Kwame Nkrumah University of Science and Technology
Kumasi, Ghana

ASSESSMENTT OF GROUNDWATER POTENTIAL IN ANKOBRA RIVER BASIN

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MSc. Thesis
February 2009

WRESP – KNUST
Faculty of Civil and Geomatic Engineering
Department of Civil Engineering

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Thesis submitted to
the Department of Civil Engineering,
Kwame Nkrumah University of Science and Technology
in Partial Fulfilment of the Requirements for the Degree of

MASTER OF SCIENCE
Faculty of Civil and Geomatic Engineering
College of Engineering

February 2009

CERTIFICATION

I hereby declare that this submission is my own work towards the MSc. 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 other degree of the University, except where due acknowledgement has been made in the text.

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Dedication

My Family

Abstract

Ankobra river basin is endowed with many rich natural resources. The mining activities in the basin and the proposed hydropower generation on the Ankobra river as well as oil discovery in the western region would lead to the establishing of new industries in the basin. These would certainly lead to potential population growth. As a result of these developments, there would be stress on surface water resources and therefore there would be demand for groundwater.

A research was carried out to assess groundwater potential in the river basin as alternative source to surface water supply. Hydrogeological data was used to evaluate the groundwater storage in the basement complex, regolith. The relevant aquifer characteristics or parameters (extent of the study area, thickness of the groundwater zone in the regolith, the porosity and specific capacity of the aquifer zones) were used to compute total groundwater storage and recoverable storage. The groundwater contribution to streamflow was computed using mean monthly discharge data from the filled data and a hydrograph drawn. The baseflow was then determined from the hydrograph separation using the straight line method.

The groundwater potential in the Ankobra basin is 45.82x $10^9 m^3$ while the recoverable groundwater storage is 29.39x 10^9 m^3. The baseflow computed was $13.75 m^3/s$. Investigations into groundwater chemistry with particular reference to physico-chemical parameters (quality) was analysed, the constituents fall within the acceptable limits of the Ghana Standard Board (GSB) for drinking water standard and are satisfactory for human consumption. However, Tamso, Wantenem, Gyaman, and Beyin communities exceeded the GSB's recommended values of pH (6.5-8.5) and Chloride (250mg/l) respectively for drinking water standard.

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List of Abbreviations and Acronyms

CSIR	Council for Scientific and Industrial Research
CWSA	Community Water Sanitation Agency
DWL	Dynamic Water Level
GSB	Ghana Standard Board
GWCL	Ghana Water Company Limited
ITCZ	Inter-tropical Convergence Zone
NGOs	Non-governmental Organization
SWL	Static Water Level
UN	United Nations
WHO	World Health Organization
WRI	Water Research Institute
WRC	Water Resources Commission
WWC	World Water Council

Acknowledgements

First and for most I would like to gratefully acknowledge the Water Resources and Environmental Sanitation Project under Civil Engineering Department of Kwame Nkrumah University of Science and Technology, Kumasi for granting me the opportunity to study Water Resources Engineering and Management.

I am deeply indebted to my supervisor Dr. S. N. Odai for his supervision, encouragement and guidance he has provided me throughout my research. His critical comments and helpful guidance's gives me a chance to explore further. I have learned a lot from him.

My deepest gratitude goes to my second supervisor, Mr K. A. Adjei and Mr F. O. Annor. Their support and encouragement gives me strength right from the inception of the topic to the last minute of the research.

I gratefully acknowledge all offices and personalities who have given me data for my study, especially messrs Mawuli Lumor and Tsidzi of Water Resources Commission, Ankobra River Basin and CWSA, Takoradi respectively.

My profound gratitude goes to my beloved wife Obosuo for your prayers, words of encouragement and support through thick and thin. My absence in the house created a vacuum but you stood in to take care of the house and family which made it possible for me to carry out this work. To my Children Ellen, Afriyie, Adom and Adibrosu, I appreciate your cooperation.

I would like to extend my appreciation to my course mates for their support, socialization and help each other. Every body was wonderful in the class. Abaka, Charles and Eugene you are unforgettable.

Also, I would like to thank my lecturers for granting me opportunity to build upon the foundation in Engineering.

Finally, I am most grateful to the Almighty God for His divine provision and protection during my research work and my entire stay on campus

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The former UN Secretary General and Nobel Prize winner Kofi Annan once said, "... *On our need for water, we have a problem all over the world. As population expands, there is a need for more food. The way we are managing water and reducing water table....The world is not ours, the earth is not ours. Is a treasure we hold in trust for future generations and I often hope that we will be worthy of the trust*".

Ankobra basin (one of the most important economical river basins in Ghana) is based principally on groundwater (Kortatsi, 2003). The basin is endowed with mineral resources that include some of the richest gold and the only manganese mines in the country and therefore commercial activities which require utilization of water resources can not be over emphasized. There is the need to study the groundwater and groundwater supplies.

Modern development and population growth have increased demands for water resources globally. Thus the welfare of every society is tied to the sustainable exploitation of water resources (Bear, 2000). Information from the World Water Council's Report on Sustaining Water show clearly how alarming the situation is: "In 1950, only 12 countries with 20 million people faced water scarcity; by 1990 it was 26 countries with 300 million people; by 2050 it is projected to be as many as 65 countries with 7 billion people, or about 60 percent of the world's population, mainly in the developing countries" (WWC, 1996). In addition to these, current global climatic change processes are expected to affect both the spatial and temporal water availability. The water resources base is, therefore, under threat.

The importance of groundwater is often overlooked. It is a mysterious resource – out of site and out of mind. However, some 97 percent of all freshwater found on the earth is stored underground (excluding frozen water in glaciers). The resource is naturally fairly resistant to drought, storing up water in times of plenty, and releasing it in times of need; also the quality of groundwater tends to be good and is much less vulnerable to contamination than surface water. Its availability is influenced by many factors such as the lithology of the area, the annual rainfall, evapotranspiration and water quality.

The largely unseen nature of groundwater has resulted in the development initiatives that are unaware of the hydrodynamic limits of the resource and unable to regulate the resulting patterns of abstraction. The consequences ranges from the drawdown of water levels beyond the limits of dug wells and manual pumping technologies to more subtle and deferred environmental health impacts resulting from the withdrawal of groundwater resources on the sustainable basis to meet the future challenges. For sustainable management of groundwater over-exploitation therefore occurs when abstraction rate exceeds the long-term average recharge. The over abstraction of groundwater can result in:

- Yield reduction
- Increased pumping cost
- Drying up of shallow wells, springs, streams, ponds and wetlands
- Gradual compaction of subsurface materials resulting in land-surface subsidence and ultimately
- The lost of the resource.

Retroactive solution to groundwater problems are technologically demanding, extremely expensive and time consuming. "Prevention is better than cure" is particularly true in the case of groundwater.

1.2 Problem Statement

There are a number of non-governmental organizations (NGOs) and governmental departments engaged in the exploitation of groundwater in Ghana for the supply of potable drinking water for the rural communities. During the last 30 years large numbers of boreholes have been drilled in the rural communities across the country. Almost all the groundwater is being tapped with inadequate attention to the potential of the various aquifers. Decline in groundwater levels have been observed in certain parts of the country (Dapaah-Siakwan and Gyau-Boakye, 1999). This may be due to poor spacing of wells which manifest themselves in low yields, over exploitation of the aquifers or low recharge resulting from observed decline in rainfall in the last decade in certain areas. The population of the basin is rapidly increasing due to mining activities and it is expected that new industries will be established in the basin as a result of the proposed hydropower generation on the Ankobra river as well as oil discovery in the western region, which will lead to potential population growth. This development will certainly increase stress on groundwater due to the increase in the demand for various purposes like domestic and industrial. There is the tendency of over-exploiting groundwater resources in the near future, which may have serious repercussions on the environment. This therefore calls for quantitative assessment of this resource for a planned and optimal utilization.

This thesis, therefore, focuses on the need to quantify the groundwater resource. The activities of the mining companies had generated a lot of public concern. Dumasi River near Bogoso which serve as drinking water had dried up and it is expected that after the mining companies had folded-up or closed down as results of their mining activities, many more streams, rivers and springs would dry up.

1.3 Objectives

The aim of the thesis is to assess the groundwater potential in the Ankobra river basin. To accomplish this aim, the research was undertaken with the following specific objectives to:

1. Estimate the total and recoverable quantities of groundwater storage in the regolith in the Ankobra river basin.
2. Estimate groundwater contribution to streamflow in the basin.
3. Investigate groundwater chemistry with particular reference to physico-chemical parameters (quality) in the Ankobra river basin.

1.4 Justification

Notwithstanding the perceived abundance of water in Ghana, its production and utilization for consumptive and non-consumptive uses is not at an optimal level. The basin experiences inadequate water supply in certain parts particularly during the dry season. Water scarcity problems in parts of Ankobra are expected to worsen owing to increasing population and degradation of available water resources by mining activities. Mountains, hills and highlands which serve as sources of water to springs, stream, rivers etc. are target for mining activities. Consequently, surface water resources would be polluted. This development would certainly increase stress on surface water resources and therefore there would be demand for groundwater.

1.5 Organization of thesis

Chapter one of the thesis presents the background, the problem statement, justification and the objectives of the study. In chapter two, pertinent literature is reviewed followed by description of the study area in chapter three. Chapter four explains the research methodology. Chapter five presents the results and discussion of the study and chapter six summaries the findings and give recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concept of Groundwater Occurrence

2.1.1 Hydrological Cycle

Groundwater does not exist in isolation but it is part of an integral link in the hydrological cycle and a valuable supporter of terrestrial ecosystem, (Freeze and Cherry, 1979).

An adequate supply of water is vital to life on earth. With increasing demands on this finite resource, scientists have given a great deal of attention to the exchange of water among the oceans, the atmosphere, and the continents. This unending circulation of the earth's water supply is called the hydrologic cycle. It is a gigantic system powered by energy from the sun in which the atmosphere provides the vital link between the oceans and continents.

Water from the oceans and to a much lesser extent from the continents, is constantly evaporating into the atmosphere. Winds transport the moisture-laden air, often great distances until the complex processes of cloud formation are set in motion that eventually result in rainfall. Portions of the water that falls onto the continents soak into the ground, some of it moving downward and then laterally until it finally discharges into a spring, stream, lake, wetland or the ocean, or is taken up by plants or extracted by wells.

The passage of water from the surface to the ground is called infiltration and its downward movement to the saturated zone at depth is described as percolation. At some depth, the pores of the soil or rock are saturated with water. Water stored in this zone of saturation is known as groundwater and this move toward rivers, lakes and the seas, a process known as groundwater flow, where it is evaporated and returned to the land as clouds of water vapour which may precipitate as rain or snow. Thus a cycle of events exist, namely precipitation on land, infiltration and percolation, groundwater flow to open water bodies, evaporation and then precipitation, so starting another cycle. This cycle is represented in Fig. 2.1

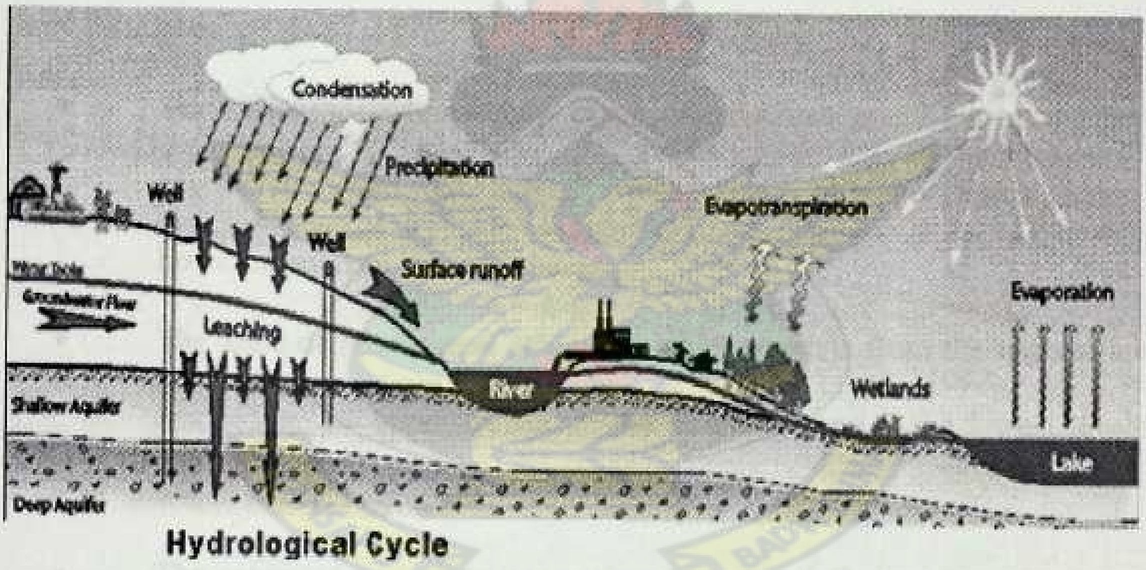


Figure 2.1: Hydrological cycle (www.ec.ge.ca/water/en/nature/grdwtr/e_cycle.htm)

The seas and oceans contain approximately 97% of all the water presently involved in the cycle, a little less than 2% is in the form of snow and ice and less than 0.1% is water vapour. The remaining 0.9% is distributed in lakes, rivers and groundwater (Blyth and Freitas, 1986).

2.1.2 General Occurrence of Groundwater

Generally, the rocks that form the crust of the earth are in few places, if anywhere, solid throughout. They contain numerous open spaces, called voids or interstices, and these spaces are the receptacles that hold the water that is found below the surface of the land and recovered in part through springs and wells (Fetter, 1994). Many kinds of rocks exist and they differ greatly in number, size, shape, and arrangement of their interstices and hence in their properties to store water. Based on this reasoning, Meinzer, (1923) stated that "the occurrence of water in rocks of any region is determined by the character, distribution and structure of the rocks it contains-that is by the geology of the region". Groundwater occurrence can usually be discerned in three distinct zones (Duff, 1996):

- The unsaturated or phreatic zone where pores and fissures are never completely filled but through which water migrates. Some water is however retained in pores spaces.
- The zone of intermittent saturation which extends from the highest level reached by the upper surface of the saturated zone to the lowest level to which if falls in drought
- The saturated or vadose zone where pores and fissures are permanently filled by the water.

Groundwater in the regolith or the saturated zone can occur as:

- Phreatic groundwater where the piezometric water level or water table is below the top of the aquifer. Such an aquifer is called unconfined.

- Confined or pressured groundwater where the water level is above the aquifer. In this case the groundwater is under pressure and the aquifer is said to be confined. Confining (overlying and underlying) layer could be an aquitard or aquiclude.
- Artesian groundwater occurs when the level or pressure head in a confined aquifer rises above the surface. Here groundwater flows spontaneously to the surface.
- A groundwater body may develop on top of an impermeable layer in the unsaturated zone. Such an aquifer, which has no contact with the deeper laying groundwater body, may be called a perched aquifer.
- Groundwater may also occur as springs where the groundwater cut or emerge on the earth surface. This is most likely to occur where a permeable formation is set against an impermeable formation.

2.1.3 Groundwater Occurrence in Crystalline Rocks

Intrusive igneous and highly metamorphosed crystalline rocks generally have very little, if any primary porosity. In order for groundwater to occur, there must be openings developed through fracturing, faulting or weathering. Fractures can be developed by tectonic movements, pressure relief to erosion or overburden rock, shrinking during cooling of rock mass and the compressional forces caused by regional tectonic stresses.

In general, the amount of fracturing in crystalline rocks decrease with depth

(Fetter, 1994). This was however found to be not always true from two test wells drilled in northern IIIionois as exploratory holes for a possible pumped hydroelectric storage project (Davis and Turk, 1964). These wells drilled penetrated from a depth of 664m to 1669m and 664m to 1600m yet fractures were found in an area of Paleozoic bedrock overlying crystalline bedrock comprised of biotite granite.

2.2 History of Groundwater Development

History of Groundwater development dates as far back as the beginning of time. Many of our ancient civilizations obtained their water supplies from groundwater as well as surface water.

The ancient Persians constructed tunnels and shafts to tap groundwater. The early Egyptians and Chinese were familiar with drilling methods that enabled them to sink boreholes to obtain water from underground. About 2100 BC, near the end of the 11th Dynasty, one leader of Mentuhotep's Egyptian forces report sinking 14 wells with an army of 3000 men. Some four centuries later, Senachrib used pulleys to raise water from well, (Davis and DeWeist, 1996).

General interest in drilling rather than digging well developed in the 12th century with the successful drilling of a well at Artois, France, in 1226. The term 'artesian' is derived from the name of this community. An artesian well completed in 1841 at Grenelle near Paris was for many years the deepest well in the world. Drilling of this well started in December 1833, and it was finally completed at a depth of 548m.

The science of deep well drilling received great impetus through experience gained in drilling the Passy well of Paris, which was completed in 1857. The successful completion of wells in France was followed by deep borings in England and Germany. Some of these wells were of relatively large dimensions and they provided geologists with an opportunity to inspect the crust of the earth at relatively great depths.

The history of groundwater development in Ghana can be traced back to the 19th century. During these initial periods, communities relied on simple unlined wells (traditional wells) dug at the initiative of individuals and communities. In the period between 1920 and 1945, the Colonial Administration undertook a nation-wide hand-dug well programme under the auspices of the Rural Water Division, an offshoot of the Coast Geological Survey Department. 55% of the estimated 60,000 hand-dug wells scattered throughout the country were constructed between 1980 and 1990 (Bannerman and Allison, 1993).

2.2.1 Borehole Drilling in Ghana

Borehole drilling in Ghana began in the 1940s to provide water for larger rural communities. Since then, large numbers of both shallow and deep boreholes have been drilled by national and international organizations. Based on this, Bannerman and Allison, (1993) stated that "since 1974" a number of externally aided drilling programmes have been executed throughout Ghana, and some 10,000 boreholes and hand pumps installed.

The first major borehole project in the Ankobra river basin was drilled in the early 1980s under the "3000 Wells Project". Until then, groundwater development in the basin was not different from other parts of the country. The people relied on traditional hand-dug wells, surface water (streams, rivers, ponds, dug-outs), springs and rainwater for their domestic water consumption.

2.2.2 Hydrogeologic Framework in Ghana

The hydrogeological condition of an area is highly influenced by the characteristics and structure of basic geology and climate. In Ghana, the hydrogeological regions and their characteristics are very similar to the local geological conditions, because the climate zones of the country are mostly conformable to the geological regions (British Geological Survey, 1993).

Presently, a lot of hydrogeological studies have been conducted in the country in a bid to increase water supply particularly to the rural community. From the most recent study conducted, Ghana is divided into two major hydrogeological provinces (Dapaah-Siakwan and Gyau-Boakye, 2000). The main units are described as follows;

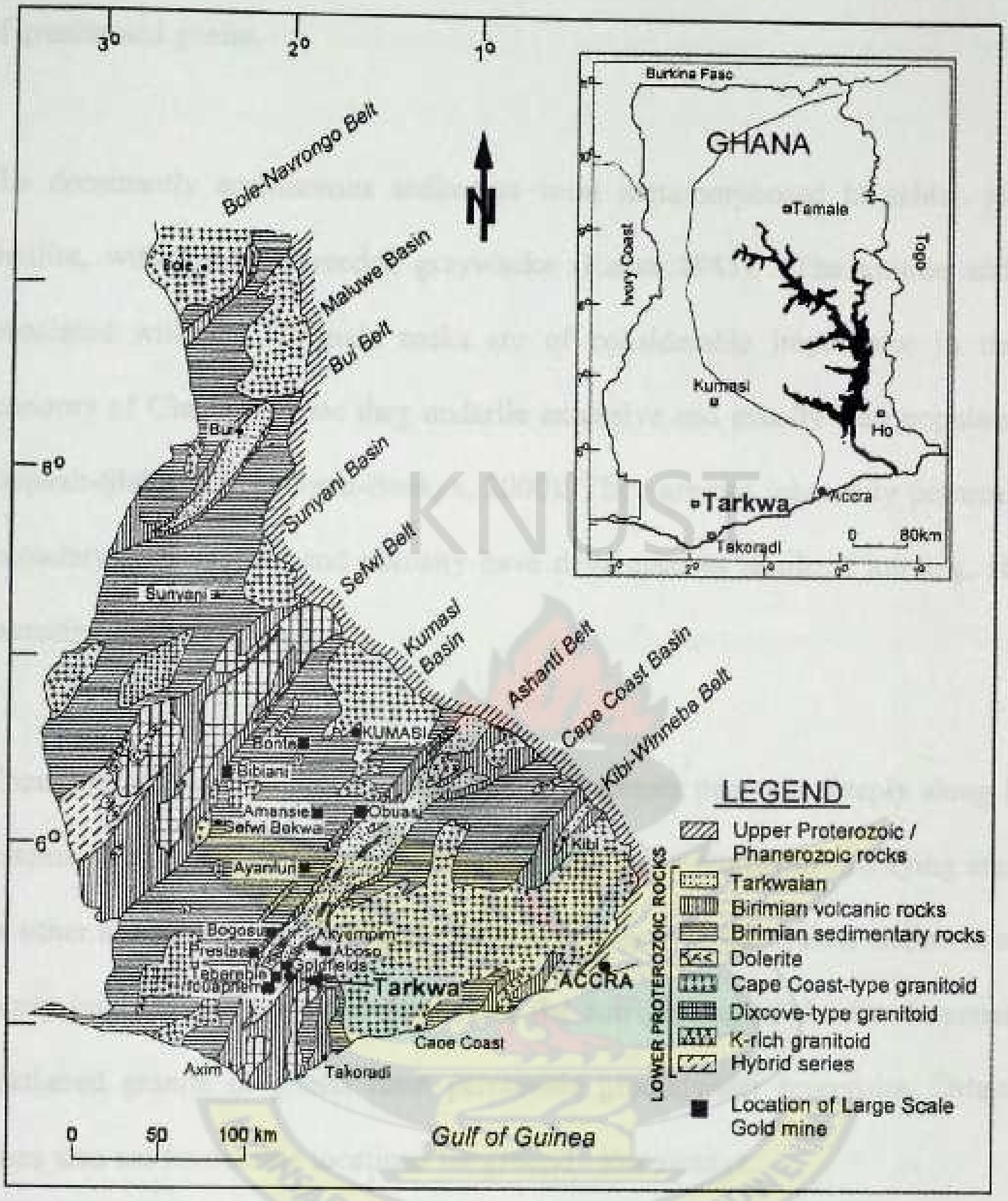
- The Basement Complex, composed of Precambrian crystalline igneous and metamorphic rocks and
- Palaeozoic sedimentary formation.

Minor provinces consist of (1) Cenozoic, Mesozoic, and Palaeozoic sedimentary strata along narrow belts on the coast, and (2) Quaternary alluvium along the major stream courses.

The Basement complex is further subdivided into sub-provinces (Figure 2.2) on the basis of geology and groundwater conditions (Gill 1969). Precambrian crystalline igneous and metamorphic rocks can be subdivided into Birimian, Granite, Dahomean, Togo, and Tarkwaian formation. These formations consist mainly of phyllite, schist, gneiss, migmatite, granite-gneiss and quartzites. The Basement Complex underlaid about 54% of the country.

The Palaeozoic which is a consolidated sedimentary formation (locally referred to as the Voltaian formation) underlies the Volta Basin and consist mainly of sandstones, shale, arkose, mudstone, Sandy and pebbly beds and limestones. It underlies about 45% of Ghana.

The Cenozoic, Mesozoic, and Palaeozoic sedimentary strata (Coastal Provinces) underlie the remaining 1% of the country. They consist of unconsolidated alluvial sediments, beach sand, red continental deposit of mainly alternating limonitic sand, sandy clay gravel, marine shale, limestone and glauconic sandstone (Kortatsi, 2004).
The basin area falls within the Basement Complex and so for the purpose of this research, further literature will concentrate on this province. The main rock types belonging to this terrain are identified as granites, granodiorites, phyllites, schists, migmatites as well as variety of sandstones and shales.



Source: (Kuma, 2004)

Figure 2.2: Simplified Geological Map of Southwest Ghana.

The Basement Complex of Ghana is made up of the Birimian Volcanics and Sediments systems, which extend from the north through the mid-west to the south-western parts of the country. These rocks consist of a great thickness of isoclinals folded, metamorphosed sediments intercalated with metamorphosed tuff and lava. The latter are predominant in the upper part of the system, whereas the sediments are predominant in the lower part. The entire sequence is intruded by batholithic masses of granite and gneiss.

The dominantly argillaceous sediments were metamorphosed to schist, slate and phyllite, with some interceded greywacke (Kesse 1985). The granite and gneiss associated with the Birimain rocks are of considerable importance in the water economy of Ghana because they underlie extensive and usually well populated areas (Dapaah-Siakwan and Gyau-Boakye, 2000). They are not inherently permeable, but secondary permeability and porosity have developed as result of jointing, shearing, fracturing and weathering.

Where precipitation is high and weathering processes penetrate deeply along fracture systems, the granite and gneiss commonly have been eroded to low-lying areas. On the other hand, where the precipitation is relatively low, the granite occurs in massive poorly jointed inselbergs that rise above the surrounding lowlands. In some areas, weathered granite or gneiss form permeable groundwater reservoirs. Major fault zones also are favourable locations for groundwater storage.

2.3 Groundwater Resources

The rocks of the basement complex have little or no primary porosity. Groundwater occurrence is thus associated with the development of secondary porosity. This has given rise to two main types of aquifers (Dapaa-Siakwan and Gyau-Boakye, 2000) namely:

- Weathered zone aquifers

- Fractured zone aquifers

Boreholes have higher yields in the mid-sections around Kumasi and surrounding areas than in other areas such as Winneba and Wa. The average well yield is $9.3m^3/h$. The reason could be attributed to the high rainfall in and around Kumasi, which results in a thicker weathered zone and hence greater well yields (Dapaa-Siakwan and Gyau-Boakye, 2000).

Again Dapaah-Siakwan and gyau-Boakye (2000) reported that most of the boreholes in the Birimaian System are fitted with hand pumps and have an average depth of about 35m and in the granites where it is very difficult to construct successful wells; boreholes are drilled to an average depth of 60m.

The Birimain phyllite, schist, slate greywacke, tuff and lava are generally strongly foliated and fractured. Where they crop out or are near the surface, considerable water may percolate through them. Boreholes tapping the Birimain Volcanics and Sediments have an average yield of about 60 l/min. A summary of borehole yields in the various sub-provinces of the Basement complex in Ghana is given in the Table 2.1

There have been varying opinions concerning the groundwater potential of the Precambrian Basement complex, particularly the safe yield of the aquifers of these rocks and their associated saprolites.

Ogunkoya (1987) discussed the conflicting claims on the merits of basement complex rocks as aquifers. The argument was on:

- The low porosity and permeability of the basement complex rocks generally have insufficient thickness of the saprolites overlying these rocks.
- The high frequency of occurrence of outcrops in some areas and the irregular nature of the basal surface of weathering, and
- Even in amphibolites, schist's and gneissose rocks with their relatively deep layer of saprolites, the clayey nature of the saprolites associated with most rocks promote low yield.

Table 2.1: Yields of the Basement Complex in Ghana

Hydrogeologic Subprovince	Borehole Completion Success Rate (%)	Range of yields M3/h	Average yield (m3/h)
Lower Birimain System	75.0	0.41 – 29.8	12.7
Upper Birimian System	76.6	0.45 – 23.6	7.4
Dahomeyan System	36.0	1.00 – 3.00	2.7
Tarkwaian System	83.0	1.00 - 23.2	8.7
Togo Series	87.9	0.72 - 24.3	9.2
Buem Formation	87.9	0.72 – 24.3	9.2

(Source: Dapaah-siakwan and Gyau-Boakye, 2000)

Oteze (1977) in his research in Nigeria also commented that "the Basement Complex of crystalline rocks which covers about half of the surface area of Nigeria is not usually regarded as being rich in groundwater because of the much localized nature of the aquifers".

Another group (Assez, 1975; Bannerman, 1973; Bannerman, 1975; Faniran, 1975; Omorinbola, 1982; and Omorinbola, 1983) noted that the weathering front in the basement complex, though irregular, did not restrict the occurrence of groundwater zones in the saprolites from being widespread and almost regional as the water table in the saprolites lies a considerable height above the uneven basal rock surface. It further affirmed the existence of relatively thick zones of saturation in the weathered mantle, suggesting the occurrence of groundwater. Owolabi and Anthony (1988) emphasized the positive future economic potential of basement rocks as aquifers in south western Nigeria so long as the limitations of such rocks and their products as a source of water supply are clearly recognized.

On the yield of wells, a study of crystalline rock wells in the United States has shown that the yield, expressed in gallons per minute divided by the depth of the saturated zone penetrated by the well, decreases rapidly with depth (Davis and Turk, 1964). However, jointed crystalline rock in Piedmont of the eastern United States is known to be fractured to depths of 150m (Stewart, 1962). Legrand (1954) observed that well yield in crystalline rocks are greater when the wells are located on valley bottoms. He concluded that the valley bottoms probably developed along fracture traces. The possibility of obtaining high-yielding wells in crystalline rocks during drilling is higher if drilling takes place in areas where fractures are concentrated and interconnected.

2.4 Groundwater Resources in Tropical African Regolith

Omorinbola (1984) under took a study in the tectonically inactive African shield which consists mostly of Precambrian basement complex rocks which, because of their crystalline nature, are poor aquifers. Deep chemical weathering has, however produced from the rocks relatively thick regoliths (overburden) in which extractable groundwater resources abound.

According to Omorinbola (1984), the greatest challenge posed by the hydrogeology of tropical Africa is to obtain reliable estimates of the groundwater resources in the regoliths. The determination of how much groundwater is contained in or extracted from tropical regolith can be tackled with relevant hydrogeological parameters in a refined version of Schoeller's (1967) model to quantitatively evaluate groundwater resources.

$$Q_r = \alpha \gamma h A \qquad (1)$$

where: Q_r = Recoverable groundwater storage (m^3)

α = Percentage of the study area underlain by groundwater

γ = Specific capacity ($m^3/h/m$)

h = Thickness of the saturated zone (m)

A = The extent of the study area (m^2)

2.5 Assessment of Groundwater Potential

The earliest groundwater assessment in Ghana was carried out by Gill in 1964. In spite of the fact that this assessment was national in scope, it was based on limited data available at the time. Gill (1964) recognizing the limitation of his assessment recommended future groundwater assessment when the data was available.

The first major groundwater assessment based on large data was carried out by Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR) between 1984 and 1995. This assessment was based on simple statistical analysis of well records on approximately 8,000 boreholes nationwide divided into regions.

Kortatsi (1997), conducted assessment of groundwater resources in White volta, Black Volta, Daka and Oti basins and adopted the refined version of Schoeller model to quantitatively evaluate the groundwater resources in the above basins.

The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specified period. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system.

To assess the change in ground water storage, the water levels are observed through a network of observation wells spread over the area. The water levels are highest in the rainy season and lowest in dry season. The change in storage can be computed from the following equation:

Change in storage, $\Delta S = \sum h A S_y$

where, h = change in water level (m); A = area influenced by the well (m^2); and Sy = specific Capacity ($m^3/h/m$). The specific capacity may be computed from pumping test, Kumar (2001)

2.6 Groundwater Balance Equation

The basic concept of water balance is:

Input to the system - outflow from the system = change in storage of the system (over a period of time). The general methods of computations of water balance include:

(i) Identification of significant components,

(ii) Evaluating and quantifying individual components, and

(iii) Presentation in the form of water balance equation.

Considering the various inflow and outflow components, the terms of the ground water balance equation can be written as:

$$Ri + Rc + Si + Ig = Et + Tp + Se + Og + \Delta S$$

where Ri = recharge from rainfall; Rc = recharge from canal seepage; Si = influent seepage from rivers; Ig = inflow from other basins; Et = evapotranspiration; Tp = draft from ground water; Sb = Baseflows; Og = outflow to other basins; and ΔS = change in ground water storage.

This equation considers only one aquifer system and thus does not account for the interflows between the aquifers in a multi-aquifer system. However, if sufficient data related to water table and piezometric head fluctuations and conductivity of intervening layers are available, the additional terms for these interflows can be included in the governing equation. All elements of the water balance equation are computed using independent methods wherever possible. Computations of water balance elements always involve errors, due to shortcomings in the techniques used. The water balance equation therefore usually does not balance, even if all its components are computed by independent methods. The discrepancy of water balance is given

as a residual term of the water balance equation and includes the errors in the determination of the components and the values of components are not taken into account.

2.7 Porosity

There is no specific data on porosity on the fractured rocks at the study area. However, comparisons were made with other site areas in the literature with similar rock types to obtain a possible range of values that was used in this study. DeWeist (1966) for example indicates porosities in weathered igneous and metamorphic fractured rock of up to 35%, and suggests porosity of non-weathered fractured rock in the range 2% to 10%. Freeze and Cherry (1979) notes non-fractured samples of igneous and metamorphic rock have porosities rarely greater than 2%. They quote fractured weathered basalt having a permeability of $10^{\wedge-4}$ to 1 m^2/day having a porosity of 10%. Spitz and Moreno (1996) indicates porosity in fractured dolomite in the range 7% to 18% and fractured granite in the range 2% to 8%. Asomaning (1993), and Acworth (1987) also stated that the porosity of the basement complex regolith is in the range of 5% and 8%.

2.8 Pumping Test

The main principle underlying a pumping test is to pump water from a well and measure its discharge. The pump selected for the test depends on the diameter of the well. Suction pumps placed outside the well are used for small diameter wells where the water table is shallow, and submersible pumps are used for large diameter deep wells. About 80 to 90 per cent of the aquifer should be screened to enable the water to flow horizontally into the well; this makes calculation easier. For partially penetrating well, however, the necessary corrections due to the vertical component should be made (Kruseman, 1991).

Pumping should be done for several days especially in unconfined, leaky and fractured aquifers to enable very wide drawdown's in piezometers placed at distances in the range of 100 to 200m from the well to be measured. Kruseman (1991) gave a number of factors upon which distance of the piezometers from well depends on as follows:

- The type of aquifer (i.e. confined, unconfined or leaky)
- The transmissivity (the higher the transmissivity the wider and flatter the drawdown and vice versa)
- The duration of the test (the longer the duration the wider the drawdown)
- The discharge rate (the higher the discharge rate, the wider and deeper the drawdown)
- The length of the well screen
- The degree of fracturing, weathering, orientation of fracture planes and the material filling the fracture.

The groundwater resources sustainability therefore depends greatly on the method of pumping and response of the underlying aquifer to pumping. Carrying out pump test on a well at constant discharge rate and the change in drawdown measured over time will enable the computation and evaluation of hydraulic property of the material such as the specific capacity or transmissivity and storativity of the aquifer (Fetter, 1994). Clark (1974) gave three main reasons for carrying out pumping test on boreholes:

- To measure well performance
- To estimate well efficiency or variation of well performance with the discharge rate
- To measure aquifer characteristics of specific capacity, storativity, hydraulic conductivity, and transmissivity.

Most successful hand-pump boreholes constructed in the basin were each subjected to pumping test for a period of four (4) to six (6) hours at a constant rate followed by recovery test of half the time of constant discharge.

2.9 Groundwater Contribution to Streamflow (Baseflow)

During periods of little or no rainfall, streamflow is assumed to be composed almost entirely of ground water (baseflow). The total stream flow can be viewed as consisting of mostly two parts, direct runoff and baseflow, as a result, the amount of streamflow contributed by ground water can be estimated. Three methods were used to estimate ground-water contribution to streamflow:

- hydrograph separation,
- field measurements during droughts, and

- linear-regression analysis of streamflow duration

Atkins et al. (1996) estimated ground-water contribution to streams in the central Savannah River Basin using hydrograph-separation techniques and a drought-streamflow analysis.

(Atkins, 1996), compared the results of the three methods using four basins in southwest Georgia, US and found that the fixed-interval and sliding-interval methods are biased toward baseflow; and thus, over predict groundwater contribution to streamflow.

Many studies have compared groundwater discharge to streams using the flow-duration characteristics of a stream. Stricker (1983) found that the shape of streamflow-duration curves is affected by the lithology of the Coastal Plain sediments.

2.10 Water Quality

Although groundwater is generally of good quality and less vulnerable to bacteriological contamination than surface water, quality can occasionally be poor. It may contain many dissolved minerals because of the processes that take place during its movements in the soil or rocks. During groundwater recharge, surface water or precipitation percolates through soils and rocks dissolving ions. The dissolution may be due to high solubility of particular minerals and in other cases due to action of carbon dioxide in the water. The purpose of water quality analysis is to determine the suitability of water for a proposed usage (Raghunath, 1992). These dissolved minerals can increase the concentration of ions in the groundwater. The anions most commonly found in groundwater quality analysis include: Cl^-, SO_4^{2}, NO_3^-, NO_2^-, F^- ; CO_3^-- and HCO_3^-; whilst the commonly found captions are: Na^+, K^+, Mn^{2+}, Mn^{2+} and Fe^{2+}.

CHAPTER THREE

3.0 STUDY AREA

3.1 Geographical location

The Ankobra river basin is located in south-western part of western region within latitude 4°15'N to 6°30'N and longitude 1°30'W to 2°45'W. This basin is sandwiched between the Pra and Tano river basins. The basin has a total drainage area of 8400km^2 and a stream length of about 209km. The Ankobra river takes its source from Bebianiha hills about 568m above mean sea level in the Sefwi Bekwai district. It then flows north to south through thick forest and enters the Atlantic ocean through gulf of Guinea near Axim. There are few rapids in the upper reaches where the gradient is steep. The lower reaches of the river are however very gentle in slope. The basin has a flat to gentle sloping topography with elevation lying between 0 and 152m above sea level. There are however, a few areas with elevation lying between 152 to 305m above mean sea level. The principal tributaries to the Ankobra are the Bonsa, Mansi, Fure, Nwhini Rivers (Figure 3.1).

3.2 Climate

Ankobra river basin is situated on the border of two climatic regions. The south part belongs to the south western equatorial climatic region and the northern part has a wet semi-equatorial climate. Generally the rainfall pattern follows the northward advance and the southward retreat of the inter-tropical convergence zone (ITCZ) that separates dry air from Sahara and the moisture-monsoon air from the Atlantic Ocean. The north air mass, locally called the Harmattan, brings in hot and dry weather during December to February (Dickson & Benneh 1995). The area is characterized by double rainfall maxima. The first and largest peak occurs in June, whilst the second and smaller peak occurs in October. Around 53% of all rain in the region falls between March and July. The mean annual rainfall is approximately 1874 mm with minimum and maximum values of 1449 mm and 2608 mm respectively. The mean pH of the rain water in the area during 2000-2001 was 6.07, (Kortatsi 2004). The area is very humid and warm with temperatures between 26-30C°, (Dickson and Benneh 1995)

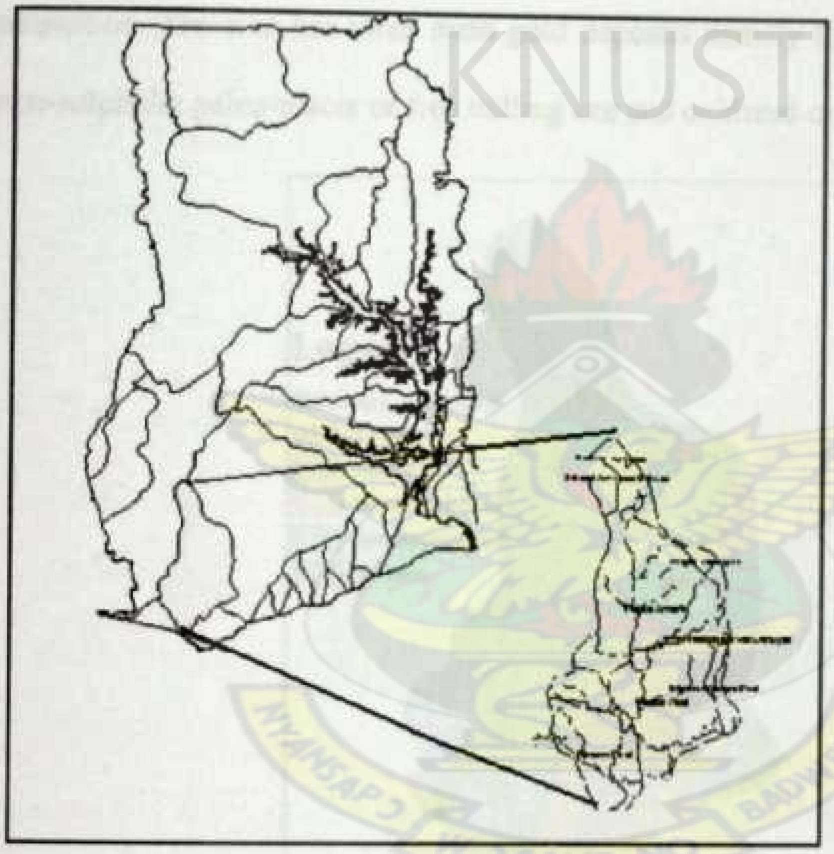


Figure 3.1: Map of Ankobra basin

3.3 Geology

The geomorphology of the Ankobra basin consists of a series of ridges and valleys parallel to each other and to the strike of the rocks. The strikes of the rock are generally in north-south direction (Kortatsi 2004). Both the Tarkwaian and Birimian systems are folded along axes that trend northeast (Gyau-Boakye and Dapaah-Siakwan 2000). The general type of topography reflects the underlying geology (Kortatsi 2004). The geology of the Ankobra river basin is shown in figure 3.2. The basin is underlain mainly by the Birimian formation with some areas in the east underlain by the Tarkwaian formation while other small areas especially in the northern and western portions of the basin are underlain by granite. Basic intrusive rocks within the Tarkwaian consist of gabbro, dolerite, epidiorite, norite and serpentine. The area has three main gold deposits namely Placer or alluvial deposit, non-sulphidic paleo-placer or free milling ore and oxidized ore.

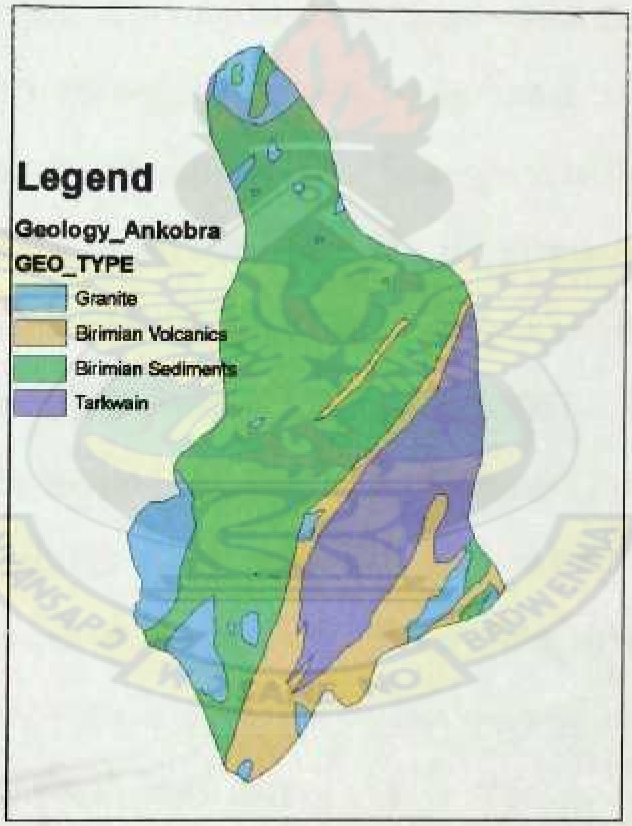


Figure 3.2 Geological map of Ankobra River Basin

Alluvial deposits occur in streams draining areas with auriferous deposits where the bedrock only is slightly metamorphosed and intruded by Dixcove granite particularly in Birimian rock areas.

Non-sulphidic paleo-placer ore occurs mainly in hard rock. It is particularly associated with Banket conglomerates of Tarkwa formation. Oxidized ore occurs in weathered rocks and is derived from sulphides, arsenopyrite, realgar (AsS), opiment (As_2S_3), pyrites etc (Kortatsi 2004).

3.3.1 The Birimian system

The Birimian system consists of a great thickness of isoclinally folded metamorphosed sediments intercalated with metamorphosed tuff and lava. Large masses of granite have also intruded the Birimian system (Dapaah-Siakwan and Gyau-Boakye, 2000). The Birimian system is largely folded. It is fissured to a larger extent compared to the Tarkwaian system. This system is divided into Birimian sediments and volcanics Series (Kortatsi, 2004). The sediments are predominant in the lower part of the system. These sediments have been metamorphosed to schist, slate and phyllite (Dapaah-Siakwan and Gyau-Boakye, 2000).

The upper part of the system is dominantly of volcanics and pyroclastic origin. The rocks consist of bedded groups of green lava. Lava and tuff dominate this part (Dapaah-Siakwan and Gyau-Boakye, 2000). Several bands of phyllite occur in this zone and are manganiferous in places. The thickest sequence occurs in Nsuta where manganese is being mined (Kortatsi 2004).

In the Birimian system, gold occurs in five parallel, more than 300km long, northeast trending volcanic belts. They are separated by basins containing pyroclastic and meta-sedimentary units. The gold occurrence is 2 to 30 ppm in quartz veins of laterally extensive major ore bodies. They deeply penetrate fissures and shear zones in contact between meta-sedimentary and meta-volcanic rocks. The veins consist of quartz with carbonate minerals, green sericite, carbonaceous partings and metallic sulphides and arsenides of Fe, As, Zn,Au, Cu, Sb and Pb (Dzigbodi Adjimah 1993).

The Birimian system has a higher content of heavy metals than the Tarkwaian system.

3.3.2 The Tarkwaian system

The Tarkwaian system is an elongated and narrow syncline about 250 km long and 16 km wide (Kortatsi, 2004). The system consists of slightly metamorphosed, shallow-water, sedimentary strata. It is chiefly sandstone, quartzite, shale and conglomerate and is resting on and derived from the Birimian system (Dapaah-Siakwan and Gyau-Boakye, 2000). Intrusive igneous rocks contribute to about 20% of the total thickness of the Tarkwaian System in the basin. These range from hypabyssal felsic to basic igneous rocks (Kuma, 2004). Granitoids of the Dixcove Granitoids systems has also intruded the Tarkwaian system in many places. The rocks of the Tarkwaian system consist of the Kawere Group, The Banket Series, the Tarkwa Phyllite and the Huni Sandstone. Table 3.1 shows the thickness and composition of the divisions of the Tarkwaian system. Most of the rocks that resemble sandstone at the surface are weathered equivalents of parent quartzites (Kuma & Younger 2001).

3.4 Hydrogeology

Groundwater is the main source of water supply in the study area. Most major towns in the area except from Tarkwa rely solely on groundwater. To match the demand for potable water the number of boreholes and hand dug wells are increasing rapidly. Surface water taken from the River Bonsa at Bonsaso is treated and distributed to

Tarkwa town and its environs. Some villages between Bonsaso and Tarkwa are also connected to the pipe (Nankara, 2004). Yield varies from 0.4-18 m^3h^{-1} with an average of 2.4 m^3h^{-1}.

The borehole depth varies between 18m to 75m with an average of 35.4m but has little or no effect on borehole yields (Kortatsi, 2004).

In the basin groundwater occurrence is associated with the development of secondary porosity through fissuring and weathering. The rock underlying the area lack primary porosity since they are consolidated. The weathering depth is greatest in the Birimian system where depths between 90m and 120 m have been reached. Also in granites, porhyrites, felsites and other intrusive rock the weathering depth is great. In the Tarkwaian system however, and especially in the Banket series quartzites, grits, conglomerates and Tarkwa phyllite, the weathering depth rarely exceed 20 m. Clay, silts, sandy clays and clayey sands are mostly the result of the weathering. In this area two types of aquifers occur. The weathered aquifer occurs mainly above the transition zone between fresh and weathered rock. Due to the soils content of clay and silt, these aquifers have high porosity and storage but low permeability. The aquifer in the fractured/fissured zone occurs below the transition zone. They have relatively high transmissivity but low storage (Kortatsi 2004).

The recharge of groundwater in the area occurs mainly by direct seepage or infiltration. In some places groundwater is in hydraulic contact with rivers and recharge from them can also take place.

Groundwater circulation in the study area is mainly localized due to the numerous low hills that act as groundwater divides. Groundwater circulation is mainly restricted to quartz veins and fissures-faults-brecciated zones. Groundwater velocities are not known. Low conductivity values of the groundwater in the area indicate that the water is unable to react with the rock matrix to equilibrium which indicates short resident times (Kortatsi, 2004).

Table 3-1: Division of the Tarkwaian system (Kuma & Younger, 2001)

Series	***Thickness (m)***	***Composite lithology***
Kawere Group	*250-700*	*Quartzites, grits, phyllites and conglomerates.*
Banket Series	*120-160*	*Tarkwa phyllite transitional beds and sandstones, quartzites, grits breccias and conglomerates.*
Tarkwa Phyllite	*120-400*	*Huni sandstone transitional beds, and greenish-grey phyllites and schists.*
Huni Sandstone	*1370*	*Sandstones, grits and quartizes with bands of phyllite*

CHAPTER FOUR

4.0 RESEARCH METHODOLOGY

The methodology used in the assessment of groundwater potential in the Ankobra river basin is divided into three main sections. These are:

- desk study
- field visit and data collection
- data analysis and interpretation

Brief explanation of these approaches and methodologies are given below.

4.1 Desk Study

Information on boreholes which have been drilled in the basin since 1980, were obtained from the offices of CWSA in Takoradi, GWCL Drilling Unit-Kumasi, Water Research Institute, Accra and Tarkwa-Nsuaem Municipal Assembly. Contractors and consultants on projects on groundwater development also provided information. Other relevant data such as hydrometeorological data, geological reports and maps, hydrogeological data and topographic maps were also collected and collated from both governmental and non-governmental organisations in Accra and Takoradi. The data and their sources from which they were obtained are as shown in Table 4.1.

4.2 Data Collection

During the field survey, visits were made to some of the beneficiary communities in the basin to locate their groundwater point sources. Where work was on-going, the process of pumping test, drilling logging and well depth and location measurement were observed.

4.3 Post Field Activities

The methodology adopted at the post fieldwork stage was divided into three phases namely Discharge data, hydrogeological (boreholes) approach, and water quality analyses.

Table 4.1: Data Collection Sources

Data	Sources
Hydrometeorological data (Rainfall and Temperature)	Ghana Meteorological Agency, Takoradi
Geological reports	Geological Survey Department, Accra
Hydrogeological data	Water Research Institute (WRI)– Accra, Ghana Water Company Limited (GWCL), Geohydrotech Consult– Kumasi, Kingaka Construction LTD– Accra Geocore and Environmental Services–Accra and the Municipal Assembly–Tarkwa-Nsuaem
Topographic maps	Survey Department, Kumasi
Other related literature	Libraries and the Internet

4.4 Hydrogeological Data Analysis

The borehole locations tracked during the field visits were plotted using software Arc GIS. Borehole parameters such as well depths, static water level (SWL), dynamic water level (DWL), yield and geological logs were obtained from hydrogeological reports from the basin. The boreholes were then grouped according to the various geological formations with the aid of the drilling logs.

For each formation, the ranges of the borehole parameters were determined. The specific capacity where possible was computed using the relation below (Fetter, 2001).

$$Sc = Q/S \qquad 4.1$$

where,

Sc = Specific capacity in $m^3/h/m$

Q = Discharge in m^3/h

S = Drawdown in (m)

To determine aquifer characteristics for the formations in the study area pumping test data were analysed. Time verses drawdown curves were plotted for each well and Cooper and Jacob method used to determine the aquifer characteristics for the four major geological formations with the aid of a spread sheet (Appendix C). This method has been simplified as shown below.

$$T = 0.183Q/\Delta s \qquad 4.2$$

where T = Transmissivity in m^2/day; Q = Discharge in m^3/day; Δs = Drawdown per log cycle for pumping test from semi-log plots (m).

4.5 Determination of Hydrogeological Potential

Because groundwater is a precious resource, the question of how much there is and how more can be made available are important. There are many terms and concepts associated with the quantity of groundwater available in a basin, this section discusses some of the more common terms used to represent groundwater quantity in Ankobra basin.

4.5.1 Total Groundwater Storage

Groundwater can be seen as how much reserve is underlying a given area. The total groundwater storage in the Ankobra basin was determined using the following formula model after Schoeller, 1967.

$$Q_t = \alpha \theta H A \qquad 4.3$$

$$Q_r = \alpha \gamma H A \qquad 4.4$$

where, Qt = total groundwater storage, (m^3); Qr = recoverable groundwater storage (m^3); α = percentage of study area underlain by groundwater zone; γ = specific yield, ($m^3/h/m$); θ = porosity (%); H = mean thickness of the saturated zone, (m); A = extent of the study area, (m^2).

4.5.2 Recoverable Groundwater Storage

Recoverable or usable storage capacity is the amount of groundwater that can be sustainably withdrawn from a basin as a source of long term annual supply. It was computed using equation (4.1). A brief description of how the parameters for estimating both the total and recoverable storage is given section (4.2).

4.6 Determination of Baseflow (Hydrograph Separation)

For the determination of baseflow, streamflow data at the Prestea gauging station was used. The data had gaps. Gap infilling method applied was drainage area ratio method (reference). Where the data gaps were more than 1 year, that data set was ignored. Mean monthly discharge was then computed from the filled data and a hydrograph drawn. The baseflow was then determined from the hydrograph using the straight line method: a straight line was drawn from the point where the hydrograph begun to rise (rising limb) to the point where discharge reached the same point again on the falling limb. Two perpendicular lines are drawn from the recession limb and the rising limb to the time axis. The area enclosed by the polygon is calculated as the baseflow.

4.7 Groundwater Quality Analysis

Groundwater availability does not only depend on its quantity, its quality is also a matter of great concern. Reports on water quality were collected from Community Water and Sanitation Agency in Takoradi and Water Research Institute, Accra. The reports were analysed comparing the parameters tested against WHO and Ghana Standard Board.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Boreholes in the geologic formations

Granite, Birimian Sediments and Birimian Volcanics and Tarkwaian are the four major geological formations identified in the Ankobra River Basin. The distribution of the boreholes in these formations is shown in the figure 5.1. Available records show that about 344 boreholes exist in the study area. Out of these, 35.17% were drilled in the granites, 25.58% in the Birimian Sediment and 21.51 % in the Birimian Volcanics. The boreholes are not fairly distributed in the basin, considering the aereal extent of the various formations in the basin, due to the nature of settlement of the communities.

5.2 Aquifers

Usually, lateritic clay and/or soft or silt clay layers (aquitards) of thickness ranging from 1 to 27m were encountered at most sites in the granites and Birimian sediments extending from south - eastern through eastern to the northern part of the study area. Weathered and/or fractured granite, schist, tuff and phyllite are present beneath these aquitards, which underlay the second aquitard. Thus, groundwater in the basin exists under confined and semi-confined conditions. This is justified by the fact that water levels in the boreholes rise several meters above the levels at which water was struck (Table 5.2).

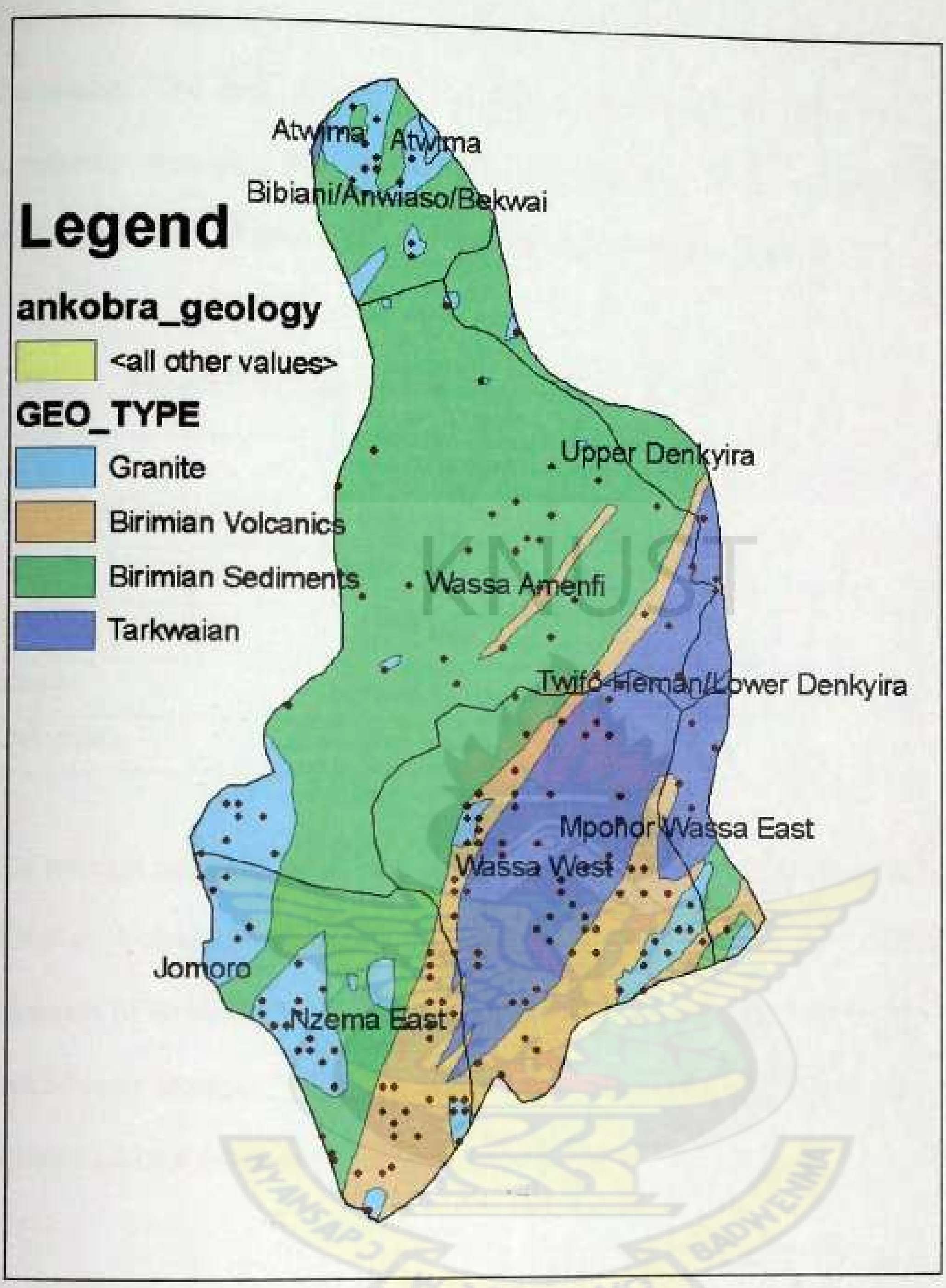


Figure 5.1: Borehole locations map in the Ankobra river basin

5.3 Saturation Zone

Weathering process helps to facilitates movement and accumulation of water in the weathered zone. Weathering profiles observed from borehole drilling reports in the basin revealed that the depth of weathering varies greatly in the various formations

(Table 5.1). The lowest value of 0.0m was recorded in both the Granite and Tarkwaian. The rock is near the surface or it outcrop at Kesekrom, Akrumasi, Kunkunso, Ayawura, Praso and Ebi river shelterbelt forest reserve. The highest saturated zone of 63.86m was in the Birimian Sediments at Jamang.

Table 5.1: Summary of Saturation Zone in Ankobra Basin

Geological Formation	Saturation Zone (m)	
	Range	Mean
Birimian Volcanics	0.20-46.27	16.67
Birimian Sediments	0.32-63.86	22.2
Granite	0.00-42.39	11.23
Tarkwaian	0.00-42.80	13.89

The average saturation thickness in the granites, Tarkwaian, Birimian Sediment and Birimian Volcanics were 11.23m, 13.89m, 22.2m and 16.67m respectively. The thickness of weathered zone facilitates water accumulation which eventually leads to groundwater storage. The aquifer dimensions which defined the saturated thickness determined how much water that could be supplied to a well.

5.3.1 Borehole Depths

Generally borehole depths relate to the zone or suspected saturation, i.e. the lowest level that groundwater can occur. The range of borehole depth in the four geological formations in the study area is shown in Table 5.2. Available data on boreholes revealed that the Birimian Volcanics rock record the shallowest depth of 16m at Yamiriwa whiles the deepest well depths of 80m occurred at Mahamamo in the granite and with a mean value of 42.37m. Most boreholes are drilled for domestic rural water supply and therefore the drilling can be stopped whenever water is encountered. The boreholes do not fully penetrate the aquifer and therefore in severe drought some are likely to dry up and affect groundwater withdrawal.

Table 5.2: Summary of borehole depths in the study area

Geological Formation	No of Boreholes Analysed	Range of Depth (m)	Mean Depth (m)
Birimian Volcanics	74	16-62	35.88
Birimian Sediments	88	23-79	40.16
Granites	121	18-80	42.37
Tarkwaian	61	21-62	36.49

5.3.2 Static Water Level

The static water level (SWL) is the level of groundwater in equilibrium with atmospheric pressure in the casing of a well when no water is being abstracted from the aquifer. In the study area the static water levels ranges from 0.0 to 41.30m. A summary of static water levels and their perspective formations is shown in Table 5.3 Generally, the static water level rise above the overburden and also above the depth at which the water was strike. This shows that the aquifers are semi-confined or confined.

5.3.3 Borehole Yields

The yield of a well is simply interpreted as the maximum possible sustainable pumping rate compatible with the stability of the supply from the aquifer (Freeze and

Cherry, 1979). It is an important hydrogeological parameter which can be used with other factors to determine the groundwater storage potential of an area. The boreholes yield in the basin is shown in Table 5.4.

Table 5.3: Summary of Static Water Level in Ankobra Basin

Geological Formation	Static Water Level (m)	
	Range	Mean
Birimian Volcanics	1.34-17.97	6.54
Birimian Sediments	1.44-24.47	8.22
Granite	0.58-41.30	9.27
Tarkwaian	0.00-29.67	6.63

The Birimian Sediments and Birimian Volcanics formation have the highest yielding boreholes ranging from 0.9 to 18m3/h, 0.72 to 18.0m^3/h. This is followed by the Tarkwaian which has yield ranging from 0.36 to 7.20m^3/h, whereas the minimum and maximum productive wells in the granite are 0.24 to 6.0m^3/h respectively.

Table 5.4: Summary of Borehole Yields in the Basin

Geological Formation	Borehole Yield (m^3/h)	
	Range	Mean
Birimian Volcanics	0.72-18.0	3.74
Birimian Sediments	0.90-18.0	6.31
Granite	0.24-6.0	2.20
Tarkwaian	0.36-7.20	2.13

A plot of the borehole yields in the various geological formations (figure 5:2) in the basin indicates that high yielding borehole is concentrated within the Birimian sediments and volcanics whiles low yielding borehole is equally widespread in the basin. The map gives an indication of areas where productive borehole could be exploited.

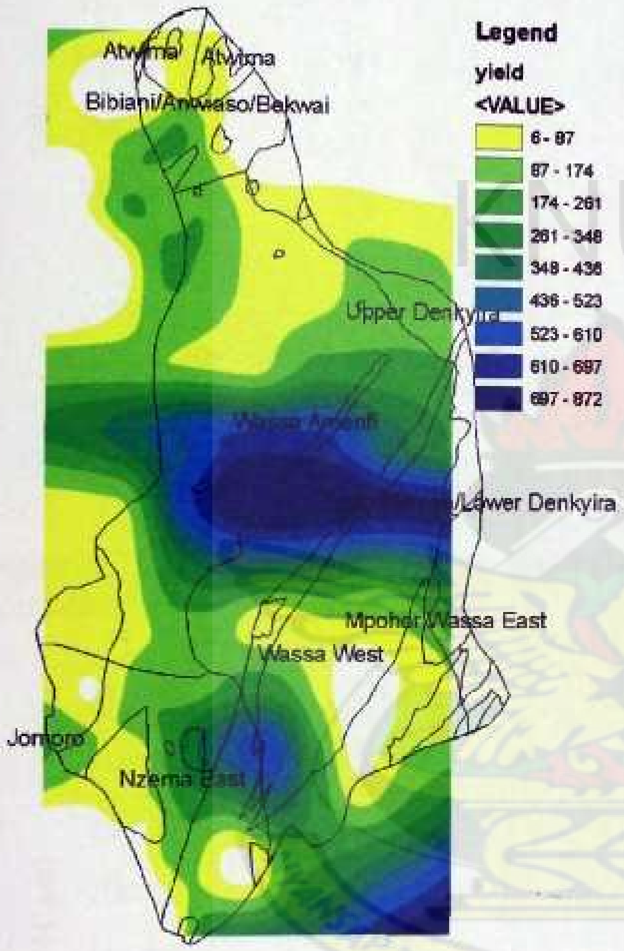


Figure 5.2: Borehole Yields in the Ankobra River Basin

5.3.4 Relationship Between Borehole Depth and Yield

According to Kortatsi (2004), the hydrogeology of the Ankobra basin is controlled by secondary porosities, the deeper the borehole, the higher the probability that it will intercept a lot of fissures and consequently the higher the yield. A plot of borehole yield against borehole depth (Fig. 5.3a, b, c, and d), however has shown no discernible picture since some boreholes as shallow as 25m has yield above $18.0m^3h^{-1}$ while others as deep as 80m has yields less than $4.0m^3h^{-1}$.

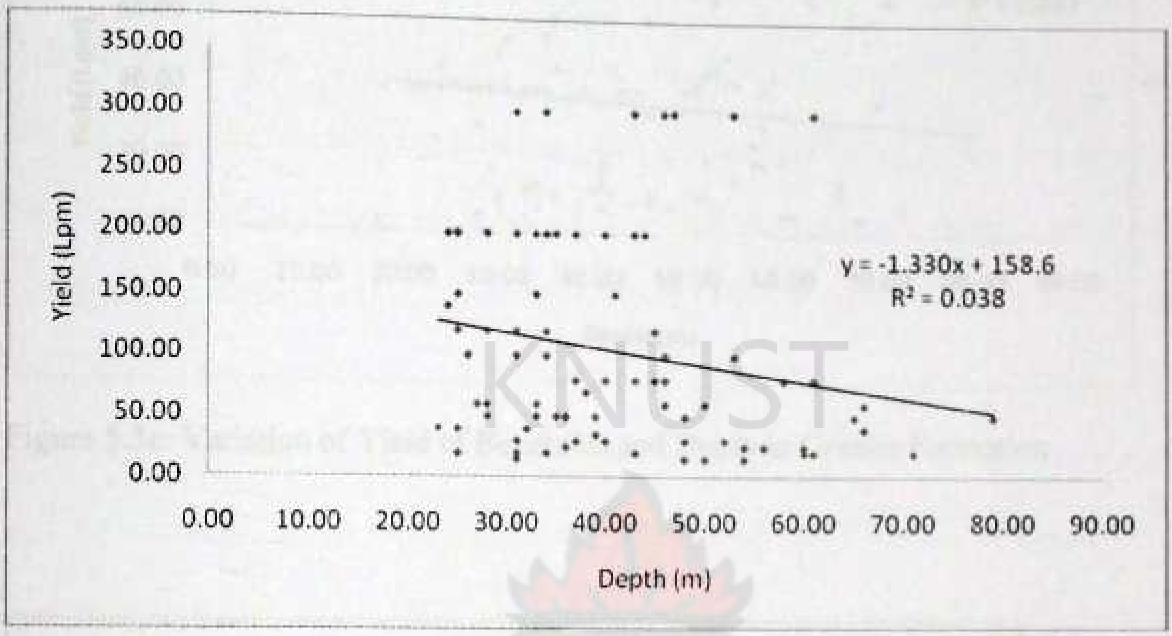


Figure 5.3a: Variation of Yield of Boreholes and Depth in Birimian Sediments Formation

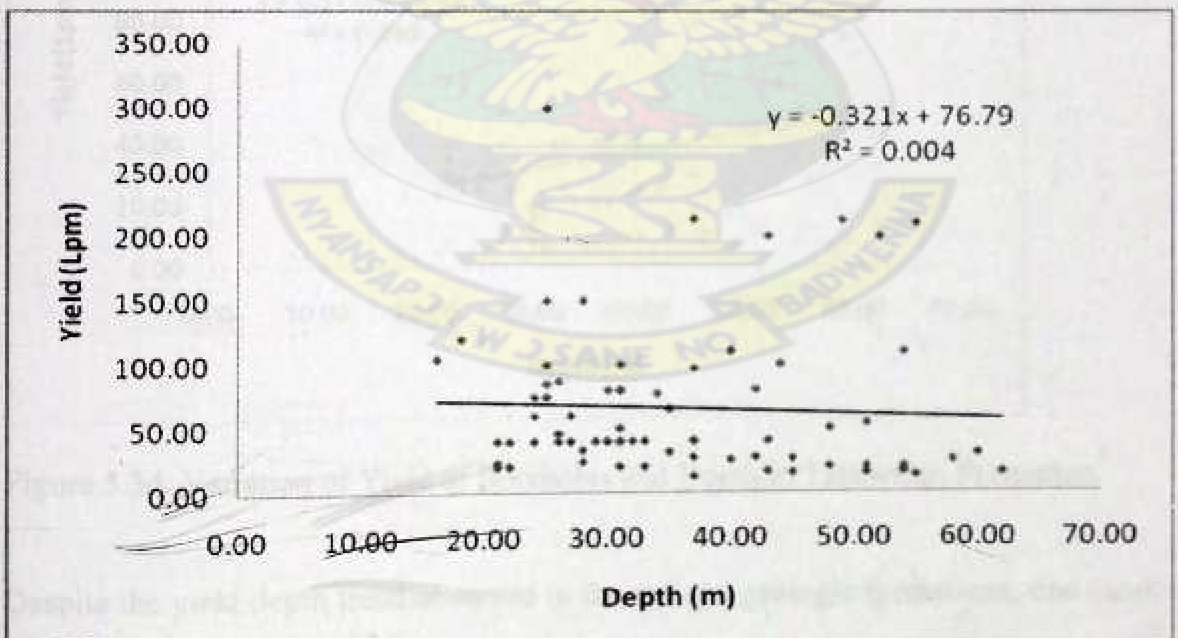


Figure 5.3b: Variation of Yield of Boreholes and Depth in Birimian Volcanics Formation

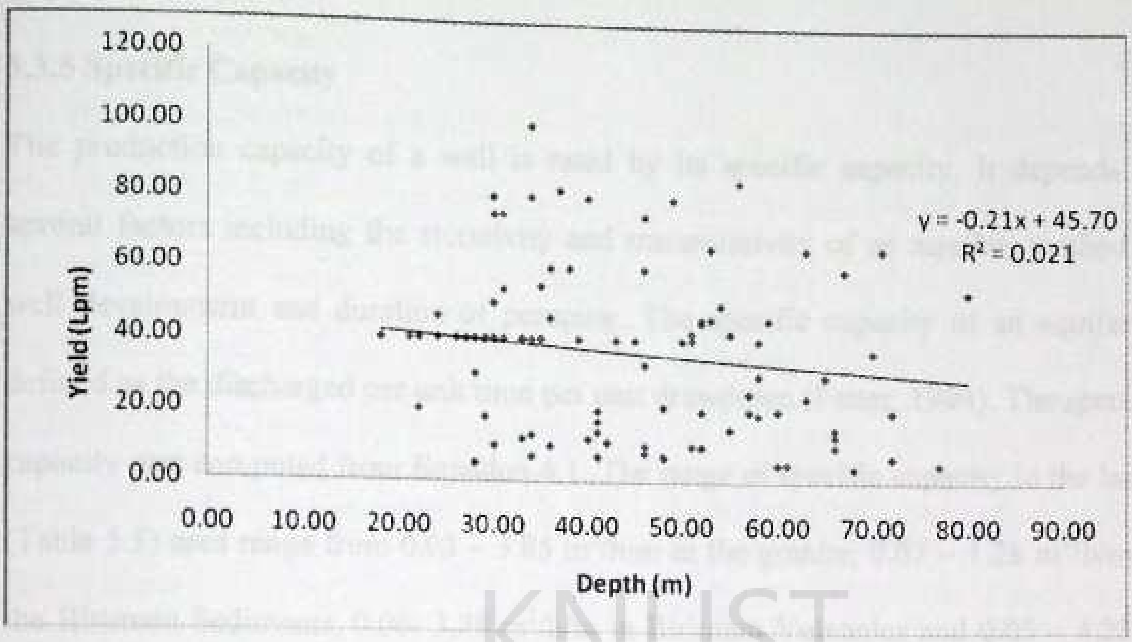


Figure 5.3c: Variation of Yield of Boreholes and Depth in Granite Formation

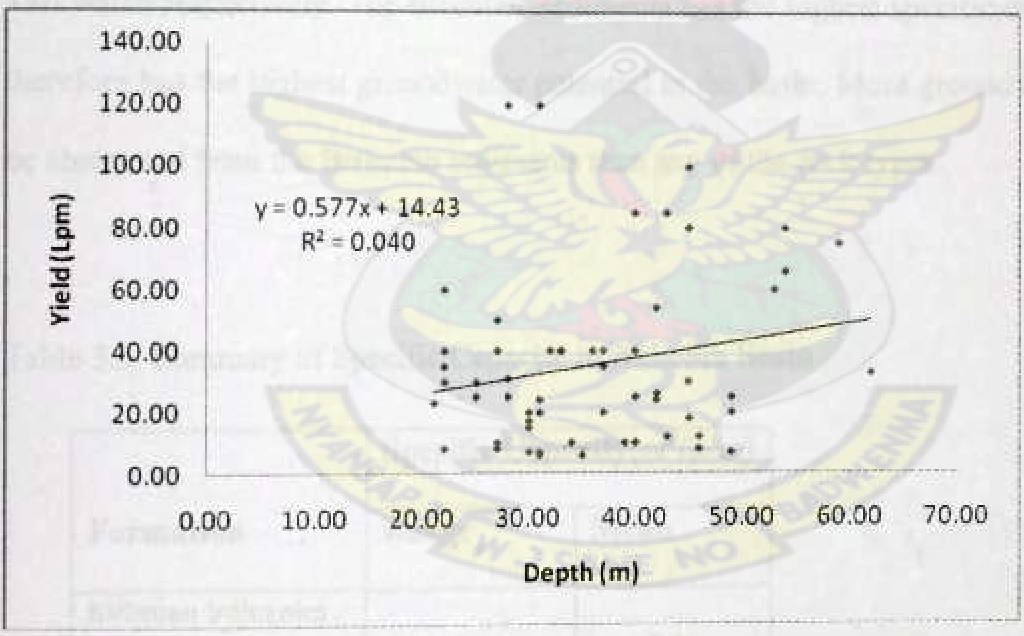


Figure 5.3d: Variation of Yield of Boreholes and Depth in Tarkwaian Formation

Despite the yield-depth trend observed in the various geologic formations, one cannot draw justifiable conclusion from them due to the small magnitude of the correlation coefficient between the two parameters for four of the geological formations, namely; Birimian Sediments, Birimian Volcanics, Tarkwaian and Granite respectively.

5.3.5 Specific Capacity

The production capacity of a well is rated by its specific capacity. It depends on several factors including the storativity and transmissivity of an aquifer, method of well development and duration of pumping. The specific capacity of an aquifer is defined as the discharged per unit time per unit drawdown (Fetter, 1994). The specific capacity was computed from Equation 4.1. The range of specific capacity in the basin (Table 5.5) area range from 0.03 – 3.85 m^3/h/m in the granite, 0.07 – 1.28 m^3/h/m in the Birimain Sediments, 0.06- 3.28 m^3/h/m in Birimain Volcanics and 0.05 – 4.25 in Tarkwaian. The mean specific capacities are 0.12 m^3/h/m, 0.24 m^3/h/m, 0.30 m^3/h/m and 0.11 m^3/h/m for the Granites, the Birimain Volcanics, Birimain Sediments and Tarkwaian respectively. The Birimian Sediments has the highest specific capacity and therefore has the highest groundwater potential in the basin. More groundwater could be abstracted from the Birimian sediments than any of the rock types.

Table 5.5: Summary of Specific Capacity in Ankobra Basin

Formation	Specific Capacity(m^3/h/m)	
	Range	**Mean**
Birimian Volcanics	0.06 -3.28	0.24
Birimian Sediment	0.07 -1.28	0.30
Granites	0.03 – 3.85	0.12
Tarkwaian	0.05 -4.25	0.11

5.4 Groundwater Storage

The aquifers in the regolith are produced in poorly to moderately decomposed rocks. The mean saturated thicknesses of the poorly to moderately weathered rock (aquifer horizon) are; 16.67m, 22.20m, 11.23m and 13.89m for Birimian Volcanics, Birimian Sediments, Granite and Tarkwaian respectively. Adopting porosity from similar basin characteristics of the aquifer materials (the poorly to moderately decomposed rocks) are 35.3 % to 40.1%, Asomaning (1993). These are in Table 5.6. The Ankobra basin has an approximate area of 8400 km^2. The total groundwater in reserve is equal to $4.58 \times 10^9 m^3$. The recoverable or sustainable groundwater in temporary storage is equal to $2.94 \times 10^9 m^3$. The latter could be described as groundwater in the temporary storage forms 64% of the total groundwater reserves. The difference in groundwater reserve is attributable to groundwater abstractions, groundwater contribution to streamflow (baseflow) and springs.

Table 5.6: Values of Parameters used to Determine Groundwater Storage

Study Area (Ankobra River Basin)	Areal Extent Km^2	% of Study area underlain by zone of saturation*	Mean Thickness of Saturated zone (m)	Mean Specific Capacity ($m^3/h/m$)	Mean Porosity of Saturated zone (%) '
Birimian Volcanics	1208.95	77	16.67	0.24	40.1
Birimian Sediments	4584.36	75	22.2	0.30	39.8
Granite	948.99	65	11.23	0.12	35.3
Tarkwaian	1527.95	83	13.89	0.11	38.5

*CWSA

'Asomaning, 1992

Table 5.7: Computed values of total groundwater volume and recoverable groundwater storage

Study Area (Ankobra River Basin)	Total Groundwater Volume $X10^9m^3$	Recoverable Groundwater Volume $X10^9m^3$	Quantity of Recoverable Groundwater Storage as % of Total Groundwater Volume
Birimian Volcanics	6.21	3.72	59.90
Birimian Sediments	30.38	22.90	75.38
Granite	2.45	0.83	33.88
Tarkwain	6.78	1.94	28.61

Table 5.8: Summary of Total Groundwater in storage

PARAMETER	STORAGE ($10^9 m^3$)
TOTAL GROUNDWATER STORAGE	45.82
RECOVERABLE GROUNDWATER	29.39

5.5 Groundwater Contribution to Streamflow

Ankobra river is based principally on groundwater contribution (Kortatsi,2004).

The hydrograph gave two peak discharges which occurred in June and October. The value thus obtained for the baseflow is 13.75m^3/s (figure 5.4).

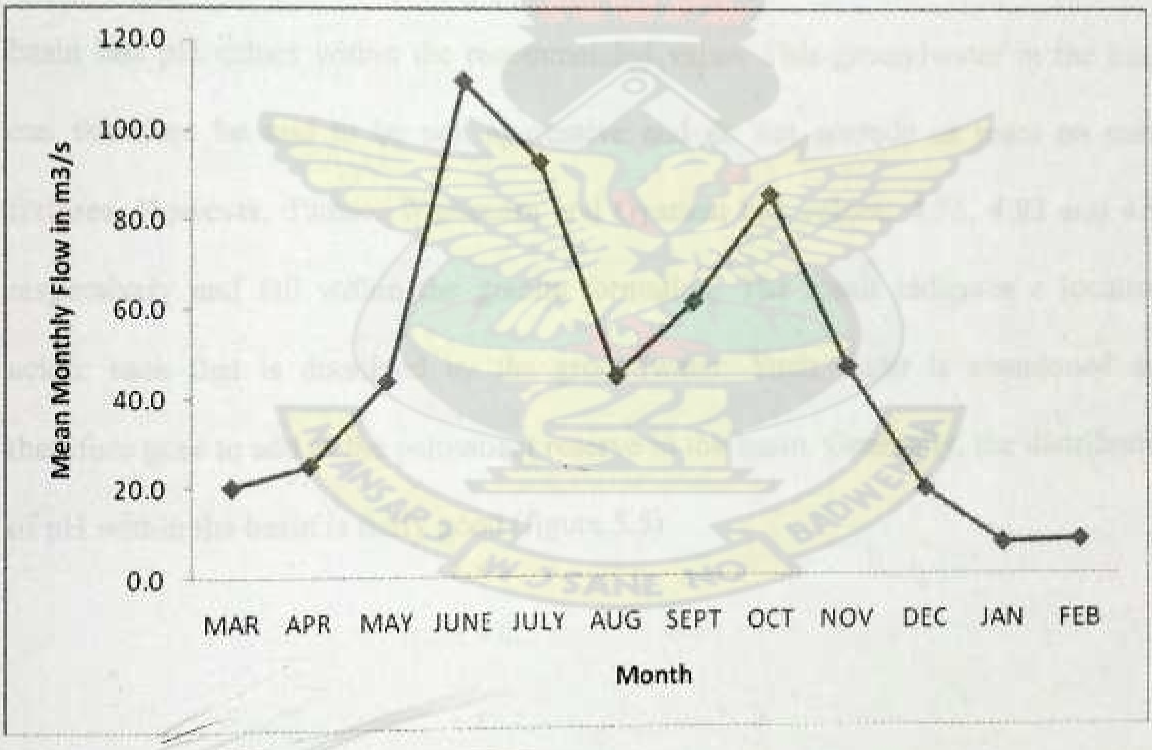


Figure 5.4: Hydrograph Separation on Ankobra River at Prestea Gauging Station

5.6 Water Quality

Water quality is a measure of the suitability of water for its particular use. The water quality standard adopted for this project is that of the Ghana Standard Board and where this was not available WHO guidelines were resorted to. The results from water quality analysis shows that values for most of the parameters analyzed fall within acceptable limits of the Ghana Standard Board (GSB) recommendations for potable drinking water except the following:

- **pH**

The recommended pH value by the Ghana Standard Board for potable drinking water is between the range of 6.5 and 8.5. Water from most of the borehole sample in the basin had pH values within the recommended value. This groundwater in the basin can therefore be said to be non aggressive and do not corrode or react on metal fixtures. However, Tamso. Wantenem and Gyaman had values: 4.75, 4.92 and 4.92 respectively and fall within the granite formation. The result indicates a localised acidic rock that is dissolved by the groundwater. Such water is abandoned and therefore goes to add to the permanent reserve in the basin. Generally, the distribution of pH within the basin is fairly good (figure 5.5)

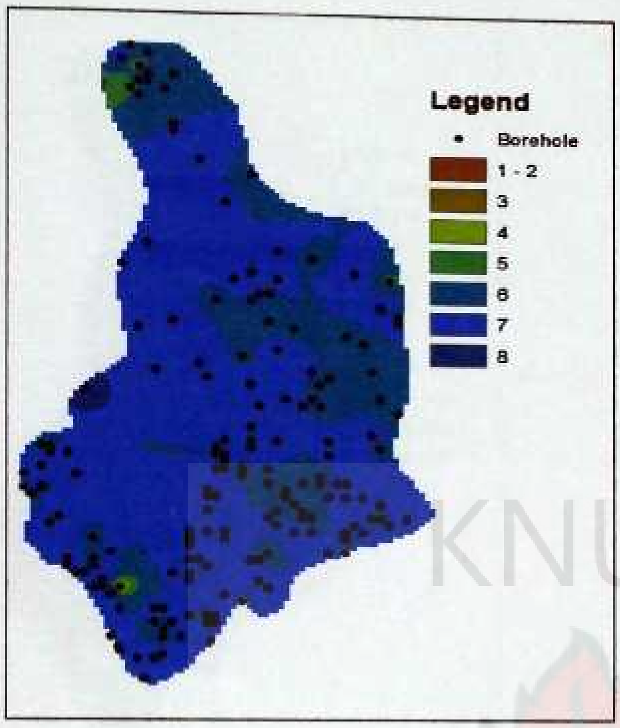


Figure 5.5: Distribution of pH in the Ankobra basin

- **Total Hardness**

All the water sampled had hardness within the acceptable limit of 500 mg/1 of Ghana Standard Board recommended standard. The highest value of 260 mg/1 was recorded at Twifo Mampong whilst the lowest value of 14mg/I was recorded at Tamso. All samples analyzed had values below 140 mg/l.

- **Chloride**

WHO guideline value for chloride in drinking water is 250mg/l. All the Analyses indicate satisfactory results except Beyin and Bokazo communities recorded 600mg/l and 730mg/l chloride are distributed within the Birimian sediments and Birimian Volcanics in the basin (figure 5.6).

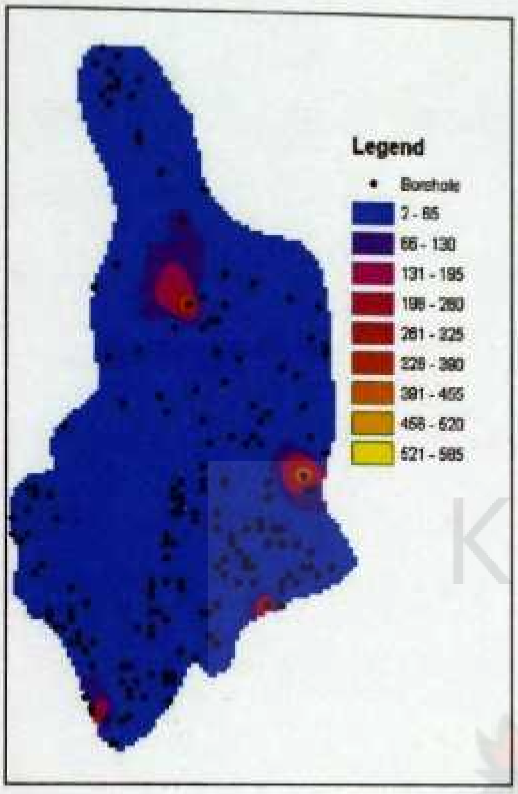


Figure 5.6: Distribution of Chloride in Ankobra basin

- **Colour**

The presence of colour in water in not objectionable from health point of view, but may spoil the colour of clothes being washed in such waters, and also objectionable from aesthetic and psychological point of view, as people may not like to drink coloured water. Majority of the water sampled fall within recommended value of 15Hz by GSB, however, Jedua, Anyimabrim and Odumasi had values of 25Hz, 20Hz and 25Hz respectively and therefore not satisfactory for human consumption. This may be as result of over disturbance of the weathering zone during drilling which has a lot of clayey material.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

- The groundwater potential in the basin is $45.82x10^9m^3$ and recoverable groundwater storage in the Ankobra river basin is $29.39x10^9m^3$ which translates into 64% of water that could be abstracted for use. The Birimian Sediments and Volcanics formations within the basin have high yields and could be exploited. Hydrogeologist prospecting for groundwater in the basin should concentrate on these two formations.

- The Ankobra River is mainly due to baseflow ($13.75m^3/s$) in the dry season and therefore the importance of baseflow contribution cannot be overemphasized.

- Water quality analyses from boreholes in the Ankobra River Basin showed that values for most physico-chemical parameters analysed fall within the acceptable limits of the GSB for drinking water standard and are satisfactory for human consumption. pH and chloride values, however for some communities: Gyaman in Birimian Sediment, Wantenem in Tarkwaian and Beyin in Granite exceeded the GSB's recommended values of 6.5-8.5 and 250mg/l respectively for drinking water.

6.2 Recommendations

- Some of the boreholes in the basin have shallow static water level and depth to aquifer hence little soil cover, and will therefore provide little or no attenuation to contaminant migrating from runoff. It is therefore recommended that a study be carried out to assess the risk of groundwater pollution in the basin.

- Groundwater exploitation should be such that its over-exploitation, pollution and negative ecological effects should be reduced to a minimum to ensure its economic efficiency of exploitation.

- Groundwater monitoring wells should be drilled and automatic data loggers (divers) installed to measure water levels and quality in the basin.

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APPENDICES

Appendix .A: Hydrogeological data of Birimian Sediments Formation

COMMUNITY	Overburden (m)	Depth (m)	Yield (Lpm)	SWL (m)	DWL (m)	Pumping Rate (l/min)	X	Y	Specific Capacity (l/min/m)	Thickness of the Saturation Zone(m)
Bomapkole	48	48.00	15.00	6.46	17.99	5.00	-2.33	5.00	0.434	41.54
Bomapkole	48	48.00	15.00	6.46	17.99	5.00	-2.33	5.00	0.434	41.54
Domiabra	18	31.00	15.00	9.54	16.25	12.00	-2.07	5.87	1.788	8.46
Domiabra	18	31.00	15.00	9.54	16.25	12.00	-2.07	5.87	1.788	8.46
Ankasi	54	54.00	15.00	9.84	16.09	8.00	-2.27	5.93	1.280	44.16
Ankasi	54	54.00	15.00	9.84	16.09	8.00	-2.27	5.93	1.280	44.16
Anyimabrim	27	50.00	15.00	12.07	18.25	10.00	-2.22	5.75	1.618	14.93
Anyimabrim	27	50.00	15.00	12.07	18.25	10.00	-2.22	5.75	1.618	14.93
Jamang	12	31.00	20.00	3.51	9.82	13.00	-2.03	5.82	2.060	8.49
Jamang	12	31.00	20.00	3.51	9.82	13.00	-2.03	5.82	2.060	8.49
Hiawa	34	34.00	20.00	3.70	10.58	9.00	-2.15	5.62	1.308	30.30
Hiawa	34	34.00	20.00	3.70	10.58	9.00	-2.15	5.62	1.308	30.30
Adina	27	43.00	20.00	6.07	13.36	16.00	-2.08	5.67	2.195	20.93
Adina	27	43.00	20.00	6.07	13.36	16.00	-2.08	5.67	2.195	20.93
Ashienso	28	61.00	20.00	7.95	14.10	7.00	-1.98	5.73	1.138	20.05
Ashienso	28	61.00	20.00	7.95	14.10	7.00	-1.98	5.73	1.138	20.05
Moseaso	51	71.00	20.00	8.22	16.03	15.00	-2.03	5.75	1.921	42.78
Moseaso	51	71.00	20.00	8.22	16.03	15.00	-2.03	5.75	1.921	42.78
Domiabra	15	25.00	20.00	9.55	13.60	20.00	-2.07	5.87	4.938	5.45
Domiabra	15	25.00	20.00	9.55	13.60	20.00	-2.07	5.87	4.938	5.45
Gyapa Amfi	60	60.00	20.00	16.39	20.90	8.00	-2.02	5.85	1.774	43.61
GyapaAmafi	60	60.00	20.00	16.39	20.90	8.00	-2.02	5.85	1.774	43.61
Samang	29	36.00	25.00	10.27	13.83	24.00	-2.13	5.80	6.742	18.73

Appendix B: Hydrogeological data of Birimian Volcanics Formation

COMMUNITY	Overburden (m)	Depth (m)	Yield (l/min)	SWL (m)	DWL (m)	Pumping Rate (l/min)	X	Y	Specific Capacity (l/min/m)	Thickness of the Saturation Zone (m)
Bepoase	28	29.00	40.00	3.84	4.36	40.00	-2.15	5.33	76.92	24.16
Bogoso	27	43.00	200.00	12.29	15.30	200.00	-2.02	5.55	66.45	14.71
Chamso	21	21.00	40.00	4.80	5.43	40.00	-2.05	5.13	63.49	16.20
Simpa	14	25.00	300.00	5.29	10.30	300.00	-2.12	5.10	59.88	8.71
Chrobo	30	33.00	40.00	5.23	5.96	40.00	-2.25	5.07	54.79	24.77
Mpeasem	5	28.00	150.00	4.66	7.40	150.00	-2.08	5.48	54.74	0.34
Mpeasem	9	18.00	120.00	5.50	7.86	120.00	-2.08	5.48	50.85	3.50
Biriwa	14	27.00	40.00	6.75	7.57	40.00	-1.85	5.33	48.78	7.25
Bojuri	30	52.00	200.00	12.51	16.87	200.00	-2.12	5.42	45.87	17.49
Adasan	25	49.00	212.00	3.46	8.47	212.00	-2.22	5.03	42.32	21.54
Adamso	21	37.00	213.00	3.23	8.69	213.00	-2.17	5.05	39.01	17.77
Abrodiem	25	44.00	100.00	2.43	5.30	100.00	-2.18	5.18	34.84	22.57
Wuwuoso	15	31.00	80.00	14.80	17.49	80.00	-1.88	5.72	29.74	0.20
Simpa	15	25.00	150.00	2.40	7.57	150.00	-2.12	5.10	29.01	12.60
Bepoasi	10	27.00	40.00	5.25	6.64	40.00	-2.15	5.33	28.78	4.75
Abalebo	16	26.00	87.00	1.34	4.93	87.00	-2.22	5.03	24.23	14.66
Bogoso	27	43.00	200.00	12.29	15.30	70.00	-2.02	5.55	23.256	14.71
Brumasi	15	25.00	100.00	5.07	10.02	100.00	-2.12	5.47	20.20	9.93
Mpeasem	5	28.00	150.00	4.66	7.40	54.00	-2.08	5.48	19.708	0.34
Mpeyo	30	55.00	210.00	11.65	22.31	210.00	-1.85	5.45	19.70	18.35
Wiawso	20	31.00	50.00	14.44	17.09	50.00	-2.18	5.25	18.87	5.56
Ebokro	21	31.00	80.00	4.19	8.49	80.00	-2.20	5.00	18.60	16.81
Yamiriwa	16	16.00	105.00	3.04	8.95	105.00	-1.90	5.37	17.77	12.96

Appendix C: Hydrogeological data of Granite Formation

COMMUNITY	Overburden (m)	Depth (m)	Yield (Lpm)	SWL (m)	DWL (m)	Pumping Rate (Lpm)	X	Y	Specific Capacity (l/min/m)	Thickness of the Saturation Zone (m)
Mwianaw	20.00	68.00	4.00	7.48	19.83	4.00	-2.30	6.30	0.324	12.52
Sukusuku	33.00	77.00	5.00	2.56	31.42	5.00	-2.15	5.03	0.173	30.44
Ananekrom	34.00	61.00	5.00	3.47	25.13	5.00	-2.07	6.10	0.231	30.53
Kwabadu	16.00	28.00	5.00	10.15	20.12	5.00	-2.12	5.43	0.502	5.85
Muhamamo	24.00	60.00	5.00	18.24	21.95	5.00	-1.88	5.23	1.348	5.76
Tonsuosim	14.00	34.00	7.00	3.88	11.25	7.00	-2.17	6.13	0.950	10.12
Domenebo Number 1	23.00	41.00	7.00	5.61	24.85	7.00	-2.27	6.38	0.364	17.39
Brahababum	34.00	41.00	7.00	5.61	24.85	7.00	-2.27	6.33	0.364	28.39
Twinsisim	19.00	34.00	7.00	5.70	9.67	7.00	-2.17	6.13	1.763	13.30
Subri	22.00	48.00	7.00	7.50	22.04	7.00	-2.28	6.28	0.481	14.50
Muanu	17.00	72.00	7.00	11.88	24.94	7.00	-2.30	6.30	0.536	5.12
Himan	18.00	48.00	7.00	11.90	17.65	7.00	-2.13	5.45	1.217	6.10
Anwiawso	20.00	46.00	8.00	10.91	20.45	8.00	-2.27	6.33	0.839	9.09
Muano	24.00	66.00	10.00	5.04	14.19	10.00	-2.30	6.30	1.093	18.96
Mwonaw	24.00	46.00	10.00	6.10	14.78	10.00	-2.28	6.28	1.152	17.90
Adubrim	13.00	30.00	10.00	6.41	13.67	10.00	-2.33	5.10	1.377	6.59
Pataboso	30.00	52.00	10.00	6.65	16.39	10.00	-2.28	6.32	1.027	23.35
Nhwinisuraw	23.00	51.00	10.00	7.26	11.37	10.00	-2.43	5.28	2.433	15.74
Patabosso	14.00	36.00	10.00	9.90	17.61	10.00	-2.28	6.32	1.297	4.10
Praso	13.00	42.00	11.00	16.88	20.40	11.00	-2.27	6.33	3.125	
Bonsaso	20.00	33.00	12.00	4.00	23.76	12.00	-1.83	5.28	0.607	16.00
Tanoso	28.00	40.00	12.00	16.13	24.06	12.00	-2.27	6.33	1.513	11.87
Mawnaw	15.00	66.00	13.00	7.54	20.86	13.00	-2.28	6.28	0.976	7.46

Appendix D: Hydrogeological data of Tarkwaian Formation

COMMUNITY	Overburden(m)	Depth (m) (m)	Yield (Lpm)	SWL (m)	DWL (m)	Pumping Rate (Lpm)	X	Y	Specific Capacity (l/m/m)	Thickness of the saturation zone (m)
Opon Valley	14.00	31.00	6.00	1.78	7.16	6.00	-1.85	5.70	1.115	12.22
Subri	32.00	35.00	6.00	2.42	9.31	6.00	-1.82	5.45	0.871	29.58
Bodiabawu	14.00	31.00	7.00	2.88	7.54	7.00	-2.07	5.18	1.502	11.12
Tuwuhufu	19.00	30.00	7.00	3.70	11.13	7.00	-1.97	5.55	0.942	15.30
Aboso	15.00	49.00	7.00	12.30	17.57	7.00	-1.93	5.37	1.328	2.70
Sumahu	18.00	27.00	8.00	4.41	10.21	8.00	-2.00	5.35	1.379	13.59
Opong Valley	8.00	22.00	8.00	5.50	9.94	8.00	-1.85	5.70	1.802	2.50
Tamso	34.00	46.00	8.00	6.76	13.57	5.00	-2.02	5.27	0.734	27.24
Banso	21.00	34.00	10.00	3.48	6.44	9.00	-1.97	5.28	3.041	17.52
Bompeaso	36.00	39.00	10.00	4.54	9.29	10.00	-1.92	5.43	2.105	31.46
Bonsa	24.00	34.00	10.00	5.92	10.60	10.00	-2.05	5.18	2.137	18.08
Huni Shaft Cpd	7.00	27.00	10.00	7.16	12.63	10.00	-1.97	5.37	1.828	
Abenakrom	12.00	40.00	10.00	8.18	12.60	10.00	-1.97	5.37	2.262	3.82
Yakwakrom	22.00	40.00	10.00	12.14	16.02	10.00	-1.97	5.30	2.577	9.86
Beni	9.00	43.00	12.00	3.72	9.33	12.00	-1.83	5.48	2.139	5.28
Abontuakun	25.00	46.00	12.00	11.50	15.16	12.00	-1.98	5.32	3.279	13.50
Mpenkro	13.00	30.00	15.00	3.66	10.36	15.00	-2.03	5.40	2.239	9.34
Huni Valley	20.00	30.00	17.00	7.05	14.65	17.00	-1.92	5.47	2.237	12.95
Subri	30.00	45.00	18.00	3.85	9.86	18.00	-1.78	5.53	2.995	26.15
Yaokrom	6.00	31.00	20.00	2.12	6.96	20.00	-1.83	5.63	4.132	3.88
Tamso	9.00	37.00	20.00	3.23	8.12	12.00	-2.02	5.27	2.454	5.77
Tamso	7.00	49.00	20.00	3.48	8.47	12.00	-2.02	5.27	2.405	3.52
Besiasi	30.00	30.00	20.00	4.76	10.97	20.00	-1.78	5.75	3.221	25.24

Appendix E: Streamflow Data at Prestea Gauging Station (m^3/s)

YEAR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB
1959-60	8.01	33.43	128.32	110.82	147.70	6.97	32.56	139.86	58.13	16.02	10.58	9.07
1960-61	19.04	84.11	41.33	146.55	97.16	42.25	19.32	54.38	25.17	7.50	2.49	0.36
1961-62	6.47	14.34	9.24	52.75	165.76	25.87	26.88	108.28	35.14	15.57	3.19	13.89
1962-63	23.16	19.99	67.37	158.56	119.17	58.41	20.89	121.13	102.23	62.52	15.29	18.26
1963-64	29.74	22.32	33.07	66.14	147.36	103.54	166.66	240.55	56.08	25.56	20.86	7.25
1964-65	13.52	19.26	42.00	118.75	74.20	21.28	17.64	49.00	19.38	19.21	4.76	16.55
1965-66	17.33	16.91	35.84	114.63	164.28	70.31	91.48	98.67	30.44	12.15	3.05	6.02
1966-67	3.36	17.64	26.04	115.19	102.06	111.44	128.80	85.65	60.20	14.73	1.12	5.60
1967-68	26.32	35.84	23.52	183.12	61.46	8.12	28.45	48.66	40.85	10.39	9.24	8.46
1968-69	17.36	26.49	29.46	182.56	247.16	284.12	353.16	207.45	81.00	41.13	20.16	14.06
1969-70	24.30	31.84	63.98	137.98	86.55	29.79	16.60	45.02	74.56	17.08	6.58	5.29
1970-71	30.77	50.60	104.27	137.12	34.27	22.43	64.82	91.84	84.34	24.78	9.13	3.89
1971-72	11.09	25.20	20.78	47.26	67.98	27.16	26.66	39.17	18.23	13.75	2.35	4.17
1972-73	9.52	19.24	36.79	116.20	60.26	31.36	20.41	44.32	3.36	12.07	5.10	5.77
1973-74	6.24	15.76	16.86	6.30	43.96	42.98	78.06	51.72	22.71	9.77	3.11	8.18
1974-75	12.85	12.54	53.09	77.36	104.97	66.89	124.01	53.23	29.82	8.93	4.23	11.03
1975-76	13.05	15.01	44.35	69.30	156.94	32.17	14.48	46.06	34.89	25.70	4.93	8.09
1976-77	6.89	14.31	56.84	189.73	50.06	18.96	8.76	12.46	33.94	7.56	4.23	3.28
1977-78	6.61	10.39	8.32	58.10	9.10	14.42	8.26	29.82	10.47	5.91	0.98	8.29
1978-79	4.62	20.47	34.02	158.00	18.82	9.86	19.21	27.10	15.04	7.34	4.96	3.28
1979-80	11.45	5.01	28.08	90.58	108.89	52.64	189.39	153.86	85.06	23.21	10.14	5.15
1980-81	24.25	25.42	63.36	155.04	60.62	54.07	122.81	206.39	48.80	22.18	6.19	4.51
1989-90	0.53	3.50	9.80	47.74	78.65	56.87	73.11	92.40	27.86	9.10	2.58	2.21
1990-91	4.54	11.34	22.32	51.18	44.38	12.10	49.17	54.09	27.08	27.50	8.74	6.75
1991-92	6.41	17.36	70.81	73.92	110.26	44.77	26.29	23.13	17.50	7.59	4.56	14.22
1992-93	31.61	19.10	21.36	37.16	17.47	5.52	13.66	25.26	25.09	10.14	3.50	5.12
1993-94	12.77	33.99	11.79	73.67	58.86	15.01	38.75	93.38	25.45	14.03	6.52	4.87