ADDIS ABABA UNIVERSITY

COLLAGE OF NATURAL SCIENCES

SCHOOL OF EARTH SCIENCE

AQUIFER CHARACTERIZATION OF ASSOSA AREA, BENISHANGUL-GUMUZ REGIONAL STATE, WESTERN ETHIOPIA

A Thesis submitted to The School of Graduate Studies in Partial Fulfillment of the Requirements for the Master of Science Degree in Hydrogeology.

BY *GADISA BEKELE*

Advisor: *Dr. Seifu Kebede*

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AQUIFER CHARACTERIZATION OF ASSOSA TOWN, BENISHANGUL-GUMUZ REGIONAL STATE, WESTERN ETHIOPIA

BY GADISA BEKELE

HYDROGEOLOGY STREAM

Approved by Board of Examiners

Dr. Seifu Kebede	___________	___________
Advisor	signature	date
Prof. Tenalem Ayenew	_________	_________
Internal Examiner	signature	date
Dr.Dessei Nedaw	__________	_________
Internal Examiner	signature	date
Dr. Balemewal Atnafu	___________	_________
Chairman, School of Earth sciences	signature	date

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Acronyms

AD	Afar Depressions
ANS	Arabian Nubian-Shield
ASU	Assosa University
BGRS	Benishangul-Gumuz Regional State
BH	Bore Hole
ECSA	Ethiopian Central Statistical Agency
FAO	Food and Agricultural Organization
GSE	Geological Survey of Ethiopia
M.a.s.l	Meter above Sea Level
MER	Main Ethiopian Rift
MWR	Ministry of Water Resource
NMSA	National Meteorological Sendee Agency
PWL	Pumping Water Level
SWL	Static Water Level
WES	Western Ethiopian Shield

Abstract

This study assessed in Assosa catchment of Benishangul Gumuz Regional State, Western Ethiopia which is aimed to characterize Assosa Town ground water systems with the help of different methods and approaches that includes desk review of hydrogeological and geological map of the region, pumping test data and the collected data has been analyzed with the help of different software applications like Aquifer test 2011.1, ArcGIS 10.1, Global Mapper16, Surfer10, Strater Demo 4 and Microsoft Excel. The study area comprises different rock units like basalt, basement outcrops, and quaternary sediments; and geological structures which was the reason for the formation of different landforms, primary and secondary permeability with porosity that contributes significant role on the aquifer properties. Aquifers developed in the area is due to secondary processes and in similar fashion, degree of variations in the groundwater productivity is mainly linked with extent of differences in the effect of these processes in the rocks. Hydrodynamic analyses of the catchment aquifers reveal that, hydraulic conductivity is ranged from 0.0677 to 1.544 m/d with a mean value of 0.59 m/d and for that of transmisivity it ranged from 2.76 to 44.3 m^2/d with a mean value of 18.993 m^2/d; from these hydraulic parameters and geomorphologic set up and geologic units of the area, the determined potentiality degree of the catchment aquifer is classified as moderately productive fissured aquifer, low productive fissured aquifer and aquitards/ aquicludes. Generally, the study area is mostly covered by crystalline basement rocks (hard rocks) which is regionally known to be called aquicludes; therefore, site selection for ground water investigation needs a very care full attentions due to less existence of secondary structures that enables ground water formation.

Keywords: - Groundwater, Aquifer, Assosa catchment, Pumping test, Hydraulic conductivity, Transmisivity, Ethiopia.

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is essence food and the basic component of life. The need for water is strongly ascending and has diversified purpose, which is not only important for drinking purpose but also vital for any development activities. It is the most essential resource affecting municipal, agricultural and economic activities. Any development is related either directly or indirectly to water utilization. But it becomes more complex due to population growth, urbanization and industrialization. More than 98% of the available global fresh water is ground water (Fetter, 1994), which is one of the most precious resources that nature has provided and occurs under the ground in rock unit (s).

Groundwater potential in Ethiopia is low compared to surface water resources. But, the total exploitable groundwater potential is high. Current estimates put the available groundwater resources in the country to be about 2.6 billion m^3 (Ministry of Water Resource, 2001). It is a precious and most widely distributed resource of the earth. Unlikely any other mineral resource, it gets in annual replacement from the meteoric insight. Many of us depend on ground water for our very existence.

Several methods are available in groundwater for the evaluation and estimation of the hydraulic characteristics of aquifers, like transmisivity, hydraulic conductivity, and Storativity. The most commonly used methods involve conducting pumping tests followed by analysis and interpretation of pumping test data. However, it should be appreciated that such tests are capital and labour intensive, requiring several boreholes, many operatives, and a considerable amount of equipment. Furthermore, the estimation of hydraulic conductivity is crucial for the reliable simulation of the groundwater flow of one aquifer.

As Lohman (1972), states aquifer is an underground layer of water-bearing permeable rocks or unconsolidated materials from which groundwater can be extracted using water well. Aquifer characterization takes into account how the different geological formations get a water-bearing nature; how the arrangement of these water-bearing geological formations with adjacent impervious layer looks like and the potentiality nature of the aquifer (Sen, 1995; Nedaw, 2003).

An aquifer in a given area could be a basement rocks origin depending on the degree of interconnection of fractures, joints, and the prevailing hydrogeological condition; Alamerew et al. (2003). According to Tesfaye Chernet (1993), occurrence of groundwater in basement terrain is limited to zones of fracturing and weathering. Successful identification of these groundwater bearing geologic layers requires application of different techniques and methods. The characterization may require the use of existing pumping test data, geologic map, hydrogeological map, soil map, and lithology obtained from well logs, aquifer thickness as well as well inventory (Singhal and Gupta, 1999; Matthess, 1982).

The study area is underlain by basement rocks; and found within Abbay basin, where intermittent and ephemeral streams are common. It is very close to Ethiopian-Sudan border and also near to Ethiopian Grand hydroelectric dam construction and with elevations that ranges from 1500 to 2000m above sea level and the topography is moderately undulating (go up and down gracefully) with flat plan. The local hydrogeology of the study area is mainly influenced by topography & geology of the area; due to these ground water hydrogeology in the volcanic and basement rocks are contained in the weathered, Fractured & in thick unconsolidated sediments. Therefore researcher tried to characterize the aquifer of the study area based on the pumping test of the well from different sites of the area. The regional ground water system recharge is depending up on annual precipitation, surface run off and seasonal rivers.

1.2 Objectives of the study

1.2.1 General Objectives

The overall aim of the research programme is to characterize Assosa Town ground water systems.

1.2.2 Specific Objectives

- ✓ Characterization of aquifer systems and aquifer units in the study area
- ✓ Understanding the hydrogeology of the area provide with classification of water bearing layers based on qualitative and quantitative parameters.

- ✓ Determine hydraulic properties of Aquifer like Transmisivity and Hydraulic conductivity from the pumping test data.

1.3 Significance of the study

There are different findings/out puts/ from this research. The following are some of it:-

- ➢ Be helpful to planners in the development and management of aquifer Characterization and aquifer related works in the study area.
- ➢ Be essential to propose the mechanism of sustaining and obtaining the maximum benefit from the aquifer(s) in a given terrain i.e. without affecting the aquifers.
- ➢ Use full for Earth science students, researchers and research institution such as universities they can gain empirical evidence from the research work.

1.4. Methodology

To achieve the general and specific objectives written above, the methods and approaches conducted are pre-field, field work and post fields. Different activities that undertaken are desk review of hydro geological (1:250,000 scale) and geological map (1:50,000 scale), and topographic sheet analysis at office level. Borehole data collected from different bureaus at regional level and Ministry of Water Resources that concerned to the study area. According to the data that collected from Assosa town Water supply and sewerage Enterprise, there are about twenty two (22) wells that were drilled since 1977-2003 E.C and out of them six wells are nonfunctional and nonproductive and rest sixty (16) wells are productive; however from these sixty boreholes, about thirteen (13) boreholes haven't written document like lithologic well log data and pumping test data. Due to this, from the total twenty two (22) boreholes, the well those with lithologic well log data and pumping test data are only three wells; two wells from Selga site which give all serves for the population of Assosa town and one well from Assosa University that provide potable water for communities of the University. In the catchment, due to the unavailability of piezometer data, pumping data were collected from the pumping well itself which is analyzed using Neuman curve fitting method; also general views of the study area observed in addition to collecting data from various sectors. Field assessment of geological formations, hydro geological settings, geological structures, digenetic features and processes leading to porosity and permeability has been observed. At the end data collected from field survey and desk level has been analyzed with the help of different soft wares like Aquifer test 2011.1, ArcGIS 10.1, Global Mapper16, Surfer10, Strater Demo 4 and other computer codes to make easy of bulk data management and to facilitate the analysis, and interpretation of results. Generally, for this study, these methods are employed in order to achieve the objectives of this research.

1.5 Previous work

Some studies were undertaken on the study area and in general on the Western Ethiopia in different approaches which includes:

There are a number of previous work were done regional wise on related topic with my present study. For instance; the first regional hydro geological study that encompasses the study area is the hydro geological map of Ethiopia by Tesfaye Chernet (1993). According to the above statement this map (scale 1:2,000,000) rock units in the western Ethiopia are classified into three hydrogeologic units. Namely: the Precambrian basement classified as regional aquicludes, the Wollega basalt having moderate permeability and productivity and unconsolidated sediments consisting of alluvium, elluvium, collivium and lacus- trine, which are classified as extensive aquifers with intergranular permeability.

Besides, the hydro geological map of Assosa-Kurmuk sheet by Alamerew et al. (2003) is also another regional hydro-geological work that includes the present study area. According to this work, the rock units within the study area are classified into two hydrogeologic units. Namely: (1) the moderately productive fractured aquifers that incorporate the alkaline olivine basalt exposed as pockets within the study area and (2) the dominant basement unit that cover most of the study area and classified as low productive fissured aquifer. The basement unit exposed in the study area consists of Precambrian stratified rocks (Amphibolites and quartzofeldspathic schist, metasediments and quartzofeld- spathic and graphitic schist) and Precambrian intrusive rocks (metagranodiorite and metagranite). The porous aquifers which developed locally along intermittent stream valley and at the base of mountains are mentioned to be not mapable at the scale of 1:250,000.

As Tamiru Alemayehu (2006) discussed, the classification of the igneous and metamorphic rocks of Ethiopia including those in western Ethiopia as hard rocks that are devoid of primary water bearing structures. According to this work, groundwater occurrence and movement in hard rocks takes place along open fracture system and in upper weathered mantle. Recharge in hard rocks dominantly takes place from streams where the open fractures cross or closely follow the surface water channel/course or through the weathered pervious portion of the unit. Moreover, Tamiru Alemayehu (2006) has described that the groundwater in basement terrain of Ethiopia is characterized by regionally extended aquifer in near surface zone. In the same work the author identified geological and physiographic features that are important for groundwater occurrence and movement in basement rock namely;

• Major and minor fracture zones or lineation resistant topographic troughs or ridges that do not confirm to the regional trends,

• Contact zones between two or more rock types,

• Features such as pegmatite, dikes which frequently contain zones of low permeability or highly fractured zones of high permeability,

• Zones of regolith

In addition to the above previous work, the Benishangul Gumuz regional water bureau also described the local geology, mineralogy, degree of weathering and fracturing, vegetation conditions and used as criteria to locate water well drilling sites for communities residing in the study area. Generally, concerning the study area, there is a shortage of previous work done except the above works.

1.6 Problem Identification

Regarding the aquifer characteristics of the study area, number of Hydrogeologists have been undertaken researches and investigations. According to the Hydrogeological map of Asosa-Kurmuk sheet by Alamerew et al. (2003), the rock units within the study area are classified into two hydrogeologic units; namely (1) the moderately productive fractured aquifers that incorporate the alkaline olivine basalt exposed as pockets within the study area and (2) the dominant basement unit that cover most of the study area and classified as low productive fissured aquifer. Also as hydro geological map of Ethiopia by Tesfaye Chernet (1993), the Precambrian basement classified as regional aquicludes. Since the study area is located beneath the hard rocks environment /or basement area there are some limitations within the area.

Based on this, in hard rocks the main problem for the hydrogeologist is that, the absence of the primary porosity and to undertake ground water exploration is to find the fracture pattern within a maximum storage capacity. Another huge problem in hard rock is also to know that, where the recharge is takes place and ground water occurrence. Therefore, parameters to be considered are:

_Fractures information like opening fractures, frequency of fracture and origin of fractures that play great role for ground water formation.

_ Hydrogeological and geological structures that makes ground water formations.

_Hydrology, Hydrogeology and Geology information of the catchment.

_Weathering information that enables precipitations to infiltrate to ground and suitable for ground water formations.

_Geomorphology and rainfall of the study area are also another essential parameters that to be considered.

1.7. Research Structure

This research paper includes chapter six (6). Chapter one deals about introduction, objectives of the research, Significance of the study, Research Methodology; Previous work, Problem Identification, this Research Structure it self and chapter two expresses about description of the study area, like Location and Accessibility, Physiography and drainage, Climate of the Area, Temperature, Runoff, Mean monthly and annual flows, Hydrology, Soil and Vegetation cover, Demographics and socio-economics. Chapter three tells about Geology and chapter four states about Hydrogeology like; Hydrogeological Classification /Characterization/, Aquifer Classification of the Area ,Ground Water Potential (Aquifer Potential), Aspects of Ground Water Recharge and Discharge ,Ground water Flow System and Water Points of the Area. Chapter five defines about Result and Discussions that include Aquifer Parameters from Pumping Test Data like, Hydraulic conductivity, Transmisivity, and Storage coefficient (Storativity) etc. And the end chapter discussed with two terms; both Conclusions and Recommendations. References and annexes are also written next to chapter six respectively.

CHAPTER TWO

Description of the Study Area

2.1. Location and Accessibility

Assosa town is the capital of Benishangul Gumuz Regional State (BGRS), which is one of the nine regional states comprising the Ethiopian federal structure. According to information obtained from municipality of the town, Assosa is a town founded in 1984, which is located in western extreme part of Ethiopia about 687km from Addis Ababa in Benishangul Gumuz Regional State**.** So, the town could be taken as one of the border towns in the country and located at 90 km away from the Ethio-Sudanese border. It is situated on a flat plane at an average altitude of 1,550 m.a.s.l (MWR, 2001). The town geographically located between 10° 00' and 10°03' north and between 34°35' to 34°39' east and lies on an area of about 982.5 hec. It is surrounded by resettlement villages: in the North by Amba 8, in the South by Amba 38 and Amba 3, in the East by Amba 4 and in the West Komosha town (National Urban Planning Institute, 1995: 12). The area can be accessed through ground and air transportation. The ground access is via Ambo- Nekemte-Gimbi-Nejo-Mendi-Bambasi and then to the study area (Assosa). The road from Addis Ababa to Assosa is partly asphalt.

Assosa town is located in the 'Kola' climatic zone. It has mean maximum and minimum temperatures of 30.6C° and 15.8C° respectively. The maximum temperature varies between 28.5C° to 30.6C°; while the minimum shuttles between 15.8C° to 18.9C°. The maximum temperature occurs in February. The rainy season extends from April to November, but the maximum rainfall occurs in summer season (i.e. between June and August).

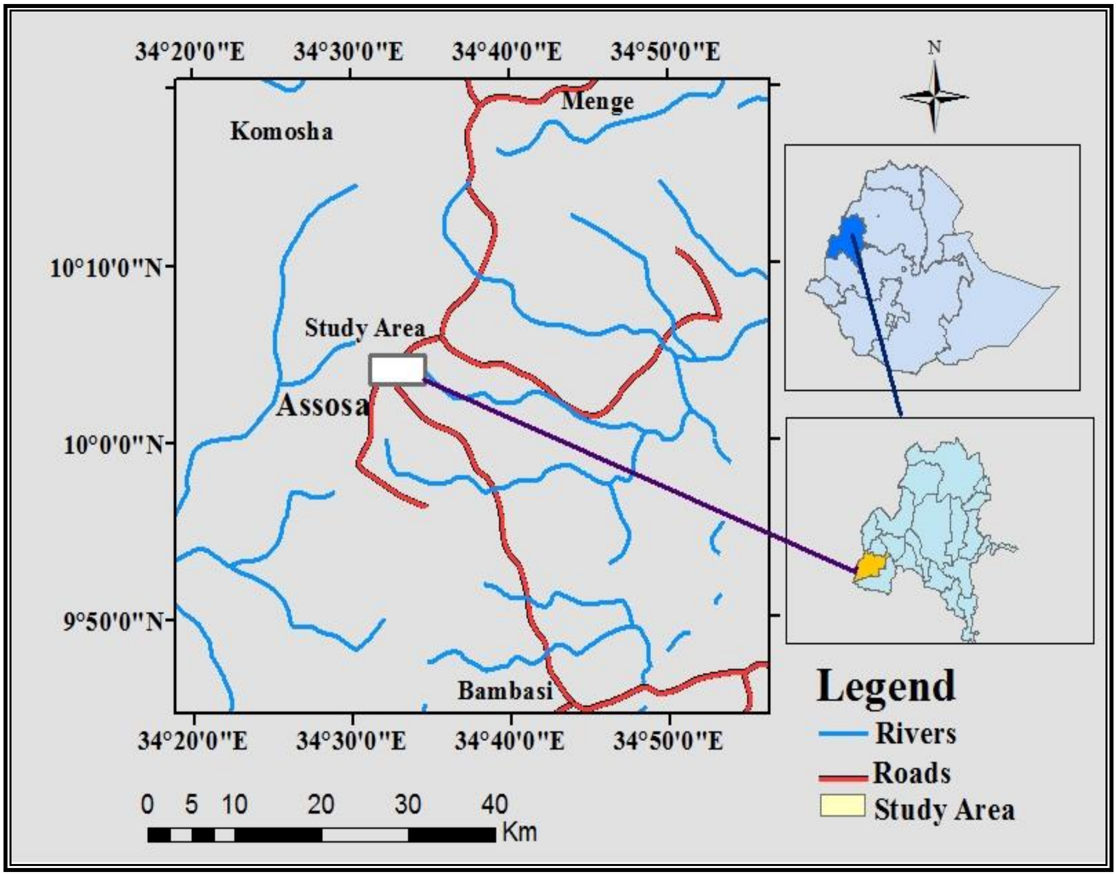


Figure 2. 1 Location map of the study area

2.2 Physiography and drainage of the Area

Ethiopia can be divided in to four major physiographic regions, widely known as the western plateau, southeastern plateau, the Main Ethiopian Rift (MER) and the Afar Depression (AD). From this four major physiographic regions, the study area is located at western plateau; which its geomorphology is an outcome of repeated tectonism, with associated intrusion and erosion. The drainage density and pattern are also partly or wholly controlled by the tectonic activity and geological variation in the area. This drainage density is higher in the relatively elevated areas especially when the weathered section is thick or when the pattern of structures crossing the rocks are higher. The region characterized by a variable land escape, narrower flat plain following stream line at some places surrounded by relatively high lands and moderate to hilly slopes. The main geomorphologic features of the area can be grouped as follows:

2.2.1 Volcanic Plain

A flat plain land with rolling landform covered by basalt in rocks characterizes some part of the Assosa and its surroundings. The trap series lay uncomformably on the Precambrian rocks in the catchment, and it is texturally hard aphanitic basalt with some plagioclase phenocryst is observed in the area. In the lowlands, relatively wider river channels are found. Some these rivers are Afa River, Hoha River, Selga River those are the tributaries of the Dabus River which the biggest river near to the area and it drains toward northeast to join the Blue Nile. These river channels and tectonized terrains form the lowest or flat lying areas and Assosa town itself located on this flat plain landform.

2.2.2 Ridges and Isolated Hills

The granitoids form a relatively high relief standing above the plain. Most of the hills and ridges formed are due to this formation. In general, narrow deep to shallow gorges are found in the highland. The granitoids form a relatively high relief standing among the plain, noticeably visible in the south of Assosa at Inzi area.

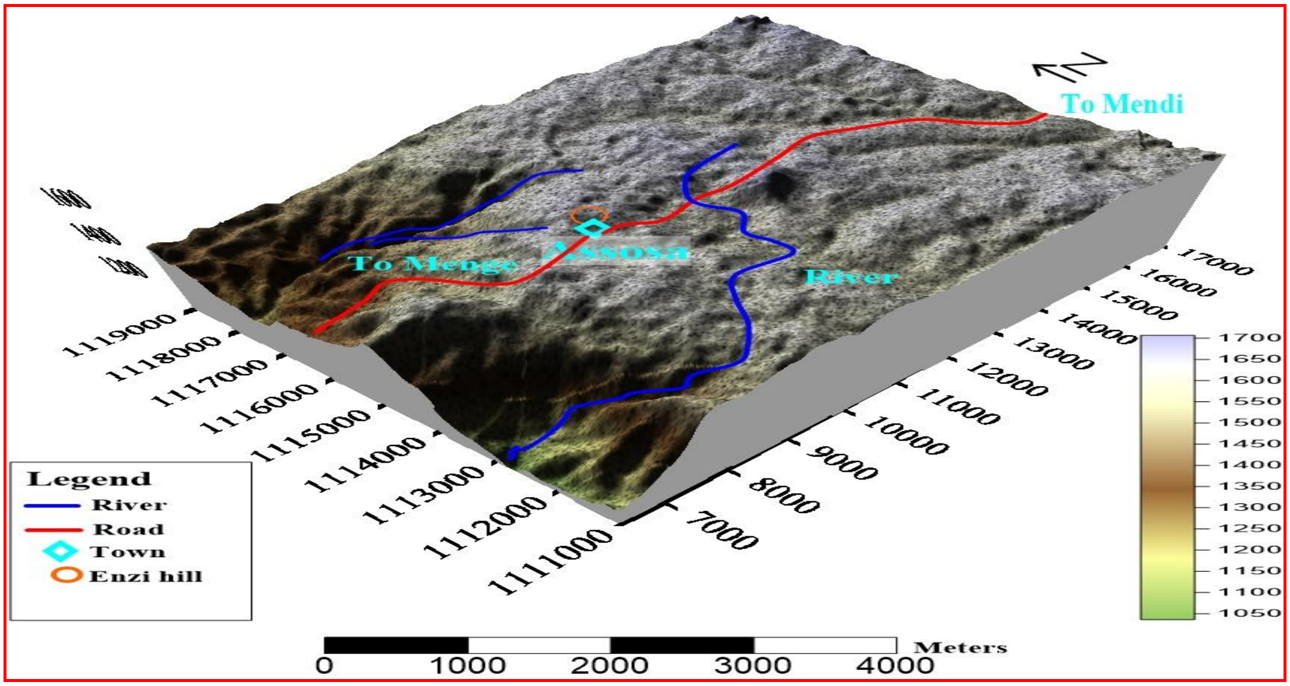


Figure 2.2 Physiographic map of the study area

2.3. Climatic Condition of the Area

2.3.1 Seasonality of Rainfall in the study area

Precipitation is the most commonly measured meteorological data. Rainfall records of one station are used to analyze monthly mean rainfall, mean annual rainfall, rainfall coefficient and areal depth of precipitation. The areal pattern of the seasonality of rainfall in the study area determined by analyzing long term mean monthly rainfall data for one station in the study area. The mean monthly and annual mean rainfall as recorded by National Meteorological Sonde Agency (NMSA) at the station Assosa are shown in below (table 2.1) and figure (2.3) below.

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual total	Mean monthly
Assosa	0.4	4.3	24	58.6	143.9	190.8	217.6	225.3	225.3	117.2	20.0	1.2	1258.6	104.9

Table 2.1 Mean Monthly rainfall in Assosa station (mm)

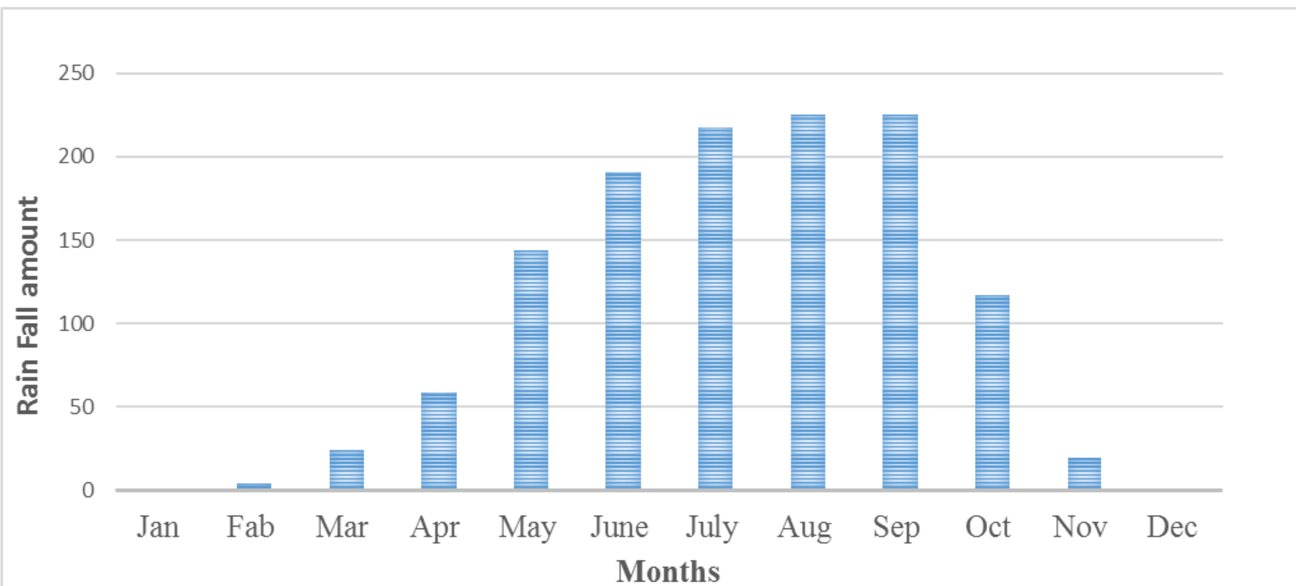


Figure 2. 3 Mean Monthly rainfall of Assosa station

2.3.2 Temperature

In the study area, as in all other places of Ethiopia, the altitude of the sun is always high, making solar radiation intense. Temperature is high during the day and is considerably reduced at night causing the daily range of temperature to be large. The mean maximum temperature of Assosa town varies between 28.5C° to 30.6C° and the mean minimum temperature varies between 15.8 C° to 18.9C°. More than 75% of the state is classified as 'Kola' (law lands) which is below 1500m a.s.l. The maximum and minimum temperature data for Assosa stations for the years (2009-2015) are available and mean monthly temperature has been done as shown below graphically. The data shows that lowest temperature occurred in year 2012 and 2014, in the months of December and November while the minimum occurred in year 2009 and 2010 during the months of January, February and March. Variation of the mean monthly temperature is described below.

	Years						
	2009	2010	2011	2012	2013	2014	2015
Mean Maximum Temperature (C°)	30.6	30.6	29	30.2	30.5	28.5	30
Mean Minimum Temperature(C°)	17.1	18.9	16.6	15.8	17.6	16.3	18.1

Table 2.2 Maximum and Minimum Temperature of Assosa Town (2009-2015)

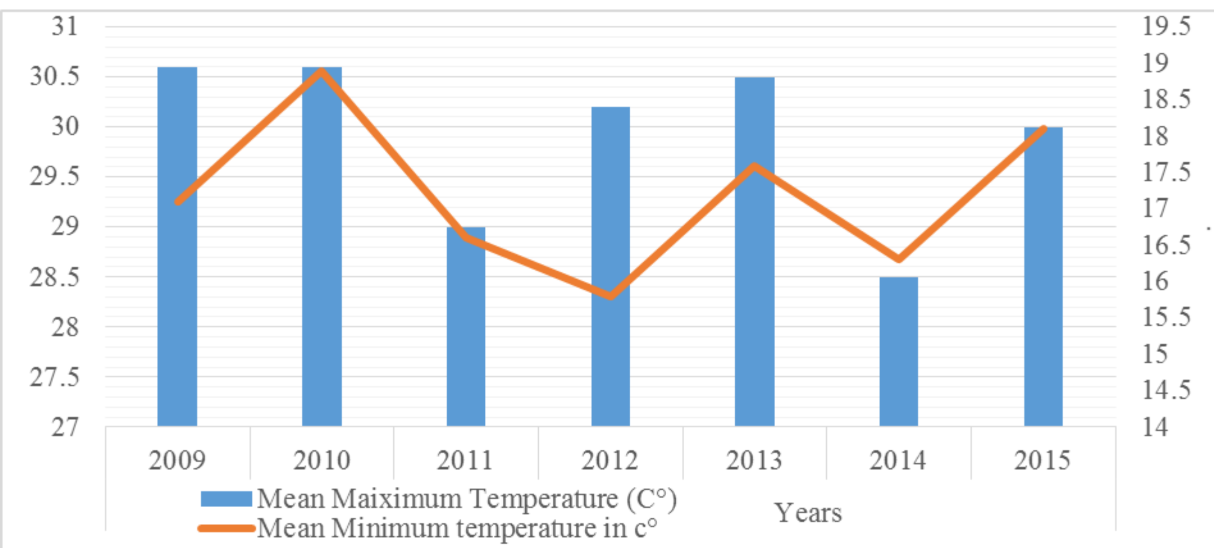


Figure 2. 4 Maximum and Minimum Temperature of Assosa Town (2009-2015)

2.4 Hydrology

The study area is mainly found in Dabus sub-catchment of Abbay River basin that starts from Begi woreda in the Oromia Region, south of the BGRS and flows towards north into the region and known with two flow gauging stations in Assosa area one at Dabus and the other one at Hoha river. The flow discharge for two stations measured in 1974 by Ministry of Water Resources is 3.41and 0.142 m^3/s, respectively. The first three gauged near Assosa town. Hoha, Afa and Selga Rivers are tributaries of the larger Dabus River which is one of the major tributaries of Abbay (Blue Nile) river. Both perennial and/or intermittent stream rivers exist in the area. Hoha, Afa, Gembela, and Selga Rivers are perennial which mostly drain the central and southern parts of the area from west to east direction of the area. The hydrological characteristics of the study area is described by the Hoha and Afa rivers that discharges most of the runoff from the area.

The prevailing drainage pattern in the area is structural controlled and shows rectangular to sub parallel type. All the streams draining the area show such drainage pattern whereas, the major rivers that drain the east of the area do have parallel drainage pattern.

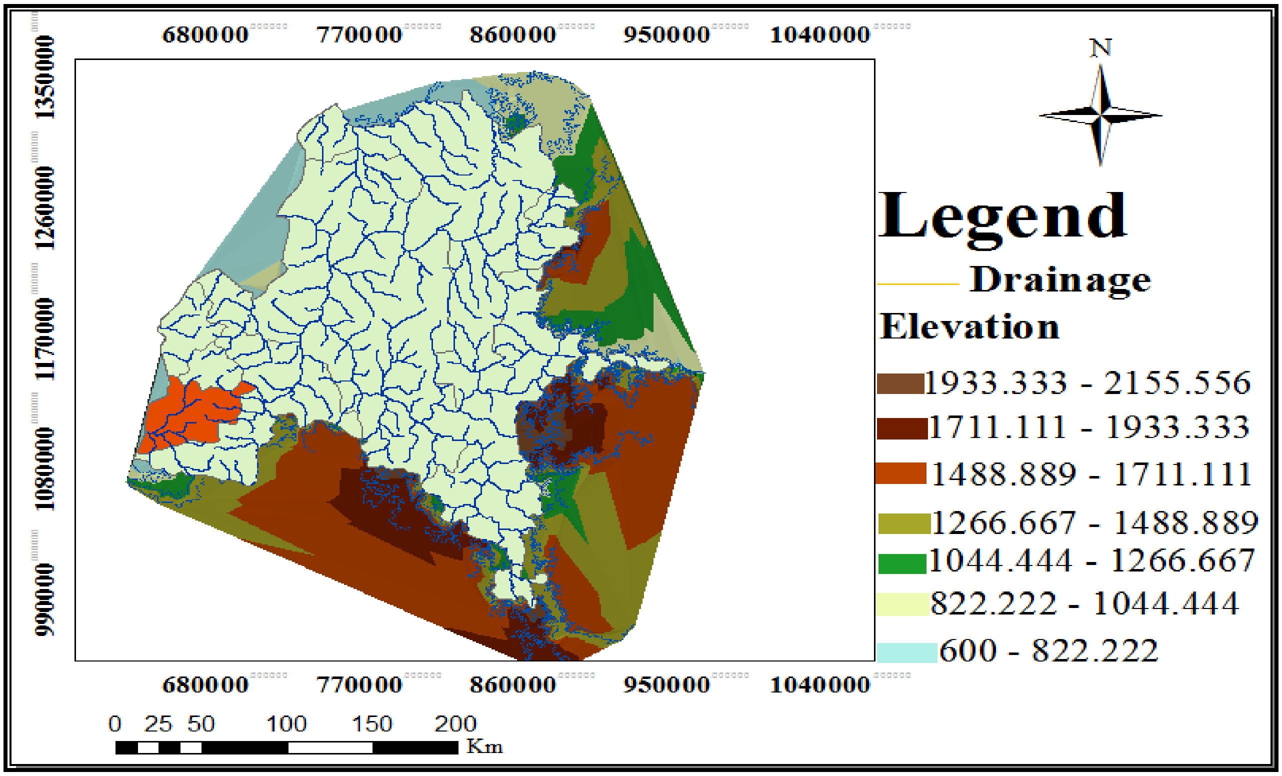


Figure 2.5 Drainage pattern of the study area

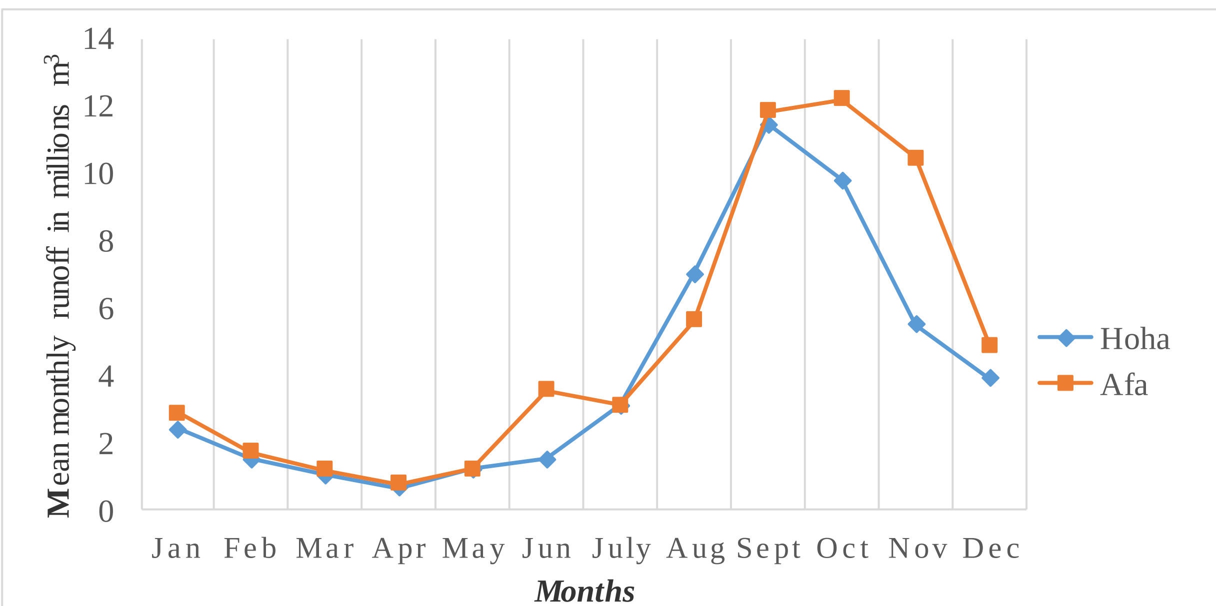


Figure 2. 6 Mean monthly stream flow Hoha and Afa River near Assosa town (1974-2005).

The Hoha River has a relatively similar river discharge and run off compared Afa River from January to May; but during June it has lower runoff and discharges and from July relatively higher values of runoff and discharges than Afa River; however, from September to December it has relatively lower river discharge and runoff than that of Afa River. This Seems due to data taken from Hoha is at its upstream course or the volume differences of two rivers.

2.5 Soil and Vegetation cover

The whole surface of the Assosa volcanic plateau is covered with the laterite layer up to 30m thick. Pisoliths are formed at the horizon, which is temporary saturated and unsaturated with groundwater. The lateritic cover with visible tabular and Pisoliths structures. (Geological survey of Ethiopia, Explanatory notes on hydrogeological and hydrochemical maps of Asosa-Kurmuk sheet, 2004). The characteristic of the vegetation is the reflection of climate. Thus, the vegetation of the town and its surroundings mainly consists of woodland and savanna. They are mixed deciduous woodlands and savanna with various types of acacia. Most of the trees are deciduous that shed their leaves during the dry season.

Although there are different types of trees in the town, the dominant species is Mango tree. The Mango tree gives dual purposes: giving shade to the town on the one hand and edible Mango fruits on the other. The other types of trees growing in the town include eucalyptus, Neam and Papaya. Despite the location of the town in the hot climate, temperature is relatively cool because of the good vegetation cover (trees) which has a moderating effect. In fact, the researcher observed that the best tree to create cool temperature is the Neam tree under its shade. The tree is well adaptable to and grows fast in places with hot climatic conditions. It is worth mentioning that all the trees in the town have been planted by individuals inside their compounds and there are trees along road sides that could provide shade for pedestrians (Somebody who is traveling on foot.)

Extensive forest cover is not present in the map area. The plateaus are naturally covered by deciduous leaf forest. The tree cover decreases in the low-lying areas, where scattered trees and especially bamboo may be encountered. Bamboos are among the plants most widely used by humans. They are used for constructing houses, rafts, bridges, and scaffolding. Split and flattened culms can be used as flooring and interwoven to make baskets, mats, hats, fish traps, and other articles; culms of large species may be used as containers for liquids. Paper is made from bamboo pulp, and fishing rods, water pipes, musical instruments and chopsticks from other parts. Many bamboos are planted as ornamentals and young shoots are eaten as a vegetable. The grain is also consumed as a food. Some dense vegetation is found along stream and river courses. The composition of the riverine forests varies widely and special features characterize the main rivers. In spite of this, it is possible to see in the riverine vegetation pattern some general links reflecting temperature influence. The major riverine forest in Benishangul-Gumuz Region is found in the lower part of the Abbay River, the Beles, Didesa and Dabus. This can be *Oxytenanthera abyssinica*, *Phoenix reclinata*, *Ficus sur*, *Ficus vasta*, *Ficus sycomorus, Syzygium guinecnse, Cordia africana* are among the major species in the riverine forest. With a growing population the tree cover is decreasing because of continued use for local construction and through annual burning. Most of the area is underlain by crystalline basement and is apparently unsuitable for agriculture.

2.6 Demographics and socio-economics

According to Central Statistical Agency (CSA) in 2005, Assosa has an estimated total population of 20,226 of whom 10,929 are men and 9,297 are women. The percent of the population growth of the city about 5.5 according to 2007 population and Housing Report. Assosa has about 35,000 residents of which male and female residents constitutes 51.5% and 48.5% of its population respectively. The annual growth rate of Assosa population, however, is expected to mostly due to an investment activities, rural- urban and urban –urban migrations and establishment of new public services like Hospital, University and different colleges. Based on the 1994 national census report a total population for Assosa town of 11,749 in 2,825 households of whom 6,324 men 5,425 were women. There are about six largest ethnic groups in Assosa town. These are Oromo (41.19%), Amhara (29.93%), Berta (17.39%), Tigre (5.43%), Gurage (1.35&), and Silte (1.29%). All other ethnic groups made about 3.42% of the population. Among these ethnic groups, Afan Oromo was spoken as a first language by 44.42%, 31.53% Amharic, 15.98 % Berta, and 4.43% Tigrinya and the remaining 3.64% spoke all other primary languages reported.

Within the area, there are various types of religion. But, the well-known and the dominant are Muslim, orthodox, Christian protestant, catholic and traditional believe followers. Both Muslim and orthodox Christian constitutes the majority of the Population of the region with regard to population size given above.

Ethnic Group	Amount of Ethnic Group in %	Spoken Language in %
Oromo	41.19	44
Amhara	29.93	31
Berta	17.39	15.9
Tigre	5.43	4.4
Gurage	1.35	1
Silte	1.29	0.8
Others	3.42	0.7

Table 2. 3 Population size and spoken language of Assosa

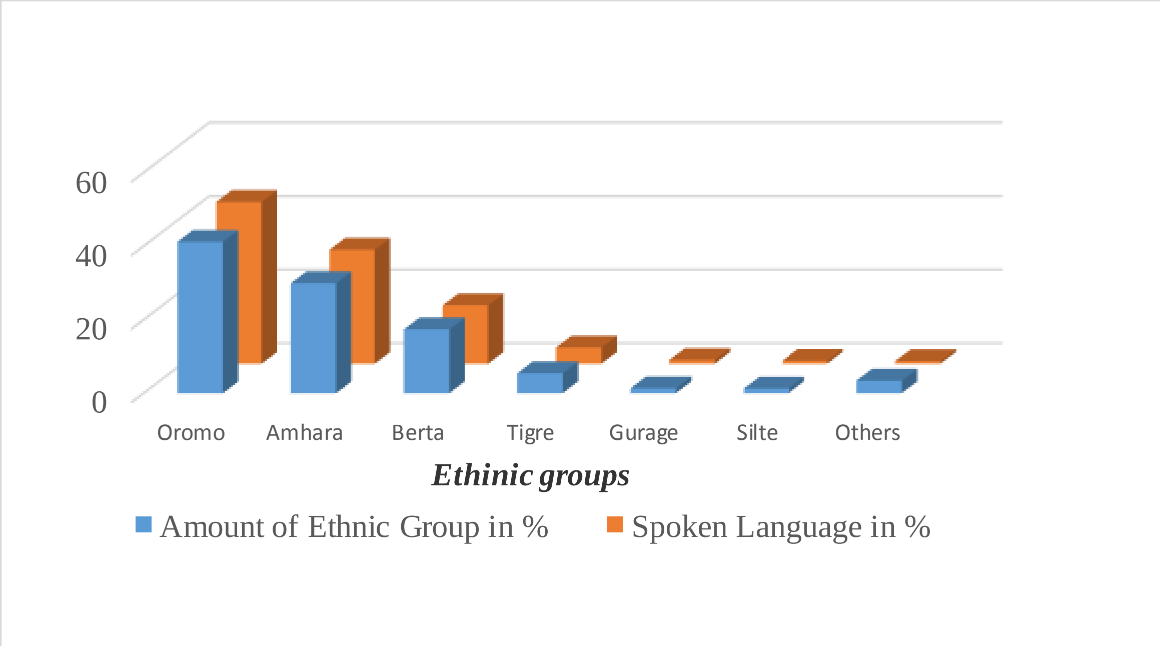


Figure 2. 7 Population size of and Spoken Language in Assosa Town (%)

Source: Population & Housing Census, Analytical Report, CSA 2005

CHAPTER THREE

3. GEOLOGY

3.1 Geology and Geotectonic Evolution of the Western Ethiopian Shield (WES)

Western Ethiopian Precambrian terrain is considered to contain lithological components common to both the Arabian-Nubian shield (ANS) in the North and Mozambique Belt (MB) in the South as stated by (Kazmin et al.1978, 1979). Precambrian geology of the Western Ethiopia at different scales (UNDP, 1972, de Wit, 1977b; Kazmin, 1978; Kazmin et al, 1979; Davidson, 1983; Amenti, 1989; Mengesha ,1987; Mengesha and Berhe,1987; Ayalew and Moore,1989; Tedase and Tsegaye, 2000; Solomon and Mulugeta, 2000; Getahun, 2002), consists of (1) high-grade gneiss and migmatites, (2) Low grade metavolcano-sedimentary rocks and associated intrusive rocks and, (3) metavolcano-sediments and associated mafic to ultramafic of probable ophiolitic origin. The high grade gneiss migmatites referred to Low Complex (UNDP, 1972; Kazmin, 1972), are considered as the northern continuation of the Pan-African Mozambique Belt. These rocks regarded as Archean in age mainly on the basis of correlation with similar rocks in East Africa (Kazmin, 1972, Kazmin et al. 1978).

The Low grade metavolcano sedimentary rocks referred to as Upper Complex (Kazmin, 1972; UNDP, 1972), and considered as the southern continuation of the Pan-African Arabian Nubian Shield. Geochronological investigation from plutonic rocks suggest that the age of Low grade rocks range from 830~540 Ma (Ayalew et al.1990). Based on field, lithologic, and geochemical evidence the low grade rocks of western Ethiopia were correlated to the Juvenile Pan African assemblage of northern Ethiopia, Eritrea, and the southeastern Sudan. Low grade metavolcano-sedimentary rocks and associated intrusive rocks is remarkably persistent and can be traced for the entire length of the Precambrian of western Ethiopia.

According to Kazmin et al. (1978) classification, geology can be grouped in to five tectonic zones; namely, (1) an eastern block of high grade pre Pan African rocks, (2) an ophiolite belt, (3) a zone of diorite/granodiorite, batholiths and associated intermediate volcanics, (4) a metavolcano-sedimentary belts and (5) western block of high grade pre Pan- African basement.

Northwest of the study area especially along Abbay basin and boarder of Sudanese (North West) is characterized by high grade terrain and north east of area is mainly dominated by low grade terrain. The similar relationship is observed that high grade terrain lies west (along Sudanese border) and east of the low-grade belt which stated by Kazmin et al., 1979.

3.1.1 Tectonic subdivision of the Region

Tectonic subdivisions of the region is done by Allen and Gebremedhin Tadesse (2003). As these authors put, the rocks in the Gimbi-Assosa area, the Tuludimtu Belt consists of a variety of moderate to high grade gneisses and low to moderate grade metasedimentary rocks intruded by deformed and undeformed ultramafic, mafic, intermediate and felsic igneous bodies. They categorized these rocks into five major domains those discussed as shown below.

3.1.1.1 Didesa Domain

This domain is located between Gimbi town and Didesa River to the East from Assosa. It extends from approximately 5km east of Didesa River in Wollega area covering about 70km up to about 25km west of Gimbi town. It is differentiated from the adjacent Kemashi Domain to the west by distinctive lithological and structural characteristics. The rocks within this domain are moderate grade para-gneisses which consist of interlayered biotite- amphibole gneiss, garnet-biotite gneiss and quartzofeldspathic gneiss and ortho-gneisses which consist banded mafic gneiss. Moderate-grade polydeformed and metamorphosed gneisses intruded by deformed gabbroic and granitoids bodies and post-kinematic mafic and felsic plutons.

3.1.1.2 Kemashi Domain

This terrain is characterized by a sequence of metasedimentary rocks of marine origin, including pelagic sediments, cherts, and quartzite's, interlayered with abundant mafic to ultramafic volcanic material, all metamorphosed to upper green schist-epidote amphibolite facies grade. Low-grade metasedimentary and ultramafic–mafic metavolcanics rocks intruded by deformed and undeformed ultramafic–mafic and intermediate plutons.

3.1.1.3 Dengi Domain

The Dengi Domain is interpreted as a volcanic arc related to the Tuludimtu Ophiolite to the east. This volcano-sedimentary sequence has all the hallmarks of an arc assemblage, including mafic to felsic volcanic and plutonic rocks, abundant andesitic lavas and pyroclastic rocks, and the association of clastic and carbonate sedimentary rocks. Low-grade metasedimentary rocks, mafic to felsic metavolcanics rocks and moderate grade gneisses intruded by deformed and undeformed gabbroic to granitoids bodies.

3.1.1.4 Sirkole Domain

The Sirkole Domain was understood to occupy west of Assosa town extending into Sudan, and therefore its western limit is unknown. It consists of different N–S elongated blocks which have only a few km widths. This domain consists of either medium grade gneisses or metavolcanics rocks intruded by foliated and massive granitoids. There are two major units that make up the areas gneissic lithology. The first one is Tosho gneiss, heterogeneous gneiss which includes undifferentiated complex of biotite-amphibole gneiss and amphibolite and granitoids gneiss. Alternating sequences of moderate grade polydeformed and metamorphosed gneisses and low- to moderate-grade metasedimentary rocks and mafic to felsic metavolcanics rocks intruded by deformed and undeformed granitoids plutons.

3.1.1.5 Daka Domain

The Daka Domain consists predominantly of gneissic rocks, which are subdivided into three lithological units. Two of the units are correlated with the two gneissic units of the Sirkole Domain, i.e. the Tosho Gneiss, and the Yangu Granitoids Gneiss. The relationship between these two units is more clearly delineated in this domain. The amphibolite facies Tosho Gneiss grades from east to west into the granitoids gneiss through a zone of increasing metamorphic grade and migmatisation and this terrain is Moderate-high grade polydeformed gneisses, intruded by Syn- kinematic granitoids. The map that produced by the authors which shows the types of domains is given fig. 3.1 below.

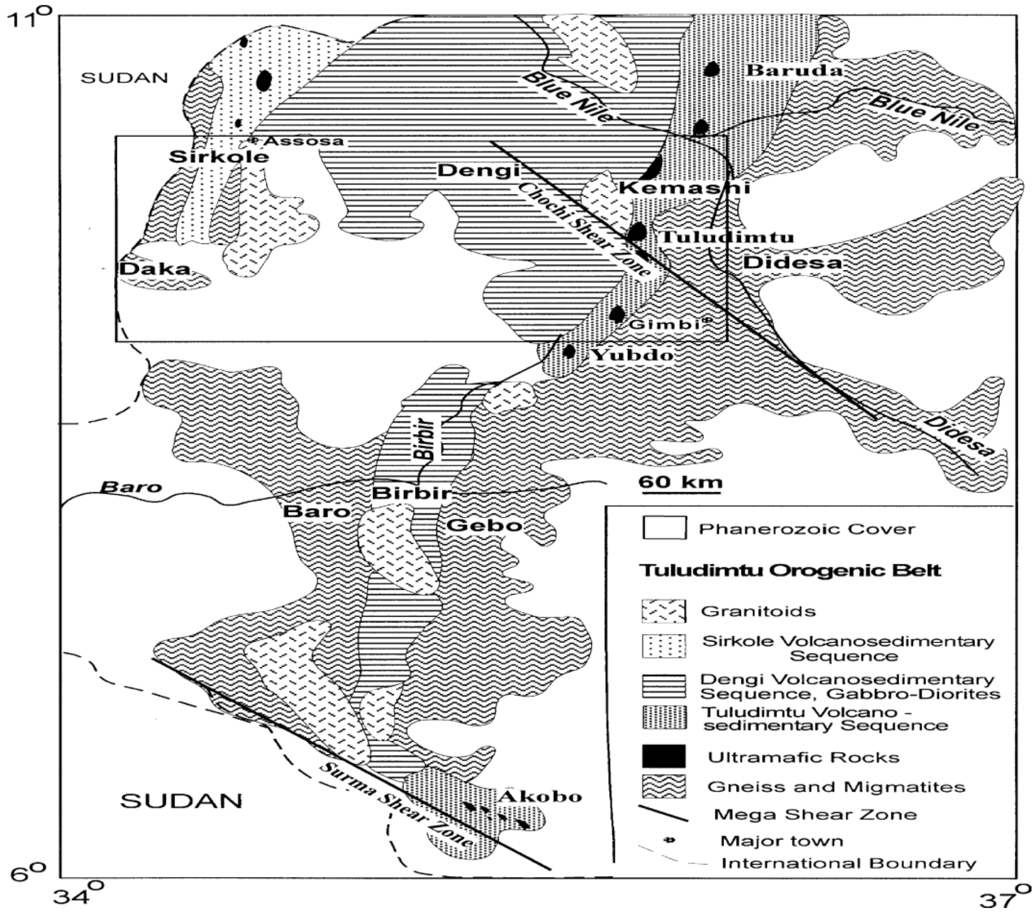


Figure 3.1 Generalized geology of the Tuludimtu Belt in western Ethiopia by Allen and Gebremedhin Tadesse (2003).

3.2 Geology of Assosa Area

3.2.1 Litho-Stratigraphy

Within the study area various lithologic units are exposed that incudes Precambrian rocks, Tertiary age groups of volcanic rocks and Quaternary age groups of lacustrine and alluvial deposits Mengesha Tefera (1991).

3.2.1.1 Precambrian Rocks of the area

There are two types of precambrain rocks; Precambrian stratified rocks and Precambrian intrusive rocks. Different types of units that can be categorized as Precambrian stratified rocks are Biotite and hornblende-biotite gneiss, Biotite and biotite-hornblende gneiss, Meta-ultramafic rocks, Amphibolite, Amphibolite and quartzofeldspathic schist, Metasediments, Metasediments and metavolcanics, Marble and also Precambrian intrusive rocks includes various outcrops of the rock units such as Metagabbro, Metaquartz diorite, Metatonalite, Metagranodiorite, Metagranite, Granite and Alkali granite, cited by Mengesha Tefera (1991). From these both types of the precambrain rock units, few of them are known within the catchment and when compared with other outcrops of the catchment these units are located at higher elevations and some this rock types are discussed below.

Metagranite

It is one types of intrusive precambrain rock that dominantly appears light to pinkish grey and crops out within stream cuts. It is made up of medium to coarse grained minerals with commonly visible minerals like quartz, feldspars and micas and it is occurs in association with other granitoids such as granites.The metagranite forms relatively higher altitude land forms. The rocks are characterized by several fracture systems. Quartz vein and pegmatite have filled some of these fracture system. Rock outcrops of the granite gneiss are frequent along the course and beds of the Hoha, Selga and Afa rivers and their tributaries. The granitic mass north of Asosa has an irregular shape, but north-south trending foliation. Small unmapable granite outcrops are common within the Tertiary basalt terrene in the vicinity of Asosa. Most of the area underneath the basalt cover appears to be underlain by the same metagranite mass. Relatively large masses of metagranite occur in, north of Assosa. Some of these plutons were probably emplaced during the last stages of regional deformation and are late tectonic, since they show evidence of local deformation. The unit is generally massive except few localities where it exhibits strong deformational fabrics and in some area this units known with small amount of fractures which is probably the effect of post tectonic granite intrusion in the area.

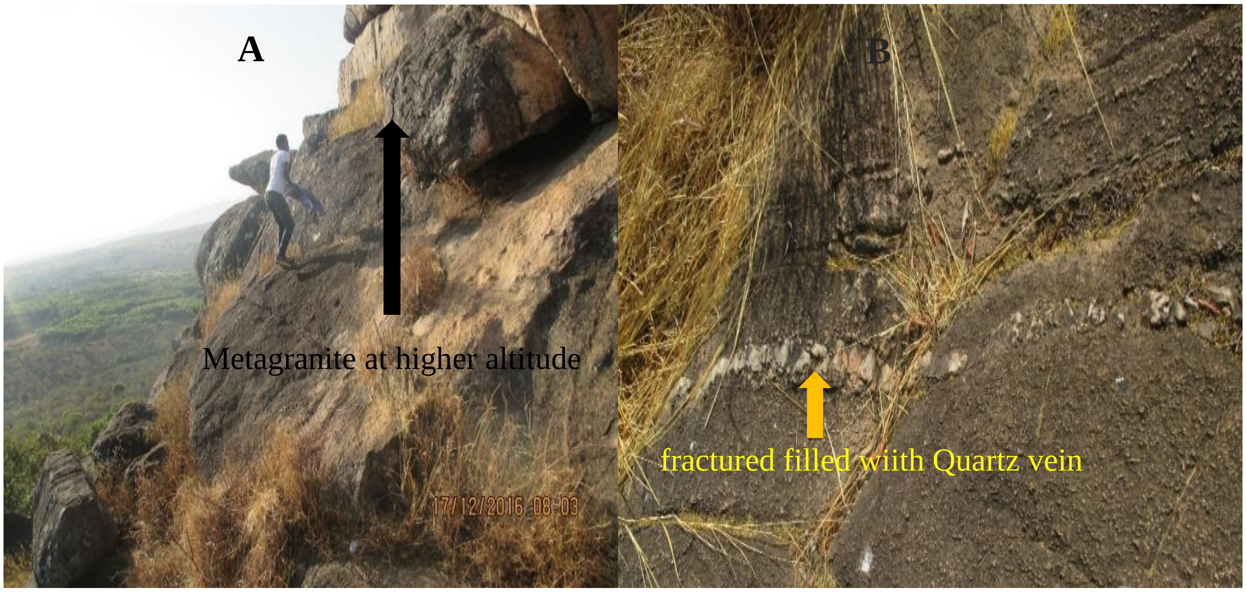


Figure 3.2 Metagranite with Quartz Vein filled, from field

Metasediments (Pcms1)

It varies in composition, texture, structure and degree of weathering and deformation from place to place. Generally, it comprises graphite schist, chlorite schist, talc-chlorite schist, amphibole-biotite-feldspar-quartz schist, amphibole-biotite schist, muscovite-feldspar-biotite-amphibole schist, chlorite-biotite schist, quartz muscovite schist, biotite schist and quartz-muscovite-sericite schist of volcanic origin. The unit varies from weakly deformed massive varieties to strongly deform schistose and foliated varieties at place it is intensely weathered. There are three major occurrences of metasediments schists units. One is in the north-western part of the area extending from Geissan southward, the second one occurs east of Geissan extending southward from northwest of Mudul village past Menge town, and the third one occurs in the south-western corner of the area, extending from northwest of Assosa around Kashmangal village south-west ward to the edge of the mapped area. These three occurrences are separated from each other by granitoids intrusive masses and Tertiary volcanic cover rocks.

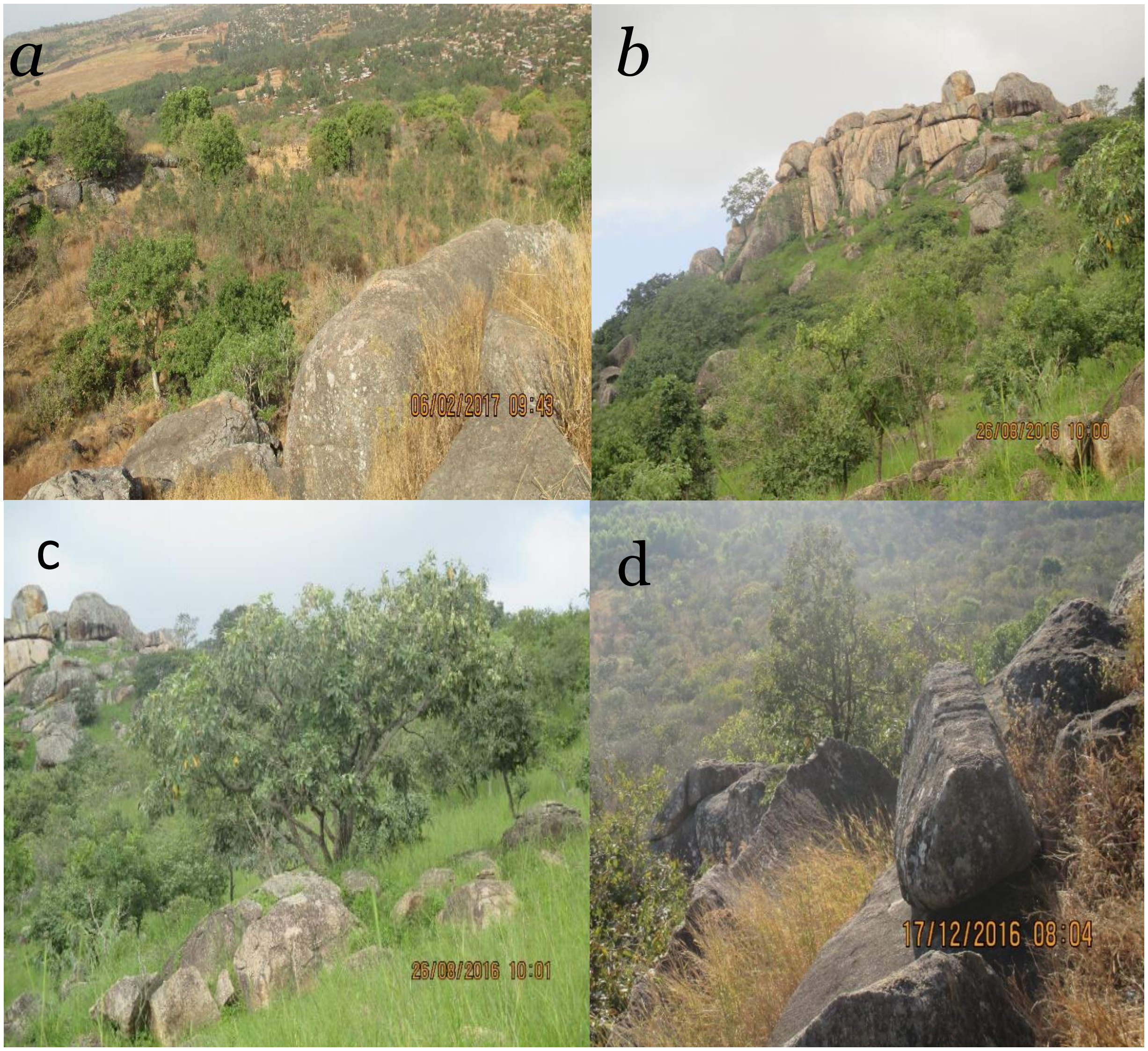


Figure 3.3 some field photos of Precambrian rock types of the study area

3.2.1.2 Tertiary volcanic rocks

This flow extends to the Assosa area and its surroundings. The trap series lay uncomformably on the Precambrian rocks in the Assosa area; it affected by weathering effect of warm climate forming laterization. At Selga boreholes basalt have encountered at depth 37 and 30 meters and was not penetrated. In general the basalt occupies lower elevation than the basement rocks in the area. The thickness of the tertiary volcanic rocks is less than 100 m and they are intensively weathered and bear lateritic crust. Alkali olivine basalt (Te) remnant caps of basalt flows occur over a relatively small part of the area. The thickness of these occurrences is less than 100 m. In the western part of the area the basalts are intensively weathered and bear a lateritic crust.

3.2.1.3 Quaternary Sediments

Alluvial Sediments

The alluvial deposits are mainly confined to the river valley of the major rivers. This type of sediment is mainly observed at Hoha River and Selga sites underlying thin flows of basaltic layers which includes gravel, sand and silt deposit of an old river. A possible continuation of this formation is expected to be along the current Hoha river valley and these sediments are recent deposits confined to river valleys. This unit mainly consists of sand and gravel derived from mechanical disintegration of granitoids and gneiss and at some places the basalt has been transported and deposited by the rivers along their course. Many of these deposits are sources of placer gold to that of ground water sources.

Eluvial Deposits

These deposits are generally chemical weathering product materials found in situ over parent rocks. Laterite is the common eluvial deposit observed in the Assosa area. Its formation probably took place under tropical climate with dry and wet periods where there is forest and high rainfall. The red clay soil formed by weathering of the basalt characterizes most parts of the area, like at Assosa University well and Selga well including other parts of the other parts of research area; and where the land is gently sloping and flat, the soil is dark and it is loamy clay storing water and forming marshy ground.

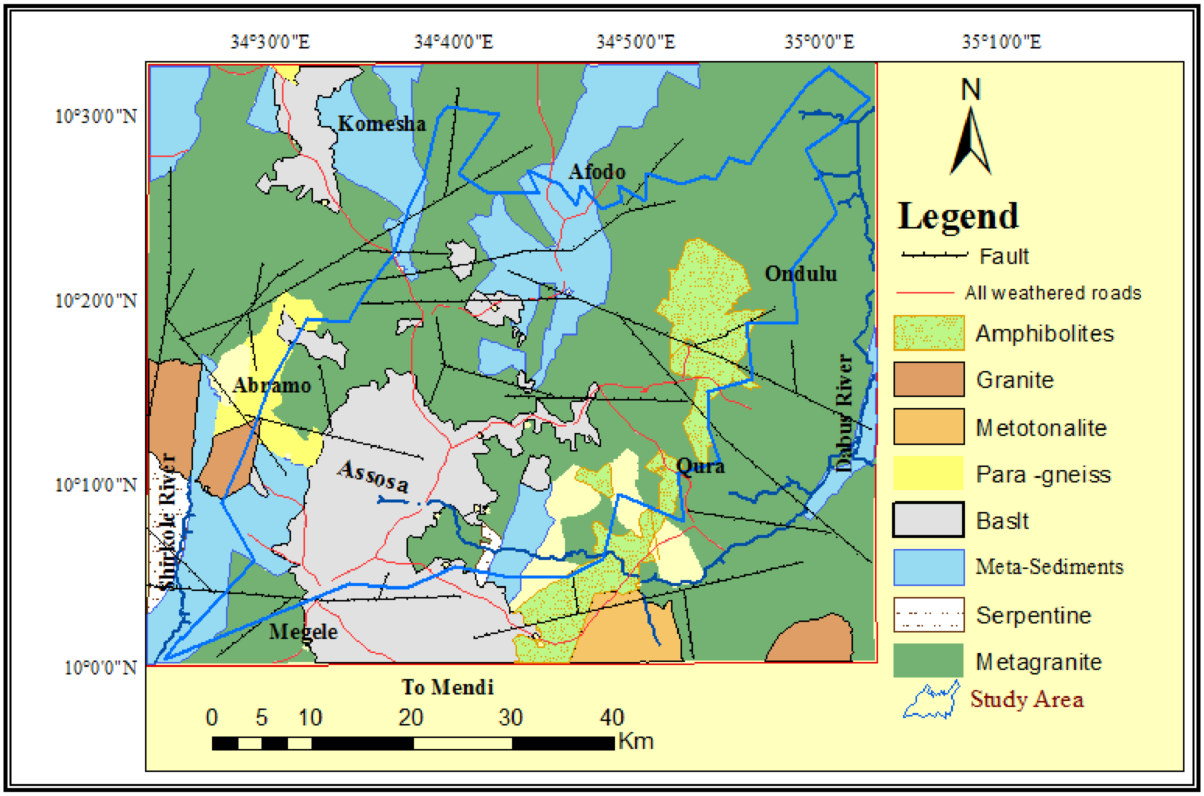


Figure 3.4 Lithologic Map of the area (adopted from Tefera, 1987)

3.3 Geological Structures

Foliation, schistosity and gneissosity are the dominant planar structures in the crystalline basement rocks of the map area. They generally strike north-south as in the basement rocks elsewhere in western and south-western Ethiopia. However, north-easterly strikes predominate in the western part of the map Linear structures are represented mainly by mineral aggregate lineation and to a lesser extent by the long axes of mineral lenticels and prismatic minerals such as amphiboles. They trend parallel or sub parallel to the strike of foliation and generally plunge gently toward north or south throughout the map area.

Faults: Two sets of lineaments are prominent in the map area. These are a northwest to north-northwest set and a northeast to north- northeast set. These two sets of lineaments are common in western and south-western Ethiopia; Seife and Rothery (1986). Most of them have been traced from air photos. Some have been proven to be faults during ground traversing, with horizontal offsets ranging unto several kilometres. Northerly and north-westerly trending lineaments are most prominent in the western part of the map area. Movement on some is shown by sheared and mylonitized zones. According to description of Assosa - Kurmuk geologic map by GSE (2004), faults with both dextral and sinistral sense of displacement are present; those of dextral sense appearing to dominate and both lateral and vertical movements are thought to have taken place along the Kurmuk fault which separates the Kurmuk plain on the west from the uplifted Ethiopian plateau on the east. It is also a major boundary between the high grade terrains on the west and throw grade terrain to the east. The main structural and tectonic features trend E-W, N-S, N-W and N-E throughout the area.

CHAPTER FOUR

4. HYDROGEOLOGY

Hydrogeology is the area of geology that deals with the distribution and movement of groundwater in the soil and rocks of the Earth's crust (commonly in aquifers). There are three important geological patterns that control the nature and distribution of hydro-geological units in geologic system. These are lithology, stratigraphy and structures of the geologic formation. Lithology is the physical make-up of the sediments (rock) that make up the geologic system, example mineral composition, grain size and grain packing. Stratigraphy describes the geometrical and age relationships between various formations in geologic system. Structural features, such as fractures and faults are the geometrical properties of geologic system produced by tectonics or during crystallization.

According to Tesfaye Chernet (1993) the aquifers of Ethiopia are classified based on aquifer type and productivity. Concerning aquifer types the country is classified into five aquifer types: (1) Extensive aquifer with intergranular permeability (unconsolidated sediments: alluvium, eluvium, colluvium, lacustrine sediments, and poorly cemented sandstone). (2) Extensive aquifer with fracture and/or karstic permeability (consolidated sediments and metamorphosed carbonates: limestone, sandstone, evaporate, marble associated with shale, marl). (3) Extensive aquifer with fracture permeability (volcanic rocks: basalt, rhyolite, trachyte, ignimbrites). (4) Localized aquifer with fracture and intergranular permeability (noncarbonated metamorphic rocks, granitic intrusive, dolorites) and (5) Main geothermal areas, common occurrence of thermal groundwater in fractured volcanic rocks and subordinate unconsolidated sediments and also based on the productivity of the aquifer, the different aquifers are classified into three that includes (1) High productivity aquifer permeability value ranging 0.62-124 m/day; (2) Moderate productivity aquifer permeability value ranging 0.14-62 m/day and (3) Low productivity aquifer permeability value ranging 0.004-0.14 m/day.

4.1 Aquifer Classification of the Area

Classifications of different lithological units are made based on hydrogeological characterization of various rock types. According to Bayissa Asfaw (2003) both Qualitative and Quantitative parameters are used to classify the hydro geological unites into aquifer/aquitards system. He stated that, in the various formations, the variations in ground water storage, transmission and yield are the basis for the classification of aquifers.

4.1.1 Qualitative Parameters

The qualitative classification is based on the ground water point data and pump test data, the major hydrogeological units that are characterized into pours, fissured and/or karst permeability and permeability rocks of groundwater (Geological survey of Ethiopia, Explanatory notes on hydrogeological and hydrochemical maps of Asosa-Kurmuk sheet, 2004).

4.1.2. Quantitative Parameters

This parameter is based on the hydrogeological characteristics of various rock types, such as permeability, aquifer thickness and yield obtained. Based on qualitative and quantitative hydrological criteria and geomorphologic setting, different lithological units are classified in the following aquifer and aquicludes system.

4.2 Moderately productive fissured aquifers

Alkali Olivine Basalt

The basalt cover usually forms flat-topped outcrops and lies non-conformably on the crystalline basement in those areas. In the central part of the area, however, the basalt occupies lower elevations than the basement rocks. The thickness of the outcrop is also variable reaching about 100m in the thickest part, and as low as about 15m at other locations. The degree of weathering is also variable from place to place. In some places it is highly laterized, and in others it is moderately weathered; but in other massive. This unit dominantly cover areas of Selga wells and some part of ASU area including its borehole. Several intercalated pebble layers are found in a well of Hoha River.

Thus, the hydrogeological property of the basalt shows local variation from place to place. If the soil cover is thick and oxidized its permeability (percolation to depth) will be high as the clay content of such special soils is less. This will enhance better groundwater storage capacity in the underlying fractured parts of the rocks. Generally, the basalt is seen to have aquifers of moderate yield (mainly with fracture permeability). According to GSE this formation has ranges of aquifer parameters: T = 100 – 10 m^2/d, Q = 5 – 1 l/s. When we compare transmisivity values that obtained from pumping test data done using Neuman method, with that of GSE above, it is clearly similar to each other; i.e. 44.3m^2/d. This values is one of the value that found in the intervals determined by GSE above. Therefore, parameters that done by the GSE is clearly proved based on the values obtained from the pumping test data using Neuman method analysis.

4.3 Low productive fissured aquifer

This tpye of aquifer is the composition of basement rock that cover most part of the area. Some of the outcrops of this aquifer like Metagranite which is coarse in grain size and occurs in association with other granitoids such as granites; the hydraulic conductivity, groundwater storage, and yield of springs within the rocks are variable from place to place. In places where there are penetrative faulting and associated brecciated parts of the rock, local groundwater accumulation is expected. In some localities where the proportion of the basic mineral components are higher, or the assimilation with other rocks such as diorite is higher, the thickness of the weathered zone is higher. In such areas, local groundwater accumulation and springs with low yield is expected. This unit cover most part of the study area when compared with that of another units of the catchment.

Figure 4.1 Metagranite units the Low productive fissured aquifer of the area

Generally, Geological Survey of Ethiopia, (2004) and Tesfaye Chernet (1993) states that, Low productive fissured aquifer of the region has transmisivity (T) value that ranges from 1-10m^2/d; also the result of Hydraulic parameters that investigated from pumping test data, can verify this parameters stated above i.e. ranged from 2.76 to 9.92 m^2/d.

4.4 Aquitards

It includes some intrusive rocks. Trachyte and phonolite plugs are few examples of an aquitard out crops in the catchment that occur in clusters and along fracture lines. phonolite Plugs are fine grained igneous rock; which is light colored volcanic rock that characterized by the presence of alkali feldspar and porphyritic nepheline phonolite, with phenocrysts in an altered groundmass. These plugs form conspicuous topographic features, and range in diameter for several meters. Several plugs rise as much as 200 meters above their surroundings. Trachyte is also a volcanic rock type which is fine grained and characterized by presence of alkali feldspar minerals. Thin flows of trachyte and phonolite are locally associated with these volcanic plugs. Because of the topographic position, small extent and relatively low permeability the trachyte and phonolite plugs are considered as aquitards. GSE determined that this formation has ranges of aquifer parameters of: (T= 0.01 -1 m^2/d, Q = 0.05– 0.5 l/s).

4.5 Ground Water Potential (Aquifer Potential)

From the investigation of the geological formations, in the Assosa area, it seems that the aquifer characteristics of the hard rock are poor. However, coarse alluvial sediment deposits such as the buried river channels and surface deposits, the lateritic weathered part of the basalt and basement rocks and fractured zones of rocks can be considered as aquifers from moderately to aquitards. Recharge to groundwater in this area can occur through these fractured and weathered zones of the basaltic rock and basement outcrops. It is also expected that the loose alluvial sediments along the above river courses are recharged by these rivers wherever their thickness is sufficient and the water table is below the river level. The Assosa area with its good rainfall is assumed to be an area with much surplus water to infiltrate for groundwater recharge. But it is hard to say the development of ground water for community water supply is sufficient and there is a shortage of water supply in the town. Therefore it is better the ground water potential in terms of hand dug wells, drilled deep wells and spring development.

4.6 Aspects of Ground Water Recharge and Discharge

4.6.1 Ground water Recharge

The main source of recharge to groundwater in the area is from direct precipitation. Indirect recharge from the surface flow of the different perennial rivers and streams to the groundwater of local aquifers is also possible. A seasonal (localized) but significant amount of recharge to localized aquifers also possible from most of the intermittent streams. This type of infiltration dominates in aquifers of low-lying areas. Several other streams show higher flow in the upstream but it dramatically decreases downstream within only a few kilometers, at a similar elevation, and with similar temperature conditions. This indicates that the streams have an effluent condition and recharge the groundwater).

Two modes of groundwater recharge are expected in the Assosa area. The first and the most important is recharge from the infiltration of precipitation to groundwater. The second, and not common for the whole area, is recharge from rivers and stream to the fractures and alluvial deposits along their courses. The Assosa area with its high rainfall is assumed to be an area with much surplus water to infiltrate for groundwater recharge. Recharge to groundwater in this area can occur through fractured and weathered zones of the basaltic rock and basement outcrops. It is also expected that the loose alluvial sediments along the above river courses are recharged by these rivers wherever their thickness is sufficient and the water table is below the river level.

4.6.2 Ground Water Discharge

Groundwater discharge areas are formed by moderate depressions especially in the highlands, while most of the elevated areas are groundwater recharge areas. Most parts of the weathered rock recharge the inter mountain depressions located adjacent to or below them. As there is a very high elevation difference (more than 1000m) between the high cliffs and deep gorges, a lot of springs emerge in the middle of the high cliffs or even at the top of the cliffs due to several reasons. Some of these reasons as observed during the field trip that are the presence of thin impermeable layers at the middle or the top part of the ridges, variation in the extent of weathering of the same rock along the cliffs, lithological variation along the cliffs and therefore difference in the hydraulic conductivity of the different rocks, variation in the degree of penetration of structures, etc. With the exception of these, topographically high areas can generally be considered as recharge areas as explained above and topographically low areas can be generally considered as discharge areas. The springs that emerge at the contact of the weathered parts and fresh parts of rocks, or contacts of different rocks on the cliffs northwest of Assosa and Baruda village are examples of exceptions to the above generalizations.

4.7 Ground water Flow System

Movement of ground water in a given area depends on geomorphology, presence of vegetation and soil cover, drainage density, geological and structural formation of the area, rainfall intensity and duration, sunshine hour and strength etc. Its flow direction is expected to follow surface water flow direction. Local flow direction deviations due to the impact of bedding of sediments; foliations or some hidden structures can exist. Variation in the hydraulic conductivity of the different rocks can also cause local deviations to the general groundwater flow direction. As shown in the hydrogeological map of Assosa town groundwater flow to the East and West directions from nearly east of Assosa town. The groundwater divide is NE-SW and Assosa town is close to the surface water divide, and it is the recharge zone of the groundwater system. In general the groundwater flow direction and the surface water flow direction are the same (Geological survey of Ethiopia, Explanatory notes on hydrogeological and hydrochemical maps of Asosa-Kurmuk sheet, and 2004).

4.8 Some Water Points of the Area

According to the data that obtained from Assosa town Water supply and sewerage Enterprise, there are about 8 deep wells that were drilled since 1977 EFY and out of them two are nonfunctional and not giving service (See table below). The average depth of the wells are 90 meter and approximately all wells are giving about 4.6 L/sec. Six wells were constructed along Selga river catchments and most of them are near to each other; and for future it is difficult to get enough ground water potential for the town.

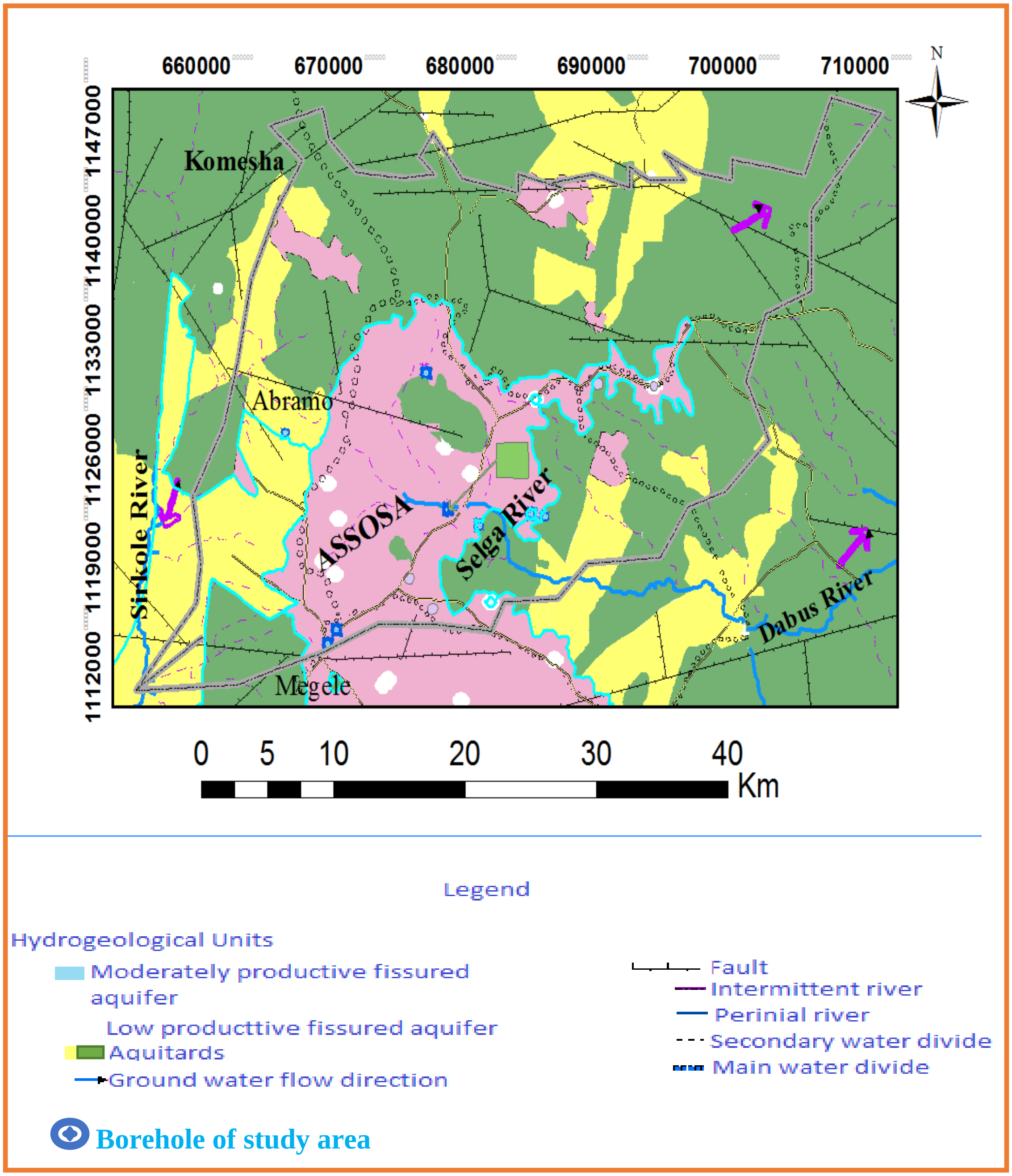


Figure 4.2 Hydrogeological map of the area adopted from hydro geological map of Assosa-Kurmuk sheet by Alamerew et al. (2003). Borehole of the area.

CHAPTER FIVE

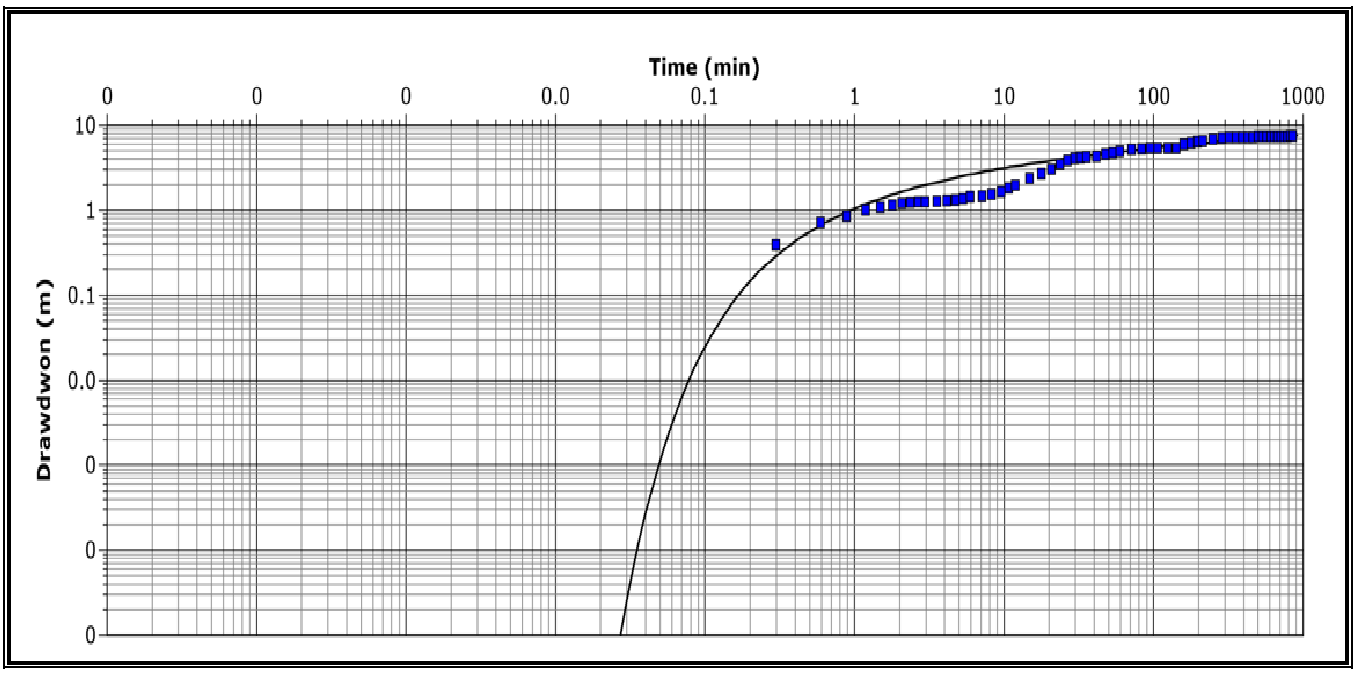
Result and Discussions

5.1 Result

5.1.1 Determination of Aquifer Parameters from Pumping Test Data

5.1.1.1 Aquifer Parameters from Constant Discharge Rate of Assosa university well

Constant discharge pumping test was conducted without interruption for the total duration of 24 hours with constant pumping discharge rate 4 l/sec. The total drawdown (TDD) measured for the range of pumping time is 75.53 meter. Constant discharge data sheet given in an (annex 1c). Time versus Drawdown plot from Constant Test Rate Data that collected from borehole pump test data's are plotted in log to log in below diagram.

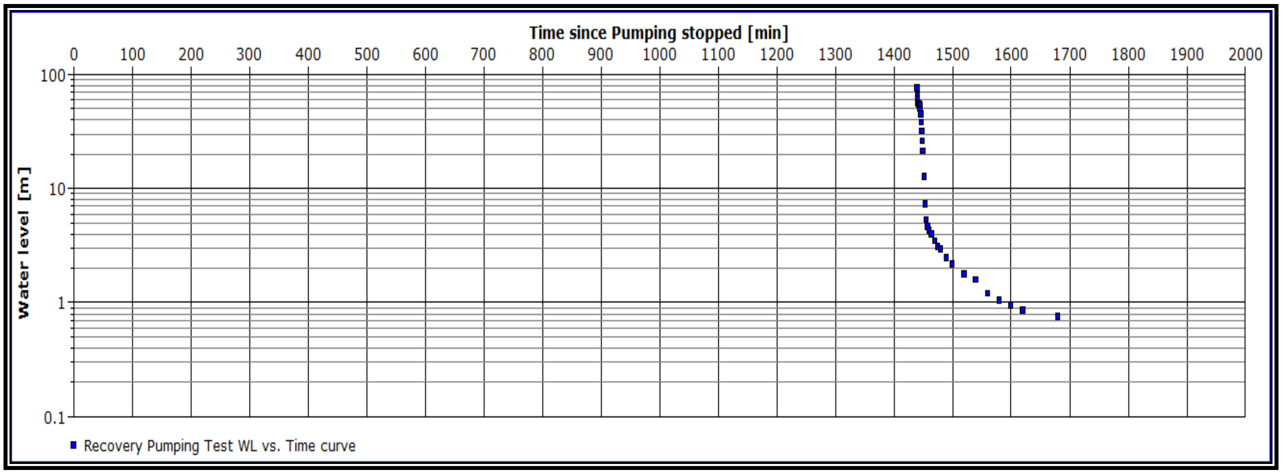


Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
ASU Well constant Pumping Test	2.76×10^{0}	6.79×10^{-2}	5.00×10^{-1}	1.98×10^{-5}	1.00×10^{1}	0.25

Figure 5.1 Time versus Draw Down plot from constant test rate data of ASU

5.2 Aquifer Parameters Recovery Test of ASU

Recovery Test was conducted after constant discharge test for the duration of 3 hours after pumping had been shut off. With the span of time, the total Residual Draw down (RDD) or recovery of the well is 0.75. The Recovery Test data sheet is given in the (annex 1b) and its graph with hydraulic values based on the analysis that done by Neuman method, from water level vs. time, is given as shown in figure 5.5 below.



Calculation using Neuman						
Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
Recovery Pumping Test WL vs. Time curve	8.64×10^{-8}	2.13×10^{-9}	1.03×10^{-29}	1.03×10^{-2}	1.03×10^{2}	0.25

Figure 5.2 Time vs. Water Level plot from Recovery test data.

5.3 Determination of Transmisivity and Hydraulic Conductivity from Constant Pumping Test of the ASU well 1

Transmisivity (T) indicates the rate at which water flow through a vertical strip of the aquifer 1m wide that extending through the full saturated thickness and how much water will move through the formation. It is the production of the average hydraulic conductivity and saturated thickness of the aquifer**;** i.e. T=Kb. Constant pumping tests and recovery tests rate were used primarily to determine transmisivity of the aquifer. Recovery data should be taken to verify the accuracy of pumping test data's and will be more reliable because no pumping is required. Moreover, analysis of recovery data's have the advantage that the pumping discharge rate is constant. Also, the recording of recovery data helps in assessing the response and extent of the aquifer concerned, that is, for an aquifer system which is to exploited for groundwater, the recovery levels must be adequate and yet recovery measurements should be recorded with the same frequents as those taken during the constant yield test portion of the aquifer and /or well.

Transmisivity from Constant Yield Test

Transmisivity (T) =Kb

T= $2.76*10^0$ =2.76 (m^2 /d), (from drawdown vs. time plot, using Neuman analysis method).

Hydraulic Conductivity (K) is a measure of the ability of a fluid to move through interconnected void spaces in the sediment or rock. Hydraulic conductivity is a function of both the medium and the fluid. Therefore based on equation 1 above we can calculate value of Hydraulic Conductivity of ASU well. To do that, aquifer thickness (length of total screen casings) must be first determine. We can determine it from the Lithological log i.e. 40.65m and the value of Transmisivity that calculated from the Constant Yield test which is $2.76*10^0$ m^2 /d. Now by rearranging the equation 1 above, hydraulic conductivity of ASU well is done as shown below.

K= T/b→ $2.76*10^0$ (m^2 /d) /40.65m =$6.77*10^{-2}$m/d; therefore hydraulic conductivity of ASU well is about $6.77 *10^{-2}$ m/d and specific yield = $5.00*10^{-1}$, Radial Distance to PW= 0.25m.

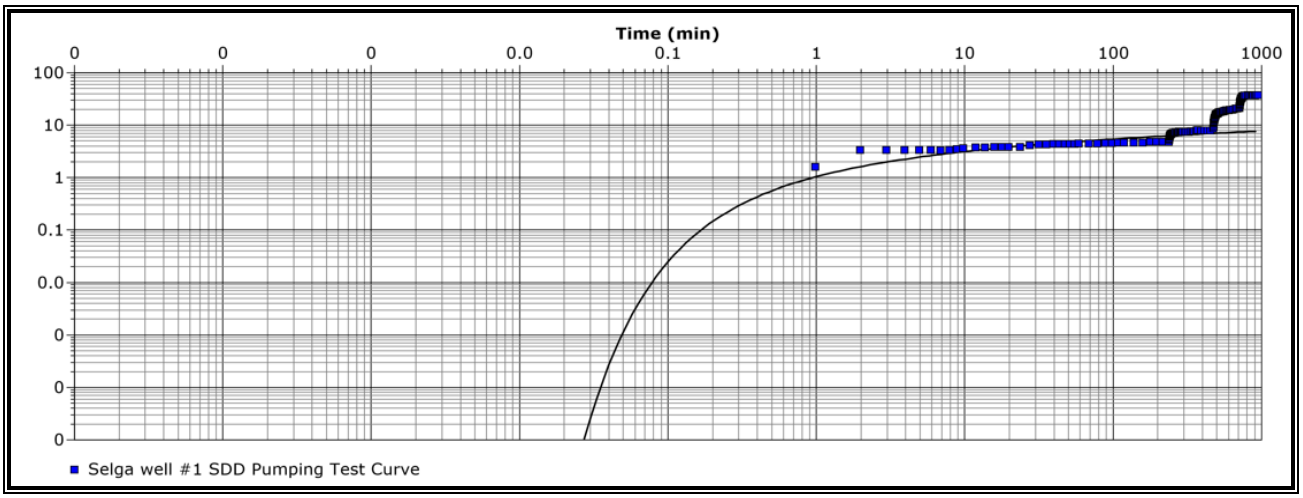
5.4 Determination of Aquifer Parameters from Pumping Test Data (Selga Well Site)

5.4.1 Aquifer Parameters from Selga Well #1 Pumping Tests

Pumping test of Selga well no.1 was conducted during 2011, and before starting of pumping test, static water level was measured for several times to understand actual static water level and a provisional pumping test was conducted in order to determine the appropriate discharge rate to be taken for the step draw down (variable) test. For the provisional pumping test of Selga well No.1 the pump was positioned at depth of 98.6m below the reference point (ground surface) and the pumping was conducted at full capacity of the pump (12 l/sec.) for a period of 1 hour. The observed drawdown with this rate was about 58m and water was recovered to its static water level of 6m within 4 hours.

5.4.3 Step Drawdown Test of Selga 1

After provisional test and recovery of the water level to its initial static water level (SWL) four steps drawdown test (SDDT) was conducted with variable discharge rate of 4, 6, 8 and 10 l/sec. for duration of 2 hours each. To confirm the data, the SDDT was also repeated with a variable discharge rates of 4, 6, 8 and 10 l/sec for duration of 2 hours each. The observed drawdown versus time for each variable discharge rate test is presented in the table under (annex 2c).

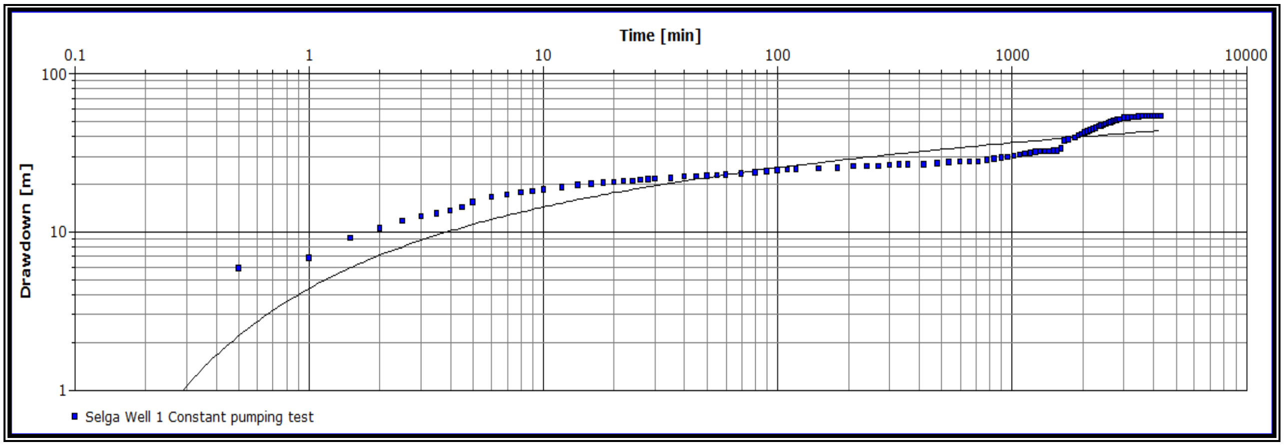


Calculation using Neuman						
Observation Well	Transmis sivity [m²/d]	Hydraulic Conductivity [m/d]	Spe cific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
Selga well #1 SDD Pumping Test Curve	2.44×10^{1}	3.86×10^{-1}	5.00×10^{-1}	1.00×10^{-5}	1.00×10^{1}	0.41

Figure 5.3 Selga well 1 DD vs. Time from SDD pumping Test curve

5.4.4 Aquifer Parameters of Constant Discharge Test of Selga 1

After the provisional test and Step Drawdown test had been conducted, a constant discharge rate test was carried without interruption for a total duration of 72 hours with selected constant pumping rate of 7 l/sec. For this test, the pump was positioned at 100 m below the reference point. The total drawdown (TDD) measured with this rate 7 l/sec over 72 hours of continuous pumping was 53.75m Table in an (annex 2a), shows that constant raw data test and whereas the analyzed data curve was shown in next figure 5.8 Time versus Drawdown plot from Constant Test Rate Data are plotted in log to log.

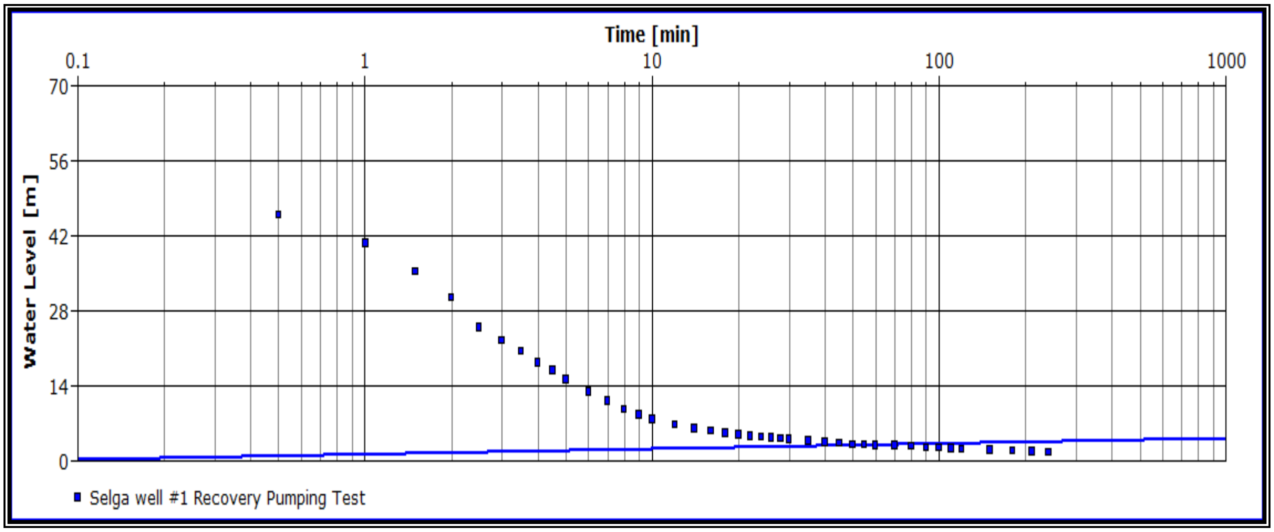


Calculation using Neuman						
Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
Selga Well 1 Constant pumping test	9.92×10^{0}	1.57×10^{-1}	5.00×10^{-1}	1.49×10^{-2}	1.00×10^{1}	0.41

Figure 5.4 Selga well 1 Drawdown vs. Time Curve of Constant Test curve

5.4.5 Aquifer Parameters of Recovery Test of Selga 1

Recovery test was conducted following the end of the constant discharge test for the period of 4 hours just immediately after pumping had been shut off. With the span of time, the total residual drawdown (RDD) or recovery of the well is 32.62m. Within this duration of time, the well could recover up to 96.68% of the TDD. (Annex 2b) shows Recovery Test Data Sheet and its Water Level vs. Time curve is in below figure 20.



Calculation using Neuman						
Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
Selga well #1 Recovery Pumping Test	8.64×10^{-3}	1.37×10^{-9}	1.03×10^{-29}	1.09×10^{-2}	1.09×10^{2}	0.41

Figure 5.5 Selga well 1 WL vs. Time of Recovery Pumping Test Rate Curve

5.5 Hydraulic Parameters of Selga well # 1 from Constant Yield Test

Transmisivity (T) =9.92*10^0 m^2/d=9.92m^2/d **(**from Drawdown vs. Time of Constant pumping test rate; using Neuman analysis methods).

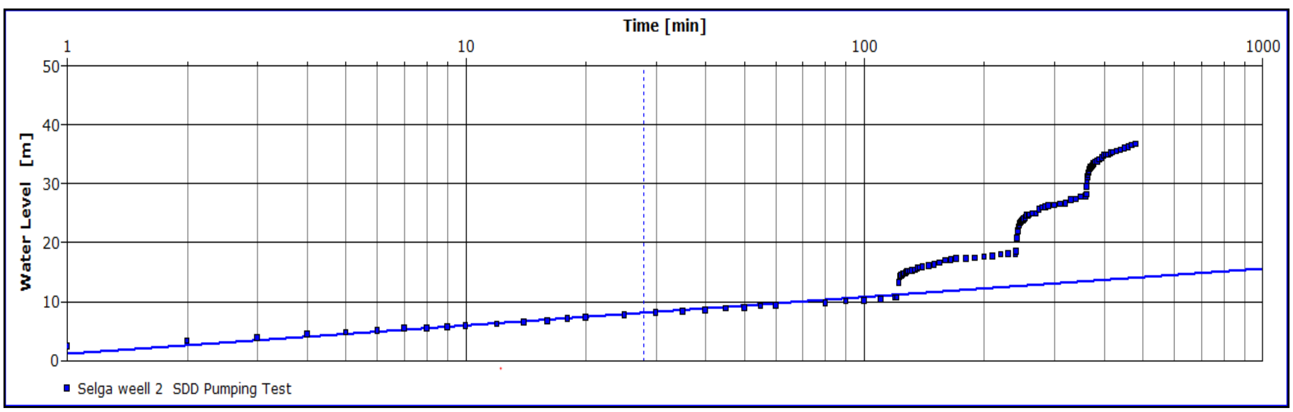
Hydraulic Conductivity (K) can be calculated from both Transmisivity and aquifer thickness or the total length of the screen casings (b). From lithological log of the well, the value of the aquifer thickness is 63.14m. Then by rearranging the equation T=Kb easily hydraulic conductivity can expressed as K=T/b, so K= 9.92m^2/d/ 63.14m= 0.1571m/d**.** From the Neuman analysis method we can see also the calculated values of some parameters like, specific yield, ratio of Sy/s, ratio of Kv/Kh and radial distance to PW.

5.6.1 Aquifer Parameters from Pumping Test of Selga Well 2

Pumping test of Selga well no.2 conducted during 16/05/2011**.** Before pumping test started ,static water level is measured for several times to understand the actual static water level and provisional pumping test for 1 hour has been conducted in order to determine the appropriate discharge rates for the step drawdown (variable) test. For the provisional pumping test of Selga well No.2 the pump is positioned at depth of 55m below the reference point (ground surface) and the pumping is conducted at full capacity of the pump (25 l/sec.) for a period of 8 hour. The observed drawdown with this rate was about 45m and water is recovered to its static water level of 6m within 2 hours.

5.6.2 Aquifer Parameters Step Drawdown Test of Selga 2

After provisional test and recovery of the water level to its initial static water level (SWL) four steps drawdown test (SDDT) has been conducted with variable discharge rate of 12, 16, 20 and 24 l/sec. for duration of 2 hours each. Variable discharge rate test data sheet is presented in the table under (annex 3b). The observed drawdown versus time for each variable discharge rate test curve is here.



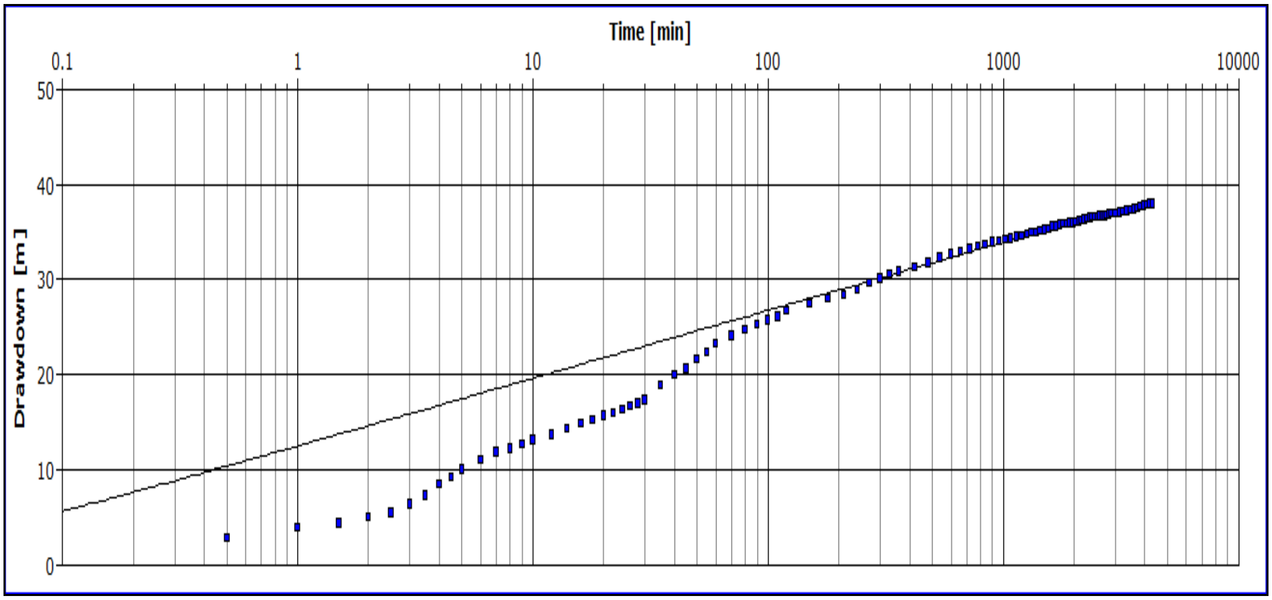
Calculation using Neuman						
Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
Selga weell 2 SDD Pumping Test	2.12×10^{-7}	7.39×10^{-9}	5.50×10^{-4}	2.20×10^{-2}	1.17×10^{1}	0.3

Figure 5.6 Time vs. Water Level of SDDT curve and Hydraulic parameters.

5.6.3 Aquifer Parameters from Constant Discharge Test of Selga well 1

After the provisional test and Step Drawdown test had been conducted, and the well had recovered to acceptable static water table (99% of its static water level), a constant discharge rate test is carried without interruption for a total duration of 72 hours with selected constant pumping rate of 20 l/sec. For this test, the pump was positioned at 56 m below the reference point. The total drawdown

(TDD) measured with this rate 20 l/sec over 72 hours of continuous pumping was 39.63m. Selga well No.2 constant rate test data sheet is given in (annex 3a) and analyzed data curve was shown below in figure 5.12

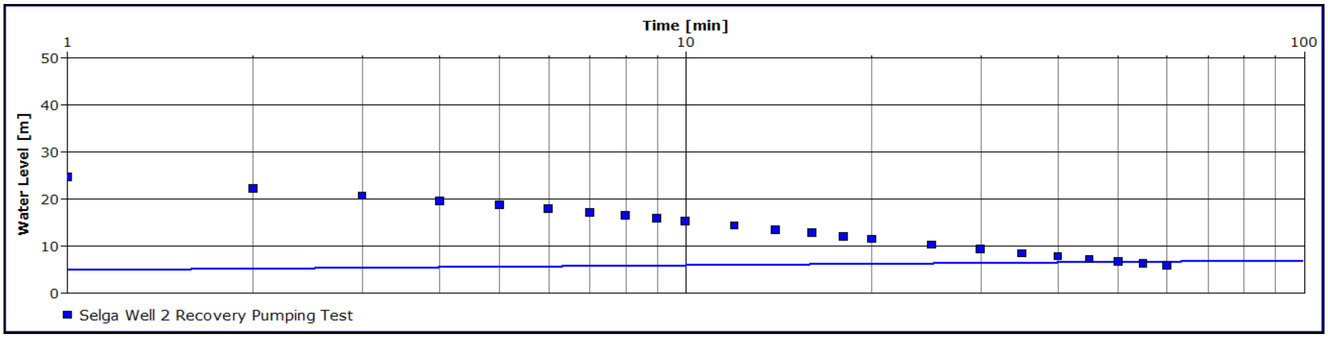


Calculation using Neuman						
Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
Selga well 2 Constant Pumping Test	4.43×10^{1}	1.54×10^{0}	1.33×10^{-1}	6.10×10^{-3}	1.00×10^{1}	0.3

Figure 5.7 Selga well 2 Time vs. Drawdown constant rate curve & Hydraulic parameters

5.6.4 Recovery Test of Selga 2

Recovery test was conducted following the end of the constant discharge test for the period of 4 hours just immediately after pumping had been shut off. With the span of time, the total residual drawdown (RDD) or recovery of the well is 32.62m. Within this duration of time, the well could recover up to 96.68% of the TDD. The recovery test data was shown in an (annex 3c).



Calculation using Neuman						
Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [m]
Selga Well 2 Recovery Pumping Test	8.64×10^{-3}	3.01×10^{-9}	1.97×10^{-29}	1.03×10^{-2}	1.03×10^{2}	0.3

Figure 5.8 Selga well 2 Time vs. Water Level of Recovery rate curve

5.7 Hydraulic Parameters of Selga well # 2 from Constant Yield Test

The results of the analyses of the constant discharge rate & recovery tests, by using Neuman methods are as shown below.

Transmisivity (T) = $4.43x10^1$ $m^2/d=44.3m^2/d$ (from Drawdown vs. Time constant yield test) Hydraulic Conductivity (K) = T/b → $44.3m^2/d/28.70m$ = 1.54355 m/d. Another hydraulic parameters are also calculated from Time vs. Drawdown constant rate curve.

5. 8 Discussions

The rock units that constitute the catchment and play great role as an aquifer are basalts, granites and the other is Quaternary age deposit like alluvial deposits. These rocks get their water bearing nature mainly due to secondary processes which includes fracturing and weathering. As observed from the lithological well logs of the study area, the water bearing layers are due to these secondary processes. In the same rock units of the area where there is no such secondary processes, reservoir rocks cannot be find; this easily seen from lithologic logs of ASU borehole 2 which made the well nonproductive.

Therefore, degree of groundwater productivity in the study area is entirely depends on secondary porosity and permeability that develop as a result of weathering and fracturing.

The Aquifer types of the study is identified through plotting curve from the pumping test with the help of construction diagnostic plots and specialized plots. After plotting the curve and then compare it with different types of aquifer curves, unconfined aquifer is identified and Neumann's curve fitting method is used to determine the hydraulic parameters from the pumping test. Neumann's curve fitting method is a method that used in the unconfined aquifer type. Neuman (1972, 1973, 1979); and Gambolati (1976) according to these authors, Time-drawdown curves of constant pumping test on log-log paper usually show a typical **S**-shape, from which we can recognize three distinct segments that include:

- ❖ The steep early-time segment that covers only a brief period after the start of pumping (often only the first few minutes). At early pumping times, an unconfined aquifer reacts in the same way as a confined aquifer; the water produced by the well is released instantaneously from storage by the expansion of the water and the compaction of the aquifer.
- ❖ The flat intermediate-time segment reflects the effect of the dewatering that accompanies the falling water table and the effect of the dewatering on the drawdown is comparable to that of leakage. After a few minutes to a few hours of pumping, the time-drawdown curve may approach the horizontal and
- ❖ The relatively steep late-time segment reflects the situations where the flow in the aquifer is essentially horizontal again and the time-drawdown curve once again tends to conform to the Theis curve.

So based on this Neumann's curve fitting method, the aquifer types of the study failed beneath unconfined aquifer which is anisotropic. Because, from the result, the ratio of both horizontal and vertical hydraulic conductivity of the aquifer is different from one.

As Alamerew et al. (2003) states hydrogeologic units of the catchment classified into three; namely, the moderately productive fractured aquifers, the dominant basement unit that cover most of the study area and classified as low productive and thirdly aquicludes units. According to the result from pumping test data shows, this statement also true with transmisivity values of 2.76 m^2/d (ASU Well), 9.92 m^2 /d (Selga 1) and 44.3 m^2/d (Selga 2), also with the hydraulic conductivity values of $2.13*10^{-4}$,0.1124 m/d and 1.5434 m/d respectively. Also in the study area to classify the aquifer, depth of the out croups and aquifer thickness also play a significant role; aquifer thickness of the study area is ranged from 28.70 to 63.14m and depth ranged from 57m to 120m and this depth can show us the borehole is a shallow borehole depths.

From these values and geologic units of the catchment, aquifer types of the area is categorized in to three; namely moderately productive fissured aquifer; which is basalt and highly to moderately fractured and weathered.

Therefore, in the study area this unit is the most known aquifer units due to its secondary structures and classified as moderately productive fissured aquifer. The second types of aquifer in the area is Low productive fissured aquifer which known with the units of metagranite, mic-schist, amphibolite, granite and Metasediments. These rock units are classified as basement rocks in which ground water formation is low due to the lack of more secondary structures.

Aquitards are another third types of aquifer in the study area that include metodiorite, serpentinite and para-gneiss (basement rocks) and Trachyte and phonolite from that of igneous rocks.

According to the hydro geological map of Ethiopia by Tesfaye Chernet (1993) and GSE, region of the study has different types of aquifer that based on the productivity of the aquifer and ranges from highly productive fissured aquifer to aquicludes. This classification and that result evaluated from the pumping test data of the study area is compared in the below table.

Reliability of the present study with that the previous work done regional wise which include the study area.		
Aquifer types based on productivity	Hydraulic property values taken from Tesfaye Chernet (1993) & GSE	Hydraulic property values of study area from pumping test data.
Moderately productive aquifer	T=100-10 m^2 /d	T = 44.3 m^2 /d

	K=0.14-62 m/d	K = 1.5434 m/d b = 28.70m depth = 57m
Low productive aquifer	T=10-1 m^2 /d K=0.004-0.14 m/d	T = 9.92-3.0 m^2 /d K = 0.1124 m/d b = 63.14m depth = 102m
Aquitards	T= 0.01 -1 m^2/d	T = $8.64*10^{-8}$ m^2 /d K = 2 .$13*10^{-4}$ m/d b = 40.65m depth = 120m

Table 4.1 comparison of hydraulic values of area with that of Ethiopian Hydrogeological map (Tesfaye Chernet 1993) & (GSE 2004)

From these two comparison, it is clearly seen that the parameters that obtained in the present study is found in between the result interval that is discussed in previous work. This shows that the former study and the recent one is almost similar and no more difference between them; but one which is their difference is that within the study area locally there is no highly productive aquifer types. Regionally this highly productive aquifer type is known with rock units like sandstone and limestone with that of secondary structures. Alamerew et al. (2003). Unfortunately such like units doesn't located specifically at the study area; so no highly productive aquifer find within the study. Generally, the values that investigated from the pumping test data recently verify that the hydraulic values done by Tesfaye Chernet (1993) formerly.

CHAPTER SIX

6. Conclusion and Recommendations

6.1 Conclusions

Precambrian basement rocks are the most units that cover mostly the study area. However, it is not good water bearing due to absence of more secondary structure that govern infiltration to make ground water; for this reason these units ranged as low fissured aquifer to aquitard/aquicludes in the area. Metagranite, granite, and Metasediments are some basement rock types of the study area. Next to basement rocks, the unit that exposed in the catchment is Tertiary volcanic rocks which includes alkaline olivine basalt and can be considered as the main water bearing layer of the study area due to secondary structures. Moderately productive fissured aquifer types of the study area is mainly as a result of alkali olivine basalt units.

Assosa town is located in the 'Kola' climatic zone. It has mean maximum and minimum temperatures of 30.6C° and 15.8C° respectively. The maximum temperature varies between 28.5C° to 30.6C°. While the minimum shuttles between 15.8C° to 18.9C°. The rainy season extends from April to November, but the maximum rainfall occurs in summer season (i.e., between June and August). The geomorphology of the area indicates an outcome of repeated tectonism, with associated intrusion and erosion and the main geomorphologic features are Volcanic Plain, Ridges and Isolated Hills.

The main source of recharge to groundwater in the catchment is from direct precipitation. Indirect recharge from the surface flow of the different perennial rivers and streams to the groundwater of local aquifer is also possible and this infiltrations occur through fractured and weathered zones of basaltic rocks and basement outcrops. Also the loose alluvial sediments along the above river courses are recharged by the rivers, where ever their thickness is sufficient and the water table below river level. In the area Groundwater discharge mainly due to moderate depressions especially in the highlands while its flow direction is controlled by geological structures and geomorphology. Based on the hydrogeological map of the study area, ground water flow direction is the same with that of surface water flow direction; i.e. flow to East and West direction.

Besides, on the base of hydrogeological investigation as well as existing well log data, the main aquifers identified in the study area is fractured and weathered basalts.

Aquifer Types of the study area is unconfined aquifer which is identified with the help of construction diagnostic plots and specialized plots by Neuman method analysis. Time-drawdown curves of constant pumping test on log-log paper usually show a typical S-shape, from which we can recognize three distinct segments: a steep early-time segment, a flat intermediate-time segment, and a relatively steep late-time segment.

Results obtained from pumping test data indicates that the minimum and maximum transmisivity values to be 2.76 and 44.3 (m^2/d) respectively and hydraulic values has minimum and maximum values 0.0677 and 1.544m/d respectively. These results are calculated from the constant pumping test of the well; because, the constant pumping test was more reliable. From both transmisivity values and physiography of the area, the potentiality degree of the catchment aquifer is known; that is moderately productive to low productive fissured aquifers.

6.2 Recommendations

Concerning the study area different recommendations are given that include the following one.

Low success rate of drilling productive wells are the most challenges that encountered in hard rocks environment; due to this, site selection for the well during exploration should be assigned in a proper location before drilling starts in order to overcome non-productivity of the boreholes and to save at least the cost of construction materials and time.

From the study area, it is observed that, some of the boreholes are nonfunctional due to over pumping and most of them haven't recorded data like pumping test data that describes the wells. So, wisely use pumping processes in order to fit the well performance and avoidance of the non-functionality of the wells is recommended for the study area and information that deals about boreholes characteristics should be maintain in order to be understand more about the wells and aquifer types of the catchment.

Appropriate environmental protection measures should be done in an areas with permeable geologic formations like Selga well field and in areas surrounding Assosa where flashing of surface runoff is expected to pollute groundwater. Because of Selga wells are too close to the town, researcher deeply recommend to protect and manage the well fields so as to avoid risk of contamination of the aquifer that can be encountered by inland use activities.

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APPENDIXES

Appendix 1: ASU Well 1 Pumping Test Raw Data Sheet

Annex 1a: Provisional Pumping Test data sheet

Well depth=120 meter		Pump position=98 meter
SWL=2.10 meter		discharge measuring device:- barel & w.meter
Riser Pipe diameter=2"		productive PVC casing diameter =6
Area :-Assosa University		pump type:- submersible pump
		pumping rate=5 lit/sec.
Time since pumping started (min)	Water Level (meter)	Draw Down (meter)
0	2.1	0
1	9.9	7.8
2	13.6	11.5
3	15.3	13.2
4	16.1	14
5	16.6	14.5
6	16.9	14.8
7	17.45	15.35
8	17.97	15.87
9	18.42	16.32
10	18.84	16.74
12	19.59	17.49
14	20.39	18.29
16	20.97	18.87
18	22.98	20.88
20	23.98	21.88

25	27.75	25.65
30	30.6	28.5
35	34.3	32.2
40	37.8	35.7
45	41.2	39.1
50	43.42	41.32
55	45.05	42.95
60	46.64	44.54
70	49.25	47.15
80	51.28	49.18
90	53.31	50.95
100	54.5	52.4
110	55.9	53.8
120	56.02	53.92
130	56.1	54
140	56.23	54.13
150	56.27	54.17
160	56.3	54.2
170	56.48	54.38
180	59.05	56.95

Appendix 1b: ASU well 1 Recovery Test data sheet

Riser pipe diameter=2"		Pump position=98m	
Well depth=120m		productive PVC casing diameter =6"	
		pump type :-submersible pump	
Time since pumping	Time Ratio	Water Level Recovery	Residual Draw Dawn

stopped (Min)	t/t'	(meter)	(meter)
1440	0	77.63	0
1440.5	2881	68.12	66.02
1441	1441	62	59.9
1441.5	961	56.8	54.7
1442	721	56.16	54.06
1442.5	577	56.1	54
1443	481	56.05	53.95
1443.5	412.43	55.98	53.88
1444	361	55.9	53.8
1445.5	321.22	55.76	53.66
1445	289	51.85	49.75
1446	241	46.39	44.29
1447	206.71	40.23	38.13
1448	181	33.64	31.54
1449	161	27.96	25.86
1450	145	23.38	21.28
1452	121	14.76	12.66
1454	103.86	9.35	7.25
1456	91	7.37	5.27
1458	81	6.69	4.59
1460	73	6.38	4.28
1465	58.6	6.06	3.96
1470	49	5.53	3.43
1475	42.14	5.2	3.1
1480	37	5.02	2.92
1490	33.11	4.55	2.45
1500	30	4.26	2.16

1520	27.64	3.87	1.77
1540	25.67	3.67	1.57
1560	22.29	3.29	1.19
1580	19.75	3.14	1.04
1600	17.78	3.04	0.94
1620	16.2	2.95	0.85
1680	14	2.85	0.75

Appendix 1c: ASU well 1 Constant Test data sheet

Area :-Assosa University	pump position =98 meter	
Riser pipe diameter=2"	pump type=submersible pump	
Well Depth=120 meter	pumping = 4 lit/sec	
SWL=2.10meter		
Time since pumping started (min)	Water level (meter)	Draw dawn (meter)
0	2.1	0
0.5	6	3.9
1	9.3	7.2
1.5	10.8	8.7
2	12.15	10.05
2.5	13.1	11
3	13.7	11.6
3.5	14.1	12
4	14.45	12.35
4.5	14.6	12.5
5	14.79	12.69
6	14.97	12.87
7	15.07	12.97

8	15.35	13.25
9	15.7	13.6
10	16.45	14.35
12	16.96	14.86
14	17.85	15.75
16	18.8	16.7
18	20.25	18.15
20	21.88	19.78
25	26.2	24.1
30	29.12	27.02
35	32.89	30.79
40	37.38	35.28
45	40.73	38.63
50	42.84	40.74
55	44.09	41.99
60	44.52	42.42
70	45.96	43.86
80	47.97	45.87
90	50.02	47.92
100	51.9	49.8
120	54.24	52.14
140	55.24	53.14
160	55.95	53.85
180	56.02	53.92
210	56.14	54.04
240	56.44	54.34
270	61.7	59.6
300	64.62	62.52

330	66.35	64.25
360	67.65	65.55
420	71.09	68.99
480	73.8	71.7
540	74.56	72.46
600	74.58	72.48
660	74.8	72.7
720	75.4	73.3
780	75.5	73.4
840	75.69	73.59
900	75.8	73.7
960	75.9	73.8
1020	75.94	73.84
1080	75.95	73.85
1140	76.06	73.96
1200	76.6	74.5
1260	76.63	74.53
1320	76.9	74.8
1380	77.1	75
1440	77.63	75.53

Appendix 2: Selga Well 1 Pumping Test Raw Data Sheet

Annex 2a. Selga Well 1 Constant Pumping Test

Area :- Selga ,Assosa Riser pipe diameter=2" Well Depth=102 meter pump position =98.6 meter pump type=submersible pump	Aquifer thickness=63.14m PWL/DWL=60 m.b.g.l TDD= 53.8 meter

pumping rate= 7 lit/sec SWL=6.05meter								
Time since pumping started (min)	Water Level(m)	DD (m)	Time since pumping started (min)	Water Level(m)	DD (m)	Time since pumping started (min)	Water Level(m)	DD (m)
0	6.05	0	100	30.5	24.4	1680	43.6	37.6
0.5	11.95	5.9	110	30.7	24.6	1740	44.1	38.1
1	12.9	6.85	120	30.8	24.71	1860	45.1	39
1.5	15.15	9.1	150	31.1	25	1920	46.6	40.5
2	16.52	10.47	180	31.3	25.25	1980	47.3	41.3
2.5	17.7	11.65	210	31.8	25.77	2040	48	42
3	18.5	12.45	240	31.9	25.86	2100	48.9	42.9
3.5	19.05	13	270	32	25.95	2160	49.7	43.6
4	19.6	13.55	300	32.4	26.35	2220	50.3	44.2
4.5	20.3	14.25	330	32.5	26.43	2280	51.1	45.1
5	21.4	15.35	360	32.5	26.45	2340	52	45.9
6	22.65	16.6	420	32.6	26.55	2400	52.7	46.6
7	23.15	17.1	480	33.1	27.05	2460	53.1	47.1
8	23.7	17.65	540	33.4	27.35	2520	54	47.9
9	24.06	18.01	600	33.7	27.6	2580	54.6	48.6
10	24.45	18.4	660	33.7	27.66	2640	55.1	49
12	25.12	19.07	720	33.8	27.75	2700	55.7	49.7
14	25.63	19.58	780	34.4	28.3	2760	56.1	50
16	26	19.95	840	34.9	28.81	2820	56.8	50.8
18	26.33	20.28	900	35.2	29.1	2880	57.2	51.1
20	26.6	20.55	960	35.7	29.69	3000	58.4	52.4
22	26.9	20.85	1020	36.1	30.05	3120	58.6	52.6

24	27.03	20.98	1080	36.7	30.62	3240	58.8	52.8
26	27.21	21.16	1140	37	30.95	3360	59	53
28	27.42	21.37	1200	37.5	31.42	3480	59.3	53.3
30	27.57	21.52	1260	37.8	31.75	3600	59.4	53.3
35	27.9	21.85	1320	38	31.95	3720	59.4	53.4
40	28.2	22.15	1380	38.1	32.05	3840	59.5	53.4
45	28.45	22.4	1440	38.3	32.25	3960	59.6	53.5
50	28.56	22.51	1500	38.4	32.35	4080	59.6	53.6
55	28.76	22.71	1560	38.5	32.43	4200	59.7	53.7
60	29	22.95	1620	39.5	33.45	4320	59.8	53.8
70	29.37	23.32						
80	29.7	23.65						
90	30.13	24.08						

Appendix 2b. Selga Well 1 Recovery Pumping Test

	Step 1 (Q=4 l/sec		Step 2(Q=6 l/sec)		Step 3(Q=8 l/sec.)		Step 4(Q=10 l/sec.)
Time (min)	WL (m.b.g.l) DD(M)	Time (min)	Wl (m.b.l) DD (m)	Time (min)	Wl (m.b.g.l) DD (m)	Time (min)	Wl (m.b.g.l) DD (m)
0	6.05	120.5	16.06	240.5	24.01	360.5	49.5
0.5	9.35	121	17	241	25.5	361	51.05
1	13.1	121.5	17.6	241.5	26.96	361.5	53.45
1.5	13.1	122	18.3	242	28.4	362	55.65
2	13.1	122.5	18.83	242.5	29.3	362.5	56.85
2.5	13.1	123	19.17	243	30.32	363	58.8
3	13.08	123.5	19.46	243.5	31.25	363.5	62.6

3.5	13	124	19.86	244	32.2	364	63.35
4	13.06	124.5	19.97	244.5	32.96	365	63.7
4.5	13.26	125	20.2	245	33.8	366	64.95
5	13.55	126	20.3	246	34.46	367	66.1
6	13.9	127	20.56	247	35.1	368	69.1
7	13.97	128	20.72	248	36	369	71
8	14.05	129	20.85	249	37.1	370	72.43
9	14.07	130	20.95	250	38.12	372	73.65
10	14.09	132	21.03	252	38.91	374	74.8
12	14.14	134	21.17	254	39.8	376	75.4
14	14.54	136	21.25	256	40.54	378	77.85
16	14.9	138	21.35	258	41.1	380	80.05
18	15.02	140	21.41	260	41.55	382	80.2
20	15.12	142	21.51	262	41.86	384	80.55
22	15.18	144	21.55	264	42.26	386	81.2
24	15.2	146	21.6	268	42.64	388	81.9
26	15.25	148	21.63	270	43.05	390	82.4
28	15.26	150	21.65	275	43.5	400	82.8
30	15.28	155	21.68	280	43.82	410	84.4
35	15.35	160	21.7	285	44.6	420	83.1
40	15.43	165	21.8	290	45.45	430	82.8
45	15.56	170	21.97	295	46.07	440	83.96
50	15.62	175	22	300	46.5	450	82.9
55	15.68	180	22.07	305	46.6	460	82.72
60	15.72	185	22.24	310	46.8	470	83.95
70	15.77	190	22.65	315	47.3	480	84
80	15.85	200	22.22	320	47.5		
90	15.92	210	22.29	330	48.21		

100	15.93	220	22.36	340	48.5		
110	15.98	230	22.42	350	48.85		
120	16.08	240	24.01	360	49.5		

Appendix 2c: Selga Well 1 Step Drawdown Pumping Test

Time since pumping started (min)	Water Level(m)	DD (m)	Time since pumping started (min)	Water Level(m)	DD (m)
0	59.8	53.75	22	10.8	4.75
0.5	52	45.95	24	10.65	4.6
1	46.65	40.6	26	10.5	4.45
1.5	41.4	35.35	28	10.35	4.45
2	36.7	30.65	30	10.15	4.3
2.5	31.05	25	35	9.9	4.1
3	28.67	22.62	40	9.67	3.85
3.5	26.6	20.55	45	9.45	3.62
4	24.5	18.45	50	9.23	3.4
4.5	23	16.95	55	9.2	3.18
5	21.25	15.2	60	9.15	3.15
6	19	12.95	70	9.08	3.03
7	17.3	11.25	80	8.9	2.85
8	15.8	9.75	90	8.7	2.65
9	14.75	8.7	100	8.65	2.6
10	13.95	7.9	110	8.45	2.4
12	12.9	6.85	120	8.3	2.25
14	12.1	6.05	150	8.18	2.13
16	11.65	5.6	180	8.05	2
18	11.33	5.28	210	7.92	1.87
20	11.05	5	240	7.8	1.75

Appendix 3: Selga Well 2 Pumping Test Raw Data Sheet

Appendix 3a. Selga Well 2 Constant Pumping Test Data Sheet

Time (mi)	Water Level (m.b.g.l)	Drawdown (m)	Time (mi)	Water Level (m.b.g.l)	Drawdown (m)	Time (mi)	Water Level (m.b.g.l)	Drawdown (m)
0	4.34	0	90	31.2	26.86	1680	41.63	37.29
0.5	8.8	4.46	100	31.7	27.36	1740	41.72	37.38
1	9.85	5.51	110	32.1	27.76	1800	41.8	37.46
1.5	10.4	6.06	120	32.75	28.41	1860	41.85	37.51
2	11.05	6.71	150	33.4	29.06	1920	41.9	37.56
2.5	11.46	7.12	180	33.92	29.58	1980	41.95	37.61
3	12.4	8.06	210	34.35	30.01	2040	42.03	37.69
3.5	13.25	8.91	240	34.95	30.61	2100	42.1	37.76
4	14.42	10.08	270	35.6	31.26	2160	42.21	37.87
4.5	15.16	10.82	300	36.1	31.76	2220	42.3	37.96
5	16.02	11.68	330	36.55	32.21	2280	42.39	38.05
6	17	12.66	360	36.8	32.46	2340	42.46	38.12
7	17.8	13.46	420	37.3	32.96	2400	42.5	38.16
8	18.2	13.86	480	37.7	33.36	2460	42.56	38.22
9	18.65	14.31	540	38.2	33.86	2520	42.6	38.26
10	19.1	14.76	600	38.6	34.26	2580	42.65	38.31
12	19.7	15.36	660	38.9	34.56	2640	42.68	38.34
14	20.3	15.96	720	39.15	34.81	2700	42.71	38.37
16	20.8	16.46	780	39.47	35.13	2760	42.78	38.44
18	21.2	16.86	840	39.6	35.26	2820	42.82	38.48
20	21.6	17.26	900	39.85	35.51	2880	42.87	38.53
22	21.955	17.61	960	40	35.66	3000	42.97	38.63

24	22.27	17.93	1020	40.17	35.83	3120	43.07	38.73
26	22.6	18.26	1080	40.34	36	3240	43.1	38.76
28	22.9	18.56	1140	40.47	36.13	3360	43.15	38.81
30	23.3	18.96	1200	40.62	36.28	3480	43.26	38.92
35	24.85	20.51	1260	40.74	36.4	3600	43.4	39.06
40	26	21.66	1320	40.85	36.51	3720	43.49	39.15
45	26.65	22.31	1380	40.96	36.62	3840	43.67	39.33
50	27.65	23.31	1440	41.08	36.74	3960	43.72	39.38
55	28.3	23.96	1500	41.15	36.81	4080	43.8	39.46
60	29.3	24.96	1560	41.35	37.01	4200	43.9	39.56
70	30.1	25.75	1620	41.5	37.16	4320	43.97	39.63
80	30.7	26.36						

Appendix 3b. Selga Well 2 Step Drawdown Pumping Test Data Sheet

Time (min)	step 2 Q=16 l/s	Time (min)	Step 3 Q =20 l/s	Time (min)	Step 4 Q =24 l/S
	water level (m)		water level (m)		Water level (m)
121	16.6	241	24.45	361	34.15
122	19.2	242	26.7	362	35.5
123	20.15	243	27.93	363	36.5
124	20.4	244	28.6	364	37.1
125	20.55	245	29	365	37.45
126	20.7	246	29.25	366	37.85
127	20.8	247	29.4	367	38.1
128	21	248	29.5	368	38.43
129	21.1	249	29.64	369	38.55
130	21.1	250	29.75	370	38.7
132	21.2	252	29.95	372	38.8

134	21.3	254	30.2	374	39.05
136	21.6	256	30.5	376	39.25
138	21.7	258	30.6	378	39.45
140	21.85	260	30.7	380	39.64
145	22	265	30.8	385	39.78
150	22.25	270	30.9	390	40.05
155	22.5	275	31.6	395	40.34
160	22.9	280	31.9	400	40.8
165	23.05	285	32	405	40.85
170	23.2	290	32.2	410	40.9
180	23.3	300	32.3	415	41.1
190	23.37	310	32.5	420	41.3
200	23.5	320	32.6	430	41.45
210	23.7	330	33.2	440	41.7
220	23.9	340	33.3	450	41.9
230	24	350	33.7	460	42.15
240	24.1	360	33.8	470	42.46
				480	42.75

Appendix 3c. Selga Well 2 Recovery Pumping Test Data Sheet

Time since pumping stopped (min)	water level(m.b.g.l)	Residual DD
0	48.85	45.85
1	30.7	27.7
2	28.2	25.2
3	26.7	23.7
4	25.6	22.6
5	24.75	21.75
6	23.9	20.9

7	23.1	20.1
8	22.5	19.5
9	21.9	18.9
10	21.3	18.3
12	20.35	17.35
14	19.5	16.5
16	18.8	15.8
18	18.1	15.1
20	17.55	14.55
25	16.3	13.3
30	15.35	12.35
35	14.5	11.5
40	13.8	10.8
45	13.25	10.25
50	12.7	9.7
55	12.4	9.4
60	12	9

Appendix 4: Pumping Test Data Results

Well Name	UTM E	UTM N	Hydraulic Parameters	Aquifer Type
Selga Well 1	670178	1114182	Transmisivity (T)=9.92*10^0 m^2/d	Unconfined
	>>	>>	Hydraulic Conductivity (K)=0.1571 m/d	
	>>	>>	Specific yield (Sy) = 5.00*10^{-1}	
	>>	>>	Duration of pumping (t) = 72 hrs.	
	>>	>>	Rate of pumping (Q)=7 l/sec.	
	>>	>>	SWL (m)=6.05m	
	>>	>>	Well depth =102m	
	>>	>>	TDD=53.75m	
	>>	>>	PWL (DWL) =60M.b.g.l	

	>>	>>	Aquifer thickness 63.14m	
	>>	>>	Elevation =1555m	
Selga Well 2	6700561	1114186	Transmisivity (T)=$4.43*10^1$ m^2/d	Unconfined
	>>	>>	Hydraulic Conductivity (K)=1.544m/d	
	>>	>>	Specific yield (Sy) =$1.33*10^{-1}$	
	>>	>>	Duration of pumping (t) = 72 hrs.	
	>>	>>	Rate of pumping (Q)=20 l/sec.	
	>>	>>	SWL (m)=6m	
	>>	>>	Well depth =57m	
	>>	>>	TDD=39.63m	
	>>	>>	PWL (DWL)=43.5m	
	>>	>>	Aquifer thickness 28.70m	
	>>	>>	Elevation =1550m	
ASU Well 1	673069	1120704	Transmisivity (T)=$2.76*10^0$ m^2/d	Unconfined
	>>	>>	Hydraulic Conductivity (K)=$6*10^{-2}$m/d	
	>>	>>	Specific yield (Sy) =$5.00*10^{-1}$	
	>>	>>	Duration of pumping (t) = 24 hrs.	
	>>	>>	Rate of pumping (Q)=4 l/sec.	
	>>	>>	SWL (m)=2.10m	
	>>	>>	Well depth =120m	
	>>	>>	TDD=75.53m	
	>>	>>	Aquifer thickness 40.65m	

Appendix 5: Lithological Log of the Wells

Annex 6a. Lithological log of the well site Amba 08 Kebele (Assosa University).

Lithological log of the well site Amba 8 Kebele (ASU)			
Depth penetrated(meter)	Lithological Description	Longitude	Latitude

0-2m	silt (clay soil)	673069 E	1120704 N
2-14m	Top soil mixed with highly rounded gravel to boulder size materials		
14-22m	Highly fractured volcanic (basalt rock the first aquifer)		
22-32m	slightly massive basalt		
32-38m	slightly fractured basalt		
38-54m	slightly massive basement rocks		
54-70m	Fractured like mud dominantly granite the second aquifer		
70-80m	Highly massive granite		
80-98m	Slightly fractured granite		
98-104m	Fractured like mud dominantly granite		
104-108m	Highly massive basement rocks		
108-120m	Highly massive basement rocks		

Annex 6b. Lithological log of the well site Amba 05 Kebele (Assosa University).

Depth Penetrated (Meters)	Lithological Description
0-3	Top soil (clay soil)
3-6	Highly weathered (clay soil)
6-9	Slightly massive basalt
6-44	Highly massive basalt
44-60	Highly massive to boulder basalt

Annex 6c. Lithological log of the well site Selga 1.

No	Depth Range (m)	Geological description
1	0-2m	Gray silty clay soil

2	2-4m	Sticky black silty clay soil
3	4-6m	Sticky yellow clay soil
4	6-16m	Sticky reddish clay soil
5	16-22m	Completely weathered yellowish basalt (aquifer)
6	22-30m	Highly weathered basalt (aquifer)
7	30-34m	Moderately weathered basalt
8	34-38m	Slightly weathered basalt
9	38-58m	Dominantly massive basalt with thin layers slightly weathered basalt.
10	58-64m	Massive basalt
11	64-70m	Moderately weathered basalt (aquifer)
12	70-78m	Massive basalt
13	78-84m	Moderately weathered basalt
14	84-86m	Moderately to highly weathered and fractured basalt.
15	86-92m	Fractured basalt with quartz vein
16	92-94 m	Massive basalt
17	94-95m	Slightly weathered granite
18	95-102m	Massive granite

Annex 6d. Lithological log of the well site Selga 2.

No.	Depth range (m)	Geological description
1	0-2	Black cotton clay soil
2	2-20	Reddish ,sticky ,wet, clay soil
3	20-26	Fine alluvial gravel deposit (aquifer)
4	26-40	Massive basalt
5	40-50	Moderately weathered and fractured basalt
6	50-52	Highly fractured basalt
7	52-57	Massive granite

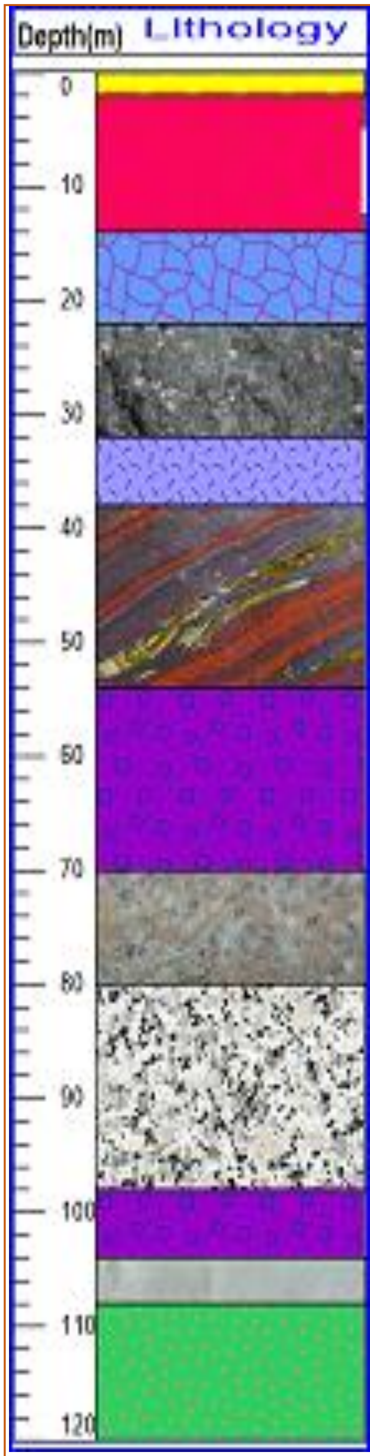
Appendix 7 Water Point data of the study area

No	Well site	Pump type	Yield of water l/sec	SWL (meter)	KW	Depth {m}	Year of construction	Pipe inch	Status
1	No.1(near Water bureau store	Submersible	3.5	50	7.5		1977	2	**NF**
2	No.5 hospital	>>	5.6	70	13	90	1988	2	F
3	No.6 behind meteorology	>>	6.5	70	22	95	1995	2	F
4	No.7 behind meteorology	>>	7.5	70	22	110	1999	2	F
5	No.8 near new asphalt bridge on Selga river	>>	7.5	70	22	110	2003	3	F
6	No.9 behind new high school	>>	19	110	30	58	2003	4	F
7	Amba1, No.1		7.5	50	7.5	90	1996	2.5	NF
8	Amba1, No.2	>>	7.5	50	7.5	90	1996	2.5	F(but less)
9	Amba1Gefi No.1	Service	80	70	50	-	1996	4	F
10	Amba1 No.2	>>	80	70	50	-	-	4	F
11	M/church No.1	>>	60	70	30	-	1996	3	F
12	M/churchNo.	>>	60	70	30	-	1996	3	F

	2								
13	M/churchNo. 3	>>	60	70	30	-	1996	3	F
14	ASU Well 1	>>	-	-	-	60	2008	-	NF
15	ASU Well 2	>>	7	98	13	120	2008	2	F
16	Selga 1	>>	7	96	13	102	2011	2	F
17	Selga 2	>>	20	34	15	57	2011	2	F
18	Hoha 1	>>	6	-	-	95	2001	-	F
19	Hoha 2	>>	4.99	-	-	94	2001	-	NF
20	Selga 5	>>	5.05	-	-	60	1995	-	NF
21	Selga 6	>>	4.17	80	7.5	84	1995	-	F
22	Selga 7	>>	6.0	90	9.5	94	2003	-	F

Appendix 8 Lithological Logs of the Wells as built Profile

Appendix 8a ASU Well 1 as built profile



Lithology descriptions

Silt (clay soil)

Top soil mixed with highly rounded gravel to boulder size materials

Highly fractured Volcanic (basalt rocks the 1rst aquifer)

Slightly Massive basalt

Slightly fractured basalt

Slightly massive basement rocks

Fractured like mud dominantly granite (2nd aquifer)

Highly massive granite

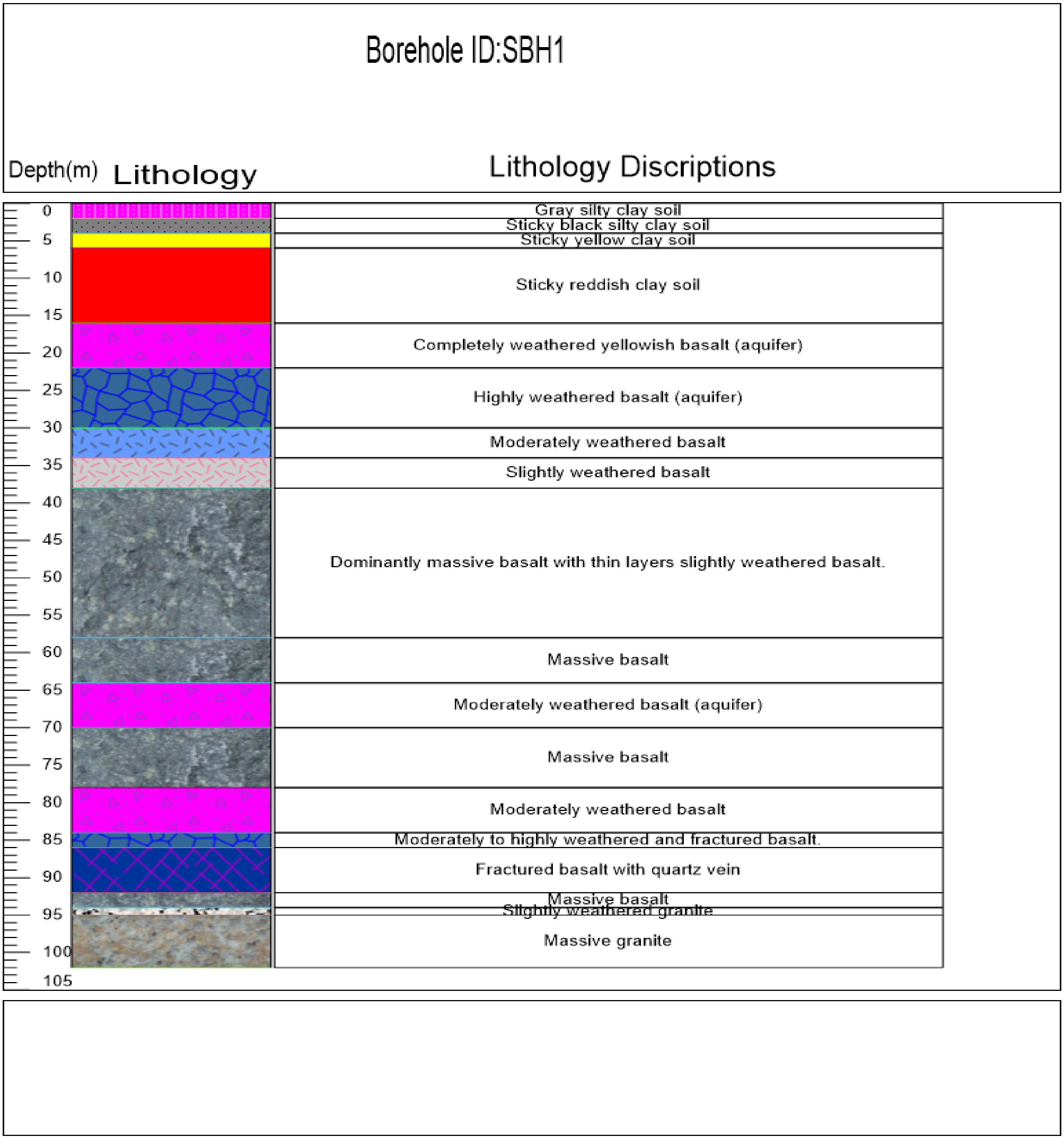
Slightly fractured granite

Fractured like mud dominantly granite

Highly massive basement rocks

Highly massive or powder basement rocks

Appendix 8b Selga Well 1 as built profile



Appendix 8c Selga Well 2 as built profile