KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI,

GHANA

HYDROGEOLOGICAL EVALUATION OF GEOLOGICAL FORMATIONS IN ASHANTI REGION, GHANA

By

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MASTER OF PHILOSOPHY

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DECLARATION

I hereby declare that this submission is my own work towards the MPhil and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The execution of any hydrogeological project to exploit groundwater using boreholes requires prior knowledge on some of the hydrogeological parameters of the underlying geological formation at the planning stage for smooth and successful implementation of such project. These parameters include the yield from the aquifer, the expected final depth of the borehole, the expected overburden thickness, static water level, specific capacity and the quality of water. This study employed Geographical Information System to assess some of these parameters in the geological formations of Ashanti Region; namely the Birimian and its intrusive undifferentiated Granitoids, Tarkwaian and Voltaian, using data from 2788 drilled boreholes. The ordinary kriging interpolation method was used to produce maps of the airlift yield, overburden and final borehole depths, static water level, specific capacity and the occurrence of higher amounts of iron in the groundwater of the study area. The study results indicate that the Birimian is generally within the medium (30 – 60 l/min) and high (> 60 l/min) yield zones at a success rate of 90.6 % and average final depth of 52.5 m whilst the undifferentiated granitoids are, mostly, within the low yield (less than 30 l/min) zones with isolated high yield boreholes and have average borehole depth and success rate of 49.6 m and 72.3 % respectively. Aquifers within the Tarkwaian group are generally within the medium yield zone with a success rate of 79.5 %. The groups within the Voltaian formation –i.e. Kwahu, Oti Pendjari and Obosum– are classified mainly within the low yield zones with 53.5 %, 60.0 % and 66.7 % success rates respectively, but significant high yield zones occur within the sandstone formation underlying the westernmost part of the region. Also, about 21 % of successful boreholes had unsuitable water quality with high iron, nitrate, manganese and low pH being their main problems. About 11.7 % of these boreholes were located within the Birimian and intrusive undifferentiated granitoids and had high iron concentrations above the accepted

guideline value for drinking water.

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LIST OF ABBREVIATIONS

AFD	Agence Française de Développement
AfDB	African Development Bank
CERSGIS	Centre for Remote Sensing and Geographical Information System
CIDA	Canadian International Development Agency
CWSA	Community Water and Sanitation Agency
DANIDA	Danish International Development Agency
DWL	Dynamic Water Level
ESRI	Environmental Systems Research Institute
EU	European Union
GIS	Geographical Information System
GSD	Geological Survey Department
GPS	Geographical Positioning System
GSS	Ghana Statistical Services
GWCL	Ghana Water Company Limited
HDW	Hand Dug Well
IDA	International Development Agency
IDW	Inverse Distance Weighting
ISD	Inverse Square Distance
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaufbau
KNUST	Kwame Nkrumah University of Science and Technology
LP	Local Polynomial
MCDA	Multi Criteria Decision Analyses
MLGRD	Ministry of Local Government and Rural Development

NGO	Non-Governmental Organisation
PIG	Plan International, Ghana
PWQ	Poor Water Quality
PVC	Polyvinyl Chloride
RMS	Root-Mean-Square
RS	Remote Sensing
STPS	Small Towns-Piped Systems
SWL	Static Water Level
RWL	Recovery Water Level
UNICEF	United Nations International Child Emergency Fund
UTM	Universal Transverse Mercator
WRRI	Water Resources Research Institute
WVI	World Vision International

CHAPTER ONE

INTRODUCTION

1.1 Background

Groundwater is an essential resource for sustainable development all over the world. The welfare of every society is tied to the sustainable exploitation of its water resources. In Ghana, groundwater is becoming the most important source of water for domestic, industrial and agricultural purposes due to the unreliability of surface waters as most of them dry up in the dry season and are highly polluted by industrial waste, chemicals from unconventional mining activities (popularly known as "galamsey"), and leaching of pesticides, fungicides and fertilisers used for agricultural purposes (Nyarko et al., 2014). It is, mainly, tapped through the drilling of boreholes and digging of hand dug wells (HDW) to serve as potable water for domestic and, recently, industrial usage in both rural and urban settings. This has tremendously helped in reducing the inadequate supply of potable water and many water borne diseases in the country.

Groundwater usage has become attractive in Ghana because aquifers exist in most parts of the country, which can be exploited at shallow depths and near the demand areas without the need to install long distribution lines. Also, it is easily accessible and capable of being managed by individuals and small groups. Thirdly, the aquifers yield sufficient quantities of water, in most cases, are protected naturally from evaporation and are more reliable in dry seasons because of their large storage capacities. Other factors that have enhanced groundwater usage are their outstanding chemical and microbiological quality and less capital is required for its development unlike the development of surface waters.

As a result, the Government of Ghana and several Non-Governmental Organisations (NGO) have been providing rural communities with boreholes and HDW to meet their drinking and other domestic water needs. The government finances such projects solely or seek loans and grants from its development partners such as AFD, KfW, CIDA, DANIDA, EU, IDA, UNICEF, WVI, PIG, JICA and AfDB in undertaking such projects. Mostly, the projects are organised in two (2) categories; i.e. hand pump boreholes/HDW and mechanised boreholes. The hand pumped boreholes/HDW are for communities with population below 2000 whereas the mechanised boreholes serve communities with population between 2000 and 5000. The mechanised boreholes are distributed either as limited mechanisation where the water is stored in reservoirs (usually a plastic tank) and fetched through taps constructed close to the borehole or as Small Towns Piped Systems (STPS), where an overhead reservoir (usually constructed of concrete or stainless steel) stores the water and it is distributed to households and pipe stands erected at vantage points in the town. The unreliability of piped water delivery system in the cities and major towns has also increased the exploitation of groundwater by individuals for domestic usage. Boreholes and HDW are, therefore, drilled and scattered within urban communities.

The commercial exploitation of groundwater has become the source of livelihood for many; the water is sold by bottling, bagging in sachet and distributing to households using tanker vehicles. Operators of vehicle washing bays have also resorted to the use of boreholes and HDW as water source for their work. In the agricultural sector, it provides water for livestock and irrigation in the dry season. Many industries and factories also rely on it as their primary water source.

Despite its usefulness, accessing groundwater within Ghana comes with some challenges which include:

1. Limited source of funding for projects.
2. Uncertainty of obtaining sufficient amount of water especially within the Voltaian Formation (which covers 45 % the country), Dahomeyan and the granites and gneiss associated with the Birimian.

3. Water quality problems especially acidity (lower pH), salinity (in the Voltaian Formation and along the coast) and excessive amount of fluoride, manganese, arsenic and iron.

In the Ashanti Region, the predominant problems include:

- Insufficient yields especially within the granitic and Voltaian Formations (Anornu et al., 2009) and
- Poor water quality owing to excessive amounts of some chemicals such as iron, manganese, fluoride, arsenic and turbidity (British Geological Survey, 2000; Nyarko et al., 2014; Gyau-Boakye and Dapaah-Siakwan, 2000; Anornu et al., 2009; CWSA, 2008).

About 40% of drilled boreholes in the country with iron and manganese concentrations above the Ghana Water Company Limited (GWCL) guideline values are abandoned whilst usage of the remaining percentage is drastically reduced for drinking, cooking and laundry purposes by the beneficiary communities. This means about 20% of the government's investment in groundwater is under threat of being wasted translating to a loss of between $600 and $900 on every borehole drilled in the affected regions (CWSA, 2008).

Hydrogeologists, geotechnical engineers as well as environmental engineers require prior hydrogeological information of a project area for proper planning and smooth implementation. Different rock types have different hydrogeological properties controlling the flow, storage and quality of water within them. Knowledge of the underlying rock of a project area generally indicates the probability of obtaining sufficient and quality water. Also in crystalline rock formations, for example, sufficient water is obtained in the deep weathered zones even when there is not enough in the bedrock. Thicker overburden also tends to cave in during drilling, which may necessitate the use of water drilling instead of air drilling method. The average final depths of boreholes influence the budget of projects as well as serving as a guide in groundwater geophysical explorations.

Aside the primary study of groundwater in relation to its use as a resource, it is also useful for geotechnical and environmental purposes. The depth to groundwater is typically important in the design and construction of high-rise buildings and roads, the location of landfills and waste water disposal sites, and also for groundwater monitoring (Matson and Fels, 1996; Snyder, 2008). Dam leakages and inflows to tunnels and open pit mines arise as a result of excessive rates and quantities of groundwater flow. The presence of excessive fluid pressures from groundwater also influences land subsidence and slope instability (Freeze and Cherry, 1979).

It is therefore evident that if some of these hydrogeological information (rock type, thickness of overburden, expected depth, quantity of water, likely chemical composition and the hydraulic properties of the aquifer) for a prospective project is available, the budget, duration, likely challenges and the appropriate remedies can be adequately planned to enhance the smooth implementation of the project. They will also serve as reference data for future studies and ultimately contribute to the national development. Also, Geographical Information System (GIS) software, which has user-friendly pre-processing and post-processing interfaces and uses digital techniques to integrate various conventional methods (geological, hydrogeological and photogeological) with satellite image/remote sensing (RS) techniques, are available for storing and visualising the data (which are inherently spatial in nature), and for the prediction of future conditions (Kresic and Mikszweski, 2013; Chenini et al., 2010; Machiwal et al., 2011; Talabi and Tijani, 2011).

1.2 Study Purpose and Specific Objectives

This research, therefore, seeks to employ GIS techniques to evaluate and delineate the hydrogeological parameters of the various geological formations in Ashanti Region to aid in easy and successful exploitation of groundwater. The specific objectives of the study are to:

i. Determine the hydrogeological parameters of aquifers in the geological formations of the study area, ii. Generate surface maps of the various hydrogeological parameters within the geological formations, and iii. Delineate areas with major groundwater quality problems.

1.3 Scope of Study

The study assessed the hydrogeological parameters of aquifers in the geological formations of the Ashanti Region with emphasis on the availability of sufficient amounts of water and their potability. The ArcGIS software was used to assess secondary data of existing boreholes and produce surface maps of some of the hydrogeological parameters of aquifers in the study area including the airlift yield, overburden thickness, final depth of successful boreholes, static water level elevation, specific capacity and the occurrence of iron employing the ordinary kriging interpolation method. The study also attempted to establish the relation and effects of these parameters on each other as well as analyse the quality of water obtained from the various geological formations. The study, however, did not involve drilling of boreholes or conducting of pumping tests.

This report is in 6 chapters. The background, problem statement, justification and scope of work are presented in Chapter 1. Chapter 2 presents a review of literature of previous studies done whilst a brief description of the study area is covered in chapter 3. The methods employed in this study are presented in chapter 4 while the results obtained are produced, analysed and discussed in chapter 5. Chapter 6 contains some conclusions and recommendations from the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Flow of Groundwater in Aquifers

The flow of groundwater is influenced by multiple factors. According to Freeze and Cherry (1979), within a geologic system, groundwater flow is controlled by lithology (mineral constituents, size and packing of the grains of the rock particles), stratigraphy (geometry and similarity in age of the lenses, beds, and formations of geologic system of sedimentary origin) and presence of structures in geologic formations (cleavages, fractures, joints, folds, and faults). In unconsolidated deposits, they attributed lithology and stratigraphy as the most important controlling factors. The overall controlling factors that ease groundwater flow are the porosity and permeability of the rocks. The connectivity of the pores and/or fractures increases the permeability. Knowledge of the porosity and permeability of the rocks leads to an understanding of the aquifers.

The aquifer's hydrogeological parameters also influence the flow and abstraction of groundwater in the rocks. In solving groundwater flow problems, the hydraulic characteristics of the geological formations through which the groundwater is moving are determined by hydrogeologists and engineers to aid in decision making. Various assumptions are made depending on the homogeneity or isotropy of the lithology, and the type of aquifer (Bilpinar, 2003; Kruseman and Ridder, 2000). An effective method, among others, used to determine the hydraulic parameter values is conducting of pumping tests. Some of the parameters include hydraulic conductivity (K), transmissivity (T) and specific capacity (q). The estimation of these parameters are governed by Darcy's law, which states that in a porous medium, the flow rate is proportional to the head loss, and inversely proportional to the length of the flow path; mathematically expressed as:

$$V = K\frac{\Delta h}{\Delta l} \tag{2.1}$$

where $V = Q/A$ referred to as specific velocity (m/s), Q is the volumetric flow rate (m^3/s), A is cross sectional area normal to the flow direction (m^2), Δh is the head loss, Δl is the length of the flow path (m) and K is a constant of proportionality known as the hydraulic conductivity (m/s).

Hydraulic conductivity, which describes the easiness with which water, under a hydraulic gradient, passes through porous spaces and fractures in soil or rock, and dependent upon the saturation and permeability of the soil or rock, is generally determined using pumping tests, permeameter tests (constant head and falling head methods), auger-hole method (for an unconfined aquifer with homogeneous soil properties and a shallow water table), piezometer method (for soils in an unconfined aquifer with a shallow water table) and slug-test (for unconfined and confined aquifers) (Garrick, 2016; Kruseman and Ridder, 2000). Transmissivity can also be determined directly from the average horizontal permeability and thickness of an aquifer, and is defined as the flow rate under a unit hydraulic gradient through a cross-section of unit width over the saturated thickness of the aquifer (Kruseman and Ridder, 2000). It is usually determined using the Cooper and Jacob (1946) method using equation (2.2):

$$T = \frac{0.183Q}{\Delta s} \tag{2.2}$$

where Q is the discharge in m^3/day and $\Delta s$is the change in drawdown in metres per log cycle.

2.2 Hydrogeological Studies in Ghana

The Geological Survey Department (GSD), Ghana, developed a hydrogeological map of Ghana in 1969 and came out with two (2) major hydrogeological Provinces; i.e. the Basement complex consisting Precambrian (now Paleoproterozoic) of crystalline igneous and metamorphic rocks and the Palaeozoic (Neoproterozoic) sedimentary formations (Figure 2.1).

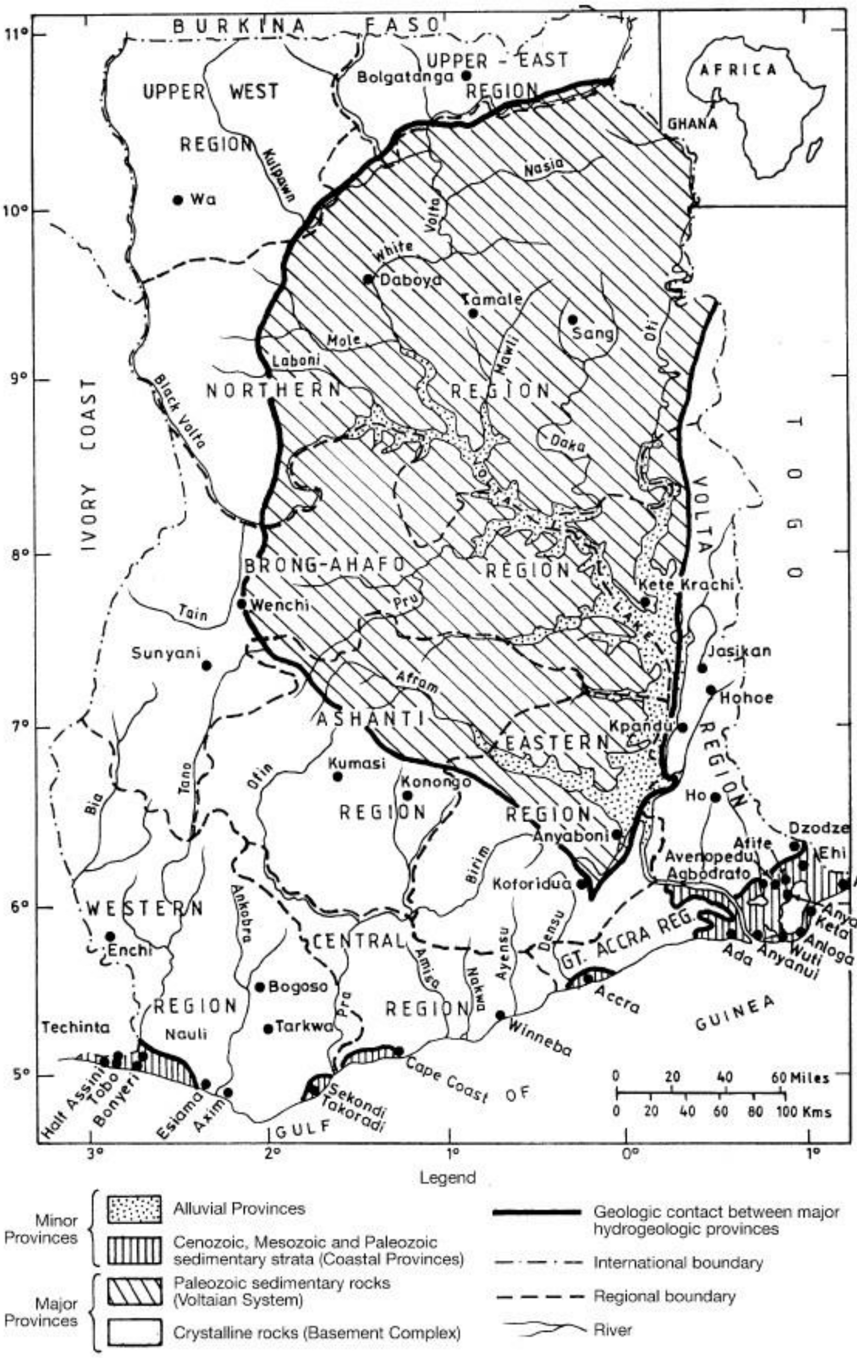


Figure 2.1: Hydrogeological provinces and river systems of Ghana (GSD, 1969)

Other provinces consisting of Cenozoic, Mesozoic and Palaeozoic sedimentary alluvium along narrow belts on the coast and Quaternary alluvium along the major stream courses were also proposed. Based on hydrogeologic conditions, the provinces were divided into sub-provinces.

The sub-provinces within the Paleoproterozoic Province are the Lower Precambrian (Dahomeyan System), the middle Precambrian (Birimian System and associated intrusive granitoids) and the Upper Precambrian (Tarkwaian System, Togo Series and the Buem Formation). For the Neoproterozoic Province, the sub-provinces are the Upper Voltaian (Kwahu) and the Lower Voltaian (Oti Pendjari and Obosum Groups) (Gill, 1969; GSD and BGR, 2009).

In a bid to understand the groundwater system of Ghana, further studies have been conducted. These include studies on a large scale with the Ashanti Region being inclusive or within some particular localities or districts within the Ashanti Region touching on the success rate and yield of boreholes within respective formation, quality of groundwater for potable use and the hydraulic properties of the groundwater (Dapaah-Siakwan, 2000; Anornu et al., 2009; WRRI, 1994; BGS, 2000; Buamah et al., 2008; Nyarko et al., 2014). Dapaah-Siakwan and GyauBoakye (2000) upon analysis of borehole data in Ghana concluded that the mean depth of boreholes in the Lower Birimian rocks and the associated granites were 35 m and 60 m respectively. They estimated the yield of boreholes in the Birimian to be about 212 l/min (12.7 m^3/h) and characterised the Lower Voltaian as the least explored because it is sparsely inhabited. Their study, however, did not indicate the depth to the aquifers and also generalised the quality of water without specificity to the geological formations.

Anornu et al. (2009) estimated the rate of aquifer replenishment in the Ejisu-Juaben District of the Ashanti Region using chloride mass balance and water balance equations. They successfully analysed data of existing boreholes in the district by relating the geology to yield and depth of aquifers. They observed that there were poor relations between borehole yield and depths in both the Birimian rocks and the granitoids because they were all crystalline and behaved the same way under weathering and groundwater conditions. They concluded that the transmissivity of the boreholes varies between 0.12 and 125 m^2/day from pumping tests data. Excess amounts of iron and manganese were observed as the main water quality related problems within the district. Unfortunately, no map was produced to give a spatial distribution of the situation in the district.

In 1994, a borehole yield map of Ghana was prepared by the then Water Resources Research Institute (now Water Research Institute) of the Council for Scientific and Industrial Research (CSIR) using data from 11,500 boreholes as shown in Figure 2.2 (WRRI, 1994). The map indicated the expected yield in any particular area when a borehole is drilled there. This map however did not indicate the depth at which these aquifers were intercepted, the relation between the aquifers and geology nor the quality of the water.

The quality of groundwater within the geological formations with respect to inorganic constituents in Ghana was well assessed by the British Geological Survey (BGS) and GyauBoakye and Dapaah-Siakwan in the year 2000. According to the BGS studies, excess iron, manganese, fluoride and arsenic as well as iodine deficiency were the major problems as outlined in Table 2.1. Studies by Gyau-Boakye and Dapaah-Siakwan (2000) also attest to these chemicals and low pH (acidity) being the major water quality problems.

Other studies within the study area abound, which affirm some of their findings. Buamah et al. (2008) assessed the water quality of 290 boreholes within the gold-belt zone in the Ashanti,

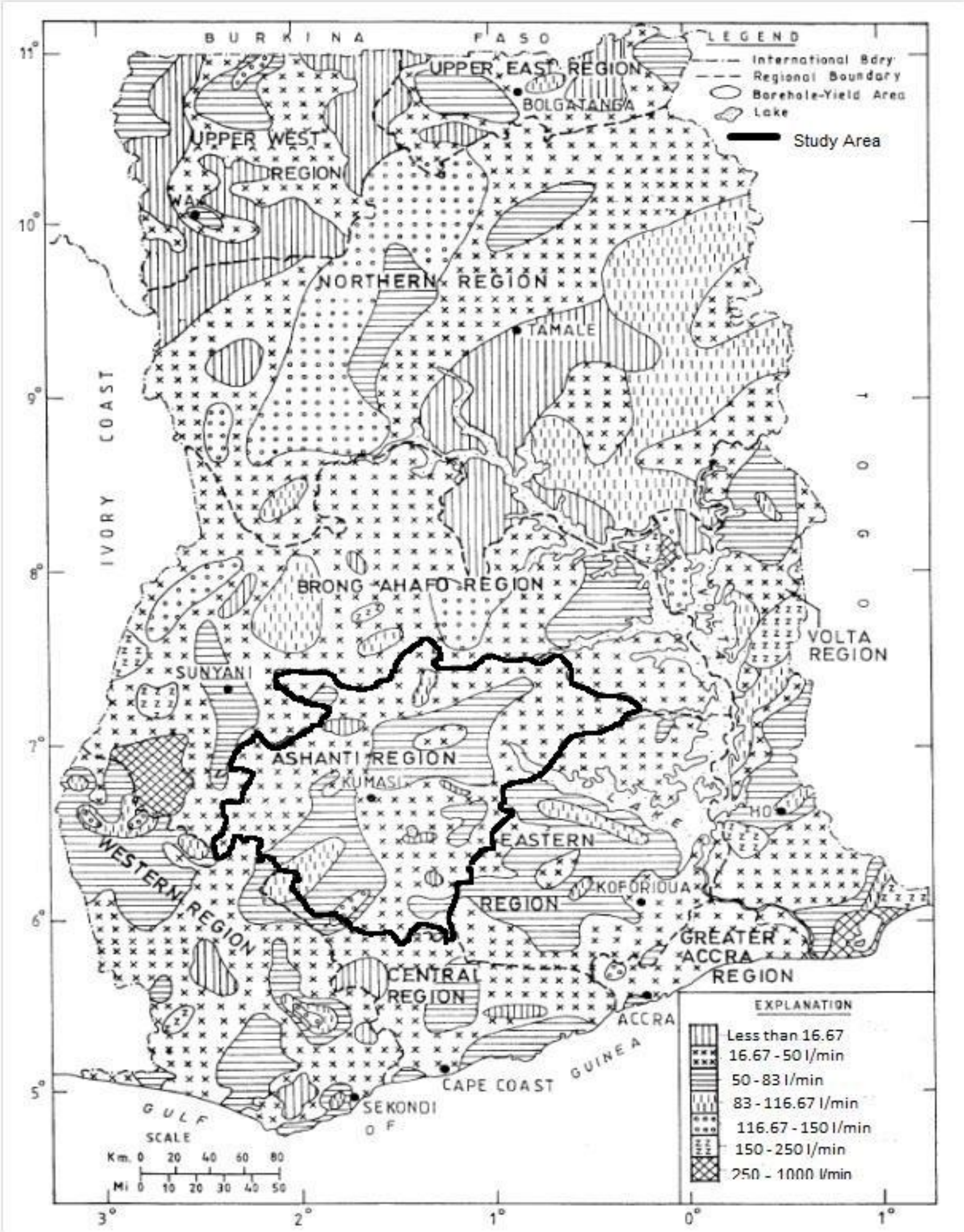


Figure 2.2: Distribution of borehole yields in Ghana (WRRI, 1994)

Table 2.1: Summary of groundwater quality problems in Ghana (BGS, 2000)

Chemical	Geological formation	Location
Iron	All aquifers	Many locations
Manganese	All aquifers	Several locations
Fluoride	Granites and some Birimian rocks	Upper Regions
Iodine	Birimian rocks, granites, Voltaian	Northern Ghana (especially Upper Regions)
Arsenic	Birimian rocks	South-west Ghana (gold belts areas)

Brong Ahafo and Western Regions. About 5 – 12 % of data had excess amount of arsenic above the WHO guideline values across the three regions; all these were within the Birimian and Tarkwaian Formations and may be attributed to the presence of arsenopyrites in close association with sulphide mineralised veins (BGS, 2000). Iron and manganese levels within the Ashanti Region were also found to be above the WHO guideline value by 25 % and 13 % respectively. For their studies in the Ejisu-Juaben district, which is underlained by Birimian Formation and associated granitoids, Anornu et al. (2009) identified that 20 % and 0.4 % of boreholes had excess iron and manganese respectively above the WHO guideline values.

Acidity and excess iron were similarly identified as the main water quality problems in the Ashanti Region by Nyarko et al. (2014) with the former being predominant in the Birimian phyllites, intrusive granites and sandstones, and the later within the Birimian phyllites and intrusive granites. Even though all these studies identified the main groundwater problems and associated them with the geology, they failed to delineate the localised areas with specific problems but instead generalised formations as having the stated problems.

2.3 GIS Tools in Groundwater Studies

GIS tools are used to assemble, store, manipulate, retrieve at will, transform and display both spatial and non-spatial data from the real world for specific purposes in a quick, efficient and organised way (Burrough and McDonnell, 1998; Das, 2009). Data processing approaches such as integration, geo-referencing aggregation and spatial analyses are enhanced using GIS. Its capability to put together data from different sources to allow spatial analysis has increased its application in fields such as architecture, zoology and city planning (Kennedy, 2013), and makes it possible to bring different sources of data together for spatial analysis. The spatial and geostatistical tools are among some of the tools used to explore and interpolate data for map creation (Johnston et al., 2001).

Groundwater study has been enhanced with the advancement of GIS technique. It has been integrated with remote sensing (RS) for groundwater delineation/zoning within the last two decades (Magesh et al., 2012; Deepika et al., 2013 and Dinesan et al., 2015). For example, Fashae et al. (2003) utilised the combination of multi-criteria decision analysis (MCDA), RS and GIS techniques to delineate potential groundwater zones in the crystalline basement terrain of south-west Nigeria and validated the results with existing borehole and well yield data. They integrated thematic maps of geology, geomorphology, rainfall, soil, lineament density, drainage density, slope, land use and drainage proximity. In an attempt to determine the important contributing parameters among slope, lithology, stream networks, lineaments, and topography that indicate the groundwater potential of the central part of the Easting Desert in Egypt, Abdalla (2012) used the raster calculate module of GIS to produce groundwater prospective zones of the area. Gumma and Pavelic (2013) also used GIS, RS and spatial modelling to delineate groundwater potential zones in Ghana. Yidana et al. (2015) analysed the hydrogeology and groundwater flow in crystalline rocks in the Afigya Sekyere South District of the Ashanti Region with a similar approach. They used GIS tools to produce the geometry of the groundwater system and estimated the spatial variations in the hydraulic conductivity of aquifers in the area using data from borehole yields. Although all the above authors used GIS tools for their prediction, their study did not utilise actual information from drilling neither did they employ the geostatistical analytical tool.

GIS tools have also been used in generating altitude to depth of water table maps. The groundwater-altitude and depth to groundwater maps for Utah, United States, were generated by Buto and Jorgensen (2005) using groundwater data from 1971 - 2000. Snyder (2008) used a similar approach to estimate the depth to groundwater for the Oregon area in the USA. Within the study area, Ofosu et al. (2014) developed a groundwater level map using data from 37 boreholes, which is relatively small for the study area. Results from their study showed that, water in a well can be influenced by the variation in depth of groundwater within a radius of 65 km from the well. However, the crystalline nature of most of the rocks and the existence of geological contacts means the 65 km is too large for such an influence to be felt. There is, therefore, the need to increase the number of samples to obtain meaningful results.

2.4 Creating Surface Maps Using Geostatistical Techniques

There are two main categories of interpolation methods used in creating surfaces from measured points namely deterministic and geostatistical (Johnston et al., 2001; Jie et al., 2013).

Deterministic methods utilise the extent of similarity of the data (e.g. Inverse Distance Weighted) or fit a mathematical function to the measured points depending on the degree of smoothness (e.g. global and local polynomial and radial basis function). Geostatistical methods however compute the spatial autocorrelation among measured points that account for the spatial configuration of the sample points around the prediction location. They create surfaces by incorporating the statistical properties of the measured data. By this, it produces a prediction surface as well as the error or uncertainties associated with the generated surface giving an indication of the success of the prediction. The main geostatistical method is kriging, which first quantifies the spatial structure of the data (known as variography) by fitting a spatialdependence model to the data and secondly to produce a prediction by using the fitted model from the variography, the spatial data configuration and the values of the measured sample points around the prediction location (Johnston et al., 2001).

The kriging interpolation method of the geostatistical analyst tool has been widely used in fields such as soil science, hydrology, atmosphere science and groundwater (Kumar and

Remadevi, 2006) because it is capable to produce a prediction surface as well as providing some measure of the prediction's certainty or accuracy (Snyder, 2008; Ofosu et al., 2014; Rabah et al., 2011; Kumar and Remadevi, 2006). In comparing it with the inverse distance weighting (IDW), Jie et al. (2013) concluded that kriging is more suitable for data whose samples have high spatial correlation. Also kriging puts emphasis on the whole trend of data whereas IDW focuses on the values of neighbouring locations. According to Kumar and

Remadevi (2006), kriging produces smoother map and reliable estimates than the Inverse Square Distance (ISD) method from their study. It also produced the most accurate prediction of chloride concentration and groundwater level in comparison with IDW and Spline in studies by Rabah et al. (2011). Other studies, which proved that the kriging interpolation method produces best results in spatial analyses of groundwater data and surface map generation include Coulibaly and Becker (2007), Ibrakhimov et al. (2007), Shamsudduha (2007) and Sun et al. (2009).

Kriging as a predicting method, assume all random errors to be of second-order stationarity. This means the errors have zero mean and the covariance between any errors depends solely on the distance and direction between them, but not their exact locations (Johnston et al., 2001).

The general formula for the kriging interpolation is given as:

$$\hat{Z}(S_o) = \sum_{i=1}^{N} \lambda_i Z(S_i) \tag{2.3}$$

where $Z(S_i)$ is the measured value at the ith location, λ_i is an unknown weight for the measured value at the ith location, S_o is the prediction location and N is the number of measured values. The kriging process includes exploratory statistical analysis of the data using the exploratory spatial data analysis (ESDA) tools and the semivariogram modelling.

The ESDA tools include Histogram, Normal Quantile-Quantile (QQ) plot, Trend analysis and

Semivariogram/covariance cloud. The Histogram and Normal QQ plots are used to check for the normality of the data. Although kriging does not require normally distributed data, its predictions are better than all the interpolation methods when the data is normally distributed (Johnston et al., 2001). According to the guide for the ArcGIS software, a distribution is termed as near normal distribution using the histogram when the mean and median are almost the same, the skewness is near zero (0) and Kurtosis is also near 3. For the Normal QQ plot, the distribution of each dataset is compared to that of a standard normal distribution. The closer the data is to the standard normally distributed line, the closer the distribution is to normal. Non-normal distributions (skewed data) can be transformed to be normal using the Box-Cox, log and arcsine transformations. Data transformed before creating predictions surfaces are transformed back to the original scale for the interpolated surface.

A trend is a linear function of the geographic coordinates of the data constructed in such a way that the squared deviations of the data from the trend are minimised. It is thus the fixed effects composed of spatial coordinates used in linear models (Davis, 2002; Johnston et al., 2001). The trend analysis is performed by visualising the data in a 3D plot to observe the presence or otherwise of any large scale trends. The data is projected onto the XZ and YZ planes as scatter plots, which are fitted with a polynomial curve. Directional trends can also be detected by rotating the data whilst observing the angle at which a trend may exist. Trends are removed (to satisfy the assumptions of stationarity) by specifying the order of the polynomial curve (Johnston et al., 2001). The removal of trends also implies the random short-range variation in the residual is being modelled. The trend is added back to obtain reasonable predictions.

A semivariogram, a graphical representation used to provide a pictorial view of the spatial correlation in the dataset, is used to model the spatial relationships of the dataset. To calculate the semivariogram, the variances of each data point in the data set with respect to all other data points are determined and plotted against the distances between the points. It is then used to compute the weights that are used in the interpolation (Davis, 2002) and mathematically expressed as:

$$\gamma_h = \sum_i^{n-h}(x_i - x_{i+h})^2/2n \tag{2.4}$$

where x_i is a measurement of a regionalised variable x taken at location i, and x_{i+h} is a measurement taken at h intervals away, and n is the number of points. The size of a distance class into which pairs of locations are grouped to reduce the large number of possible combinations, known as the lag size, and omnidirectional parameters such as nugget, range, partial sill and shape are set to fit the model. The effects of anisotropy, which can be caused by the presence of a geological structure, is also statistically quantified and accounted for. The accuracy of these parameters and the selected model are provided by the prediction error statistics (the difference between the measured and predicted value). The prediction error statistics are obtained using cross-validation, whereby a point in the dataset is sequentially omitted, and a value is predicted for the location of that point using the rest of the data. The measured and predicted values are then compared using the prediction error statistics, which include a mean error close to 0 (meaning predictions are unbiased), a root-mean-square (RMS) standardized error close to 1 (meaning standard errors are accurate) and RMS error and average standard error that are as small as possible and close to each other (meaning predicted values do not deviate much from the measured ones) (Johnston et al., 2001). Owing to the fact that the value of the mean prediction error depends on the scale of the data, standardised values known as prediction standardised errors, obtained by dividing the prediction errors by their standard

errors are used. The means of these should also be near zero.

CHAPTER THREE

DESCRIPTION OF STUDY AREA

3.1 Location and Size

The Ashanti Region is located in the middle belt of Ghana between longitudes 0.15^o W to 2.25^o W and latitudes 5.50^o N to 7.46^o N. It shares boundaries with the Brong Ahafo Region to the north and west, Eastern Region to the east, Central Region to the south and Western Region to the south west (MLGRD, 2016a). It covers about 10.2 % (24,389 km^2) of Ghana's total land area, which makes it the third largest region after Northern (70,384 km^2) and Brong Ahafo (39,557 km^2) Regions. (MLGRD, 2016b). The population of the Region is about 4,780,380 representing 19.4 % of Ghana's population and a population density of 196 people per square kilometre according to the 2010 population and housing census report. Nearly 61 % of the region's population lives in urban areas. More than 92 % of the population in the region have access to 'improved' (piped-system, boreholes and protected HDW) source of drinking water with groundwater in the form of boreholes and protected wells constituting 42 %. Boreholes are required to help improve the water sources for about 7 % (308,335) of the inhabitants who still rely upon unprotected HDW, dug outs, streams and rivers as their source of drinking water (GSS, 2013).

Administratively, there are 30 decentralised assemblies in the region, comprising one metropolitan, 7 municipal and 22 districts (Figure 3.1) headed by Metropolitan, Municipal and District Chief Executives respectively. The administrative capital is Kumasi.

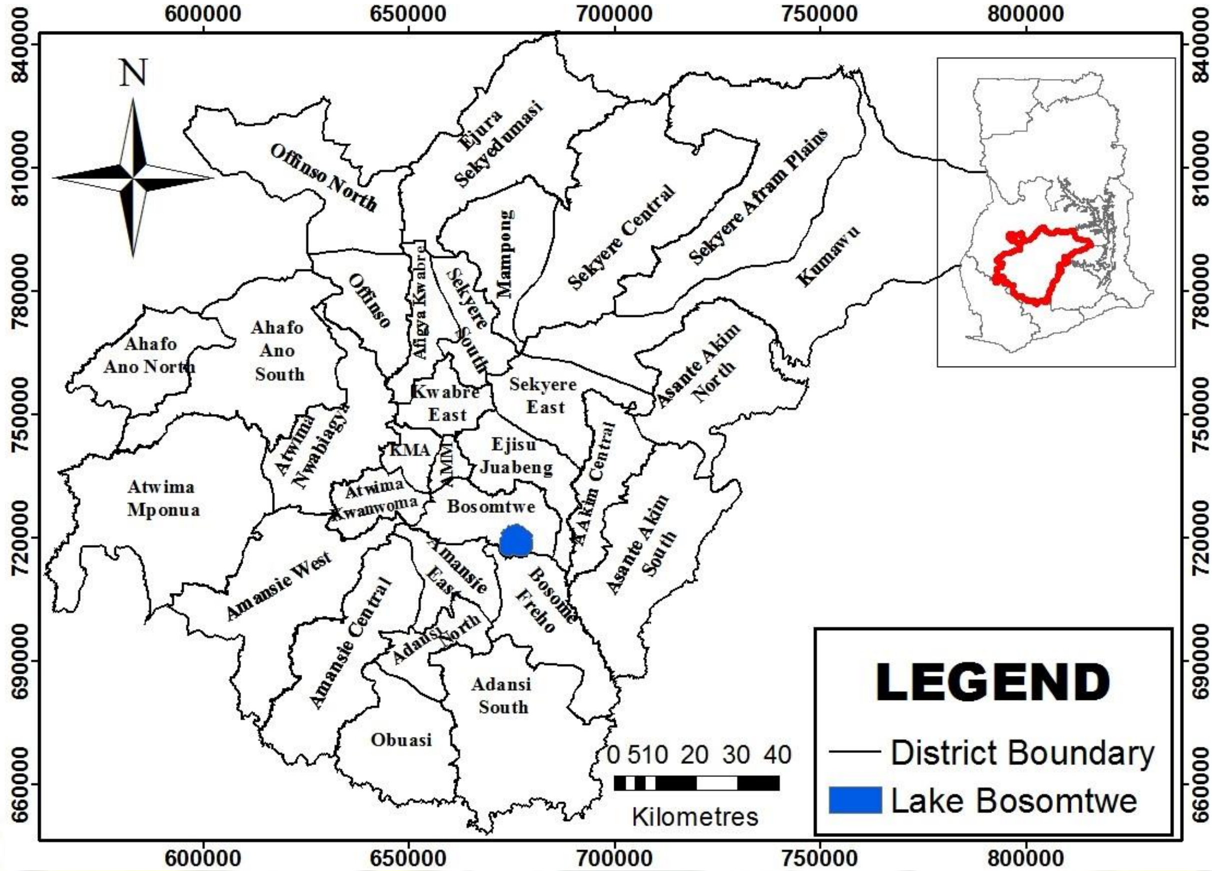


Figure 3.1: Map of Ashanti Region showing the administrative districts

3.2 Topography, Vegetation, Climate and Drainage

The study area lies between an elevation of 50 and 700 metres above mean sea level with most areas located between 150 and 300 metres. Majority of the region lies within the wet, semiequatorial forest zone. The forest vegetation of parts of the region, particularly the northeastern part, has been reduced to savannah as a result of human activities and bushfires.

The mean annual rainfall in the region is about 1,270 mm with a mean annual daily temperature of 27 ^{o}C (MLGRD, 2016b). It experiences the bimodal rainfall pattern with the main rainy season between mid - March to the end of July and minor rainy season from

September to mid-November. It experiences dry season between mid-November and mid-March (MLGRD, 2016b).

There are attractive forest reserves, national parks and lakes such as the Owabi Arboretum, Bongobiri wildlife sanctuary and Lake Bosomtwe (the largest natural lake in the country) which serve as tourist sites. Some notable rivers that drain the region are Rivers Offin, Pra, Afram, Oda and Owabi. Residents of some localities in the region depend on these and other smaller rivers and streams as sources of drinking water (MLGRD, 2016b).

3.3 Geology and Hydrogeology

The study area is divided into two main lithostratigraphic / lithotectonic complexes, namely the Paleoproterozoic supracrustal and intrusive rocks and the Neoproterozoic to early Cambrian lithologically diverse platform sediments as revised by the GSD in cooperation with Bundesantalt für Geowissenschaften und Rohstoffe (BGR) in 2009. The Paleoproterozoic rocks consist of the Birimian Supergroup, Tarkwaian Group and the Eburnean Plutonic Suite, which were formed between 2195 Ma and 2072 Ma whereas the Neoproterozoic comprises the Voltaian Supergroup made up of the Kwahu and Oti Pendjari Groups formed between 1000 Ma and 950 Ma. Within the Voltaian Supergroup is a late Neoproterozoic to early Cambrian Obosum Group formed after 630 Ma.

The Ashanti Region covers four hydrogeological sub-provinces of the two major Provinces (Figure 2.1) namely the Middle Precambrian, the Upper Precambrian, the Lower Voltaian and Upper Voltaian. The Middle Precambrian sub-province is generally referred to as the Birimian System and it is made up of metamorphosed sediments intercalated with metamorphosed tuff and lava. These are intruded by large masses of undifferentiated granites and gneisses. It occurs in two main stratigraphic successions; namely the Upper Birimian (Birimian volcanic), which consists of metamorphosed lavas and pyroclastic rocks and the Lower Birimian (Birimian sediments) comprising phyllites, schist, and greywackes. The Birimian is characterised by structural features such as well developed joint and fracture systems as well as quartz veins within the phyllite bodies. These structural features as well as the extent of weathering determine groundwater occurrence in the Birimian System. The best aquifers are located at where significantly decomposed materials have been accumulated, which are usually along the slopes of the synclinal troughs. Localised tension joints developed on top of hills also enhances the development of aquifers. The predominantly argillaceous sediments have metamorphosed into schist, slate, phyllite and greywacke. The tuff and lava range from mafic to silicic composition with many of the mafic extruded under water. The contact between the saprolite and the saprock is the most productive groundwater zone within the Birimian System as they usually complement each other in terms of permeability and storage (Carrier et al., 2008). The occurrence of varying amounts of carbonaceous, ferrous, manganiferrous and calcareous materials within the Birimian pose serious localised water quality problems in some parts of the study area. The intrusive granitoids include hornblende and biotite granites, granodiorites and granite–gneisses of the Cape Coast and Dixcove suites which are, basically, characterised by crystalline basement hydrogeologic conditions. The fracture systems within the granitoids are localised with overlying porous weathered profile serving as storage reservoir.

The second sub-province, the Upper Precambrian, consists of the Tarkwaian Group, which is the oldest of the series of formations. It is intruded by laccoliths and sills of epidorite and is folded along axes, which run northeast to southwest (Gill, 1969; Kesse, 1985; Dapaah-Siakwan and Gyau-Boakye, 2000). The Tarkwaian rocks consist of quartzites, phyllites, grits and conglomerates. Groundwater occurrence in this Group is similar to that of the Birimian System (Gill, 1969; Kesse, 1985; Dapaah-Siakwan and Gyau-Boakye, 2000).

The Lower Voltaian sub-province (Kwahu Group), the third sub-province, is underlained by the basal sandstones consisting mainly of quartz-sandstone and pebbly grits and grits with ripple marks and galls. The fourth sub-province is the Middle Voltaian sub-province, which comprises generally of flat lying or gently dipping interbedded argillaceous Obosum beds and arenaceous Oti Pendjari beds. The Obosum rocks are predominantly shale, mudstone, siltstone, sandstone, arkose and conglomerate. The Oti beds also comprise rocks of the Obosum beds as well as grits and minor limestone. A common feature of the basin is inter-bedding of the different geological units even though areas of uniform lithology also exist. The upper sandstones and the Oti beds yield substantial amount of groundwater with the aquifers developing within bedding planes, fractures and porous strata. Owing to their impermeability, the shales and mudstones of the Obosum bed have very low groundwater potential even though shallow aquifers exist in areas with good surface water hydrology (Kesse, 1985).

3.4 Water Supply

The WHO and UNICEF (2000) classified water sources as ‘improved’ or ‘unimproved’. The ‘improved’ sources include public piped systems transmitted to homes and standpipes, borehole, HDW, protected spring and rainwater collection whilst unprotected wells, springs and tanker-trucks supply constitute the ‘unimproved’ sources. About 93 % of the population in the Ashanti Region depend on the improved sources for drinking water (Table 3.1). About 31 % of them depend on groundwater in the form of boreholes and HDW as the main sources of water for drinking and other domestic uses (GSS, 2013). The major sources of water are the pipe-borne system and groundwater. The pipe borne system, which is the distribution of treated water from Owabi and Barekese dams through pipes to individual homes, is primarily found within the Kumasi metropolis and its adjoining districts.

About 41 % of the population within the study area depend on the pipe borne system. Groundwater, in the form of boreholes, hand-dug wells and springs is used by about 54 % of the population spreading throughout the study area (GSS, 2013). The water is usually fetched through hand pumps, or mechanised system and distributed through stand pipes within the community or to individual homes. Commercially, the water from boreholes is packaged in plastic sachets and bottles and sold for drinking purposes. About 5.3 % of the population still drink water from rivers, dugouts, ponds and lakes whilst about 6 % use them for other domestic purposes.

Table 3.1: Sources of water for drinking and domestic usage in the Ashanti Region (GSS, 2013)

Source of Water	Drinking (%)	Other domestic use (%)
Pipe-borne inside dwelling	22.0	22.8
Pipe-borne outside dwelling	18.7	18.3
Public tap/Standpipe	10.1	10.0
Bore-hole/Pump/Tube well	30.9	31.5
Protected well	7.2	9.0
Rain water	0.1	0.2
Protected spring	0.4	0.4
Bottled water	0.3	-
Sachet water	3.7	-
Tanker supply/Vendor provided	0.4	0.5
Unprotected well	0.7	0.9
Unprotected spring	0.1	0.2
River/Stream	5.2	5.8
Dugout/Pond/Lake/Dam/Canal	0.1	0.2
Other	0.1	0.2

CHAPTER FOUR

METHODOLOGY

4.1 Data Collation

Borehole records were obtained from the Community Water and Sanitation Agency (CWSA), Ashanti Regional branch in Kumasi, Geohydrotech Limited and World Vision International (WVI). The data, which span from 1991 to 2011, were compiled from hydrogeological reports submitted by Consultants for different projects under the supervision of the CWSA. The projects were mainly in two parts; point sources and piped system. The point source boreholes are fitted with hand-pumps and are required to sustain a minimum yield of 10 l/min for a sixhour constant rate pumping test (CWSA, 2010a) whereas the piped system, which require a minimum pumping test yield of 85 l/min are mechanised and distributed to individual houses or stand pipes erected within the community (CWSA, 2010b). The information gathered from the reports included:

- GPS coordinates of the boreholes in UTM Zone 30N format and their elevation with respect to mean sea level (msl),
- Borehole construction details such as final constructed depth, location of slotted and plain PVC and gravel pack positions,
- Geological logs detailing different rocks intercepted at different depths, overburden thickness, depths at which water was struck and the volume of water obtained at the specific depths expressed in litres per minute (l/min) and the final airlift yield recorded during development,
- Summary of pumping test results including the pumping yield, static water level (SWL), dynamic water level (DWL) after six (6) hours of pumping and recovery water level (RWL) after three (3) hours of cessation of pumping. All water level measurements were with respect to ground level, and
- Results of the physico-chemical and bacteriological analyses of the water samples.

To ensure data quality, inconsistent and doubtful records were discarded. The discarded records included boreholes without GPS coordinates or those with wrong coordinates that could not be verified from other reports or site visits. For some records, there were inconsistencies in the screen positions and final depths for the same borehole in the progress and final construction reports. Owing to the unreliability of pumping test data, as it is mostly done by non-professionals who do not adhere to the pumping test procedure, airlift yields were used for the study instead of pumping test yields.

The geological, district, hydrogeological and town maps of the study area were obtained from the Centre for Remote Sensing and Geographical Information Services (CERSGIS) of the University of Ghana and the GIS Laboratory of KNUST. Microsoft Excel 2010 and the Statistical Package for the Social Sciences (SPSS) software version 20 were used in entering and for statistical analyses of the data. The data were randomly divided into two parts termed Training (90 %) and Test data (10 %) using ArcGIS version 10.2.1 software. The Training data was used for the analyses and the Test data for validation of the results.

The ranges used in creating the maps were generally guided by the mean and median values, as well as accepted limits for that particular parameter. For example, for the airlift yield map, the CWSA's limit of a minimum 10 l/min for hand-pump boreholes and 85 l/min for mechanised boreholes were taken into consideration. Whereas a 10-metre range was used to clearly identify difficult or lower yield areas, wider ranges were used for the medium and high yield zones to bring out variations in these zones. Similarly, the minimum guideline value of 0.3 mg/l for iron concentration was used to delineate possible iron free zones. The nomenclature, 'litres per minute' (l/min), was adopted for this study as it is the commonest one used in Ghana.

All SWL measurements, which were received with respect to ground level, were converted to mean sea level by subtracting them from their respective elevations with respect to mean sea level. Specific capacity (q) values were calculated from the data using equation 4.1:

$$q = \frac{Q}{S_w} \qquad (4.1)$$

where Q is discharge in m^3/day and S_w is the maximum drawdown.

4.2 Data Organisation

The data was organised into the various hydrogeological sub-provinces within the study area. As a result of the revision of the lithostratigraphic / lithotectonic complexes, it was appropriate to organise them per the new provinces. Data within the Birimian and its associated metasediments were considered together owing to their similar hydrogeological properties and those within the intrusive crystalline granites, diorites, gneiss and granodiorites were also classified together and referred to as undifferentiated granitoids. For the Voltaian subprovinces, the Middle Voltaian is divided into the Obosum and Oti Pendjari Groups, whereas the Lower Voltaian is referred as the Kwahu Group. The Tarkwaian Formation is retained as the Tarkwaian Group. The overburden thickness, pumping test and water quality analyses were not available for all the boreholes. As a result, only the boreholes with such information were used for the analyses.

4.3 Creation of Surface Maps

The ArcGIS version 10.2.1 was used to analyse the spatial distribution of the data to produce maps to aid in the visual appreciation of the hydrogeology of the Region. Surface maps were created for depth of successful boreholes, overburden thickness, airlift yield, SWL, specific capacity and iron concentration. The geostatistical analyst tool of the software was used for the spatial analyses using the ordinary kriging interpolation method. For comparison purposes, similar surfaces were generated using the Inverse Distance Weighting (IDW) and Local Polynomial (LP) interpolation methods. The general procedure involved in fitting the required surface are to represent the data, explore the data, fit a model, perform diagnostics analyses and compare models.

4.4 Exploratory Statistical Analysis of Data

The distribution of each dataset was examined to ascertain whether it is normally distributed using the histogram and the Normal Quantile-Quantile (QQ) plot tools. The trend analysis tool of the geostatistical analyst tool was also used to ascertain the presence or otherwise of a trend in the distribution. Where a trend was observed, it was removed using the appropriate equation.

Figure 4.1 shows the semivariogram / covariance modelling dialog box where parameters were set to fit the model using the spatial relationship of the dataset. The lag size, nugget, range, partial sill and shape were set to fit the model. Each dataset was examined to ascertain the existence of anisotropic (directional) influence. A limit was set to the data used to define the circle or ellipse that encloses the points used for the prediction of values at unmeasured locations. The maximum and minimum number of data, the radius and number of sectors of the circle or ellipse used for the prediction were specified from the "searching neighbourhood" dialog box (Figure 4.2).

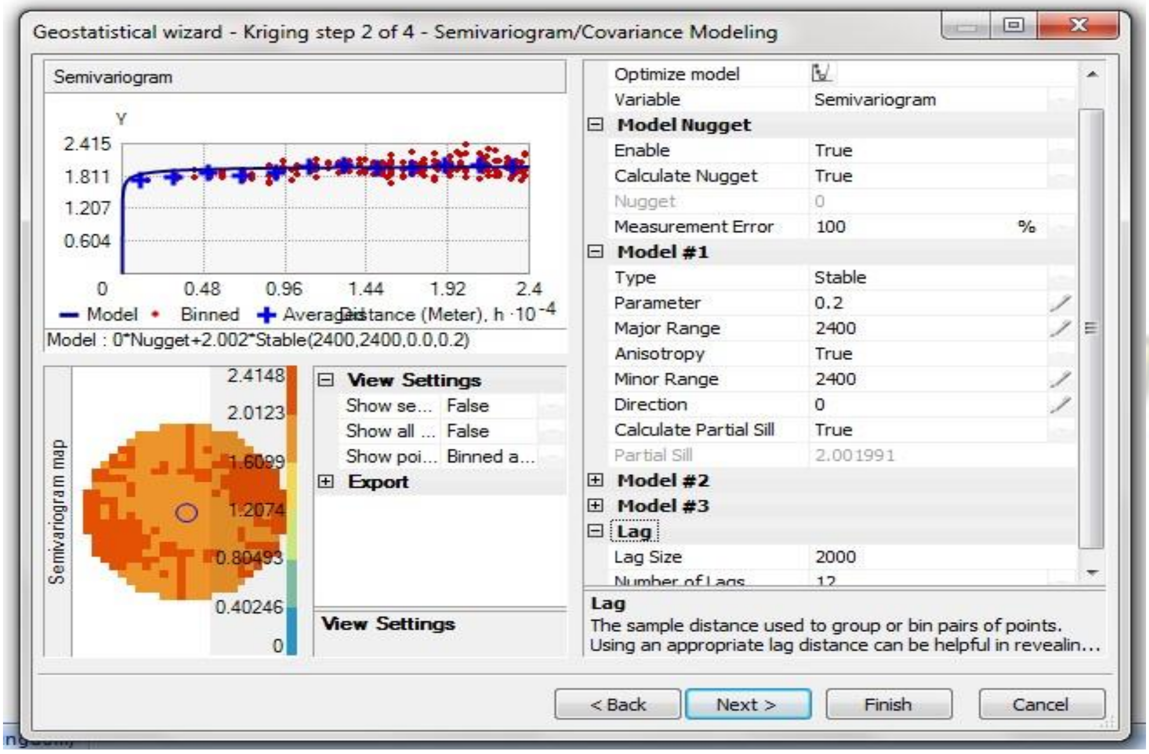


Figure 4.1: The semivariogram / covariance modelling screen

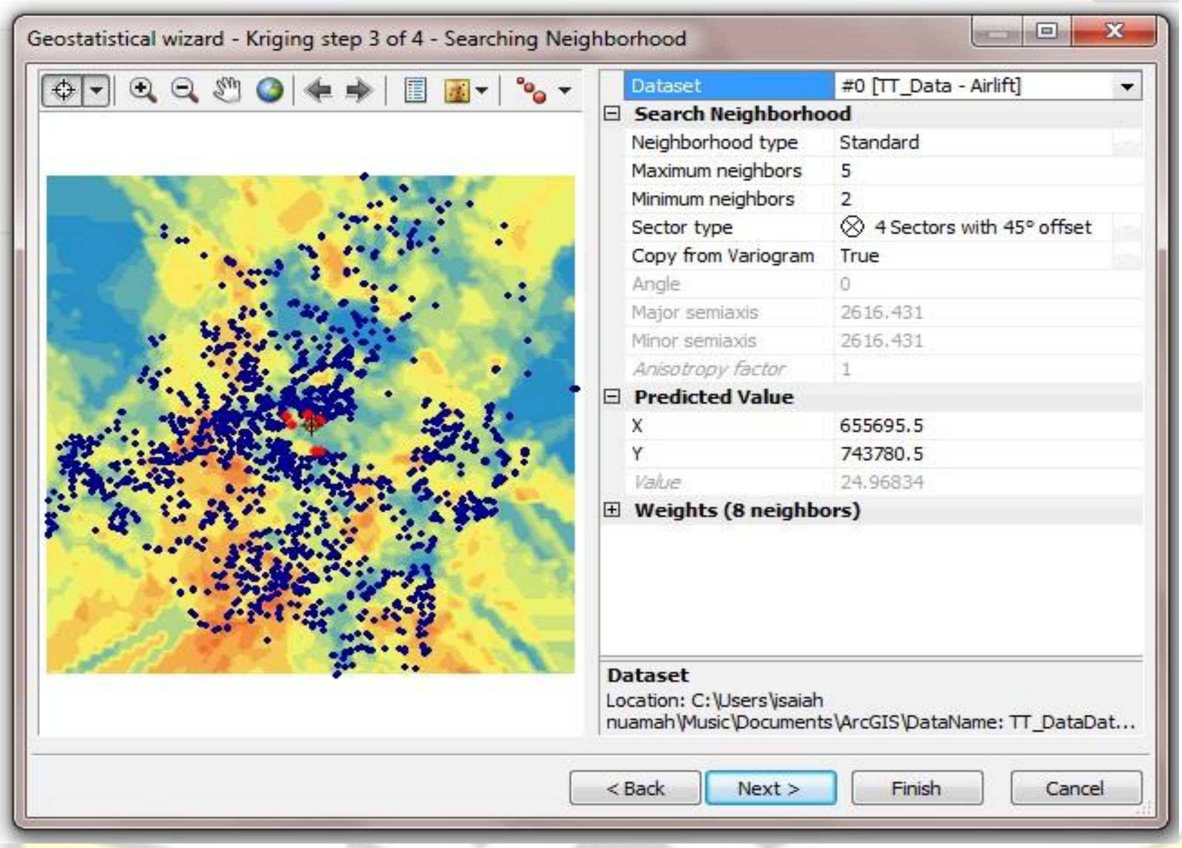


Figure 4.2: The searching neighbourhood dialog box

A cross validation comparison was done to select the model with the most accurate predictions using their resultant prediction error statistics as shown in Figure 4.3. The test data was also used to validate the generated surface map using its standardised error (which should be close to zero). The model that produced best cross validation and test data validation prediction error was selected. The test data was further plotted on maps generated using all the interpolation methods i.e. kriging, IDW and LP to determine the one with the best results.

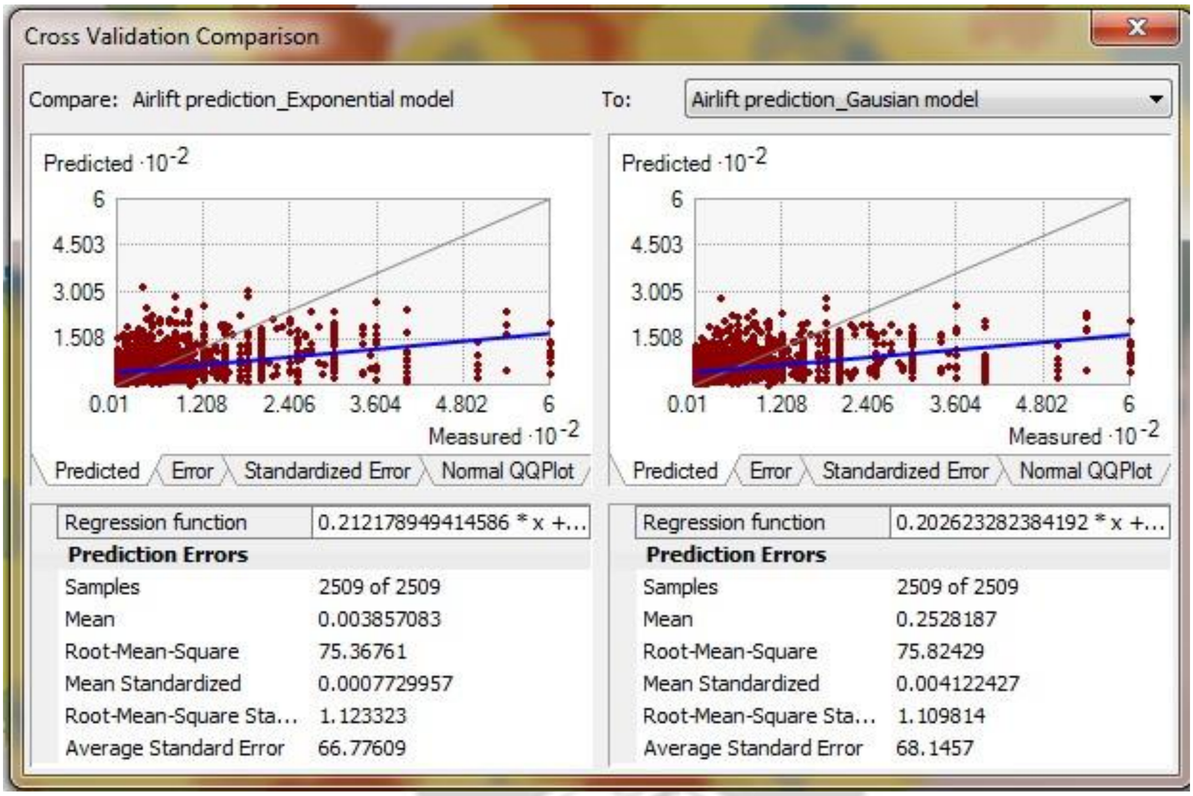


Figure 4.3: Comparison of different model types using cross validation

4.5 Water Quality Analyses

The laboratory results of some of the boreholes were collated and those with unsuitable quality (values of chemical analyses results outside the Ghana standards) were plotted on the geological map of the study area. The data was analysed to ascertain the major parameters that were outside the guideline values and their predominance within the geological formations. A surface map similar to what was produced for the hydrogeological parameters was produced for iron (the major water quality problem) using the values from the water quality results.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Data Distribution and Analyses

Records of 2788 boreholes were finally accepted and used for the study. It comprises 2331 constructed boreholes, 433 dry holes and 24 holes, which were abandoned due to their poor water quality, as shown in Figure 5.1. A summary of the data from the boreholes within the various geological formations is presented in Table 5.1. Data was not available for certain areas such as the north eastern part of the study area as well as the Ahafo Ano North district (south west of Tepa); therefore conclusions could not be made for such areas in this study.

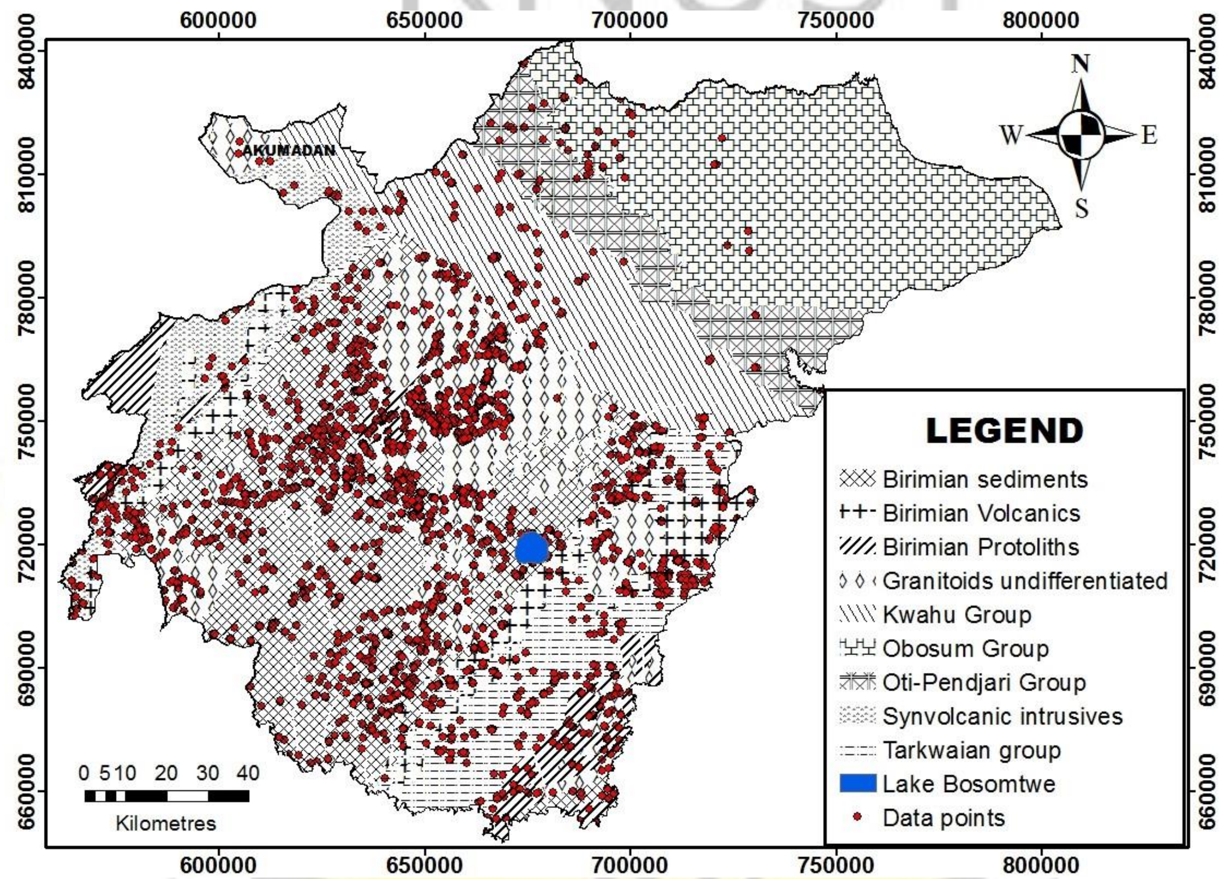


Figure 5.1: Distribution of boreholes on geology of the study area

Table 5.1: Summary of boreholes within the geological formations

Geological Formation	No. of holes	Success rate (%)	Overburden thickness range (m)	Successful Boreholes		SWL range (m)	Specific capacity range (m^3/day/m)
				Depth range (m)	Airlift yield range (l/min)		
Birimian S & V	1279	90.6	33 - 72	22 - 85	10 - 600	0.1 - 56.9	0.2-99.7
Granitoids undifferentiated	1047	72.3	1 - 50	22 - 85	10 - 600	0.0 - 40.0	0.3-88.5
Tarkwaian	290	79.3	2 - 52	27 - 77	10 - 216	1.1 - 37.2	0.3-65.1
Kwahu	103	54.4	1 - 27	32 – 80	10 - 300	1.7 - 54.4	0.2-72.0
Oti Pendjari	30	60.0	1 - 8	34 - 81	12 - 400	0.0 - 19.7	0.4-33.0
Obosum	39	66.7	-	28 - 99	10 - 300	2.1 - 28.7	0.4-47.8

About 45.9 % of the drilled points are located within the Birimian S & V of which 1159 were successful whilst 38 % of the boreholes were drilled within the granitoid undifferentiated formation with 757 successful. The Tarkwaian Group also contained 10.4 % of the total out of which 230 were successful. The groups within the Voltaian Supergroup had least data, primarily, because it is least explored especially the north easternmost parts and also it was difficult getting details of some of the boreholes. The Kwahu Group contained only 3.7 % of the entire data with 54 of them being successful. The Oti Pendjari and the Obosum Groups contain 1.1 % and 1.4 % respectively with each having 18 and 26 successful boreholes respectively.

5.2 Semivariogram Modelling and Surface Maps Generation

The number of samples, data transformations and trend removals used in generating each of the prediction maps, and the prediction error statistics are presented in Table 5.2. The overburden thickness dataset was near normal and was, therefore, not transformed whereas the rest were transformed using the Box-Cox method except SWL elevation dataset, which was logtransformed. The exponential model returned the best prediction error statistics for depth of successful holes, airlift yield and specific capacity data whereas the Gaussian and Spherical models were used for the overburden and SWL data respectively.

Table 5.2: Transformations, trend removals and cross validation results

Description	**Airlift yield**	**Final depth of successful holes**	**Overburden thickness**	**SWL elevation**	**Specific capacity**	**Iron concentration**
No. of boreholes	2509	2021	800	2035	1838	1627
Transformation type	BoxCox	Box-Cox	None	Log	Box-Cox	Box-Cox
Detrending method	None	None	None	2nd order polynomial	None	None

Model type	Exponential	Exponential	Gaussian	Spherical	Exponential	Spherical
Mean	0.0038	0.0023	0.0650	0.0014	-0.0348	-0.0024
Root-meansquare	75.3676	10.0788	10.0396	11.6100	11.8085	0.6881
Mean standardised	0.0008	0.0002	0.0054	0.0140	-0.0026	-0.0033
Root-meansquare standardised	1.1233	0.9540	0.9134	1.2869	0.9692	0.9287
Averaged standard error	66.7761	10.5616	10.9996	8.5049	12.1488	0.7428

The percentage of test data that fell within exact zones of the map generated using the three interpolation methods are presented in Table 5.3 whereas the prediction standardised error results for the hydrogeological parameters using the test data are presented in Table 5.4. The SWL elevation map had the best predictions for all the methods followed by the iron concentration map. Even though IDW interpolation method had the best results for the iron concentration map, it failed to correctly predict any of the test data with higher values of iron above the guideline values whereas kriging predicted 60 % of them. The kriging method was accepted as best for the study and maps generated from it were used for the analyses. The test data validation results are discussed under each hydrogeological parameter in Section 5.3.

Table 5.3: Accuracy of test data in target zones on parameter maps

Hydrogeological parameter	**Interpolation method**		
	Kriging	**Inverse Distance Weighting**	**Local Polynomial**
Airlift yield	55	52	46
Success depth	37	39	32
Overburden thickness	47	56	49
SWL elevation	91	90	91
Specific capacity	49	43	47
Iron content	78	83	63

Table 5.4: Predicted standardised error results across the geological formations

Geological Formation	**Airlift yield**	**Final depth of successful holes**	**Overburden thickness**	**SWL elevation**	**Specific capacity**	**Iron concentration**
All formations	-0.0843	0.0375	0.0384	-0.0712	-0.2658	0.0057
Birimian S & V	-0.0858	-0.0202	-0.0238	-0.0318	-0.0676	0.0031

Granitoids undifferentiated	-0.2371	0.1861	0.1321	-0.0789	-0.7451	0.0106
Tarkwaian	0.0867	-0.0447	0.1115	0.0184	-0.0578	0.0077
Kwahu	0.1024	0.3952	-0.3297	-0.4711	0.3688	0.0002
Oti Pendjari	1.0802	-	0.0606	-	-	-
Obosum	0.1677	-0.7692	-	-0.9134	0.4308	0.00002

5.3 Evaluation of Hydrogeological Parameters

5.3.1 Airlift Yield

The Birimian S & V and the undifferentiated granitoids had airlift yield range between 10 and 600 l/min at standard deviations of 101 and 71 respectively. The Tarkwaian Group recorded an average airlift yield of 41 l/min at standard deviation of 37. The successful boreholes within the Kwahu, Oti Pendjari and the Obosum Groups had mean airlift yields of 66, 77 and 68 l/min respectively, which were higher than those for the undifferentiated granitoids and the Tarkwaian Group. Their respective airlift yield standard deviations were 61, 104 and 79.

Figure 5.2 presents an overlay of the airlift yield map generated on the geological formations. Three distinct zones are seen from the map; yields below 30 l/min (shades of green), those between 30 and 60 l/min (yellow) and those above 60 l/min (shades of red). These are termed low, medium and high yield zones for the purpose of this study. The Birimian sediments are generally noted to be within the medium and high yield zones as indicated by a NW-SE trend from the east of Abesewa to the south of Obuasi and a NE – SW trend, which begins NW of Agogo through areas around the Lake Bosomtwe and ends just south of Fomena (Figure 5.2).
This may be attributed to the highly-fractured and sheared rocks especially in areas underlain by phyllites. Another high yield zone is located in the Birimian formation east of New Edubiase.

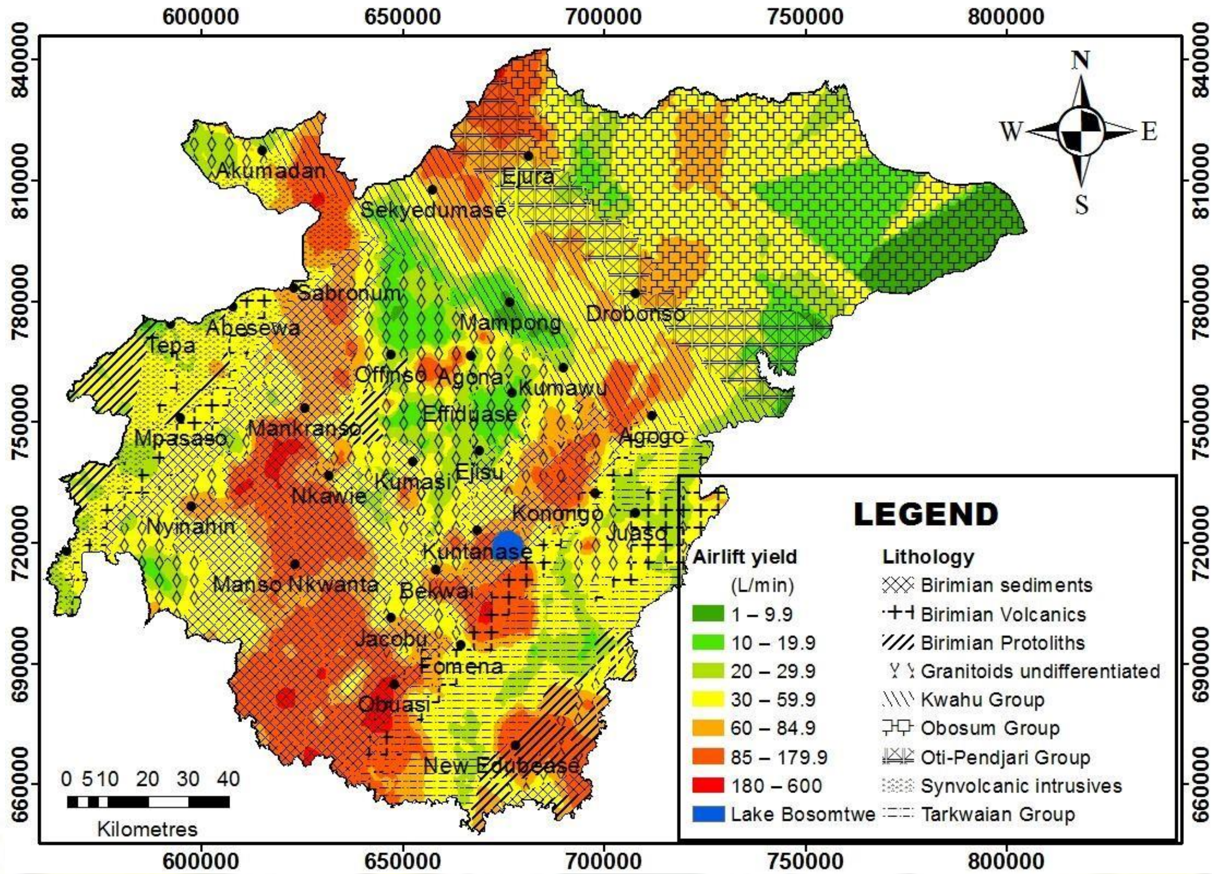


Figure 5.2: Overlay of airlift yield on the geological formations

The undifferentiated granitoids are generally within the low yield zone as observed just beneath the central portions of the Kwahu Group. A high yield zone in the granitoids is located along the stretch between Offinso and Agona. Similarly, a high yield zone is found within the synvolcanic intrusive rocks south east of Akumadan (Figure 5.2). Groundwater flow within the crystalline rocks is controlled by the availability and connectivity of joints and fractures

(Singhal and Gupta, 1999; Cook, 2003). According to the revised geological map of Ghana, by GSD and BGR (2009), whereas the synvolcanic intrusive rocks were formed within the Birimian Supergroup period (2195 – 2135 Ma), the undifferentiated intrusive granitoids were formed in the Eburnean Plutonic Suite period (2120 – 2115 Ma) as a result of partial melting of slightly older Birimian sediments during the Eburnean tectono-thermal event. From the study, it is observed that the synvolcanic granitoids yield significant amount of groundwater than the undifferentiated intrusive granitoids, which may be due to the fact that the former has well developed and connected fractures than the latter. It must, however, be stated that isolated high yielding boreholes were also recorded within the Eburnean plutonic granitoids.

Within the Voltaian Supergroup, all the airlift yield zones are present with an overlap of zones among the sub-groups. The western half of the Obosum Group (where data was obtained) are low, medium and high yield zones moving towards the western border (Figure 5.2). Generally, the Obosum Group consists of beddings of sandstones, arkose, conglomerates and subordinates of mudstones and siltstones. The sandstones, which exhibit secondary porosity as a result of joints and fractures, produce much water whereas areas underlained by the mudstones and siltstones produce less water as a result of the absence of secondary porosity (Acheampong and Hess, 1998). According to Yidana et al (2008), there is a NNE-SSW fracture system which controls the hydrogeology of the Voltaian formation in general. A similar trend is observed in the study area beginning from the north westernmost part of the Obosum Group (north of Ejura) and extends through the Oti Pendjari Group, and finally terminates within the Kwahu Group. The lower portion of the Kwahu Group is generally not favourable for groundwater development. About 36 out of 51 boreholes yielded less than 10 l/min at a mean depth of 69 m.

The prediction standardised results (Table 5.4) using the test data shows that the airlift yield prediction were very good (closer 0). The Birimian S & V and Tarkwaian Group had best prediction results with the Oti Pendjari Group being the least. When the test data was plotted on the airlift yield map (Figure 5.3), it was realised that about 55 % of them fell within the expected zones. The major deviation was the location of lower yield boreholes within a higher yield zone. In some instances especially within the undifferentiated granitoids and Birimian sediments, some data points were located within yield zones lower than their yields. For those that did not fall within their expected zones, about 72 % of them fell within a higher zone.

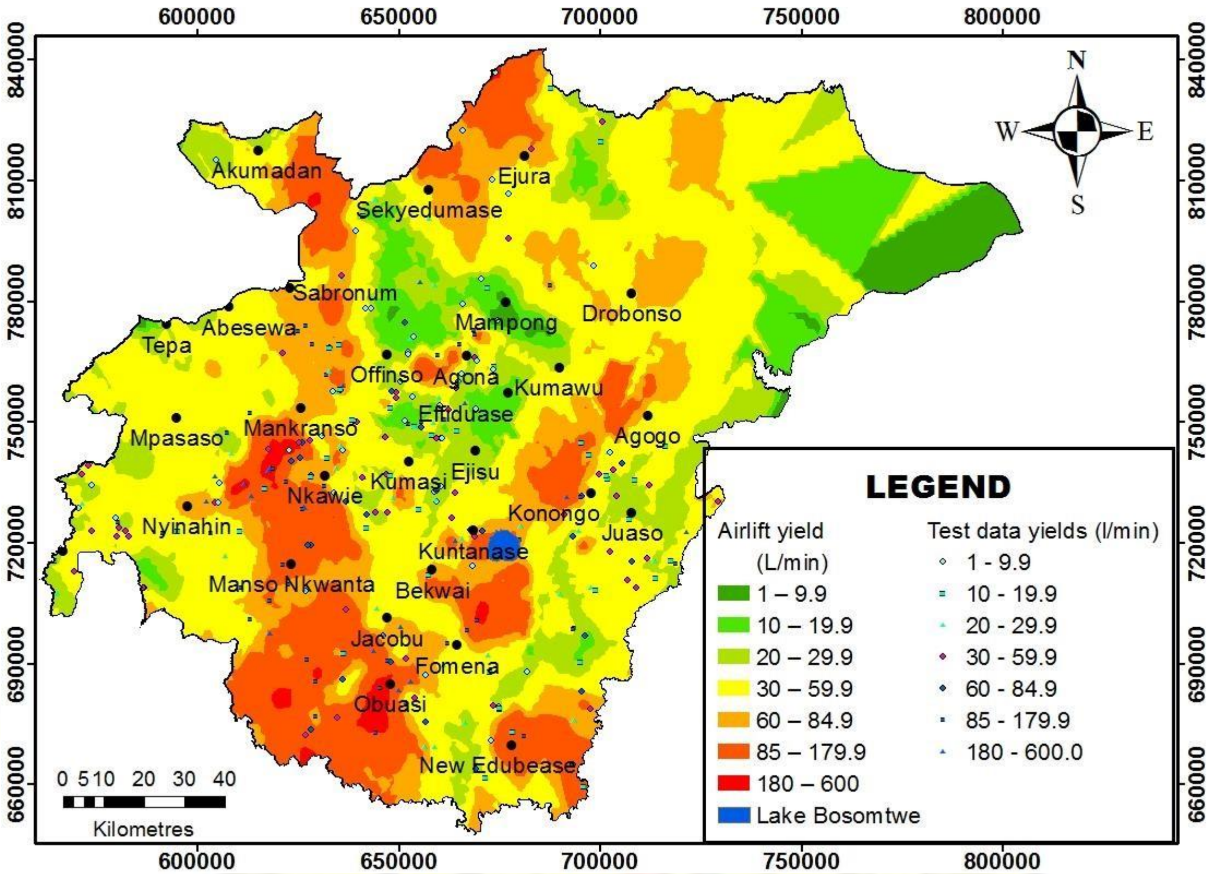


Figure 5.3: Plot of airlift yield test data on airlift map

Some factors that may account for the deviations are inability to install temporary casings in deeper overburden thickness areas resulting in tapping water within the overburden instead of drilling through the bedrock and the non-connectivity of joints and fractures. For example, in south east of New Edubiase (Figure 5.3) is a borehole with an airlift yield of 17 l/min. The overburden thickness and final depth are respectively 40 and 46 m with a screened depth of 39 – 45 m. There is the likelihood that this hole could not be continued to the aquifer zone owing to the difficulty to install temporary casings to the 40 m depth. Within the granitoids, for example, it is possible to locate a high yielding aquifer within a low yield zone as groundwater flow is controlled by the availability and connectivity of joints and fractures. A typical example is found to the north east of Wiamoase, where a high-yielding borehole (300 l/min) is located within a low yield zone in Figure 5.3. The geological log data confirms that the underlying rock is granitic.

5.3.2 Depth of Successful Boreholes

The successful boreholes in the Birimian S & V and Obosum Group had mean depths of 53 m whilst the undifferentiated granitoids, Tarkwaian, Kwahu and Oti Pendjari Groups had mean depths of 50 m. Expectedly the final depths of the unsuccessful boreholes were deeper than the successful ones. The average depth for the unsuccessful boreholes in the Birimian S & V, undifferentiated granitoids, Tarkwaian, Kwahu, Oti Pendjari and Obosum Group were 69, 63, 69, 76, 88 and 86 m respectively.

The map showing the depth of successful boreholes is shown in Figure 5.4. A larger portion of the study area lies within the 40 – 50 m and 50 – 60 m zones. This is characteristic of all the geological formations with an overlap of zones at various geological contacts. Similarly isolated areas with final depths of more than 60 m also exist within all the formations. The standardised predicted results (Table 5.4) using the test data shows that predictions for the final depth of successful boreholes were very good for the Birimian S & V and Tarkwaian Group but poor within the Voltaian Supergroup, especially within the Obosum Group, which can be largely attributed to limited data relative to its large area. When the test data was plotted on the final depth map, only 37 % of them fell within the expected zones. This increases to 68% with a plus or minus of 5 metres. Within the Voltaian Supergroup, very few of them fell within their expected zones, which may be attributed to the sparse distribution of the data. The major deviation within the other formations was the location of boreholes with depths greater than 60 m falling within lower depth zones.

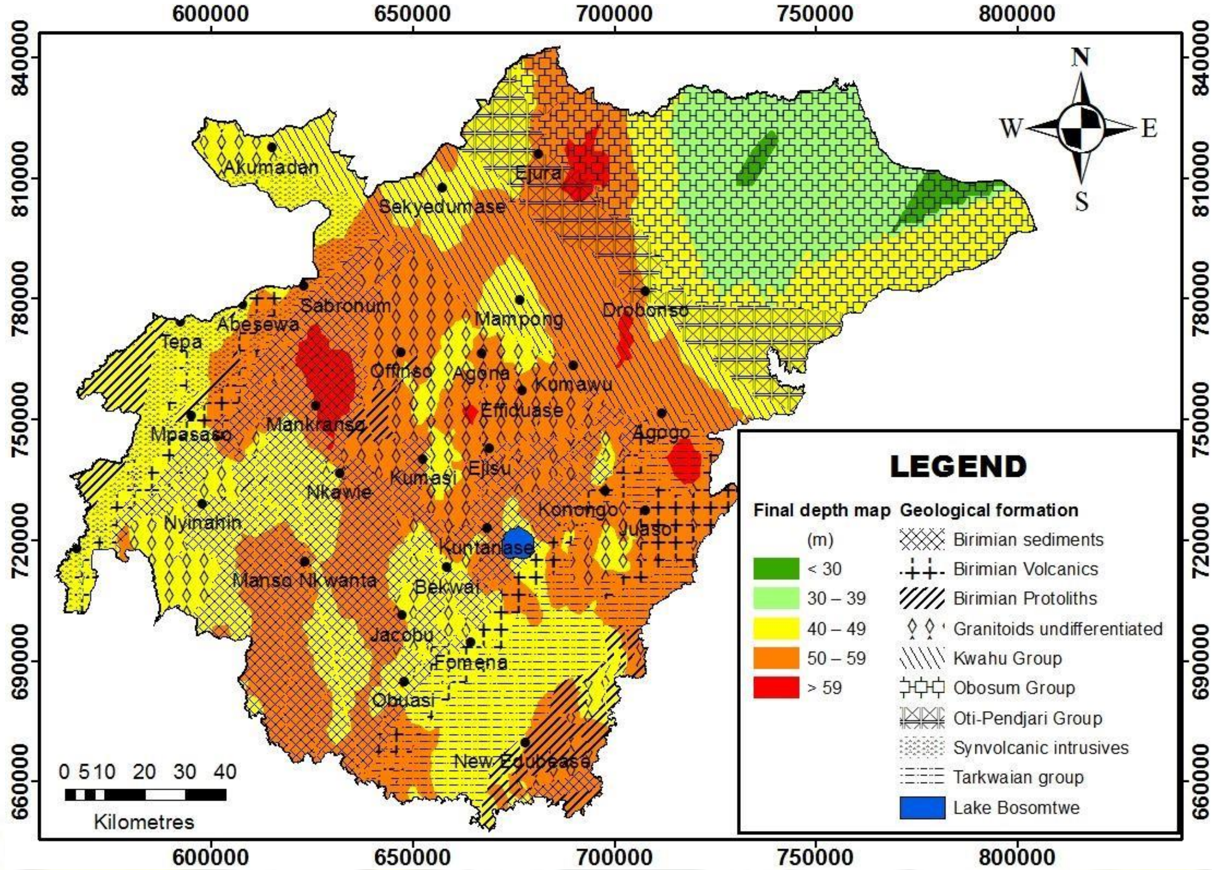


Figure 5.4: Overlay of borehole depth on geology

5.3.3 Overburden Depth

The overburden depths of only 895 of the entire data were available. They comprise 388, 344, 133, 27 and 7 within the Birimian S & V, undifferentiated granitoids, Tarkwaian, Kwahu and Oti Pendjari respectively. Their respective means are 27, 24, 20, 7 and 5. No record was available for the Obosum Group.

The overburden thickness map, which depicts the weathering depths for the study area is presented in Figure 5.5. Three major zones namely 0 – 10, 10 – 20 and 20 – 30 m are observed from the map. A fourth zone of more than 40 m is also recognised within the Birimian and extending to adjacent formations.

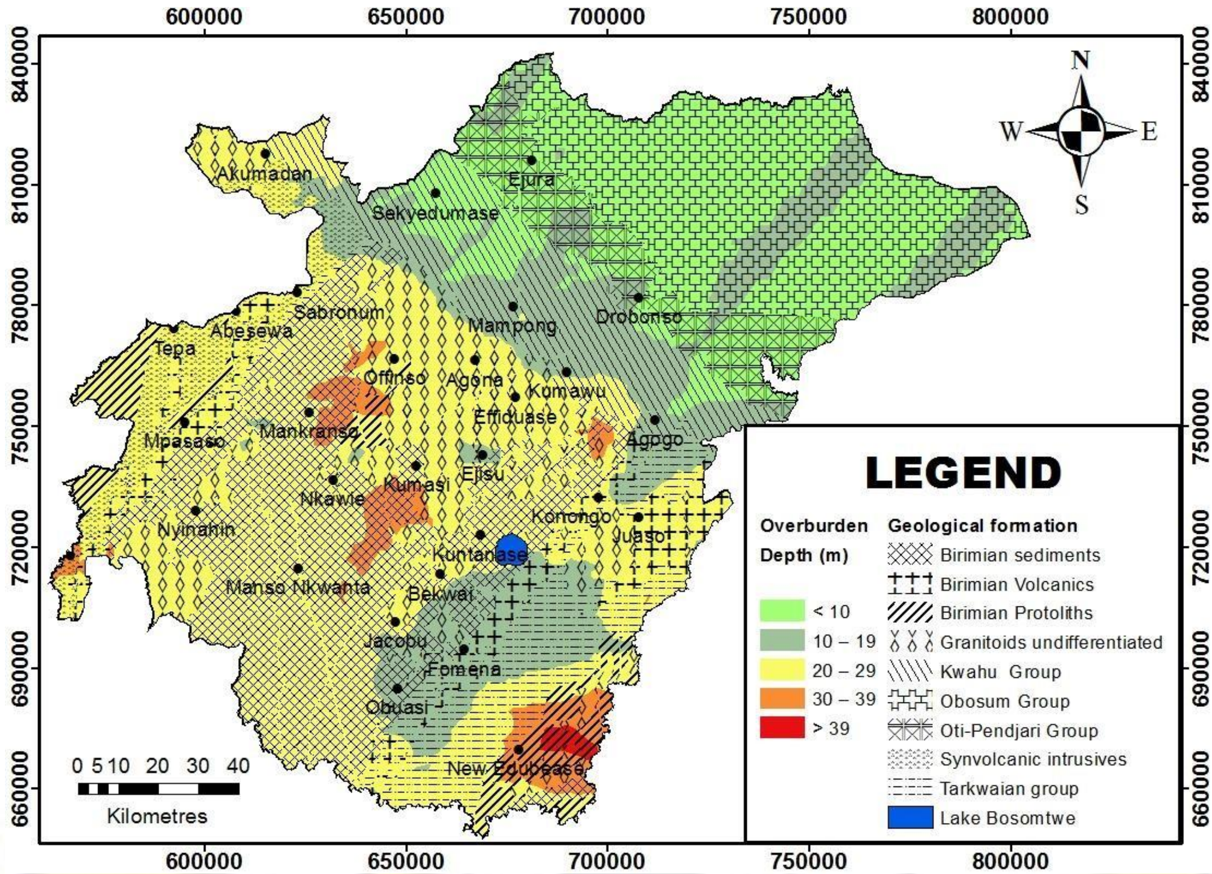


Figure 5.5: Overlay of overburden thickness on the various geological formations

The overburden thickness is of significant importance to a prospective groundwater developer during the installation of temporary casing to forestall caving when drilling and the occurrence of significant amount of water in the overburden and at the contact between it and the bedrock. Caving is predominant in areas with thicker overburden and this usually leads to abandoning the hole as a result of difficulty in installing temporary casings. If successfully drilled, constructing the borehole or turbidity of the water when the gravels (filter media) do not descend to cover the slotted PVCs becomes a problem. In the study area, this is typical of the Birimian sediments and Tarkwaian Group as well as areas underlain by granites. About 13 of such cases were recorded in this study within the Birimian S & V, granitoids and Tarkwaian rocks. Within the Voltaian Supergroup, the weathered zones were generally shallow and dry posing no serious problems with temporary casing installation. In this study, the temporary casing installation depths of 30 boreholes within the Voltaian Supergroup averaged 6.96 m at an average final depth of 65 m.

Secondary permeability is enhanced in intense weathered rocks and serves as better aquifers (Yidana et al, 2008; Yidana et al, 2015). The contact between the overburden and bedrock usually serve as the water-bearing zones. Within the crystalline granitoids, significant amount of water was encountered in the saprolites of the thicker overburden holes and are tapped where enough is not obtained within the bedrock. Out of the 774 constructed boreholes whose overburden thicknesses were obtained, about 206 (27 %) had their slotted PVCs placed within the overburden or about 2 m below the overburden and bedrock contact. These are represented by 100, 72, 29 and 5 within the undifferentiated granitoids, Birimian S & V, Tarkwaian and Voltaian rocks respectively. Within the Birimian S & V and Tarkwaian rocks, most of the fractures were intercepted close to the contact zone.

The prediction standardised results (Table 5.4) for the overburden thickness using the test data was very good with a value of 0.0384 with the Birimian S & V having the best result. When the test data was plotted on the overburden thickness map (Table 5.3), only 47 % of them fell within the expected zones using kriging interpolation method. The major deviation was the location of boreholes with weathering depths thicker than 30 m in the 20 – 30 m zone, which is predominant in areas underlained by the undifferentiated granitoids and Birimian sediments.

5.3.4 Static Water Elevation

The SWL values of 2017 of the data were available. They ranged from just below the ground level (0.04 m) to 56.92 m. An artesian flowing borehole with SWL of 2.86 m above ground level was recorded within the granitoids. The average SWL values of 14 m, 13 m, 12 m, 19 m, 8 m and 11 m for the Birimian S & V, undifferentiated granitoids, Tarkwaian, Kwahu, Oti Pendjari and Obosum Group respectively implies the SWL are generally not deep.

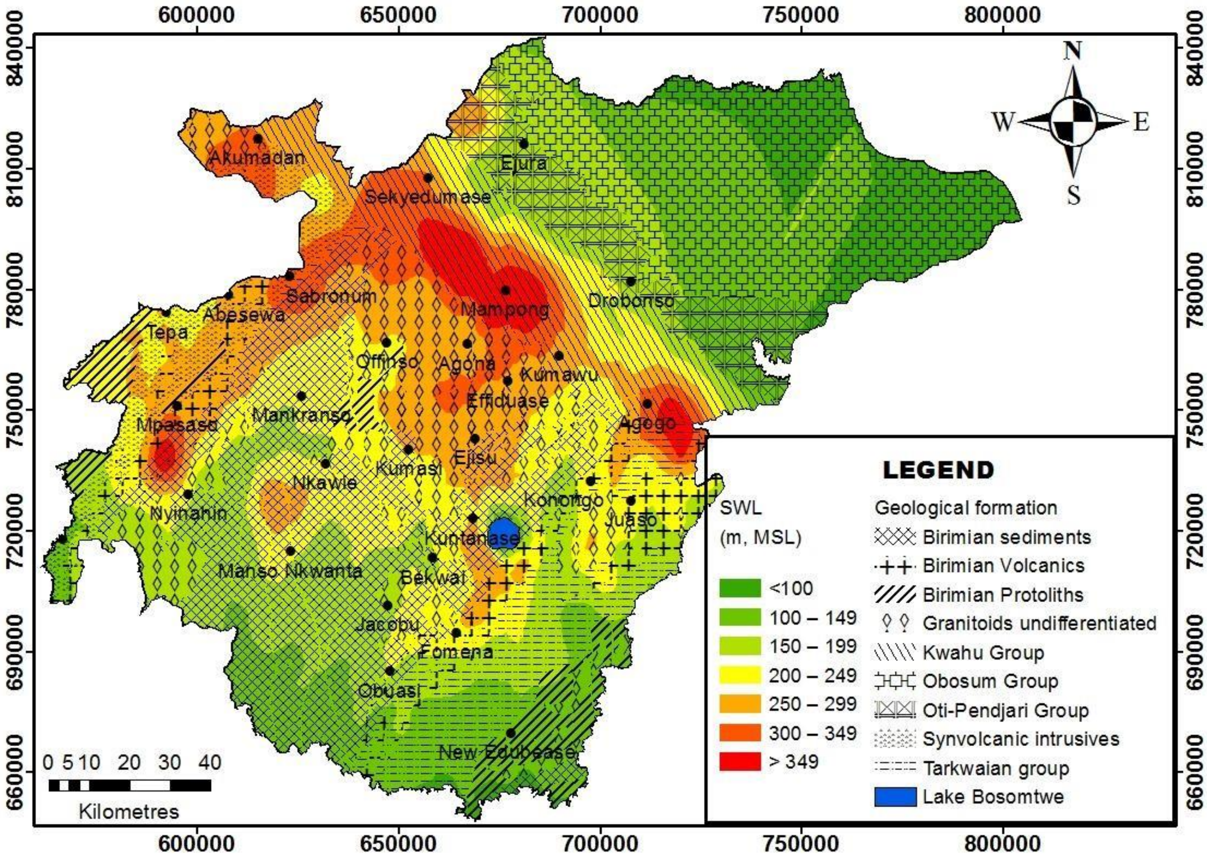


Figure 5.6: Overlay of SWL elevation on the geology

The SWL elevation map, as presented in Figure 5.6**Error! Reference source not found.**, shows that the highest point generally is around Nsuta and north of Wiamoase within the Kwahu Group and progressively decreases outwards of the other adjoining formations. Two other higher elevations are located south of Mpasaso (within Birimian sediments) and Agogo (within the Kwahu Group). The SWL elevation map mimics the general topography of the study area which conforms to standard knowledge.

The SWL elevation had prediction standardised error of 0.07 and 91 % of the test data fell within their expected zones for the kriging method (Table 5.3 and Table 5.4). The Kwahu and Oti Pendjari Groups within the Voltaian Supergroup had the least accuracy of prediction as seen from the prediction standardised error results (Table 5.4).

5.3.5 Specific Capacity

The specific capacity of the aquifers within the study area for 1838 of the boreholes had mean and standard deviations of 8 and 12 m^2/day respectively. The Oti Pendjari Group had the narrowest range of specific capacities with the Birimian S & V recording the widest range.

The specific capacity map is presented in Figure 5.7. Majority of the aquifers in the study area have specific capacities below 10 m^2/day followed by zones between 10 and 15 m^2/day. The highest zone of specific capacities greater than 20 m^2/day is entirely within the Birimian S & V. The Voltaian Supergroup has less than 10 m^2/day except the westernmost part where zones with values greater than 10 m^2/day are observed extending from the Obosum Group through the Oti Pendjari Group and terminates at Mampong in the Kwahu Group. The undifferentiated granitoids are entirely below 10 m^2/day except areas within the synvolcanic intrusions (below Akumadan and east of Abesewa). The Tarkwaian Group is predominantly within the less than 10 m^2/day zone with the exception of a smaller zone between Obuasi Junction and New Edubiase, where it is between 10 and 15 m^2/day. The Birimian sediments generally contain the higher specific capacity zones, which mimics the NW-SE (east of Abesewa to the South of Obuasi) and NE – SW (NW of Agogo – Lake Bosomtwe – Fomena) trends observed in the airlift yield map even though it is interspersed with lower zones.

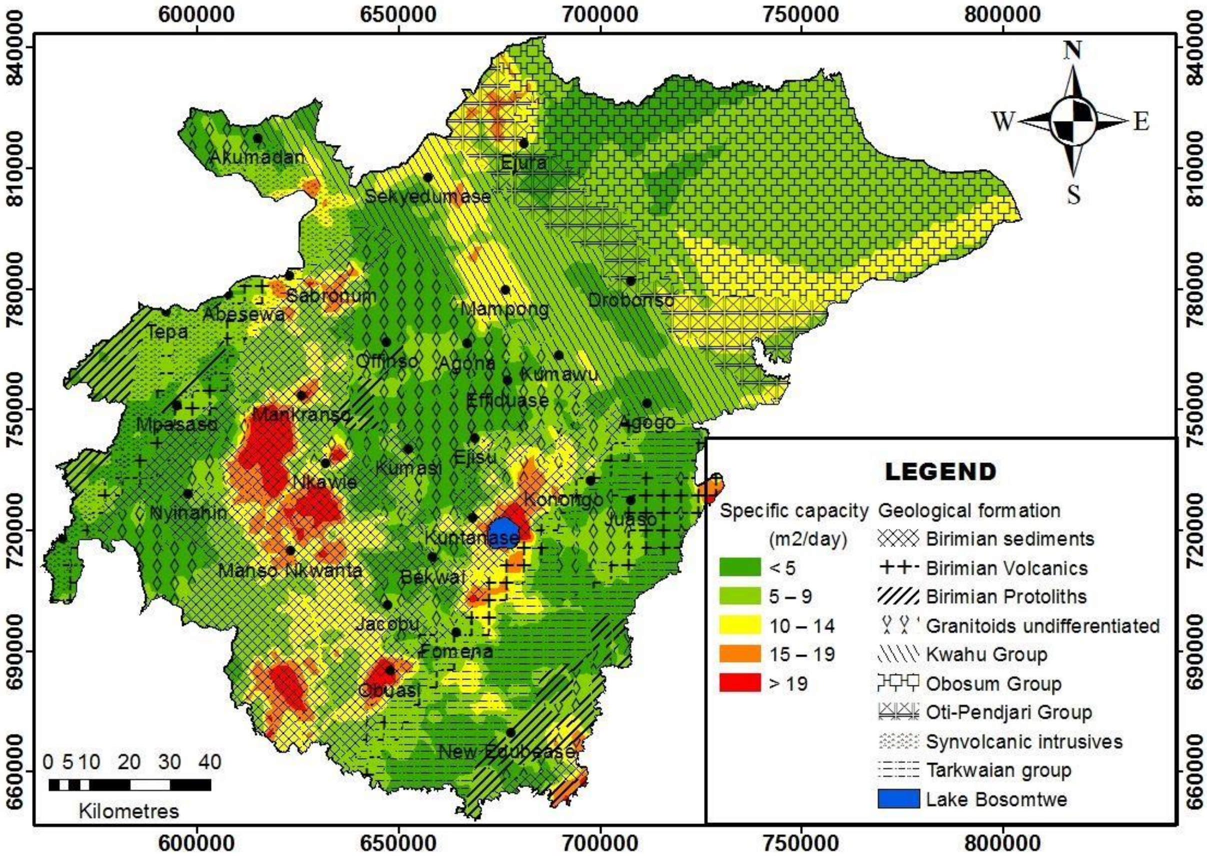


Figure 5.7: Map of specific capacity variation of Ashanti Region

Only the Birimian S & V and Tarkwaian Group had prediction standard errors that were closer to zero (0) as presented in Table 5.4. The accuracy of predictions within the undifferentiated granitoids was the poorest among all the formations, which may be attributed to their crystalline nature which means the groundwater flow can be different with no dependence on the closeness of data points.

5.3.6 Water Quality Analyses

Records pertaining to the quality of 1627 boreholes were collated with about 21 % having values outside the GWCL guideline for the physico-chemical parameters. The major poor water quality parameters (PWQ) were pH, iron, manganese, nitrate, arsenic, fluoride and lead (Table 5.5 and

Figure 5.8). About 8.6 % of the PWQ boreholes had multiple problems in relation to pH, iron, manganese, nitrate and arsenic.

Table 5.5: Groundwater quality evaluation within the various geological formations

Geological formation	No. of holes	Parameter	pH	Fe (mg/l)	Mn (mg/l)	NO_3 (mg/l)
		GWCL standard	6.5 – 8.5	≤ 0.3	≤ 0.10	≤ 10
Birimian S & V	846	Range	3.7-6.3	0.3-5.5	0.12-3.29	13.6-46.9
		% PWQ	6.6	10.9	0.95	0.7
Granitoids Undifferentiated	521	Range	5.0-6.0	0.3-6.0	0.12 -3.69	-
		% PWQ	12.3	17.1	0.19	0
Tarkwaian Group	161	Range	4.7-6.0	0.3-6.0	1.5	16.3-29.6
		% PWQ	8.1	5.00	0.62	1.2
Kwahu Group	61	Range	4.5-5.5	-	-	-
		% PWQ	4.9	0	0	0

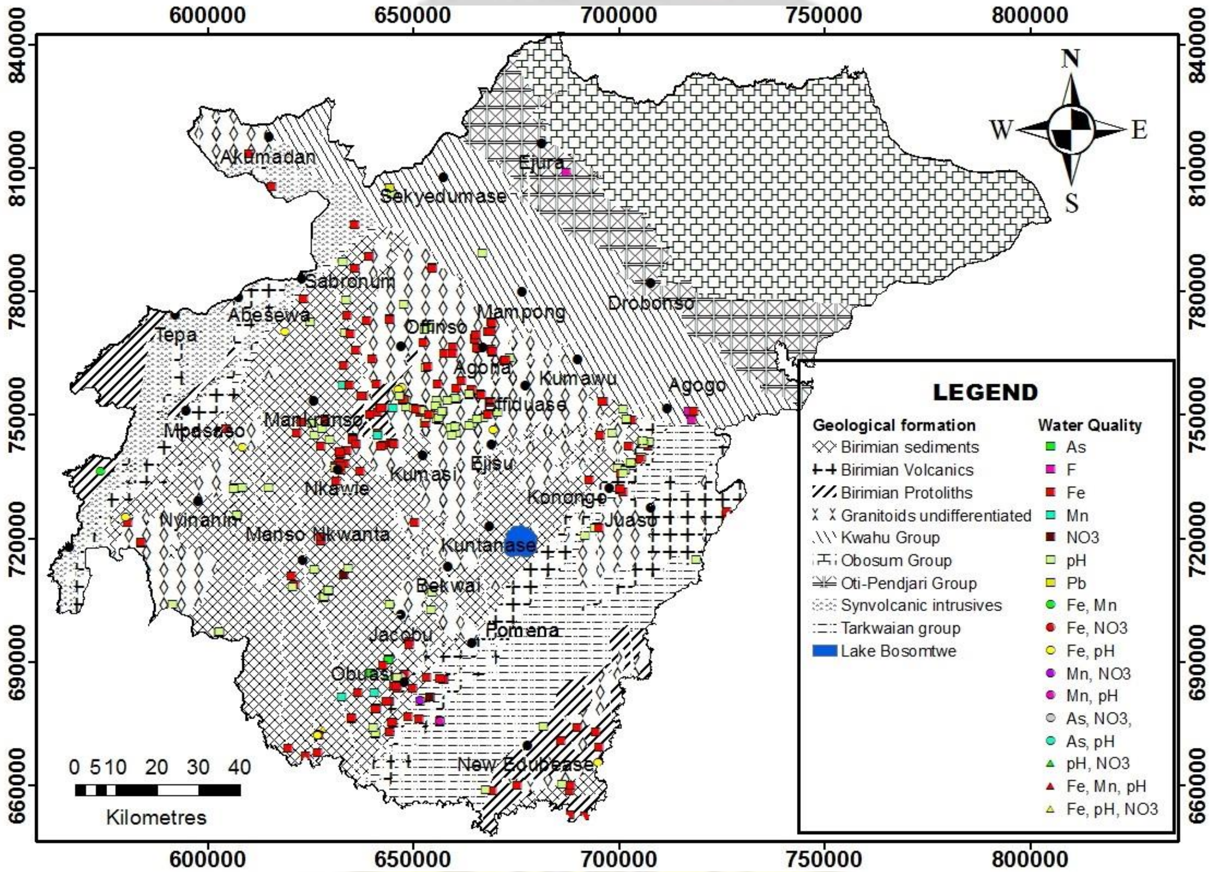


Figure 5.8: Map showing location of boreholes with poor water quality

The major contributing parameters as shown in Figure 5.9 are iron, low pH, manganese and nitrate. Their occurrences are prevalent within the Birimian S & V, the granitoids, Tarkwaian Group and the Kwahu Group (Figure 5.10). Higher values of fluoride were recorded within the Kwahu (range of 1.8 – 2.4 mg/l) and Oti Pendjari (3.0 mg/l) Groups. The only occurrence of lead (Pb) above the GWCL guideline value was recorded within the Kwahu Group with a value of 4.5 mg/l. Similarly, higher values of arsenic were also recorded within the Birimian S & V. Interestingly, no occurrence of poor water quality is associated with the Obosum Group. About 83 % of high manganese concentrations were within the Birimian S & V.

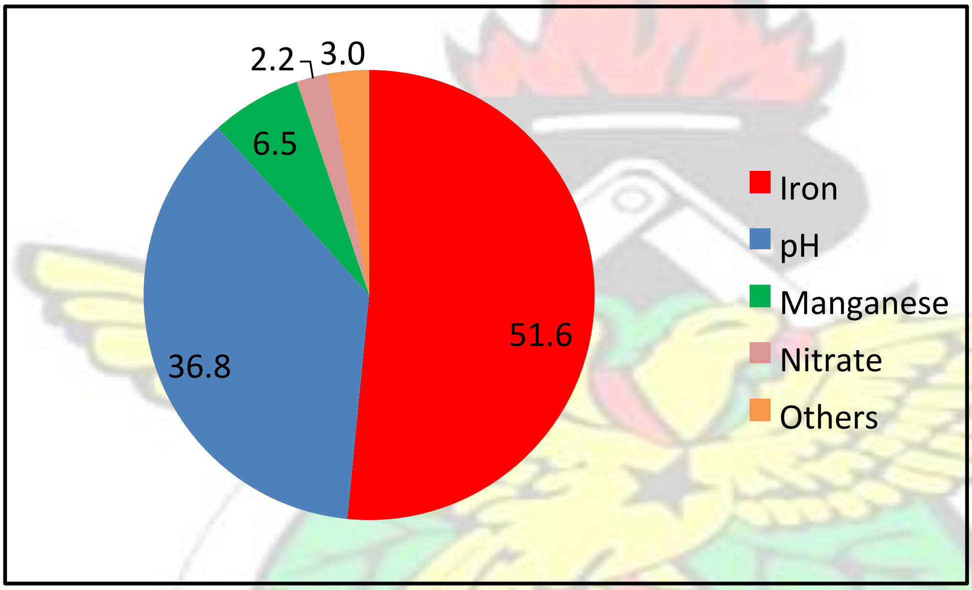


Figure 5.9: Composition of chemical parameters contributing to poor water quality

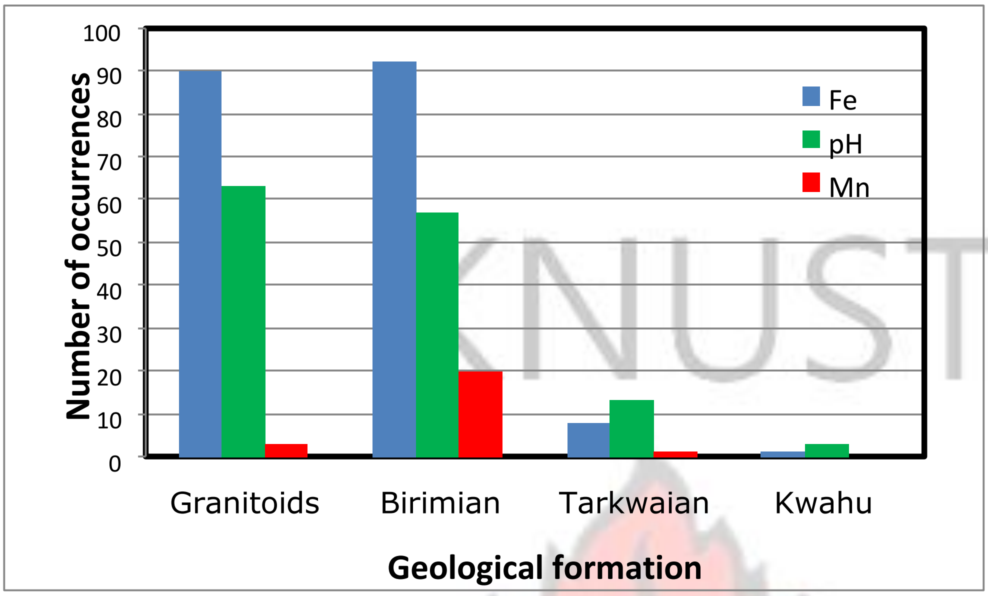


Figure 5.10: Major poor water quality parameters in the various geological formations

Figure 5.11 shows the map for iron concentration. Delineated zones of concentrations greater than 1 mg/l are observed within the Birimian S & V, undifferentiated granitoids and the Tarkwaian Group, which are within urban and peri-urban communities (Obuasi, Offinso, Juansa, etc.) with large population. The validation results for the iron concentration map were very good with less than 1 % prediction standardised errors (Table 5.4) within all the formations. About 78 % of the test data were located within their expected zones.

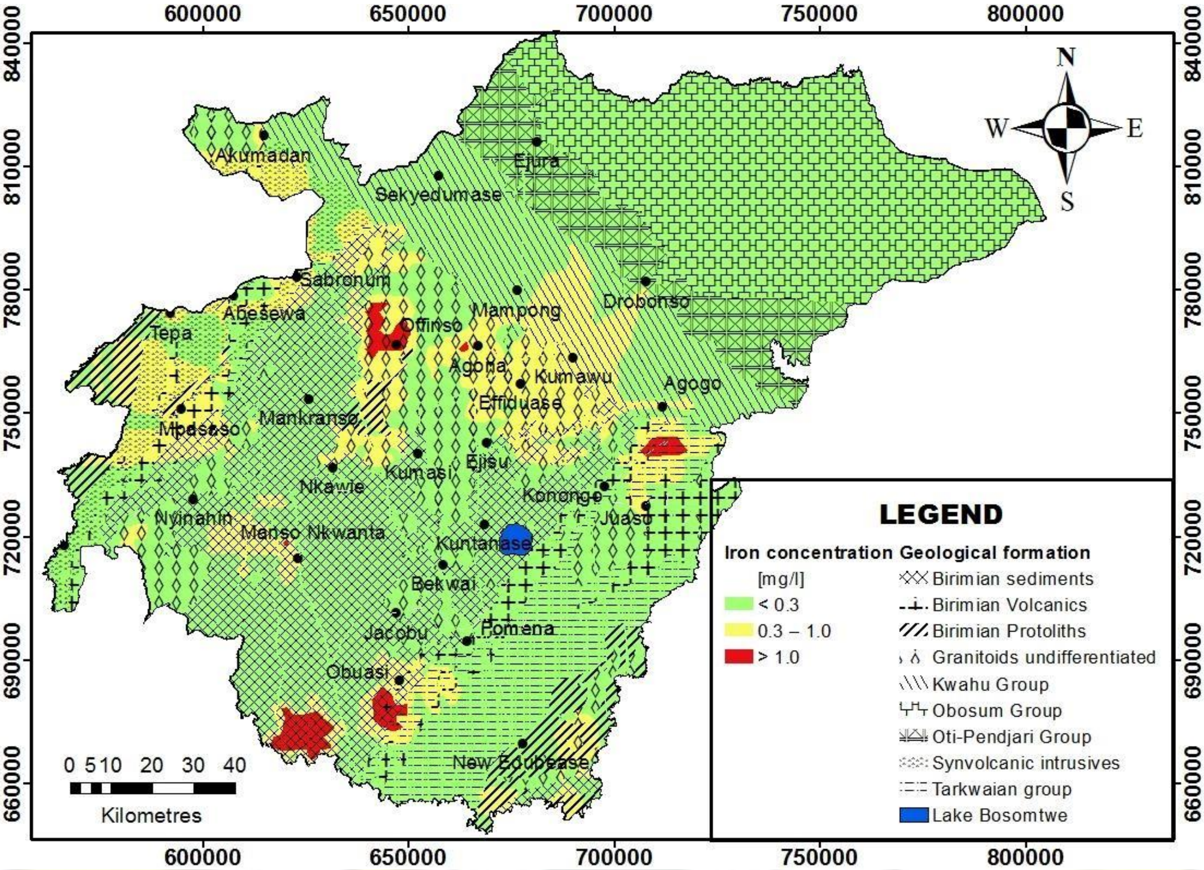


Figure 5.11: Overlay of iron concentration on geological formations

Although concentrations of up to 3 mg/l can be drunk by persons who drink anaerobic well water without any health problems, aesthetic problems particularly colouring of utensils, laundry and sanitary wares, taste, appearance and unpleasant odour often leads to the abandonment of such boreholes (WHO, 2003; CWSA, 2008). About 11.68 % of available water quality results have higher iron concentrations.

The problem with poor water quality is attributed to dissolution of some elements in water (Nyarko et al., 2014). This usually occurs during rock weathering processes leading to the exchange of chemicals between the soil and water (Hesterberg, 1998; Yidana et al., 2008).

A substantial amount of the boreholes had pH values outside GWCL guideline value (135 below the minimum guideline value and one above the maximum guideline value) across all the geological formations except the Oti Pendjari and Obosum Groups. Its effect of mildly sour taste has generally not been objected by consumers; hence, the continuous usage of all the boreholes with low pH. However, water with low pH (<6.5) could leach metal ions from the aquifer (Oram, 2016). About 14 % of the occurrences of pH outside the guideline value was with excess of other chemicals; 84 % being iron. The problem of low acidity in groundwater is often attributed to the deficiency of carbonate in the rocks leading to poorly buffered waters with acidity and associated problems (Smedley et al., 1995). Furthermore, mining of gold and base metals can also lead to oxidation of natural sulphides, thereby acidifying the groundwater and dissolving trace metals into the groundwater.

5.4 Discussion

The geological formations of the study area yield significant amount of groundwater even though lower yield zones also exist. Within the delineated airlift yield zones, there are discrete locations, which have airlift yields different from the zones within which they are located. A similar scenario exists for the overburden thickness, final depth, SWL elevation and specific capacity maps. This may be a result of the generally fracture dominated permeability of the different rocks, which may imply aquifers are localised.

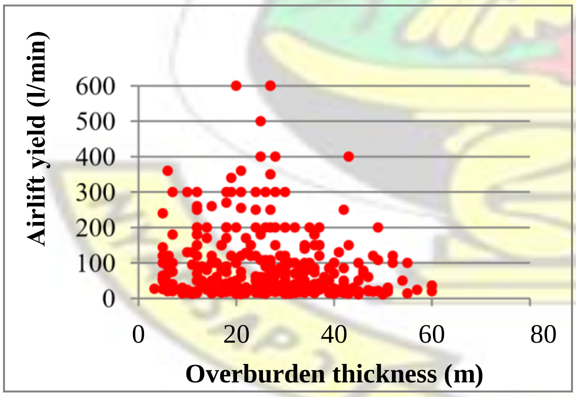
Generally there is poor correlation among the different parameters. Figure 5.12, for example, shows that there is no relation between overburden thickness and airlift yields within the geological formations. According to Carrier et al. (2008), the most productive groundwater zones are mainly the lower and upper parts of the saprolite and saprock respectively. This is affirmed by this study as 37 % out of the 707 successful boreholes whose overburden thickness were available, tapped water at about 5 m just below the weathered zone (Table 5.6) whilst 14 % tapped some or all its water from the overburden. The number of dry boreholes tends to be increasing with increasing overburden thickness and the mean airlift yields of the successful boreholes also did not increase with an increase in overburden thickness in the 3 intense weathering formations (Table 5.6), which means the assertion by Dapaah-Siakwan and GyauBoakye (2000) and Yidana et al. (2008) that, intense weathering enhances secondary permeability thereby forming permeable groundwater reservoirs have noticeable exceptions.

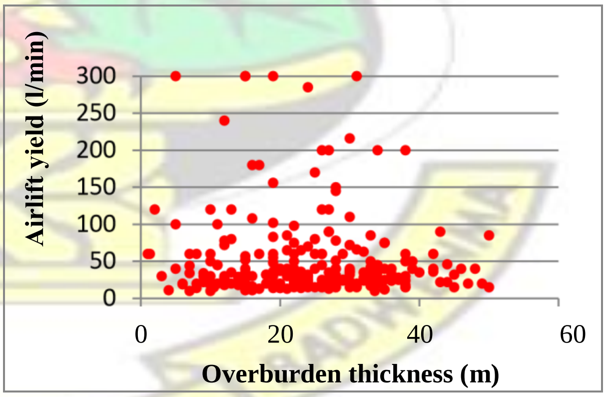
The mean depth of successful boreholes within the Birimian and undifferentiated granitoids from this study are respectively 53 and 50 m, which are almost the same as the 51 and 53 m obtained by Anornu et al. (2009) in their studies in the Ejisu-Juaben District. Similarly, it is comparable with mean depths (35 and 60 m respectively) obtained by Dapaah-Siakwan and

Gyau-Boakye (2000) for their studies, which covered the whole of Ghana.

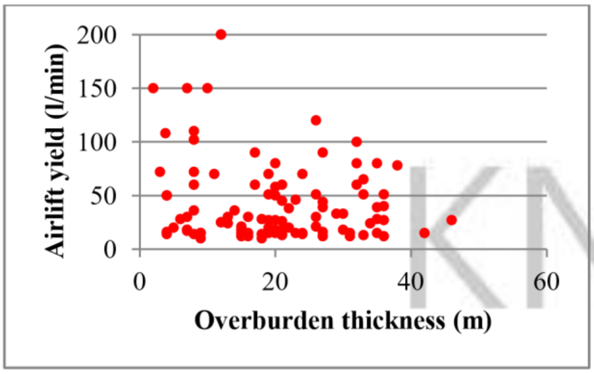
Table 5.6: Mean airlift yield and dry boreholes from the overburden

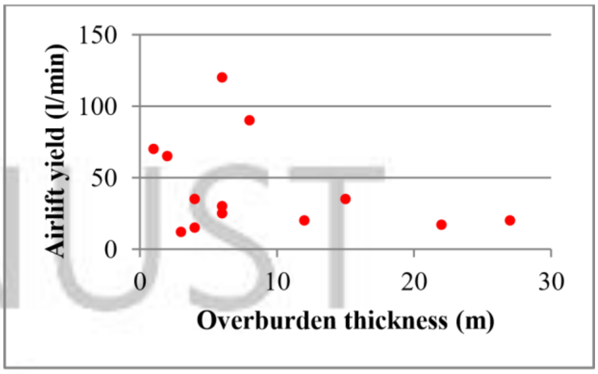
Overburden thickness range	**Birimian S & V**		**Granitoids undifferentiated**		**Tarkwaian group**	
	Mean airlift yield (l/min)	No. of dry boreholes	Mean airlift yield (l/min)	No. of dry boreholes	Mean airlift yield (l/min)	No. of dry boreholes
0 - 10	85	3	67	17	55	6
10 – 20	111	9	59	19	43	10
20 – 30	109	15	66	39	36	6
Above 30	64	15	52	26	42	5





(a) Birimian S & V **(b) Granitoids undifferentiated**





(c) Tarkwaian Group **(d) Groups within the Voltaian Formation Figure 5.12: Variation of airlift yield with overburden thickness within the various rock formations**

About 21 % of the boreholes had PWQ and were recorded within the different geological formations in the study area. It is imperative that prospective groundwater developers adequately plan on the requisite remedies to adopt to improve the quality of the water as drinking groundwater containing some of the chemicals is hazardous health wise. About 31 % of these PWQ boreholes have airlift yields within the CWSA criteria for Small Town Piped System (STPS). The contributing parameters are iron (75), low pH (25), nitrate (6), manganese (10), arsenic (2) and fluoride (1). This is worrisome as high-yielding aquifers, which should be helping in solving water shortage problems are unwholesome for household and commercial usage. These are generally attributed to the geology, as evidenced by the location of the few cases of high concentration of arsenic within the Birimian sediments in the Obuasi Municipality where it may likely be attributed to the presence of arsenopyrites in close association with sulphide mineralised veins (BGS, 2000). Leaching of metal ions from the aquifer owing to low acidity (Oram, 2016) may also be a contributing factor as about 8 % of boreholes with iron above the GWCL guidelines also had low pH. Financial resources, which could have been used to provide other facilities for the communities are rather used to install iron removal plants or drill new boreholes.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The hydrogeological parameters of the geological formations of the Ashanti Region have been evaluated under this study with the production of maps for the airlift yield, overburden thickness, depth of successful boreholes, static water level (SWL), specific capacity and iron concentrations. These were achieved by collecting and collating data from about 2800 existing boreholes and analysing them with the aid of Geographic Information System (GIS) for the different geological formations underlying the region, i.e. Birimian, the undifferentiated granitoids (granites, diorites, granodiorites and gneiss), Tarkwaian and Voltaian. Geostatistical kriging method using ArcGIS software was used for the analyses. The quality of the water with particular emphasis on known chemicals, which make the water unsuitable for their intended purposes were also assessed.

The study has shown that:

- The Birimian formation (metasediments and volcanics) generally falls within the medium yield (30 – 60 l/min) and high yield (> 60 l/min) zones, had specific capacity values that lie in the range of 0.21 – 99.65 m^2/day and a success rate of 90.6 %.
- The undifferentiated granitoids have 72 % drilling success rate (influenced by tapping water within the weathered saprolites) and are generally within the low yield zone (less than 30 l/min), even though airlift yield as high as 600 l/min was recorded in some areas. Its specific capacity values range from 0.3 to 88.5 m^2/day.

- The Tarkwaian Group had a drilling success rate of 79.5 % and is generally within the low and medium yield (30–60 l/min) zones. Its specific capacity values are between 0.3 and 65.1 m^2/day.
- The sub-groups within the Voltaian Supergroup were within the low yield zone except the north westernmost parts, predominantly underlained by sandstones, which were within the high-yield zone. The success rate for the Kwahu, Oti Pendjari and Obosum groups are respectively 53.5 %, 60 % and 66.7 % respectively. Their respective specific capacity values range are 0.2 –72 m^2/day, 0.4 - 33 m^2/day and 0.4 - 48 m^2/day.
- The Voltaian formation has the lowest overburden depth in comparison with the other formations, which range between 20 and 30 m. On the other hand, the static water elevation of the study area mimics the general topography.
- About 21 % of the successful boreholes had high concentrations of iron and manganese, and low pH; these were predominant within the Birimian, undifferentiated granitoids and the Tarkwaian formations. Minor occurrences of high arsenic and nitrate concentrations were recorded within the Birimian formation. Similarly, high concentrations of fluoride were recorded within the Kwahu and Oti Pendjari groups.

6.2 Recommendations

It is recommended that:

- Further studies be conducted within the delineated zones to ascertain the continuity or otherwise of the aquifers to aid in their easy exploitation and management.
- Data for this study should be updated with future drilling data to improve the accuracy of the maps, especially within the Voltaian Supergroup where the data for this study was limited.

- Pumping yields, when available in future, should be used in re-creating the yield map to improve on its accuracy, especially within the Voltaian Supergroup where the data for this study was limited.

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