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ASSESSING THE IMPACT OF SEPTIC TANKS ON GROUNDWATER QUALITY OF SELECTED COMMUNITIES AROUND KNUST CAMPUS

BY

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ASSESSING THE IMPACT OF SEPTIC TANKS ON GROUNDWATER QUALITY OF SELECTED COMMUNITIES AROUND KNUST CAMPUS

By

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(BSc Natural Resources Management)

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MASTER OF PHILOSOPHY IN ENVIRONMENTAL RESOURCES MANAGEMENT

DECLARATION

I, Jeremiah Kasalku Takal hereby declare that this submission is my own work towards the MPhil. Environmental Resources Management and that, to the best of my knowledge it contains no material previously published by another or material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Water is an indispensable resource to mankind and life in general. Over the world, issues of water scarcity and quality are becoming pronounced with increasing global population, industrialization and urbanization. As a result, groundwater has become an important source of water supply throughout the world. The pressure on land and its resources in the study communities as they serve as residence for students, lecturers and the business community has impacted on groundwater quality. Small pieces of land acquired for building virtually does not give room for considering the siting of septic tanks and underground water. The quality of groundwater from eight boreholes/wells from Ayeduase, Boadi and Kotei in the Oforikrom Sub-Metro of the Ashanti Region were analyzed between February and July 2017. Water samples were collected from the eight boreholes/wells within the three communities and analyzed for temperature, pH, and some selected anions NO^{3-}, SO_2^{-4} and Cl^- and bacteriological parameters such as total coliform and faecal coliform. The GPS locations of other 54 boreholes and the closest septic tank were taken and the kriging interpolation was applied to extrapolate values of the measured parameters at these locations. The results from the analysis showed that pH of the water was slightly acidic (4.8 to 5.9). With the chemical parameters measured, all of them were within the WHO guidelines for drinking water, ranging from 11.7587 to 53.4723 mg/L, 0.00048 mg/l to 19.4753mg/l, and 4.22 to 40.32 mg/l for chlorides, sulfates and nitrates respectively. Both the total coliform and the faecal coliform levels were low, 0.07 CFU/100ml – 7.94 CFU/100ml for the total coliform count and 2.59 CFU/ml – 19.89 CFU/ml for the faecal coliform count. The research also measured the effect of septic tank-borehole/well distance on the variables measured. A regression analysis revealed that there was zero to weak correlation in all the parameters measured, with the "r" values as -0.02, -0.05, -0.04, 0.06, -0.09, 0.11 and -0.42 for total coliform, sulfate, pH, faecal coliform, nitrates and chlorides respectively.

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TABLE OF CONTENTS

DECLARATION ii

ABSTRACT iii

ACKNOWLEDGMENT iv

TABLE OF CONTENTS v

LIST OF TABLES viii

LIST OF FIGURES ix

LIST OF ABBREVIATIONS x

Chapter One 1

Introduction 1

1.1 Background Information 1

1.2 Problem Statement 3

1.3 Research Aim and Objectives 5

1.4 Research Questions 6

1.5 Research Hypothesis 6

1.6 Research Materials and Approach 7

1.7 Expected Outcome 10

1.8 Structure of Thesis 10

Chapter Two 12

Literature Review 12

2.1 Improving Access to Potable Water and Sanitation 12

2.2 GIS Applications in Groundwater Analysis 13
2.3 Borehole/well contamination 14
2.4 Groundwater Resources of Ghana 15
2.5 Bacteriological analysis 16
2.5.1 Total coliform bacteria 16
2.5.2 Faecal coliform 16
2.5.3 Physio-Chemical analysis 18
2.6 Septic Tanks 21
2.7 Geostatistics 22
2.7.1 Mathematical Functions for Ordinary Kriging (OK) 23
2.8 Study area 24
2.8.1 Location and size 24
2.8.2 Climate 25
2.8.3 Vegetation 26
2.8.4 Relief and Drainage 26
2.8.5 Geology, Minerals and Soil 27
2.8.6 Land-use and Land cover 28
2.9 Summary 29
Chapter Three 30
Methodology 30
3.1 Research Model 30
3.2 Sampling Sites 31
3.3 Field Measurements 32

3.4 Sample Collection 32

3.5 Determination of Physio-Chemical Parameters 32

3.5.1 Temperature 32

3.5.2 pH 33

3.5.3 Chlorides 33

3.5.4 Sulphates 34

3.5.5 Nitrate-nitrogen 34

3.6 Bacteriological Analysis 35

3.7 Geo-Statistical Analyses 36

Chapter Four 38

Results and Discussion 38

4.1 Determining the spatial location of the boreholes/wells and the distances between the boreholes/wells and the septic tanks. 38

4.2 Determining the concentration of the physio-chemical and bacteriological 44

4.3 Relationship between septic tank to well/borehole distance and the levels of 50

4.4 Integrating spatial locations of boreholes/wells and the various types of contaminants 53

4.5 Challenges and Limitation of the research 57

Chapter Five 58

Conclusions and Recommendations 58

5.1 Conclusions 58

5.2 Recommendations 59

References 61

LIST OF TABLES

Table 1.1 Overview of formulated research objectives, questions and methodologies. 9

Table 4.1 Predicted groundwater quality parameters at Ayeduase, Boadi and Kotei............ 39

Table 4.2 Cross validation results for chloride parameters.. 42

Table 4.3 Fitted parameters of the theoretical variogram model for groundwater quality parameters 43

LIST OF FIGURES

Figure 1.1 Problem Tree 5

Figure 2.1 Map of study area 25

Figure 3.1: Research Model 31

Figure 4.1 A graph showing the count of the various bacterial contaminant in the 44

well/boreholes 44

Figure 4.2 Correlation graph of distance against (a) total coliform, (b) sulphate, (c) chloride and (d) nitrate 52

Figure 4.3 Correlation graph of distance against (a) pH and (b) faecal coliform 53

Figure 4.4: Spatial distribution of a) sulphate, b) chloride 55

Figure 4.4 Spatial distribution of c) total coliform, d) faecal coliform, e) nitrate concentrations and f) temperature g) pH in the study area 56

LIST OF ABBREVIATIONS

EBK	Empirical Bayesian Kriging
EPA	Environmental Protection Agency
GIS	Geographic Information System
GPS	Global Positioning System
GPRS	Growth and Poverty Reduction Strategy
GWCL	Ghana Water Company Limited
IDW	Inverse Distance Weighting
IFH	International Forum on Home Hygiene
KMA	Kumasi Metropolitan Assembly
KML	Keyhole Markup Language
KNUST	Kwame Nkrumah University of Science and Technology
LPI	Local Polynomial Interpolation
MCL	Maximum Contaminants Level
MDG	Millennium Development Goal
NGO	Non-Governmental Organization
OK	Ordinary Kriging
pH	Power of Hydrogen
RBF	Radial Basis Function
RMSE	Root-Mean Square Error
RMSS	Root-Mean-Square Standardized
TDS	Total Dissolved Solids
US	United States
UTM	Urchin Tracking Module
WHO	World Health Organization

Chapter One

Introduction

1.1 Background Information

According to a national water sector assessment report by Binat Sarwar and Mason (2017) out of the populace in rural part of Ghana, 44% uses safe water, whiles the urban populace has a 61% access. This suggests about the rest of rural populace of 56% and 39% of the urban populace cannot access safe water. These group for the most part, rely upon groundwater as a household water source for cooking and drinking, while the wealthy homes depend chiefly on filtered water as their principal source of drinking water (Tay and Kortatsi, 2008). In Ghana, groundwater pollution by septic tank location has been overlooked in many communities with population increase. The septic tank uses a natural process to break down solids and liquids in wastewater by action bacteria, through an anaerobic process, culminating in the name "septic" (Hammond *et al*., 1905). The discharge from the septic tanks, referred to as the effluent contain very large amounts of microscopic organisms and supplements, including nitrates, chlorides and sulfates, which can possibly degrade the quality of groundwater (Hammond *et al*., 1905). According to Guo *et al.* (2016), effluent discharge and urbanization are the main causes of environmental degradation. In as much as residents in the Kumasi metropolis depend on drilled wells and boreholes for water, septic tanks also happen to be the commonest system of waste disposal in the metropolis.

As stated by Balakrishnan *et al.* (2011), groundwater has become an essential source of water supply for the present reality and it is one of most essential sustainable and broadly circulated resource of the earth. Since human welfare and health has a direct link water quality, then water quality is of concern for mankind (Remoundou and Koundouri, 2009). Several developmental activities of man such as agricultural, residential, industrial, commercial, and municipal activities can lead to the contamination of groundwater, resulting in poor quality of drinking water from groundwater sources, health problems, high cost of treatment of the water/clean-up, and high cost of using alternative sources of water (Hespanhol, (1998) ; O'Driscoll *et al.* (2010)) identified industrialization and urbanization, inorganic cations, hydrocarbons, inorganic anions O'Driscoll *et al.* (2010), pathogens, synthetic organic chemicals, and radionuclides as major sources contaminants for underground water. Water scarcity is becoming an issue especially with population increase and urbanization. Households and industries are now excessively depending on groundwater, which has an excellent microbiological and physio-chemical quality but is becoming contaminated by other anthropogenic causes, including septic tanks and sewage disposal.

Siting of septic tanks, poor design, the age of tanks, distance (too close) between the tank and groundwater sources such as wells/boreholes, etc. can increase the chances of contamination from the septic tanks to the groundwater sources (Arwenyo *et al.* 2017) The rate of population growth and urbanization in the Kumasi Metropolis of the Ashanti Region is alarming, resulting in water shortages due to the pressure of demand for water for domestic and industrial uses (Ghana Statistical Service 2014). In an attempt to mitigate the shortage in water supply from the Ghana Water company, households have now decided to use their own constructed boreholes and hand-dug wells, mostly sited within the household's perimeter. Due to the high cost of land within the city and within the study communities mainly because the communities are the hub for residence of both students and lecturers of KNUST including the business community as well, septic tanks are also cited within the same compound without due recourse to the same distance from the water source. This presents the opportunity for sewage to leak into the groundwater, resulting in contamination and also leading to some waterborne diseases.

In recent times, issues having to do with the rate at which groundwater resources are deteriorating both in quality and quantity has been pronounced (Van der Gun, 2012). Geographic Information System (GIS), has emerged as a high-performance computer-based tool which plays an important role in groundwater resource quality management and pollution study. It is also a tool for storing, analyzing, and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields. It is based on the above views that the research is conducted to measure the impact of septic tanks on groundwater quality of selected communities around KNUST Campus using GIS.

1.2 Problem Statement

Population increase over the years has led to acute water problems in many parts of Ghana, of which Kumasi is no exception. The rapid population growth around the KNUST as a result of increasing intake of students has necessitated protection and most effective use of groundwater for sustainable development. This is necessary because there has been accelerated degradation in the quality of water because of increased activities in the home and industries. For both rural and urban communities of third class countries, several tons of people do not have access to improved water (Asiedu, 2014). Potable and treated water from Ghana Water Company is usually not enough and cannot satisfy the needs of all households within the metropolis. A few privileged suburbs in the metropolis have access to this pipe-borne water (Songsore, 2009). In the peri-urban areas, most households have no access to service pipelines, let alone pipe water. As a result, affluent individuals and households have resorted to the drilling of wells and boreholes in order to have access to potable water. Individuals and household that cannot bear the cost of drilling wells or boreholes must buy water from households who have them. As a result of increased demand for land, cost of buying land, most people are constrained to build on small pieces of land, leaving barely any space to construct their septic tanks and to also drill boreholes or wells. In most cases, these boreholes and wells are cited near septic tanks, which can lead to the contamination of the water. Some effluents from the septic tank may seep into underground water, leading to water-borne diseases such as typhoid fever, cholera, diarrhea, etc., when the water is consumed. In developing nations, the occurence of diarrhea diseases linked to water usage differ greatly between communities because of varying water quality and other behavioral and Socio-economic factors (Eisenberg *et al.,* 2007). As a result of these anthropogenic influences on groundwater quality which is a major water source for many households, it is important to carry out an assessment on the level of pollution to these sources of domestic water. The results of this study are expected to serve as baseline information on groundwater quality and contamination based on some selected physio-chemical and bacteriological parameters. The spatial maps will assist decision makers and be useful in advising the government on the formulation of policy and laws in relation to regulation for private groundwater provision in the country and also advise on monitoring of groundwater quality for use in the homes and large-scale industrial use in the country.

The root causes and the effects of the problem are depicted pictorially in the problem tree in Figure 1.1.

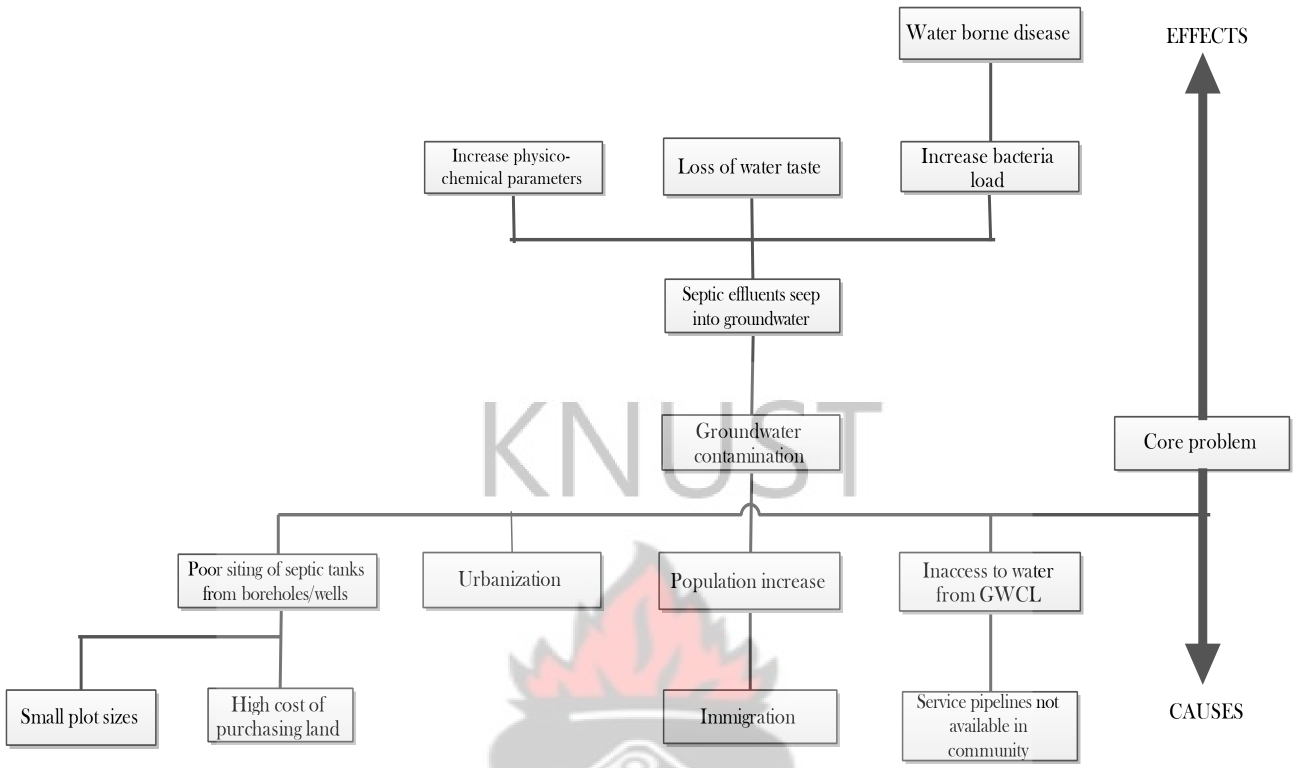


Figure 1.1 Problem Tree

1.3 Research Aim and Objectives

The aim of the research is to determine the effects of septic tanks on groundwater quality of selected communities around the KNUST campus. The specific objectives formulated to meet the above aim are:

1. To determine the spatial location of the boreholes/wells and the distances between the boreholes/wells and the septic tanks.
2. To determine the concentration of the physio-chemical and micro bacterial parameters of water samples from the boreholes/wells.

3. To determine the relationship between septic tank to well/borehole distance and the levels of contamination
4. To integrate spatial locations of boreholes/wells and the various types of contaminants

1.4 Research Questions

The study attempts to address the following questions in order to meet the above objectives:

1. What are the spatial locations of boreholes/wells in the study area and how is water quality related to its geology?
2. What are the distances between the boreholes/wells and the septic tanks, and its relationship to the chemical and bacteriological contaminants?
3. What are the concentrations of chemical and physical parameters in groundwater of the selected boreholes/wells?
4. How can GIS be used to integrate borehole/well locations and chemical/bacteriological contaminants as an aid in the understanding of the relationship between measured points?
5. What relationship exists between the water quality indicators within the study zone and that of the World Health Organization (WHO) guidelines?

1.5 Research Hypothesis

The research is based on the hypothesis below:

H_0: There is no significant impact of septic tank effluents on the quality of groundwater in the study area.

H_1: There is significant impact of the effluents of septic tanks on groundwater quality in the study area.

1.6 Research Materials and Approach

The materials used for the research are as follows:

- Handheld GPS (Garmin e trex) – for observing spatial locations
- ArcGIS software– for integrating spatial location and non-spatial information about septic tank and boreholes
- 100 m tape- for measuring well/borehole to septic tank distance.
- 1.50ml bottle- for collecting sampled water
- Ice chest – for transporting samples to the laboratory
- Thermometer- for measuring the temperature of sampled water
- pH meter – for measuring the pH of sampled water
- Camera- for taking pictures of some sampled wells/boreholes
- Chromocult Coliform Agar
- Argentometer – for detection of chlorides
- The Hach Programs using Powder Pillows-for detection of sulfates and nitrates

The approaches used in answering the research question are outlines below:

- **GPS observations**

  GPS was used to observe the spatial location of the septic tanks and boreholes in the study area. This was used to answer research question one.

- **Laboratory tests.**

The Membrane filter technique using Chromocult Coliform Agar method was used in the study to detect the presence of the various coliform bacteria in the samples collected. For the determination of chlorides in the water samples, the Argentometric method was used. SulfaVer 4 Method was used for sulfur and the Cadmium Reduction Method for nitrate. This answers research objective two.

- The 100m tape was used to measure the distances from the wells/boreholes to septic tanks and the R statistical method was used to establish any form of correlation existing between the two variables. This answers objective three.
- The ArcGIS was used to integrate the spatial locations of the wells/boreholes and to generate the spatial maps. This answers research objective four.

Table 1.1 links the formulated research objectives, questions and methodologies.

Table 1.1 Overview of formulated research objectives, questions and methodologies.

RESEARCH OBJECTIVES	RESEARCH QUESTIONS	METHODOLOGIES
1. To determine the spatial location of the boreholes/wells and the distances between the boreholes/wells and the septic tanks.	1. What are the spatial locations of boreholes/wells in the study area and how is water quality related to its geology? 2. What are the distances between the boreholes/wells and the septic tanks, and its relationship to the chemical and bacteriological contaminants?	GPS device was used to collect the spatial locations of the boreholes/wells The distances between the septic tanks and the boreholes/wells were measured using a 100m tape measure
2. To determine the concentration of the physio-chemical and bacteriological parameters of water collected from the boreholes/wells.	3. What are the concentrations of chemical and physical parameters in groundwater of the selected boreholes/wells?	Membrane filter technique using Chromocult Coliform Agar method, Argentometric method, the SulfaVer 4 Method, and the Cadmium Reduction Method
3. To determine the relationship between septic tank to well/borehole distance and the levels of contamination	4. What correlation exist between septic tank distance from the wells/boreholes and the levels of contaminants in them?	The R statistical package was used to find the correlation between the two variables
4. To integrate spatial locations of boreholes/wells and the various types of contaminants	5. How can GIS be used to integrate borehole/well locations and	Kriging interpolation

	chemical/bacteriological contaminants as an aid in the understanding of the relationship between measured points?

1.7 Expected Outcome

The following will be obtained at the end of the study:

- Maps for the study area showing the distribution and concentration of contaminants will be produced.
- The distances between septic tanks and groundwater sources will be established.
- The suitability map showing areas of groundwater for drinking purposes will be established.
- The main sources of water contamination in the research communities will be known.

1.8 Structure of Thesis

The thesis is divided into the following chapters:

- **Chapter one: Introduction**

  This covers the introduction, which exposes the problem to research, background information of the study area, prior works, justification/motivation research objectives, research questions and the expected outcomes.

- **Chapter two: Study Area and Impact of Septic Tanks on Groundwater Quality**

This chapter deals with the revision of literature in relation to the study and also looks at the existing environmental conditions and baseline data of the study area.

- **Chapter three: Methodology**

  This chapter highlights on the study communities, the approach and methods employed to undertake the research.

- **Chapter four: Results and Discussions**

  This chapter contains detail results obtained and their discussions of all the study components. This chapter is a presentation of the research findings and their interpretation in the framework of groundwater and septic tank management principles.

- **Chapter five: Conclusions and Recommendations**

  This chapter highlights the conclusions and recommendations from the results and discussions.

Chapter Two

Literature Review

2.1 Improving Access to Potable Water and Sanitation

It is the fundamental human right of every citizen to have access to portable, safe, clean water and improved sanitation. Approximately 1.8 million people die annually due to inaccessibility to safe water, sanitation and proper environmental hygiene (Fawell et *al.,* 2004). This is rather more prevalent in the developing world, with about 99.8% occurrence and 90% are children(International Forum on Home Hygiene (IFH), Nath, Bloomfield, and Jones, 2006). These deaths could have been reduced or eliminated with the provision of a portable, safe and clean water for household use. The provision of water is featured in both the new Ghana Poverty Reduction Strategy II (GPRS II) and the past one. Relevant five of GPRS II states: "Improving access to potable water and sanitation is critical to achieving favorable health outcomes, which in turn facilitate economic growth and sustained production"(Ministry of Water Resources, 2007). The United Nations Millennium Development Goals have set as their aim to reduce to half by 2015 the number of people without adequate opportunity to safe drinking water" (Hutton and Bartram, 2008). In line with the Millennium Development Goals (MDGs) on water and sanitation, several and successive governments, and non-governmental organizations (NGOs) have made frantic efforts to provide safe, clean, portable and adequate water supply to its citizen. These efforts to supply water services, where they exist are unreliable, and not sustainable because of population pressures, climate change and were difficulties in management. In recent times, close to one out of every six people in world do not have the opportunity to use improved source of drinking water and rather tend to drinking from rivers, streams, ponds or unprotected springs and hand dug wells. In a report by Hutton and Bartram, (2008) throughout the world about 2% of urban population do not have access to improved drinking water compared to 780 million (11%) of rural population. This is worse in sub-Saharan Africa where 272 million (35%) of the rural population have no access to safe water compared to 54 million (7%) of urban population.

2.2 GIS Applications in Groundwater Analysis

GIS has much application in diverse fields including Environment, Urban planning, Natural Hazard Management, Archaeology, Agriculture and Geology (Sharma *et al.*, 2017).Different statistical and geostatistical approaches are available and have been used in the past to estimate the spatial distribution of groundwater contaminants. These methods can be used to make out the spatial allocation of groundwater characteristics at points that were not sampled. Geostatistics is, therefore, a very useful tool for the study spatial allocation of groundwater contamination and quality indicators. Most of the commonly applied techniques include the Ordinary Kriging (OK) and Cokriging Methods*,* Inverse Distance Weighting (IDW), Empirical Bayes kriging (EBK), Radial Basis Function (RBF), etc.

Where the intensity of sampling is low, the use of right methods for predicting geostatistical phenomena can be employed to generate accurate spatial variability maps with. Sarangi *et al.* (2005) used geostatistics, employing the principles of kriging and co-kriging to generate the rainfall spatial variability map of St Lucia accurately, using low-intensity samples from the mountainous regions. Again, Heuvelink and Webster (2001); Jeihouni *et al.*, (2014) and Tan and Xu(2014) also showed in their work that, geostatistical interpolation techniques were better than the deterministic statistics and judicious combinations of geostatistical techniques could generate spatial variability maps with acceptable accuracy. Igboekwe and Akankpo (2011) applied the integrated land and water information system (IL- WIS 2.2) a low cost PC-based GIS software that integrates conventional GIS techniques, digital image processing and raster based spatial modeling to analyze the effects of various data layers (topographic slope, groundwater table variation, soil porosity and land use activities) on groundwater pollutants and their distribution in the Nigerian city of Uyo

Empirical Bayesian Kriging (EBK) has been found to be most appropriate for spatial estimation of Total Dissolved Solids (TSD) in drinking water (Ali *et al.,* 2011). Also, for the estimation of groundwater quality and pollution Sankar *et al.* (2016) reported that EBK model was the best of all the geostatistical models such as OK and IDW and most suitable to use. Bhunia et al., (2018) also reported that, OK was a superior method with the least RMSE and highest R2 value for interpolation of SOC spatial distribution.

2.3 Borehole/well contamination

Many factors, including rainfall, the geology of the area, land use types and depth of boreholes/wells usually affect the quantity and quality of groundwater(Meybeck *et al.*, 1996). Though it is believed that groundwater is clean and can be without pollution, in comparison with surface water. However, it is susceptible to pollution and once polluted restoration is difficult and long-term measures are needed. Traditionally, naturally occurring materials such as dissolved inorganic salts have some effects on the value of a groundwater supply. When the quantity of minerals is high, it implies that the water quality is low. The types of waste generated within local areas, methods of handling and disposing of the waste, the likelihood of an accidental or unreported spill and leaks, and the hydrogeology of intervening materials also impact greatly on the groundwater quality. Industrial activities, urbanization, wrong agricultural activities, waste disposal, including the incidence of septic tank leakages/seepages have a noticeable effect on the quality of groundwater. As land use change, an aquifer with near pristine quality at the time of development may deteriorate (Elhatip *et al.,* 2003). Majority of the microorganisms such as bacteria, viruses, parasites, and fungi that contaminate well water can be traced to the disposal of faecal matter from homes through the use of channels such as the septic tank, open defecation and other animals (Pandey *et al*., 2014).

2.4 Groundwater Resources of Ghana

Ghana is blessed with lots of water resources. Covering a total land area of 70% of the country's water landmass is the Volta river system basin, which is made up of the Oti, Daka, Pru, Sene and Afram rivers as well as the white and black Volta rivers. Again, 22% of the country is covered by the southwestern river system watershed whose composition include the Bia, Tano, Ankobra and Pra rivers. The coastal river system watershed, made up of the Ochi-Nawuka, Ochi Amissah, Ayensu, Densu and Tordzie rivers, encompasses the rest of the 8% of the country. Moreover, underlying the Volta lake basin is groundwater which is available in Mesozoic and Cenozoic sedimentary rocks and in sedimentary formations. One of the largest lakes made by man in the whole wide world is the Volta Lake with a total surface of 8,500 km^2. In all, the total actual renewable water resources are estimated to be 53.2 billion m^3 per year (Brucet *et al.*, 2013).

2.5 Bacteriological analysis

The bacteriological analysis involves the determination of the following variables:

2.5.1 Total coliform bacteria

As indicated by Tekpor *et al.* (2017) "All out coliform microbes incorporate a wide scope of aerobic and facultatively anaerobic, Gram-negative, non-spore-forming bacilli equipped for developing within the sight of generally high groupings of bile salts with the fermentation of lactose and gas waste products when incubated at 350C for 48 hours. The total coliform group of bacteria incorporates species, for example, Enterobacter, Klebsiella, Citrobacter and Escherichia". These microorganisms can ordinarily be found in the faecal excreta of individuals and animals. They have the ability to create their very own sustenance and can recreate in oceanic situations and soil conditions. The presence of Total Coliform in water does not generally show ongoing water contamination by faecal waste (Elhatip *et al.,* 2003).

The World Health Organization guidelines provide that, quality drinking water should contain a coliform count of zero (0) in each 100 ml. When there are some Total Coliform organisms each 100 ml of sample, it shows that there is some level of contamination (Gorchev and Ozolins ,2011).

2.5.2 Faecal coliform

Faecal coliforms can be found in the intestinal walls of warm-blooded animals, including human beings, which can be discharged through the faecal excreta of these organisms and when found in water, they are good indicators of contamination from humans or animal wastes. Their presence is an indication of an exposure to disease-causing organisms than total coliforms. Their presence in sewage and water in excessive amounts indicates the risk of pathogens induced illnesses in humans(Pitt *et al.,* 2014). Faecal coliforms are capable of causing diseases that include typhoid, dysentery, cholera, salmonellosis, and many more. They are also associated with disease-causing bacteria such as Salmonella spp, Vibrio cholera, Shigella spp, Yersinia enterocolitica Campylobacter jejuni, Campylobacter coli, and pathogenic *E. coli* (Odonkor and Ampofo, 2013).

McQuillan (2004) reported groundwater contamination by septic tanks with microorganisms and that feacal coliforms have been detected in some private domestic wells in areas contaminated by septic tank systems. The distance between grazing animals and domestic animals and water sources have proved to have a pivotal role in how severe faecal contamination of water sources is (Obiri-Danso *et al.*, 2002). They additionally opined that numerous analysts have announced faecal coliform tally more prominent than 104 from streams, lakes and wells in tropical nations. Work done by Nkansah (2010) in Ghana on microbial and physio-chemical nature of water from hand – dug wells in Kumasi city, discovered that the hand dug well had faecal coliform organism levels beneath the base recognition levels of 20 MPN/100ml. Also, Adekunle *et al.* (2007) indicated that there was a positive relation existing between faecal and total coliform bacteria and the distance from pollution source irrespective of the season. Adekunle *et al.* (2007), detailed an Overwhelming high coliform contamination record for hand-dug wells close to contamination sources in the wet season than in dry season and that individuals living about 3m to landfills must not utilize hand-dug wells and boreholes in their homes for household purposes because of wellbeing dangers. Olowe *et al.* (2005) likewise gave an account of the unsatisfactory quality of hand dug well water with a faecal coliform scope of 1200 - 1800 CFU/100ml in the Osogbo Metropolis, Nigeria. The

World Health Organization guidelines again stipulates a faecal coliform tally of zero (0) in each 100 ml of sample. Coliform bacteria found in 100 ml of sample demonstrate some level of faecal contamination.

2.5.3 Physio-Chemical analysis

Physio-Chemical analysis involves the determination of following variables:

Chloride

Chloride is found in the crust of the earth as a minor constituent. It is found in natural water sources in minute quantities such as rainwater, which contains less than 1 ppm in rainwater. From natural sources, industrial wastes, sewage, urban runoff, etc., chlorides often find their way into drinking water sources such as wells and boreholes (Balakrishnan *et al.,* 2011). Chloride is a chemical compound containing chlorine. They are usually formed through the reaction between metals, metal oxides or inorganic base. Though there are a few exceptions, a majority of these chloride salts can dissolve in water. In humans, there are some nutritional and health effects of these chloride salts. They include health problems such as asthma, hypertension, infertility in males, chest pain, etc. when taken in higher amounts. Chlorides are also beneficial because they are needed for the absorption of metallic minerals, the breakdown of proteins, regulation of acids, etc. Adefemi and Awokunmi (2010), recorded chloride levels of 78.10mg/L to 156.20 mg/L in water in the wells of Itaogbolu, Nigeria.

Nitrates

Nitrates are compounds that contain a nitrogen atom linked together by a triatomic oxygen. Their major source is atmospheric nitrogen, animal excreta, leguminous plants, and plant debris. Bacteria that fix Nitrogen into the soil are relevant in keeping the soil supplied with nitrates. Artificial fertilizers which contain nitrate are frequently used for agricultural production. These nitrates from the fertilizers find their way into groundwater sources, causing contamination especially in some agricultural areas (Balakrishnan *et al.,* 2011). However, according to Wakida and Lerner (2006), the major non-agricultural sources of nitrate concentrations in groundwater are related to urban development. They established that the nitrate concentrations in lands that were not cultivated was much lower as compared to their concentrations in lands being used for agriculture and construction. The most significant source of exposure by a human to nitrate is through meat, where it is used as a preservative and vegetables. Also, drinking water sources can be identified as making a significant contribution to the quantity of nitrate in man (World Health Organization, 2011). Nitrate concentration in natural water is less than 10 mg/L. When the concentration of nitrates in water is more than 100 mg/L, it leads to bitter taste and causes physiological distress. According to Manassaram *et al.* (2010), high concentrations of NO_3 can potentially cause medical conditions such as methaemoglobinaemia, particularly in pregnant women. In a study by McQuillan (2004), it is accounted for that the main source of groundwater nitrate pollution/contamination incorporate; sewage treatment plants, wastes from nitric acid, animal wastes, septic tanks, commercial fertilizers, natural geologic sources, Lightning and radiation during rain and thunderstorm activities create nitrates in the atmosphere. Balakrishnan *et al.* (2011)also reported the fundamental source of nitrate and other pollutants of urban groundwater is sewage and nitrate seep into the aquifer by sewer leakage and, on location transfer systems, for example, septic tanks. WHO guideline value in drinking water for nitrate is 50 mg/l. from the study by Balakrishnan *et al.* (2011), they found out that, about 73.68% of the wells sampled had their concentration of nitrate the nitrate concentration exceeding the MCL given in WHO guidelines.

Sulphate

The Sulphate ion is a polyatomic compound with the empirical formula SO_4^{2-}. It is made up of a central Sulphur atom and four oxygen atoms, surrounding the central Sulphur atom. Sulphate can form salts with a host of elements including calcium, potassium, barium, magnesium, and sodium. Drinking water containing high concentrations of sulphate is usually not desirable. This is as a result of the offensive taste, corrosiveness and the laxative property of the water. This ordinarily comes from the leaching of magnesium sulfate or sodium sulfate (Krenkel, 2012). The sources of sulfate into water are; draining from soils, rotting plant and animal matter which discharge sulfate into the water, the activities of man, for example, the burning of non-renewable energy sources and harsh gas handling discharge sulfur oxides to the air, some of which is changed over to sulfate. WHO guidelines values for sulfate in drinking water is 250mg/l. Nkansah (2010) reported sulfate levels of 3.0 mg/l to 37.0 mg/l in dug wells in Kumasi city which are well within recommended guidelines for sulfate levels in groundwater.

Power of Hydrogen (pH)

Power of Hydrogen (pH), is the expression of how acidic or basic a solution is; in particular, it is the negative normal logarithm of how active or concentrated hydrogen ions are; $pH = - \log[H+]$ pH is regularly observed for appraisals of aquatic biological system wellbeing, recreational waters, water irrigation system sources and releases, domesticated animals, drinking water sources, industrial discharges and stormwater runoff.

Lower values in pH are demonstrative of high acidity brought about by the testimony of corrosive shaping substances in precipitation, decay of high natural substance bringing about humic and fulvic acids, trade of carbon dioxide with the air and mineral acids. High acidic water has the tendency to corrode metal piping and containers or has a bitter or metallic taste and alkaline water results in scale formation in piping systems (Guyer, 2018). WHO optimum limits of pH levels in drinking water are between 6.5and 8.5. Nkansah (2010)and Shittu *et al.* (2008) reported pH levels of 6.3 to 7.7 in dug wells in Kumasi, Ghana and 6.8 to 7.3 in Abeokuta, Nigeria respectively.

2.6 Septic Tanks

In a related work by Yates (1985), septic tanks accounted for the greatest amount of wastewater volume generated. Yates further argued that septic tanks are the most frequently reported cause of contamination to groundwater and eventually lead to the outbreak of majority of water-related diseases. These diseases are often caused by bacteria and viruses that are found in contaminated water from septic tanks. In the U.S, places with a higher density of septic tanks have been identified and designated by the environmental protection agency as areas most likely to have groundwater contamination. As stated by Wakida and Lerner (2006) Cl- and NO3 The major indicators of sewage contamination, Cl- and NO3- are the major indicators of pollution from sewage sources including septic tanks. They again indicate that one of the main sources of nitrate is on-site disposal systems such as septic tanks.

2.7 Geostatistics

Geostatistics can be said to be the application of the theory of random functions to spatially distributed data. It is a type of statistics that is employed for the prediction and analyses values associated with spatiotemporal occurrences or spatial phenomena. Geostatistics apply an iterative three-step approach which involve: 1. Doing an exploratory analysis to suggests a model; 2. Estimate the parameters and 3. Validate the model, which may show the way to a better model (Wackernagel, 2014)

Due to the difficulty and resources involved to be able to collect adequate data on field observations, there is the need to make good use of available data to make estimation of the parameters that you need (Kitanidis, 1997)

'Kriging is the method of interpolation deriving from regionalized variable theory. It depends on expressing spatial variation of the property in terms of the variogram, and it minimizes the prediction errors which are themselves estimated' (WEBSTER, 1990)

The kriging interpolation method was chosen because, in a work done by Sankar *et al.* (2016) where Five interpolation methods; *IDW* (inverse distance weighting), *LPI* (local polynomial interpolation), *RBF* (radial basis function), *OK* (ordinary kriging) and *EBK* (Empirical Bayes kriging) were compared, he found out that, the OK was the best method with the least RMSE and highest R^2 value for interpolation of soil organic carbon spatial distribution. Curtarelli *et al.* (2015) in their work also concluded that, out of OK, IDW, LPI and RBF, OK had the lowest RMSE and higher correlation coefficient. The Ok method is also widely used in literature and one of the simple and user-friendly methods.

The R statistical package was employed to find the relation between the wells/boreholes and the septic tanks on the levels of the bacteriological and the physic-chemical parameters measured.

2.7.1 Mathematical Functions for Ordinary Kriging (OK)

Kriging is a widely used geostatistical term for predicting optimally, linear spatial processes, it is mostly used in geology, hydrology, environmental monitoring and other fields to interpolate spatial data. Kriging weights the surrounding measured values to derive a prediction for locations that were not measured. It relates the semivariogram, half the expected squared difference between paired data values $z(x)$ and $z(x+h)$ to the distance lag h, by which locations are separated.

$$\gamma(h) = \frac{1}{2}E\lfloor z(x) - z(x+h)\rfloor 2 \qquad (2.1)$$

For discrete sampling sites the function is written in the form:

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[z(x_{i)-z(x_i+h)}\right]2 \qquad (2.2)$$

Where $z(xi)$ is the value of the variable Z at a location of xi, h is the lag, and $N(h)$ is the number of pairs of sample points separated by h. For sampling that show an irregular pattern, it is uncommon for the distance between the sample sets to be actually equivalent to h. Along these lines, h is frequently represented by a distance interval. A semivariogram plot these by computing estimations of the semivariogram at various lags. These values are then typically fitted with a hypothetical model: spherical, exponential, or Gaussian. The models give data about the spatial structure just as the input parameters for the Kriging interpolation. Kriging is viewed as an ideal spatial interpolation method, which is a type of weighted moving average.

2.8 Study area

2.8.1 Location and size

This research was conducted in Ayeduase, Boadi and Kotei, found within the Kumasi Metropolitan Assembly (KMA). Kumasi is one of the most populous cities in Ghana (Ghana Statistical Service ,2014). Kumasi Metropolis is one of the several districts in Ashanti Region. It is located on Latitude: 6° 41' 18.53" N and Longitude: -1° 37' 27.95" W and hoisted 250 to 300 meters above ocean level. The Metropolis is bounded by Kwabre East and Afigya Kwabre Districts toward the north, Atwima Kwanwoma and Atwima Nwabiagya Districts toward the west, Asokore Mampong and Ejisu-Juaben Municipality toward the east and Bosomtwe District toward the south. It is around 270km north of the national capital, Accra. It has a surface territory of roughly 214.3 square kilometers which is about 0.9% of the land area in the region. Be that as it may, it inhabits about 36.2% of the area's populace.

Figure 2.1 is the map of the study area showing the study communities.

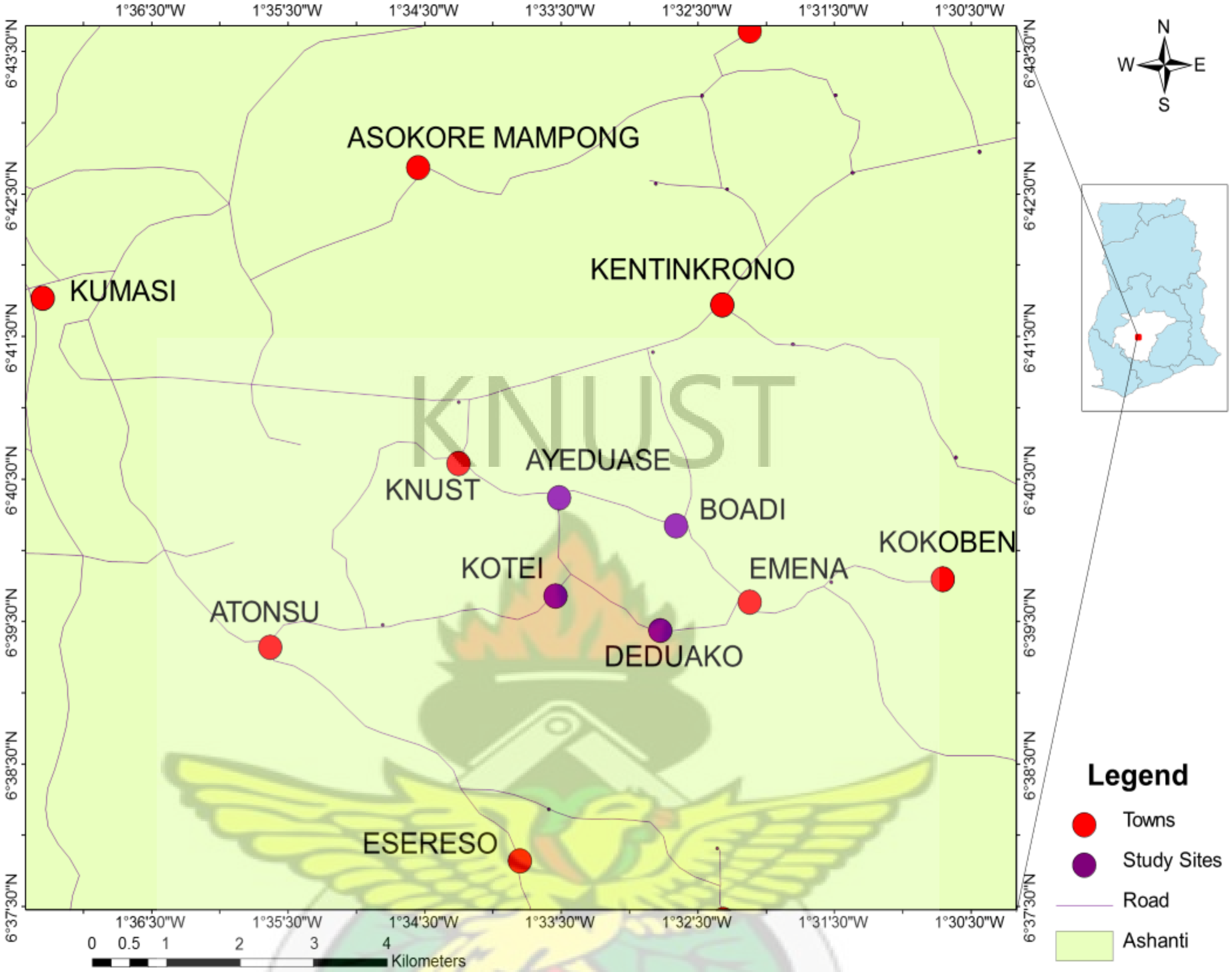


Figure 2.2 Map of study area

2.8.2 Climate

The climate type for the metropolis is within the wet sub-equatorial, specifically. Generally, the temperature within the KMA ranges from a minimum of 21.5ºC to a maximum of 30.7ºC. Humidity is generally high, averaging around 84.16% at during the day and 60% at night. The Metropolis has a double maxima rainfall pattern, the first occurring in June (about 214.3mm) and the second in September (about 165.2mm). These climatic factors have led to the migration of people into the region and the KMA, leading to the direct increase in population of the Metropolis (Greenland et al., 2016)

2.8.3 Vegetation

The Kumasi Metropolis is located in the transitional forest zone, most specifically within the ecological zone known as the moist semi deciduous South-East Ecological Zone. The most common flora found within this area are *Ceiba, Triplochlon, Celtis* and foreign and local tree types. For agriculture and crop production, the soils are fertile and rich in nutrients for these purposes (Osei, 2015).

The Metropolis is generally green, with the visible presence of many vegetative covers. This accounts for why Kumasi earned the nick name as the "Garden City of West Africa". Notwithstanding this, in recent years, lots of the vegetative cover has been destroyed to make way for construction due to population growth and urbanization. However, certain portions of the Metropolis, including areas like KNUST, Kumasi Zoological Gardens, Manhyia Gardens and Nhyiaso still have lots of trees, making the environments green and beautiful, for which efforts must be made to conserve them (Abass *et al*., 2018).

2.8.4 Relief and Drainage

The Kumasi Metropolis exists in the level of the South – West physical area which ranges from 250-300 meters above ocean level. There are rivers and streams that run through the Metropolis including Wiwi, Owabi, Nsuben, Aboabo, Subinand Sisai. The topography is undulating. These rivers and streams, especially the Owabi river, serves as the main source of drinking water for the occupants of the Metropolis and numerous different zones inside the region. Though these water bodies play a major role in the socioeconomic affairs of the residents, anthropogenic activities in and around the water bodies are a threat to the survival of these water bodies. Construction of houses by estate developers, road, industrial and agricultural activities are part of the anthropogenic activities that have polluted these rivers and streams. Floods are a common phenomenon in the Metropolis, which could partly be attributed to the above reasons (Amoateng *et al*., 2018).

2.8.5 Geology, Minerals and Soil

The Metropolis has a unique geological structure. This structure presents both a good and a bad impact on the local economy. The Metropolis has a number of construction industries due to the existence of Precambrian Rock. The bedrock material here is the Dahomeyan series, and undifferentiated granitoids, composed of the lower Birrimain rocks; gneisses, greywackes, phyllites and schists. Their deposits date back in geological times and due to pressure and heat, they have been altered and hardened. They are usually deeply weathered, with their weathered phyllites being soft and easy to break, and found about 2-3 m below the surface. Usually, during weathering, stones and gravels result from the breaking of quartz in veins and stringers. The gravels and stones reduce the ability of the subsoil to hold water and plant nutrients. The phyllites, which are clayey are generally not fertile, containing few plant nutrients and not suitable for agricultural use (Adu, 1992).

Since the geology contains veins, which are lines of rock faults, water can easily percolate through these lines. Again, the weathered materials are also said to be soft and easy to break. This could make the materials to have little resistance to percolation, infiltration and ground flow of materials.

Therefore, materials especially, nutrient materials can easily be transported over long distances as a result.

There exist in the area some artisanal mining, stone Quarrying and Sand Winning Industries. The presence of these industries has resulted in uncontrolled extraction of resources, leading to the degradation of the environment, though these have provided job opportunities for residents. The Forest Ochrosols are the main soil type in the KMA. The detailed soil associations are the following: Kumasi-Offin Compound Association; Bomso–Offin Compound Association; Nhyanao-Tinkong Association; Bomso–Suko Simple Association; Bekwai–Oda Compound Association and Bekwai–Akumadan-Oda Compound Association (Frimpong and Asante 2013). The soils are generally rich and enables urban agricultural practices in the periphery of the Metropolis. Due to rapid commercial growth and urbanization, agriculture in the Metropolis has seen a great change over the most recent two decades. The demand of inhabitants for, residential, industrial and commercial land uses has turned out to be much a need than that of agricultural land use. in the wake of this, the Town and Country Planning Department in 2013, estimated that 95 percent of the agricultural lands has been replaced by the development of houses and other physical infrastructure (Cobbinah and Amoako, 2012).

2.8.6 Land-use and Land cover

Within the study communities, the major land use type includes the "non-biotic constructed surface" and "urban settlement". It is mostly made of urban settlement and shrublands. Little agricultural activities are found in the study communities. This implies that, contamination of groundwater here cannot be attributed to agricultural sources. The land use type also implies that, most of the land area is covered by settlement. Contamination to groundwater could therefore be related to anthropogenic activities.

The major land cover in the study communities is urban settlement interspersed by shrubs. The urban nature of the settlements is an indication of high population, commercialization and industrialization. These have the potential of increasing pressure on land and water resources, increasing the quantity of domestic waste generated and therefore increasing the chances of polluting groundwater.

2.9 Summary

Groundwater is soon becoming a scarce resource as a result of the activities of man that are impacting negatively on the quality and quantity of groundwater. Several studies have been done on related groundwater quality parameters including physio-chemical contaminants such as chlorides, fluorides, sulphates, nitrates, sodium, etc. and bacteriological parameters including *E. coli,* salmonella, faecal coliforms, total coliforms, etc. these pollutants in many situations are linked to sources such as effluents from septic tanks.

Innovations in GIS have been discovered to be useful for the study of groundwater pollution/contamination, the distribution/spread of the contaminants and mapping out of areas with water not suitable for human consumption and domestic use. Since the EBK model has been found to be the most efficient method for the estimation of groundwater quality and pollution, this model will be used for the interpolation and overlay analysis. The model has also been found to give the smallest root mean square error. This makes it suitable for this study.

Chapter Three

Methodology

3.1 Research Model

The generic conceptual model adopted for the research is depicted in Figure 3.1 in this model, both spatial and non-spatial data were collected. The non-spatial data included the water samples that were collected for laboratory analysis for physio-chemical and bacteriological parameters. For the spatial data, the geographic locations of the sampled wells and other unsampled wells/boreholes were taken with the aid of a GPS device. These locations saved as waypoints were imported into the ArcGIS using the UTM projections and zone 30, and then converted to point features. This spatial data was then linked with the non-spatial data and kriging interpolation method was used to generate spatial maps.

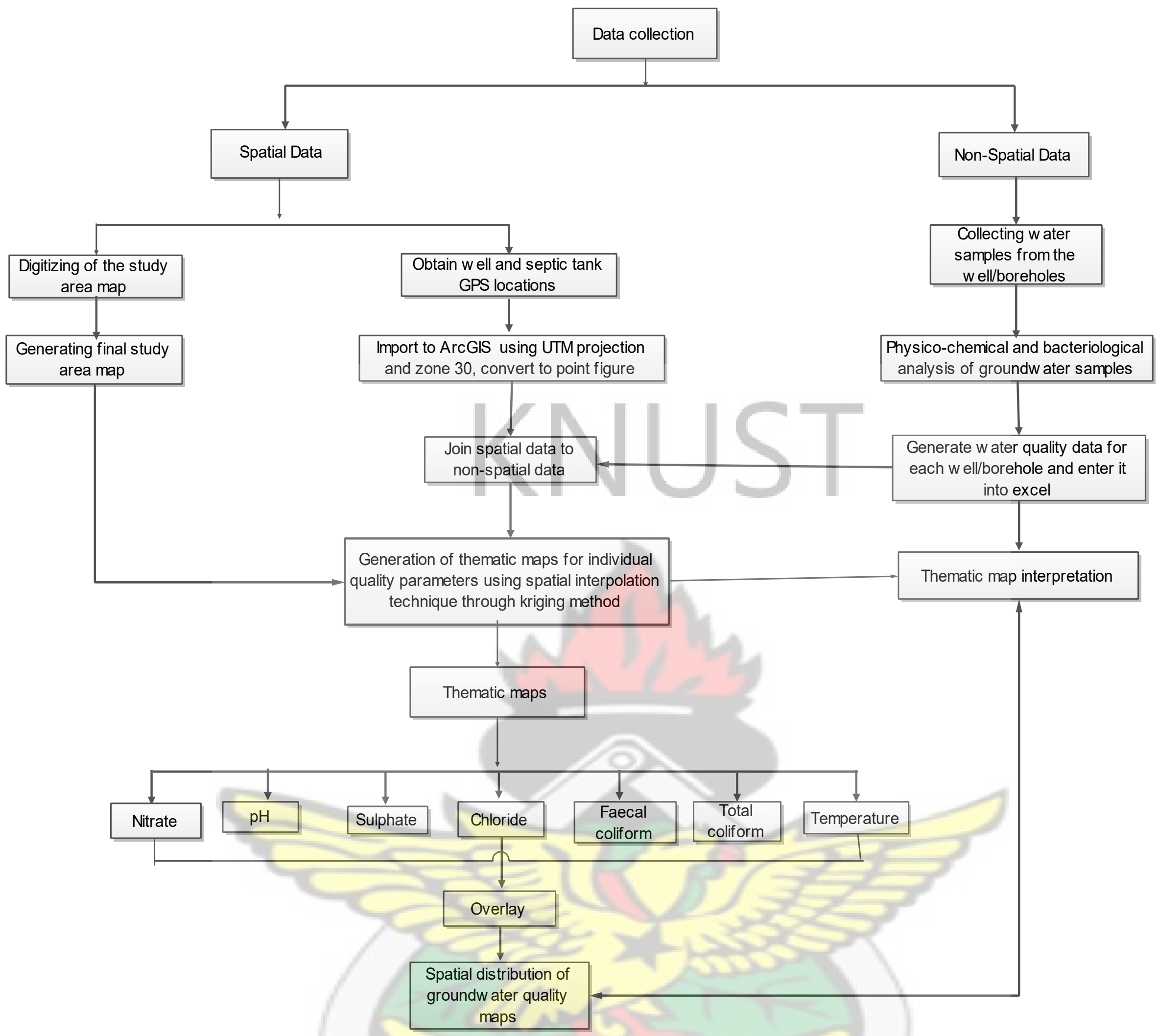


Figure 3.1: Research Model

3.2 Sampling Sites

The sampling communities in Kumasi were blocked into three suburbs; Ayeduase, New Site and Kotei. Within these communities, eight boreholes/wells with reference to septic tanks were purposively selected and sampled, and the distances between the boreholes and septic tanks measured. For the control experiment, one well in Ayeduase which has no reference to a septic tank was used.

3.3 Field Measurements

The distances between the boreholes/wells and the nearest septic tank were measured using a 100 m tape measure and the distances measured recorded. The geographical locations of the boreholes/wells and the septic tanks were determined with the aid of a handheld GPS device, using the UTM zone 30N and the point collected as waypoints and finally converted to the KML format. Inspection of the selected boreholes/wells, their sanitation state, the septic tanks, and their immediate environs was done visually.

3.4 Sample Collection

The sampling of the water was done on 15th February 2017. Plastic water bottles with the 1.50 l volume were used to collect the water samples. Bottled mineral water was bought, and the bottles were emptied at the sampling site, the bottle rinsed with the water to be sampled, and then sampling begun. The bottles were filled to the brim with the sample water and tightly closed and kept in an ice chest with ice packs. Then the samples were then transferred to the water quality laboratory for examination. The sampling was done in the early hours of the day (between 5:00 am and 8:00 am).

3.5 Determination of Physio-Chemical Parameters

3.5.1 Temperature

In-situ measurement and recording of the temperature of the water sampled was done immediately the water samples were drawn from the borehole/well with the use of a digital thermometer. The thermometer was inserted into all the samples to know their various temperatures and recorded.

3.5.2 pH

A pH meter which consists of the electrode was used to determine the pH of the water samples. The pH meter was first calibrated. pH Mode was selected and the temperature control knob set to 25°C. The cal 2 knob was adjusted to read 100%.

The electrode was rinsed with deionized water and blot dry using a piece of tissue. The electrode was placed in the solution of pH 7 buffer, allowed to stabilize and, then the display was set to read 7 by adjusting cal 1. The electrode was removed from the buffer, rinsed with deionized water and blot dry using a piece of tissue. On the field, the meter was always rinsed with deionized water and dried with tissue before use. The water was then sampled into the bottle, allowed to stabilize and the temperature of the water measured using a thermometer. The pH meter was then adjusted to match the temperature of the water. The probe of the pH meter was completely immersed into the sampled water and the meter allowed to reach equilibrium, then the reading was taken.

3.5.3 Chlorides

The Argentometric method was used to determine the presence of chloride as stipulated. With this method, 1.0mL K_2CrO_4 indicator solution was added to 20mL of the sampled water. Titration of the solution was done with standard $AgNO_3$ titrant to a pinkish yellow endpoint. This technique was repeated for an equivalent volume of refined water, representing the blank. The concentration of chloride was computed using the equation below:

$$\text{mg Cl}^-/\text{L} = \frac{(A - B) \times N \times 35.45}{\text{mL sample}} \quad (3.1)$$

where: A = mL titration for sample, B = mL titration for blank, and N = normality of $AgNO_3$ (0.0141M)

3.5.4 Sulphates

For Sulphate test, SulfaVer 4 Method using Powder Pillows was employed. Precipitation of cloud of barium sulphate is formed as Sulphate ions in the sample were reacted with barium in the SulfaVer 4. Turbidity is formed, whose amount is directly proportional to the concentration of sulphate. The SulfaVer 4 also contains a stabilizing agent, which has the capacity to suspend the precipitate.

The Program 680 Sulfate was chosen from the Hach Programs and used for the detection of Sulfate presence. A neat, round sample cell was loaded up with a known sample volume diluted to 10mL and the content of one SulfaVer 4 Reagent Powder Pillow added to it. The sample cell was whirled to blend the content and the clock icon pressed to start a five-minute response period. Another sample cell was loaded up with 10mL refined water (the blank) and set in the cell holder of the spectrophotometer after thoroughly wiping it. The 'Zero' button was pressed and a 0.00 mg/L SO_4^{2-} concentration was shown. After the five-minute response period, the prepared sample was likewise set in the cell holder after wiping the sample cell and the 'Read' button was pressed. The concentration of sulfate was shown in mg/L SO_4^{2-}.

3.5.5 Nitrate-nitrogen

The Cadmium Reduction Method was utilized for the Nitrate-Nitrogen test. Cadmium metal converts nitrates in the example to nitrite. The nitrite ions respond in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to shape a golden hued solution.

The concentration of Nitrate-nitrogen was controlled by choosing Program 353 N, Nitrate MR from the Hach Programs. A spotless, round sample cell was loaded up with a known sample volume diluted to 10mL and the content of one NitraVer 5 Nitrate Reagent Powder Pillow added to it. The sample cell shook energetically to blend the substance and the clock icon pressed to start a one-minute response period. The clock symbol is squeezed again after the one-minute response for a five-minute response period to start. Another sample cell was loaded up with 10mL refined water (the blank) and put in the cell holder of the spectrophotometer after completely wiping it. The 'Zero' button was pressed and a 0.00 mg/L NO_3^- concentration was shown. After the five-minute response period, the readied sample was likewise set in the cell holder after wiping the sample cell and the 'Read' catch was pressed. The concentration of Nitrate-nitrogen was shown in mg/L NO_3^-.

3.6 Bacteriological Analysis

Faecal coliforms and total coliforms analysis were performed for the bacteriological analysis. The membrane filter technique utilizing Chromocult Coliform Agar was used. To decide the presence or absence of coliform organisms, salmonella and *E. coli* in the water (Pal, 2014). With this technique, the water sample was passed through the membrane layer. This holds the microbes on the layer. Filtration was then done and the film which contain the bacterial cells is set on the media for incubation at a temperature of 36 ± 1°C for 24 ± 1 h. At the point when colonies that are Salmon to red in shading show up, they are recorded as coliforms, while dull blue to violet once are recorded as E. coli. Colonies that are additionally green to turquoise are considered salmonella.

Total coliforms are recorded when Salmon to red, dim blue to violet and turquoise provinces are seen.

With this technique, 1 mL of the water sample was added to 99 mL of dilution water. Three sequential dilutions with a 99 mL dilution of dilution water and 1 mL of the subsequent solution were performed and the final solution was separated through a sterile micro pore filter by suction, in this manner trapping any coliforms. The Chromocult Coliform Agar was put in a Petri dish and the membranes set aseptically and rolled onto the Chromocult Coliform Agar with the assistance of sterile forceps. The dish was turned upside down, shut and incubated at the temperature of 35°C for 24 hours. After incubation was done, the quantity of Salmon to red colonies observed was recorded as coliforms by visual examination, the dull blue to violet colonies were recorded as *E. coli* and the aggregate of these two colonies was recorded as total coliforms.

3.7 Geo-Statistical Analyses

In view of the location data that was gotten, point features were prepared to show the position of the boreholes/well. These points were added and shape files were created. The non-spatial database was composed of the water quality information obtained from the laboratory analysis of water samples. This data was stored in Excel format and connected with the spatial information by join option in ArcMap. The spatial and the nonspatial database generated was integrated for the generation of spatial distribution maps of the water quality parameters.

The data obtained was transformed to remove outliers and skewness using mainly the logarithmic technique. From the toolbar of the geostatistical analyst, the wizard button was clicked and kriging was selected. The dataset and attribute field were selected and ordinary kriging chosen. The specification of the semivariogram models was done, and the results was thoroughly examined on the cross-validation dialog box, the finish button was clicked to produce the kriged reports. Again, to be satisfied that the data had a normal distribution and that, the data did not have outliers, exploratory data analysis was done, using the logarithmic technique. The Voronoi map technique was employed to identify outliers in the data set. Out of a number of different parameters associated with the Voronoi map, the entropy parameter reflected the possibility of local outliers. Cross-validation statistics was used to validate the selected model of best semivariogram. The best semivariogram model obtained for the measured locations were used to predict the values for 62 locations using the geo-referenced points over the study area. Kriged maps were generated using the measured locations and the predicted locations.

Chapter Four

Results and Discussion

4.1 Determining the spatial location of the boreholes/wells and the distances between the boreholes/wells and the septic tanks.

Within the study area, a total of eight water samples were taken. The geographical locations of these 8 wells/boreholes and 54 other wells/boreholes within the study area were taken, and the kriging interpolation used to predict values for those boreholes. Table4.1. show the predicted values obtained through kriging. To be sure whether the data followed normal distribution patterns or not, the Voronoi maps, normal QQPlots and histograms were studied for all the quality indicators measured. All the parameters measured (chloride, sulphate, nitrate, faecal coliform, pH, temperature and total coliforms) did not show any normal distribution. This can be attributed to the fact that, the number of boreholes/wells sampled were lesser. For all these parameters, a log transformation was applied to make the distribution closer to normal. Normal distribution or close to normal distribution provides a more accurate prediction of unsampled locations. For each water quality parameter, an analysis trend was made and it was determined that there is no universal trend for all parameters. In this study, circular, spherical, tetra-spherical, Penta-spherical, exponential, Gaussian, rational quadratic, hole effect, K-Bessel, J-Bessel, and stable models, which are semivariogram models were tested for each parameter data set. The results are presented in the table 4.2. Cross-validation was used to examine the accuracy of prediction performance. The table 4.3 below is the cross-validation results for the chloride parameter. Table 4.1 presents the predicted bacteriological and physio-chemical parameters for the study area.

Table 4.1 Predicted groundwater quality parameters at Ayeduase, Boadi and Kotei.

Well	Latitude	Longitude	Distance	Chloride	Sulfate	Nitrate	Temperature	Feacal coliform	Total coliform	pH
1	**6.6598650**	**-1.5600850**	**12.0**	**40.7781**	**13.7935**	**32.4264**	**27.2297**	**0.675533**	**8.65598**	**5.09406**
2	**6.6599464**	**-1.5607316**	**39.1**	**21.7777**	**5.25372**	**20.4183**	**26.502**	**0.299826**	**4.67549**	**5.20645**
3	**6.6601000**	**-1.5588450**	**29.1**	**12.4786**	**1.10154**	**14.6864**	**26.1136**	**0.0719873**	**2.59331**	**5.25744**
4	**6.6602080**	**-1.5614966**	**21.5**	**18.6342**	**3.80831**	**18.2748**	**26.412**	**0.269621**	**4.12551**	**5.22832**
5	**6.6609883**	**-1.5586033**	**32.5**	**27.5995**	**7.57347**	**22.6332**	**27.0171**	**0.746661**	**6.9832**	**5.20521**
6	**6.6611400**	**-1.5633267**	**11.9**	**28.6216**	**8.16873**	**23.9306**	**26.9252**	**0.617701**	**6.70987**	**5.18388**
7	**6.6613584**	**-1.5622016**	**38.9**	**43.5919**	**14.8395**	**32.9937**	**27.5684**	**0.988966**	**10.1082**	**5.10106**
8	**6.6624265**	**-1.5591000**	**21.2**	**42.5401**	**14.3981**	**32.5233**	**27.4921**	**0.927535**	**9.75045**	**5.10392**
9	6.6624317	-1.5590934	36.4	53.4723	19.4753	40.3159	27.7377	0.943794	11.3845	5.02058
10	6.6629715	-1.5602500	32.9	36.2112	11.2402	26.5003	27.6925	1.39785	10.26	5.18281
11	6.6630000	-1.5603317	8.8	37.827	11.9712	27.5599	27.7084	1.31801	10.3361	5.16652
12	6.6630080	-1.5602233	28.1	13.3291	1.00711	14.9398	27.5033	7.94336	19.8933	5.86788
13	6.6631550	-1.5612717	40.5	15.6169	2.99166	10.5243	28.0001	1.99839	9.01395	4.79807
14	6.6636020	-1.5610816	13.3	15.8581	2.95611	10.6163	28.0008	1.99079	9.06934	4.83132
15	6.6657186	-1.5586300	31.1	17.0336	2.79317	10.9216	28.0031	1.95575	9.30282	4.9986
16	6.6657434	-1.5571867	46.3	17.5726	2.65503	10.9152	28.011	1.93219	9.39214	5.08546
17	6.6671750	-1.5603650	5.7	18.1679	2.36104	10.9386	28.0471	1.88365	9.49479	5.17374
18	6.6673784	-1.5603700	38.1	17.9565	2.44065	11.0208	28.0412	1.89121	9.47799	5.13056
19	6.6681633	-1.5615367	18.3	18.8129	2.10676	11.1311	28.0829	1.8327	9.62181	5.2493
20	6.6681880	-1.5610033	38.2	21.4927	1.30043	13.6693	28.2093	1.53642	10.7329	5.34866
21	6.6684230	-1.5608883	10.2	23.8419	0.57952	16.4571	28.315	1.23129	12.0218	5.36418
22	6.6685250	-1.5620084	37.6	25.4449	0.0386011	18.3746	28.3943	1.01462	12.9384	5.36979
23	6.6690370	-1.5582334	20.5	14.8821	1.20985	5.92359	27.8474	1.97732	10.2458	5.34138
24	6.6692900	-1.5600200	40.0	14.6698	1.28848	5.95138	27.8035	1.97066	10.4502	5.30975
25	6.6693500	-1.5621034	42.2	14.4468	1.38293	6.00731	27.7574	1.96599	10.6765	5.27328
26	6.6693516	-1.5630800	23.4	18.8041	2.79446	10.047	27.8714	1.87316	9.9337	5.32867

Note: The first eight were the sampled boreholes and wells.

Cont. of Table 4.1

Well	Latitude	Longitude	Distance	Chloride	Sulfate	Nitrate	Temperature	Feacal coliform	Total coliform	pH
27	6.6693650	-1.5571667	18.5	19.7243	3.17452	11.0713	27.8817	1.85899	9.84851	5.32353
28	6.6693935	-1.5623567	45.0	20.8236	3.7215	12.628	27.8888	1.86831	9.77674	5.29661
29	6.6694070	-1.5594300	46.1	22.1446	4.36142	13.7806	27.8576	1.82194	9.82582	5.29623
30	6.6694784	-1.5572700	26.2	22.1901	4.46549	14.2823	27.8572	1.87629	9.84206	5.28141
31	6.6695150	-1.5630534	35.2	21.9211	4.32817	14.0029	27.8638	1.87839	9.82757	5.28195
32	6.6695200	-1.5630584	35.1	18.1978	2.58353	10.7901	27.9999	1.92124	9.48899	5.19902
33	6.6697550	-1.5616133	22.3	16.883	2.84868	10.9291	27.998	1.96668	9.27756	4.97566
34	6.6697650	-1.5581500	26.6	16.9176	2.80859	10.9025	28.0031	1.95898	9.28202	4.9814
35	6.6698050	-1.5632400	41.7	17.8876	2.47548	10.9343	28.0341	1.90184	9.4508	5.13066
36	6.6698300	-1.5632850	19.8	17.9339	2.45077	10.9924	28.0391	1.89451	9.46887	5.13057
37	6.6700616	-1.5630417	11.4	18.231	2.34551	11.2487	28.0567	1.86214	9.57097	5.14575
38	6.6703715	-1.5634717	23.0	19.1206	2.04176	11.6034	28.0971	1.7919	9.78622	5.24017
39	6.6704550	-1.5625267	7.1	18.7496	2.12938	11.0983	28.0794	1.83823	9.60639	5.24362
40	6.6705000	-1.5634533	9.0	20.5098	1.56971	12.4802	28.1688	1.66023	10.2099	5.34297
41	6.6705600	-1.5628583	18.3	20.2885	1.56151	11.8392	28.1723	1.70451	9.94726	5.38335
42	6.6706100	-1.5623217	38.1	21.5237	1.28941	13.6908	28.211	1.53323	10.7434	5.35059
43	6.6707134	-1.5454900	13.4	23.1822	0.805617	15.8143	28.281	1.31152	11.7111	5.34548
44	6.6707134	-1.5454900	9.6	23.8738	0.569316	16.4967	28.3164	1.22697	12.0404	5.36417
45	6.6708136	-1.5625184	22.5	25.5487	0.000476	18.4985	28.3999	1.00018	12.9993	5.36999
46	6.6708965	-1.5635200	28.9	24.7352	0.300872	17.6134	28.3547	1.10894	12.5606	5.36011
47	6.6710434	-1.5633733	28.4	22.2537	1.16929	15.2033	28.2243	1.41636	11.3673	5.29646
48	6.6710600	-1.5454184	35.9	19.3665	2.07265	12.8462	28.0936	1.72632	10.1994	5.16056
49	6.6713514	-1.5631300	37.4	19.9477	1.37252	9.67326	28.2643	1.85231	8.73698	5.56993
50	6.6713550	-1.5634217	18.8	53.2558	19.3775	40.1775	27.7297	0.939929	11.3404	5.02191
51	6.6716866	-1.5615367	14.4	24.3255	5.4202	15.3231	27.7997	1.68121	9.88482	5.29022
52	6.6719832	-1.5614166	44.5	19.1206	3.02072	10.2893	27.8395	1.84506	10.0083	5.32143
53	6.6725500	-1.5615750	31.3	18.8657	2.91212	10.0057	27.8347	1.84518	10.0157	5.32397
54	6.6725770	-1.5615484	23.0	14.5495	1.41957	6.08952	27.7576	1.96191	10.6605	5.27529
55	6.6727033	-1.5586833	34.9	13.6274	1.10379	5.18704	27.7422	1.98871	10.7828	5.26884

Cont. of Table 4.1

Well	Latitude	Longitude	Distance	Chloride	Sulfate	Nitrate	Temperature	Feacal coliform	Total coliform	pH
56	6.6734567	-1.5634100	35.4	14.6708	1.28691	5.9495	27.804	1.97078	10.4479	5.31014
57	6.6735435	-1.5634950	4.2	17.0138	1.11336	6.68875	28.104	1.98613	8.98046	5.52398
58	6.6735682	-1.5587850	26.9	11.7587	1.01955	4.22003	27.5645	1.99788	11.6773	5.14495
59	6.6736035	-1.5585966	46.7	20.8429	1.03383	8.1833	28.5409	1.9954	6.7989	5.83571
60	6.6736884	-1.5577300	25.8	17.1931	1.32207	7.29911	28.0665	1.96191	9.20915	5.47775
61	6.6737165	-1.5580000	19.2	18.4464	1.45076	8.37475	28.1585	1.9319	8.85735	5.5165
62	6.6598650	-1.5600850	34.3	25.4473	0.037565	18.3778	28.3944	1.01425	12.9401	5.36975

Table 4.2 indicates that when different models are applied to different parameters, they may give better results. For water quality parameters, RMSS ranged from 0.68 to 1.01.

Table 4.2 Cross validation results for chloride parameters

Models	**Prediction errors**				
	Mean	**Root-Mean-Square**	**Mean Standardized**	**Root-Mean-Square Standardized**	**Average Standard Error**
Tetraspherical	0.2641	19.432	0.073	0.88	19.67
Spherical	0.2730	19.223	0.0256	0.69	19.901
Exponential	0.2884	19.128	0.027	0.85	19.663
Circular	0.263	19.446	0.022	0.76	19.651
Gaussian	**0.258**	**19.686**	**0.012**	**1.01**	**19.534**
Hole Effect	0.2661	19.532	0.016	0.88	19.587
J-Bessel	0.261	19.498	0.024	0.75	19.810
Stable	0.2731	19.232	0.027	0.76	20.00
K-Bessel	0.266	19.433	0.0221	0.81	19.831
Rational Quadratic	0.3244	18.847	0.030	0.84	19.900
Pentaspherical	0.2883	19.187	0.0276	0.68	19.782

Table 4.3 shows the most suitable models for predicting each of the water quality indicators measured in this study. This was as a result of applying different models to predict each water quality parameters that were examined in this study. The best model results were determined after cross validation was used to calculate the errors.

Table 4.3 Fitted parameters of the theoretical variogram model for groundwater quality parameters

Parameter	*Model*	**Mean**	**Root-Mean-Square**	**Mean Standardized**	**Root-Mean-Square Standardized**	**Average Standard Error**
Temperature	Rational Quadratic	0.02	0.861	0.01	1.006	0.845
Nitrate	**Hole effect**	**0.154**	**15.181**	**0.011**	**1.002**	**15.197**
Sulphate	Circular	0.176	8.892	0.0186	1.009	8.834
Chloride	Gaussian	0.258	19.686	0.012	1.01	19.534
Faecal coliform	Circular	0.0110	3.199	0.012	1.228	2.328
Total coliform	Stable	0.06	7.443	0.008	1.191	6.08
pH	Stable	-0.01	0.477	-0.019	0.996	0.479

For the chloride parameter the model that was best fit is the Gaussian model having a standardized mean error of 0.012. This happens to be the closest to zero, with a root-mean square standardized value of 1.01, which is closest to 1. From the results of the cross validation, when the average estimated prediction standard errors are close to the root-mean-square prediction errors, then there is confidence that the prediction standard errors are appropriate (Johnston, Ver Hoef, Krivoruchko, and Lucas, 2001). For the chloride sample, the root-mean-square prediction errors were closest to average estimated prediction standard errors of 19.686 and 19.534 respectively in the Gaussian model. This result proves that the Gaussian model is the best one.

4.2 Determining the concentration of the physio-chemical and bacteriological parameters of water samples from the boreholes/wells.

Figure 4.1 shows the graphical illustration of the occurrences of the various bacterial contaminants found in each of the wells/boreholes. Total coliform counts were generally and relatively higher in all the well/boreholes. It was highest in open well one and least in closed well two. Generally, the contaminants were higher in the open well sampled and lower in the closed wells and boreholes.

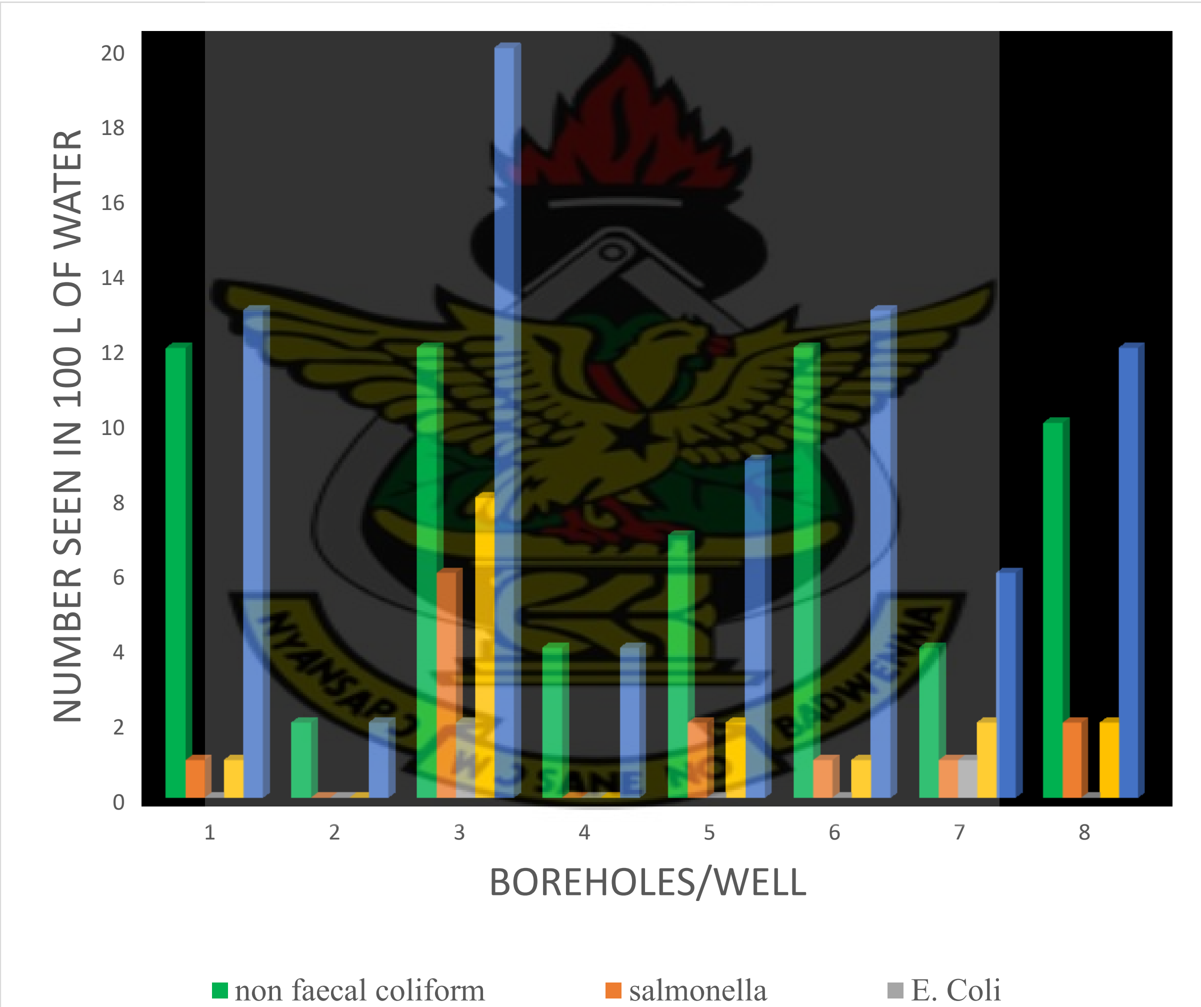


Figure 4.1 A graph showing the count of the various bacterial contaminant in the well/boreholes

Chloride

Chlorides in nature, occur in different concentrations in water. In freshwater bodies, chlorides occur in low concentrations. However, with an increase in the mineral content of the water, chloride content also increases (Ayuba *et al.,* 2017). Some anthropogenic sources of chlorides include sewage discharge, agricultural activity, effluents from landfill sites, etc. In natural water bodies, the occurrence of chloride ion is in fairly lower amounts, usually lower than 100 mg/L, unless in marine water bodies.

The chloride concentration of groundwater within the study area as shown in table 4.1 ranged from 11.7587 to53.4723 mg/L. These figures fall within the acceptable World Health Organization's (WHO) International Standards for Drinking-water, which suggest that concentration of chloride greater than 600 mg/liter would noticeably hamper upon the wholesomeness of the water (WHO, 2007). Also, concentrations of about 250 mg/liter in water, can lead to a detection of a change in the taste of the water. Also, concentrations above 150 mg/L are toxic to crops and generally unsuitable for irrigation. For industrial use, water containing more than 350 mg/L chloride concentration is not suitable. It implies therefore that concentrations of less than 250 mg/liter of chloride in water are safe for all kinds of use, especially domestic usage. When a water source is close to marine water, the chloride content of such a water source can be altered. A high content of chloride in water leads to a salty taste of the water.

Nitrate

Nitrate pollution in groundwater is a global issue and is especially related to the use of nitrate fertilizers for agricultural production. Agricultural activities account for a majority of groundwater contamination by nitrates. Nitrate is a common contaminant in groundwater due to its mobility in water. However, in the urban areas, septic tanks and other non-agricultural sources could also contribute to localized contamination of groundwater by nitrates. Contamination of groundwater by nitrate is a universal problem. Nitrate concentrations above 45 mg/1 in drinking water have been found to be detrimental to the health of infants under the age of one year, leading to the condition known as methaemoglobinaemia. WHO International Standards for Drinking-water recommends nitrates levels of less than 45 mg/l in water (WHO, 2007). Nitrate concentrations in the study area ranged from 4.22 mg/l to 40.32 mg/l as shown in the kriged results in table 4.1 and were within the WHO and GWC prescribed acceptable limit of 50.0 mg/l. The well 9, with the highest nitrogen content, is an open well, with cracks on its walls in a low-lying area. The high nitrogen content there could be attributed to this factor because runoffs with agricultural waste could easily find its way into the well.

Nitrogen may exist as nitrates and nitrites. In smaller concentration, nitrogen like any other nutrient is harmless but become harmful increase in their concentrations

Sulfate

Sulfates in nature principally emanate from releases from chemical industries and naturally in many minerals. Groundwater sulfates could also come from natural sources. In humans, sulfates are taken in mostly through food and water. The current data don't distinguish a dimension of sulfate in drinking water that is probably going to cause unfavorable human wellbeing impacts. In any case, there is a discernible change in the taste of the water that contains sulfate levels of more than 500 mg/liter. At these levels, it may also lead to the corrosion of water pipelines and other distribution channels. 1958 WHO International Standards for Drinking-water suggest that the taste and portability of the water will be hampered when sulfate concentrations exceed 400 mg/liter (WHO, 2003). However, from table 4.1, within the study area, sulfate concentrations were found to be very low, with predicted values ranging from as low as 0.00048 mg/l to maximum values of 19.4753mg/l. these are way below the WHO standards and will be no threat to domestic consumption, agricultural or industrial use.

The impact of sulfate depends generally on the weight of a organisms - the lesser the organism, the more severe the impact. Increased sulfate levels can lead to a lack in trace minerals which can add to a depressed development rate and infertility in a herd. The most impacting is the lack of thiamine. The major physiological impact resulting from the intake of large amounts of sulfate leads to catharsis, dehydration, and gastrointestinal irritation. Water containing magnesium sulfate at levels over 600 mg/l serves as a laxative in people.

Temperature

The temperature of the well/borehole water in the study area ranged from 26.1 to 28.5ºC, as shown in Table 4.1. The water temperature is generally low in the sampled well/borehole. This could be due to the fact that sampling was done very early in the morning during the hours of 5:00 am to 8:00 am. For domestic use, the water temperature is usually not a major problem of concern to water users especially in relation to the quality of the water. No guidelines exist for the acceptable temperature limits for drinking water. Therefore, using temperature as an indicator of quality of the water is usually the discretion of the individual in terms of their taste and preference.

pH

The International guidelines for Drinking-water quality by the WHO have set the pH of between 6.5 and 9.2 as the permissible levels in water.

In all the borehole where sampling and prediction were done, the pH values were found to fall below the WHO accepted standards, as shown in the table 4.1 above, with the values ranging from as low as 4.79807 to 5.86788, all within the acidic medium. Though the pH levels here do not pose any threat to consumers, it is an indication of some sort of contamination of the water within the study area.

Water with a pH of less than 6.5 or greater than 9.2 is classified as not being portable. On health grounds, no baseline value has been proposed for pH. The facts remain that, pH usually has no direct impact on consumers, it remains one of the most valuable operational water quality parameters (World Health Organisation, 2007). In humans, pH tolerance is higher, with drinkable levels ranging from 4-11 with minimal gastrointestinal irritation. This notwithstanding, there is still the cause for concern. pH levels below 4 and above 11 have been found to cause irritations to the eyes and skin of animals, including man. At extremely low pH, irreversible damages can occur to the skin (Bhusal, 2017). Some studies in the study area has attributed the low levels of pH to the oxidation of sulfide minerals in the aquifer rocks.

Faecal Coliform

Faecal coliform is the sum total of the presence of salmonella and *E. coli***.** According to the WHO guidelines, *E. coli* or coliform bacteria that are tolerant to heat must not be found present in 100-ml water sampled which is intended directly for drinking, or any water entering the system for distribution. In Ayeduase and Kotei, faecal coliforms were found in the samples taken from the boreholes. Though not at high levels, the presence is still a concern to the quality of the water. The faecal coliform levels ranged from 0.07 CFU/100ml – 7.94 CFU/100ml. The coliform bacteria are usually found in the soil, in the intestines of animals, and man and also in water bodies. Faecal coliforms are usually present in large numbers in faecal matter and in mammals, including man. They usually find their way into water bodies from faecal waste disposal systems such as poorly functioning septic tanks, and other waste disposal systems. Waste from animals also releases significant amounts of coliforms. Animals such as cats and dogs in the urban areas contribute to faecal coliforms in surface water. Sediment loads during runoff can also carry these bacteria and deposit them in water bodies. Higher temperatures, high nutrient contents could all contribute to high faecal coliform organisms. In the study area, the low levels of faecal coliforms in the water samples could be attributed to the relatively low temperatures, few/no animals kept in the households, little runoff and sediment loads, due to the clustered nature of settlement in the area. The US Environmental Protection Agency, for instance, requires all drinking water systems to monitor faecal coliforms not to exceed 5%of the samples in each month. For drinking water, there should be no faecal coliform found in the water. For other domestic and other uses such as for swimming, the faecal coliform levels must not be more than 200 faecal coliforms per 100ml.

Total Coliform

Total coliforms can be referred to as a group of related harmless bacteria to man except a few of them that may be harmful. Though mostly not harmful to man, total coliform is an indication of the presence of disease-causing organisms. The US. EPA also requires zero total coliforms in drinking water because researchers found out that low amount of total coliforms caused water-borne diseases. In the study area, examination of the sampled water revealed some amounts of total coliform in the water. This ranged from as low as 2.59 CFU/ml – 19.89 CFU/ml. checks at the KNUST Hospital has revealed a considerable number of typhoid and diarrhea (water-borne diseases) in the KNUST fringe communities, recording as high as 860 cases of typhoid in 2011, 704 cases in 2013, 683 cases in 2014, 653 cases in 2015 and 402 cases in 2016. Also, for diarrhea, the incidence ranged from 302 in 2010, 301 in 2011, 266 in 2012, 295 in 2013, 297 in 2014, 219 in 2015 and 195 in 2016. This in a way can be attributed to the presence of total coliforms in the drinking water source in these communities.

4.3 Relationship between septic tank to well/borehole distance and the levels of contamination

The effects of distance on the levels of contamination was examined using the R statistical package. Figures 4.2 and 4.3 outline the interrelationship existing between the physio-chemical and bacteriological contaminants that were found present in the well/boreholes in connection with their distance from septic tanks. In Figure 4.2(a), the regression analysis shows no significant statistical relation exists between the two variables, having a coefficient of 0.02 (Callaghan, 1996). This demonstrates that, as the ell/borehole to septic tank distance increases, there is no significant correlational change in the levels of total coliform counts. This implies distance has no consequences on the level's total coliform in the wells/boreholes. Figure 4.2(b) speaks to relation existing between distance from the septic tanks to the wells/boreholes and the quantity of sulfate detected in the sampled wells/boreholes. In spite of the fact that the correlation appears to be positive and having a R estimation of 0.05, the relationship between the two variables is extremely weak/immaterial since it is near zero. In the Fig. 14.2(c), there exist a very poor/no correlation between the septic tank to well/borehole distance and the chloride levels in the sample, having an R coefficient of 0.09. This means that, the distance between the well/boreholes and the septic tanks did not have a significant effect on the relative abundance of chloride in the wells/boreholes. Figure 4.2(d) is a Correlation graph of distance against the concentration nitrate in the groundwater sources. For these variables too, it showed a very weak/no correlation between the measured variables. As distance to the septic tank increases, there is no correspondent increase in the nitrate levels in the wells/boreholes. In Fig. 4.3(a), which is a graph showing the relation between distance from the water sources and pH in the samples. There was no significant correlation between the variables of interest, with R as 0.05. Finally, Figure 4.3(b) presents the relationship between the septic tank distance and faecal coliform count in the water samples. The results show no correlation between the two variables as well.

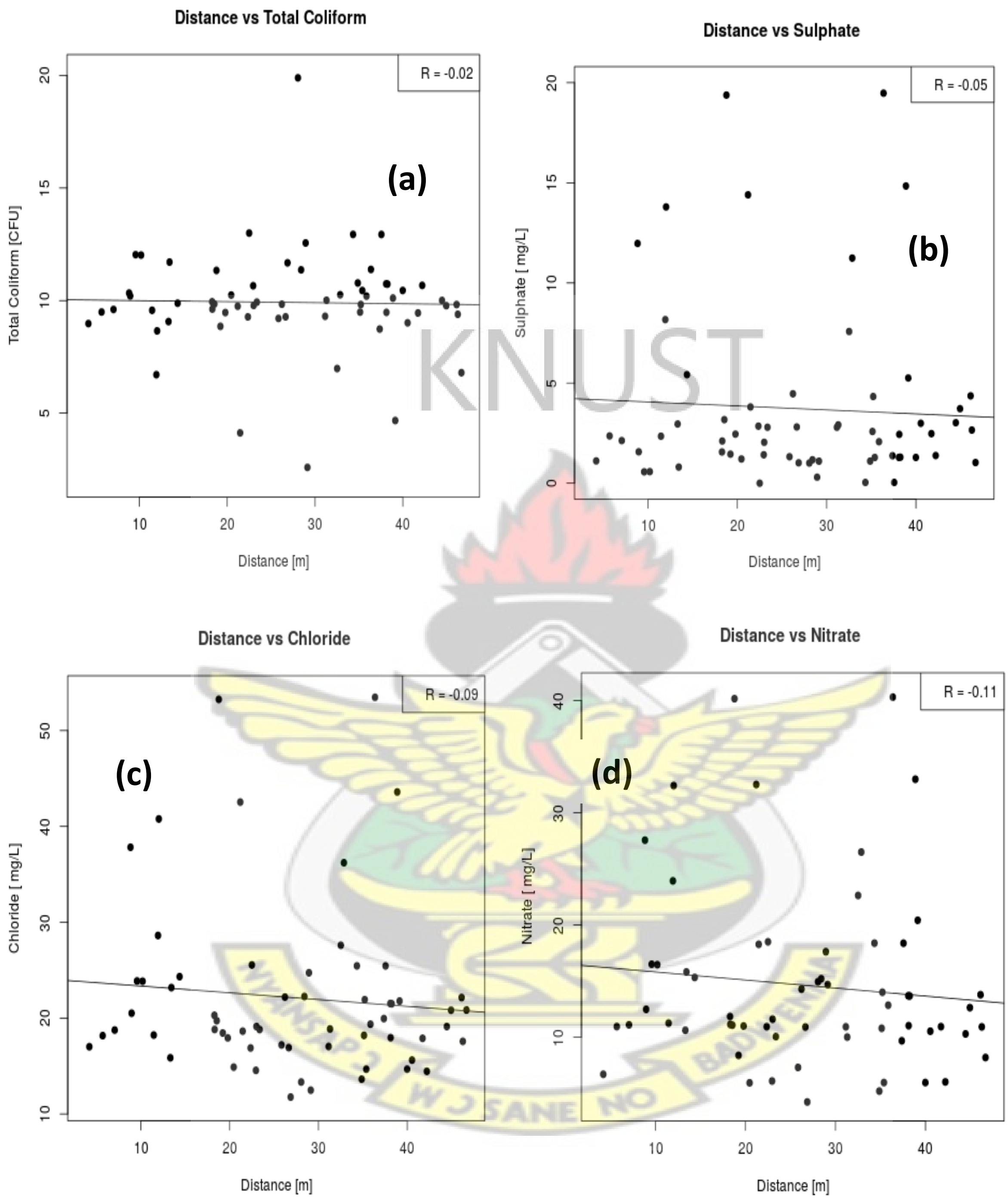


Figure 4.2 Correlation graph of distance against (a) total coliform, (b) sulphate, (c) chloride and (d) nitrate

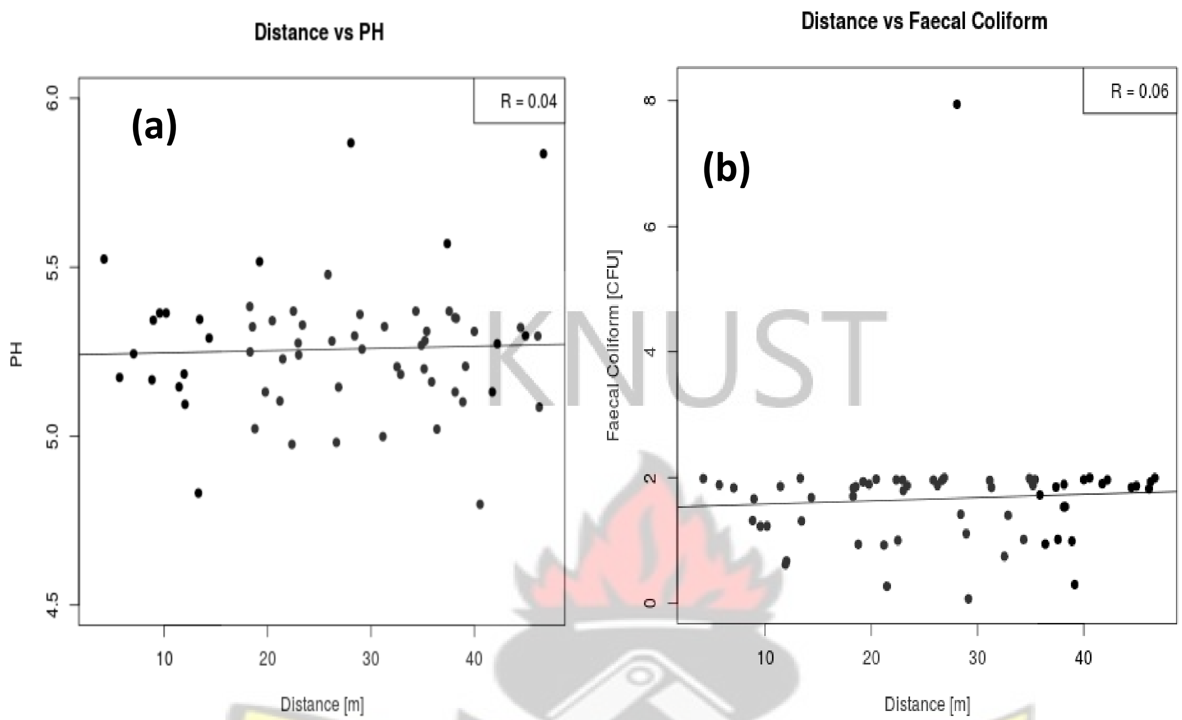


Figure 4.3 Correlation graph of distance against (a) pH and (b) faecal coliform

4.4 Integrating spatial locations of boreholes/wells and the various types of contaminants

The spatial locations of the wells/boreholes and the various groundwater contaminants were integrated in the ArcGIS environment and the spatial maps shown in figures 4.4 were generated. For sulfate distribution within the study area as shown in figure 4.4 (a), the relative higher concentration was found within the South-western part of the area whiles the lower concentrations were within the North-western area. A greater percentage coverage of the study area had average concentration of sulfates.

For the spread of chlorides, the highest concentrations were found to the west of the study area, with the lowest concentration found to the south-western part of the area. A larger proportion of the area especially to the East of the study area had generally low concentrations of the chlorides. The figure 4.4 (b) shows the spread of chloride in the area.

For total coliform count, the figure 4.4(c) shows that the South-western part of the study communities recorded the highest count of the coliforms, while the North-western part recorded the lowest count. Figure 4.4(d) shows that, faecal coliform counts were higher within a small area to the south of the study communities. The rest of the areas generally had low counts of faecal coliforms. For nitrates as seen in figure 4.4(e), the South-western part also recorded the highest concentration, with a portion on the North-western side as well. Generally, through the middle and the eastern side of the zone had lower concentrations. For temperature, the figure 4.4(f) shows a lower temperature across the study area, except the zones that the sampling was a little bit late in the day, that had relatively high temperatures. Also, for pH, the concentrations were generally low across the study communities with few portions to the West recording relatively higher pH levels.

In general, all the parameters were relatively higher to the south-western part of the study communities. This can be attributable to the concentration of student population in the south-western part of the communities, leading to the generation of more septic and other forms of waste that can find their way into groundwater resources.

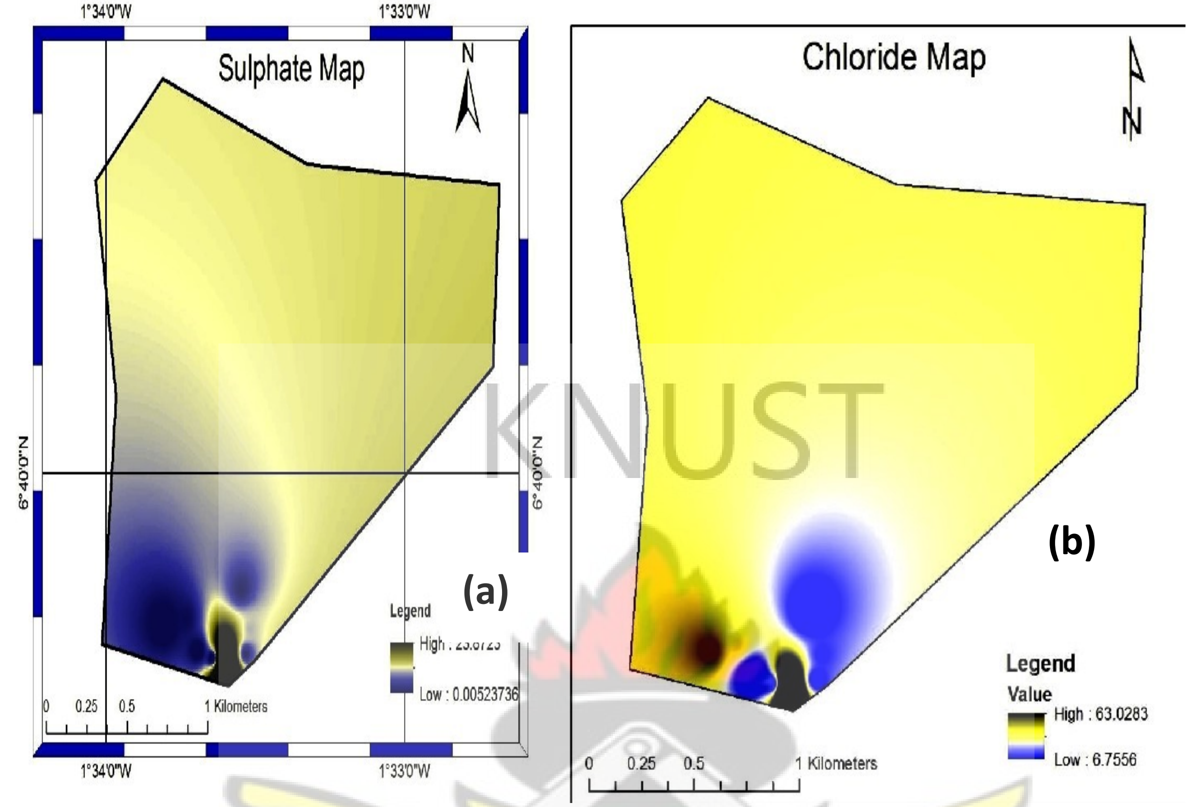
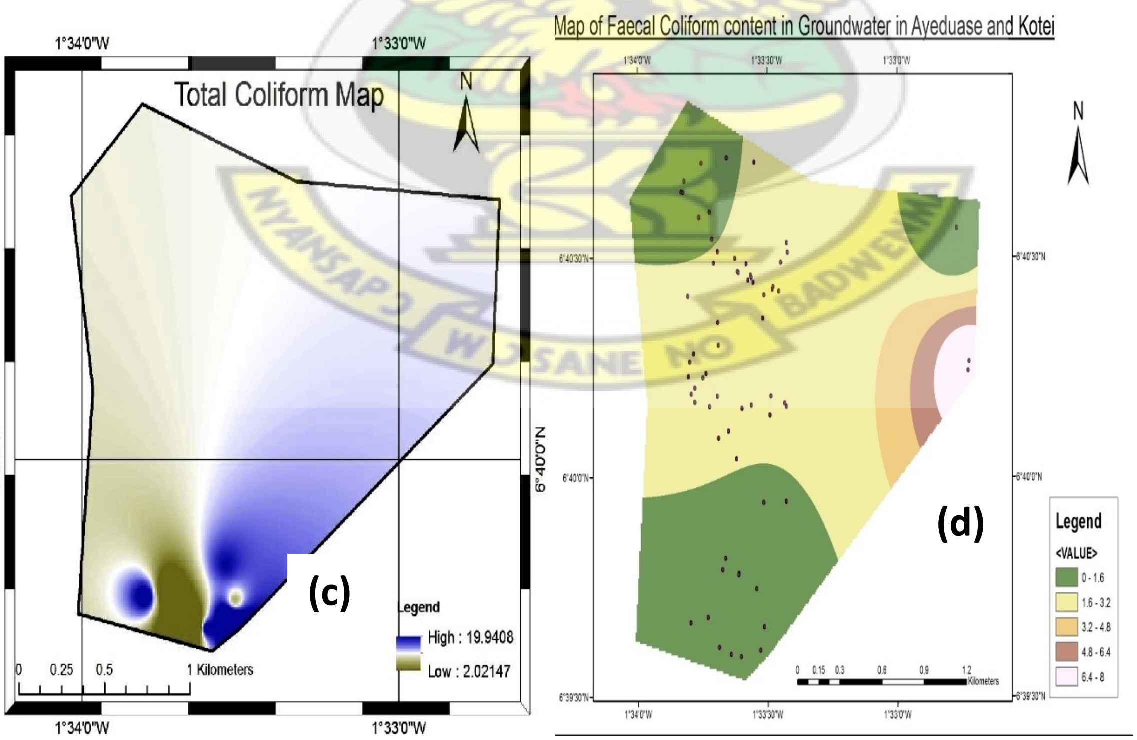


Figure 4.4: Spatial distribution of a) sulphate, b) chloride



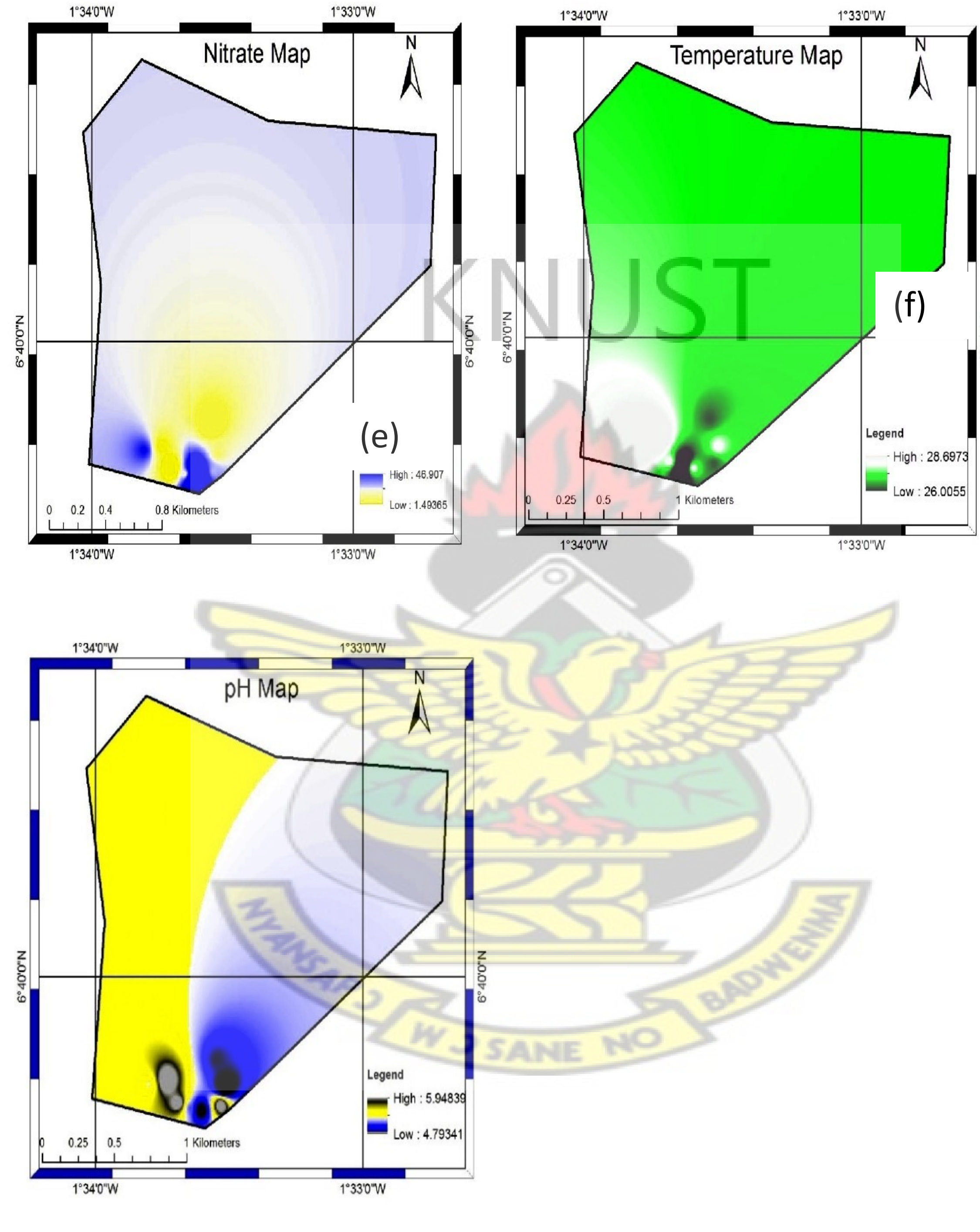


Figure 4.4 Spatial distribution of c) total coliform, d) faecal coliform, e) nitrate concentrations, and f) temperature g) pH in the study area

4.5 Challenges and Limitation of the research

The research work was not without challenges and limitations. The following were encountered during the course of the research.

Due to resource constraints, and the cost of laboratory analysis of samples, more samples could not be collected to make the work more representational, but for the use of technology. As a result of these resource challenge, the research could not separately deal with the two main groundwater sources within the study communities; boreholes and wells. They were both put together and dealt with as groundwater sources.

Again, in looking at the potential contamination of groundwater in these communities in relation to siting of septic tanks, the research could not also look at the septic tank density in each locality, which may also influence the levels of contamination of the water.

Finally, the research did not also consider the wholesomeness of receptacles used for drawing water especially from the wells, which can be a source of contamination.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

Access to safe, affordable and portable water is still a major issue of concern over the world, and most especially in the developing world. In line with this, increased access to portable/clean water forms a very important component of Ghana's economic development and poverty reduction policy. Despite the efforts from successive government, the Ghana Water Company Limited is still not able to provide enough treated water to meet the needs of the Ghanaian population, hence, a great percentage of the population depend on groundwater, whose quality cannot always be guaranteed.

Results of this study are significant because, a good number of households in the study communities depend mostly on septic tanks and wells/boreholes. As a result, residents may be at a high risk of suffering from water and sanitation related diseases after using water from these sources without treatment. The study indicates that present distances between wells/boreholes and septic tanks are not all within recommended range for siting these to prevent contamination.

From the results of the study, the physio-chemical parameters measured in the study communities were all within the WHO prescribed guidelines for drinking water. On the other hand, bacteriological contaminants were also found in the water within the area, though in small quantities. For water to be used for drinking purposes, the guidelines of the WHO prescribe that, no coliform bacteria should be found in any 100ml of water sampled. It can be concluded from the findings that, the status of water quality in the Ayeduase and Kotei communities using physio-chemical parameters as indicators can be said to be of acceptable limit for domestic use and human consumption. On the other hand, with the microbiological indicators, the water can be said to be unsafe and could account for water borne diseases in the study communities.

Finally, with the relationship between the distance of groundwater sources and septic tanks, the study showed no strong correlation existed between the distances between the septic tanks and boreholes and the parameters measured. Therefore, the pollution indicators found in some of the water samples cannot directly be linked to the septic tank locations.

5.2 Recommendations

From the conclusions of the study, it is recommended that:

- The boreholes/wells in the study area be analysed for water quality indicators at regular intervals to monitor the rate of contamination and relative quantity of the high or low contaminants detected.
- Further education should be given to residents on the best ways to site their boreholes away from septic tanks, taking into consideration the slope and the distance.
- Future research could focus individually on eithers wells or boreholes separately to establish impact on these sources individually.
- Receptacles used for drawing water especially from the wells should be kept clean and protected from all forms of contaminations.
- Further research is also needed in the area to assess impacts of septic tank density on quality of groundwater resources within the study communities.
- To improve upon planning for the effective treatment of the sewage systems and minimize the rate of contamination of groundwater by sewage through the identification of the

amount of domestic sewage from septic tanks and other sources that find their ways into the different groundwater sources in the study communities.

- Further research is also needed to establish the cause of the low pH in the water and ways to remedy it.

References

Abass, K., Adanu, S. K. and Agyemang, S. (2018) Peri-urbanisation and loss of arable land in Kumasi Metropolis in three decades: Evidence from remote sensing image analysis. *Land Use Policy*, *72*, 470–479.

Adefemi, S. O., and Awokunmi, E. E. (2010) Determination of physico-chemical parameters and heavy metals in water samples from Itaogbolu area of Ondo-State, Nigeria. *African Journal of Environmental Science and Technology*, *4*(3), 145–148.

Adekunle, I. M., Adetunji, M. T., Gbadebo, A. M. and Banjoko, O. P. (2007) Assessment of groundwater quality in a typical rural settlement in southwest Nigeria. *International Journal of Environmental Research and Public Health*, *4*(4), 307–318.

Ali, J., Hussain, A., Abid, H. and Rahman, Z. (2011) Bacteriological quality assessment of drinking water from Khyber agency and its impacts on public health, *44*(2), 73–76.

Amoateng, P., Finlayson, C. M., Howard, J. and Wilson, B. (2018) A multi-faceted analysis of annual flood incidences in Kumasi, Ghana. *International Journal of Disaster Risk Reduction*, *27*, 105–117.

Arwenyo, B., Wasswa, J., Nyeko, M. and Kasozi, G. N. (2017) The impact of septic systems density and nearness to spring water points , on water quality, 11, 11–18.

Asiedu, A. B. (2014) Household Access To Water and Sanitation Facilities : a Case Study of the Offinso South Municipality.

Ayuba, R., Tijani, M. N. and Omonona, O. V. (2017) Hydrochemical Characteristics and Quality Assessment of Groundwater from Shallow Wells in Gboloko Area , Central Nigeria, *15*, 65–76.

Balakrishnan, P., Saleem, A. and Mallikarjun, N. D. (2011) Groundwater quality mapping using geographic information system (GIS): A case study of Gulbarga City , Karnataka , India, *5*, 1069–1084.

Bhunia, G. S., Shit, P. K. and Maiti, R. (2018) Comparison of GIS-based interpolation methods for spatial distribution of soil organic carbon (SOC). *Journal of the Saudi Society of Agricultural Sciences*, *17*(2), 114–126.

Bhusal, S. R. (2017) Study of Water Quality in Urban Streams: Mätäjoki and Haaganpuro.

Binat Sarwar, M., and Mason, N. (2017). How to reduce inequalities in access to WASH Rural water and sanitation in gha. Retrieved from www.odi.org/twitter

Brucet, S., Pédron, S., Mehner, T., Lauridsen, T. L., Argillier, C., Winfield, I. J. and Holmgren, K. (2013) Fish diversity in E uropean lakes: geographical factors dominate over anthropogenic pressures. *Freshwater Biology*, *58*(9), 1779–1793.

Callaghan, K. (1996) The Correlation Coefficient. *Explorations in College Algebra: Discovering Databased Application*, (c), 553–557.

Cobbinah, P. B. and Amoako, C. (2012) Urban sprawl and the loss of peri-urban land in Kumasi, Ghana. *International Journal of Social and Human Sciences*, 6(388), 397.

Curtarelli, M., Leão, J., Ogashawara, I., Lorenzzetti, J. and Stech, J. (2015) Assessment of spatial interpolation methods to map the bathymetry of an Amazonian hydroelectric reservoir to aid in decision making for water management. *ISPRS International Journal of Geo-Information*, *4*(1), 220–235.

Eisenberg, J. N. S., Scott, J. C. and Porco, T. (2007) Integrating disease control strategies: Balancing water sanitation and hygiene interventions to reduce diarrheal disease burden. *American Journal of Public Health*, *97*(5), 846–852.

Elhatip, H., Afşin, M., Kuşçu, I., Dirik, K., Kurmaç, Y. and Kavurmaci, M. (2003) Influences of human activities and agriculture on groundwater quality of Kayseri-Incesu-Dokuzpinar springs, central Anatolian part of Turkey. *Environmental Geology*, *44*(4), 490–494.

Fawell, J. K., Ohanian, E., Giddings, M., Toft, P., Magara, Y. and Jackson, P. (2004) Sulfate in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality. *World Health Organization*, 8.

Frimpong, O. and Asante, M. R. K. (2013) Assessment of Quality of Groundwater Near a Dump Site. A Case Study of Kwadaso Sub-Metro in the Ashanti Region, Ghana.

Ghana Statistical Service. (2014) 2010 Population and Housing Census, District Analytical Report. *Ghana Statistial Service*, 1–109.

Gorchev, H. G. and Ozolins, G. (2011) WHO guidelines for drinking-water quality. *WHO Chronicle*, 38(3), 104–108.

Greenland, K., de-Witt Huberts, J., Wright, R., Hawkes, L., Ekor, C. and Biran, A. (2016) A cross-sectional survey to assess household sanitation practices associated with uptake of "Clean Team" serviced home toilets in Kumasi, Ghana. *Environment and Urbanization*, 28(2), 583–598.

Guo, J., Xu, Y. and Pu, Z. (2016) Urbanization and its effects on industrial pollutant emissions: An empirical study of a chinese case with the spatial panel model. *Sustainability*, *8*(8), 812.

Guyer, J. P. (2018) *An Introduction to Chemical Cleaning of Industrial Water Systems*. Guyer Partners.

Hammond, C., Tyson, T. and Engineers, E. (1905) Septic Tank Design and Construction.

Hespanhol, I., in: Helmer, R. and Stellman (Eds.), J. M. (1998) *Water Pollution, Encyclopaedia of Occupational Health and Safety*. *International Labour Organization publications, Geneva, Switzerland*.

Heuvelink, G. B. M. and Webster, R. (2001) Modelling soil variation: Past, present, and future. *Geoderma*.

Hutton, G. and Bartram, J. (2008) Global costs of attaining the Millennium Development Goal for water supply and sanitation. *Bulletin of the World Health Organization*, 86(1), 13–19.

Igboekwe, M. U. and Akankpo, A. O. (2011) Application of Geographic Information System (GIS) in Mapping Groundwater Quality in Uyo, Nigeria, 394–397.

International Forum on Home Hygiene (IFH), Nath, K. J., Bloomfield, S. F. and Jones, M. (2006) Household water storage, handling and point-of-use treatment.

Jeihouni, M., Toomanian, A., Shahabi, M. and Alavipanah, S. K. (2014) Groundwater Quality Assessmen for Drinking Purposes Using GIS Modelling (Case Study: City Of Tabriz), 15–17.

Johnston, K., Ver Hoef, J. M., Krivoruchko, K. and Lucas, N. (2001) Using ArcGIS geostatistical analyst. *Analysis*, 300, 300.

Kitanidis, P. K. (1997) *Introduction to geostatistics: applications in hydrogeology*. Cambridge University Press.

Krenkel, P. (2012). *Water quality management*. Elsevier.

Manassaram, D. M., Backer, L. C., Messing, R., Fleming, L. E., Luke, B. and Monteilh, C. P. (2010) Nitrates in drinking water and methemoglobin levels in pregnancy: A longitudinal study. *Environmental Health: A Global Access Science Source*, 9(1), 60.

McQuillan, D. (2004) *Ground-water quality impacts from on-site septic systems*. *Proceedings, National Onsite Wastewater Recycling Association,* 13th Annual Conference.

Meybeck, M., Kuusisto, E., Mäkelä, A. and Mälkki, E. (1996) Chapter 2 - Water Quality.

Ministry of Water Resources, W. and H. (2007). National Water Policy. *National Water Policy*, 79.

Nkansah. (2010) Assessment of the Quality of Water from Hand-Dug Wells in Ghana. *Environmental Health Insights*, (May 2014), 7.

O'Driscoll, M., Clinton, S., Jefferson, A., Manda, A. and McMillan, S. (2010) Urbanization Effects on Watershed Hydrology and In-Stream Processes in the Southern United States. *Water*.

Obiri-Danso, K. S., Adjei, B., Stanley, K. and Jones, K. (2002) Microbiological quality and metal levels in wells and borehole water in some peri-urban communities in Kumasi, Ghana. *Science And Technology*, *3*(1), 059–066.

Odonkor, S. T. and Ampofo, J. K. (2013) Escherichia coli as an indicator of bacteriological quality of water : an overview Development of indicators : the, 4(Table 1), 5–11.

Osei, S. K. (2015) Well Water Quality of the Oti Community in the Kumasi Metropolis of Ghana.

Pandey, P. K., Kass, P. H., Soupir, M. L., Biswas, S., and Singh, V. P. (2014) Contamination of water resources by pathogenic bacteria. *AMB Express*, 4(1), 1–16.

Pitt, R., Lalor, M. and Easton, J. (2014) Potential Human Health Effects Associated with Pathogens in Urban Wet Weather Flows, 1–23.

Remoundou, K. and Koundouri, P. (2009) Environmental effects on public health: An economic perspective. *International Journal of Environmental Research and Public Health*, *6*(8), 2160–2178.

Sankar, G., Kumar, P. and Maiti, R. (2016) Comparison of GIS-based interpolation methods for spatial distribution of soil organic carbon (SOC). *Journal Of The Saudi Society Of Agricultural Sciences*.

Sarangi, A., Cox, C. A. and Madramoto, C. A. (2005) Geostatistical methods for prediction of spatial variability of rainfall in a mountainous region. *Transactions of the ASAE*.

Sharma, Y., Purohit, D. G. M. and Sharma, S. (2017) Applicability Aspects of Geoinformatics in Geotechnical Engineering. *American Journal of Engineering Research (AJER)*, 6(10), 71–75.

Shittu, O. B., Olaitan, J. O. and Amusa, T. S. (2008) Physico-chemical and bacteriological analyses of water used for drinking and swimming purposes in Abeokuta, Nigeria. *African Journal Biomedical Research*, 11(3), 285–290.

Songsore, J. (2009) The urban transition in Ghana: Urbanization, national development and poverty reduction. *University of Ghana, Legon–Accra*.

Tan, Q. and Xu, X. (2014) Comparative analysis of spatial interpolation methods: an experimental study. *Sensors and Transducers*, 165(2), 155.

Tay, C. and Kortatsi, B. (2008). Groundwater Quality Studies : A Case Study of the Densu Basin , Ghana. *West African Journal of Applied Ecology*, *12*.

Van der Gun, J. (2012) *Groundwater and Global Change: Trends, Opportunities and Challenges | International Groundwater Resources Assessment Centre*. *Unesco*.

Wackernagel, H. (2014) Geostatistics. *Wiley StatsRef: Statistics Reference Online*.

Wakida, F. T. and Lerner, D. N. (2006) Short Communication Potential nitrate leaching to groundwater from house building, 2081, 2077–2081.

WEBSTER, R. (1990) Kriging: a method of interpolation for geographical information systems AU - Oliver, M. A. *International Journal of Geographical Information Systems*, 4(3), 313–332.

World Health Organisation. (2007) pH in drinking-water. *Guidelines for Drinking Water Quality*.

World Health Organization. (2011) Nitrate and nitrite in drinking-water. *Background Document for Development of WHO Guidelines for Drinking-Water Quality*, 37(4), 227–231.

Yates, M. V. (1985) Septic tank density and ground-water contamination. *Groundwater*, 23(5), 586–591.