LEVELS OF RADON AND HYDROCHEMISTRY OF HAND-DUG WELLS IN THE KETA MUNICIPALITY

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SCHOOL OF NUCLEAR AND ALLIED SCIENCE
UNIVERSITY OF GHANA

MPhil

2020

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This thesis was submitted to the

DEPARTMENT OF NUCLEAR SCIENCES AND APPLICATIONS

By

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(10705309)

In partial fulfilment of the requirements for the degree of

MASTERS OF PHILOSOPHY

in

NUCLEAR AND ENVIRONMENTAL PROTECTION

October, 2020

DECLARATION

I, Sefakor Esinam Ahiave, do hereby declare that this thesis is a research work I personally carried out in the Keta Municipality. Aside references made to work by other authors, which have been duly cited, this research was undertaken wholly in the Department of Nuclear Science and Application, Graduate School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Prof. J.R Fianko and Dr. Mrs. Irene Opoku-Ntim.

.... 19/07/2021 ....

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Dr. Mrs. Irene Opoku-Ntim. (Co-Supervisor) — Date

ABSTRACT

Over exploitation of hand-dug wells in the Keta municipality is on the rise though less works on the radon levels and the hydrochemistry of hand-dug wells, have carried out in Keta. The objective of the research is to assess the quality of hand dug wells in the Keta Municipality with respect to Radon (^{222}Rn) levels and hydrochemistry. The study was carried out in 10 communities in the Keta Municipality. Water samples were collected from 30 sampling points from November to March. Physical parameter (pH, salinity, alkalinity, TDS) were analysed in the field, whereas chemical parameters were analysed in the laboratory for radon and the hydrochemistry parameters. A t-test was conducted to find the differences in the seasons using mathematical analytical tool MATLAB R2015a (The Math Works Inc., Natick, Massachusetts US. MATLAB R2015a, 2015). Differences were considered significant at a p-value of 0.05. The results revealed significant differences in pH (7.14 –9.29), salinity (200 mg/L- 3830 mg/L), TDS (149mg/L-9870 mg/L), chloride (17.99 mg/L- 2823 mg/L), Calcium (38.40 mg/L- 180.8 mg/L), Sodium (30 mg/L- 497 mg/L) and sulphate (2.81 mg/L-37.35 mg/L). Phosphate, magnesium, salinity, Total hardness, chloride and sulphate were beyond the WHO recommended levels. The water quality index had most of the water to be poor and unfit for drinking. The Comprehensive Pollution Index results showed 80% of the samples to be moderately polluted. The Sodium Adsorption Ratio values obtained showed that the water have permeability issues with 93.33% being sodic waters having values above 13. Radon levels in the water ranged from 0.4 Bq/l - 111 Bq/l. The highest radon levels were recorded in Tetevikope. The annual effective dose for ingestion and inhalation ranged from 0µSv/y - 642.4µSv/y and 1.26µSv/y - 277µSv/y respectively. About 60% of the total samples were above the water quality limits set by World Health Organization (2011) and United State Environmental Protection Agency (2010). Based on the results obtained, it can be concluded that the water quality of the hand dug wells are unsafe for drinking and irrigation. However, the water from the hand dug wells present no significant health risk with respect to radon to the inhabitants. The results also show that the sea water intrusion into the groundwater aquifer has huge effects on the hydrochemistry of the hand-dug wells in the Keta Municipality.

DEDICATION

I would like to dedicate this work to my parents Mr Wilson Cosmos Adikah and Chief Insp. Juliana Tsagli as well as my siblings namely, Selorm Yayra Ahiave and Seyram Edem Ahiave.

ACKNOWLEDGEMENTS

Firstly, I would like to thank the Almighty God in whom I live and have my being for the grace bestowed on me to get to this point in life. My profound gratitude goes out to my supervisors Prof. J.R Fianko, School of Nuclear and Allied Science and Dr. Mrs. Irene Opoku -Ntim for their supervision and insight that made this project a success. A big thank you also goes to Prof Dampare, Dr Akiti, Dr Obirikorang and Miss Priscilla Esinu Lartey for their contributions towards this research.

Special thanks also go to my parents, Mr. Wilson Cosmos Adikah and Chief Insp. Juliana Tsagli for their crucial role in funding this project.

A huge thank you goes to the experts that took time to help me in the analysis of this research work: Mr John Senu, Mr. Godfred Ayanu, Mr George Crabbe, Barbara Aboagye, Nana Ekua Garbrah, Terry Nartey, Ophelia Wornyo and Daniel Brako all of the Ghana Atomic Energy Commission Chemistry Laboratory. Their inputs and passionate participation helped greatly in this research.

My immense gratitude goes out to my friends Dina, Diop, Regina, Kaleb, Divine, Emma, Confidence, Lebene, Christabel and everyone who contributed in a way or the other to make this research a success. God richly bless you all.

LIST OF ABREVIATIONS AND ACRONYOMS

AED	Annual Effective Dose
AEDG	Annual Effective Dose due to Ingestion
AEDH	Annual Effective Dose due to Inhalation
Bq/kg	Becquerel per kilogram
Bq/L	Becquerel per liter
CPI	Comprehensive Pollution Index
EPA	Environmental Protection Agency
GAEC	Ghana Atomic Energy Commission
GPS	Global Positioning System
GSS	Ghana Statistical Service
GWCL	Ghana Water Company Limited
HDW	Hand Dug Wells
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
M.Phil.	Master of philosophy
NNRI	National Nuclear Research Institute
NAS	National Academy of science
pH	Power of Hydrogen
Ra 222	Radon
SAR	Sodium Adsorption Ratio
SSNDTs	Solid State Nuclear Tracks Detectors
TDS	Total Dissolved Solids

U-238	Uranium-238
UNSCEAR	United Nation Scientific Committee on the Effect of Atomic Radiation
USEPA	United State Environmental protection Agency
WHO	World Health Organization
WQI	Water Quality Index
WRI	World Resources Institute

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

The basic needs for mankind's existence are water, food and air. Without these basic needs the existence of mankind will be threatened. About 71% of the surface of the earth is filled with water and out of this, 97% is found in the oceans and 3% is freshwater (Srithala *et al.*, 2014). The presence and accessibility to freshwater contributes to factors that determines the settlements of mankind at a location. Out of the 3% of freshwater present on earth, 0.62% is groundwater, the rest are found in rivers, lakes, glaciers and in the atmosphere.

For sustainable development to occur, access to safe drinking water is of importance. Reports by the World Health Organization indicates that about 1.1 billion people do not have access to safe drinking water (WHO, 2004). Ghana as a country have various water resources, however, surface water which is easily accessible to the rural folk are polluted hence most residents in the rural areas resort to the use of all sorts of water for domestic activities. Due to the deficiency in water supply in the Municipality, inhabitants of the Keta Municipality resort to the use of hand dug wells as the main source of water to meet the daily water requirements, the quality of which is in doubt hence the manifestation of waterborne water-related diseases such as diarrhoea, guinea worm, cholera etc.

Groundwater usage is of economic importance in many rural communities in Ghana. The exploitation of groundwater for water supply needs of inhabitants of the Keta Municipality has been on the increase in the last decade. Many communities in Keta Municipality uses groundwater as an alternative source of water to pipe borne water (Chierici and Fransson

2009). The Groundwater serves as a principal source of water for drinking, irrigation and other domestic use in the municipality. However, groundwater resources in the potential Keta Municipality are under serious threat due to urbanization, increased population density as well as domestic and industrial usage.

In recent times there has been an increase in the population, increase in the land use activities such as constructions of buildings and more settlements, increase in waste production and disposal as well as farming within the Keta Municipality, hence pressure on the available water resource has increased. These developments make it essential to determine the quality of the water consumed by the inhabitants. The quality of drinking water is an environmental determinant of health (WHO, 2010). Water plays an indispensable role in sustenance of life, and it is a key pillar of health determinant. Lack of quality water for domestic activities and poor sanitation has been linked to 80% of diseases in developing countries (Ajayi, 2010).

Groundwater has been of good quality since groundwater is less vulnerable to pollution. However, studies in Ghana have revealed that groundwater is also vulnerable to pollution due to anthropogenic activities (Duodu, 2014). Ackah et al. (2011) reported that borehole water contamination occurs through domestic wastewater and livestock manure if there is a fracture in a layer of soil.

The salinity of both the coastal surface waters, the Keta lagoon and the cost of connecting pipe borne water into the various communities makes it difficult for the members of the communities to access quality water for domestic activities hence the over dependence on groundwater. Groundwater quality varies with the depth of the water Table, the geology of the area, seasonal changes and total dissolved solids in the water which is a function of the environment in which the groundwater is found (Srithala *et al.*, 2014). Groundwater is heterogeneous in nature hence hydrochemistry and other parameters varies from place to place and from season to season.

Groundwater development in the Ghana have often been hampered among other things by the improper disposal of solid waste, leakage of underground storage tanks, and seepage of agrochemicals from vegetable farms. Chemical, weathering and microbiological activities are the major threats to total reliance on groundwater as source of drinking water. Ground water may contain various elements including heavy metals and radionuclides such as radon (^{222}Rn) and their radicals associated with it in an ionic equilibrium. Radioactive pollution of boreholes and hand dug wells is high as compared to other sources of water such as lakes, streams and rivers. This due to the stagnant nature of groundwater which does not allow adequate aeration.

Radon gas (^{222}Rn) is a natural radioactive noble gas emitted as one of the end products of the decay series of uranium or thorium. It becomes toxic when it attaches itself to aerosols, dust particles and other suspended particles in the air. The attached particles may be inhaled leading to lung and other cancer related diseases (D'Alessandro and Vita, 2003). Humans get exposed to radon through ingestion of radon in water or inhalation through air (Bem *et al.*, 2014). Natural radioactivity from geological materials such as radon (^{222}Rn) exposure, is considered a risk factor for human health. These health impacts are mostly associated with daughter nuclides, lead (Pb-208) and polonium (Po-218); which can aggregate to the ambient aerosols and thus be inhaled and deposited in the epithelial lungs, tissues, causing neoplasm (Tangaru *et al.*, 2011).

It is estimated that approximately 3% to 20% of all lung cancer deaths are attributed to radon exposure worldwide (Kim *et al*., 2016). Water coming from granite formations of cratonic areas turn to have the highest concentrations of radon and other radionuclides (D'Alessandro and Vita, 2003). According to WHO (2009), the effective dose rate of drinking water consumed should not exceed 0.1mSv/year. Pollution of groundwater and its effect to human health has become alarming. Many studies have identified several contaminants in groundwater resources in Ghana (Fianko et al, 2011, Anim et al 2011, Kwakye-Nuako et al, 2005). These include radioactive materials, nitrogen compounds, heavy metals, faecal coliform and pesticides. Areas near refuse disposal sites were identified to have a greater possibility of groundwater contamination because of the potential pollution from leachate originating from the landfills. Such contamination of groundwater resources poses substantial risks to human health and the environment.

In the Keta Municipality, majority of household rely on water extracted from hand dug wells for their domestic activities. Some household draw water from newly constructed septic tanks which have water intruded into them, while others use water from sources with unguaranteed. Water has been identified as the major source of the spread of water borne diseases such as dysentery and cholera and therefore, needs to be constantly monitored (USEPA, 2005). Rapid urbanization with indiscriminate construction of hand dug wells and the use of subsurface water from septic tanks by households for domestic activities present a complex array of potential nonpoint pollution source to groundwater in the Keta Municipality.

1.2 Problem Statement

In the Keta Municipality, the main source of water for domestic activities is groundwater. The dependence on groundwater resources in the Municipality is as a result of degradation of the quality of surface water system (streams, river and ponds) in the catchment.

Groundwater resources in the Municipality are under serious threat due to lack of sanitation facilities, improper waste disposal and high population growth. The groundwater system in the Municipality is under a threat because of increasing pollution input of anthropogenic origin from point and nonpoint sources. Rapid population growth, extensive use of agrochemicals in peri urban vegetable farming and lack of proper water supply from surface water system and sanitation services in the Keta Municipality has put groundwater resources under increasing pressure.

There has been an increase in indiscriminate drilling of hand dug wells by individuals irrespective of where they are sited. Some hand dug wells are sited near vegetable farms, septic tanks, public toilets and cemeteries. The presence of septic systems, public toilets and cemeteries near hand dug wells can contaminate the water with bacteria, viruses, nitrates, detergents, oils, and other toxic chemicals. Contaminated groundwater resources have important implications on health and the environment. A lot of infectious diseases are shared by water via oral and faecal pollution. Increase in cholera and diarrhoea in infants and children is because of the usage of polluted water and unhygienic practices (Oladipo *et al*., 2009; Tortora *et* al., 2002). Toxic inorganic substances present in contaminated water, may lead to serious or acute health effects. The lack of good water supply is associated with the prevalence of sickness and deaths due to faecal related diseases like typhoid, river blindness, cholera, burulli and dysentery. Indiscriminate siting of refuse dumps and other human activities have adversely affected the quality of groundwater.

Radon (^{222}Rn) is dangerouss to human health. Higher levels of ^{222}Rn in ingested water causes health issues like, stomach cancer, cholera, fluorosis, typhoid, lung cancer, premature baby and other issues, especially in babies. Radon and other radioactive isotopes have been found to occur naturally in coastal areas (Almeida *et al*., 2004). The change in the geological formations is huge enough to cause a good spread in radon concentrations dissolved in water (Idriss *et al.*, 2011). Areas with higher concentrations of Ra^{222} are usually linked with granitic rocks. Since the geological background of the Keta Municipality is cretaceous, sandstones as well as granite. There is a high probability of the presence of radon in the groundwater. The Keta Municipality depends on hand dug wells. Hence the type of bedrock is a vital influence on the dissolved radon in groundwater from the Municipality.

Despite the popularity of groundwater in the Keta Municipality there is scarce information on radon levels in hand dug wells and the geochemical as well as the biogeochemical processes that directly or indirectly affect groundwater quality in the municipality.

1.3 Purpose Of Study

1.3.1 Main Objective:

To assess the groundwater quality of hand dug wells in the Keta Municipality with regard to groundwater chemistry and Radon (^{222}Rn) distribution.

1.3.2 Specific Objectives:

1. To assess the levels of key physico-chemical parameters of hand dug well water.

2. To predict the effect of the groundwater aquifer on the hydrochemistry of the hand-dug wells.
3. To establish the presence and distribution of Radon (222Rn) in the hand dug wells.
4. To assess the seasonal variations in the distribution of radon gas present in the hand dug wells; and,
5. To estimate the annual effective dose (ingestion and inhalation) of Radon-222.

1.4 Significance and Justification of the Study

The vital role of water to mankind makes availability of portable water a necessity for human survival. Groundwater water is an excellent freshwater resource in Ghana. The vital source of water supply for industrial, agricultural and domestic purposes is groundwater in the Keta Municipality. The Keta Municipality depends on hand dug wells. Groundwater resources in the Municipality have been found to be under serious threat due to insanitary conditions, improper waste disposal and high population growth. There has been an increase in drilling of hand dug wells by individuals irrespective of where they are sited. Septic systems that are not properly sited, designed or maintained can contaminate groundwater. Contaminated water can pose serious health threats to human life.

Radon and other radioactive isotopes have been found to occur in coastal areas (Almeida *et al*., 2004) and areas with higher concentrations of ^{222}Rn are usually linked with granitic rocks. Since the geological background of the Keta Municipality is cretaceous, sandstones as well as granite, there is a high probability of the presence of radon in the groundwater. Higher levels of ^{222}Rn and other contaminants in drinking water may lead to health problems such as lung cancer, stomach cancer and water borne issues.

Despite the popularity of hand dug wells in the Keta Municipality scarce information is available on the hydrochemistry and Ra^{222} levels on groundwater quality in the Municipality. The results obtained from this investigation would be used to evaluate the quality of hand dug wells in the Keta Municipality and provide baseline data to aid the assessment of the potential risk associated with the consumption of groundwater on the inhabitants. Additionally, it will contribute to the mapping of the radon (Ra^{222}) levels of groundwater in Ghana.

1.5 Scope of the Study

For sustainable development to occur, access to safe drinking water is of importance. Ghana as a country have various water resources, however, surface water which is easily accessible to the rural folk are polluted. Most residents in the rural areas therefore resort to the use of all sorts of water for domestic activities. Groundwater serves as a principal source of water for drinking, irrigation and other domestic use in the Keta municipality. However, groundwater resources in the potential Keta Municipality are under serious threat due to urbanization, increased population density as well as domestic and industrial usage.

This study focused primarily on the levels of radon and the hydrochemistry of hand-dug wells in the Keta Municipality. The study assessed the groundwater quality of hand dug wells in the Keta Municipality with regard to groundwater chemistry and Radon (^{222}Rn) distribution. It also assessed the levels of key physico-chemical parameters of hand dug well water in the Municipality and to predict the effect of the groundwater aquifer on the hydrochemistry of the hand-dug wells as well as establish the presence and distribution of Radon (222Rn) in the hand dug wells. The study also considered the seasonal variations in the distribution of radon gas present in the hand dug wells and finally estimated the annual effective dose (ingestion and inhalation) of Radon-222.

The dynamics of groundwater in the Keta Municipality may differ from other MMDAs but the findings, conclusions, and recommendations may be applicable to contemporary situations with similar social backgrounds.

1.6 Organization of the Study

Chapter one is an introduction of the study. It handles the important subtopics like the background of the study, the problem statement, the justification, the objectives of the study and its significance to Ghana. Relevant literature to the study was reviewed in chapter two. Chapter three captures the methods and materials used in the thesis. Chapter four is made up of the results obtained and the discussion of the results and chapter five summarizes, concludes and makes recommendations from the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The earth surface is filled with several water bodies found on the surface which are fed by precipitation. In the movement of water from the atmosphere to the earth surface, it goes through several channels. The movement of water via different waterways on the earth surface forms the hydrological cycle. Water is lost from the earth mainly via evaporation, seepage and percolation; however, it is replenished by precipitation. A large catchment area like a lake or the sea, gains more water from precipitation relative to smaller catchment areas like a river or a stream. The water inputs and losses or discharge determines the quantity or size of the water body. In the oceans the evaporation rate is higher compared to the precipitation rate, the net difference equals movement of water vapour over land that comes in form of rainfall and goes back into the sea as groundwater discharge and river runoff (Mook and Rozanski, 2000). The water cycle is repeatedly moving through systems like river channels, soil, land ice, lakes, groundwater etc. Only 6% of the total groundwater discharge out of 30% of the precipitation that runs off into the seas goes into the seas. Just a small portion of the precipitation gets stored temporarily in rivers and lakes (Mook and Rozanski, 2000). Factors such as temperature, humidity, evaporation rate, geology, condensation rate, rainfall, movement on the land surface and in the earth, seas, mountains, plants contributes directly or indirectly to the hydrological cycle.

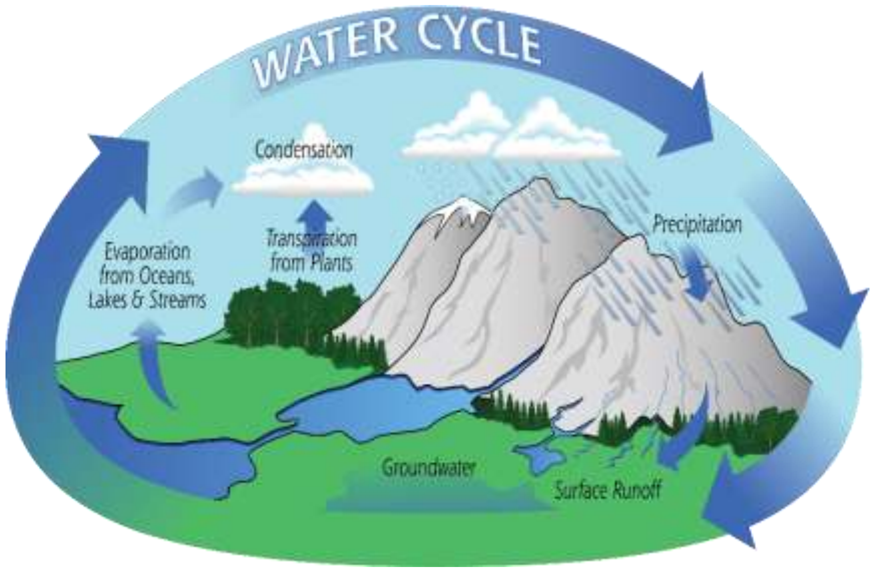

Figure 2.1: The hydrological cycle

Source: www.awesomestories.com accessed on August 24, 2020.

2.2 Groundwater

Groundwater is basically the water found beneath the earth. Groundwater falls under freshwater category. It is stored in confined and unconfined aquifers in the soil. Before urbanization, groundwater is fed or recharged by the infiltration of rainfall through pervious surfaces into the soil, or directly into streams, lakes, rivers etc. Rainfall that gets into the soil to recharge groundwater is relatively uncontaminated. However, due to urbanization and developments of infrastructure, there has been a reduction in the permeable surface area for percolation to occur hence less groundwater recharge (Pitt et al., 1999). Additionally, pollution and presence of impervious surfaces has led to increase surface runoff and the water available for recharge become highly polluted before it goes into the ground.

Inhabitants of places with less surface water and a shallow water Table mainly resorts to the usage of groundwater, due to its accessibility. Groundwater contaminants include, sulphate, phosphate, bicarbonate, heavy metals, pesticides, fertilizers etc. Nitrate is a major contaminant frequently found in groundwater (AWWA, 1990), there is usually more nitrate contaminants in groundwater than phosphorus contaminants. The presence of natural nitrogen in the air contributes to the nitrate contamination of groundwater. Residual exchange of ammonium occurs in areas with no weathered sedimentary deposits in the soil, which under the right conditions becomes oxidized to nitrate, through leaching the nitrates contaminates groundwater. The use of fertilizers in agricultural activities also adds up to the nitrate levels in groundwater. Phosphorus sorption per unit of percolation liquid reduces yearly as the recharge occurs. (White & Dornbush, 1988).

Groundwater contaminants include, sulphate, phosphate, bicarbonate, heavy metals, pesticides, fertilizers etc. As showed by Grundfelt (1977) and confirmed by Butler (1987) in Texas, a correlation exists between pesticide loading runoff of water and the distance it covered by the runoff before infiltration and the area of impervious cover. Across the globe alluvial aquifers hydraulically linked to a water course are idea locations to produce drinking water due to the closeness to demand areas, the manufacturing ability and the relatively easy exploitation of the shallow groundwater (Doussan et al., 1997). However, the over exploitation of groundwater has effects on the ecosystem and the wetlands fed by groundwater, therefore it is imperative to protect and sustainable use groundwater resources.

2.3 Groundwater development in Ghana

There are enough surface water resources in Ghana such as rivers, lakes, springs etc. Research shows that there are 10 major rivers in Ghana and quiet several springs, however, the exact number of springs in other regions have not been clearly stated unlike Volta region which has 143 constantly flowing springs (Kortasti, 1994).

In the mid-1970s and early 1980s rural water development programs had boreholes drilled at weathered zone and hand pump was used to these exploit low yielding aquifers. These took place for a while till programs were developed that probed deeper leading to higher yield of water to supply water to communities in Ghana (Anku et.al., 2007). Ground water development is a cost-effective means of meeting demand for water supply in many rural communities (Anku et. al., 2007). The rural water division which served as a wing of the Gold Coast Survey Department developed a national hand dug well program in the 19th century in Ghana that served as an access to portable drinking water for many communities.

Groundwater serves as the most cost effective source of water for many rural and urban communities in Ghana thus, it has led to the drilling of more than 45,000 hand-dug wells and 10,000 boreholes across the country (Kortatsi, 1994). It is abstracted in many forms in the country. Over 56,000 abstracting systems exist across the country. According to Gyau-Boakye and Dapaah-Siakwan (1999)

in year 1915 there was an establishment of a modern well in Ghana, located at the Accra railways station and was dug through shale and clay, having about 22 m depth and giving roughly 90 L/h of brackish water. It was further drilled to 52 m depth through shale and hard rock. Portable water was struck in between 40 m and 52 m, producing of 450 L/h to 545 L/h

2.4 Groundwater Usage in Ghana

The indigenes of Ghana exploit groundwater for various purposes. This is highly influenced by the cost of other alternative sources, the quality and the quantity of water present at the location. The major reason for groundwater exploitation is for domestic use such as cooking, washing, bathing cleaning etc. The quantity of water from borehole abstraction used for domestic and drinking purposes is 1.38 x 108 m^3 (Kortatsi, 1994). For instance, the Greater Accra region has most of its underlying rock to be gneiss, hence groundwater from there is mostly high in salinity, making the quality poor for consumption. However, there is a vast distribution of pipe-borne water which is mostly used by the inhabitants, therefore only small farming communities in this region use groundwater for drinking and other domestic purposes.

Most of the hand-dug wells in the Ghana are highly polluted hence about only half of all hand-dug wells are used for drinking, almost 66% of them are used for both domestic and drinking purposes. The total quantity of water from hand-dug wells used for domestic activities equals 7.3 x 107 m^3 (Kortatsi, 1994). In all, 2.11 x 108 m^3 of groundwater is abstracted for domestic purposes, making 84% of the entire groundwater abstracted yearly. For irrigational use of groundwater, mostly the people found in the southern part of the Volta region mainly engage in such activities via hand-dug wells. For a community such as Keta located in the southern Volta, about 60% of the hand dug wells are mainly used for irrigational purposes. The wells are spaced 100m apart and have a depth reaching from 1m to 5m. Amid 1.0 to 22.6 m^3 of water is used daily from these wells, averagely about 2.7 m^3 of water is used per day (Gray, 1992). The main crop produced in this part of the region is shallot hence the farmers fix irrigational pumps that are powered lowly on these wells to pump the water for irrigating huge hectors of their farm land. 70% of the boreholes drilled in the Accra plains are for agricultural purposes out of which 33% are used in irrigation (Kankam-Yeboah, 1987). In the dry season periods in the upper regions of Ghana, dug outs are made from temporal streams for irrigation.

Two-third of the livestock and poultry in Ghana depend on groundwater for their source of water. Most of these animals are allowed to roam in search of food in the communities, especially in rural areas, this makes them drink from ponds, puddles, streams and other groundwater they find on their way. Moreover, the most commercial poultry and livestock famers use groundwater for preparing feed and as drinking water for their animals.

However, groundwater is barely used for fish farming in Ghana. Fish farmers usually use surface waters such as lakes, and rivers for these activities. Groundwater is gradually being used in mineral water production. Research indicates a high potential in mineral water production from groundwater found in the southern sector of the country such as Keta basin, the mid Volta sections and the Accra plains (Kortatsi, 1994).

2.5 Hydrochemistry/Quality of Groundwater

The hydrochemistry of groundwater plays a vital role in determining the quality of the water for use. The quality of groundwater has been a public health concern due to its frequent use. The properties of water both physical and chemical are influenced by both natural and anthropogenic activities and in some instances the recharge quality, the velocity, soluble salts etc. In a work done by (Ayibotele, 1985), almost 30% of boreholes in Ghana have high iron issues. The geological formations of the lands presents a high iron concentrations in boreholes. Many of the hand dug wells in Ghana are turbid and polluted because they have a high amount of nitrate and coliform in them (Gray, 1992). The WHO (2012) has given some parameters to examine in the determination of the quality of groundwater, such parameters include: electrical conductivity (EC), pH, salinity, alkalinity, total dissolved solids (TDS), Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, SO_4^{2-}, NO^{2-}, NO3-, and PO_4^{3-} of the groundwater. The hydro geochemical properties and the quality of groundwater can be used to identify the relationship between the activities on the earth surface and their contribution to the quality of groundwater (Yidana *et al*., 2008). For example, places with high salinity content affects the ability of the soil to absorb water due to the high osmotic pressure present (Vrenzen et.al., 2007).

Higher TDS leads to elevated conductance which gives water a mineral taste, also pH affects the acidity and the basicity of water (Kumar *et al.,* 2012). Calcium, sodium, bi carbonate, potassium, salinity, TDS, chloride, phosphate and alkalinity of water are factors that determines the quality of water for use. Dissolved ions concentration in groundwater is high due to the groundwater stored in rocks, during storage the groundwater interacts with these rocks thereby adding to the dissolved ion content. The higher the dissolved ions, the denser the water, this is likely to reduce the hydraulic conductivity of the water (Singh and Singh, 2011)

The quality of groundwater is also influenced by the seasonal changes. The climatic conditions like high rainfall, salinity etc., contributes to the quality of groundwater at a particular time. The movement of water in the ground may lead to metals such as potassium, iron, sodium and manganese dissolving in groundwater at various point causing variations at different ground levels (Ojo-Awo *et al*., 2018). The lower the mineral content present in a water source the more suitable it is to be used for domestic and irrigational purposes. The quality of groundwater in Ghana found in most of the hydrogeological terrains have been noticed to be affected mainly by water-rock interactions (Yidana *et al*., 2008). In a study conducted in the eastern region of Ghana by Fianko et al. (2011), most of the sampled groundwater in the region were found to be between moderately mineralized and weakly mineralized with the dominant ions being Cl^-, Na^+ and HCO_3^-. The data obtained from the hydrochemistry showed that the agricultural and industrial processes have a huge effect on the groundwater of the place. As much as 50% of the boreholes sampled during the study had high concentrations of NO_3^-N.

2.6 Importance of drinking water quality

Access to quality water is a basic human right of all humans irrespective of your location in the world. Human health is greatly affected by the quality of water they consume. Several water borne diseases such as polio, diarrhoea, cholera and dysentery have linked to improper sanitation practices and the consumption of polluted water, (WHO, 2018). In 1978, the eight sections of the primary health care needs stated at the international conference on primary health care included the provision of quality and adequate supply of water (Edema et al., 2001). In a report by the WHO (2018) a minimum of 2 billion people across the world make use of water contaminated with fecal matter. High levels dissolved mineral elements in drinking water contaminates the water and renders it, polluted causing disease outbreaks upon consumption (Ntengwe, 2003).

The water quality situation is alarming in rural areas where folks barely get access to treated water. The source, the distribution systems, the storage and treatment of water prior to distribution influences the quality of water present. However, rural communities have their Ojo-Awo, N. A., Agbabiaka, H. I., & Ilesanmi, A. O. (2018). Refuse dumpsite and its associated pollutants: Spatial variations of the impact of leachates on groundwater quality. Management of Environmental Quality: An International Journal. (Schelly, 2015).

This together with other factors has hindered the growth and developments of the rural communities. Water quality assessment and determination of factors influencing the quality of water is essential in decision making to reduce or eradicate water borne diseases and manage water resources, hence this makes water quality important in the survival of mankind.

Water intake helps in digestion in the human body, transportations of essential mineral elements, excretion and the general functioning of the human metabolism. The definite water intake of individuals varies based on the individuals' environments, diets, health conditions etc. However, averagely an individual consumes 2 liters of water daily (WHO, 2011). Insufficient intake of water leads to dehydration whose intensity varies based on the degree of water loss.

2.7 Radon

A product of a radioactive decay of uranium is radon, it has a half-life of 3.8 days and is formed by the breakdown of uranium found in soils, rocks and water. Uranium is considered one of the most toxic radioactive elements present in almost all the different types of rocks, water, sand and soils, (Henshaw *et al*., 1990). Research shows that where uranium is present on the earth surface, a high amount of radium is present which further leads to huge concentration of radon gas being expected and the dangers associated with it becomes evident by the dangers associated with it.

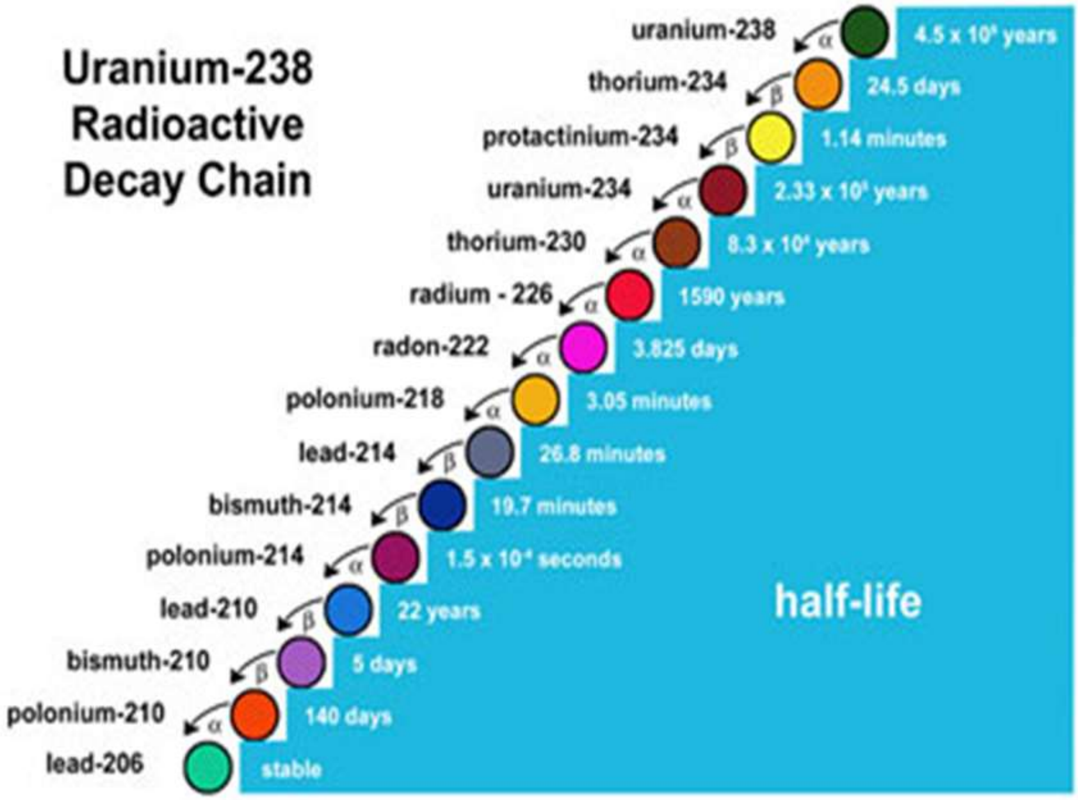

Figure 2.2: Decay Series Uranium

Source: https://geoinfo.nmt.edu/resources/uranium/what.htmL

Radon-222, Radon-219 and Radon-220 are three naturally occurring isotopes of radon. According to the (USEPA, 1993) Radon has been in existence for several years, however had not gotten much attention until 1980's, when higher levels of radon was reported in houses in the U.S.A. In a higher imbalance with its parent radium isotope, it seems to have a particular importance. The highest form of radionuclide that humans get exposed to, is from the inhalation of radon gas and its progenies, this accounts for the unique interest in it by mankind (Kumar et.al., 2012). Almost 70% of the total effective dose of radiation that humans get exposed to from natural sources is from radon and its progeny (Najeeb *et al*., 2010). The radiation that one gets from the ingestion of water containing radionuclides is less as compared to that received from inhalation of radionuclides except in extreme cases. Additionally, most of the radon gas present at homes are produced from the earth crust and moves via diffusion or movement through groundwater, therefore studying and understanding the science behind its production, transport etc., is important in predicting its occurrence and abundance at a place (Cecil and Green, 2000).

Areas with high uranium concentration will have high radon concentration and the number of radon formed is governed by the number of radium present, aside other factors like wind, soil and rock type, depth etc. radon gas comes from, the inorganic particle and enter the open spaces in the soil based on; the location of the atom present in the particle, the size, permeability, temperature and texture of the particle. Radon gas is a soluble gas in nature, hence when it is produced in the ground, it can dissolve in ground water and organic solvent, this accounts for its presence in groundwater and soils. According to Kumar et.al., (2012) the emanation rate of radon is dependent on the nature of rocks presents and the environmental conditions. Due to its gaseous and odourless nature, it spreads easily from the ground into the environment and gets inhaled unconsciously by humans. Radon gas also could get attached to particles thus it travels with dust. The decay rate of 3.87 days however makes the level reduces quickly when stored for a period. The gas is easily lost to the air when present in springs and lotic water such as rivers and streams due to the agitation that comes with the movements of the water (Abdallah *et al*., 2007).

Radon can be used as tracers to determine the discharge of groundwater in the earth. According to (Singaraja *et al.*, 2016) when it comes to the radon isotope (222Rn) because it is normally enriched as you go deeper in the ground, as compared to the other decay products of uranium, radon-222 is often used to trace and validate atmospheric transport models. Due to its inert property it's used as an environmental tracer in geochemistry, oceanography and hydrology for determining transport pathways in surface waters and aquifer systems (Singaraja *et al.*, 2016). For instance radon has been widely used in examining water interactions in on-shore regions and coastal areas (Schmidt *et al*., 2008). Several factors contribute to the amount of radon present and these levels varies based on the elevation of the location.

2.8 Radon in Water

Radon due to its parent nuclide is found in the soil and in the earth crust. Its nature makes it dissolve in water when it encounters it in the subsoil, hence its presence in groundwater. In recent times, emphasis have been done on determining radon levels in groundwater and soils since, most of the radon gas present in the atmosphere is from radon present in water (Durrani, 1993). The presence of radon gas in water is an indication that the gas can travels via physical and biological media such as soils, vegetation and aquatic organisms. Wells, a groundwater source, has been used to supply both large and small groups of communities with water. Private well is common in most family houses in various communities, this serves as a domestic water supply for families. Radon levels in well water from private homes, are relatively higher, as compared to commercial sources because, water from commercial sources is usually stored by the municipalities for a period, during this period of storage the radon gas may decay because of its short half-life (Najeeb *et al*., 2010).

Radon dissolved in water become released into the atmosphere upon usage, which may increase the amount present and inhaled, this serves as the primary concern with regards to radon in water (ICRP, 2008). Though radon in water's risk to cause cancer is minimal, the presence of radon in water can contribute to an increase in radon in air (Abdallah *et al.*, 2007). Studies on radon in water, have intensified in the past two decades because it is a public health hazard and has to do with the injection of water with radon present in it, causing stomach cancer (Abdallah *et al.*, 2007). The concentration of radon in water is higher in groundwater than in surface waters because it could evaporate in surface waters due to aeration (Najeeb *et al.*, 2010).

A research done by (UNSCEAR, 2000), concluded that about 90% of the dose associated with radon in water are from inhalation, hence, setting a guideline for screening and limits for ingestion of water containing radon is not necessary, besides the process of screening of the radon may contain the additions from the progenies of radon which is the source of levels from the ingestion of radon (WHO, 2008). Movements of water contributes to radon travelling to long distances in via water. Aeration of water also plays a role in the levels of radon present in it. About, 30% to 70% of all radon dissolved in water gets lost through aeration making the gas present for inhalation (Hoene and Von Gunten, 1989). The diffusion constant for radon in air and water are $10 - 2\ cm^2/sec.$ and 10 - 5 cm^2/sec. respectively (Hoehn and Von Gunten, 1989).

The activities of radon in ground water is mainly influenced by the thorium and uranium content of the groundwater, the hydro chemical properties of the groundwater and the interaction between the water and the rock and the influence of the geothermal heat flow (Ayotte et al., 2011). Moreover, due to the nature of radon, its behavior is highly affected by the physical properties rather than the chemical properties. Large surface water bodies have less contact with radon emanating surfaces hence the radon in water at such areas is relatively low as compared to sediments and groundwater (Schimdt *et al*., 2008).

2.9 Health implication of radon and other radiations

Naturally occurring radioactive elements are present in the environment in different forms and quantity. They are present in water, plants, soils, outdoor and indoor air, therefore getting exposed to them is inevitable. Radiation has been used in the field of medicine for treatment and diagnosis of diseases. This has made exposure to artificial radiations quite common in the world. The second report of NAS in 1999 on radon in water estimated that almost 89% of all the cancers resulting from radon in drinking water are out of inhalation of the radon that gets released into the atmosphere and the remaining 11% is from ingestion leading to stomach cancer.

The global dose a person receives from all sources of radiation annually has been approximated to be 3.0 mSv/year, out of this (2.4 mSv) which represent 80% out of radiations from naturally occurring sources, (almost 0.6 mSv) representing 19.6% is from the medical usage of radiation in diagnosis and treatment, whiles the final (around 0.01 mSv) representing 0.4% is from man-made radiation sources (UNSCEAR, 2008). Radiations are present in water due to natural processes such as uranium and thorium decay, potassium-40, radium-226, lead-210, radium-228 uranium-234, these are present in water due to soil absorption, or processes that includes artificially occurring radioactive materials, like in mining and producing phosphate fertilizer.

2.10 Risk Associated with radon

The risks associated with getting exposed to radon, has been well spelt out over the years which is cancer. All humans get exposed to doses of cosmic radiations depending on the height above sea level, longitude and latitude (ICRP, 2008). Naturally occurring radionuclides has the ability to enter water supply at any different points before it gets consumed, this makes their present in water uneasy to control. They give doses of radiations higher than the ones from artificially generated ones, this makes it of huge concerns (WHO, 2004).

A preventive risk management approach is used to curb the risks associated with radiations in water. Care should be taken in the action to assess and manage radiological risk to ensure that the energy is not shifted away from other vital public health issues. Exposure caused by radiations are mainly due to ^{222}Rn, ^{228}Ra, and ^{210}Po radionuclides (Bem *et al*., 2012). The underlying health risks from radon in water is lung cancer from inhaling radon discharged from water during usage (ICRP, 2008). Though small, there's some risk of getting stomach cancer from drinking radon contaminated water. In terms of radon in water, the risk involved in developing cancer from ingestion of water with radon is minimal. However, in the use of such water for bathing, washing and other domestic activities, the risk involved in inhaling the radon gas, increases due to the contribution it does to the already existing radon gas present in the atmosphere, resulting in levels above the permissible limit. Homes with private wells, are particularly at higher risk of getting exposed to increased radon concentration due its direct use at home.

The generally accepted "rule of thumb" is that for every 10,000 pCi/L of radon found in water supply, roughly 1.0 pCi/L will be "released" to the home's indoor radon concentration. Currently there is not any guidance for actions on radon in water levels above the recommended limit for private homes (USEPA, 2000). According to (ICRP, 2008) the minimal risk coefficient for cancer caused by radiation incidence is 5.5×10^{-2} /Sv/year, when a multiplication of that is done with an IDC of 0.1 mSv/year that comes from drinking-water gives a projected risk getting cancer of approximately 5.5×10^{-6} annually.

Man-made radionuclides can exist in water bodies for a period. These originates from discharges from nuclear fuel stations or facilities, discharges from medical facilities and hospitals sometimes contains nuclear waste materials that gets into groundwater. There is an evidence showing an increased in the risk of getting cancer, when water containing radionuclides with doses above 100 mSv are ingested after a long exposure to it, below this there hasn't been an epidemiological study to prove an increase in risk (Brenner *et al.*, 2003). There is an assumption that, the relationship between risk and exposure is linear with limit below which there is no risk. There is a dose criterion used for individuals which is 0.1 mSv/year, this represents an extremely low risk which should not pose and visible adverse effect on the health.

2.11 Methods and Instrumentation of Radon Analysis

Radon gas determination can be done in various ways. The duration equipment used determines the type of measurement done. The measurement can be done for a short period where it is referred to as a short-term measurement or determination of the gas. These methods usually ranges from three to five days to hours and minutes depending on the instruments being used. The measurement can also be for a loner duration, this makes it to be referred to as long term measurements, which last for months.

There are several methods for analysing radon some of which are solid state nuclear track detection (SSNTD), liquid scintillation counting, Electret Passive Environmental Radon Monitor (EPERM), RAD7.

2.11.1 Solid State Nuclear Track Detection

The Solid State Nuclear Track Detection (SSNTD) is quite easy and less expensive to do, however, it cannot be used to detect radon at very low levels because it's less sensitive as compared to the others. In this method, when the sample is exposed to nuclear radiation it becomes etched and is examined microscopically. Its advantages over other detectors is that it gives detailed information on specific parts and it can be measured over a long period of time, however it's quite robust.

2.11.2 RAD7 detector:

This is a type of an electronic detector which is connected to water accessory such as a bubbling kit for a period. This enables it to release the radon gas into the air in an enclosed loop. A 250 mL capacity reagent bottle which is radon tight is used to take a sample of the water and connected in a close circuit with a scintillator detection chamber coated with zinc sulphide that detects the alpha activity. A glass bulb filled with calcium chloride is also attached to serve as a desiccant which will aid in the moisture absorption, this is needed at all times to dry the steam before it enters the RAD7. The air is circulated for a period of 5 to 10 minutes in a closed circuit and till the radon is uniformly mixed and the alpha activity that results is recorded to give the radon concentration. RAD7 is portable, faster, less labour intensive and requires minimal work as compared to other methods.

2.11.3 Liquid Scintillation Counter

Measurement of radon in water can be done by a new technique whereby a radon bubbler is attached with a ZnS (Ag) Liquid Scintillation cell based radon monitor (SRM). A 150 cm^3 volume is used to sample the radon through a progeny filter and thoron discriminator in which a pump eliminates radon progenies and thoron gas using SRM. A photomultiplier tube counts the alpha scintillations regularly and gives the counting period together with other counting electronics, processed by a microprocessor unit to show the concentration of radon. It accounts for the portion of radon decay products. Before used the instrument is calibrated, it has a trace value effect and humidity effect of less than 5% and it can detect a minimum of 0.05 Bq/L radon. This method is inherently easy, fast and used often. The cost involved however makes minor companies and individuals resort to the use of other less expensive methods.

2.11.4 E-perm

Measurement of radon using the E-perm detector has proved to be an effective method for measuring radon in water. The E-perm is used with radon in water test kits where samples are taken in a premeasured containers and exposed to a suspended E-perm placed inside a large sealed measurement jar. The radon in air is calculated and then the radon in water concentration is determined. The system is made up of three parts, an electrostatically charged Teflon disk that picks the ions electret, a conductive plastic ion chamber into which the electret is loaded, and a voltage reader that records the voltage of the electret. Using E-perm for determining radon in water concentrations have shown to be an accurate and rather easy method (Tai-Pow *et al*., 1992). In other studies of radon in air and in water, E-perms have also been employed and proved to give results comparable to the other techniques like emanation methods and liquid scintillation counters (Tai-Pow *et al*., 1992; Hamlat *et al*., 2003). In instances where there's the need to do repeated measurements it is a cost effective method. (Kotrappa *et al*., 1988, 1990; Kotrappa, 1999)

Figure 2.3: An E-perm set up

2.12 Works Done In Ghana

Several works with regards to groundwater quality and assessment has been done across Ghana. Yidanna et al., (2010) worked on the groundwater quality using the spatial and multivariate analysis in the Keta basin of Ghana. Results indicated that the groundwater quality showed that 51.5 % of the samples collected from the hand-dug wells had good quality for drinking, 38.5% were fairly for consumption and 10% were of marginal quality for consumption. There were high levels of fluoride, nitrate and TDS concentrations contributing to the water quality results obtained. The water quality results obtained, according to the research were associated to the seawater effects and the silicate weathering when analyzed using the multivariate methods. The domestic water discharge and agricultural activities were the reasons associated to the high concentrations of nitrate in the study area. In their map, the weathering of minerals is a prevalent method that affects the quality of the groundwater in the basin of Keta. On salinity basis, four different types of water were identified; in a cluster analysis done which showed a group being good for irrigational activities, another marginally good for irrigational and the final one being extremely saline to use in irrigational activities.

Egbi et al (2018 worked on the hydrochemistry of shallow groundwater and surface water in the lower Volta river of Ghana. The water types identified were HCO_3-Ca and NaCl facies, mixed Na, K, HCO_3 and Ca, Mg, Cl. A realization was made such that there was an increasing electrical conductivity due to mixing of the freshwater and the seawater. This led to the groundwater moving from HCO_3-Ca type of water to NaCl type of water in the study area. There was varied extent of the seawater effects on the groundwater regardless of the sampling point during the period of sampling. According to (Fianko et al,, 2011) in a relationship between the land use and the groundwater quality, the results indicated that the activities of mankind have an impact on the ecosystem. They realized that chloride and total dissolved solids had high concentrations in places with high residential activities, moreover the highest concentrations of Na, Ca, SO_4^{2-} and NO^{3-} were found in highly populated areas and places where agricultural activities are extensive. Almost half of the boreholes had increased concentrations of NO^{3-} coming from the agricultural runoff.

Anku et al. (2008) reported slightly acidic and basic pH of the groundwater in Bongo and the communities surrounding it in the North Eastern part of the Upper East Region of Ghana. The TDS, calcium, magnesium, electrical conductivity and sodium were generally below the set by the WHO. In the Western part of the Bongo communities where population density was high, there were high nitrate concentrations ranging from 50-194 mg/L in some of the boreholes which proved that anthropogenic activities had an effect on the groundwater quality. Fluoride had elevated levels ranging from 1.5- 4 mg/L which was above the 1.5 limits set by WHO found in Bongo and the communities surrounding it, in the North Eastern part of the upper east region of Ghana. The study showed that there were low salinity content of the groundwater found in the fractured aquifers in the area.

A few works have been conducted in Ghana with regards to radon concentrations in ground water as compared to radon in air and in soil. Ackah *et al*. (2012) did a research on the sachet water present in the Accra Metropolis and identified a wide variations in the physicochemical parameters of the water. The highest concentrations of the parameters were recorded in the samples from the Accra metropolis. The results showed that the water met the standard guideline for physical and chemical qualities of drinking water as stated by the Ghana Standard Authority. However there was high concentrations in Pb levels in most of the samples collected.

Also, in a research done by Irene Opoku-Ntim *et al*., (2009) on the risk assessment of radon in some bottled water on the Ghanaian market, the study showed that the concentration of radon in bottled drinking water in greater Accra region were within the maximum contaminant level that is 11 Bq/L. the research indicated that the radon levels doesn't have any serious health risk to the public. It was of low risk and posed no hazards. However, the annual effective dose differed in due to the increase in radon concentration and were lower WHO, (2011) and UNSCEAR, (2010) limits for the public consumption 0.1 mSv/y, they further recommended that the data acquired be seen as preliminary such that further intensive studies is done on a large scale such that further detailed oriented studies is carried out on other drinking water on the markets to curb possible hazards and increase the awareness.

2.13 Works Done Worldwide

In a work done by (Kumar et al, 2012) the results indicated that the concentrations of radon in water samples found in places of Rajasthan and Delhi, had Delhi region ranges from 0.58 to 1.54 Bq/L and Rajasthan region ranges from 0.03 to 3.45 Bq/L. They recorded the highest value in Biasau of Rajasthan region and suggested that it may be as a result of leaching of high levels of radioactive rocks at the location. The values were lower in all the places than the recommended limits set by the USEPA which is 11 Bq/l. This made it good for drinking and other purposes. However, the pH of the water samples were all below the recommended limits set by WHO (1971) which is 7.0 to 8.5 except Pitampura from New Delhi which recorded 8.11. They varied from 7.02 to 7.25 for Rajasthan and 7.29 to 8.11 for Delhi regions. Three of the water samples had conductivity above the recommended limits which had no significant health effect on mankind. However, in a research conducted by (Srilatha *et al*., 2014) on the radon concentrations and the physicochemical parameters of groundwater present in Tumkur, Ramanagara and Karnataka districts in India, they realized that about 64% of the samples had radon concentrations above the maximum levels set by the EPA that is, 11 Bq/L. Also they discovered that twelve locations, representing 40% had their annual effective dose higher than the safe limit (0.1 mSv/y) set by the WHO. The contribution of the dose from the source to stomach ranged between 0.07 to 7.53 µS/y and had an average of 1.12 µS/y. All the water quality parameters tested for were below the standard set by the Bireau of Indian Standards except that of electrical conductivity, fluoride and nitrate which had values above the standard limits.

In a publication done by Najeeb *et al*. (2010) they reported high concentrations of radon in groundwater in Siwalik and Garhwal Himalayas, it ranged from 5 -887 Bq/L, Bangalore of Karnataka ranged from as high as (55.96 -1000 Bq/L), Punjab in the Doon valley of Himachal Pradesh, it ranged from 25-95 Bq/L and finally springs Uttarakhand, Sikkim, Bhutan and West Bengal 0.1 - 441.2 Bq/L. In a research done by Hamzah et.al., (2011) they found that the concentration of radon and radium in water from the sampled points were within the acceptable limits, however they varied at different points due the pathways, source and depth from which they come from.

The use of the E-perm measurement kit in the assessment of radon in water by Kitto et al. (2007) showed that the concentration of radon in water is 14% negatively biased for the EIC measurements and 12% in terms of the standard solutions. Furthermore the results from the duplicated samples of water that the LS counting varied by 5% the electret based procedure differed by 10%. A suggestion was made to give correction addition of 13% would lead to the generation of accurate results in terms of the electret-based procedure.

Skeppström & Olofsson, (2006) in a study on the prediction method for radon in groundwater using GIS and multivariate statistics, realized that there is a correlation of radon concentration with the type of bedrock, the distance from the fracture zone and the depth of the well. Additionally, the study stated that the spread and presence radon in groundwater are influenced by several factors that can help in the prediction of radon generally. However, no direct data on the geochemical process of flow was stated.

Hamzah et al. 2011 worked on determining radon activities using liquid scintillation counter. Results indicated that the radon concentrations in the unfiltered water were slightly higher than the filtered water. This was associated with the fact that, the suspended solids in the water were removed in the filtration process and the radionuclide present got lost. There were differences in the activities due several factors. In the analysis of radon and physiochemical properties of water in Delhi India done by Srithala et al. (2014), the results for the physicochemical properties of the samples in the study area, indicated that, the pH for all the samples were within the standard limits except that of Pitampura in New Delhi which had pH value of 8.11. The total dissolve solids in the water samples were varying between 0.399 - 1.966 ppt. There conductivity of the samples were ranging from 0.397 - 3.92 mS/cm. Generally, the physiochemical parameters for the towns were in the recommended limits set by the WHO. However, three towns that had conductance above the recommended limits set, due to natural mineralization but it had no significant health effect.

CHAPTER 3

METHODOLOGY

The methodology focused on the description of the study area, choice of sampling sites, samples, sampling techniques and sample preservation method. It also describes the sample preparation and sample analyses as well as data analysis and quality control.

3.1 Research Proposal Approval and Ethical Consent

The research project was approved by the Department of Nuclear Sciences and Applications, School of Nuclear and Allied Sciences. Permission to conduct the study in the communities were obtained from the community heads whiles permission to use the individual hand dug wells for the study was obtained from the heads of households where the hand dug wells were located. The study is entirely academic and participation of households with hand dug wells in the study was voluntary. The purpose of the study was explained to all the households and oral consent was obtained from each household. All households were assured of confidentiality.

3.2 The Study Area

The study was conducted in the Keta Municipality which is located in the Volta Region of Ghana. Keta Municipality is a low-lying coastal plain located between longitude 0.3^0E – 1.05^0E and latitude 5.45^0N – 6.005^0N at the east of the Volta estuary which is about 160 km from Accra (Fig. 3.1). It shares common borders with Akatsi South District to the north, Ketu North and South District to the east, South Tongu District to the west and the Gulf of Guinea to the south.

The main towns that makes up the municipality include: Tegbi, Xekpa, Vui, Nukpesekorpe, Dzelukope, Abutiakope, Kedzikope, Keta, Vodza and Kedzi. The total surface area of the Municipality is 753.1 km^2. The Keta Municipality has a household population of 144,747 with a total number of 37,705 households. The total population of the Municipality is 147,168 and the average household size in the Municipality is 3.8 persons (GSS, 2014).

Figure 3.1: Map of the study area

3.2.1 Relief and Drainage

The Municipality is a low-lying coastal plain with the highest point of 53 meters above sea level and the lowest between 1 to 3.5 meters below sea level there by making it vulnerable to tidal waves and sea erosion. The Municipality falls within three main geographic belts which are the narrow coastal strip, the lagoon basin of the middle belt and the plains of the north. The coastal strip is marked by sand bars with a few sea cliffs bordering the coast. The Lagoon Basin is generally marshy and is made up of lagoons and islands such as Atiavi, Alakple, Seva, Anyako and Dudu. The major lagoons include Keta, Angaw Agbatsivi, Logui, Nuyi and Klomi. Into this basin drains some streams such as Angor, Avida, (near Hatorgodo), Awafla (near Awaflakpota), Nukpehui (in the north-western part of the Municipality), Tordzie and Kplikpa and tributaries of the Volta River. (GSS, 2014)

3.2.2 Climate and Vegetation

There are two clearly defined seasons in the municipal, the dry season and the wet season. The rainfall season is between April and July, however there are minor falls between September and early November each year. June and July serve as the periods with the highest rainfall in the year. During the early hours and evenings of the day, the humidity is high. The Keta Municipality has quite high temperatures. In the warmest month, the mean temperature goes as high as 30^0 C which is March and can go as low as 26^0 C in august during the coldest month. The Municipality lies in the coastal savannah zone, its vegetation, consists of the short trees, coconut trees, short grasses, mangrove swamps, palm trees, shrubs and neem trees. (GSS, 2014)

3.2.3 Geology

The Keta basin is filled with Cretaceous-Eocene marine sediments consisting of limestone, shale and glauconitic sandstone outcrops in the eastern side of the basin near the boundary between Togo and Ghana (Jorgensen and Banoeng-Yakubo, 2001; Yidana *et. al.* 2013). It lies along the Gulf of Guinea and consist of the early precambian dahomeyan gnesis, schists and migmatities. It has scattered deposits of Neogene continental sediments covering the Cretaceous-Eocene limestone and sandstones, found in the north-eastern sections of the basin.

The Keta basin is dominated by Quaternary unconsolidated coastal sediments, marine sands and gravels, which are 30 m thick on the average, in the central part of the basin they however, thicken going towards the Volta River Estuary (Yidana *et al.,* 2013). The geology of a land closer to a water source has a high possibility to affect the concentration of radon gas present. Groundwater present at areas with granite and metamorphic rocks, usually has relatively high radioactivity due to the radium, uranium and radon isotopes present (Singaraja *et al*., 2016). Keta basin lies on the extreme southeastern part of Ghana's Gulf of Guinea region. It is in between the chain of sedimentary basin of Mesozoic and tertiary age. It is made up of a mixture of marine and non-marine sediments of about 870 m Paleozoic. These sediments are overlain by 3,600 m of Mesozoic- tertiary deposits.

The soil type of the place is as a result of the parent rock present hence since the parent rock is sedimentary the soil formed is easily leached making the soil highly infertile. This is shown by a low presence of mangroves at the location (Manson *et al*., 2013). The basin is made of rocks such as sand, shale, clay, gravels and siltstones with layers of fossiliferous limestone. It has a tectonic block and it's made up of syn-transform rocks of the early cretaceous age at the on-shore and off-shore areas. The Keta basin went through gradual subsidence, block faulting and graven filling followed by extensional faulting in the earliest cretaceous age.

3.2.4 Socio-Economic Activities

The Keta Municipality is mainly an agricultural district, with the majority of the population engaged in crop farming, livestock farming, fishing and other related trading activities. A wide range of smallscale industrial activities also take place in the Municipality. The industrial activities are Agro-based (fish processing, cassava processing, sugar cane juice distilling, and coconut-oil extraction), Mining (salt mining and sand winning), Wood-based (carpentry, standing brooms), Textile (kente weaving, tailoring/dressmaking), Straw weaving (straw mat weaving (Ketsiba) and pouch weaving (Kevi),

3.3 Reconnaissance Survey/Selection of Sampling Site

A field reconnaissance visits were undertaken to the entire study area to identify sampling locations. The field survey, spanned over a period of four weeks included visits to the Municipal Assembly, towns and various communities within the Municipality as well as individual homes where hand dug wells exist. The choice of sampling sites was based on the source of water for domestic activities, the bulk of human activities and population densities.

Sampling location targeted the hand dug wells in the Municipality that are used for domestic activities. Ten Major communities within the Municipality where hand dug wells were the only source of water for domestic activities were identified and earmarked for the study (Fig. 3.2). Hand dug wells in these communities earmarked for the study were private owned but are used by the other members of the communities.

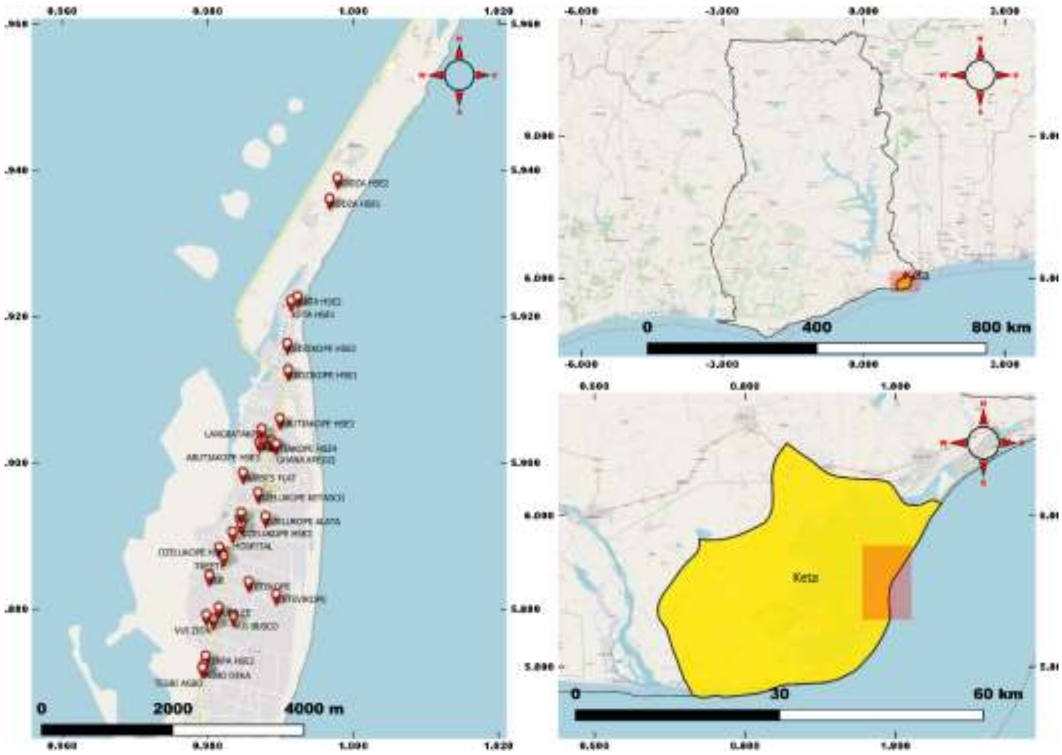

Figure 3.2: Map of the Keta Municipality showing the sampling points

3.4 Sampling

3.4.1 Sample containers

High density polyethylene (HDPE) containers (500 mL) were used for collection of samples for physico- chemical analyses while 68 mL Sampling Bottles with Teflon® gasket screw caps were used to collect samples for radon analysis. All the sample containers were thoroughly washed with soap and water. The high-density polyethylene (HDPE) bottles were immersed in warm liquid soap bath for two days, rinsed with de-ionized water and immersed in 10 % HNO_3 at room temperature for three days. Bottles were further rinsed with de-ionized water and dried overnight in a clean oven at 60 ºC. The bottles were then removed from the oven and allowed to cool-down, capped tightly and double bagged in re-sealable polyethylene bags and stored (US EPA, 1983).

3.4.2 Collection of Sample/Field Analysis

Sampling was done between November 2019 and March 2020. The water samples were collected from hand dug well in private homes from ten selected communities (Table 3.1).

Table 3.1: List of Communities where hand dug well water samples were taken

Name of Community	No. of hand dug wells sampled
Vui	4
Xekpa	2
Dzelukope	4
Abutiakope	6
Keta	2
Kedzi	2
Vodza	2
Tegbi	2
Langbatakpo	2
Tetevikope	4

Overall, 30 hand dug wells were sampled. The samples were collected separately from private hand dug wells with strict adherence to the sampling protocol as described by standard methods (APHA, 1998). Water samples were collected from the hand dug wells using the existing infrastructure which is made up of a plastic bucket tied to a rope (Fig. 3.3).

Figure 3.3: Sampling of water from hand dug well using infrastructure.

Sampling was done early in the morning and in the evenings. At each sampling point, three samples were collected for cations, anions, and radon analyses. Samples for radon analysis were collected into a 68 mL glass bottle. The glass bottle was inserted into the bucket containing the water and filled to the brim. The bottle was capped in the bucket water to ensure that no air gets into the bottle and kept for radon analysis. Samples for physico-chemical analyses were collected into 500 mL High density polyethylene (HDPE) containers. The GPS coordinates of each sampling points was taken and recorded using the eTrex Vista GPS device. The depth of each of the hand dug well from the ground to the surface of the water was determined using a rope and a surveyor's tape. The age of each hand dug well was recorded from the owners of the hand dug wells.

Samples for physico-chemical analysis were carried on ice in an ice cooler from the field and stored in a refrigerator at 4 ^{0}C prior to analysis. It was further transported to the Nuclear Chemistry and Environmental Research Centre (NCERC) of the Ghana Atomic Energy Commission whiles radon samples were transported to the Nuclear Detection Laboratory of the National Nuclear Research Institute (NNRI) of Ghana Atomic Energy Commission.

3.5 Field Analysis

Water samples collected were analysed by both classical and automated instrumental standard methods for the analysis of water and wastewater. Water temperature, electrical conductivity (EC), total dissolved solids (TDS), salinity, turbidity and pH were measured at each sampling site using the multi-parameter LaMotte Tracer pH/TDS/Salt PockeTester portable meter (Fig. 3.4). Alkalinity was determined in the field using titration (APHA, 1998).

Figure 3.4: Measurement of physical parameters with LaMotte Tracer PockeTester meter

3.6 Laboratory analysis

3.6.1 Radon Analysis

Each water sample was placed in an individual 68 mL glass vial which was then placed in the bottom of large glass measurement jar. The initial volt of radon in the detector E-Perm (Fig. 3.5) was taken and recorded. The 68 mL glass containing the water was slightly opened and the E-perm was then placed in each of the measurement jars and suspended in the air above the water. The lids of the measurement jars were closed and sealed to make them radon-tight. The date of sampling, time of sampling, time of fixing it in the jar was then recorded and each glass jar was labelled with the sample ID. Radon reaches equilibrium between the water and air, which the E-perm measures. After 3 days, which serves as the exposure period, the measurement jars were opened and the E-perms were removed and the volt of radon recorded in an excel sheet.

Figure 3.5: An E-perm detector used to measure Radon

The concentration of radon in the analysed hand dug well water was computed using equation

$$RnC = \left(\frac{[I-F]-(IVD\times D)}{(CF\times D)} - (BG \times G) \times elevCF\right) \qquad \text{(Equation 1)}$$

Where;

- RnC the radon concentration in units of pCi/L
- I the initial electret voltage
- F the final electret voltage

- D the exposure period in units of days
- CF the calibration factor
- BG the background gamma

$$D = 3 + \frac{8}{24} = 3.333$$

3.6.2 Groundwater Hydrochemistry

Hand dug water samples collected were analysed by both classical and automated instrumental standard methods for the analysis of water and wastewater (APHA, 1998).

3.6.3 Determination of chloride (Cl^-)

The argentometric method was used to determine the level of chloride in the water samples. Water sample (25 mL) was measured into a 250 mL conical flask and 3 drops of 5% potassium dichromate indicator added and mixed thoroughly. The mixture was titrated against 0.0141 M Silver Nitrate solution (0.0141 M $AgNO_3$) until the colour changed from yellow to brick-red. A blank sample (distilled water) was subjected to the same treatment. The titre value was recorded and the concentration of chloride computed using the formula:

$$Cl^-(mg/l) = \frac{(V_A - V_B) \times M \times 35.45 \times 1000}{V}$$

$VA = Volume\ of\ Silver\ Nitrate\ for\ sample$

$VB = volume\ of\ Silver\ Nitrate\ for\ blank$

$M = Molarity\ of\ titrant$

$35.45 = Equivalent\ weight\ of\ Chlorine$

$V = Volume\ of\ sample\ taken\ (mL)$

3.6.3.1 Determination of sulphate (SO_4^{2-})

The turbidimetric method was used to determine sulphate in the water samples. Sulphate ion is converted to barium sulphate suspension under controlled conditions. The resulting turbidity is determined spectrophotometrically (Fig. 3.6) at a maximum wavelength of 420 nm. The equation for the reaction of barium and sulphate is

$$SO_4^{2-}{}_{aq} + Ba^{2+}{}_{aq} \text{ -----> } BaSO_{4\ s}$$

Water samples (10 mL) was measured into a test tube and 1mL of acid salt solution added to it and stirred gently. Glycerol (0.5 mL) was then added to the mixture followed by the addition of $BaCl_2$ (0.05 g) and stirred for 1 minute. The mixture was poured into a spectrophotometer cell and the absorbance read after five minutes at wavelength of 420 nm. A calibration curve was prepared using serially diluted sulphate standards solutions (0, 10, 20, 40, 80) mg/L. The concentration of sulphate in the water samples were deduced from the calibration curve and expressed using the formula.

$$SO_4^{2-}\ (mg/L) = \frac{Concentration\ from\ calibration\ curve\ \times 1000}{Volume\ of\ sample\ (m/L)}$$

Figure 3.6: Analysis of Sulphate, phosphate and nitrate using the spectrophotometer.

3.6.3.2 Determination of total phosphate

The ascorbic acid method was used to determine phosphate in the water samples. Acid digestion is used to release phosphates from combination of organic matter as orthophosphate. Ammonium molybdate and potassium antimonyl tartrate react in acidic medium with dilute solution of orthophosphate to form antimonylphosphomolybdate complex which is reduced to intensely blue complex by ascorbic acid and measured spectrophotometrically at a wavelength of 880 nm (APHA, 1998).

Water samples (10 mL) was pipetted into a dry clean 100 mL conical flask and one drop of phenolphthalein added to it. To the mixture was added 2 mL of combined reagent and mix thoroughly. The mixture was allowed to stand for 5 minutes and the absorbance of the solution read at a wavelength of 880 nm on a spectrophotometer. A calibration curve was prepared using serially diluted phosphate standards solutions (0, 0.2, 0.4, 0.6, 0.8, 1.0) mg/L. The concentration of phosphate in the water samples were deduced from the calibration curve and expressed using the formula

$$PO_4^{3-} - P \ (mg/L) = \frac{Concentration\ from\ calibration\ curve\ \times 1000}{Volume\ of\ sample\ (m/L)}$$

3.6.3.3 Nitrate Determination

The brucine method was used to determine Nitrate levels in the water samples. Water samples (5 mL) was pipetted into a test tube and 1mL of 30% sodium chloride (NaCl), 5mL of 6.5 M sulphuric acid (H_2SO_4) and 0.25mL of Brucine were added respectively. The mixture was heated in a water bath for 20 minutes at 98 ºC and was allowed to cool for 5 mins. The absorbance mixture was determined using a UV spectrophotometer at a wavelength of 410 nm.

A calibration curve was prepared using serially diluted KNO_3 standards solutions (0, 0.02, 0.04, 0.06, 0.08, 0.1) mg/L. The concentration of nitrate in the water samples were deduced from the calibration curve and expressed using the formula

$$NO_{3-} - N \ (mg/L) = \frac{Concentration\ from\ calibration\ curve\ \times 1000}{Volume\ of\ sample\ (m/L)}$$

3.6.3.4 Total Hardness Determination

Total hardness of the water samples was estimated titrimetrically using Ethylendiaminetetraacetic acid (EDTA). Water samples (25 mL) was transferred into a conical flask and a 2.5 mL ammonium buffer solution added to it. The mixture was mixed thoroughly and titrated with 0.012 M EDTA using 3 L of Erichrome Black T indicator until the colour changed from blue-black to light blue.

The total hardness of the water was calculated in mg/L using the formulae:

$$Total\ \text{hardness as CaCO3 (mg/l)} = \frac{\textbf{Titre}\times\textbf{B}\times\textbf{1000}}{\textbf{25ml}}$$

Where B: 1 M of EDTA equivalent to 1milligram of calcium carbonate

3.6.3.5 Determination of Calcium and Magnesium

Calcium levels in the water samples were determined by the complexometric method using EDTA**.** Water sample (25 mL) was measured into a conical flask and 2 mL of 1 M NaOH added to it. The mixture was thoroughly mixed by swirling and 0.1g of murexide indicator added to it. The pink mixture was titrated with 0.01 M EDTA solution until it reached a purple colour end point. The calcium concentration was then calculated using the formulae:

$$Calcium\ Hardness\ as\ CaCO3\ (mg/l) = \frac{A\ \times 1000}{V}$$

$$Ca^{2+}\ (mg/l) = Calcium\ Hardness\ as\ CaCO3\ (mg/l)\ x\ 0.4$$

Where

A= mL of EDTA titrant

V= Volume of sample used

3.6.3.6 Determination of Magnesium

The concentration of Magnesium in the water sample was estimated as the difference between total hardness and Calcium hardness.

$$Mg\ Hardness\ as\ mg/L\ CaCO3\ =\ [Total\ Hardness - \ Calcium\ Hardness]$$

$$Mg2+\ (mg/L)\ =\ \ Magnesium\ Hardness\ as\ CaCO3\ (mg/L)\ x\ 0.243$$

3.6.3.7 Determination of Total Alkalinity

Water samples (50 mL) of was measured into a 200 mL conical flask and 2 drops of methyl orange indicator added. The mixture was titrated against 0.1 M HCl until the colour changed from yellow to orange (APHA, 1998). The Alkalinity of the sample was calculated using the following relation:

$$Alkalinity\ as\ CaCO3\ (mg/l)\ =\ \frac{A\ x\ M\ x\ 50{,}000}{V}$$

Where

A = volume of acid used (mL)

V = volume of water sample (mL)

M = Molarity of standard acid used.

3.6.3.8 Determination of Sodium and Potassium

The flame photometer was used for the sodium and Potassium analysis. The Flame Photometer, (Sherwood Flame Photometer Model 420) (Fig. 3.7) was switched on for 15 minutes before use to achieve optimum operation of the equipment. The machine was calibrated with distilled water which served as a blank and a mixed sodium and potassium standards solution (100 mg/L). The calibrated solution was prepared by adding about 2 mL of lithium standard (100 mg/L) to 5 mL of the blank (distilled water) and 5 mL of the mixed sodium and potassium standard. After the calibration, 5 mL each of the filtered water samples was analysed by adding 2 mL of the lithium standard to the various samples and aspirated through the photometer to record the corresponding values of sodium and potassium.

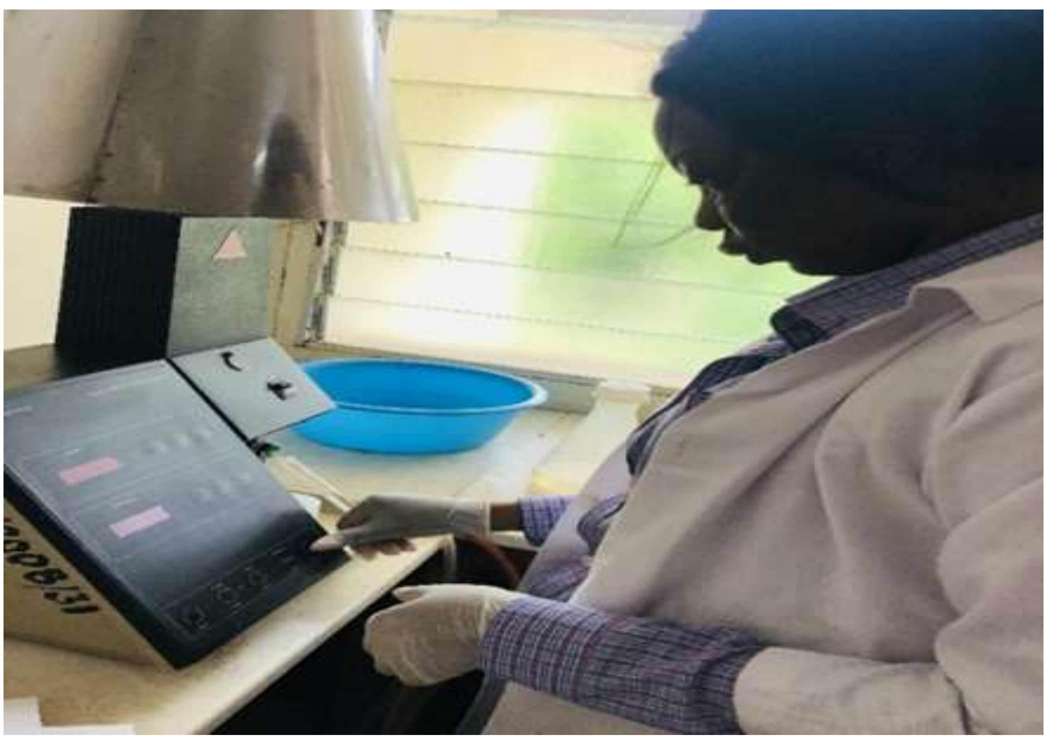

Figure 3.7: Analysis of sodium and potassium using the Sherwood 420 flame photometer

3.7 Data Analysis

The data obtained from the laboratory analysis were analysed using mathematical analytical tool MATLAB R2015a (The Math Works Inc., Natick, Massachusetts US. MATLAB R2015a, 2015). MATLAB allows matrix manipulations, plotting of functions and implementation of algorithms. Results were also plotted into graphs using MATLAB. The spatial/ location-based variations in the parameters was conducted. A t-test was also conducted to show temporal and seasonal variations in the measured parameters. Differences were considered significant at 95% confidence level.

3.8 Assessment Methods

Data obtained during the laboratory analysis were used in the evaluation of Annual Effective Dose of Radon due to Ingestion, Annual Effective Dose due to Inhalation, Comprehensive Pollution index (CPI), Sodium Adsorption Ratio and Water Quality Index.

3.8.1 Annual Effective Dose of Radon Due to Ingestion

The annual effective dose due to the ingestion of radon from groundwater (Hing), was calculated according to equation 2 (Tabassum et al., 2012; Thabayneh, 2015; Opoku-Ntim et al., 2019)

$$H_{ing}\ (mS/yr)\ =\ C_{Rn}\ x\ D_{ing}\ x\ L$$

Where

H_{ing}; committed effective dose, $mSvy^{-1}$

C_{Rn}: radon concentration in water, $Bq\ell^{-1}$;

D_{ing}: conversion factor, 1x10^{-8} $SvBq^{-1}$;

L: annual water consumption by an adult in litres.

The daily water consumption by an adult of 2 litres (730 litres per year) was used. (UNSCEAR, 1993). UNSCEAR has estimated that the conversion factor for ingestion of radon in water is 10^{-8} $SvBq^{-1}$ for an adult, 2x10^{-8} $SvBq^{-1}$for a child and 7x10^{-8} $SvBq^{-1}$for an infant (UNSCEAR, 1993). According to UNSCEAR, doses to children and infants for similar consumption rates could be a factor of 2 and 7 higher, respectively (UNSCEAR, 2000).

3.8.2 Annual Effective Dose Due to Inhalation

The annual effective dose due to the inhalation of radon (H_{inh}) resulting from the radon concentration in drinking water, was calculated using the relation (Tabassum et al., 2012; Thabayneh, 2015; Opoku-Ntim et al., 2019):

$$H_{inh}\ (mSv/yr) = C_{Rn} \times R \times F \times T \times D$$

Where

C_{Rn} - radon concentration in water, in Bqm^{-3},

R – air to water concentration (10^{-4}),

F - Equilibrium factor between indoor radon and its progeny (0.4).

T - Exposure time in hours (8760 hy^{-1})

D - Dose conversion factor 9 mSv $(Bqhm^{-3})^{-1}$ (UNSCEAR, 2000).

3.8.3 Comprehensive Pollution Index

The Comprehensive Pollution Index (CPI) is a method used to determine the quality of water. This index is determined using the concentration of the water parameters in the water sample divided by the standard limits set for water quality. It is used to find the quality status of the water.

The Equation for calculating $\text{CPI} = \frac{1}{n}\sum_{i=1}^{n} PI$

$$PI = Ci/Si$$

Where PI equals the pollution index of the i^{th} parameter.

The concentration of the i^{th} parameter is Ci

The standard permissible limit for that parameter is Si

n is the total number of parameters.

The Pi value when is less than 1 indicates that the quality of the water is up to the recommended standard, however when the PI is greater than 1 it indicates that the water is polluted. The category of ranking the water quality is given below.

Table 3.2 Comprehensive pollution index and ranking

CPI	Ranking
0 - 0.2	Clean
0.21 - 0.4	Sub clean
0.41 – 1	Slightly polluted
1.01 – 2	Moderately polluted
≥ 2.01	Severely polluted

3.8.4 Water Quality Index

Different water quality indices have been developed since the early 1960s to assess the suitability of water for drinking and other purposes (Harkins, 1974; Horton, 1965). An efficient, useful and reliable way of assessing and communicating the quality of water is by the use of Water Quality Index (WQi)

$$WQi = \frac{\Sigma\, QiWi}{\Sigma\, Wi}$$

Where, Qi = Quality rating,

Wi = Relative (unit) weight for nth parameter.

$$Wi = \frac{1}{Si}$$

Si= Standard permissible value for nth parameter

1 = Proportionality constant.

Si = the standard values of the water quality parameter

$$Qi = \frac{(Vactual - Videal)}{(Vstandard - Videal)} \times 100$$

Where,

Qi = Quality rating of ith parameter for a total of n water quality parameters

V_{actual} = Actual value of the parameter attained from the laboratory analysis

V_{ideal} = Ideal value of that parameter obtained from the standard Tables.

V_{ideal} for pH = 7 but all other parameters it is zero.

$V_{standard}$ = Recommended WHO standard of the water quality parameter. (WHO 2004; ICMR 1975).

Table 3.3 Parameters, standard values, ideal and assigned weighing factor.

Parameter	**Standard value, Si**	**Ideal value, Cid**	**1/Si**
p H	8.5	7	0.117647
TDS	1000	0	0.001
Conductivity	1500	0	0.000667
Alkalinity	200	0	0.005
T. hardness	500	0	0.002
Chloride	250	0	0.004
Sulphate	500	0	0.002
Nitrate	50	0	0.02
Sodium	200	0	0.005
Potassium	30	0	0.033333
Calcium	200	0	0.005
Magnesium	200	0	0.005
Phosphate	0.3	0	3.333

The calculated WQI values were then used to rate the groundwater quality as excellent, good, poor, very poor and unfit for human consumption (Table 3.4).

Table 3.4 Water Quality Index Scales

WQI VALUE	**WATER QUALITY**
< 50	Excellent
50 -100	Good Water
100 – 200	Poor water
200 – 300	Very poor water
>300	Water unsuitable for drinking

Source: (Bureau of Indian Water standards, 1991)

3.8.5 Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio was calculated to determine the permeability of ions in the groundwater using the formulae:

$$SAR = \frac{Na}{\frac{\sqrt{Ca}+\sqrt{Mg}}{2}}$$

Values above 13 were considered to have a sodium hazard.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results of the hydrochemistry of groundwater, particularly hand dug wells in the Keta municipal have been tabulated and presented in graphs and charts. The data obtained was compared to the World Health Organization's (WHO, 2011) and Ghana standard authority (2005) recommended guideline values for drinking water.

4.2 Hydrochemistry of Groundwater

The pH of the water samples from the hand dug wells analysed ranged between 7.14 –9.29. The highest pH was obtained in March in ABH2 and the lowest in November DZH1 (Table 4.1). Few of the samples were above the WHO (2011) and the Ghana standard board (2010), recommended limits for pH in water. The pH levels recorded were statistically different between the periods of sampling, differences were at a p-value of 0.0000017. The results showed that water in the hand dug wells were between neutral to basic. High pH values is said to influence the taste of water and may lead to the accumulation of calcium and magnesium in pipes (Egbi et al, 2011)

The conductivity of the water samples ranged between 309 µS/cm and 11370 µS/cm indicating high variability in salinity. The highest conductivity was recorded in DZH4 and the lowest recorded in XEH2. The conductivity of most freshwaters ranged from 10 to 1000µScm^{-1} (Karikari *et. al.*, 2007). The WHO, (2011) and Ghana standard Authority, (2005) recommended limits for conductivity in water is 1000mg/l hence 23% of the hand dug wells (Fig. 4.1) have water with conductivity above the guideline values.

Table 4.1 Physical Characteristics of hand-dug wells in in the Keta Municipality

	pH		Temp(°C)		Conductivity(Ms)		Salinity(ppmS)		TDS(ppm)	
Sample code	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
VI	7.54	8.75	31.2	31.3	828	1989	990	4580	1360	5760
XEH1	7.65	8.59	29.2	30.1	438	877	200	4890	310	6130
XEH2	7.26	8.40	29.1	30.5	309	1179	1600	6760	2120	8230
DZH1	7.14	8.00	29.5	30.0	1037	1549	780	4600	1120	7160
DZH2	7.55	8.65	29.1	30.0	900	945	660	4980	450	6390
DZH3	7.7	8.80	29.9	32.5	856	889	420	4950	600	6200
DZH4	7.55	8.58	30.2	31.1	945	11370	560	5260	800	6600
ABH1	7.61	9.15	31.5	32.7	569	1313	240	650	360	910
ABH2	7.72	9.29	32.6	33.3	857	1002	490	4760	740	5990
ABH3	7.65	9.19	31.1	32.8	573	836	250	4590	480	5830
ABH4	7.77	9.18	31.2	31.5	642	847	300	4720	440	5910
KEH1	7.61	8.98	30.3	30.7	976	1705	780	5380	149.62	7380
KEH2	7.3	8.59	31.2	32.0	320	1057	1700	5940	2280	6170
KDH1	7.44	8.75	30.6	31.0	887	1079	520	4880	830	7720
KDH2	7.38	8.82	30.5	31.4	1170	1484	730	6270	1020	6450
VIB	7.38	8.77	31.3	31.6	877	1248	600	5040	860	6460
VDH1	7.75	9.23	31.3	32.8	923	1020	490	5140	700	9870
VDH2	7.45	8.78	32.1	32.1	696	1414	840	3830	4860	5880
TRT	7.52	8.82	31.0	31.0	744	842	350	4690	520	6420

GKZ	7.59	8.65	30.9	31.0	921	1297	630	5050	890	6460
TTK	7.54	8.73	31.5	32.5	933	1353	650	5140	930	6340
AGD	7.65	8.50	31.1	31.6	906	1209	630	5060	870	6600
NFT	7.61	8.75	31.1	31.6	945	1189	570	5260	820	6730
JBL	7.36	8.48	28.8	29.4	964	1065	500	5370	730	6050
LGK	7.69	8.65	30.5	30.7	865	870	410	4770	600	6510
VIZ	7.18	8.52	30.4	30.4	741	932	350	5180	510	6630
TGA	7.26	8.76	30.8	31.6	943	1032	490	5290	700	5850
ECG	7.67	8.82	29.6	31.0	511	838	230	4660	350	700
HPL	7.48	7.90	29.3	31.9	773	896	370	4990	530	4960
TTV	7.74	8.89	32.3	31.8	906	1028	490	6310	720	7380

There were no significant differences in the conductivity values obtained. The extremely high conductivity values recorded in DZH4 may be due to refuse damp located by the hand dug well. Conductivity of groundwater is influenced by the rate of flow (viscosity), the pressure, charge and temperature (McNeil and Cox, 2000). Viscosity of water which is temperature dependent, relatively high temperatures recorded due to the lack of rainfall activities could cause the viscosity of the groundwater to be low and movement of water in the soil will be relatively higher, leading to high conductivity values recorded. Also the increased in sea water intrusion into groundwater aquifer during dry season causes high conductivity levels in water, this explains the high conductivity recorded.

The total dissolved solids (TDS) in groundwater is a factor of the ions dissolved in the water. TDS values recorded ranged from 149 mg/L - 9870 mg/L. TDS values for some communities was extremely above the 1000mg/L limits set by the WHO. Sea water encroachment into groundwater during dry season where the water Table is low could contribute to a high TDS concentration. At VDH2, the wells were extremely close to the sea hence the sea water intrusion could account for the high value.

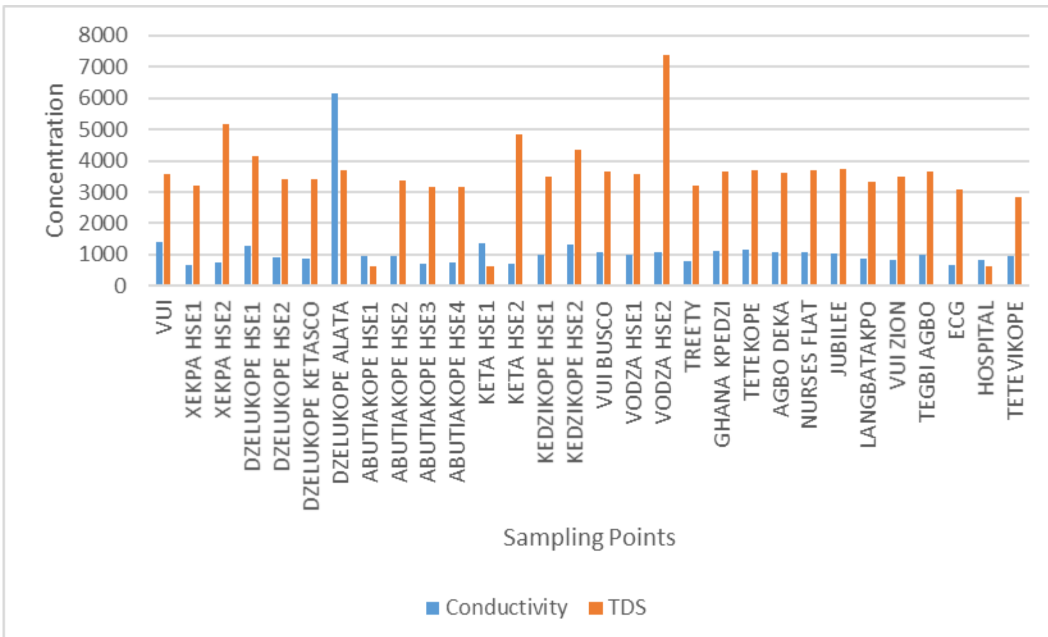

Figure 4.1: A graph of mean conductivity and TDS in the municipality

The results of the analyses indicate that water from hand dug wells in the Keta Municipality was not fresh since the total dissolved solids (TDS) of the water samples not exceed 500 mgL^{-1} (Kattan, 2006). The conductivity registered also give cause for concern since the water from the hang dug wells is used for domestic activities without treatment.

The salinity (Fig. 4.2) of the sampled hand dug well waters ranged between 200mg/L - 3830 mg/L. There were significant differences in the salinity for the sampling period the differences were significant at a p-value of 0.0000021. High salinity values is associated to the periodic sea water intrusion and the weathering of the minerals in the soil. There is a variations of groundwater hydrochemistry with the distribution of salinity. A series of factors adds to the salinity content of groundwater in coastal regions such as Keta, these changes the hydro chemical components of the groundwater. Highly saline water is capable of hindering the permeability of soils, reduces the presence of water stored in the soil thereby decreasing the osmotic crop potential necessary for crop yield which may cause low productivity of plants and soils (Yidanna et al, 2010).

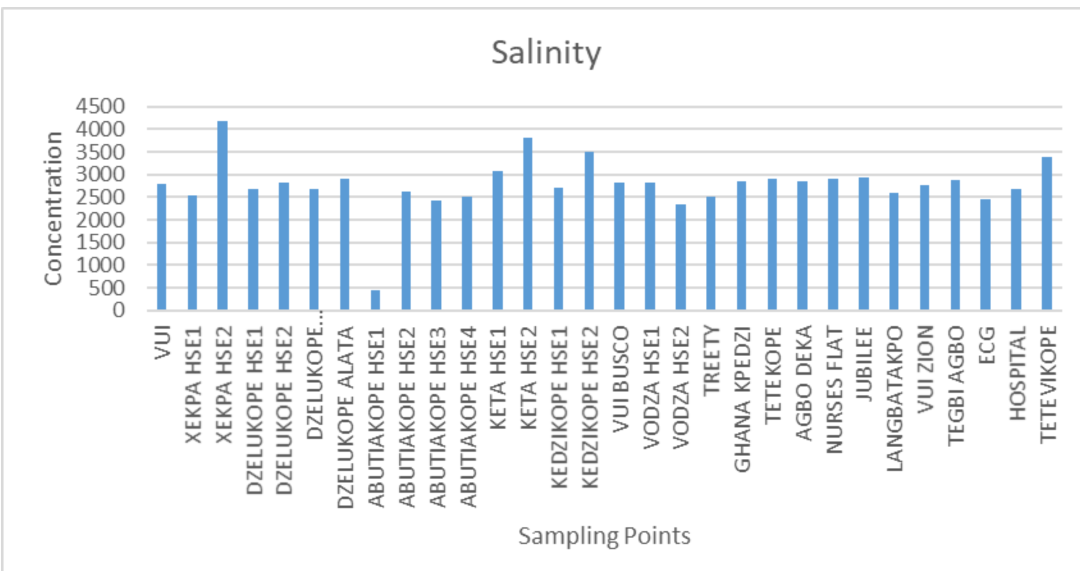

Figure 4.2: A graph of mean salinity in the municipality

4.3 Chemical characteristics of hand dug wells in the Keta Municipality

Raw water from hand dug wells in the Keta Municipality is used by the communities for diverse purposes such as drinking, cooking and informal irrigation. The results of the chemical characteristics of water from the hand dug wells revealed considerable variations. Chloride ions concentration ranged from 17.99 mg/L – 2823 mg/L (Table 4.2). The highest concentration was found in VDH2 and 23.33% of the samples were above the (WHO, 2011) limits of 250 mg/L. Proximity of XEH2, KDH2 and VDH2 to the Keta Sea and the lagoon could account for the high chloride levels.

Table 4.2: Chemical Characteristics of hand dug wells in the Keta Municipality

	SO_4^{2-} (mg/L)		NO_3^- - N (mg/L)		PO_4^{3-} - P(mg/L)		Cl^- (mg/L)	
Sample code	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
VI	6.43	26.23	1.54	1.56	0.11	1.42	27.99	195.94
XEH1	3.77	13.73	0.35	1.04	0.05	0.39	19.99	49.98
XEH2	13.41	24.01	0.35	0.98	0.08	0.13	611.81	833.74
DZH1	17.07	36.54	0.57	0.94	0.81	1.07	139.96	209.93
DZH2	4.76	12.53	1.12	2.63	0.11	0.29	55.98	87.97
DZH3	6.02	18.46	1.59	1.83	0.36	0.47	47.99	51.98
DZH4	14.69	19.69	0.96	1.01	0.9	1.05	87.97	101.97
ABH1	2.81	11.11	0.77	1.05	0	0.15	17.99	19.99
ABH2	6.89	17.47	1.05	1.33	1.08	2.13	67.98	71.98
ABH3	4.92	5.19	0.45	0.86	0.03	0.06	19.99	23.99
ABH4	3.39	8.89	0.89	1.57	0.01	0.1	27.99	33.99
KEH1	13.16	22.9	1.85	1.93	1.27	1.55	135.96	203.94

KEH2	19.5	30.8	1.19	1.81	1.15	1.29	469.85	497.85
KDH1	11.6	20.99	1.16	2.03	0.11	0.3	69.98	79.98
KDH2	12.77	34.44	0.29	1.38	0.69	0.78	131.96	793.75
VIB	12.47	26.48	0.97	1.52	0.29	0.33	139.96	157.95
VDH1	19.95	36.79	0.89	1.01	0.15	0.3	87.97	207.94
VDH2	6.04	37.35	1.1	1.29	0.17	0.23	291.91	2823.12
TRT	5.65	15.74	0.86	1.03	0.2	0.57	59.98	63.98
GKZ	11.37	38.7	1.05	1.11	0.34	0.6	97.97	113.96
TTK	10.78	32.28	1.09	1.56	0.08	0.18	163.95	187.94
AGD	7.53	14.58	0.24	1	0.43	0.54	19.99	89.97
NFT	15.29	24.69	1.2	1.84	0.17	0.47	115.96	127.96
JBL	14.21	25.56	0.49	0.86	0.52	0.86	109.97	171.95
LGK	5.95	11.36	1.07	1.69	0.63	0.66	53.98	55.98
VIZ	8.24	11.23	0.32	1.55	0.28	0.42	59.98	135.96
TGA	10.53	23.64	0.39	1.11	0.17	0.34	159.95	221.93
ECG	3.41	33.77	0.57	1.37	0.24	0.67	61.98	107.97
HPL	5.68	14.26	0.64	1.09	0.78	0.95	69.98	75.98
TTV	8.9	22.72	0.55	0.98	0.22	0.46	105.97	111.97

Chloride ions in groundwater may come from seawater intrusion, soil, precipitation from wind-blown sea salts and waste from domestic and industrial sources (Kumar et al, 2013). Relatively low concentrations of sulphate, nitrate, and phosphate were found in water samples from the hand dug wells in the Keta Municipality. The water samples exhibited an overall anionic dominance pattern of $Cl^- > SO_4^{2-} > NO_3^- - N > PO_4^{3-} - P$. Results from the study indicated that anionic constituents of water from the hand dug wells were extremely low and may not pose any significant effect on the usability of water from the hand dug wells for domestic purposes.

The maximum phosphate levels in water samples from the hand dug wells was 2.13 mg/L. As much as 66% of the phosphate levels were above the <0.3 mg/l recommended limits set by the (WHO, 2011) (Fig. 4.2). The high phosphate levels could be attributed to anthropogenic activities such as washing activities in which most of the inhabitants do by the hand dug wells and the use of fertilizers and pesticides in their farming activities.

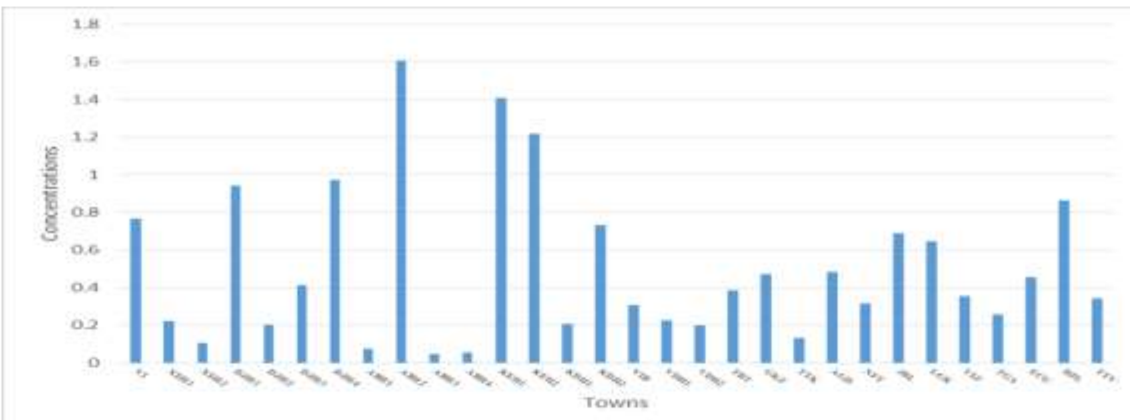

Figure 4.3: A graph of mean phosphate levels in the Keta municipality

4.4 Metals in water samples from hand dug wells in the Keta Municipality

The levels of metals in water samples from hand dug wells in the keta Municipality were comparatively low because of low level of industrial activities in the area. Sodium and magnesium were the dominant metals recorded in the hand dug well water samples (Table 4.3). Sodium concentration in the water samples ranged from 30 mg/L – 497 mg/L. The highest was recorded in KEH1. Only 26.67% of the samples, recorded levels above the (Ghana Standard board, 2005) limits. Communities with levels above the recommended limits include: VI, DZH1, DZH4, ABH2, KEH1, KEH2, KDH2 and VDH2. Magnesium concentration was between 14.97mg/L -178.3 mg/L. Only VDH2 had level above the recommended limits of 150mg/L set by the (WHO, 2011).

The calcium concentration ranged from 38.40 mg/L –180.8 mg/L. High calcium levels were found in XEH2, KEH2 and VDH2, while Magnesium levels ranged from 14.97 mg/L - 178.3 mg/L. The calcium levels were within the 200mg/L recommended limits set by the (Ghana Standard board, 2005). The source of the calcium could be associated with dissolution of $CaMg(CO_3)_2$ and $CaCO_3$ when groundwater recharge occurs (Lakshmanan et al. 2003). The levels of all the metals occurred recorded will not pose much health problem to users of the water. However, the low concentration of these metals notwithstanding continuous consumption of water containing them over a period of time could result in ailments since they are often cumulative. Consumers of water from the hand dug wells in the Municipality are at risk of developing Kidney stones as they consume water with calcium concentrations above 10 mg/l (Bellizi, 1999).

Table 4.3: Metal content of hand dug wells in the Keta Municipality

	Ca^{2+}(mg/L)		**Na (mg/L)**		**K(mg/L)**		**Mg^{2+} (mg/L)**	
Town	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
VI	56	105.6	79.8	248	10.3	61	28.18	194.4
XEH1	38.4	57.6	30	83.2	7.4	15.3	21.97	65.6
XEH2	171.2	180.8	34.1	94.6	29	44.9	139.19	431.2

DZH1	99.2	108.8	106.2	293	89	101.6	60.46	195.2
DZH2	68.8	84.8	78.8	87.4	24.7	27.9	32.85	143.2
DZH3	60.8	72	56	86.9	20	24.4	30.9	132
DZH4	83.2	91.2	92.7	314	55.4	67	50.74	244.8
ABH1	44.8	46.4	40.7	80.7	5.8	6.5	16.33	61.6
ABH2	56	75.2	85.9	258	44.5	65	35.96	160.8
ABH3	56	70.4	31.7	80.2	4.9	5.6	17.5	109.6
ABH4	49.6	83.2	47.6	81.2	8.9	10.5	25.86	116.8
KEH1	75.2	83.2	106.9	497	108.7	120	61.43	180.8
KEH2	131.2	177.6	83.6	431	75.3	94	76.98	406.4
KDH1	104	110.4	89.9	152	17	18.5	50.54	237.6
KDH2	60.8	86.4	88.5	353	16	37.4	44.52	209.6
VIB	80	107.2	95.1	271	52.6	58	44.71	240.8
VDH1	67.2	88	102.3	197	33	40.5	38.1	144
VDH2	92.8	158.4	115.3	246	117.3	198	141.71	733.6
TRT	57.6	67.2	74.4	83.9	13.2	16.8	33.63	132.8
GKZ	88	113.6	92.6	105.4	38.9	45.4	56.38	254.4
TTK	70.4	104	96.4	200	31.6	44	48.02	208
AGD	57.6	72	50	87.6	17	39.4	44.71	130.4
NFT	81.6	96	94.6	140	50.4	55	64.74	240
JBL	76.8	89.6	98.1	139	40	48.5	62.99	158.4
LGK	57.6	83.2	51.9	85.3	24	27.8	48.21	188.8
VIZ	65.6	70.4	53.5	92.9	6.8	15.2	52.1	157.6

TGA	73.6	80	90.9	113.1	15.2	18.9	54.04	236
ECG	44.8	92.8	80.6	83.7	11	29.7	28.97	227.2
HPL	41.6	65.6	57.4	84	14.6	17.3	31.69	142.4
TTV	44.8	76.8	74	90.6	29.4	39.1	60.07	215.2

4.5 Interpolation Maps of TDS and Chloride

An interpolation map (Fig. 4.4) was drawn to determine the spatial distribution of the ions in the study area and to compare the TDS concentrations with the chloride ions concentrations in the study area. The map shows the highest concentration for TDS and Chloride are both found in the same area as shown in the blue legend. The differences in the concentrations found in the sample location may be from to anthropogenic sources. The location with the high concentrations is found at the coastline of the map, this serves as a confirmation that the source of the ions in water samples from the hand dug well is the sea water intrusion. Anthropogenic activities such as washing, domestic waste and effluents from industries around sampling points which contributes to the chloride ions present in the water.

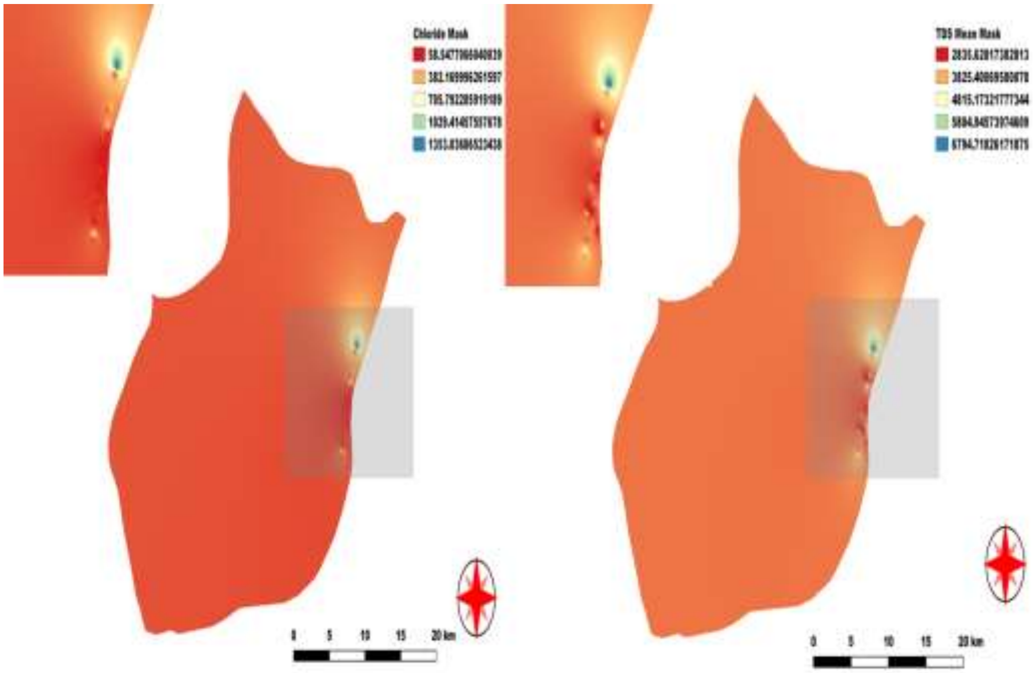

Figure 4.4: An interpolation map of TDS and Chloride levels

4.6 Water Quality

4.6.1 Water Quality Index

Water quality index is an assessment tool used to determine the quality of water for consumption. It is a reliable, useful and efficient method for assessing and communicating the information on the overall quality of water. (Asadi et al., 2017). The water quality classification employed in this study was according to the Bureau of Indian standards (1991) (Table 4. 3)

Table 4.4: Water Quality Classification

WQI VALUE	WATER QUALITY
Less than 50	Excellent
50 -100	Good Water
100 – 200	Poor water
200 – 300	Very poor water
Above 300	Water unsuitable for drinking

The computed WQI values for water samples from hand dug wells in the Keta municipality ranges from 29.19 to 1806.09 (Table 4.5). This categorizes the quality of all water from the hand dug wells to be between excellent water and water unsuitable for drinking.

Table 4.5: Water quality Index of hand dug wells.

Town	WQI	RATING
VI	867.96	Unfit for drinking
XEH1	258.61	Very Poor
XEH2	130.06	Poor
DZH1	1064.59	Unfit for drinking
DZH2	236.39	Very Poor
DZH3	473.08	Unfit for drinking
DZH4	1096.83	Unfit for drinking
ABH1	93.20	Good

ABH2	1806.09	Unfit for drinking
ABH3	29.16	Excellent
ABH4	75.47	Good
KEH1	1589.94	Unfit for drinking
KEH2	1374.67	Unfit for drinking
KDH1	241.62	Very Poor
KDH2	828.38	Unfit for drinking
VIB	359.37	Unfit for drinking
VDH1	267.91	Very Poor
VDH2	253.51	Very Poor
TRT	441.48	Unfit for drinking
GKZ	538.52	Unfit for drinking
TTK	163.01	Poor
AGD	549.23	Unfit for drinking
NFT	369.40	Unfit for drinking
JBL	779.52	Unfit for drinking
LGK	731.13	Unfit for drinking
VIZ	401.18	Unfit for drinking
TGA	295.63	Very Poor
ECG	519.49	Unfit for drinking
HPL	967.40	Unfit for drinking
TTV	398.44	Unfit for drinking

Only 1 hand-dug well from ABH3 representing 3.33% of the samples was classified as excellent while 2 hand-dug wells (ABH1 and ABH4) representing 6.67% were classified as good. Water from hand dug well XEH2 and TTK representing 6.67% were classified poor and 6 hand dug wells (XEH1, DZH2, KDH1, VDH1, VDH2, and TGA) representing 20% were classified as very poor. Water from majority of the hand dug wells in the study area (19 hand-dug wells) representing 63.33% according to the WQI classification were not fit for drinking. The water quality of the samples was hugely affected by the high levels of phosphate in the water which could be as a result of the use of fertilizers in farming activities and washing with soap around the sampling points.

4.6.2 The Comprehensive Pollution Index (CPI)

The variation of comprehensive pollution index values shown in Table 4.6 indicate that majority waters from the hand dug wells are moderately polluted which is an indication that the water quality is not up to the recommended standard based on the parameters used. The CPI values vary in the range of 0.42 to 2.83. Only 13.33 % of the analysed water samples from the hand dug wells (XEH1, ABH1, ABH3 and ABH4) were found to be slightly polluted with a CPI value ranging between 0.41 – 1.0. Majority of the hand dug wells (80 %) had their water samples classified as moderately polluted with CPI values ranging between 1.01 –2.0. Water samples from KEH2 and VDH2 (6.67%) registered CPI values greater than 2.01 which is an indication that the water was severely polluted. Hand dug well KEH2 is situated at the main market in the municipality while VDH2 is closer to the lagoon which are high density areas. The numerous anthropogenic activities that takes place at these areas may contribute to the pollution status of these hand dug wells.

Table 4.6: Comprehensive pollution index for the towns

TOWN	MEAN	CLASSIFICATIONS
VI	1.47	Moderately Polluted
XEH1	0.94	Slightly Polluted
XEH2	1.98	Moderately Polluted
DZH1	1.76	Moderately Polluted
DZH2	1.22	Moderately Polluted
DZH3	1.17	Moderately Polluted
DZH4	1.82	Moderately Polluted
ABH1	0.42	Slightly Polluted
ABH2	1.55	Moderately Polluted
ABH3	0.89	Slightly Polluted
ABH4	0.97	Slightly Polluted
KEH1	1.82	Moderately Polluted
KEH2	2.27	Severely Polluted
KDH1	1.26	Moderately Polluted
KDH2	1.72	Moderately Polluted
VIB	1.42	Moderately Polluted
VDH1	1.26	Moderately Polluted
VDH2	2.83	Severely Polluted
TRT	1.09	Moderately Polluted
GKZ	1.42	Moderately Polluted
TTK	1.36	Moderately Polluted

AGD	1.25	Moderately Polluted
NFT	1.45	Moderately Polluted
JBL	1.48	Moderately Polluted
LGK	1.25	Moderately Polluted
VIZ	1.16	Moderately Polluted
TGA	1.27	Moderately Polluted
ECG	1.10	Moderately Polluted
HPL	1.17	Moderately Polluted
TTV	1.33	Moderately Polluted

4.7 Irrigation Suitability

4.7.1 Sodium Adsorption Ratio

The Sodium Absorption Ratio (SAR) is used to determine the permeability of the soil, it examines sodium hazard relative to magnesium and calcium in the soil. Sodium content in water has been considered as an important factor in irrigation water quality evaluation. Plant growth and yield can be affected by sodium imbalance soil texture conditions. Large concentrations of sodium can have a negative effect on soils by causing dispersion and swelling. Excessive sodium may reduce soil permeability and reduce yield under certain soil texture conditions (Horneck et al, 2007). As the SAR increases, the danger of sodium accumulation in the soil increases with increasing sodium hazard; therefore, the suitability of water for irrigation decreases. When SAR is greater than 13, the water is called sodic water (Horneck et al, 2007). Sodium absorption ratio (SAR) value between1-3 and indicates that the water has no potential to affect infiltration rate of water into the soil (Tak et al, 2012).

The calculated values of sodium adsorption ratio for the analysed hand dug water samples from the study area ranged between 7.39 and 54.42. (Table 4.7). With SAR values of all the samples water analysed greater than 4, permeability problems are expected for soils irrigated with water from the hand dug wells. There should therefore be a degree of restriction on use of water from the hand dug wells in the study area. As much as 93.33 % of analysed hand dug well water samples were found to be sodic waters, they have SAR values greater than 13. This can reduce water infiltration when used for irrigation and results from excessive accumulation of sodium in soil.

Table 4.7: The SAR values of hand dug well waters.

TOWN	SAR	CATEGORY
VI	28.76	Very high
XEH1	13.40	Medium
XEH2	7.39	Low
DZH1	31.85	Very high
DZH2	15.87	Medium
DZH3	14.56	Medium
DZH4	33.59	Very high
ABH1	15.52	Medium
ABH2	33.09	Very high
ABH3	12.57	Medium

ABH4	13.85	Medium
KEH1	54.42	Very high
KEH2	31.72	Very high
KDH1	18.95	Medium
KDH2	38.75	Very high
VIB	29.57	Very high
VDH1	27.73	Very high
VDH2	20.94	High
TRT	16.24	Medium
GKZ	15.66	Medium
TTK	24.95	High
AGD	13.40	Medium
NFT	19.09	High
JBL	20.58	High
LGK	12.86	Medium
VIZ	13.69	Medium
TGA	17.70	Medium
ECG	16.26	Medium
HPL	15.55	Medium
TTV	15.36	Medium

4.8 Radon in Water Content

The results obtained for the radon concentration in water for the period were tabulated in Table 4.8 as shown below.

Table 4.8: Radon in water concentration and annual effective dose for ingestion and inhalation

TOWN	Rn^{222} in H_2O (Bq/l) Min	Rn^{222} in H_2O (Bq/l) Max	AED ING (10^{-6}) in (μSv/y) Min	AED ING (10^{-6}) in (μSv/y) Max	AED INH in (μSv/y) Min	AED INH Max in (μSv/y) Max
VI	4	4.7	0	21.9	0	9.4608
XEH1	2	21.7	21.9	43.8	9.4608	18.9216
XEH2	0.4	10	2.92	65.7	1.26144	28.3824
DZH1	2	13.3	14.6	51.1	6.3072	22.0752
DZH2	5	11.6	29.2	36.5	12.6144	15.768
DZH3	3	15.4	36.5	36.5	15.768	15.768
DZH4	0.4	3.9	7.3	7.3	3.1536	3.1536
ABH1	0.4	2.1	2.92	2.92	1.26144	1.26144
ABH2	0.4	12.7	2.92	14.6	1.26144	6.3072
ABH3	0.4	5.7	2.92	21.9	1.26144	9.4608
ABH4	3	40.8	21.9	65.7	9.4608	28.3824
KEH1	0.4	28.4	7.3	131.4	3.1536	56.7648
KEH2	0.4	111	2.92	576.7	1.26144	249.1344
KDH1	7	20.6	43.8	43.8	18.9216	18.9216
KDH2	2	10.5	2.92	21.9	1.26144	9.4608
VIB	22	38.3	94.9	175.2	40.9968	75.6864
VDH1	1	13.6	14.6	80.3	6.3072	34.6896
VDH2	11.7	29	65.7	233.6	28.3824	100.9152
TRT	0.4	3.1	29.2	29.2	12.6144	12.6144

GKZ	2	6.1	21.9	29.2	9.4608	12.6144
TTK	0.4	53.4	29.2	124.1	12.6144	53.6112
AGD	0.4	2	2.92	7.3	1.26144	3.1536
NFT	0.4	6	2.92	2.92	1.26144	1.26144
JBL	0.4	2.3	36.5	642.4	15.768	277.5168
LGK	0.4	0.4	2.92	14.6	1.26144	6.3072
VIZ	0.4	0.4	2.92	7.3	1.26144	3.1536
TGA	0.4	0.4	2.92	7.3	1.26144	3.1536
ECG	0.4	15.1	2.92	2.92	1.26144	1.26144
HPL	0.4	40.3	2.92	94.9	1.26144	40.9968
TTV	2	103	21.9	554.8	9.4608	239.6736

4.8.1 Radon Results and Discussion

The concentration of radon present at a place is mainly a product of the types of parent rocks present at the place. For radon levels in groundwater, the rock type, the groundwater levels and seasonal changes highly influence the concentration of radon present in the water.

As shown in Table 4.7 the concentration of radon ranged from 0.4Bq/l – 111Bq/l. The highest was recorded in KEH2. There was significant difference in the samples taken, with a p- value of 0.0021. The annual effective dose for ingestion ranged from 0µSv/y - 642.4µSv/y with the highest recorded in KEH2. There was no significant difference in the annual effective dose due to ingestion for the period with a p-value of 0.33. The annual effective dose due to inhalation ranged from 1.26µSv/y to 277µSv/y with the highest recorded in TTV. There was no significant difference in the samples taken (p-value - 0.05).

Currently, there is no standard for radon concentration in water in Ghana, so the standards set by WHO (100 Bq/l) and USEPA (11 Bq/l) was used in this study. Eighteen (18) samples representing 60% of the total samples were above the 11Bq/l. Based on the WHO (2011) standard for the treatment level of water, TTV and KEH2 water should be mitigated. 60% of samples above the recommended limits set by WHO, (2011) and USEPA, (2010) could be associated to the high permeability of the gas during the dry season. The sampling was in the dry season where there is usually a shortage of water hence, the radon gas could easily move from the bedrock into groundwater. Radon gas is likely to easily move in horizontal directions relative to vertical directions because soil particles orient their longest dimensions horizontally (King and Minissale, 1994). A similar result was obtained by (Krishan et al, 2014) in a research done on the radon concentration in groundwater samples in the coastal area of Baleshwar district of Odisha, India. The results obtained indicated that 7 out of the 10 samples taken had concentrations below the recommended limits of the USEPA, (2010) which 3 had concentrations above the limits set by the USEPA, (2010). There was a varying annual effective dose with respect to a rise in radon values, the values were significantly lesser than the 1mSv/y standards set by WHO, (2011) and UNSCEAR, (1994) for the general public. Hence, the radon levels in the hand dug wells pose no significant risk to the public. Radon gas and other naturally occurring radioisotopes present in groundwater located in coastal areas when researched by Almeida et al. (2004), Lauria et al. (2004) and Choubey et al. (2000) realized that the flow of groundwater places a significant role in determining the radon in water. Additionally, areas with minimum uranium content have had high concentrations of radon hence an increase in radon concentration in groundwater can be due to other factors aside high uranium concentrations in the bedrock, (Skeppström and Olofsson, 2006).

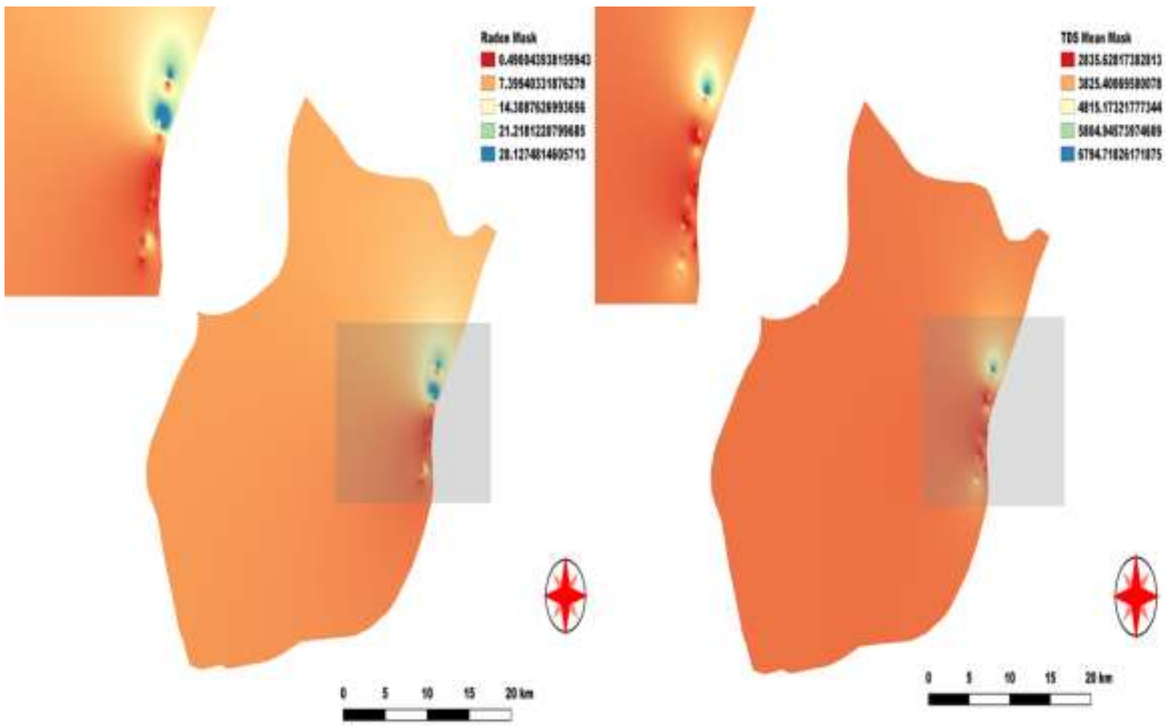

Figure 4.5: An interpolation map of radon levels and the mean TDS concentrations

The map from (Figure 4.5) above shows there is a high concentration of radon emanating from the same point as the TDS highest concentration. From the above it can be said that the TDS concentration relates directly with the radon concentrations

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this study shows that the hand-dug wells in the Keta Municipality had water parameters such as pH, conductivity, TDS, salinity, chloride, phosphate and sodium which did not meet the World Health Organisation and the Ghana standards Authority's guidelines for physical and chemical properties of water. In general, the groundwater in the Municipality was hugely polluted with inorganic constituents. The chemical parameters such as sodium, phosphate, chloride were extremely high. The levels ranged from 30mg/L -1040 mg/L, 0 – 2.13mg/L, 17.99 mg/L – 2823 mg/L, for sodium, phosphate and chloride respectively. The hand dug wells in the Keta Municipality exhibited a general ionic dominance pattern of $Cl^- > SO_4^{2-} > NO_3^-$ - N > PO_4^{3-} – P. The interpolation map for the spatial distribution of the ions showed that the highest concentrations of the TDS and Chloride ions where found at the same area which was along the coastline serving as a confirmation that the source of ions was the sea water intrusion into the shallow groundwater aquifer.

The water quality index ranged from 29.19 - 1806.09. Only 3.33% of the samples were classified as excellent, 6.67% were classified as good, 6.67% were classified poor, 20% were classified as very poor and 63.33% were not fit for drinking. The CPI values ranged from 0.42 to 2.83. The analysed water samples from the hand dug wells had 13.33 % of the samples to be slightly polluted with a CPI value ranging between 0.41 – 1.0. Majority of the hand dug wells (80 %) had their water samples classified as moderately polluted with CPI values ranging from 1.01 –2.0. 6.67% of the samples were severely polluted registered, CPI values were greater than 2.01.

The SAR had as much as 93.33 % of analysed hand dug well water samples to be sodic waters, with SAR values greater than 13. With SAR values of all the samples water analysed greater than 4, permeability problems are expected for soils irrigated with water from the hand dug wells. There should therefore be a degree of restriction on use of water from the hand dug wells in the study area.

The radon in water concentrations posed no significant health risks to the folks, the concentrations ranged from 0.4Bq/l – 111Bq/l. There were significant differences in the concentrations for the period of sampling. Differences were at a p-value of 0.0021. The annual effective dose for ingestion ranged from 0µSv/y - 642.4µSv/y. There was no significant difference in the annual effective dose due to ingestion for the period with a p-value of 0.33. The annual effective dose due to inhalation ranged from 1.26µSv/y to 277µSv/y. There was no significant difference in the samples taken (p-value - 0.05). Majority of the samples 60% of the total samples were above the 11Bq/l limits set by WHO (2011) and USEPA (2010).

Based on the results obtained, it can be concluded that the water quality of the hand dug wells in the Keta Municipality are unsafe for drinking and irrigation. However, the water from the hand dug wells present no significant health risk with respect to radon to the inhabitants. The results also show that the sea water intrusion into the groundwater aquifer has huge effects on the hydrochemistry of the hand-dug wells in the Keta Municipality.

5.2 Recommendation

1. Groundwater from hand-dug wells in the Keta Municipality should be treated before consumption, in terms of drinking.
2. Water from hand-dug wells should not be used in irrigational activities.
3. There should be a regulation on the siting of hand dug wells in the Keta Municipality by the Municipal Assembly.
4. There should be a public health education and sensitization on radon and radon in water in the Keta Municipality.
5. Further research on groundwater hydrochemistry and radon levels in the adjacent Districts should be carried out to cover a larger spatial distribution.

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APPENDIX

SAMPLE CODE	TOWNS
VI	VUI
XEH1	XEKPA HSE1
XEH2	XEKPA HSE2
DZH1	DZELUKOPE HSE1
DZH2	DZELUKOPE HSE2
DZH3	DZELUKOPE KETASCO
DZH4	DZELUKOPE ALATA
ABH1	ABUTIAKOPE HSE1
ABH2	ABUTIAKOPE HSE2
ABH3	ABUTIAKOPE HSE3
ABH4	ABUTIAKOPE HSE4
KEH1	KETA HSE1
KEH2	KETA HSE2
KDH1	KEDZIKOPE HSE1
KDH2	KEDZIKOPE HSE2
VIB	VUI BUSCO
VDH1	VODZA HSE1
VDH2	VODZA HSE2
TRT	TREETY
GKZ	GHANA KPEDZI
TTK	TETEKOPE
AGD	AGBO DEKA
NFT	NURSES FLAT
JBL	JUBILEE
LGK	LANGBATAKPO

VIZ	**VUI ZION**
TGA	**TEGBI AGBO**
ECG	**ECG**
HPL	**HOSPITAL**
TTV	**TETEVIKOPE**

Physiochemical analysis of wells in March

Town	Results										
	Date	Time	GPS Coordinates	Depth (M)	pH	Age (years)	Temperature (^{0}C)	Conductivity (µS)	Salinity (ppmS)	TDS (ppm)	Chloride (mg/L)
Ghana Standards					6.5-8.5			1000		1000	250
VUI	4/3/2020	7:47am	N05.88317 E000.98030	1.74	8.75	44	31.2	828	4580	5760	27.99
XEKPA HSE1	4/3/2020	8:00am	N05.8772 E000.98090	1.43	8.59	44	30.1	877	4890	6130	49.98
XEKPA HSE2	4/3/2020	8:10am	No5.87215 E000.97981	1.83	8.4	65	30.5	1179	6760	8230	833.74
DZELUKOPE HSE1	4/3/2020	6:01am	N05.88700 E000.98166	1.37	8	50	29.5	1037	4600	7160	209.93
DZELUKOPE HSE2	4/3/2020	6:15am	N05.89029 E000.98471	1.22	8.65	17	29.1	900	4980	6390	55.98
DZELUKOPE KETASCO	4/3/2020	6:25am	N05.89447 E000.98702	0.67	8.8	40	29.9	889	4950	6200	47.99
DZELUKOPE ALATA	4/3/2020	6:32am	N05.89122 E000.98804	0.59	8.58	49	30.2	945	5260	6600	101.97
ABUTIAKOPE HSE1	4/3/2020	9:28am	N05.9016 E00098885	0.43	9.15	58	32.7	1313	650	910	19.99
ABUTIAKOPE HSE2	4/3/2020	8:07am	N05.90461 E00099003	0.32	9.29	1	33.3	857	4760	5990	67.98
ABUTIAKOPE HSE3	4/3/2020	8:17am	N05.90143 E000.98718	0.36	9.19	43	31.1	836	4590	5830	19.99
ABUTIAKOPE HSE4	4/3/2020	8:38am	N05.90189 E000.98762	0.45	9.18	25	31.5	847	4720	5910	27.99
KETA HSE1	4/3/2020	9:49am	N05.92077 E000.99156	0.32	8.98	46	30.7	976	5380	149.62	203.94
KETA HSE2	4/3/2020	10:20am	N05.92131 E000.99246	0.32	8.59	72	32	1057	5940	7380	469.85

KEDZIKOPE HSE1	4/3/2020	11:14am	N05.91125 E000.99116	0.31	8.75	11	31	887	4880	6170	79.98
KEDZIKOPE HSE2	4/3/2020	11:03am	N05.91488 E000.99102	0.54	8.82	35	31.4	1170	6270	7720	793.75
VUI BUSCO	4/3/2020	7:55am	N05.87764 E000.98363	0.62	8.77	25	31.6	877	5040	6450	157.95
VODZA HSE1	4/3/2020	10:53am	N05.93467 E000.99685	0.25	9.23	5	32.8	923	5140	6460	207.94
VODZA HSE2	4/3/2020	10:47am	N05.93751 E000.99794	0.27	8.78	47	32.1	1414	840	9870	2823.12
TREETY	4/3/2020	6:18am	N05.88585 E000.98232	0.58	8.82	59	31	842	4690	5880	59.98
GHANA KPEDZI	4/3/2020	9:32am	N05.90112 E000.98949	0.65	8.65	5	30.9	921	5050	6420	97.97
TETEKOPE	4/3/2020	8:59am	N05.88232 E000.98572	0.75	8.73	1	31.5	933	5140	6460	187.94
AGBO DEKA	4/3/2020	8:55am	N05.87089 E000.97952	0.79	8.5	4	31.1	906	5060	6340	89.97
NURSES FLAT	4/3/2020	9:07am	N05.89719 E000.98495	0.75	8.75	42	31.1	945	5260	6600	127.96
JUBILEE	4/3/2020	7:38am	N05.87880 E000.98159	0.58	8.48	8	29.4	964	5370	6730	171.95
LANGBATAKPO	4/3/2020	9:12am	N05.90320 E000.98753	0.69	8.65	16	30.5	870	4770	6050	53.98
VUI ZION	4/3/2020	7:55am	N05.87778 E000.97988	0.78	8.52	36	30.4	932	5180	6510	135.96
TEGBI AGBO	4/3/2020	8:35am	N05.87054 E000.97935	0.64	8.76	63	31.6	943	5290	6630	221.93
ECG	4/3/2020	7:20am	N05.89171 E000.98466	5.49	8.82	57	29.6	838	4660	5850	61.98

HOSPITAL	4/3/2020	7:00am	N05.88912 E000.98350	2.13	7.9	29	29.3	896	4990	700	69.98
TETEVIKOPE	4/3/2020	9:03am	N05.88058 E000.98951	0.68	8.89	48	32.3	906	6310	4960	111.97

Physiochemical analysis of wells in March

		Results								
		Alkalinity(mg/L)	Calcium(mg/L)	Sodium(mg/L)	Potassium(mg/L)	Nitrate(mg/L)	Total hardness(mg/L)	Sulphate(mg/L)	Phosphate (mg/L)	Magnesium(mg/L)
Ghana Standards			0.003	200	30	50	500	250	0.3	
	Town									
	VUI	138	56	79.8	10.3	1.54	172	6.43	0.11	116
	XEKPA HSE1	174	57.6	83.2	15.3	0.35	148	13.73	0.05	90.4
	XEKPA HSE2	46	171.2	94.6	44.9	0.35	744	13.41	0.08	572.8
	DZELUKOPE HSE1	370	99.2	106.2	101.6	0.57	348	17.07	0.81	248.8
	DZELUKOPE HSE2	212	68.8	87.4	27.9	2.63	204	4.76	0.11	135.2
	DZELUKOPE KETASCO	176	60.8	86.9	24.4	1.59	188	6.02	0.36	127.2
	DZELUKOPE ALATA	220	83.2	92.7	55.4	1.01	292	14.69	0.90	208.8
	ABUTIAKOPE HSE1	104	44.8	80.7	6.5	1.05	112	2.81	0.00	67.2
	ABUTIAKOPE HSE2	126	56	85.9	44.5	1.05	204	6.89	1.08	148
	ABUTIAKOPE HSE3	150	56	80.2	5.6	0.45	128	4.92	0.03	72
	ABUTIAKOPE HSE4	140	49.6	81.2	10.5	1.57	156	3.39	0.01	106.4
	KETA HSE1	466	83.2	106.9	108.7	1.93	336	13.16	1.27	252.8
	KETA HSE2	274	131.2	83.6	75.3	1.19	448	19.50	1.15	316.8
	KEDZIKOPE HSE1	268	104	89.9	18.5	2.03	312	11.60	0.30	208
	KEDZIKOPE HSE2	350	60.8	88.5	37.4	0.29	244	12.77	0.78	183.2
	VUI BUSCO	228	80	95.1	52.6	1.52	264	12.47	0.29	184

VODZA HSE1	198	67.2	102.3	40.5	1.01	224	19.95	0.30	156.8
VODZA HSE2	338	92.8	115.3	117.3	1.10	676	6.04	0.23	583.2
TREETY	182	57.6	83.9	16.8	1.03	196	5.65	0.57	138.4
GHANA KPEDZI	284	88	92.6	45.4	1.05	320	11.37	0.60	232
TETEKOPE	236	70.4	96.4	31.6	1.56	268	10.78	0.18	197.6
AGBO DEKA	244	72	87.6	39.4	0.24	256	14.58	0.43	184
NURSES FLAT	346	81.6	94.6	50.4	1.84	348	15.29	0.47	266.4
JUBILEE	388	76.8	98.1	48.5	0.49	336	14.21	0.52	259.2
LANGBATAKPO	238	57.6	85.3	27.8	1.69	256	5.95	0.66	198.4
VUI ZION	290	65.6	92.9	15.2	0.32	280	8.24	0.42	214.4
TEGBI AGBO	240	73.6	90.9	15.2	0.39	296	10.53	0.34	222.4
ECG	166	44.8	80.6	11	0.57	164	3.41	0.67	119.2
HOSPITAL	180	41.6	84	17.3	0.64	172	5.68	0.78	130.4
TETEVIKOPE	318	44.8	90.6	39.1	0.55	292	8.90	0.46	247.2

Physiochemical analysis of wells in November

Town	Results										
	Date	**Time**	**GPS Coordinates**	**Depth (M)**	**pH**	**Age (years)**	**Temperature (⁰C)**	**Conductivity (µS)**	**Salinity (ppmS)**	**TDS (ppm)**	**Chloride (mg/L)**
Ghana Standards								1000		1000	250
VUI	13/11/19	1:24 PM	N05.88317 E000.98030	1.74	7.54	44	31.3	1989	990	1360	195.94
XEKPA HSE1	13/11/19	6:54 AM	N05.8772 E000.98090	1.43	7.65	44	29.2	438	200	310	19.99
XEKPA HSE2	13/11/19	7:16 AM	No5.87215 E000.97981	1.83	7.26	65	29.1	309	1600	2120	611.81
DZELUKOPE HSE1	13/11/19	6:24 AM	N05.88700 E000.98166	1.37	7.14	50	30	1549	780	1120	139.96
DZELUKOPE HSE2	13/11/19	7:45 AM	N05.89029 E000.98471	1.22	7.55	17	30	945	660	450	87.97
DZELUKOPE KETASCO	13/11/19	12:54 AM	N05.89447 E000.98702	0.67	7.7	40	32.5	856	420	600	51.98
DZELUKOPE ALATA	13/11/19	1:06 PM	N05.89122 E000.98804	0.59	7.55	49	31.1	11370	560	800	87.97
ABUTIAKOPE HSE1	13/11/19	8:08 AM	N05.9016 E00098885	0.43	7.61	58	31.5	569	240	360	17.99
ABUTIAKOPE HSE2	13/11/19	8:14 AM	N05.90461 E00099003	0.32	7.72	0.667	32.6	1002	490	740	71.98

ABUTIAKOPE HSE3	13/11/19	12:13	N05.90143 E000.98718	0.36	7.65	43	32.8	573	250	480	23.99
ABUTIAKOPE HSE4	13/11/19	12:28 PM	N05.90189 E000.98762	0.45	7.77	25	31.2	642	300	440	33.99
KETA HSE1	13/11/19	10:05 AM	N05.92077 E000.99156	0.32	7.61	46	30.3	1705	780	1120	135.96
KETA HSE2	13/11/19	10:22 AM	N05.92131 E000.99246	0.32	7.3	72	31.2	320	1700	2280	497.85
KEDZIKOPE HSE1	13/11/19	9:08 AM	N05.91125 E000.99116	0.31	7.44	11	30.6	1079	520	830	69.98
KEDZIKOPE HSE2	13/11/19	9:36 AM	N05.91488 E000.99102	0.54	7.38	35	30.5	1484	730	1020	131.96
VUI BUSCO	13/11/19	8:53 AM	N05.87764 E000.98363	0.62	7.38	25	31.3	1248	600	860	139.96
VODZA HSE1	13/11/19	10:50 AM	N05.93467 E000.99685	0.25	7.75	5	31.3	1020	490	700	87.97
VODZA HSE2	13/11/19	11:14 AM	N05.93751 E000.99794	0.27	7.45	47	32.1	696	3830	4860	291.91
TREETY	30/11/19	11:54 AM	N05.88585 E000.98232	0.58	7.52	59	31	744	350	520	63.98
GHANA KPEDZI	30/11/19	10:41 AM	N05.90112 E000.98949	0.65	7.59	5	31	1297	630	890	113.96

TETEKOPE	30/11/19	12:23 PM	N05.88232 E000.98572	0.75	7.54	1	32.5	1353	650	930	163.95
AGBO DEKA	30/11/19	9:45 AM	N05.87089 E000.97952	0.79	7.65	4	31.6	1209	630	870	19.99
NURSES FLAT	30/11/19	11:01 AM	N05.89719 E000.98495	0.75	7.61	42	31.6	1189	570	820	115.96
JUBILEE	30/11/19	12:38 PM	N05.87880 E000.98159	0.58	7.36	8	28.8	1065	500	730	109.97
LANGBATAKPO	30/11/19	10:18 AM	N05.90320 E000.98753	0.69	7.69	16	30.7	865	410	600	55.98
VUI ZION	30/11/19	12:54 PM	N05.87778 E000.97988	0.78	7.18	36	30.4	741	350	510	59.98
TEGBI AGBO	30/11/19	1:13 PM	N05.87054 E000.97935	0.64	7.26	63	30.8	1032	490	700	159.95
ECG	30/11/19	11:22 AM	N05.89171 E000.98466	5.49	7.67	57	31	511	230	350	107.97
HOSPITAL	30/11/19	11:39 AM	N05.88912 E000.98350	2.13	7.48	29	31.9	773	370	530	75.98
TETEVIKOPE	30/11/19	12:09 PM	N05.88058 E000.98951	0.68	7.74	48	31.8	1028	490	720	105.97

Physiochemical analysis of wells in November

		Results								
		Alkalinity(mg/L)	Calcium(mg/L)	Sodium(mg/L)	Potassium(mg/L)	Nitrate(mg/L)	Total hardness(mg/L)	Sulphate (mg/L)	Phosphate(mg/L)	Magnesium(mg/L)
Ghana Standards		1000	200	200	50	10		250	0.3	150
	Town									
	VUI	288	105.6	248	61	1.56	300	26.23	1.42	194.4
	XEKPA HSE1	134	38.4	30	7.4	1.04	104	3.77	0.39	65.6
	XEKPA HSE2	496	180.8	34.1	29	0.98	612	24.01	0.13	431.2
	DZELUKOPE HSE1	394	108.8	293	89	0.94	304	36.54	1.07	195.2
	DZELUKOPE HSE2	254	84.8	78.8	24.7	1.12	228	12.53	0.29	143.2
	DZELUKOPE KETASCO	212	72	56	20	1.83	204	18.46	0.47	132
	DZELUKOPE ALATA	252	91.2	314	67	0.96	336	19.69	1.05	244.8
	ABUTIAKOPE HSE1	120	46.4	40.7	5.8	0.77	108	11.11	0.15	61.6
	ABUTIAKOPE HSE2	154	75.2	258	65	1.33	236	17.47	2.13	160.8
	ABUTIAKOPE HSE3	216	70.4	31.7	4.9	0.86	180	5.19	0.06	109.6
	ABUTIAKOPE HSE4	196	83.2	47.6	8.9	0.89	200	8.89	0.10	116.8
	KETA HSE1	460	75.2	497	120	1.85	256	22.90	1.55	180.8
	KETA HSE2	402	177.6	431	94	1.81	584	30.80	1.29	406.4
	KEDZIKOPE HSE1	292	110.4	152	17	1.16	348	20.99	0.11	237.6
	KEDZIKOPE HSE2	342	86.4	353	16	1.38	296	34.44	0.69	209.6

VUI BUSCO	296	107.2	271	58	0.97	348	26.48	0.33	240.8
VODZA HSE1	208	88	197	33	0.89	232	36.79	0.15	144
VODZA HSE2	526	158.4	246	198	1.29	892	37.35	0.17	733.6
TREETY	236	67.2	74.4	13.2	0.86	200	15.74	0.20	132.8
GHANA KPEDZI	330	113.6	105.4	38.9	1.11	368	38.70	0.34	254.4
TETEKOPE	312	104	200	44	1.09	312	32.28	0.08	208
AGBO DEKA	190	57.6	50	17	1.00	188	7.53	0.54	130.4
NURSES FLAT	324	96	140	55	1.20	336	24.69	0.17	240
JUBILEE	332	89.6	139	40	0.86	248	25.56	0.86	158.4
LANGBATAKPO	234	83.2	51.9	24	1.07	272	11.36	0.63	188.8
VUI ZION	248	70.4	53.5	6.8	1.55	228	11.23	0.28	157.6
TEGBI AGBO	294	80	113.1	18.9	1.11	316	23.64	0.17	236
ECG	314	92.8	83.7	29.7	1.37	320	33.77	0.24	227.2
HOSPITAL	1000	65.6	57.4	14.6	1.09	208	14.26	0.95	142.4
TETEVIKOPE	326	76.8	74	29.4	0.98	292	22.72	0.22	215.2

Radon analysis in March

Town	Results											
	Date	Time	Detector Name	Initial Volt	Final Volt	Time In	Time out	Date In	Date Out	Radon in Water	Radon in Air	AED ING
VUI	4/3/2020	7:47am	SKR746	42	37	11:58	2:03	12/3/2020	16/3/2020	4.7	0	0.00003431
XEKPA HSE1	4/3/2020	8:00am	SKR628	124	115	12:02	2:05	12/3/2020	16/3/2020	21.7	16 ± 3	0.00015841
XEKPA HSE2	4/3/2020	8:10am	SKR670	18	15	11:11	11:36	9/3/2020	12/3/2020	0.4	-9 ± -4	0.00000292
DZELUKOPE HSE1	4/3/2020	6:01am	SKR607	394	385	11:17	11:37	9/3/2020	12/3/2020	13.3	36 ± 6	0.00009709
DZELUKOPE HSE2	4/3/2020	6:15am	SKR641	99	92	11:05	11:34	9/3/2020	12/3/2020	11.6	19 ± 4	0.00008468
DZELUKOPE KETASCO	4/3/2020	6:25am	SKR628	132	124	11:19	11:38	9/3/2020	12/3/2020	15.4	25 ± 5	0.00011242
DZELUKOPE ALATA	4/3/2020	6:32am	SKR746	47	42	11:25	11:41	9/3/2020	12/3/2020	3.9	5 ± 1	0.00002847
ABUTIAKOPE HSE1	4/3/2020	9:28am	LB3388	30	30	12:38	10:39	16/3/2020	20/3/2020	2.1	-46	0.00001533
ABUTIAKOPE HSE2	4/3/2020	8:07am	SKR641	85	78	12:41	10:41	16/3/2020	20/3/2020	12.7	3 ± 1	0.00009271
ABUTIAKOPE HSE3	4/3/2020	8:17am	SKR820	97	91	12:32	10:34	16/3/2020	20/3/2020	5.7	2 ± 0	0.00004161
ABUTIAKOPE HSE4	4/3/2020	8:38am	SKR820	109	97	12:05	2:07	12/3/2020	16/3/2020	40.8	25 ± 3	0.00029784
KETA HSE1	4/3/2020	9:49am	SKR628	114	104	12:33	10:35	16/3/2020	20/3/2020	28.4	23 ± 3	0.00020732
KETA HSE2	4/3/2020	10:20am	SKR601	476	472	12:09	2:10	12/3/2020	16/3/2020	0.4	-14 ±-5	0.00000292
KEDZIKOPE HSE1	4/3/2020	11:14am	SKR746	37	30	12:35	10:37	16/3/2020	20/3/2020	20.6	8 ± 2	0.00015038
KEDZIKOPE HSE2	4/3/2020	11:03am	SKR670	10	6	12:30	10:33	16/3/2020	20/3/2020	10.5	-11 ± -4	0.00007665
VUI BUSCO	4/3/2020	7:55am	SKR682	367	353	11:02	11:32	9/3/2020	12/3/2020	38.3	60 ± 7	0.00027959
VODZA HSE1	4/3/2020	10:53am	SKR607	376	367	12:42	10:42	16/3/2020	20/3/2020	13.6	14 ± 2	0.00009928
VODZA HSE2	4/3/2020	10:47am	SKR635	227	219	12:36	10:38	16/3/2020	20/3/2020	11.7	11 ± 2	0.00008541

TREETY	4/3/2020	6:18am	LB3388	32	31	12:11	2:13	12/3/2020	16/3/2020	3.1	11 ± 15	0.00002263
GHANA KPEDZI	4/3/2020	9:32am	SKR635	240	233	11:21	11:39	9/3/2020	12/3/2020	6.1	17 ± 4	0.00004453
TETEKOPE	4/3/2020	8:59am	SKR682	355	341	12:07	2:08	12/3/2020	16/3/2020	53.4	46 ± 5	0.00038982
AGBO DEKA	4/3/2020	8:55am	SKR635	233	228	11:56	2:02	12/3/2020	16/3/2020	0.4	-5 ± -1	0.00000292
NURSES FLAT	4/3/2020	9:07am	SKR641	92	86	12:10	2:09	12/3/2020	16/3/2020	6	1 ± 0	0.0000438
JUBILEE	4/3/2020	7:38am	LB3388	37	31	11:30	11:42	9/3/2020	12/3/2020	2.3	400 ± 95	0.00001679
LANGBATAKPO	4/3/2020	9:12am	SKR601	463	459	12:39	10:40	16/3/2020	20/3/2020	0.4	-15 ± -5	0.00000292
VUI ZION	4/3/2020	7:55am	SKR607	386	381	12:01	2:05	12/3/2020	16/3/2020	0.4	-7 ± -2	0.00000292
TEGBI AGBO	4/3/2020	8:35am	SKR820	114	109	11:23	11:40	9/3/2020	12/3/2020	0.4	5 ± 1	0.00000292
ECG	4/3/2020	7:20am	SKR670	15	10	11:59	2:04	12/3/2020	16/3/2020	15.1	0	0.00011023
HOSPITAL	4/3/2020	7:00am	SKR601	493	478	11:08	11:35	9/3/2020	12/3/2020	40.3	63 ± 7	0.00029419
TETEVIKOPE	4/3/2020	9:03am	SKR682	340	313	1:12	10:43	16/3/2020	20/3/2020	103	90 ± 6	0.0007519

Radon analysis in November

Town	Results												
	Date	Time	Detector Name	Initial Volt	Final Volt	Time In	Time out	Date In	Date Out	Radon in Water	Radon in Air	AED ING	AED INH
VUI	13/11/19	1:24 PM	SKR820	142	134	2:52	12:12	21/11/19	25/11/19	4	8 ± 1	0.0000292	12.6144
XEKPA HSE1	13/11/19	6:54 AM	SKR628	186	179	9:54	1:48	18/11/19	21/11/19	2	17 ± 4	0.0000146	6.3072
XEKPA HSE2	13/11/19	7:16 AM	SKR641	151	140	9:49	1:57	18/11/19	21/11/19	10	42 ± 6	0.000073	31.536
DZELUKOPE HSE1	13/11/19	6:24 AM	SKR682	663	656	10:04	1:55	18/11/19	21/11/19	2	9 ± 2	0.0000146	6.3072
DZELUKOPE HSE2	13/11/19	7:45 AM	SKR607	432	423	9:46	1:43	18/11/19	21/11/19	5	24 ± 4	0.0000365	15.768
DZELUKOPE KETASCO	13/11/19	12:54 AM	SKR635	285	277	2:47	12:22	21/11/19	25/11/19	3	11 ± 2	0.0000219	9.4608
DZELUKOPE ALATA	13/11/19	1:06 PM	SKR746	72	66	2:56	12:18	21/11/19	25/11/19	0.4	3 ± 1	0.00000292	1.26144
ABUTIAKOPE HSE1	13/11/19	8:08 AM	SKR746	64	60	10:16	1:38	29/11/19	2/12/2019	0.4	-3 ± -1	0.00000292	1.26144
ABUTIAKOPE HSE2	13/11/19	8:14 AM	SKR768	244	239	10:14	1:50	18/11/19	21/11/19	0.4	2 ± 1	0.00000292	1.26144
ABUTIAKOPE HSE3	13/11/19	12:13	SKR601	541	535	2:46	12:20	21/11/19	25/11/19	0.4	-2 ± 0	0.00000292	1.26144
ABUTIAKOPE HSE4	13/11/19	12:28 PM	SKR682	657	648	2:53	12:15	21/11/19	25/11/19	3	20 ± 4	0.0000219	9.4608
KETA HSE1	13/11/19	10:05 AM	SKR820	147	142	10:12	1:40	18/11/19	21/11/19	0.4	3 ± 1	0.00000292	1.26144
KETA HSE2	13/11/19	10:22 AM	SKR601	614	543	9:59	1:52	18/11/19	21/11/19	111	379 ± 20	0.0008103	350.0496
KEDZIKOPE HSE1	13/11/19	9:08 AM	SKR746	83	74	10:07	1:45	18/11/19	21/11/19	7	30 ± 5	0.0000511	22.0752
KEDZIKOPE HSE2	13/11/19	9:36 AM	SKR635	292	285	10:10	1:52	18/11/19	21/11/19	2	14 ± 3	0.0000146	6.3072
VUI BUSCO	13/11/19	8:53 AM	SKR641	139	122	2:56	12:24	21/11/19	25/11/19	22	61 ± 6	0.0001606	69.3792
VODZA HSE1	13/11/19	10:50 AM	SKR607	424	417	2:49	12:23	21/11/19	25/11/19	1	4 ± 1	0.0000073	3.1536
VODZA HSE2	13/11/19	11:14 AM	SKR628	181	160	2:52	12:17	21/11/19	25/11/19	29	81 ± 7	0.0002117	91.4544

TREETY	30/11/19	11:54 AM	SKR820	128	121	1:00	1:53	5/12/2019	8/12/2019	0.4	18 ± 4	0.00000292	1.26144	
GHANA KPEDZI	30/11/19	10:41 AM	SKR682	641	636	2:06	12:38	2/12/2019	5/12/2019	2	1 ± 0	0.0000146	6.3072	
TETEKOPE	30/11/19	12:23 PM	SKR628	152	145	1:04	1:52	5/12/2019	8/12/2019	0.4	18 ± 4	0.00000292	1.26144	
AGBO DEKA	30/11/19	9:45 AM	SKR628	159	154	2:16	12:30	2/12/2019	5/12/2019	2	5 ± 1	0.0000146	6.3072	
NURSES FLAT	30/11/19	11:01 AM	SKR670	49	45	2:12	12:35	2/12/2019	5/12/2019	0.4	-1 ± 0	0.00000292	1.26144	
JUBILEE	30/11/19	12:38 PM	LB3388	38	37	2:27	12:24	2/12/2019	5/12/2019	0.4	41 ± 57	0.00000292	1.26144	
LANGBATAKPO	30/11/19	10:18 AM	SKR820	134	128	2:19	12:27	2/12/2019	5/12/2019	0.4	13 ± 3	0.00000292	1.26144	
VUI ZION	30/11/19	12:54 PM	SKR635	277	272	2:08	12:34	2/12/2019	5/12/2019	0.4	4 ± 1	0.00000292	1.26144	
TEGBI AGBO	30/11/19	1:13 PM	SKR307	411	408	2:17	12:28	2/12/2019	5/12/2019	0.4	-10 ± -5	0.00000292	1.26144	
ECG	30/11/19	11:22 AM	SKR601	525	520	2:04	12:38	2/12/2019	5/12/2019	0.4	1 ± 0	0.00000292	1.26144	
HOSPITAL	30/11/19	11:39 AM	LB3515	80	80	2:22	12:39	2/12/2019	5/12/2019	0.4	-46 ± 0	0.00000292	1.26144	
TETEVIKOPE	30/11/19	12:09 PM	SKR641	123	116	2:10	12:33	2/12/2019	5/12/2019	2	20 ± 4	0.0000146	6.3072	