POLLUTION RISK ASSESSMENT OF GROUNDWATER USING GEOSPATIAL TECHNOLOGY AT KAMKUYWA MARKET CENTER, BUNGOMA

BY

WECHULI DINAH AYOMA

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DECLARATION

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Signature Date

WECHULI DINAH AYOMA

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Declaration by Supervisors

This thesis has been submitted for examination with our approval as University Supervisors.

…………………..…………… ………………………

Signature Date

DR. BENJAMIN MWASI

University of Eldoret, Kenya

……………………………… ……………………….

Signature Date

DR.VICTOR A. O. ODENYO

University of Eldoret, Kenya

DEDICATION

This Thesis is dedicated to the Regional Centre on Groundwater Resources Education, Training and Research in East Africa whose mandate is to undertake groundwater research to increase knowledge and understanding of aquifer characteristics for sustainable development and management of groundwater and training and public awareness on groundwater knowledge and build capacities to deliver basic services in the context of a changing climate and recurring drought and floods is crucial.

I would also like to dedicate this Thesis to my father Mr. Joseph Lubumbu.

ABSTRACT

Pathogenic contamination of groundwater due to poor sanitation has continuously posed a significant human health risk. Kamkuywa Market Center a peri-urban settlement relies heavily on shallow wells for water supply and use of pit latrines as a means of fecal waste disposal. This increases the risk of groundwater microbial contamination. The objectives of the were to establish the extent of groundwater pollution by coliforms, to determines the relationship between groundwater contamination and selected risk factors, namely: depth to the water table, distance from a shallow well to the nearest pit latrine, pit latrine depth, soil permeability and ground slope for purposes of establishing the optimal well-pit latrine separation distances under different hydro-geological conditions. 531 shallow wells and 1061 pit latrines in the study area were mapped and the separation distances compared to the recommended global and local standards. Water samples in thirty two (32) shallow wells were collected and analyzed for fecal matter content. Regression model was used to determine the relationship between coliform concentration and the selected risk factors such as the separation distances between pit latrines and shallow wells, the depths of pit latrines and shallow wells, and the soil type as well as establish the extent of contamination and optimal distancing. The results indicated that 67.6% of shallow wells did not meet the World Health Organization and the Kenya safe distance criteria. In terms of relationship, pit latrine depth and soil permeability positively correlated with contamination while a negative relationship was established between groundwater contamination and water table depth. There was no relationship established between groundwater contamination and surface slope. Out of 32 shallow wells sampled for fecal coliform analysis, 31 shallow wells tested positive for fecal coliforms. The study also established that over 75% of the study area posted a high risk for groundwater contamination. The predicted optimal distance between wells and pit latrines in the study area ranged between 31m-33m. The study concludes that fecal coliform contamination of groundwater is widespread in Kamkuywa Market Center. The widespread contamination is as a result of extensive groundwater contamination from pit latrines. The study therefore recommended the treatment of domestic water before use, adoption of community septic system and sensitization and awareness on proper siting for pit lines and shallow wells in Kamkuywa Market Center.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CIDP	County Integrated Development Plan
DEM	Digital Elevation Model
GPS	Global Positioning System
GIS	Geographic Information Systems
GWR	Geographically Weighted Regression
IDW	Inverse Distance Weighted
IPA	Innovation for Poverty Action
OLS	Ordinary Least Squares
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
UNEP	United Nations Environment Programme
WWF	World Wildlife Fund
WHO	World Health Organization

DEFINITION OF OPERATIONAL TERMS

Excreta: Faeces and urine

Ground water table: The level at which the subsoil is saturated with water.

Ground water: This refers to water found below ground level in the soil.

Improved sanitation: Improved sanitation means safe disposal and management of waste to prevent human exposure and environmental hazards.

Pathogens: Disease causing organisms.

Pit latrine: Latrine with a pit for collection and decomposition of excreta and from which liquid infiltrates into the surrounding soil.

Protected Shallow well: A protected well is defined as; a) having a lining below water level to prevent the well from collapsing and allow water to enter the well b) a lining above water level which prevents the well from collapsing and is made from non porous precast concrete rings, masonry with bricks or concrete blocks c)The well head which could be a stone, brick or concrete layer with the above ground well-lining that is raised to a convenient height for the chosen method of drawing water and provides a firm platform for users and prevents spilt water, runoff and debris from falling inside the well and also prevents sunlight keeping the water temperature low and constant.

Sanitation: Sanitation is the hygienic means of preventing human contact with the hazards of waste to promote health and environmental integrity.

Septic Tank: A disposal system for human excreta where the waste from water closets is disposed in an underground tank that allows settlement of sludge and disposes the liquid waste into a subsurface drain.

Shallow well: A hole less than 50 feet deep dug, driven, drilled or bored into the ground mainly for water extraction.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Water is scarce when there is insufficient freshwater to meet the standard water demand of a population. Hoekstra and Mekomnnen (2016) report that four billion people face water shortages and that half a billion people in the world face severe water scarcity all year round. However, the global water scarcity crisis is also compounded by water pollution. Vital as it is for human existence; water is also an important carrier of organisms and contaminants that are a threat to life. It must be noted that for water to be used for domestic purposes particularly drinking its pollution must be within specified thresholds.

According to the World Health Organization (2008), 13% of the world's population does not have access to safe drinking water. Additionally, 40% of the world's total population does not have access to improved sanitation (WHO, 2010). This translates to 2.6 billion people in the world who are unable to access a public sewage system, septic tank, or even a simple pit latrine.

Approximately 1.7 million people every year die of water-borne diseases resulting from unsafe drinking water, inadequate sanitation, and poor hygiene (WHO, 2010). Developing countries account for 84% of these deaths with 90% of them being children under the age of 5 years. The World Health Organization (2010) estimates show that up to 6% of these deaths and 9% of all diarrheal diseases could be prevented by improving the water safety, sanitation and hygiene globally.

Globally, 38% of improved water sources are contaminated by fecal bacteria (Bain *et al*.2014). It has also been established that contaminated and untreated groundwater is a major source of health problems in the developing world and a burden to these countries (Murphy *et al*., 2017). According to the World Health Organization (2012a), the goal of the United Nations through the Millennium Development Goals was to half the population living without access to sustainable sanitation by 2015. The target was to have one billion people in the urban world and 900 million people in the rural world have access to sustainable improved sanitation facilities. Unfortunately, these targets were not achieved (JMP, 2017).

To save the situation, the United Nations identified Sustainable Development Goal Number six (6) whose focus is on clean water and sanitation. The goal acknowledges that while substantial progress has been made in the world over the decades to increase access to safe drinking water and better sanitation, 637 million people globally still lack access to these basic social amenities. Therefore, this goal targets to improve the quality of water globally through reduced water pollution from agricultural waste, domestic waste, dumping sites and industrial waste by 2030 (WHO,2012a).

Most people residing in rural areas in developing countries derive domestic water from groundwater and their sanitation through pit latrines (WHO, 2012b). This unfortunately is also largely evident in urban areas where land has been greatly fragmented. Consequently, a potential groundwater contamination becomes a risk, especially when pit latrines and shallow wells are located in close proximity. This pattern is prevalent in Kenya(SRFA, 2015).According to the Ministry of Health (2016), the most common method of human waste disposal in Kenya's rural and peri-urban settlements is the pit latrine, probably because it is the cheapest, affordable, reliable and most efficient way to dispose human waste for the urban and rural populations. Expansion in improved water supply and access to improved sanitation such as sewer and water systems, water kiosks, community septic tanks and community boreholes in Kenya has been unable to match the rapidly growing population with improvements in water supply growing by only 0.9% and improved sanitation by 0.2 annually, according to the Joint Monitoring Program (2013).

In the recent times, concerns have been raised by environmentalists and public health experts on the increased use and dependency on both pit latrines and groundwater sources in low income areas in Kenya (Njuguna, 2019). Literature has shown that pit latrines can cause human and ecological health impacts largely associated with microbiological and chemical contamination of groundwater in their area of existence (WHO, 2010). The World Health Organizations minimum standards in water supply, sanitation, and hygiene promotion dictate that, pit latrines and soak ways (for most soils) should be at a safe distance of at least 30m from any groundwater source and the bottom of any pit latrine at least 1.5m above the water table.

Countries have different policies on the safe distance between latrines and groundwater sources specific to their hydro-geological factors. The Kenya Environmental Sanitation and Hygiene policy 2016-2030, guides that a latrine should be at a distance of at least 40m from a water source and its depth should be a minimum of 2m above the highest groundwater table (MoH, 2016). The 2m minimum requirement is anchored on the fact that pit latrines generally lack a physical barrier, such as concrete between the sludge and soil/groundwater (Fourie & Van, 1997). Graham (2013) established that contaminants from pit latrines over a period of time leach into underground water leading to its contamination, and potentially threaten human health.

Kamkuywa Market Center is a rapidly growing peri-urban Center in Bungoma County. Over the years, the center has grown spatially and demographically. According to the Kenya population and Housing Census of 2019, Kamkuywa Market Center has a Population of 26,569 persons (KNBS, 2019). The Kimilili Constituency Strategic Plan (2017) shows that, 90% of the households in Kamkuywa Market Center use pit latrines while 10% of the households are without pit latrines or any other method of excreta disposal. In addition, Kamkuywa Market Center does not have access to piped water supplied by Nzoia Water and Services Company. The market Center is therefore entirely dependent on groundwater and rainwater for domestic and commercial use.

Furthermore, Kamkuywa Market Center has not been planned to determine the minimum specified plot size (County Government of Bungoma, 2018). Essentially, the dimension of a plot affects the distance between the latrine and shallow well. Small plot sizes mean that the distances between the latrines and wells are shortened (Gudda *et al., 2019*). This can lead to groundwater contamination which is likely to occur potentially, due to the reduced travel times of the pathogens from latrines to the shallow wells as well as downstream water springs when the safe distance is shorter than the recommended 40 meters. (Gudda *et al., 2019*).

Typically, groundwater is characterized by long pollution residence time due to its slow flow (Twinomucunguzi *et al., 2020*). This makes groundwater pollution particularly problematic. The rate of flow and residence period is determined by several factors including soils (texture and structure), slope, and rainfall. To determine safe separation distances between a pit latrine and a well is thus not a constant factor but a function of these attributes. The specific safe distances in Kamkuywa are thus not known but rather dependent on the 40m standards by Kenya Environmental Sanitation and Hygiene policy 2016-2030.

1.2 The Statement of the Problem

In a bid to access improved water supply and sanitation, residents of Kamkuywa Market Center have resorted to shallow wells as the main source of domestic water and pit latrines for fecal waste disposal. However, there is a concern that the dependency on shallow wells and pit latrines for water supply and human waste disposal respectively could result into groundwater contamination by onsite-sanitation owing to the reduced safe distances and the existing hydro-geological factors such as soils (texture and structure), slope, and climate. This is because; the extent of groundwater contamination has been shown to depend on, among others, the depth to the water table, the soil type, and topography of the area which vary from one region to another. Given this reality in Kamkuywa Market area, the purpose of this study therefore was to establish to what extent the groundwater in Kamkuywa Market Center is contaminated, to establish whether the level of contamination Kamkuywa Market Center varies from one area to another and show the influence of hydro-geological factors such as soils, topography, and water table on spatial variation of contamination for purposes of determining appropriate well-pit latrine spacing.

1.3 Objectives

The general objective of this study is to assess the extent of groundwater contamination in Kamkuywa Market Center using geospatial technology. The specific objectives of the study were:

1. To determine the extent of fecal coliform contamination of groundwater contamination in Kamkuywa Center.

2. To assess the relationship between the level of contamination and the hydro-geological factors in Kamkuywa
3. To map high groundwater contamination risk zones in Kamkuywa Market Center.
4. To establish optimal siting for wells from pit latrines in Kamkuywa Market Center.

1.4 Research Questions

The following research questions guided the study:

1. To what extent is the groundwater in Kamkuywa Market Centre contaminated?

2. How does the variation in hydro-geological factors in the study area influence groundwater quality in Kamkuywa market center?

3. Which areas of the market are highly vulnerable to groundwater contamination?

4. What would be the optimal safe distance for pit latrine-well siting in Kamkuywa Market Centre?

1.5 Justification and Significance of the of the Study

This study sought to contribute to the achievement of goal six (6) of the United Nation's Sustainable Development Goals through sustainable use of groundwater and sanitation facilities in Kamkuywa Market Center. Goal six (6) of the SGDs is geared to towards achieving equitable and universal access to safe and affordable drinking water and sanitation services for all by 2030.

The application of geospatial technology in water resource management, particularly groundwater protection is not a new concept (Fotheringham *et al.* (2002). GIS has been used widely by geologists, hydrologists, geographers, and environmentalists to determine groundwater vulnerability, quantity, quality and flow (Fotheringham et al. (2002). In Kenya, the uptake of geospatial technology has risen steadily. Geospatial technology has constantly been evolving to be able to address global environmental problems. Currently, developers have designed GIS applications with the capabilities of carrying out groundwater modeling, sewer systems and water supply modeling, urban planning and so on (Fotheringham *et al.* (2002). This study used geospatial technology in promoting sustainable groundwater use and sanitation.

In addition, this study sought to contribute to the implementation of the Kenya Environmental Sanitation and Hygiene Policy 2016-2030 by showing how the recommended safe distances of pit latrines to shallow wells (water source) and the safe distances of the pit latrine depth to the water table have been violated in Kamkuywa Market Center. The findings of the study are also critical to physical and urban planners at the County level and other critical decision-makers on the best land use and planning practices in the area which is a fast growing peri-urban center in the County.

1.6 Scope and limitations of the Study

The study was limited to the environmental and physical factors of the market confined to the spatial location of pit latrines and shallow wells and topographical factors. The research partially explored the component of water quality testing to ascertain the extent of groundwater pollution through fecal coliform count and did not aim to provide an in-depth evaluation of groundwater quality parameter in the study area but simply to show that the groundwater in the study area is contaminated. This is because- the study of geological, chemical and biological compositions of pollutants (Nitrates and Phosphates) and health factors were beyond the knowledge scope of the researcher.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature on the study of pollution risk assessment of groundwater using geospatial technology. It contains a synthesis of the theoretical foundations of the subject under study as well as describing and analyzing, previous research on the application of GIS in groundwater pollution.

2.2 Ground Water pollution

For centuries, groundwater has been exploited for agricultural, domestic and industrial purposes (Lvovitch, 1972). Lvovitch (1972) estimated that groundwater constitutes nearly 30% of the world's fresh water resources. According to Freeze and Cherry (1979), groundwater is of fundamental importance to the global economic development and to the existence and survival of human life. Besides, the recent times have experienced a major shift in groundwater use patter from rural-agricultural to urban-industrial. The increased demand and exploitation of groundwater resources alongside industrialization, urbanization and agricultural mechanization have contributed to the deterioration of groundwater quantity and quality.

According to Sasakova *et al.* (2014), groundwater contamination occurs when pollutants and foreign materials are released into the natural underground water reservoirs. Depending on their physical, chemical and biological properties, pollutants are facilitated by water, travel from the source to reach groundwater through diffusion, absorption and dispersion.

Human activities are the major causes of groundwater contamination (Groundwater Foundation, 2017). Pollutants originating from these activities often percolate to reach groundwater reservoirs. Since the movement of pollutants within the reservoirs is usually slow, pollutants concentrate and are stored there for a very long time (Groundwater Foundation, 2017).

Groundwater pollutants originated from both point and non-point sources (Schwarzenbach, 2006). Industries, factories, households, landfills, latrines and agricultural installations are few examples of point sources of groundwater pollutants. Usually, point sources are easy to indent and control as compared to non-point sources. Examples of non point sources include phosphates, nitrates, pesticides and herbicides from agricultural activities that leach into the groundwater reservoirs as a result of surface run off, infiltration and percolation (Fawell & Nieuwenhuijsen, 2003).

In addition to this, groundwater contamination takes two forms i.e. emergency contamination and long-term contamination (Sasakova *et al.,* 2014). Emergency contamination occurs when pollutants cause immediate catastrophic impact that result in the serious damages such as death of animals or death of human being. Long-term contamination on the other hand, takes a long time to be realized and its effects are noticeable after a long-time or through water testing (Sasakova *et al.*, 2014).

Generally, groundwater pollution often goes unnoticed for a very long time. Its extent of quality and safety is often determined only after water testing or when the impact manifests in-terms of health related conditions such as physical deformities (Morris *et al.,* 2003).

Since groundwater contamination is largely facilitated by the processes of infiltration and percolation, the transportation and dispersion of pollutants is known to be influenced by the hydro-geological and climatic factors of a region (Cheremisinoff 1997).These factors include, among others, soil permeability or porosity, temperature, topography and the amount of precipitation the area or region receives. Moreover, groundwater flow tends to move in sync with the direction of a river, a lake or an ocean (Cheremisinoff, 1997).This makes groundwater contamination a trans-boundary problem. However, the direction of the flow of groundwater can be disturbed by human activities such as over harvesting of the groundwater through pumping for domestic, agricultural of industrial purposes. The effect to this disturbance is the dispersion of pollutants within the aquifer owed to the continuous pumping of groundwater. This causes further pollution a larger amount of groundwater (Iyyaki & Valli 2017).

According to the Environmental Protection Agency (2017), groundwater pollution is harmful to human and animal health. Even though, its impact is usually not immediate. Studies have shown that contaminated groundwater is a leading cause of water borne disease and health defect among human beings. Groundwater pollution is usually irreversible. Because of its nature of existence, it is nearly impossible and very expensive to remove pollutants from groundwater aquifers. Besides, pollutants in groundwater resources take a very long time to break down or disintegrate. It is therefore important to protect groundwater from pollutants.

According to Beckie (2013), ground water can be protected by identifying the source of the pollution by physically containing or redirecting the pollutants into a specially prepared wetland for treatment and recycling. Groundwater pollution can also be controlled through legislations and water regulation laws to help protect groundwater resources (EPA, 2017).

2.2.1 Major Groundwater Pollutants

The International Association of Hydrologists (2020) defines groundwater contamination as the introduction of foreign substances into groundwater through human activities. These undesirable substances include chemicals, fuels, pesticides, herbicides, microorganisms and fertilizers. Wang *et al.* (2020) observes that the remediation of groundwater once contaminated is very costly and challenging because of the nature of existence within the sub surface geological strata and long residence times.

Groundwater contaminants can broadly be classified as organic and inorganic, biological, chemical and radioactive contaminants originating from both natural and anthropogenic sources (Elimalai *et al.*, 2020). Groundwater can be polluted by naturally occurring substances in the rocks and soils. Naturally occurring sulphates, fluorides, manganese and arsenic substances dissolve into groundwater leading to contamination by changing the quality of groundwater.

Inorganic Contaminants

Nitrates, ammonia, and nitrites are common inorganic groundwater contaminants. Nitrogen contaminants are primarily anthropogenic in nature resulting from agricultural activities and disposal of domestic water (Hansen *et al.*, 2017). Anions and axynions are the most common inorganic nitrogen contaminants found in groundwater (Adimalla & Wu 2019).

Chemical Contaminants

Zinc (Zn), mercury (Hg), lead (Pb), arsenic (As), chromium (Cr) and cadmium (Cd) are some of the major chemical contaminants detected in groundwater globally. These elements are also toxic metals considered harmful to human health and the natural environment. Long exposure to these metals can result into severe health conditions and deformities (Hashim *et al.*, 2011). Exposure to hexavalent chromium has for instance been known to increase the risk to cancer (He and Li 2020). In addition, the United State Environmental Protection Agency (2017) ranked arsenic (As) as a group one (1) carcinogenic element.

Organic Contaminants

Organic contaminants on the other hand, have widely been detected in domestic water. Many of the organic contaminants are also regarded as human carcinogen by the United State Environmental Protection Agency (EPA). According to Lesser *et al.* (2018) over 200 organic contaminants have been detected in groundwater globally. While some of these contaminants are biodegradable and break down over time, some of them are persistent and take a long time to disintegrate and exist in high concentrations in groundwater (Jurado *et al.*,2012).

The major source of these groundwater contaminants is domestic sewerage and wastewater from industries and factories (Lapworth *et al.*, 2012). Organic contaminants are naturally produced from human and animal proteins, fats and carbohydrates and transformed by microorganisms into stable inorganic substances (Sorensen *et al.* 2015). Most of these contaminants are considered harmless to human health but have an effect on the quality of groundwater by reducing the dissolved oxygen. (Lapworth *et al.*, 2015). The most common groundwater organic contaminants are pharmaceuticals, hydrocarbons, halogenated compounds and plasticizers (Meffe & Bustamante, 2014). Agriculture and industrial processes produce the most persistent organic contaminants that take a very long time to degrade and permanently affect groundwater quality (Schulze *et al.*, 2019).

Radioactive Contaminants

Geological deposits are also a major source of radioactive contaminants in groundwater (Dahlgaard *et al.* 2004). However, anthropogenic activities are also a source of radioactive contaminants. Human activities that produce radioactive contaminant include nuclear plants, medical radioisotopes and nuclear weapons testing (Lytle *et al*. 2014). Through drinking, radioactive elements in groundwater find their way to human being and animals systems. However, Huan *et al.* (2012) reported that, very few cases of radioactive contaminants have been reported globally where the levels in groundwater were a risk to human health.

Biological Contaminants

Finally, there are biological contaminants which are the most common of all groundwater contaminants according to Shen & Gao (1995). Groundwater contaminants include the likes of bacteria, viruses, protozoa, helminthes and algae. Microbial organisms originate from natural sources (Flemming & Wuertz 2019). Biological contaminants present in domestic water used for drinking and cooking cause diarrhea, typhoid and cholera diseases (Lam *et al. 2018*).

2.3 Pollutant Movement into Groundwater

Understanding how pollutants move from their source to reach groundwater reservoirs is very important in groundwater pollution assessments. In addition, it is also important to understand groundwater flow systems (Boulding & Ginn, 2004). This is in terms of the ability of groundwater to dissolve natural chemical substances or contaminants. The movement of pollutants from the surface to groundwater reservoirs involves water (Boulding & Ginn, 2004).

Generally, the process of pollutant transportation is governed by three processes namely; advection, dispersion and retardation (Walter & Masterson, 2003). Advection refers to contaminant movement resulting from groundwater flow. It represents the movement of contaminants at the same speed as the average velocity of groundwater (Bear, 1979).

Dispersion refers to the movement of contaminants transverse to the main groundwater flow direction causing gradual contaminant dilution (Bear, 1987). The process of dispersion is highly affected by aquifer hydraulic conductivity and porosity (Freeze& Cherry, 1979). This process is influential in the determining the spread of non-point source contaminants but it is also used to predict contaminant transportation and spread away from the point of source (Freeze & Cherry, 1979).

Contaminants originating from the subsurface i.e. from landfills, septic tanks and pit latrines tend to disperse over a relatively large area because of their proximity to the water table or the nature of the loading pattern. Retardation is the process by which contaminants break down and biodegrade overtime or over space as they move from one point to another (Zheng & Wang, 1999).

Most chemical and organic contaminants such are chlorides, nitrates and fluorides are fully soluble in water (Walter & Masterson, 2003). Solute substances are transported through a process referred to as advection. When pollutants originate within the ground like in the case of pit latrines, septic tanks and landfills, pollutants travel downwards through underground fissures and cracks of the unsaturated zones to reach the saturated strata (Cheremisinoff, 1997). Once pollutants reach the saturated zones, they flow horizontally as defined by the hydraulic gradient. When contaminants are released into the aquifer they spread from the expected advective path to form a plume of dilute solute as a result of molecular diffusion in the direction of the concentration gradient owing to the thermal-kinetic energy of the solute particles (Cheremisinoff, 1997).

The dispersion of contaminants in the aquifer is both longitudinal and transverse (Cheremisinoff, 1997). Dense pollutants such as radioactive contaminants, i.e., lead and mercury will move vertically and accumulate at the bottom of the aquifer. On the contrary, less dense contaminants such as bacteria, viruses and protozoa will spread transverse and will tend accumulate at the water table. Nitrates and chlorides for instance will horizontally spread through the aquifer at a groundwater flow velocity rate.

Pollutants also undergo mechanical dispersion. The process of dispersion from one area to the other arises from the fissures in the aquifers, the tortuosity of the pore channels in the granular aquifer and the different speeds of groundwater flow in fissures.

2.4 Hydro-geological factors affecting contaminant movement

Geological and climatic factors have been shown to influence the movement of contaminants from their sources to the groundwater reservoirs.

2.4.1 Geological/Hydrological factors

Soil Permeability

Groundwater quality is highly affected by the type of soil in the region. Soil attributes such as permeability and porosity have been known to influence the rate of infiltration and percolation as well as the pollutant travel distance and the time (Bousenberry *et al.* 2013). The process by which water moves through the soil is defined as soil permeability (Sonkamble (2007). According to Sonkamble (2007), highly permeable soils such as sandy soils allow more and easy movement of water than soils with low permeability such as clay soils. Due to low permeability rates, clay soils allow very slow movement of water and therefore have a lower risk of groundwater contamination. Studies have shown that there is a higher risk of groundwater contamination in areas with sandy soils as compared to areas with clay soils.

Water table

The water table is defined as the boundary between water saturated soils and air saturated soils (WRMA, 2005). The water table is not fixed; its depth is measured from the ground surfaces and this fluctuates from one season to the other depending on the amount of rainfall received and the aquifer net recharge. This fluctuation in the depth can either increase or reduce the risk of contamination by reducing the travel distance. The deeper the water table the safer the groundwater is from pollution (Sonkamble, 2007).

2.4.2 Climatic Factors

The quality of groundwater is affected by the change in climatic factors of an area (Idoko, 2010). Weather events i.e. long rains and long droughts greatly affect groundwater quality (Chup & Makwe, 2013). Factors like rainfall lead to change in groundwater recharge rate and therefore variation in amount of rainfall received in an area affects the concentration of water parameters (Chup & Makwe, 2013). During dry seasons microorganisms are usually retained in the soils efficiently as there is no water to transport them to groundwater and therefore only small traces are detectable in groundwater. Heavy rainfall contributes in the collections, dispersion and dissemination of pathogens.

2.5 Groundwater Quality

Groundwater quality is described in terms of the concentration and the state of dissolved organic and inorganic elements in the water (WHO, 1991). Along with this, physical characteristics of the water such as color and odor are considered. Usually, groundwater quality is determined by on-site or laboratory measurement and examination of water samples collected. Therefore, the main elements of groundwater quality monitoring are on-site measurement, water sample collection and water sample analysis. The quality of groundwater is the sum of the natural influences and anthropogenic factors (WHO, 1996).

According to the United Nations Environmental Programme (2012), a range of groundwater quality parameters may be subjected to multi-purpose monitoring and evaluation to embrace its many variables. Biological pollutants, temperature, pH and dissolved substances are the main variables that determine the quality of groundwater (WHO, 1996). According to Cadwell (1937), there is no such thing as pure water. Cadwell (1937) further argues that naturally, water has the tendency to dissolve other substances changing its chemical and biological characteristics in the process. Therefore, to term water as clean or contaminated is a function of the intended use of the water. For example, water quality requirement for drinking are different from the requirements for swimming. The limits on the acceptable amount of impurities in water sample are defined as water quality standards (WHO, 2007).

Water quality standards can be categorized into; stream standards which include rivers and lakes. Stream standards set allowable levels of qualities like oxygen amount, water turbidity and the pH. The second category is effluent standards. Standards on effluent set limits on contaminant levels in the water. This include; suspended substances, bio-chemical dissolved oxygen and nitrogen present in the final discharge from waste water treatment plants (UN, 2012). The third category is the drinking water standards, which limit the levels of specific contaminants allowed in household domestic water (WHO, 2007).

2.5.1 Groundwater Quality Assessment and Regulation

Groundwater quality assessment is technically difficult and expensive because unlike surface water, groundwater is less accessible. This is because it is equally difficult to collect essential groundwater information. As earlier mentioned, onsite measurement, water sample collection and sample analysis are the main elements of water quality monitoring. However, for groundwater quality monitoring, the evaluation of the analyzed results, and reporting of the findings is very important. Further, the results can only be considered valid if the analysis performed on a single water sample is specific for a particular location and time at which the sample was collected.

In Kenya, groundwater quality assessment for drinking water is carried out in line with the national and international guidelines (MoH, 2016). The World Health Organization (1996) standards and guidelines provide a guide for the development of national standards and regulations for water safety. In Kenya, the guidelines on drinking water quality and effluent monitoring are provided by the Water Services Regulatory Board (WASREB, 2008).

2.5.2Groundwater Microbial Quality

Safe guarding the microbial quality of drinking water is said by the experts to be the most important objective, even ahead of its physical and chemical quality, since water represents an obvious mode of transmission of enteric diseases (Bland, 1980; Skinner & Shecon, 1997).

The most important objective in ensuring access to safe groundwater for domestic consumption is to safeguard the groundwater microbial quality ahead of the physical and chemical quality (Bland, 1980).The World Health Organization (1976), found groundwater contamination by animal and human excreta to be the greatest danger associated with drinking water in developing countries. Various methods haves been used to determine the microbial quality of groundwater over the years. Percy Frankland (1984) invented the indication organism's method to determine microbial water quality. This method uses indicator organisms that are abundant in human and animal excreta as proof of water contamination. The presence of these organisms in water is used to indicate the presence of other dangerous microorganisms (WHO, 1985).

This method is widely preferred for basic microbial water quality assessments because it saves time, labour and expenses incurred to test for all the pathogens present in a water sample. The method also provides guidelines on the idealness of an indicator organism. An ideal organism for the indicator method must be resistant to chlorine and have a higher survival rate in water than other pathogens. The organism should also be neutral than all pathogens in the water environment (WHO, 1985).

Water testing standard and guidelines for microbial water quality are provided by the World Health Organization (1985). These standards guide the process of water sample collection, storage, transportation, analysis and interpretation. The World Health Organization recommends an MPN count of less than 10 per 100ml of drinking water for total coli forms and 2.5 per 100ml of drinking water for E. Coli.

Fecal Coliforms

For a longtime fecal colifom bacterium has been used as the first indicator of groundwater contamination around the world (Pritchard *et al*., 2007). Fecal coliform bacteria is hosted in the colon of most warm blooded animals and human beings and therefore present in large numbers in human waste and excreta from these animals. Fecal coliforms are an indication of the presence of other complex pathogenic organisms harmful to human health i.e. those that cause waterborne diseases

(Ntengwe 7 Maseka, 2006). The problem of groundwater contamination by fecal coliform bacteria can be attributed to a lack of proper sewage disposal facilities in most developing countries (Nkansah *et al.,* 2010). This study used fecal coliforms as an indicator organism for testing the groundwater microbial quality in Kamkuywa Market Center.

2.6 Contaminant Transport Modeling

There have been major technological breakthroughs in groundwater hydrology over the past 50 years (Anderson *et al.,* 2015). Up to 1990, the major breakthrough in contaminant transport modeling was the development of deterministic; distribute parameters and computer simulations for the analysis of sub-surface contaminant movement. According to Coplen (1993), the application of isotopic analysis to interpret contaminant movement flow paths, leakage, duration and interaction with sub-surface water was a major contribution in contaminant transport modeling.

Mathematical models have been used to model the flow and movement of contaminants from the source to groundwater reservoirs and within groundwater reservoirs (Anderson *et al.,* 2015). Simulation and optimization mathematical models have been adopted in the analysis of contaminant movement in groundwater systems. Simulation models have been applied and used widely to study the process of contaminant transport because they have been designed to include the effects of contaminant dispersion in their prediction (Anderson & Cherry, 1979).

Some of the widely used models in modeling sub surface contaminant movement are MODFLOW and MT3D (Zheng & Wang, 1999). MODFLOW model was developed by the United Stated of America Geological Survey and has been considered to be very reliable in modeling groundwater contaminant transport (Zheng & Wang 1999). MODFLOW is a three-dimensional modular finite-difference model that uses variable grid spacing in x and y spacing directions in describing and predicting the behavior and spread of contaminants (Mcdonald *et al.,* 1988).

The MT3D model derived from the MODFLOW model is a computerized simulation model used to simulate contaminant transport in groundwater. The model uses steady-state hydraulic heads calculated by the MODIFLOW model to model contaminant transport (Mcdonald *et al.,* 1988). Other mathematical models used in sub surface contaminant transport include FEFLOW, ChemFlo, AT123D, AQUA3D, Chemflux and FLOWPATH. These models are however very sophisticated and have not been widely adopted (Anderson *et al.,* 2015).

There are however limitations in the application of mathematical models in modeling contaminant movement. These limiting factors include; geographic coverage, scarcity of data on hydrological characteristics and difficulty in determining the field coefficient of contaminant dispersion (Anderson *et al.,* 2015). Besides, these mathematical models were suitable for mathematicians and physicists and limiting for environmentalists, geographers, and public health practitioners among others (Elumai *et al.,* 2020).

Researchers have devised different methods in understanding sub surface movement of contaminants. One of the most common methods is the use of monitoring wells in determining contaminant transport and direction in groundwater (Islam *et al.,* 2016). The use of Monitoring wells in mapping the movement of contaminants has been adopted widely by researchers interested in groundwater pollution (Tufenkji, 2007). This method involves the installation of monitoring wells along the groundwater flow path from the source of contamination i.e. landfills, septic tanks and pit latrines (Lawrence *et al.,* 2001). Groundwater flow path in this case is predicted by examining the local disposition of surface water and the use of hand tubes (Feighery *et al.*, 2013).

In Kenya, studies have been carried out on the effects of pit latrines on the groundwater quality. Kiprotich and Ndambuki (2012) carried out a study in Langas informal settlement in Eldoret Town on well water contamination by pit latrines. The main objective of the study was to establish the safety of water in wells located near pit latrines on individual plots of settlement. Alongside the MODFLOW model, the study adopted monitoring wells in modeling contaminant transport. Similarly, Mzuga *et al.* (2001) in a study on contamination of groundwater resources by pit latrines in Kwale district used monitoring wells in modeling contaminant transport.

Kanoti *et al.* (2019) used monitoring wells method to determine the microbial, physical and chemical indicators of groundwater in the Kisumu aquifer system. Despite the wide use of monitoring wells, this study did not adopt this method in its methodology. Instead of establishing monitoring wells, the study selected specific already existing wells within the study area for water testing. This decision was informed by the dense distribution of pit latrines (Contaminant source) and shallow wells in Kamkuywa. However, the study adopted the sampling method used in this study in sampling 32 shallow wells tested for fecal coliform contamination.

2.7 Application of GIS in Modeling Pollutant Movement in Groundwater

Geospatial technology has been the greatest technological breakthrough in modeling groundwater contaminant transport. For over 50 years, Geographic Information System (GIS) has been used in management and modeling of many aspects of groundwater quality, flow and pollution (Atkinson & Thomlison, 1994). Since the introduction of groundwater vulnerability concept by Margat (1968) and Albeit and Margat (1970), GIS technology has been found to be an effective tool in groundwater vulnerability and risk assessment (Stafford, 1991).According to Watkin *et al.*, (1996), before the adoption of GIS in groundwater related studies; hydrologists had for many years tried to determine groundwater pollutant flow direction predict pollutant spread and establish the geographical impact of the pollution. However, the procedures employed by hydrologists were painstakingly slow and proved to be very costly (Watkin *et al.*,1996).

According to Stafford (1991), the application of Geospatial Information Systems alongside remote sensing technology in groundwater vulnerability and risk assessment is the greatest development in groundwater modeling and management. Geospatial Information Systems and Remote Sensing technology has provided effective tools for analysis of voluminous hydrological data, simulation modeling for complex subsurface flow and pollutant transport (Gosse l*et al.,* 2004).

The major advantage of Geospatial Information Systems (GIS) in groundwater vulnerability mapping can be attributed to its ability to continuously update and accommodate changes in the data parameters used in groundwater vulnerability assessment (Lake *et al.,* 2003). The application of GIS to groundwater modeling and mapping has allowed for more complicated modeling systems and analysis that can perform detailed procedures and analysis of groundwater contamination that would not have been achieved without GIS (Srivastave *et al.,* 2001).

Several models in GIS have been developed primarily for groundwater vulnerability assessment and pollutant transport (Srivastave *et al.,* 2001). Some of these Models include; DRASTIC, GOD, AVI and SINTACS (Vias *et al.*, 2006). Of these models, the DRASTIC model is the only method considered less sophisticated as compared to other models and has been adopted globally in groundwater vulnerability and pollutant transport assessment.

DRASTIC model is arguably the most used method of groundwater vulnerability assessment even though a number of other spatial models designed for groundwater pollution assessment have been proposed (Committee on Techniques for Assessing Groundwater Vulnerability, 1993). A detailed account of the model's methodology, evolution and application guidelines is offered by Aller *et al.* (1985). DRASTIC is an acronym derived from the factors the model considers for vulnerability assessment;

D-Depth to water table

R-Recharge net

A-Aquifer media (Geological Characteristics)

S-Soil media (texture)

T-Topography (Slope)

I-Impact of the vadose zone (Unsaturated zone above the water table

C-Conductivity (Aquifer hydraulic conductivity)

The goal in designing the model was to make it an easy to use, nationally applicable and a simple tool for groundwater pollution hazard assessment, formulated as a linear equation (Hopkins, 1977);

$$DI=D_rD_w+R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w$$

Where **r** is the rating and **w** is the weight for each factor. These rating vary from 1-10 to reflect the relative significance of classes within each factor. For instance, soils like clay soil which is fine textures are assumed to be less permeable than sandy soils hence, clay soils will be assigned a lower rating than the sandy soils because with other things constant, clay soils are less likely to allow infiltration of a pollutants compared to sandy soils (Hopkins, 1977). Also, areas where depth to the water table is great are assigned low ratings with an assumption that with other factors held constant, pollutants are less likely to reach the water table as compared to shallow water table. Weights (w) range from 1-5 and are designed to show the relative importance of the seven factors with regards to one another. A higher weight will indicate a greater importance while a smaller **w** indicates a lesser importance.

Finally, the index value computed by the model is considered to be the relative indicator of pollution potential of groundwater in the area of interest (Aller *et al*., 1985). Higher index score show greater vulnerability while lower scores indicate a lesser vulnerability. However, these indices must be interpreted within a specific hydro-geological setting in that the use of the indices without specific reference to the hydro-geological setting may lead to wrong interpretation of the results (Aller *et al*., 1985).

The DRASTIC model was designed and formulated on the following assumptions; (a) data required by the model is available, (b) the variables included in the model are critically related to groundwater vulnerability and lastly (c) the mathematical relationships, ratings and weightings between variables are adequately set forth in the model procedure (Aller *et al*., 1985).

Unfortunately, this model was designed to be used only for regional and not site – specific studies. This study being a site specific and conducted in a relatively small geographical area, the study did not fully apply the DRASTIC Model. However, along with other models and theories discussed, the study borrowed elements of the DRASCTIC model in formulation of the research design, data analysis and interpretation of results. The study adopted the analysis of the water table, soil permeability and slope in determining groundwater pollution risk in Kamkuywa Market Center.

A systematic review of literature on GIS-based groundwater pollution hazard assessment suggests that, even though there have been enormous efforts in the development of GIS models that can effectively determine groundwater pollutant flow, direction and spread, the available models such as the DRASTIC model still have some limitations. The review of literature further suggests that groundwater modeling is often conducted with insufficient consideration for particular model limitations and assumptions as well as the potential impacts, data deficiencies and GIS induced errors during analysis (Lasserre *et al.,* 2011).

Groundwater contamination and pollutant movement modeling and prediction have advanced since the first usage of GIS. Currently GIS software such as ArcGIS and QGIS have been updated to include different tools that can be used in modeling groundwater flow and pollutant transport (Brunsdon *et al.,* 1996).Currently using GIS, data on parameters used to determine groundwater flow and pollutant movement can easily be captured, analyzed and modeled to determine groundwater contamination flow and water quality (Brunsdon *et al.*, 1996).

As groundwater water quality assessment and vulnerability assessment models get more sophisticated, models such as Geographically Weighted Regression are becoming an important asset in modeling groundwater contamination (Nakaya *et al.,* 2005).

2.7.1 Geographically Weighted Regression

Geographically Weighted Regression (GwR) is one of the many spatial regression techniques used in geography and other disciplines and a powerful exploratory method of spatial analysis (Fotheringham *et al.,* 2002). Geographically Weighted Regression evaluates a local model of the variable being predicted by constructing a regression equation to every feature in the dataset (Brunsdon *et al.,* 1996). The equations are constructed by incorporating the dependent and the independent variables of the features falling within the neighborhood of each target feature. The neighborhood type determines the shape and the extent of each neighborhood (Gollini *et al.*, 2013). This regression technique is not ideal for small datasets and multi point data and therefore should be applied to datasets with more than hundred features.

Geographically Weighted Regression has been used to determine the effect of spatial heterogeneity on the explanatory variable in many studies globally (Mitchell & Andy, 2012). The Ordinary Least Squares (OLS) tool is a component of the Geographically Weighted Regression model. The OLS works on an assumption that relationships between independent variables and outcome variable are stationary across the area of interest. GWR on the other hand assumes that relations will vary across the area of interest and hence non-stationery (Nakaya *et al.*, 2005). In GWR, spatially varying relationships are modeled by generating individual regressions for each data point and more weight given to nearby observations. It also, minimizes the residual spatial autocorrelation and generates local coefficient maps in observing spatial heterogeneity (Amano &Ronny, 2016). Based on this, GWR has been able to show in various studies that land use changes affect groundwater quality indicators (Fotheringham *et al.*, 2003).

Geographically weighted regression can be used to carry out prediction in the study area based on the model created. To carry out prediction, it is required that each of the prediction location in the study area has specific values for each independent variable(s) provided in the model. GWR also allows for exploration of spatially varying relationships. It achieves this by creating coefficient raster so as to visualize how relationships between independent and dependent variables vary across the study area (Wheeler & Paez, 2011). The GWR tool produces several outputs, i.e., a summary of the GWR model and a statistical summary.

The application of this model has a worldwide usage. Eun-Hee *et al.* (2020) used Geographically Weighted Regression model to predict spatial characteristics of nitrate contamination: the implications for an effective groundwater management strategy in South Korea. In addition, Javi *et al.* (2014) employed geographically weighted regression model in the analysis of spatiotemporal varying relationships between groundwater quantity and land use changes in Khanmirza Plain in Iran. Further, the Model was used in the analysis of groundwater nitrate contamination in the central valley in the United States of America (Shrestha & Luo, 2017).

In Africa, Geographically Weighted Regression model has been used in modeling the temporal dynamics of groundwater pollution risks at the African scale (Issoufou *et al.,* 2020). The Model has also been used in the analysis of groundwater pollution management in Ethiopia (Muche, 2021). Despite being adopted worldwide, review of literature indicates that Geographically Weighted Regression model has not been used in Kenya in the Analysis of groundwater vulnerability, risk and pollutant transport. This study adopted Geographically Weighted Regression Model in the Analysis of Groundwater pollution in Kamkuywa Market Center.

2.8 Theoretical Framework

The following theories influenced this study.

2.8.1 Source-pathway-receptor model

The source-pathway-receptor model is a concept used by on-site situation in determining the risk of groundwater contamination (Yawar *et al.,* 2017). For groundwater contamination risk to exist there must be a pollutant source and a pathway that provides the means for the pathogens to reach the aquifer. In the study area, there is widespread distribution of pit latrines which are the major sources of contamination as well as onsite sanitation. There are three types of pathways (Carter & Hussein, 2015); 1) those that naturally occur in the subsurface as a result of existing openings like ground cracks. 2) Those that occur due to human activities and 3) those in the environmental component affected by the impacts of physical activities such as drilling, quarrying and construction. Receptors usually differ in resilience because each of them is uniquely sensitive to changes in the environment (Caraballo *et al.*, 2013).

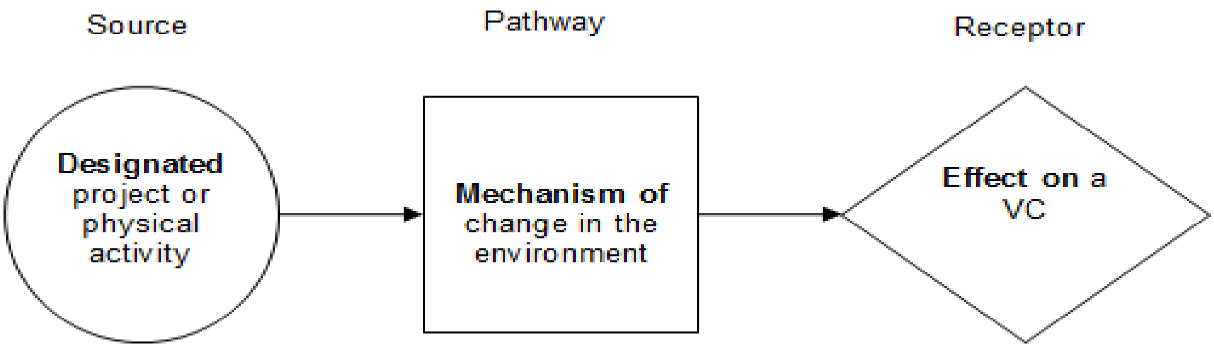

Figure 2. 1: Source-Pathway-Receptor Model

(Source: Canadian Environmental Assessment Agency)

The route the source takes to reach the receptor is known as the pathway where environmental change occurs. This can include both physical and chemical (air, water and soil) transportation. To understand groundwater contamination it is important to understand pathway mechanisms (CEAA, 2007). This theory explains how environmental factors such as soil permeability, rock structure, and pH lead to aquifer (receptor) contamination. For a contaminant to move from the source and reach groundwater there must be a pathway and other environmental factors involved. These factors might accelerate or slow down the process. It is therefore important, to understand the source and the pathways of contaminants in the sub surface environment so as to reduce the uncertainty associated with likelihood estimation of drinking water to contaminants. Additionally, knowing the source and the pathways provides room for quantification of contamination effects through accurate testing and measurement.

2.8.2Fick's law of Diffusion

This law describes the movement of particles under random thermal motion from higher concentration region to lower concentration regions (Crank, 1980). The theory can be used to explain groundwater contamination. The law mathematically categorizes three dimensional distribution and states that the concentration gradient is proportional to the diffusion flux as; (3.9) $F=-D\nabla C$

Where

C represents the concentration of diffusing elements;

F represents the flux by which is a particle per square meter per second

D is used to represent the constant in centimeter squared per second.

According to Crank (1989), the changes in particles affect the concentration gradient. In the context of this study, Fick’s law of diffusion theory explains how fecal coliform bacteria can spread from the source (pit latrines) to the surrounding environment eventually reaching the water table and contaminate it.

2.8.3 Distance Decay

The term distance decay is used in Geography to describe how distance affects spatial and cultural interactions. This refers to the decline of interactions between two locations with increase in distance. This process is described as distance decay (Yasuyuki, 2013). In simple terms it is the decrease or loss of similarity between two observations as a result of an increase in distance between them (Yasuyuki, 2013). The concept of distance decay can be graphically represented by a line that curves downwards with a concave appearance as the distance on the x-axis increases. It can also be represented mathematically given by law of inverse squares (White, 1999). This theory was used to explain how pit latrine –shallow well distance affected groundwater contamination in Kamkuywa with an assumption that the greater the distance the lower the risk of contamination as pathogens tend to die along the way and the concentration of contaminations reduces with an increase in distance.

2.9 Conceptual Framework

The transportation of microbes from pit latrines to groundwater is largely dependent on the hydro-geological and climatic factors of the area. Half of the studies conducted to assess microbiological contamination of groundwater have used experimental approaches including test well installation in the areas of study so as to measure the water quality. Some have included the collection of soils, the measurement of pit latrine depths as well as shallow well depths. According to the World Health Organization (2006), microbial and chemical factors controlling the transportation of pathogens from pit latrines to the groundwater have been subject to several reviews. This is because these factors vary from one geographic region to the other and is also strongly influenced by other driving factors like; land use changes, population growth, and urbanization among others.

Once groundwater is polluted and unfit for human consumption, the impact is grave. Among the most common effects of groundwater contamination are; water scarcity, poor groundwater quality and the frequent outbreaks of water-borne diseases, as well as higher cost of treatment. Groundwater protection and prevention from contamination is more important and easier than management of already polluted groundwater. It is therefore critical to have protection and mitigation measures in place. Such measures include; land use planning, urban and physical planning, and provision of water supply and sanitation systems, water quality management plans and most importantly adherence to the set safe distance guidelines in Kenya.

A conceptual framework was defined to establish the relationship between study variables and the expected results. The framework in Figure 2.2 is a modification of the DRSIR framework used in the strategic assessment of groundwater resource exploitation in Guwahati, India. The framework looks at groundwater pollution driving and accelerating factors in Kamkuywa as well as the impact and solutions to groundwater contamination.

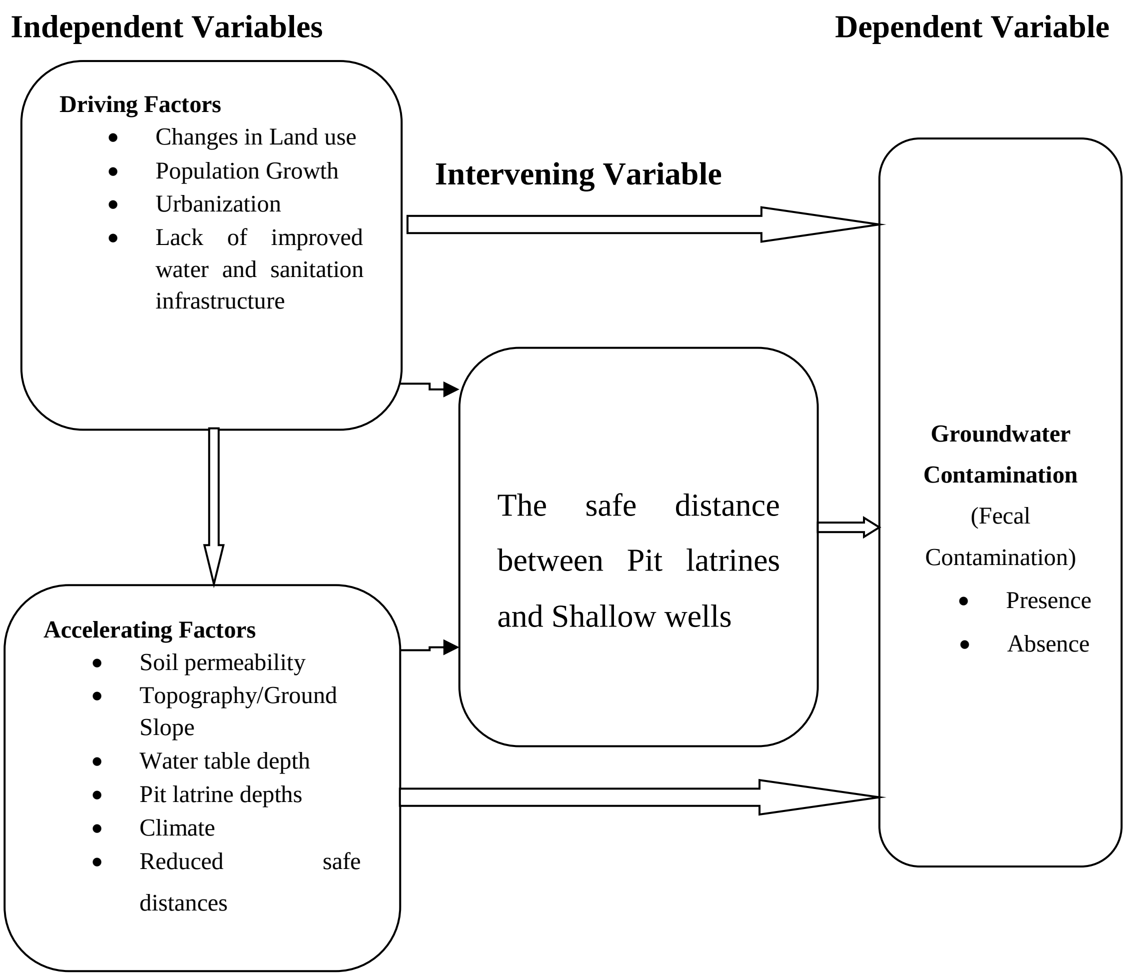

Figure 2. 2: Conceptual Framework

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the study process. The first section describes the study area. This is followed by a description of the various data sets used in the study their sources and how these data were obtained. The processes applied to some of these data before they were used in the final analysis are also described. The final section describes the data analysis techniques used in the study.

3.2 Study Area Description

3.2.1 Location

Kamkuywa Market is one of the largest open-air farm fresh-produce markets in Kimilili Constituency, Bungoma County. The market center is well known for its wide variety of fresh agricultural produce including; green maize, cereals, and horticultural products throughout the year. The center hosts the Kamkuywa Ward administrative offices and is located along Webuye- Kitale highway. Due to its strategic location, Kamkuywa Market has a population of 26,569 people according to the Kenya Population and Housing census conducted by the Kenya National Bureau of statistics in 2019 and thus has the potential of growing even bigger in the future. It is located on latitude N 0◦ 46'39.36 " and longitude E 34◦ 47' 12.48 " on a hilly topography with a gently sloping hilly terrain towards the western side of the town and gently slopes downward toward the north-eastern side. The highest point is approximately 1716m above sea level and the lowest point 1634m. Figure 3.1 shows the location of the study area.

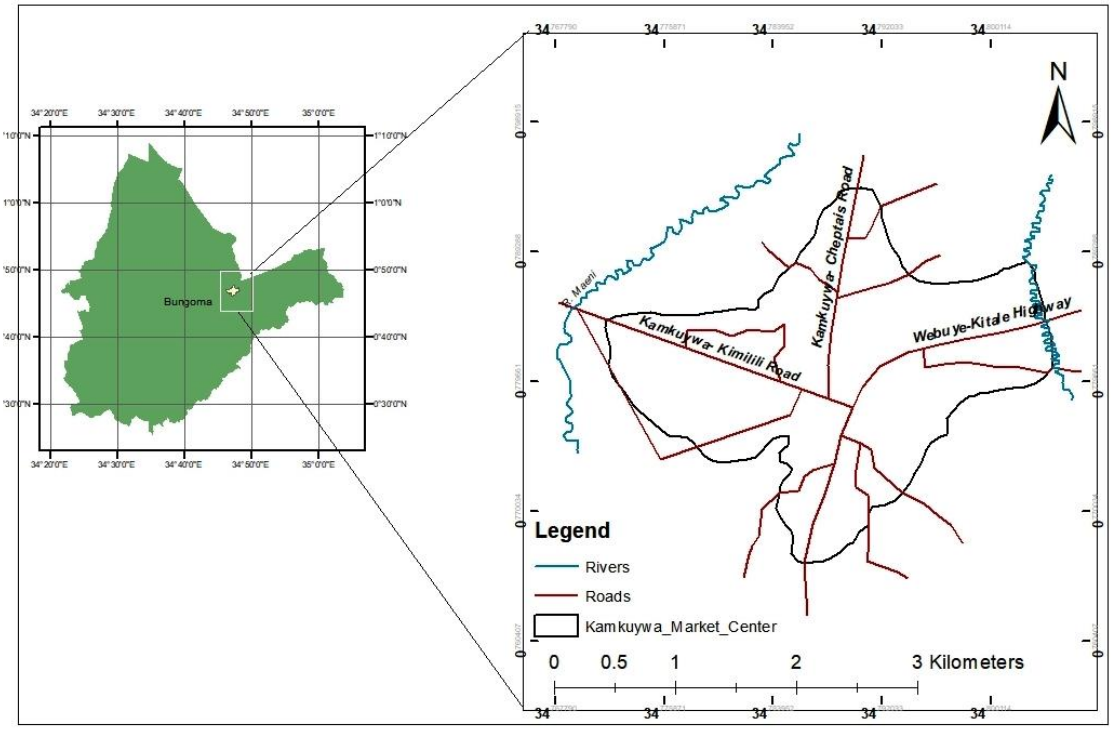

Figure 3. 1: Study Area (Kamkuywa Market Center)

3.2.1 Geology and Drainage

The geology of the market area reflects the volcanic tectonic setting of Mt. Elgon and the slope variation in Bungoma County. The study area consists mostly of metamorphic rocks occupied by a somewhat gneissose pegmatite-rich leuco-granite. The composition of the basement rock has had an influence on soil distribution in the area according to the Bungoma County draft Local Urban Development Plan (2015). The geology of an area determines the soil type. Soil attributes such as permeability and porosity have been known to influence the rate of infiltration and percolation as well as the pollutant travel distance and the time (Bousenberry *et al.* 2013). In addition, the area is traversed by River Kamkuywa which flows from south to north. The area has very fertile red loamy soils suitable for agriculture. The soilsare well-drained, deep, and vary from dark red Nitisols to dark brown Ferralsols along the rivers (Bungoma CIDP, 2013).

3.2.2Climate

According to the Bungoma County Integrated Development Plan 2013-2018. The study area receives a bimodal type of rainfall, with warm and wet climatic conditions experienced all year round. The mean annual rainfall ranges from 1250mm to1800mm, with the heaviest rains occurring between April and July (this is the time when intensive farming activities are undertaken). The mean annual temperatures range between 21 degrees and 23 degrees Celsius, with the hottest temperatures experienced between December and February. According to Idoko (2010), the quality of groundwater is greatly affected by the change in climatic factors. Chup and Makwe (2013) established that, weather events i.e. long rains and long droughts greatly affect groundwater quality in that factors such as rainfall lead to change in groundwater recharge rate and therefore variation in amount of rainfall received in an area affects the concentration of water parameters.

3.3 Data and Data Sources

From literature, the movement of contaminants through the soil medium into the groundwater is affected by several factors: First is the presence of the contaminant and its concentration. There is a higher likelihood of groundwater contamination when there is high concentration of contaminants such as fecal coliform bacteria in close proximity to a water source. Second is the depth of the water table whereby pollutants are likely to spread faster where the water table is shallow as compared to a deeper water table. Further, contaminants will spread faster on gentle slopes than steep slopes if the pollutants origin is the ground surface because the former allow for more infiltration and percolation rate than steep slopes which produce more surface runoff. Finally, contamination will spread faster in sandy soils, which have higher soil permeability than in clay soils. To address the study objectives these factors were obtained from the sources described below. It should be noted that rainfall and temperature were assumed to be uniform since the study area is fairly small.

3.3.1 Contaminant Concentration

Contaminant concentration was represented by fecal coliform densities. Fecal Coliform densities were derived from Lab analysis of thirty two (32) water samples collected from thirty two (32) selected shallow wells in the study area through stratified random sampling.

3.3.2 Water Table Depth

This was defined as the perpendicular distance between the upper ground surface and the upper most zone edge of the groundwater surface (Platz, 2010).The latter was represented by the altitude above mean sea level of the point where water is encountered during the drilling of a shallow well. This was obtained by calculating the difference between measured shallow wells depths and the altitude of the well top using the formula (Altitude - depth= Water table).

3.3.3 Soil Permeability

Soil permeability defined as the ability of the soil to transmit air and water (Orabi, 2016) represents the ease of flow of a contaminant. Soil permeability data was obtained from field analysis of soil profiles and the soil characteristics (soil colour. Soil texture, structure, land use, slope) in ten (10) thematically selected sites in the study area.

3.3.4 Slope

Slope values were extracted from a slope map generated from a digital elevation model (DEM).The DEM was generated from the geographic coordinates of all shallow wells as well as their altitude values.

3.3.5Waste Level Depth

Waste level was defined as the perpendicular distance between the upper edge of the ground surface and the bottom part of a dug pit latrine. It was represented by the difference between the pit latrine depths and the altitudes of the respective pit latrine top using the formula (Pit latrine altitude – Pit Latrine Depth= Waste level).

3.3.6 Distance between a Shallow Well and nearest Pit Latrine

The distance between each shallow well and the nearest pit latrine was automatically generated from point coordinates of 1061 pit latrines and 531shallow wells mapped using GIS-based proximity analysis tools in ArcGIS.

3.4. Data Collection and Processing

Data on fecal coliforms densities was achieved by collecting and analyzing the concentration of fecal coliform bacteria in 32 water samples collected from 32 selected wells. Data on soil permeability was collected through measurement and observation. Data on pit latrine depths was collected through measurement. Data on the slope was obtained using the GPS by obtaining the geographic coordinates for all the shallow wells in the study area. This section describes how data highlighted in section 3.3 was collected and processed.

3.4.1 Fecal Coliform Concentration as an indicator of contamination

Five hundred and thirty one (531) shallow wells were mapped in the study area. Fecal coliform concentration in water from shallow wells was used to establish how groundwater quality varied in different spatial locations in the study area. Stratified random sampling was used to select 32 shallow wells after thematically zoning the study area in eight (8) representative zones using the following criteria;

i. The density of shallow wells- The study area was stratified into 284 grids measuring 100m x100m and the grids with the highest and lowest number of shallow wells and pit latrines identified. The grid with the highest level of shallow wells had 12 shallow wells and 15 latrines.

ii. The Depth of the shallow wells
iii. The slope angle/Topography
iv. The soil permeability rate
v. The location of the shallow well with reference to the road network
vi. The status of the shallow well (protected and unprotected)
vii. The Proximity of the shallow well to the nearest pit latrine
viii. The period in which the shallow well has been in use

Based on these parameters, four shallow wells were then randomly selected from the eight (8) strata for analysis of fecal coliforms. The process of collecting water samples from the 32 selected shallow wells was conducted in accordance with the American Public Health Association Standards and Guidelines (1992) on water sample collection whereby the 32 samples were collected between 6:00 am to 7:00 am when the water in the shallow had not been disturbed. The water samples were collected using specially prepared, sterile white pack bags. The bags contained a 0.1ml of a 3% solution of sodium thiosulphate to dechlorinate and neutralize any residual halogen and prevent the continuation of bacterial action during sample transit. As a standard requirement for the sample volume of drinking water, 100ml of each sample was collected and carefully labeled. Sample Bags were numbered appropriately i.e. SW1, SW2, and SW3.

The exercise also involved the collection of geographic coordinates, nearest pit latrine, depth, and the distances (m) to the nearest pit latrine of respective shallow wells whose water samples had been collected. These data were recorded in a digital template as illustrated in table 3.1.

Table 3. 1: Sampled shallow wells datasheet

S/No	Well label	Location Lon. (DD)	Lat. (DD)	Alt. (m)	Well Depth (m)	Nearest PL Label	Dist. Nearest PL (m)	Depth of Nearest PL (m)
1.	SW1	34.791168	0.779192	1700	10.75	PL01	22	9.75
2.	SW2	34.789505	0.779333	1705	10.75	PL02	18	9.75
3.	SW3	34.789418	0.781235	1713	10.25	PL03	8	9.75
4.	SW4	34.7893	0.783087	1711	11.75	PL04	10	10.25
5.	SW5	34.789538	0.786747	1703	11.75	PL05	6	9.75
6.	SW6	34.78937	0.789465	1696	11.75	PL06	12	10.25
7.	SW7	34.788644	0.779139	1707	10.75	PL07	18	9.75
8.	SW8	34.788812	0.780993	1713	11.25	PL08	14	9.72
9.	SW9	34.788028	0.784426	1714	11.75	PL09	15	10.5
10.	SW10	34.788765	0.788373	1707	14.25	PL010	19	12.75
11.	SW11	34.785942	0.780918	1709	10.75	PL011	21.5	9.25
12.	SW12	34.785208	0.781803	1708	11.25	PL012	23	9.75
13.	SW13	34.788862	0.776948	1702	11.75	PL013	16	9.75
14.	SW14	34.78827	0.775328	1707	11.75	PL014	21	9.75
15.	SW15	34.78801	0.777848	1708	10.75	PL015	20	8.75
16.	SW16	34.786083	0.778865	1705	9.75	PL016	11	9.75
17.	SW17	34.783747	0.777538	1701	11.75	PL017	10	9.75
18.	SW18	34.788772	0.770649	1700	11.75	PL018	32	9.5
19.	SW19	34.789615	0.774611	1699	11.75	PL019	13	9.75
20.	SW20	34.791167	0.777988	1698	10.5	PL020	19	8.75
21.	SW21	34.791982	0.77861	1691	12.75	PL021	22	10.9
22.	SW22	34.795183	0.78035	1682	9.75	PL022	17	8.75
23.	SW23	34.799385	0.780735	1651	10.25	PL023	26	9.75
24.	SW24	34.798593	0.779402	1660	10.25	PL024	12	9.75
25.	SW25	34.802437	0.780495	1642	7.5	PL025	18	3
26.	SW26	34.801403	0.782613	1640	3	PL026	14	2.1
27.	SW27	34.798313	0.783864	1663	9.75	PL027	15	6.75
28.	SW28	34.793357	0.783536	1694	9.5	PL028	25	8.5
29.	SW29	34.800728	0.78339	1651	7.75	PL029	20.2	7.75
30.	SW30	34.801113	0.78491	1647	8.5	PL030	12	7.25
31.	SW31	34.802095	0.785843	1641	2.5	PL031	27	2.1
32.	SW32	34.791831	0.785959	1702	10.75	PL032	23	9.75

To validate the results of the fecal coliform count test, duplicate water samples from the selected shallow wells were required. Four shallow wells i.e. SW9, SW5, SW24, and SW30 were randomly selected from the initial 32 sampled shallow wells and their water samples were collected the next day. The waster sample collection procedure was similar to the one detailed above.

The whole process of water sample collection was carefully done as the samples were directly put in the bags from the wells to avoid contamination. All collected samples were kept cool in a 20liters cooler box and delivered to the lab for analysis within 3 hours in line with the World Health Organization (1996) guidelines.

3.4.2 Soil Permeability

The process of determining the study area's soil permeability rates was carried out in three steps: First, directed benchmark sampling was used to demarcate the study area into ten (10) plots representative of its topographical, geological, and land use characteristics as shown in Figure 3.2. This sampling method was selected because; the study area had distinct and well-defined features related to topography, and land use as shown in Appendix III

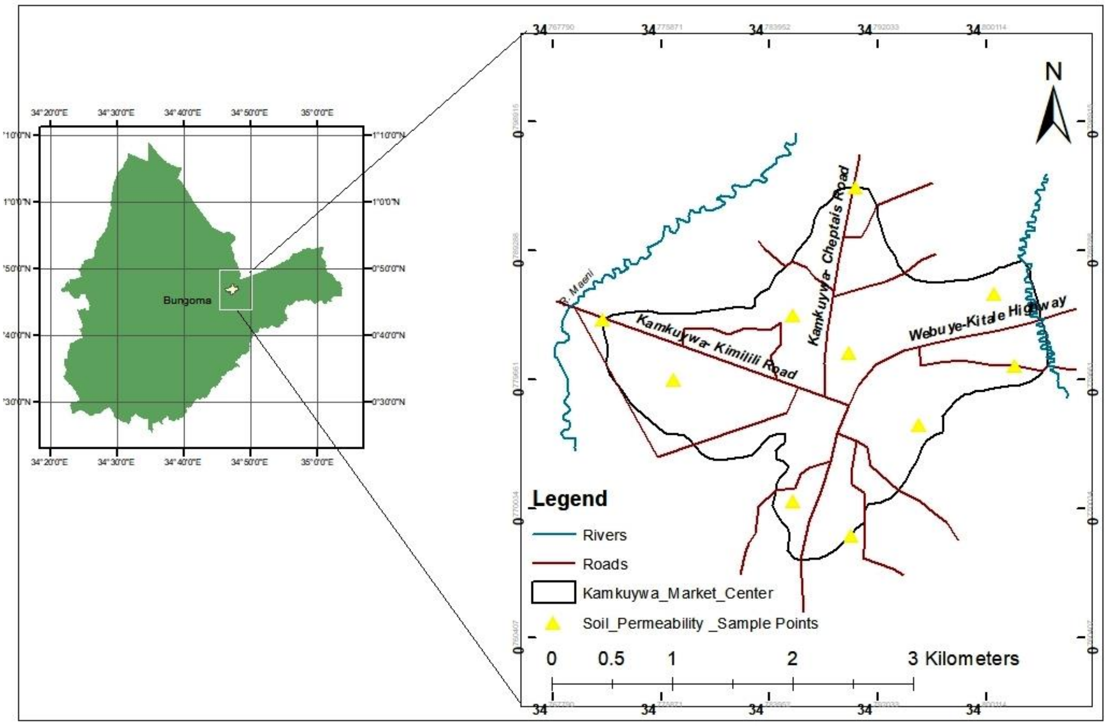

Figure 3. 2: Distribution of Soil profile Sample points

The second step in determining soil permeability rates involved digging soil profile pits in the ten (10) plots. All the 10 pits were dug to a depth of 1.22m. For each pit, the soil profile was examined according to the FAO (1977) guidelines for soil profile description as summarized in the table provided (Appendix 3). In addition to this, a simple hydraulic field test was carried out to determine the soil texture. The study adopted the Beerkan Infiltration Run (SBI) simplified method of testing soil hydraulic connectivity. The process of determining the soil texture using the hydraulic field test involved inserting a cylinder into a short soil depth and measuring the infiltration time of small water volumes that were repeatedly being applied at the surface of the confined soil that was being measured. The recorded Kfs which was the measured infiltration time was used to determine the soil texture. Kfs refers to the soils saturated hydraulic conductivity. This process was done for all the ten dug pits.

Alongside this, geographic coordinates for every dug pit were collected using mobile GPS (GIS Cloud). Finally, all the dug soil pits had their recorded characteristics analyzed and permeability rates determined as shown in Table 3.2 below according to the Kenya Survey procedures matrix for determining soil permeability.

Table 3. 2: Soil Permeability Rates

S/NO.	**Pit Label**	**Geographical Location Data**			**Permeability rate (Kfs)**
		Longitude	**Latitude**	**Altitude**	
1.	001	34.781341°	0.779757°	1692	2.5
2.	002	34.788607°	0.776864°	1705	2.5
3.	003	34.791196°	0.780220°	1701	2.5
4.	004	34.788097°	0.785051°	1712	2.5
5.	005	34.800591°	0.787440°	1647	1.3
6.	006	34.802792°	0.779682°	1637	1.3
7.	007	34.794770°	0.775871°	1673	2.5
8.	008	34.773505°	0.781755°	1660	1.3
9.	009	34.788965°	0.790635°	1710	2.5
10.	010	34.787763°	0.772974°	1708	2.5

Furthermore, thiessen polygons technique was used to generate a soil permeability map using geographic coordinates and permeability rates in Table 3.3 to determine the areas of influence of each point of measurement. The output was Figure 3.3, which is a raster layer of permeability rates. The final stage for this process was the extraction of permeability values using the ‘extract multi values to points’ tool in ArcGIS spatial analyst. The values of the underlying soil permeability map were extracted to the points representing shallow wells.

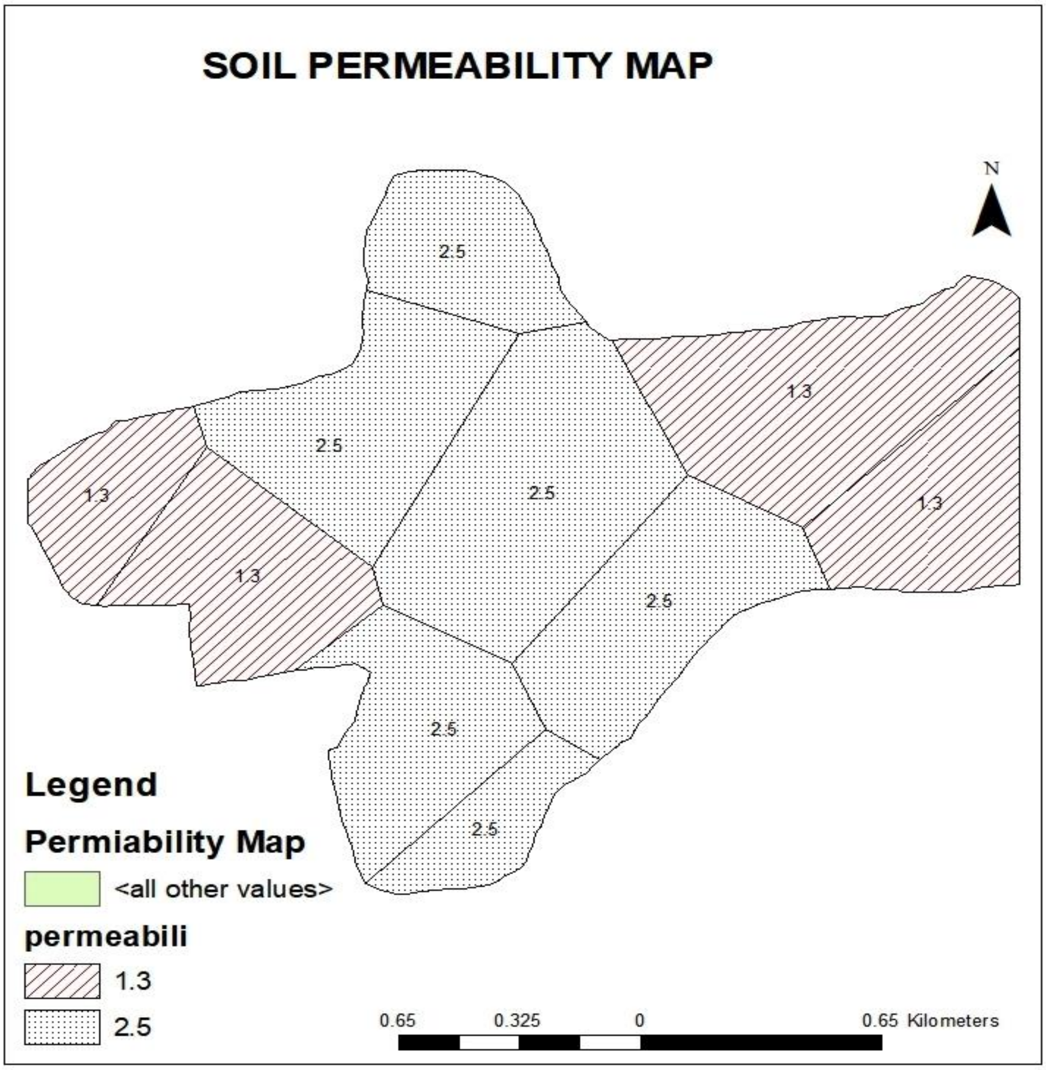

Figure 3. 3: Soil Permeability Map

3.4.3 Surface Slope

Slope data was obtained in four stages. First was the collection of location data (Longitude, Latitude, and Altitude) for all shallow wells in the study area using Cloud GIS. The collected coordinates and the elevation for the 531 shallow wells were then used to generate a digital Elevation Model (DEM) using Topo to Raster Interpolation technique in the spatial analyst tools in ArcGIS. The generated DEM was in turn used to generate a slope map (Figure 3.4) using 3D analyst tools. The generated slope map indicated the steepness of the land surface in the study area. Finally, slope values from the slope map were extracted using the 'extract multi values to points' tool in spatial analyst. Similarly, the tool extracted the values of the underlying slope map to the points representing shallow wells.

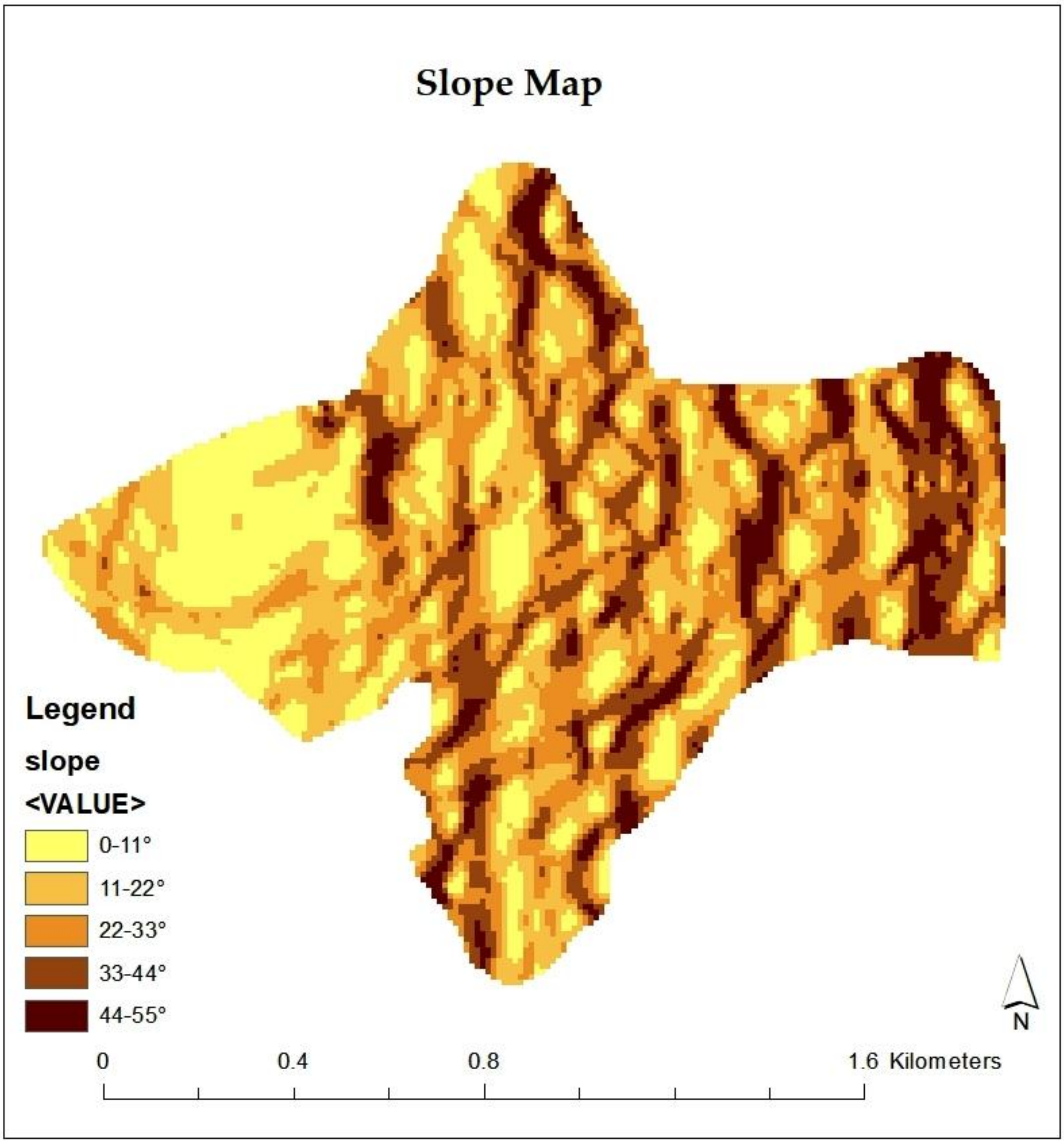

Figure 3. 4: Slope Map

3.4.4 Water Table Data

Water table data collection involved first the mapping of all shallow wells in the study area where a total of 531 shallow wells were mapped. The mapping exercise involved the collection of GPS coordinates as well as the altitudes. This was followed by the measurement of the depth of each shallow well using a 50 meters steel tape. Data for coordinates and depth of the shallow wells was recorded in a digitally prepared template in Cloud GIS (Appendix 1). The recorded depths and altitudes were in turn used to generate water table elevation (z) values using the formulae (Altitude - depth= Water table).Table 3.3 illustrates this step.

Table 3. 3: Water table (z) values

S/NO.	Latitude	Longitude	Altitude	Depth	Water table (z) value
1.	0.782286667	34.80229	1685	10.5	1674.5
2.	0.780495	34.80243667	1687	7.8	1679.2
3.	0.779743333	34.80133	1685	10.5	1674.5
4.	0.779275	34.801415	1708	10.5	1697.5
5.	0.779611667	34.80094	1713	8.25	1704.75
.					
n.					

Finally, a water table surface map (Figure 3.5) was generated through interpolation from the water table elevation (z) values in Table 3.3 using spatial analyst tool in ArcGIS. Similarly, interpolated water table values were extracted from the water table surface map to the points representing shallow wells using the ‘extract multi values to points’ tool in spatial analyst.

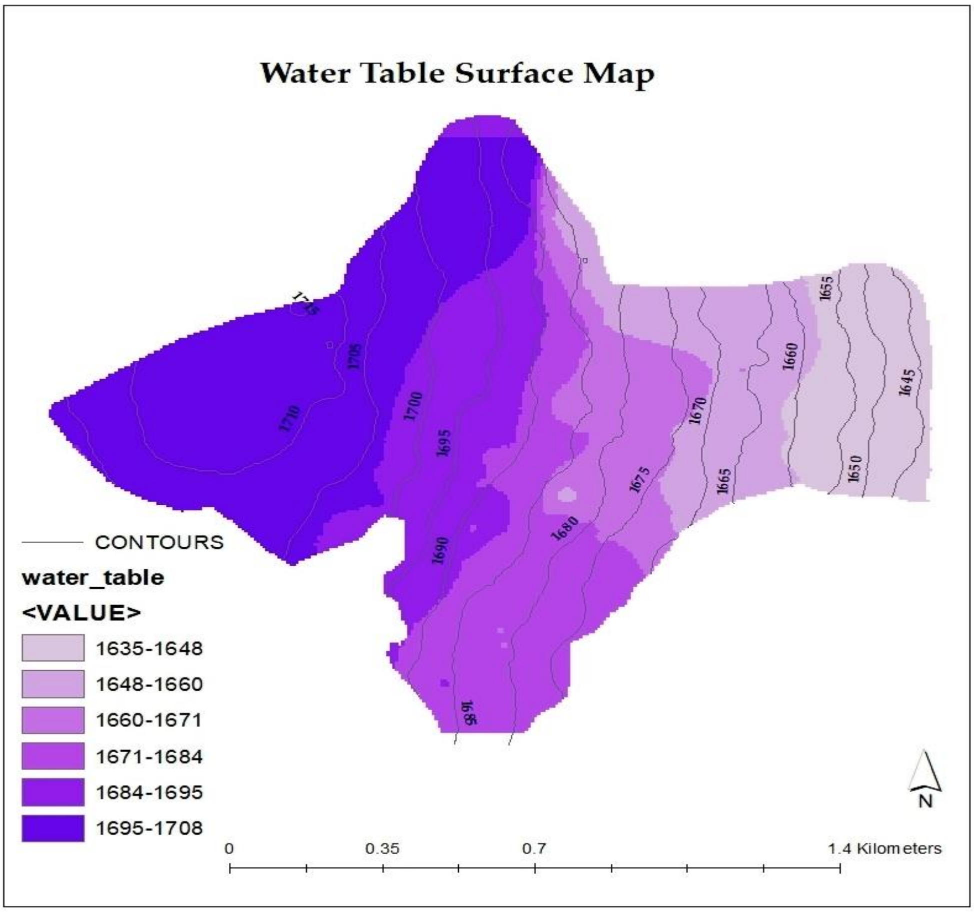

Figure 3. 5: Water Table Surface Map

3.4.5 Waste level Data

Procedure for data collection on waste level was similar to that of water table data as described in 3.4.4. It involved the collection of GPS coordinates and depths for all the 1061 pit latrines in the study area. However, unlike shallow wells, pit latrine's depths were not measured using a steel tape measure. This is because it was impractical and unhygienic to measure the depths of 1061 pit latrines in use. Therefore, the depths recorded were the initial depths of the pit latrine when they were dug. This information was provided by the owners and recorded in a digitally prepared template in Cloud GIS (Appendix I).

The altitude and the depths for the 1061 pit latrines in the study area were used to generate the waste level elevation (z) values using a formula similar to the one used in 3.4.4 (Pit latrine altitude – Pit Latrine Depth= Waste level) as shown in Table 3.4.

Table 3. 4: Waste (z) values

S/NO.	Latitude	Longitude	Altitude	Depth	Waste (z) value
1.	0.779678333	34.80317167	1637	3.25	1633.75
2.	0.779386667	34.802585	1634	8.75	1625.25
3.	0.77947	34.80263667	1645	7.5	1637.5
4.	0.780288333	34.80244667	1698	9.75	1688.25
5.	0.780511667	34.80258333	1659	10.65	1648.35
n.	0.780935	34.80257	1643	4.45	1638.55

Lastly, an interpolated waste level surface map Figure 3.6 was generated using the waste level values in table 3.4. The ‘extract multi values to points’ tool in spatial analyst was used to extract interpolated waste level values. The extracted values were exported to the values representing shallow wells.

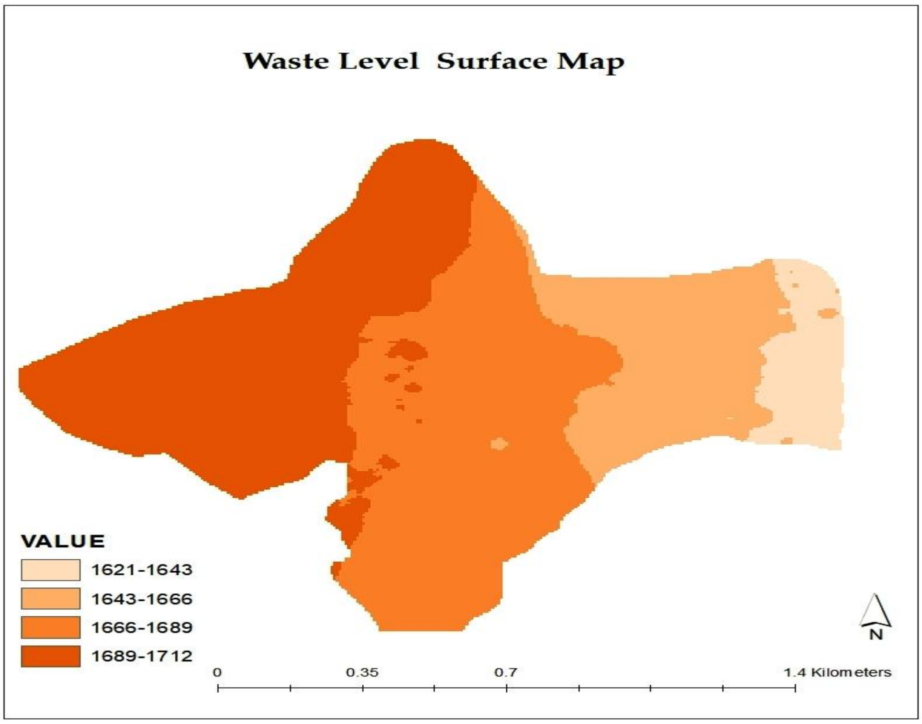

Figure 3. 6: Waste Level Surface Map

3.5 Data analysis

Data analysis was carried out in response to the four objectives. Most of the analysis was carried out in a GIS environment using ArcGIS version 10.5.

3.5.1 Determining the extent of Groundwater Contamination

Determination of the extent of contamination involved two tests. The first was the determination of the extent to which the World Health Organization and Kenya sanitation and Hygiene policy on well to pit latrine spacing had been flouted in the study area. The distance of each Shallow well to the nearest Pit latrine was calculated using nearest Proximity analysis tools in ArcGIS. The second analysis for this objective involved determining the extent of coliform contamination in the water samples. Sampled water from thirty-two (32) shallow wells underwent membrane filter test within three hours of sample collection as required under the World Health Organization water testing guidelines (1996). Specifically, a sample volume of 50ml from each sample was filtered through a membrane filter of 0.45 microns using a vacuum pump. Placed in a culture dish on a pad with growth enrichment media, the filter was incubated for 24 hours at a temperature of 44.5^{o}C.Collected bacteria cells on the filter grew into dome-shaped colonies with a gold-green sheen colour. From the dish, these dome-shaped colonies were counted and recorded. Indicator shallow wells SW5, SW13, SW24, and SW20 required a 25ml dilution to achieve a clear countable membrane.

The fecal concentration of each 50ml water sample and 25ml water sample for SW5, SW13, SW24, and SW20 were recorded as coliform densities calculated as units of the numbers of colonies per 100ml of sample water. A confirmation test was undertaken in an incubation period of 24hrs for the duplicate water samples SW5 (D), SW9 (D), SW24 (D), and SW30 (D). The result of these duplicates was used to validate laboratory analysis precision.

Finally, coliform densities point values were transformed into a raster map to show continuous distribution of groundwater fecal coliform contamination in the study area. The interpolated contamination values from the raster map were extracted to the points representing shallow wells to have 531 contamination values each for the respective shallow well. Using the extracted values, a four-class contamination level surface map was created in 3D Analyst using the Kriging interpolation technique.

3.5.2 Determining the relationship between contamination and Hydro-geological factors

Regression analysis using spatial statistics tools (modeling spatial regression) was carried out to model, predict, examine, and explore spatial relationships to find out how these environmental factors affect groundwater contamination. To enable this, dependent and independent variables were determined with contamination as the dependent variable being modeled and slope, soil permeability, distances, and depths as independent variables (explanatory variables). Regression analysis was preceded by running the Ordinary Least squares regression tool to find out whether the model is accurate. To determine the regression coefficients (β) for the exploratory variables the OLS model was runs as follows;

$yi = \beta 0 + \beta 1x1i + \beta 2x2i + \ldots + \beta nxni + \varepsilon i$ With the estimator $\beta' = (XT\ X)\text{-}1\ XT\ Y$

The result of the OLS model was an equation constructed for every location in the data set for the independent and dependent variables existing within the bandwidth of each location. There was need to ensure that the OLS residuals were spatially random and therefore, spatial autocorrelation (Global Moran I) was performed on these residuals.

Once the independent variables to be used in the Geographically Weighted Regression model had been validated by the OLS model, the next step was the running of the Geographically Weighted Regression Model. GWR was preceded by resetting the environment in the arc tool box. This involved aligning the processing extent, projection and the workspace. GWR used the following model formula to run a regression analysis of the dependent and independent variables;

$yi = \beta 0 + \beta 1x1i + \beta 2x2i + \ldots + \beta nxni + \varepsilon i$ With the estimator

$\beta'(i) = (XTW(i)\ X)\text{-}1XTW(i)Y$

where W(i) is a matrix of weights specific to location (i) such that points nearer to (i) are given greater weight than points away(Goovaert s*et al*, 2008).

3.5.3 Determination of high contamination areas

Data analysis was done by applying the results of the GWR model by reclassifying independent variables maps using the 'Raster Reclass' tool of 3D analyst based on their established relationship (positive relationship, no relationship, and negative relationship). Each layer was reclassified into 4 classes with equal intervals. Weighted Overlay tool in spatial analyst was then used by applying a common measurement scale of values using the formula (slope +soil permeability+ water table depth + waste level depth + shallow well distances to the nearest pit latrine = Groundwater Contamination Vulnerability) to create an integrated analysis showing areas of possible high to low groundwater contamination risk.

3.5.4 Determination of optimal well and pit latrines sittings

Geographically weighted prediction analysis was carried out in spatial statistics tools. The model calibrated the regression equation using known dependent variable values to create a new output prediction feature class run by modeling coliform densities against their respective pit latrine-shallow well distances. The output feature was interpreted and used to show precisely how an increase or decrease in coliform density varies outward from any one location with respect to distance, direction, and the study area's slope, soil permeability, and water table depth to give the optimal safe distance for the study area.

Finally, the results of all the four objectives were presented as maps to help in easily discerning the emergent patterns in the data to adequately answer the research questions.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents the findings from the study in line with the study's objectives namely; to determine the extent of groundwater contamination, to assess the relationship between groundwater contamination and other hydro-geological factors, to map groundwater contamination risk zones, and to establish the optimal safe distance and sitting for shallow wells and pit latrines in the study area.

4.2Extent of Groundwater Contamination in Kamkuywa

To adequately respond to this objective, results are subdivided into two sections. That is, results on the separation distances between shallow wells and pit latrine and results on fecal coliform contamination.

4.2.1 Separation distances between shallow wells and pit latrines in Kamkuywa Market Center

The analysis of the existing distances between 531 shallow wells and the nearest pit latrines in Kamkuywa Market Center showed that; 63 shallow wells, which translate to 11.8% of the total population of shallow wells in the study area, were at a distance of at least 40 meters from the nearest pit latrine. Additionally, 172 (32.4%) shallow wells were located at a distance greater than 30m from the nearest pit latrines. Further, 44.8% (238) shallow wells were a distance less that 15m from pit latrines. The distribution of pit latrines and shallow wells in the study area is shown in Figure 4.1 below.

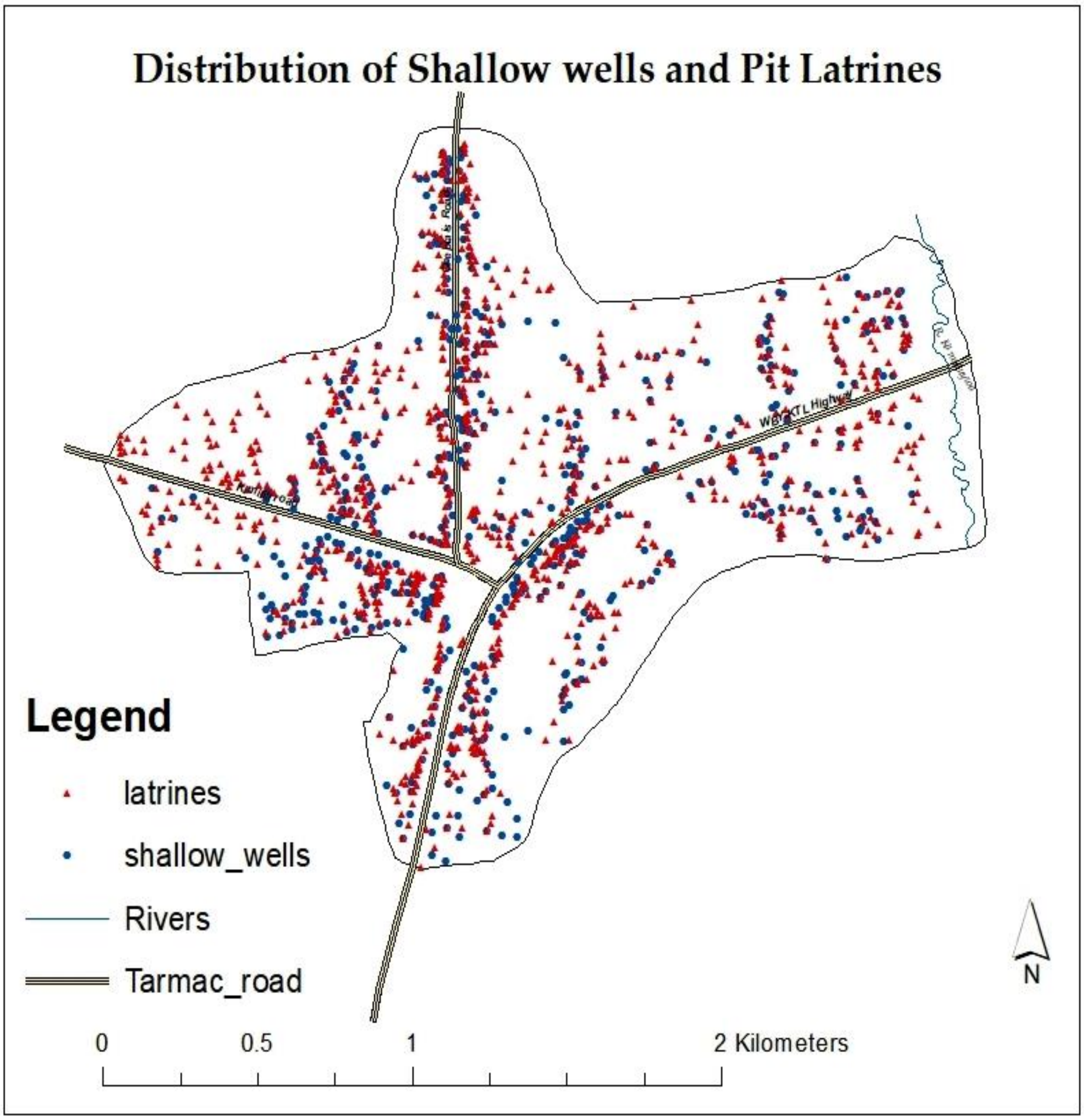

Figure 4. 1: Distribution of Shallow wells and Pit Latrines in Kamkuywa Market Center

4.2.2 Fecal Coliform Contamination

The World Health Organization requires drinking water supplies to demonstrate total absence i.e. (zero) of fecal coliform bacteria per 100ml of drinking water. The findings of the study however showed that, out of the sampled 32 shallow wells, 31 shallow wells tested positive for fecal coliforms with a coliform density range of 4-68 colonies/100ml of water. Indicator well SW18 (Protected) tested negative for fecal coliform. However, indicator well (SW 18) was located 43m away from its nearest pit latrine. Most shallow wells in the study area were protected meaning they had a lining and a concrete cover. Table 4.1 and Table 4.2 present these findings.

Table 4. 1: Fecal coliform count report

S/No	Well label	Status	No. of colonies/ 50ml	Coliform Density ([(No. of colonies)/(volume filtered)] × 100)	Well Depth (m)	Nearest PL Label	Dist. Nearest PL (m)	Depth of Nearest PL
1.	SW1	Protected	26	52	10.75	PL01	22	9.75
2.	SW2	Protected	25	50	10.75	PL02	18	9.75
3.	SW3	Protected	27	54	10.25	PL03	8	9.75
4.	SW4	Protected	33	66	11.75	PL04	10	10.25
5.	SW5	Protected	34	68	11.75	PL05	6	9.75
6.	SW6	Protected	19	38	11.75	PL06	12	10.25
7.	SW7	Protected	29	58	10.75	PL07	18	9.75
8.	SW8	Protected	20	40	11.25	PL08	14	9.72
9.	SW9	Protected	2	4	11.75	PL09	15	10.5
1(	SW10	Protected	24	48	14.25	PL010	19	12.75
11	SW11	Protected	17	34	10.75	PL011	21.5	9.25
1:	SW12	Protected	8	16	11.25	PL012	23	9.75
1:	SW13	Protected	34	68	11.75	PL013	16	9.75
1<	SW14	Protected	13	26	11.75	PL014	21	9.75
1!	SW15	Protected	30	60	10.75	PL015	20	8.75
1(	SW16	Protected	31	62	9.75	PL016	11	9.75
1;	SW17	Protected	24	48	11.75	PL017	10	9.75
1{	SW18	Protected	0	0	11.75	PL018	32	9.5
1!	SW19	Protected	13	26	11.75	PL019	13	9.75
2(	SW20	Protected	32	64	10.5	PL020	19	8.75
21	SW21	Protected	27	54	12.75	PL021	22	10.9
2:	SW22	Protected	3	6	9.75	PL022	17	8.75
2:	SW23	Protected	19	38	10.25	PL023	26	9.75
2<	SW24	Not Protected	30	60	10.25	PL024	12	9.75
2!	SW25	Protected	19	38	7.5	PL025	18	3
2(	SW26	Protected	20	40	3	PL026	14	2.1
2;	SW27	Protected	21	42	9.75	PL027	15	6.75
2{	SW28	Protected	16	32	9.5	PL028	25	8.5
2!	SW29	Not Protected	26	52	7.75	PL029	20.2	7.75
3(	SW30	Protected	11	22	8.5	PL030	12	7.25
31	SW31	Protected	9	18	2.5	PL031	27	2.1
3:	SW32	Not Protected	19	38	10.75	PL032	23	9.75

Duplicate samples for both Shallow wells (protected and unprotected) replicated the same result after analysis to confirm the results of contamination. The purpose of having duplicate samples was to confirm that the results of the first lab analysis for the 32 waters samples were accurate.

Table 4. 2: Field Duplicate Samples for Shallow wells

Indicator shallow well	No. of colonies/50ml	Coliform Density ([(No. of colonies)/(volume filtered)] × 100)
SW5(D)	34	68
SW9(D)	2	4
SW24(D)	29	58
SW30(D)	12	24

Finally, the analysis of contamination using coliform densities resulted in a continuous contamination surface map showing a 2D continous representation and distribution of fecal coliforms indicating the potential extent of groundwater contamination. Four zones of contamination interpreted per coliform densities as low (0-17), moderate (18-34), high (35-51), and very high (52-68) within the study area were defined based on the coliform densities values ranging from 0-68 as shown in Figure 4.2.This indicates that most of the study area has its groundwater contaminated.

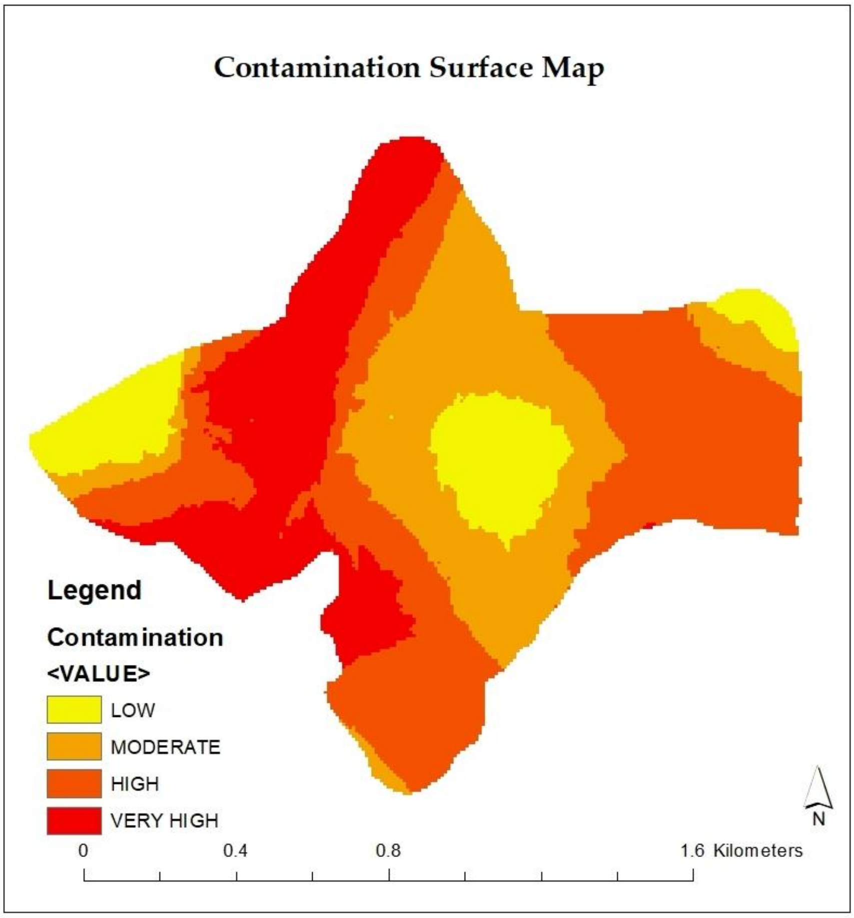

Figure 4. 2: Contamination Surface Map of Kamkuywa

4.3 Relationship between Contamination and hydro-geological factors

The second objective sought to analyze the main factors that influence groundwater contamination. Regression analysis allowed for the understanding of the factors behind observed independent variables patterns in the study and the prediction of the outcome based on these patterns using the contamination values as the dependent variable.

The OLS tool generated several outputs one of them being Figure 4.3 and a summary report that was used to validate the viability of the selected dependent and independent variable to be used for regression analysis. The residual map showed the under and over predictions of the model to be used.

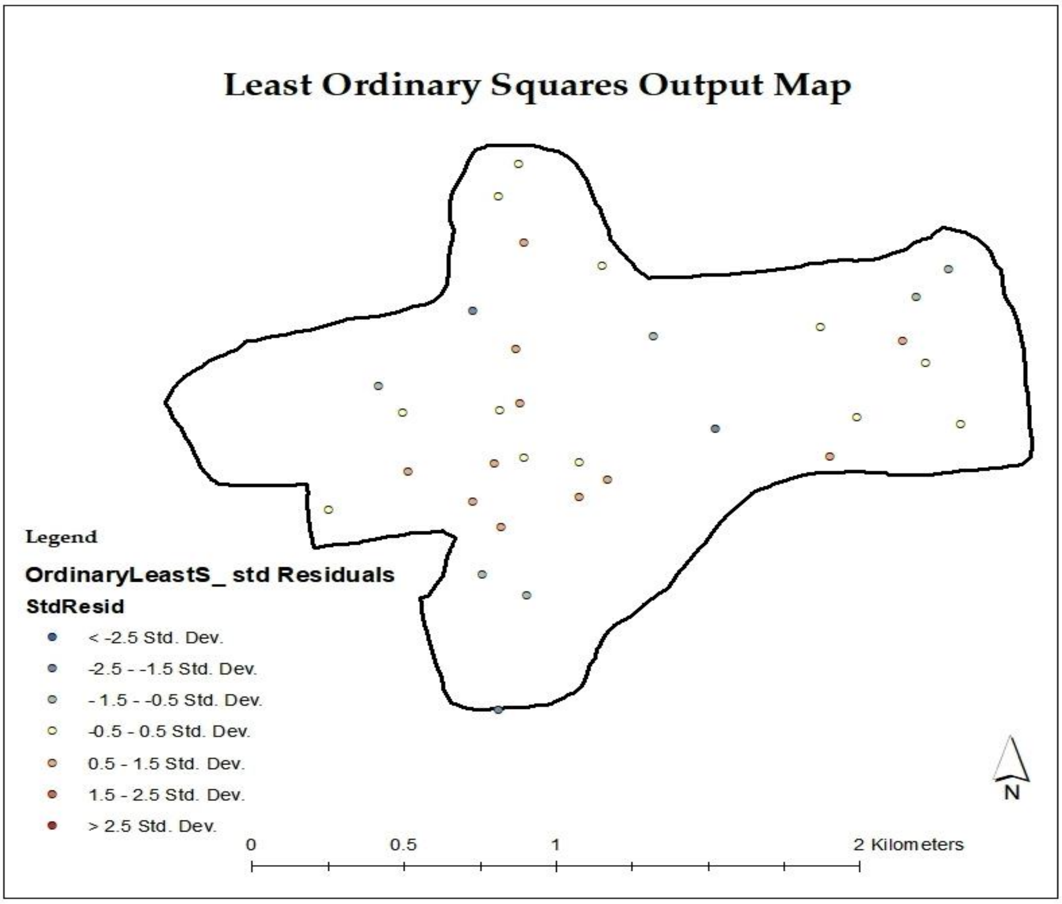

Figure 4. 3: OLS Output

The residual map (Figure 4.3) used standard deviations from the predicted values to show how far off the value was, the blue (>2.5 std. Dev) were higher than what the model had predicted, and red (<-2.5 std. Dev.) were lower than what the model had predicted. The results, however, were within the model's prediction (-2.5 - -1.5 Std. Dev. to 0.5- 1.5 Std. Dev.), hence valid in running geographically weighted analysis. The adjusted R-squared value was 0.73 after running all the independent variables and 0.31 while running each independent variable individually. The main result of the regression analysis was a summary report containing the coefficient estimates, their standard errors, and a range of diagnostic statistics shown in Table 4.3 and 4.4. Examining the coefficient distribution in the summary table of the analysis showed how much variation was present and the relationship between the variables.

Table 4. 3: Summary of GWR w Results - Model Variables

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Slope	0.000025	0.008746	3.465872	0.050085*	-0.143256	0.645983	0.523369	-2.000022
Soil Permeability	0.312915	0.002017	7.162642	0.000000*	0.003256	7.523648	0.1901849	2.000022
Water table	-0.90093	0.000325	4.305321	0.000000*	-2.100001	2.152000	0.123658	-2.000022
Waste level	0.75326	0.085053	1.568321	000000*	0.217369	0.531270	0.424169	2.000022
Distance	-0.812364	0.135689	5.782546	0.000000*	0.432845	1.685600	0.142382	2.000022

Table 4. 4: Regression Diagnostics

Input Features:	Std. Residual Map	Dependent Variable:	Contamination
Number of Observations:	531	Akaike's Information Criterion (AICc) [d]:	287.065164
Multiple R-Squared [d]:	0.023612	Adjusted R-Squared [d]:	0.043725
Joint F-Statistic [e]:	0.035065	Prob(>F), (4,29) degrees of freedom:	0.037175
Joint Wald Statistic [e]:	21.217021	Prob(>chi-squared), (2) degrees of freedom:	0.0544161
Koenker (BP) Statistic [f]:	24.823828	Prob(>chi-squared), (2) degrees of freedom:	0.041755
Jarque-Bera Statistic [g]:	2.635880	Prob(>chi-squared), (2) degrees of freedom:	0.0267686

4.4 Contamination Risk Zones

The resultant output from the weighted overlay analysis was a pollution map in figure 4.4. The map shows groundwater contamination risk in Kamkuywa Market Center based on the key factors, i.e., slope, soil permeability, and water table and waste level, and pit latrine- shallow well distance. The results showed 7.1 % and 14.3% of the study area was at low and moderate risk of groundwater contamination respectively while 73.6% of Kamkuywa market center was at a high risk of groundwater contamination and a five percent (5%) of the study area was showed to be at a very high risk of contamination.

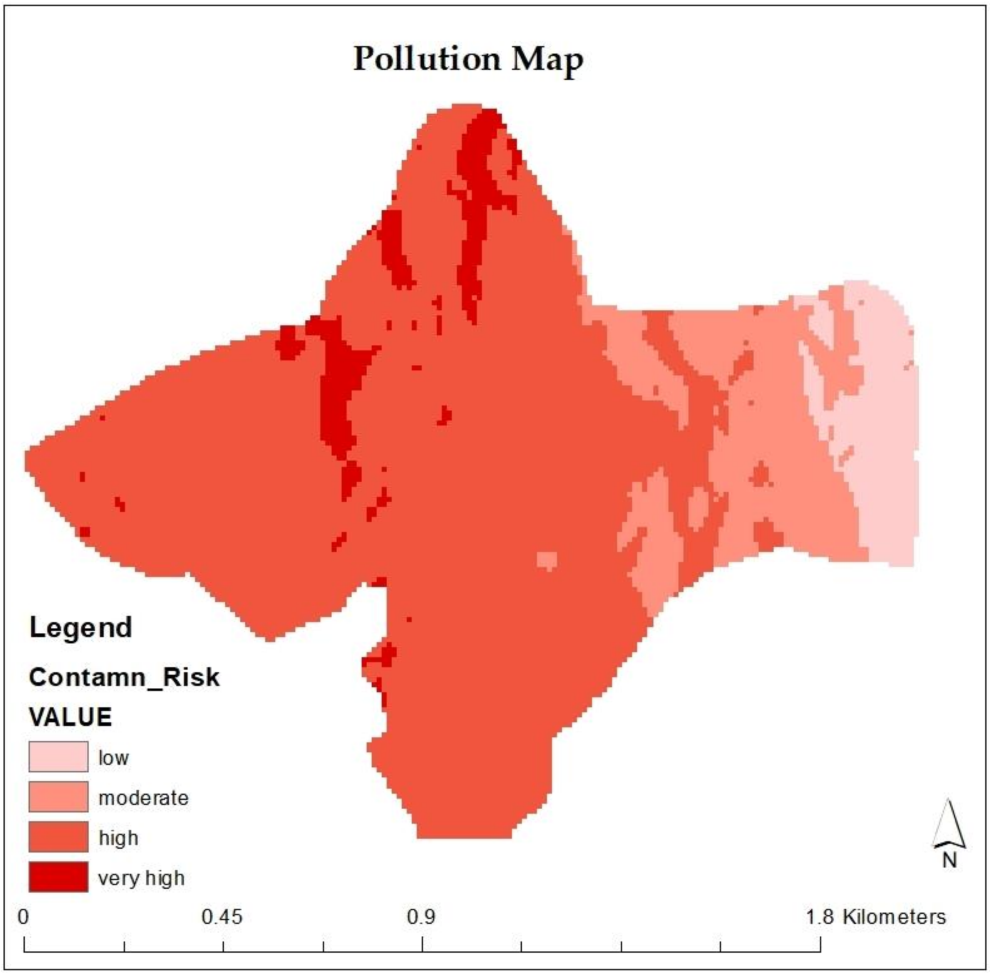

Figure 4. 4: Pollution Map

4.5 Optimal Sitting

Running of the prediction model established at what point was there no contamination. The prediction model considered the observed pattern variability of the existing hydrological factors in the study area. From the prediction model, the optimal siting (safe) distance of wells in Kamkuywa Market Center at which there was zero contamination prediction was between 31meters and 33meters, this in relation to soil permeability, topography, and water table as shown in Figure 4.5. However, this distance (31-33m) was predicted on the assumption that the waste level depth was 2m above the water table.

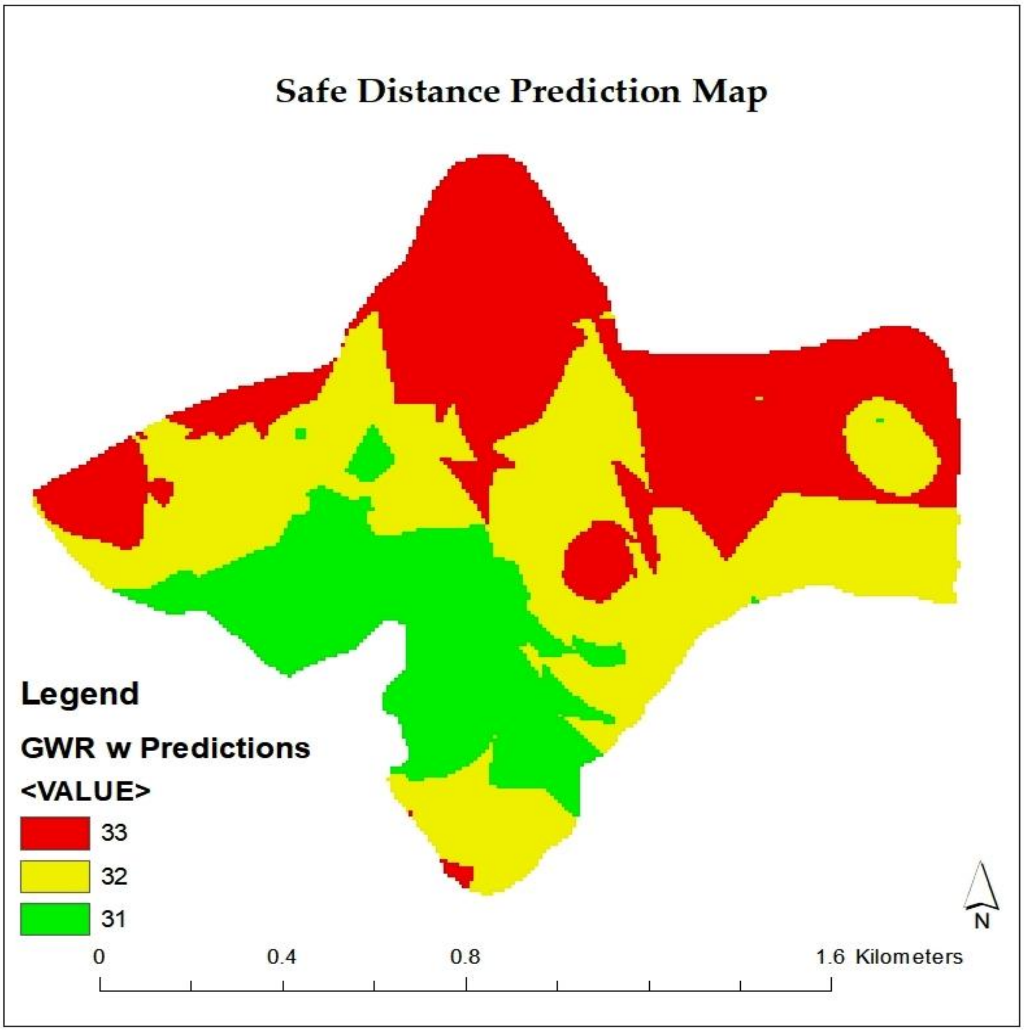

Figure 4. 5: GWR w Prediction Output

CHAPTER FIVE

DISCUSSIONS

5.1 Introduction

This chapter synthesizes and logically makes inferences of the results and findings of the study as presented in Chapter four.

5.2 Groundwater Water Contamination in Kamkuywa Market Center

Confirmed fecal contamination in 31 of the 32 sampled shallow wells in Kamkuywa indicates that groundwater is polluted with fecal bacteria. This is an indication of potential health risk for individuals using water from these shallow wells. Literature review has shown that fecal coliforms are usually non-pathogenic and not directly disease causing. However, they are contamination indicator organisms. Their presence in water has been used to indicate the presence of other pathogenic bacteria i.e. giardia and cryptosporidium.

The consequences of groundwater contamination such as; poor drinking water quality and loss of water supply are lethal to mankind. Others like water-borne diseases, high costs incurred on alternative water supply and high costs of groundwater cleanup are heavy burdens to local and national governments particularly in developing countries. Groundwater contamination often remains unnoticed for a long time because it moves relatively slowly often making the consequences of its negative impacts very serious.

The findings of the study show that two thirds (67.6%) of all the shallow wells in Kamkuywa being located at a distance of less than 30m to the nearest pit latrine indicating they were likely to be unsafe and contaminated. Additionally, forty five percent (44.8%) of the shallow wells located at a distance less than 30m from the nearest pit latrine were less than 15 meters from the nearest pit latrines. These were mainly in residential and commercial development areas and were found to have very high coliform densities as compared to the one hundred and seventy two (172) shallow wells that were at a safe distance greater than 30m from pit latrines. Twelve percent (11.8%) of all the shallow wells in Kamkuywa Market Center were located more than 40m from the nearest pit latrine. From the findings on fecal coliform contamination, these shallow wells had a coliform density of 0-4/100ml whereas sixty (60) of these shallow wells had zero coliform counts while the three that had coliform range of 2-4/100ml were unprotected shallow wells.

These findings were supported by the laboratory results for the fecal coliform count test. Shallow well SW18, the only shallow well that tested negative for fecal coliforms with zero (0) coliform density, was at a distance of 32m from the nearest pit latrine. The results of this study showed that shallow wells with high coliform densities had short pit latrine-shallow well distances.

In several other such studies on the safe distance between pit latrines and groundwater sources, varying transport distances for pathogens were established. Cadwell and Parr (1937) found the safe distance among total coliforms, anaerobe and B.Coli to be between 3meters to 25 meters depending on the degree of soil saturation and the velocity of groundwater flow. Another experimental study reported movement of coliform limited to less than 7 meters from the pit latrine in alkaline alluvium soils (Dyer, 1941). A study by Still and Nash (2002) in South Africa detected a coliform density greater than 10/100ml only one meter from the nearest pit latrine. Different countries have different recommended safe distances for pit latrines from shallow wells depending on the countries' hydro geological characteristics. Kenya has a recommended safe distance of 40mbetween a shallow well and a pit latrine. The 40m safe distance as earlier indicated does not account for in country variation in the environmental factors such as; climate, geology, hydrology, and land use. From the results, it is evident that the 40m safe distance recommendation has adversely been violated in Kamkuywa Market Center.

Further, a study on well-water contamination by pit latrine showed a high level of contamination in well water in Langas, Eldoret-Kenya (Kiprotich and Ndambuki, 2012). The study found nearby pit latrines to be the main source of groundwater contamination also noting that the state of the shallow well (protected or unprotected) was a major contributor to groundwater contamination. That study recommended for protection on wells achieved by lining the well and covering the top using concrete so as prevent contamination through surface runoff and spillage of contaminated surface run off into the shallow well. However the findings of this study show that most protected shallow wells in the study area were contaminated with fecal coliforms with some posting as high as 68 colonies/100ml of water. These findings can be attributes to the violation of safe distances in the location of these shallow wells as most of them although protected were located less than 15m from their nearest pit latrine or were surrounded by a number of pit latrines. In addition, most shallow wells were not well protected as most of them had no lining or were poorly lined but were covered with a concreate top. These allowed the movement of bacteria from the nearby pit latrines into the shallow well.

To protect groundwater from contamination, several measures have been recommended by studies conducted globally. The highly recommended measure of conservation of groundwater is the adequate protection of shallow wells, dug wells, boreholes and water springs. Studies have shown that unprotected shallow wells result in groundwater contamination largely as a result of surface runoff and leaching. Deficiencies in construction of shallow well as a result of ignorance or financial challenges allow contaminated surface runoff and any accompanying contaminants to flow and leach into the well. In Kamkuywa Market Center, 95% of shallow wells were protected yet both protected and un-protected sampled wells tested positive for fecal coliforms. Interestingly as indicated earlier, protected wells had higher coliform densities as compared to un-protected wells. This means that when it comes to groundwater contamination by pit latrine, the status of the shallow well whether protected or unprotected is a minor factor as compared to the proximity of the protected shallow well to the nearest pit latrine.

5.3 The Relationship between Groundwater Contamination and Environmental factors

The safety of groundwater in Kamkuywa Market Center is a matter of significant consequence. As earlier mentioned, it is the market's main source of domestic water. Groundwater quality can be categorized by the means of the measure of the chemical, physical, biological and aesthetic characteristics. This, however, can be affected by other factors i.e. bacteria, temperature, salinity, turbidity, and other available nutrients. Long established environmental monitoring approach has involved the measure of the main parameters mainly paying attention to physical-chemical parameters i.e. soil permeability, slope, distance, water table, and pit latrine depth. Geographically weighted regression analysis results confirmed the relationship between these factors and groundwater contamination. The Coefficient values represented the strength and type of relationship between each independent variable and the dependent variable.

5.3.1 Soil Permeability

The regression model showed a positive correlation between contamination and soil permeability rates in the study area with a coefficient value of 0.312915 indicating the higher the permeability rate, the higher the contamination level. Soil permeability influences the potential contamination of groundwater. Previous studies on this relationship have established that, a greater seepage is likely in areas with more permeable soils. The current study area had two permeability rates of 1.3kfs and 2.5kfs. Brown (2012), points out that the more permeable the soils, the faster is the movement of fecal coliform bacteria through the soil medium. His findings conform to the events in Kamkuywa Market Center. This explains why areas with a high level of contamination coincide with the soil permeability rate of 2.5kfs which is the highest in the study area.

5.3.2 Water Table

Regression analysis on the relationship between contamination and the depth of the water table showed that there is a negative relationship between the water table depth in the study area and contamination levels. The risk to groundwater contamination decreases with the increase in water table depth in Kamkuywa Market Center. In many groundwater pollution and quality assessment studies, water table depth has been found to be an important factor in understanding the groundwater availability status as well as determining the distance between the land surface and the water table, through which bacteria travel to the groundwater. The regression results on the relationship between water table depth and contamination in this study were similar to a study carried out in Ligurian Alps in Italy whose findings showed a correlation between aquifer contamination and water table concluding that the deeper the water table the less chance of contamination (Federico *et. al., 2015*).

Fluctuations in water table depth can either increase or decrease the risk of groundwater contamination. High precipitation leads to a water table raise, increased percolation and recharge of the aquifer and as a result, the safe distance between the water table and waste level is reduced and hence a higher pollution risk arises. In Areas with a shallow water table such as wetlands, pollution will occur from the surface. As water percolates it may carry with it pathogens and other contaminants to easily reach the water table.

On the other hand, a deeper water table increases the travel distance of pathogens either from the surface of the pit latrine depths and therefore reduces the risk of contamination as pathogens die off with distance.

5.3.3 Waste level Depth

From the regression analysis, it is evident that pit latrine depth affected the quality of groundwater as there was a positive coefficient of 0.075326 for waste level and therefore a positive correlation. Areas with waste levels closer to the water table are highly vulnerable to groundwater contamination.

Although pit latrines recommended depth varies from one study to the other, most studies have recommended at least 2m above the groundwater on the water table's seasonal highest level (Reed, 2010). Based on the recommendations in Banks *et al*. (2012), Franceys *et al*. (1992), Banergee (2011), and the Kenya Environmental Sanitation and Hygiene Policy (2016-2030), the 2m safe distance above the water table requirement was violated and the waste levels were too close to the water table. The depths of pit latrines increased gradually from low elevation areas to high elevation areas. It was established that the deepest pit latrines in Kamkuywa Market Center was at a depth of 37feet (11.27m) and the shallowest at 6.75 feet (2.05m).

This would then explain why high groundwater contamination was confirmed particularly in areas with a deep water table because though the water table was deep, most pit latrines in these areas were less than 2m above the water table. Additionally, in the low elevation area, the 2m requirement above groundwater was largely violated as the water table was shallow approximately 7 feet (2.1m) deep and therefore, having a pit latrine 2m above groundwater was impossible. Pit latrines in these areas were dug as deep as shallow wells.

5.3.4 Slope

The slope affects the amount of infiltration and the rate at which pathogens travel to reach the water table. Gentle slopes are more conducive to high infiltration rates than steep slopes and therefore vulnerable to groundwater contamination. The interpretation of the slope shows that most of the study area has a slope of 0° - 50° which is vulnerable to groundwater contamination. However, the results of the regression analysis on the relationship between contamination and ground slope showed that there was no correlation between slope and contamination. This can be interpreted to mean that variation in ground slope does not influence groundwater contamination in the study area. These findings were different from that of a study conducted in North Italy which established that the gradient topography of an area affected the groundwater quality. Areas with a high vertical gradient were less vulnerable to groundwater contamination (Georgios *et. al.*, 2015). This would have been the case for Kamkuywa Market Center if the source of pollution was on the surface and not pit latrines. With Pit latrines as the major source of pathogens slope as a factor does not influence groundwater contamination rather the depths of pit latrines.

5.4 Groundwater Contamination Risk Zones

Drawing from the results, the analysis carried out to determine areas of high groundwater contamination indicated that 73.6% of Kamkuywa Market Center is at high risk of groundwater contamination while 7.1% is at low risk. The high-risk zone and very high-risk zone (5%) are characterized by high population density of pit latrines and shallow wells, a soil permeability rate of 2.5, gentle slope ranging between 0-40%, very deep water table and pit latrines as well as very short safe distances between pit latrines and shallow wells. These zones are also characterized by a high population, intensive residential and commercial development as compared to the low risk and moderate risk (14.3%) zones with agriculture as the major land use and have a relatively lower population.

From the analysis, it is evident that the dense population of pit latrines in the residential and commercial areas has had an impact on the quality of groundwater due to the violation of the standard spacing guidelines. There is a long-recognized relationship between land use and groundwater pollution, although this phenomenon may take a long time to be noticed. Land use and economic activities in upcoming urban centers such as Kamkuywa Market Center with no piped water and sewage system need to be subjected to designated government regulatory control and requirement of approvals before proceeding with the construction of pit latrines and shallow wells.

5.5 Optimal Siting of Shallow wells from Pit Latrines

Geographically weighted regression prediction model (GWR w) predicted spatial variability of contamination against distance, indicating a safe distance of 31m -33m for the study area. This implies that at a distance of 31m-33m based on the variability of the specific environmental conditions of the study area; - there will be zero risk of contamination of a well from a pit latrine. This prediction was further supported by the discussions in 5.2 stemming from the results where the only shallow well that tested negative for fecal coliforms was at a safe distance of 32m, a distance that was within the model's prediction safe distance. This information is useful for the physical planning of Kamkuywa Market Center in determining the minimum specified plot size to ensure adherence to the required safe distance in protecting groundwater from contamination and also the health risks associated with it while also accommodating population growth, land-use change, and urbanization. It also contributes to the implementation of the Kenya Environmental Sanitation and Hygiene Policy 2016-2030.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the study's conclusions and recommendations with major inferences from the study highlighting the key discussion points solely based on the results.

6.2 Conclusions

Based on the results and discussion of the study, the following conclusions are drawn highlighting the key discussion points.

First, groundwater in Kamkuywa Market center is contaminated. The presence of fecal coliforms in shallow wells' water indicates contamination confirming that there is a greater risk that other pathogens may be present.

Secondly, pit latrines often promoted as safe and improved methods of sanitation are a major risk to groundwater safety especially if their density in an area is high. Therefore, the dependency on pit latrines as the main method of sanitation in Kamkuywa Market Center could result in long-term health problems unless necessary precautionary measures are taken to prevent seepage into groundwater which is the major source of domestic water.

Thirdly, reduced safe distances between pit latrines and shallow wells, and pit latrine depths and water table increase the risk of groundwater contamination. Groundwater in the study area is polluted largely due to the violation of safe distance standard guidelines.

Lastly, based on an area's environmental characteristics, pit latrine –shallow well safe distances can change or vary. Thus, 31m -33m is the minimal safe distance applicable for the Center.

6.3 Recommendations

Solely based on the results, the study recommended that domestic water from shallow wells and springs in Kamkuywa should be treated before use. Also, sensitization and awareness creation must be done for users in Kamkuywa Market Center on groundwater contamination particularly siting of pit latrines from shallow wells and springs. Besides this, deep pit latrines dug to a depth that is less than 2m above the water table should be lined to prevent pathogens from leaking into groundwater owing to the reduced safe distance to the water table. In addition, community septic systems should be adopted as a short-term measure to avoid further sinking of pit latrines in high and very high groundwater contamination risk zones in Kamkuywa Market Center. Community septic systems can reliably protect human and environmental health and avoid costly centralized sewer infrastructure development. This has been shown to work, for example in the City of Middleton, Mason County and Newton city in the United States of America. Furthermore, in the long term, an alternative source of domestic water that does not involve digging of more shallow wells in Kamkuywa Market Center is needed particularly in the areas designated as very high risk and high risk as these areas are already overwhelmed by the numbers of pit latrines and shallow wells. For domestic water, piped water or community boreholes should be explored. Lastly, there is need for the County Government of Bungoma to develop a practical water quality management plan. The Plan should employ a multidisciplinary approach in ensuring supply of safe drinking water and measures to mitigate the risk associated with the contaminated groundwater where necessary by involving urban and physical planners, health practitioners, hydrologists and geologists, sociologists, GIS experts and engineers

6.3 Proposal for Further Research

The study recommends further testing of groundwater in Kamkuywa Market Center for complex disease-causing pathogens i.e. Total Coliforms, B. Coli, Giarda, cryptosporidium among others.

The study also recommends a follow up study on the health implications of the contaminated groundwater to the residents of Kamkuywa Market Center.

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APPENDICES

Appendix I: Data collection Template for shallow wells

S.No	Well label	Location			Well Depth (m)	Well Water width (m)	Protected/Un protected	Any other observation
		Lon. (DD)	Lat. (DD)	Alt. (m)				
1.	001							
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
n.								

Appendix II: Data collection Template for pit latrines

S.No	Pit Latrine label	Location			Put Latrine Depth (m)	Years of Use	Any other observation
		Lon. (DD)	Lat. (DD)	Alt. (m)			
1.	001				7.5	7	
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
n.							

Appendix III: A Summary of Soil Characteristics of Individual Pits in Kamkuywa Market Centre

S/No	Slope	Soil color	Soil Texture	structure	Land use	Observation
1	Gently undulating	Dark reddish-brown	Loamy sandy Moderate cohesion of the material and easily breakable clods. Medium to Fine and numerous pores. Slightly Overlapping clods.	Fine to medium sub-angular blocky 'nut-like' and partially rounded structure	Agriculture	Oblique overlap indicative of free air and water movement. Loose to friable moist soils.
2	Flat to gently undulation	Dark reddish brown	Loamy sandy Moderate cohesion of the material and easily breakable clods. Medium to Fine and numerous pores. Slightly Overlapping	Fine to medium sub-angular blocky 'nut-like' and partially rounded structure	Commercial and residential	Vertical and almost straight fractures. Oblique overlap indicative of free air and water movement. Loose to firm moist soils.

			clods.			
3	Gently undulating	Dark reddish-brown	Loamy sandy Moderate cohesion of the material and easily breakable clods. Medium to Fine and numerous pores. Slightly Overlapping clods.	Fine to medium sub-angular blocky 'nut-like' and partially rounded structure	Commercial and residential	Vertical and almost straight fractures. Oblique overlap indicative of free air and water movement. Loose to firm moist soils.
4	Gently undulating	Dark reddish-brown	Loamy sandy Moderate cohesion of the material and easily breakable clods. Medium to Fine and numerous pores. Slightly Overlapping clods.	Fine to medium sub-angular blocky 'nut-like' and partially rounded structure	Commercial and residential	Vertical and almost straight fractures. Oblique overlap indicative of free air and water movement. Loose to firm moist soils.

5	Gentle-steep undulating	Dark reddish grey	Loamy Fine pores but moderately numerous	Medium to fine irregular blocky fragments Less firm blocks	Agriculture	Oblique overlap indicative of free air and water movement. Loose to friable moist soils.
6	Steeply undulating	Dark reddish-grey	Loamy Fine pores but moderately numerous	Medium to fine irregular blocky fragments Less firm blocks	Agriculture	Moderately fine-textured horizons, showing a small amount of granulation and a slight dispersion of particles. Slightly sticky wet soils.
7	Steeply undulating	Dark reddish-grey	Loamy Fine pores but moderately numerous	Medium to fine irregular blocky fragments Less firm blocks	residential	Moderately fine-textured horizons, showing a small amount of granulation and a slight dispersion

						of particles. Slightly sticky wet soils.
8	Steeply undulating	Dark reddish-grey	Loamy Fine pores but moderately numerous	Medium to fine irregular blocky fragments Less firm blocks	Commercial and residential	Angle of the block not sharp and slightly rounded. Slightly sticky wet soils.
9	Flat to gently undulating	Dark reddish-brown	Loamy sandy Moderate cohesion of the material and easily breakable clods. Medium to Fine and numerous pores. Slightly Overlapping clods.	Fine to medium sub-angular blocky 'nut-like' and partially rounded structure	Commercial and residential	Vertical and almost straight fractures. Oblique overlap indicative of free air and water movement. Loose to firm moist soils.
10	Flat to gently undulating	Dark reddish-brown	Loamy sandy Moderate cohesion of the material and easily	Fine to medium sub-angular blocky 'nut-like'	residential	Root penetration. Vertical and almost straight fractures.

			breakable clods. Medium to Fine and numerous pores. Slightly Overlapping clods.	and partially rounded structure		Oblique overlap indicative of free air and water movement. Loose to firm moist soils.

Appendix IV: Regression Analysis Interpretation

Key:

An asterisk next to a number indicates a statistically significant p-value ($p < 0.01$).

Coefficient: Represents the strength and type of relationship between each explanatory variable and the dependent variable.

Probability and Robust Probability (Robust_Pr): Asterisk (*) indicates a coefficient is statistically significant ($p < 0.01$); if the Koenker (BP) Statistic [f] is statistically significant, use the Robust Probability column (Robust_Pr) to determine coefficient significance.

Variance Inflation Factor (VIF): Large Variance Inflation Factor (VIF) values (> 7.5) indicated redundancy among explanatory variables.

R-Squared and Akaike's Information Criterion (AICc): Measures of model fit/performance.

Joint F and Wald Statistics: Asterisk (*) indicates overall model significance ($p < 0.01$); if the Koenker (BP) Statistic [f] isstatistically significant, use the Wald Statistic to determine overall model significance.

[f] Koenker (BP) Statistic: When this test is statistically significant ($p < 0.01$), the relationships modeled are not consistent (either due to non-stationarity or heteroskedasticity). You should rely on the Robust Probabilities (Robust_Pr) to determine coefficient significance and on the Wald Statistic to determine overall model significance.

Jarque-Bera Statistic: When this test is statistically significant ($p < 0.01$) model predictions are biased (the residuals are not normally distributed).

Appendix V: School of Post Graduate Studies Research Approval

University of Eldoret

P. O. Box 1125 - 30100, Eldoret, Kenya
Tel +254 53 2063257 / 2063712/13 Ext. 2838
Mob: 0725925889, Fax: +254 53 206 3257
E-mail: bpgs@uoeld.ac.ke
Website: www.uoeld.ac.ke

OFFICE OF THE DEPUTY VICE-CHANCELLOR (ASA)
BOARD OF POSTGRADUATE STUDIES
OFFICE OF THE DIRECTOR

9th March, 2020

National Commission for Science, Technology
& Innovation (NACOSTI)
Utalii House, Uhuru Highway.
P.O. Box 30623 00100
Nairobi
KENYA

Dear Sir/Madam,

RE: WECHULI, DINAH AYOMA -ADM. NO. SENV/EPM/M/018
RESEARCH PERMIT.

The above named is a student at the University of Eldoret, School of

Environmental Studies, department of Environmental Planning, Monitoring and Management, pursuing a degree leading to Master of Science in Environmental Studies (Environmental Information Systems).

Her research project is titled *'POLLUTION RISK ASSESSMENT OF GROUNDWATER AT KAMKUYWA MARKET- BUNGOMA, USING GIS'.*

This letter is to request you to issue M/s. Wechuli with a research permit to enable her proceed with the project.

Kindly accord her the required assistance.

Thank you.

0 6 MAR 2020

PROF. BEATRICE A. WERE
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

University of Eldoret is ISO 9001:2015 Certified

Appendix VI: NACOSTI Research Approval

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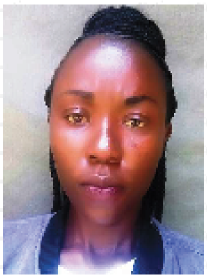

This is to Certify that Miss.. DINAH Ayoma Wechuli of University of Eldoret, has been licensed to conduct research in Bungoma on the topic: POLLUTION RISK ASSESSMENT OF GROUNDWATER AT KAMKUYWA MARKET, BUNGOMA USING GEOSPATIAL TECHNIQUES for the period ending : 15/May/2021.

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Appendix VII: Similarity Report

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