.4	2.0	33.8	67.8	5.4	13.7	3.5	3.8	15.0	4.3
	N	12	12	12	12	12	12	12	12	12	12
	average	14.4	7.3	97.4	161.2	27.7	18.4	4.4	9.7	6.4	2.2
	Min	5	5.5	43	88	9.4	6.8	0.3	2.3	0	0
Marakaru Tuuti	**Max**	24	10	285	567	109.4	33.1	10.8	20.7	21	8
	SD	5.8	1.4	68.1	133.4	30.4	8.9	3.6	5.1	6.7	0
	N	12	12	12	12	12	12	12	12	12	12
KEBS Guidelines		**< 5**	**6.5-8.5**	**< 500**	**<400**	**20**	**400**	**1**	**>10**	**0**	**0**

4.3.1 Physio-Chemical quality

The study results in (Table 4.5) showed that Total Dissolved Solids (TDS) and Conductivity ranged from 75.1 to 183.5 mg/L and 149.3 to 393.5 mg/L, respectively. These values were notably lower than the recommended standards of 500 mg/L for TDS and 2500 mg/L for conductivity according to KS 05-459. The main contributors to TDS in water are organic and inorganic substances leaching or running off from non-point sources, with the highest value of 183.5 mg/L recorded in West Sang'alo. This outcome aligns with Ashun and Bansah's (2017) research in the Athi River Basin where TDS values reached 449 mg/L in wells.

Turbidity measurements ranged between 4.0 and 14.4 mg/L NTU, with higher values observed in West Sang'alo and Marakaru wards. This indicated that certain wells exceeded the standard turbidity level of 5 NTU according to KEBS guidelines KS 05-459. Elevated turbidity is associated with poor drainage and inadequate protective infrastructure around water sources, echoing findings by Kanda et al. (2023) in Vihiga County where sampled wells displayed turbidity ranging from 4.1 NTU to 15.0 NTU.

Sulfate levels, arising from natural and anthropogenic sources such as sulfate minerals and agrochemical farming, ranged from 5.6 to 18.4 mg/L. These values were well below the recommended limit of 400 mg/L by Kenya Bureau of Standards. Similar trends were noted for phosphate, which ranged from 3.6 to 7.4 mg/L, surpassing the recommended levels of 2 mg/L by KEBS and 5 mg/L by WHO. Phosphate contamination is linked to activities like fertilizer and detergent use. The variance in contamination levels was attributed to well characteristics.

Nitrates ranged from 7.2 to 13.6 mg/L on average, exceeding the recommended 10 mg/L limit set by Kenya Bureau of Standards. High nitrate levels were associated with sewage pollution, nearby pit latrines, agrochemical farming, and grazing animals. Studies in Kisumu by Wright et al. (2013) and Ashun and Bansah (2017) in Athi River observed analogous high nitrate concentrations.

The pH values ranged from 6.4 in Sang'alo to 14.4 in Bukembe West, slightly deviating from the recommended 6.5 to 8.5 pH range by Kenya Bureau of Standards. Comparable findings emerged from Kibet et al. (2016) in Kakamega.

4.3.2 Bacteriological quality

The investigation detected total coliform counts between 4.9 and 54 CFU/100ml, and fecal coliforms between 2.1 and 14 CFU/100ml. An overwhelming majority of wells (92.0% for total coliforms and 89.8% for fecal coliforms) exhibited positive contamination. These values greatly exceeded the desirable zero CFU/100ml guideline for potable water. Factors like poor sanitation, animal access, inappropriate toilet placement, and unhygienic water collection methods were identified as potential contamination sources, echoing observations by Kanda et al. (2018) in Vihiga County and Mbaka et al. (2017) in Keiyo district of Elgeyo Marakwet county.

Consequently, water from these wells poses health risks to consumers, necessitating treatment or boiling prior to use.

4.4. Water Quality Index (WQI) for Wells and Springs

The Third objective of this research was to establish a Water Quality Index (WQI) for groundwater sources in the study area.

Water Quality Index (WQI) analysis was computed utilizing the measured physiochemical and bacteriological parameters in order to effectively assess the water pollution levels of each well and spring. In this study, the eighteen arithmetic mean approach was utilized.

4.4.1. Wells

Table 4. 4: Water quality index of sampled wells in Kanduyi Sub-county.

Name of Wards	Water Quality Index		Water Quality Class
	Mean	118	Unsuitable
Musikoma Ward (13)	Range	78-178	Very poor-Unsuitable
	Mean	136	Unsuitable
Khalaba Ward (14)	Range	64-176	Poor-Unsuitable
	Mean	152	Unsuitable
Bukembe East Ward (12)	Range	43-156	Good-Unsuitable
	Mean	68	poor
West Sang'alo Wards (12)	Range	38-190	Good-Unsuitable
	Mean	101	Unsuitable
Town ship Ward (14)	Range	56-177	Poor-Unsuitable
	Mean	81	Very poor
Bukembe West Ward (12)	Range	39-164	Good-Unsuitable
	Mean	125	Unsuitable
Marakaru Tuuti Ward (12)	Range	56-204	Poor-Unsuitable

The study shows that the water quality Index (WQI) ranged from a minimum of 38 to a high of 204 throughout the seven wards. It indicated that the average quality class fell between

Excellent and Unfit for Usage. In the wards of West Sang'alo and Bukembe East, shallow wells with the lowest water quality grades of 38 and 43, respectively, were detected.

According to the Water Quality Index data from wards deemed the wells unsafe, with Excellent being the highest grade, followed by Poor and Very Poor. The water quality index of the wells in the region under study suggests that the water is unfit for human consumption unless it has been subjected to conventional treatment. As seen in the table, despite being located in rural areas, Bukembe west, Bukembe east, and West Sang'alo reported a significant frequency of water contamination leading to unfit water quality for human consumption.

The majority of wells (51.7% of the total) were evaluated as having poor quality, while 22.5% and 20.2%, respectively, had poor and very poor water quality. This suggests that only 5.6% of wells contain potable water. Khalaba, Musikoma, and Marakaru Tuuti wards were responsible for 33.7% of improperly constructed wells.

4.4.2. Springs

Table 4. 5: WQI of sampled springs

Name of the ward	Water Quality Index		Water Quality Classification
	Mean	52.63	Poor quality
Musikoma Ward	Range	52.63	Poor quality
	Mean	52.68	Poor quality
Khalaba Ward	Range	52.68	Poor quality
	Mean	55.73	Poor quality
West Sang'alo Ward	Range	34.26-77.2	Good-Poor quality
	Mean	41.84	Good quality
Bukembe East ward	Range	32.29-51.38	Good quality
	Mean	18.54	Excellent quality
Town ship Ward	Range	18.54	Excellent quality
	Mean	32.89	Good quality
Bukembe West Ward	Range	30.44-35.34	Good quality
	Mean	27.78	Good quality
Marakaru Tuuti Ward	Range	27.78	Good quality

The results indicate that samples from springs were of higher quality than those from wells. 10% of the springs had a WQI score between 0 and 25, which indicates outstanding water quality. 50 percent of the springs had a score between 26 and 50, which indicates good water quality. The decreased water quality observed in the spring during this season can be attributed to two primary factors. Firstly, the interaction between rainwater and the sedimentary rock in the vicinity leads to the dissolution of ions into the aquifer. Secondly, anthropogenic activities, including sewage disposal, waste disposal, agricultural practices, the existence of a contaminated drainage system near the spring's water source, and pollution from a nearby dumpsite, contribute to the degradation of water quality. The results indicate that there were no wells in the 0-25 category (excellent). .

4.5 Water Quality Index mapping

The study sought to establish the categories of Water Quality Index (WQI) distribution in the study area. Through GIS applications the mapping of their distributions in the study area were indicated in table 4.10 below.

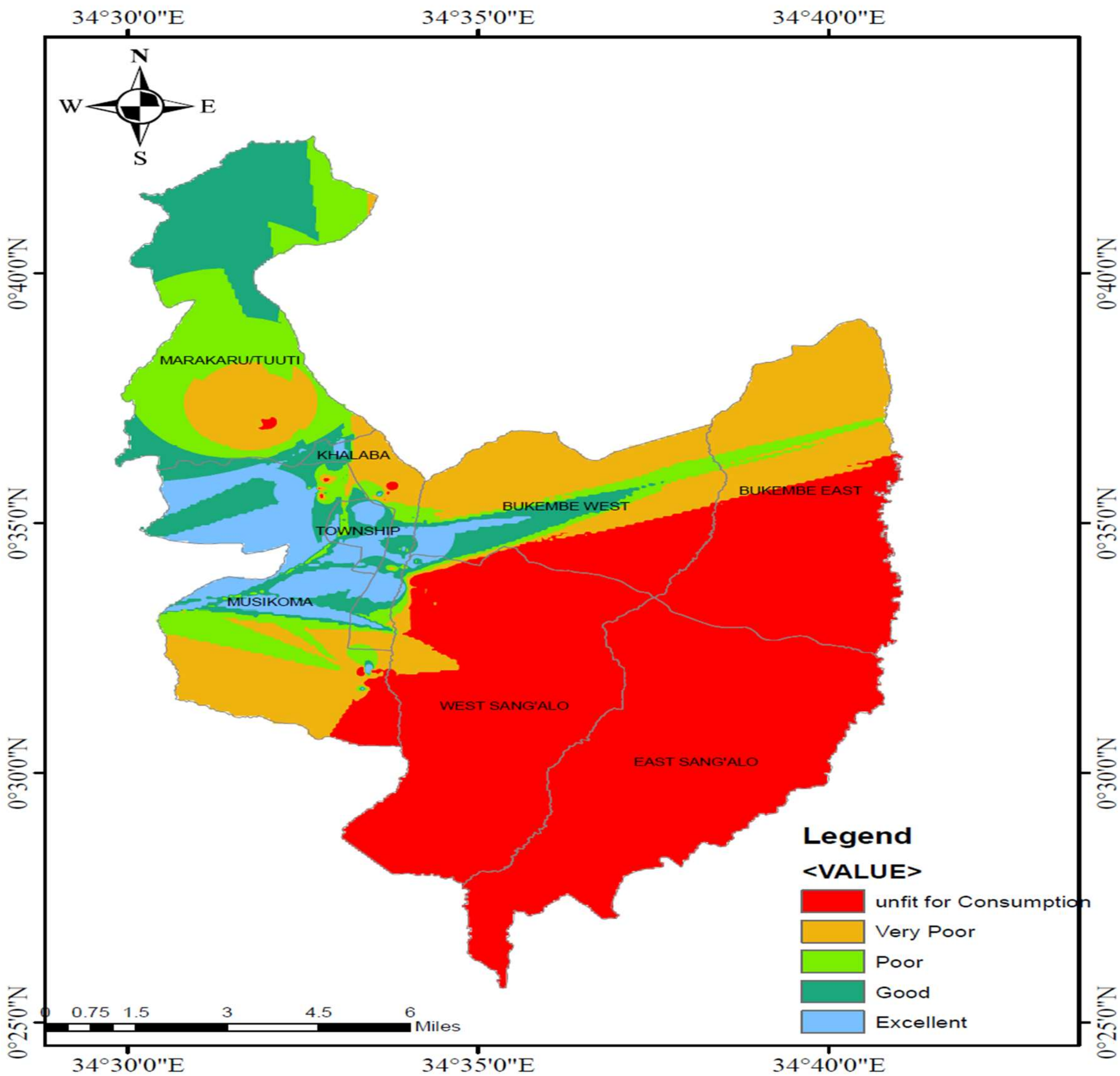

Figure 4. 9: Showing spatial distribution map of WQI wells and springs in the study area

The research results in Figure 4.10 indicated that wells and springs located in East Sang'alo and a section of West Sang'alo demonstrated the poorest Water Quality Index, rendering the water unsuitable for human consumption. This deterioration was linked to a combination of various human-related factors and inadequate sanitary conditions, all contributing to the compromised water quality. Similarly, Bukembe West, along with a portion of Bukembe East, Musikoma, and Marakaru Tuuti, exhibited a poor Water Quality Index. This decline was attributed to various human activities that negatively influenced water quality.

Conversely, the study found that wells and springs situated in the Township area, certain segments of Musikoma, as well as smaller portions of Khalaba, Marakaru, and West Sang'alo Wards, displayed good water quality. This positive result was attributed to effective sanitary practices and the protective measures in place to safeguard water sources from contamination.

Furthermore, the investigation unveiled that a few number of wells and springs within the Township and Musikoma wards demonstrated an excellent Water Quality Index. This outstanding performance was linked to the proper disposal of solid wastes through sound sanitary practices, combined with the effective protection of water sources to prevent pollution from contaminants.

CHAPTER FIVE
SUMMARY CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

5.1.1 The effects of human activities

The research revealed that poor practices of siting sanitation facilities like pit latrines and composite pits against the recommended 30m distances from the water source was identified as the most important and popular source of pollution. However other human activities that were prevalent near water springs and wells included laundry, livestock grazing, and cultivation of crops, among others These activities bear the potential to impact water quality. Notably, the findings underscored a substantial correlation between the siting of wells and sanitation facilities like pit latrines and dumpsites. There is a critical need for public awareness campaigns to emphasize the importance of maintaining a safe distance of at least 30 meters when locating sanitation facilities in relation to existing water sources. This education should empower individuals to make informed choices that prevent contamination risks.

5.1.2 The physio-chemical and bacteriological characteristics

The study showed variations in the physiochemical characteristics of water across different wells and localities. Specifically, the recorded pH values ranged from 4.5 to 15, deviating from the specified KEBS norms of 6.5 to 8.5. This divergence suggests that certain samples exhibited acidic properties, while others exceeded the permissible values established by the World Health Organization.

However, in microbiological quality, the enumeration of organisms identified in the water ranged from 0 to 20 CFU/100ml. It's noteworthy that Kenyan water quality guidelines stipulate a complete absence of CFU/100ml in potable water. The implications of positive coliform test outcomes are closely associated with causing of waterborne diseases, thus underscoring the potential health hazards linked with such forms of contamination. To minimize the potential for contamination, it is recommended that all areas situated near water wells and springs be secured. By controlling access and preventing activities that could compromise water quality, the risk of pollution can be significantly reduced.

5.1.3 The Water Quality Index for existing groundwater.

The findings revealed a spectrum of WQI values spanning from a minimum of 38 to a peak of 204 across the seven wards. This range of values illustrated that the average quality class straddled between "Excellent" and "Unfit for Use." Specifically, well water samples unveiled a distribution where 52% of them were deemed unsuitable for human consumption (WQI > 100), 19% were characterized as extremely poor (WQI 76-100), 24% were classified as poor (WQI 51-75), and 6% displayed excellent quality (WQI 26-50).

Furthermore, the results established a notable difference between the quality of samples from springs and those from wells. Spring water samples exhibited better quality. Among the springs, 10% achieved WQI scores of 0 to 25, indicating excellent water quality. Additionally, 50% fell within the range of 26 to 50, 40% scored between 51 and 75, and only 1% landed within the range of 76 to 100, signaling very poor water quality.

Observations highlighted that only two locations, West Sang'alo and Bukembe West, exhibited poor and very poor Comprehensive Water Quality Index (CWQI) values. Remarkably, except for the springs, none of the wells met the established standards for drinking water quality. The leadership within the water sector should adopt a proactive approach to monitoring the Water Quality Index (WQI) of groundwater sources. This entails consistent and systematic assessment of water quality using WQI measurements, and utilizing the collected data that will guide management efforts and track the effectiveness of the existing interventions. By staying vigilant and responsive, water sector management can ensure safety and suitability of groundwater sources.

5.2 Recommendation further Studies

The study recommends more studies on the impacts of other human activities like constructions, industrial and commercial activities in the study area.

Furthermore, the study also proposes follow up studies and water quality testing on other drinking water quality parameters like hardness and other chemical parameters.

REFERENCES

Adimalla, N. (2021). Application of entropy weighted water quality index (EWQI) and pollution index of groundwater (PIG) to assess the groundwater quality for drinking purposes: a case study. *Arch Environ Contam Toxicol*.

Agedah, E.C., Ineyougha, E.R., & Izah, S.C. (2015). Enumeration of Total Heterotrophic Bacteria and Some Physico- Chemical Characteristics of Surface Water Used for Drinking Sources in Wilberforce Island, Nigeria.

Almasri, M. (2007). *Nitrate contamination of groundwater.* Environmental Impact Assessment Review.

Ayranci E, H. N. (2005). Adsorption kinetics and isotherms of pesticides onto activated carbon-cloth. *Chemosphere*, 60:1600–1607. doi:10.1016/j.chemosphere.2005.02.040

Bai et al., O. H. (2010). Spatial variability of soil carbon, nitrogen, and phosphorus content and storage in an alpine wetland in the Qinghai-Tibet Plateau. *Australian Journal of Soil Research, 48*(8), pp. 730–736,.

Baker., A. (2003). Land use and water quality. *Hydrol Process*. doi:17:2499–2501

Baloch M. A. (2013). Groundwater vulnerability assessments: prioritizing water safety in times of austerity. *Journal of environmental health*, *76*(4), 40–42.

Baloch MA, S. L. (2011). *Environmental vulnerability assessment tool development for water pollution.* Paper presented at URISA GIS in Public Health Conference; Atlanta, GA. .

Bellingham, K. (2006). Physicochemical Parameters of Natural Waters. Stevens Water Monitoring Systems, Inc. 1–17.

Buck., e. a. (2004). Scale-dependence of land use effects on water quality of streams in agricultural catchments. *Environ Pollut*, 130:287–299. Retrieved from https://doi.org/10.1016/J.ENVPOL.2003.10.018

Chakraborti D, R. M. (2015). Groundwater arsenic contamination in Bangladesh—21 years of research. . *J Trace Elem Med Biol* , 31:237–248.

Chowdhury, R. M. (2012). Water Quality Index of water bodies along Faridpur-Barisal Road in Bangladesh. *Glob Eng Tech*, 2:1–8.

CIDP. (2018). *Bungoma County Integrated Development Plan 2018 - 2022.* Bungoma: Bungoma County.

Craun, G. C. (2003). Waterborne outbreaks in the United States, 1971–2000. In: Pontius FW, editor. Drinking water regulations and health. *New York: John Wiley & Sons*, 40–56.

DeSimone LA, H. P. (2009). The quality of our nation's waters: Quality of water from domestic wells in principal aquifers of the United States, 1991–2004—Overview of major findings. US Geological Survey Circular.;1332. Retrieved from http://pubs.usgs.gov/circ/circ1332/includes/circ1332

Deyong, Y. P. (2013). Detecting land use-water quality relationships from the viewpoint of ecological restoration in an urban area. *Ecological Engineering*, 53:205–216.

Dunn, S. V. (2005). Modelling nitrate losses from agricultural activities on a national scale. . *Water Sci Technol.,*, 51(3–4):319–27.

Edberg, S. C., Rice, E. W., Karlin, R. J., & Allen, M. J. (2000). Escherichia coli: the best biological drinking water indicator for public health protection. *Symposium series (Society for Applied Microbiology)*, (29), 106S–116S. https://doi.org/10.1111/j.1365-2672.2000.tb05338.x

Edwin Kimutai Kanda, Minyade K. Avulala, Emmy Olendo, Micah M. Mukolwe, Willis Awandu, Valery O. Lutta, Basil Ong'or (T), Alex W. Khaemba (2023). Assessment of groundwater quality in Vihiga County, Kenya; Progress in Sustainable Development Sustainable Engineering Practices, Elsevier, Pgs 249-264 https://doi.org/10.1016/B978-0-323-99207-7.00010-5

Elumalai, V. N. (2020). Groundwater quality assessment and application of multivariate statistical analysis in Luvuvhu catchment. *J Afr Earth Sci 171:103967*. Retrieved from https://doi.org/10.1016

Encyclopedia.com. (2009). Land Use Environmental Science: In Context. Retrieved Aug 9 , 2018, from https://www.encyclopedia.com/environment/energy-government-and-defense-magazines/land-use

Enetimi Idah Seiyaboh, Felix Okponanabofa Youkparigha, Sylvester Chibueze Izah, Ikpilavi Deborah Daniels (2020) Bacteriological Quality of Groundwater in Imiringi Town, Bayelsa State, Nigeria. Journal of Biotechnology and Biomedical Science - 2(2):34-40. https://doi.org/10.14302/issn.2576-6694.jbbs-20-3340

EPA (2001).Parameters of water quality: Interpretation and standards. Ireland, EPA.

Fawell, J. a. (2003). *Contaminants in drinking water: environmental pollution and health. Br. Med. Bull.* . doi:10.1093/bmb/ldg027

Foster, S. S. (2017). *Urban Groundwater Dependency in Tropical Africa, A Scoping Study of pro-Poor Implications, Report. Unlocking the Potential of Groundwater for Poor (UPGro).* Retrieved July 21, 2018, from https://upgro.files.wordpress.com/2015/09/urban-groundwater-report_0015.pdf (a

Fridrich, B. K. (2014). *Impact of wastewater from pig farm lagoons on the quality of local groundwater. Agric. Water Manag.* . doi:10.1016/j.agwat.2013.12.014

Ghebremichael, K. A. (2004). *Moringa seed and pumice as natural alternative materials for drinking water treatment.* Ph.D. thesis, KTH , Land and Water Resources Engineering.

Giri and Qiu. (2016). Understanding the relationship of land uses and water quality in twenty first century: a review. *J Environ Manag*, 173:41–48. Retrieved from https://doi.org/10.1016/J.JENVMAN.2016.02.029

Government of Canada. (2017). Groundwater contamination. Retrieved Oct 17 , 2020, from ttps://www.canada.ca/en/environment-climate-change/services/water-overview/pollution-causes-effects/groundwater-contamination.html

Government, T. M. (2006). Current status of groundwater abstraction in Tokyo Metropolitan (in Japanese).

Green, T. T. (2011). Beneath the surface: impacts of climate change on groundwater. *Journal of Hydrology* , 405, 532–560.

Gupta, D.P., Sunita, A., and Saharan, J.P. (2009). Physicochemical Analysis of Ground Water of selected area of Kaithal City (Hayana) India. Researcher, 1(2), 1-5

Hansen, B. D. (2012). Regional analysis of groundwater nitrate concentrations and trends in Denmark in regard to agricultural influence. . *Biogeosciences*, 9, 3277–3286.

Harvey, P. & Drouin, Thomas. (2006). The case for the rope-pump in Africa: A comparative performance analysis. Journal of Water and Health. 4. 499-510. 10.2166/wh.2006.0033.

Hooda PS, E. A. (2000). A review of water quality concerns in livestock farming areas. *Sci Total Environ.*, 250:143–167. doi:10.1016/S0048-9697(00)00373-9

Howard G. (2002). *Urban water supply surveillance in developing countries: a reference manual.* Loughborough University, UK, .

Hussain, Intizar; Liqa Raschid; Munir A Hanjra; Fuard Marikar; and Wim van der Hoek. (2001) “Framework for analyzing socioeconomic, health and environmental impacts of wastewater use in agriculture” IWMI working paper 26. International Water Management Institute, Colombo: Sri Lanka.

International Association of Hydrogeologists. (2020). Groundwater more about the hidden resource. Retrieved Nov 13 , 2020, from https://iah.org/education/general-public/groundwater-hidden-resource

Janardhana Raju, N. S. (2009). Fluoride contamination in groundwaters of Sonbhadra District, Uttar Pradesh, India; . *Curr. Sci., v.96(7),* , 979–984.

Jay.P.Graham, e. (2013). Pit Latrines and impacts on groundwater quality; A systematic Review. *Environ Health Perspect*. doi:121. 521-530.

Kumar, M., and Puri, A.(2012) A review of permissible limits of drinking water. Indian Journal of Occupational and Environmental Medicine, 16(1), 40–44.

Lawrence, A. R. ((2001)). *Guidelines for assessing the risk of groundwater from on-site sanitation.* Commissioned report (CR/01/142) , British Geological Survey.

Levallois P. (2003) *Bactéries hétérotrophes aérobies et anaérobies facultatives (Aerobic and Facultative Anaerobic Heterotrophic Bacteria)* Fact sheets on drinking water and human health, Water Science Group, Institut national de santé publique du Québec, Québec, Canada

Lewis WJ, F. S. (2002). The risk of groundwater pollution by on-site sanitation in developing countries. *International Reference Centre for Waste Disposal*, .

Lewis, W. J. (1980). The risk of groundwater pollution by on-site sanitation in developing countries. *A literature review, International Reference Centre for Wastes Disposal*.

Li S, G. S. (2008). Water quality in relation to land use and land cover in the upper Han River Basin, China. Catena . 75:216–222. Retrieved from https://doi.org/10.1016/J.CATENA.2008.06.005

Li, P. T. (2017). Progress, opportunities and key fields for groundwater quality research under the impacts of human activities in China with a special focus on western China. *Environ Sci Pollut Res*, 24:13224–13234.

Liu Aiguo, M. J. (2005). Nitrate contamination in private wells in rural Alabama, United States. . *SciTotal Environ*, 346:112–20.

Lu Y, T. C. (2008). Impact of septic tank systems on local groundwater quality and water supply in the Pearl River Delta, China:case study. *Hydrol Process*, 22:443–450.

Machiwa and Ngoye. (2004). The influence of land-use patterns in the Ruvu river watershed on water quality in the river system," Physics and Chemistry of the Earth A, B, C,. *29*(15–18), 1161–1166.

MacQuarrie, K. S. (2001). Numerical Simulation of a fine grained denitrification layer for removing septic ystem nitrate from shallow ground water. *Journal Hydrology*, 52:29-55.

NEERI. (2005). Impact of on-site sanitation systems on quality of groundwater and surface water sources submitted to CPHEEO-WHO.

Nyenje, P. F. (2013). Nutrient pollution in shallow aquifers underlying pit latrines and domestic solid waste dumps in urban slums. *Journal of Environmental Management*, 122, 15–24.

Otero N., Soler A. Sulphur isotopes as tracers of the influence of potash mining in groundwater salinisation in the Llobregat Basin (NE Spain) Water Res. 2002;36:3989–4000. doi: 10.1016/S0043-1354(02)00125-2. [PubMed]

P. R. Pujari, C. P. (2012). Assessment of the impact of on-site sanitation systems on groundwater pollution in two diverse geological settings—a case study from India. *Environ Monit Assess*. doi:184(1):251–263

Pavelic P., G. M. (2012). *Groundwater Availability and Use in Sub-Saharan Africa: A Review of 15 Countries.* In International Water Management Institute (IWMI) , Colombo, Sri Lanka.

Pointer, C. (2005). Groundwater and climate change. *Report on the IAH working group of groundwater and climate change meeting, University of East Anglia,*, April 4–6.

Pujari PR, P. C. (2012). Assessment of the impact of on-site sanitation systems on Groundwater pollution in two diverse geological settings--a case study from India. *Environ Monit. Assess*. doi:184(1), 251-263

Rodrigues et al., V. E.-B.-B. (2018). Effects of land use and seasonality on stream water quality in a small tropical catchment: the headwater of Córrego Água Limpa, São Paulo (Brazil). . *Sci Total Environ*, 622–623:1553–1561. Retrieved from https://doi.org/10.1016/J.SCITOTENV.2017.10.028

Salami. (2012). *Leachate characterization and assessment of groundwater quality: A case of Solous dumpsite in Lagos state.* PhD seminar paper, , Lagos state University, Epée, , Lagos, Nigeria.

Sasakova, N. V. (2014). *Protection of the Environment and Public Health, 1st Edn. Košice: UVLF.*

Scibek, J. A. (2006). Modeled impacts of predicted climate change on recharge and groundwater levels. *Water Resour Res*, 42(11):1-18.

Siebert, S. B. (2010). *Groundwater use for irrigation- aglobal inventory.*

Sorensen, J. L. (2014). Emerging contaminants in urban groundwater Sources in Africa. *Water Research*, 72, 51–63.

Su, Z. W. (2020). Temporal changes of groundwater quality within the groundwater depression cone and prediction of confined groundwater salinity using Grey Markov model in Yinchuan area of northwest China. *Expo Health*, 12:447–468.

Taylor, R. &. (2006). *Waste disposal and landfill: Potential hazards and information needs. In O. Schmoll, G. Howard, J. Chilton and I. Chorus.* Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources. London: IWA Publishing.

Tillett, T. (2013). *Pit latrines and groundwater contamination.' Environmental Health Perspectives 121(5).* Retrieved June 02, 2018, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3673209/pdf/ehp.121-a169.pdf

Toews., M. a. (2009). Evaluating different GCMs for predicting spatial recharge in an irrigated arid region. *Journal of Hydrology,*, 374:265–81.

Tu. (2011). Spatial and temporal relationships between water quality and land use in northern Georgia, USA. *Journal of Integr Environ Sci , 8*, 151–170. Retrieved from https://doi.org/10.1080/1943815X.2011.577076

Tyagi, S. S. (2013). Water quality assessment in terms of Water Quality Index. *Am J Water Resour*, 1(3):34–8.

Ugwa, A.I. and Wakawa, R.J. (2012).Study of Seasonal Physicochemical Parameters in River Usma. American Journal Environment Science, 8(5), 569-576.

UNEP. (2010). Clearing the Waters. A Focus on Water Quality Solutions. *United Nations Environment Programme (UNEP)*. Retrieved 03 08, 2019

van Grinsven, H. R. (2010). Estimation of incidence and social cost of colon cancer due to nitrate in drinking water in the EU: a tentative cost-benefit assessment. *Environ Health*, 6;9:58. doi:10.1186/1476-069X-9-58.

Van Ryneveld MB, F. A. (1997). A strategy for evaluating the environmental impact of on-site sanitation systems. *Water SA*, 23(4):279–91.

Vrba, J. a. (1994). Guidebook on Mapping Groundwater Vulnerability. *International Contribution to Hydrogeology,, 16*, 131 .

Wang, D. W. (2020). Finding high-quality groundwater resources to reduce the hydatidosis incidence in the Shiqu County of Sichuan Province, China: analysis, assessment, and management. *Expo Health*, 12:307–322.

WHO (2011).Guidelines for Drinking -Water Quality (4th Edition) WHO, Geneva

Wright, J. A.-O. (2013). A spatial analysis of pit latrine density and groundwater source contamination. . *Environmental Monitoring and Assessment* , 185(5), 4261–4272.

WWAP., W. W. (2009). *The United Nations World Water Development Report 3.* UNESCO and London: Earthscan.

Yoder J, R. V. (2008). *Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking—United States2005–2006.*

Zhou, Z. (2015). *A Global assessment of Nitrate Contamination in Groundwater.* Report IGRAC.

APPENDICES

Appendix 1: Sanitary Risk Assessment Tool for Hand dug wells

Date---Time----------------------------------

Enumerator Name--

Demographic Information

Waste disposal

1. How many people are within the household at the time of visit
2. Do you have history of water borne related diseases?
3. If YES, how often?
   a. Frequently
   b. Occasionally
   c. Rarely
   d. Not at all
4. What are the major water sources?
   a. Treated tap water
   b. Wells
   c. Spring
   d. River or stream
   e. Rain water

   If it's a well what is the depth of well in M?
5. How do you dispose of waste from the house?
   a. Composite pit
   b. Cabbage collector servics
   c. No designated dumping point on the compound
   d. Designated dumpsite within the compound
   e. Government approved site
6. What type of sanitation facility do you use?
   a. Municipal sewer line
   b. Septic tank
   c. Pour flush connected pit
   d. Pit latrine
   e. Open defecation
   f. Ablution block
7. Is the facility shared among the households? Yes No
8. Does the well have the cover lid ? Yes
9. If Yes, please describe the cover;

a. The joint between the well cover and apron surround are sealed well to prevent water from entering the well
b. The joint between the well cover and apron surround are NOT sealed well to prevent water from entering the well
c. The cover has deep cracks that needs to be repaired
d. Only part of the well is fully covered
e. The well is wholly covered

10. Is the concrete floor <1.5 m wide around the well? Yes ☐ No ☐
11. How is the concrete floor apron sloping?
    a. away from the well
    b. away towards the well
    c. the concreate floor is flat

12. Is there a latrine <10 m radius of the well? Yes ☐ No ☐
13. If YES how far in Meters
    a. Less than 10m
    b. 10-20 m
    c. 20-30m
    d. Above1 30m
14. What is the location of the sanitation facility?
    a. higher ground than the well
    b. lower ground than the well
    c. level ground with the well
15. What possible sources of pollution <10 m of the well
    a. Leachate from Dumpsites
    b. Poorly maintained drainage from animal shades
    c. Broken/overflow sewer lines
    d. Poor drainage
    e. Open defecation
    f. Storm runoff
16. How far is the pollution source in m to the well?
    a. Less than 10m
    b 10-20 m
    c 20-30m
    d. Above 30 m

10. Is there stagnant water <2 m of the well? Yes ☐ No ☐

11. Are the walls of the well-sealed at any point for 3 m below ground?

    a. The well is adequately sealed
    b. The well is inadequately sealed
    c. The well is not sealed at all

12. How is water abstracted?

a. By use of hand pump
b. Rope and bucket

If a, are the pumps well /firmly secured on the well apron? ☐ ☐

If b, are the rope and bucket left in such a position that they may become contaminated?

Yes ☐ No ☐

13. What are some of human activities <2 m around the well at the time of visit?
    a. Cloth washing
    b. Animal grazing
    c. cultivation
14. How is the Environment area around the well (> 2m)?
    a. the area around the well is dusty/muddy
    b. there are water diversion ditches around the well
15. Are there wastewater drain ditch around the well area? Yes ☐ No ☐

If YES, what is the status of the drains?

a. The drain walls are cracked leaking
b. The drain walls are cracked but not leaking
c. The drains are not lined

Appendix 2: Sanitary Risk Assessment Tool (Checklist) for Springs

SN	Item	Question	YES	NO
1	Unprotected	Is the spring source unprotected by masonry or concrete wall or spring box and therefore open to surface contamination?		
2	Masonry faulty	Is the masonry protecting the spring source faulty?		
3	Unfenced	Is the area around the spring unfenced?		
4	Animals access	Can animals have access to within 10 m radius of the spring source?		
5	Lack diversion ditch	Does the spring lack a surface water diversion ditch above it, or (if present) is it nonfunctional?		
6	Immediate latrine uphill	Are there any latrines uphill of the spring?		
7	Nearest visible latrine higher	Is the nearest latrine on higher ground than the spring?		
8	Pollution	Are there any other source of pollution (e.g., animal excreta, dump sites, rubbish) within 10 m upstream of the Spring?		
9	Animals grazing	Are animals grazing <2 m around the spring?		
10	Clothes washing	Are people washing clothes <2 m uphill of the spring?		
11	Open defecation	Is there open defecation uphill the site?		
12	Human activity	Are there farming activities around or near the spring?		
13	Ponding	Is the spring collection area not developed to minimize ponding of surface water?		
14	Vegetation	Is the spring a collection area with deep-rooted vegetation?		
15	Farming activities	Is there application of fertilizers, chemicals upstream of the spring?		

ANNEX III

Risk Assessment for Wells

Wards	**NO.**	**Total number of Risk factors questions**	**Risk answered "Yes" or potential Questions**	**% Risk Score**	**Risk Classification**
WELLS IN MUSIKOMA WARD	WELL 1	18	14	78	High Risk
	WELL 2	18	13	72	High Risk
	WELL 3	18	15	83	Very High Risk
	WELL 4	18	11	61	High Risk
	WELL 5	18	13	72	High Risk
	WELL 6	18	10	55	High Risk
	WELL 7	18	15	83	Very High Risk
	WELL 8	18	10	55	High Risk
	WELL 9	18	9	50	Medium Risk
	WELL 10	18	9	50	Medium Risk
	WELL 11	18	13	72	High Risk
	WELL 12	18	15	83	Very High Risk
	WELL 13	18	13	72	High Risk
WELLS IN KHALABA WARD	WELL 14	18	8	44	Medium Risk
	WELL 15	18	15	83	Very High Risk
	WELL 16	18	13	72	High Risk
	WELL 17	18	8	44	Medium Risk
	WELL 18	18	10	55	High Risk
	WELL 19	18	10	55	High Risk
	WELL 20	18	9	50	Medium Risk
	WELL 21	18	12	67	High Risk

Wards	NO.	Total number of Risk factors questions	Risk answered "Yes" or potential Questions	% Risk Score	Risk Classification
	WELL 22	18	11	61	High Risk
	WELL 23	18	11	61	High Risk
	WELL 24	18	10	55	High Risk
	WELL 25	18	14	78	High Risk
	WELL 26	18	8	44	Medium Risk
	WELL 27	18	9	50	Medium Risk
WELLS IN BUKEMBE EAST WARD	WELL 28	18	8	44	Medium Risk
	WELL 29	18	12	67	High Risk
	WELL 30	18	14	78	High Risk
	WELL 31	18	15	83	Very High Risk
	WELL 32	18	9	50	Medium Risk
	WELL 33	18	14	78	High Risk
	WELL 34	18	8	44	Medium Risk
	WELL 35	18	12	67	High Risk
	WELL 36	18	11	61	High Risk
	WELL 37	18	9	50	Medium Risk
	WELL 38	18	15	83	Very High Risk
	WELL 39	18	13	72	High Risk
WELLS IN WEST SANG'ALO WARD	WELL 40	18	9	50	Medium Risk
	WELL 41	18	10	55	High Risk

Wards	NO.	Total number of Risk factors questions	Risk answered "Yes" or potential Questions	% Risk Score	Risk Classification
	WELL 42	18	11	61	High Risk
	WELL 43	18	13	67	High Risk
	WELL 44	18	9	50	Medium Risk
	WELL 45	18	8	44	Medium Risk
	WELL 46	18	14	78	High Risk
	WELL 47	18	14	78	High Risk
	WELL 48	18	9	50	Medium Risk
	WELL 49	18	12	67	High Risk
	WELL 50	18	11	61	High Risk
	WELL 51	18	13	72	High Risk
WEELS IN TOWNSHIP WARD	WELL 52	18	11	61	High Risk
	WELL 53	18	12	67	High Risk
	WELL 54	18	13	72	High Risk
	WELL 55	18	11	61	High Risk
	WELL 56	18	10	55	High Risk
	WELL 57	18	15	83	Very High Risk
	WELL 58	18	9	50	Medium Risk
	WELL 59	18	8	44	Medium Risk
	WELL 60	18	12	67	High Risk
	WELL 61	18	12	67	High Risk

Wards	NO.	Total number of Risk factors questions	Risk answered "Yes" or potential Questions	% Risk Score	Risk Classification
	WELL 62	18	10	55	High Risk
	WELL 63	18	8	44	Medium Risk
	WELL 64	18	10	55	High Risk
	WELL 65	18	11	61	High Risk
WELLS IN BUKEMBE WEST WARD	WELL 66	18	8	44	Medium Risk
	WELL 67	18	13	72	High Risk
	WELL 68	18	15	83	Very High Risk
	WELL 69	18	10	55	High Risk
	WELL 70	18	12	67	High Risk
	WELL 71	18	15	83	Very High Risk
	WELL 72	18	11	61	High Risk
	WELL 73	18	13	72	High Risk
	WELL 74	18	13	72	High Risk
	WELL 75	18	12	67	High Risk
	WELL 76	18	9	50	Medium Risk
	WELL 77	18	11	61	High Risk
WELLS IN MARAKARU WARD	WELL 78	18	10	55	High Risk
	WELL 79	18	9	50	Medium Risk
	WELL 80	18	11	61	High Risk
	WELL 81	18	10	55	High Risk

Wards	**NO.**	**Total number of Risk factors questions**	**Risk answered "Yes" or potential Questions**	**% Risk Score**	**Risk Classification**
	WELL 82	18	12	67	High Risk
	WELL 83	18	11	61	High Risk
	WELL 84	18	8	44	Medium Risk
	WELL 85	18	16	89	Very High Risk
	WELL 86	18	12	67	High Risk
	WELL 87	18	15	83	Very High Risk
	WELL 88	18	12	67	High Risk
	WELL 89	18	14	78	High Risk

Appendix 3: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **386287**

Date of Issue: **01/August/2022**

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