Addis Ababa University

School of Graduate Studies

DEPARTMENT OF EARTH SCIENCES

HYDROGEOLOGY STREAM

Ground Water Resource Evaluation and Management Practices in Gilgel Abay Catchment, Tana Basin

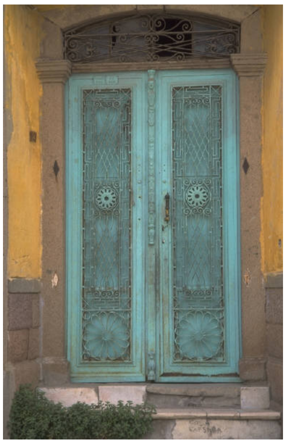
A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment for the Degree of Master of Science in Hydrogeology

BY BERUKE ABEL

JANUARY,2010

ADDIS ABEBA

Inside Story Headline



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This would be a good place to insert a short paragraph about your organization. It might include the purpose of the organization, its mission, founding date, and a brief history. You could also include a brief list of the types of products, services, or programs your organization offers, the geographic area covered (for example, western U.S. or European markets), and a profile of the types of customers or members served.

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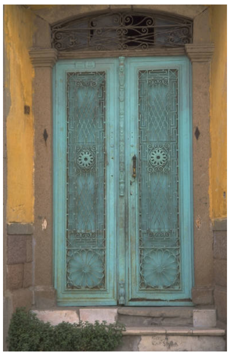

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If space is available, this is a good place to insert a clip art image or some other graphic.

Organization

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ACRONYMS

AET – Actual Evapotranspiration

AWWCE – Amhara Water Works Construction Enterprise

DWS – Domestic Water Supply

EGS – Ethiopian Geological Survey

EMA – Ethiopian Mapping Agency

FAO – Food and Agriculture Organization

HWEA – House Hold Water Economy Analysis

ITCZ – Inter Tropical Convergence Zone

JICA - Japan International Cooperation Agency

MoWR – Ministry of Water Resource

NGO - Non-Governmental Organization

NMSA - National Meteorology Service Agency

PA - Peasant Association

PET - Potential Evapotranspiration

SAR - Sodium Adsorption Ratio

UNICEF - United Nations Children's Fund

VES – Vertical Electrical Sounding

WATSAN - Water Supply and Sanitation

WHO - World Health Organization

WSS - Water Supply Schemes

RWSS- Rural Water Supply Schemes

Acknowledgement

First of all I would like to thank "Almighty God "who made it possible to begin and to finish this work successfully. My heart felt gratitude goes to my blessed mother St.Marry, for her invaluable help and support.

Special thanks go to my advisor Dr.Seifu Kebede for his support, guidance, encouragement, and comments to do my research from the very beginning of the research work. I would like to greatly acknowledge Dr.Tenalem Ayenew for his cooperation by giving me important reading material and suggestions.

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Beruke Abel

Abstract

Groundwater resource is the most important natural resource in the study area. The rapidly increasing agriculture, industry and domestic water supply requirements in the study area meet mainly from groundwater. Groundwater is usually protected against contamination from the surface by soils and covering rock layers. This why most drinking water in many areas of the world is groundwater.

Due to steep increase in population along with the associated activities, the water demand for groundwater in the study area is maximized from time to time. However, water can be constraint if not properly managed and developed. Even though the water supply coverage of the study area is increases, a significant number of the water supply schemes in the catchment are non functional due to different reasons, which implies that no effective system of groundwater management practices in the area.

The main objective of the present study is to evaluate the groundwater potential of Gilgel Abay catchment and to assess management issues in the catchment. To achieve this objective recharge to the groundwater was estimated based soil-water balance method and a value of approximately 489mm annual recharge to the catchments' aquifer was obtained. In the catchment two aquifer systems were identified based the available well log data and pumping test data namely: Quaternary vesicular basalt and Tertiary scoracious basalt. The groundwater flow direction, recharge area, and discharge area were identified using chemical plotting of trends of major ions, TDS and EC. As the groundwater moves from recharge to discharge areas along its path it evolved from Ca^{2+}-HCO_3 type to Na^+-HCO_3 type.

Concerning the management practices, five representative woredas with their respective PA which can characterize the whole water supply problem of the catchment were chosen for house hold water economy analysis. Findings of the study reveal that there are about 354 water supply points, out of which 94 non functional. Lack of skilled manpower, poor construction and maintenance, poor planning and management practices, low community participation are the main problems regarding the water supply schemes. Findings of the study also indicate high community participation, wide investment opportunity for private sector, capacity building of professionals and accountability and transparency of government officials are the main factors to sustain water supply schemes.

1 INTRODUCTION

1.1Background

Groundwater resource is the most important natural resource in the study area. The rapidly increasing domestic, agriculture, and industry water supply requirements in the study area meet mainly from groundwater. However, due to the steep increase in population along with associated activities; groundwater is becoming a scarce resource coupled with deterioration in water quality.

The water demand in the Gilgel Abay catchment is increased from time to time. Yet water resources are limited if not properly managed. Groundwater management practices in the catchment are not adequately developed. Even though the water supply coverage of the area increases, a significant number of the water supply schemes in the catchment are non functional due to various reasons. This implies that no effective system of groundwater management practices in the study area.

In the study area there is no detail work on groundwater. However, some regional groundwater investigation works were performed by different organization. In the present study the groundwater potential of the catchment will be evaluated and also related groundwater management practices in the catchment are discussed.

1.2 Previous Works

There are different researches on groundwater in the study area .The major investigations in the study area include:

Hydrological study of the Tana-Beles sub-basins conducted by SMEC, September, 2007, is the major one. In this work groundwater investigation in regional scale is performed.

Regional hydrogeological investigation of Northern Ethiopia, including 1:100.000 hydrogeological map. This report provides an inventory of drilled bores, hand dug wells and springs in the study area, including Tana basin.

Abay basin master plan, Phase 2: sectoral studies, part 3, hydrogeology (February 1998). This paper describes the geology and aquifers in the Blue Nile basin, including data sources, groundwater discharge to streams based on base flow analysis.

Groundwater resources in Lake sub-basin and adjacent areas rapid assessment and terms of reference for future study (2007).The draft report, conducted for the World Bank, provides an overview of the hydrogeology of the Tana basin. It summarizes groundwater information available from a number of reconnaissance groundwater studies, notably Bahir Dar, Dangila, Debre Tabor and Worota towns. The report suggests that there is potential for development of groundwater in locations around Lake Tana. Although it recognizes that the groundwater systems are not studied in detail, it outlines the terms of reference for a detailed hydrogelogical study of the region.

Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia (kebede et al., 2006). As part of detailed lake water balance investigation, it was suggested that the likely groundwater flow direction is from surrounding areas towards the lake. Although the groundwater component is considered to be only a minor component of the water balance, preliminary isotope studies suggest less than seven percent of the total inflow is groundwater.

Groundwater recharge, circulation and geochemical evolution in the source region of the Blue Nile River, Ethiopia (Kebede et al., 2005).The paper uses isotope and geochemical data, mainly form springs and hand dug wells to identify that recharging groundwater migrates through short local groundwater flow paths to discharge as low TDS (Ca-Mg-HCO_3 dominated) groundwater. Deeper, more regional flow systems have greater residence time in the aquifer and undergo geochemical alterations to generate higher TDS (Na-HCO_3 dominated) waters. Deeper flow systems and resultant hydrochemistry are influenced by structural effects from basin faulting.

The Tana Basin, Ethiopia, intra-plateau uplifts, rifting and subsidence (Chorowiciz et al., 1998).This paper uses remote sensing and structural analysis to describe major structural features of the Lake Tana basin. The paper indicates that the Tana basin occurs perched with in a large dome uplifted in Ethiopian plateau. Basin subsidence occurred at the focus of three converging half-grabens and is expressed in the dip and strike of the basaltic lavas and has affected the late Oligocene flood basalt pile. This structural complexity was active during the build-up of the mid Tertiary basalts. The Tana basin is impressed into the Tertiary basalts. Fault reactivation occurred in the Late Miocene-Quaternary, accompanied locally by predominantly basaltic volcanism. Fault-slip indicators are consistent with crustal subsidence centered on the present morphologic basin.

The structure of a Mesozoic basin beneath the Lake Tana area, Ethiopia, revealed by Magnetotelluric imaging, Hautot et al, (2005).The paper describes a Magneto-telluric geophysical investigation of a traverse along the southeast of the Gilgel Abay catchment and along the Debretabor graben. A 1.5-2 km thick sequence of Mesozoic sediments intruded by Tertiary dykes and sills was identified in a NW-SE trending half-graben structure. The Mesozoic sediments are overlain by 250m thick of basalts.

Inventory of water supply schemes database management, by Abay Engineering. This paper describes water supplies schemes and sanitation matter in the Amhara region.

1.3 Objectives of the Study

1.3.1 Main objective

The main objective of this research is to evaluate the groundwater resource potential of Gilgel Abay catchment and to assess management practices in the catchment.

1.3.2 Specific objectives

The specific objectives on groundwater resource evaluation include:-

- Groundwater recharge estimation
- Aquifer characterization
- Determination water quality and groundwater geochemistry

The specific objectives on groundwater management practices include:-

- To investigate management practices
- To estimate groundwater use for domestic, agriculture, and industry
- To assess appropriate water lifting technology need
- To investigate the status of water supply schemes

1.4 Research Methodology

1.4.1 Methodology followed to evaluate groundwater resources

The research work begins with identifying the problem and defining the purpose, scope and scale of the study.

1) Data Collection and Interpretation
    - ➢ Acquisition and reviewing of previous maps, report and data
    - ➢ Acquisition and interpretation of topographic maps
    - ➢ Acquisition and interpretation of metrological data
    - ➢ Acquisition and interpretation of hydrological data

- Acquisition and interpretation of well log and pumping test data

2) Field Work

From the field the following information can be obtained

- In situ chemical parameters
- Collecting water samples and referencing water points
- Verifying geological set up of the area

3) Analysis and Report Writing

The analysis and interpretation were carried out by using different softwares like Arc GIS 9.2, Global mapper 8, Surfer 8 Aquachem, etc.

1.4.2 Methodology followed to assess management practices

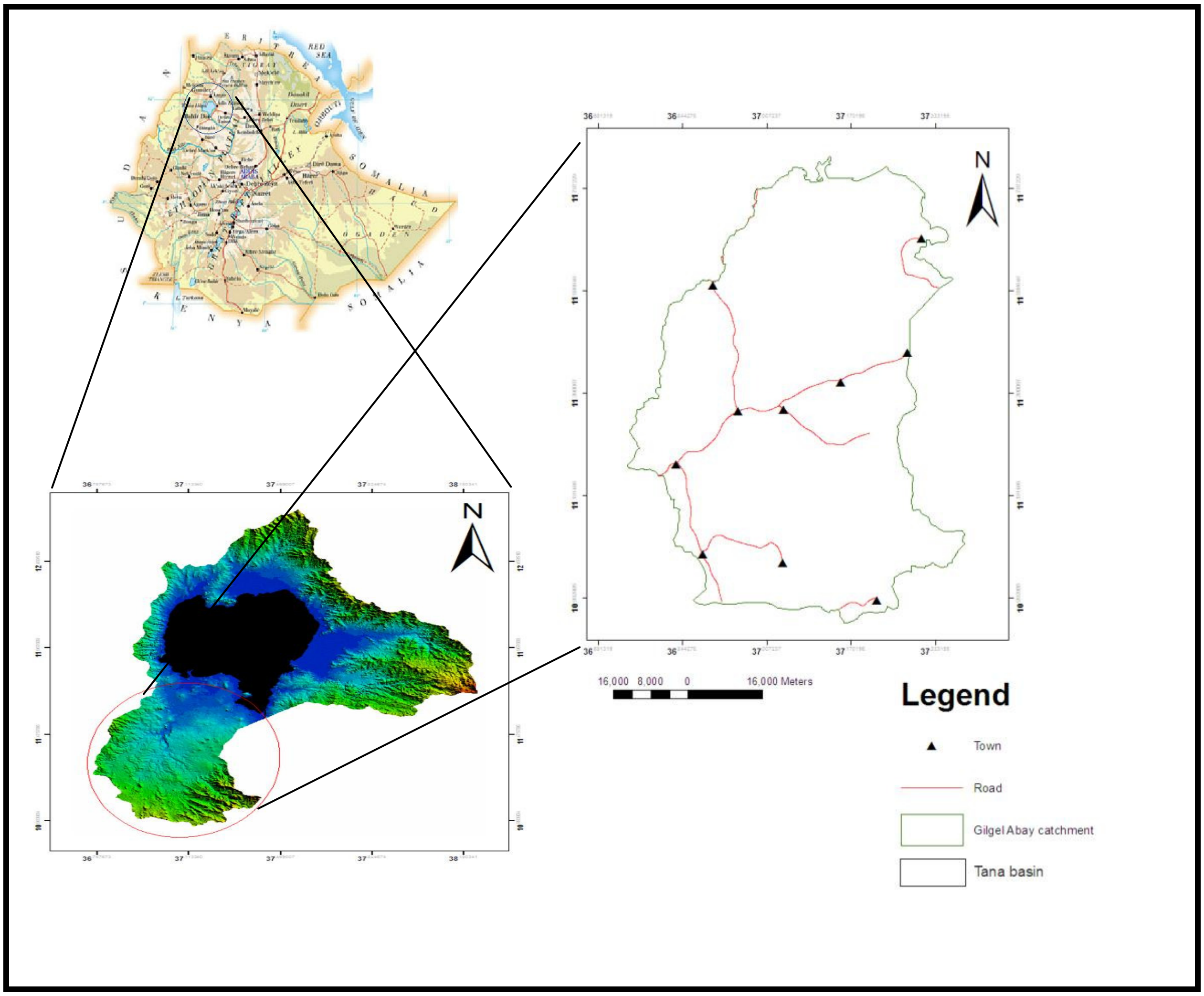
- Project documentation – a review of existing documentation held by different agencies
- Focus group discussion – conducted with the community members to give an overview of the level of community utilization, management and administration of ground water
- Key informant interviews – Data and information about the beneficiary's perception of water supply sustainability problems were collected using different methods of data collection; like structured questionnaire, interviews and discussions with beneficiaries, members of different water committees, technical staff members, and personal observations were employed to produce primary data.

2 DESCRIPTION OF THE STUDY AREA

2.1 LOCATION

The Gilgel Abay catchment is located in the Lake Tana sub-basin of upper Blue Nile basin. It is found on the basaltic plateau of north western part of the Ethiopian highlands. The study area is located in two administrative zones of Amhara region, namely West Gojam and Awi zone. Specifically the catchment area is bounded between latitude 10^0 57' 24.27''N (1210239mN) to $11^0$48'59.20''E (1306445mN) and longitude from37^0 09' 42.34'' (298862mE) to 37^0 14' 15.78'' E (308167mE).

Fig 2.1 Location map of the study area



2.2 TOPOGRAPHY

The Gilgel Abay catchment topographically characterized by rugged plateau plains having highest peak on its origin at Gish Abbay an altitude of 2728m abs. while its northern end part decreases to 1789m near Lake Tana around Bahir Dar.The main topographic feature of the area is the Gilgel Abay river, which rises in elevated terrain that occurs off the flanks of Mt. Choke and flows across largely basaltic terrain in to lake Tana. It is believed that the actual present geomorphic surface configuration of the area is the result of structural processes as faulting and uplifting during the Tertiary period. Its formation resembles the uplifting and faulting the western highlands of Ethiopia that occurred during the upper Eocene period. Close to the Lake, around Bahir Dar, the Gilgel Abay catchment landscape contains numerous well preserved Quaternary volcanic cones comprising basalt, scoria and volcanic ash. In this area, there are also very rocky outcrops standing above the plains with low lying, often swampy ground between the outcrops (SMEC, 2007).

The depression plains around Asabila River in this catchment are formed from the alluviums of the recent alluvial flats and swamps .There are also a number of flood plain areas scattered in between the basaltic flows formed by the interaction of several processes and erosional surface.

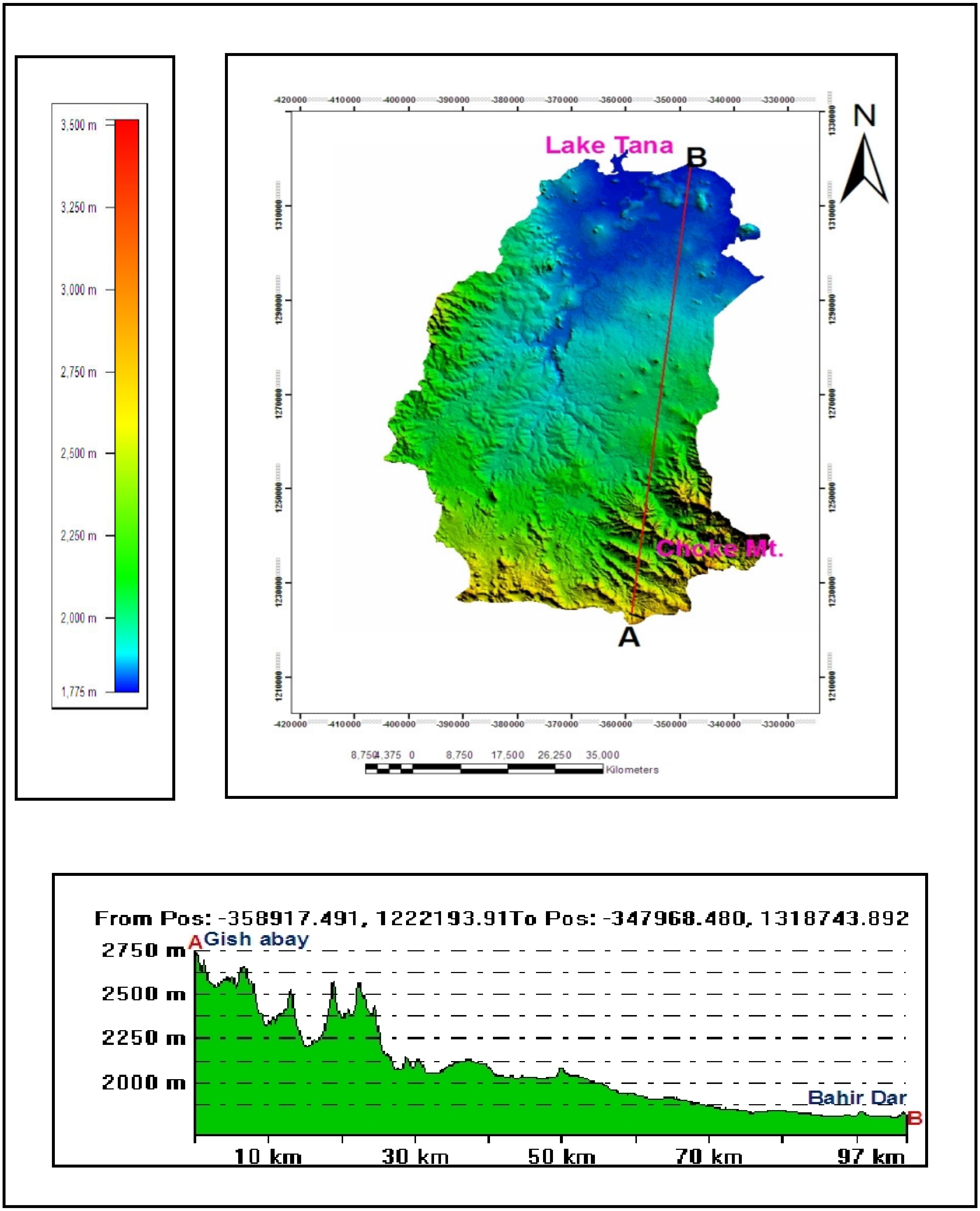


Fig 2.2 Topography of the study area

2.3 DRAINAGE PATTERN

The Gilgel Abay catchment covers the southern part of the Lake Tana sub-basin. This catchment covers a total area of 4557.8 km^2 .The Gilgel Abay river has a number small tributaries. It is mainly drained by river Koga around Merawi and river Kiliti that joins downstream before flowing in to the Lake. Some other tributaries include Hawashe, Gudbela, Andod and Amerit. The area of the catchment is covered with the volcanic rock which is vesicular basalt of plain topography with very low drainage network. Gilgel Abay River, where almost all its watershed is found in this formation has a very big base flow.There are also numerous seasonal small streams and drainage channels that have large flow during wet season but they dry up in the dry season.

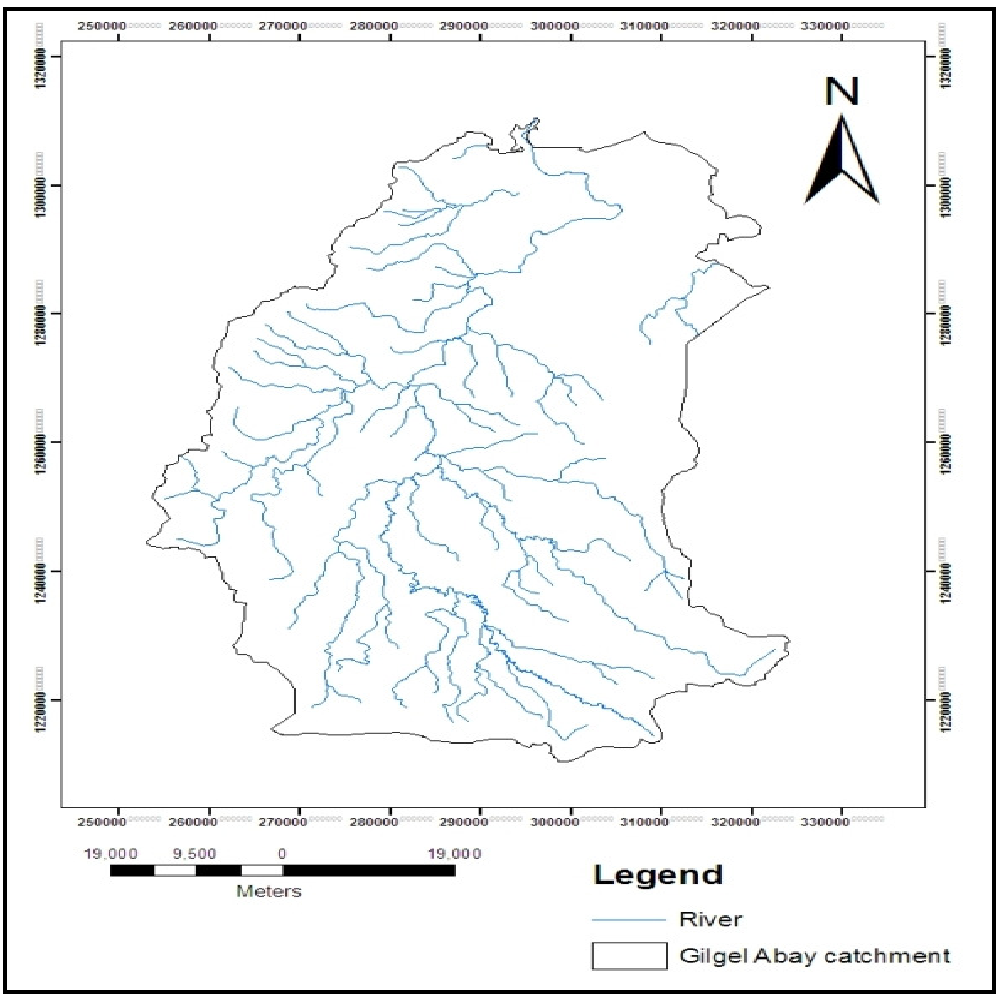


Fig 2.3Drainage Pattern

2.4 CLIMATE

The climate of Ethiopia ranges from equatorial desert to hot and cool steppe, from tropical savannah and rain forest to warm temperate, from hot lowlands to cool highlands. The country's rainfall distribution is uneven both in time and space. The temperature, wind speed and humidity are also highly variable with altitude and latitude (Alemayehu, 2006).

The Inter-annual movement of the position of the Inter Tropical Convergence Zone (ITCZ) affects the spatial and temporal variation of rainfall in Ethiopia. The ITCZ passes over Ethiopia twice a year. Its migration to north and south of the equator causes the onset and withdrawal of winds from north and south.

The study area characterized by unimodal rainfall pattern and it receive the highest rainfall in the main rainy season (From June to September). Annual rainfall of the catchment is various between 1127mm and 1870mm and the mean annual rainfall is estimated to be 1480mm.The temperature of the catchment varies with altitude. The climate in the study area is generally temperate at higher elevations and tropical at lower elevations (Conway, 1997). Annual temperature distribution of the catchment varies from 11.8 to 29.4 in degree centigrade. Mean annual relative humidity of the region is approximately 65. 7

2.5 Socio-Economic Characteristics of the Area

2.5.1 Population and Demography

The population of the catchment as per Central Statistics Agency (CSA) for the year 2008 is 1,053,188. The urban population comprises 11 percent of the total population and the remaining 89 percent of population live in rural areas. The area is one of the densely populated areas of the Tana basin.

According to 1994 CSA estimate the growth rate of the area is 2.9 per annum. The mean household size is 5 persons. The sex ratio is about 50 percent for both sexes and mortality is 116 per thousand. Life expectancy is 50 and 52 years for men and women respectively.

Majority of the rural population live in the highlands. Water sources are traditional dug wells or springs, and unprotected streams and they are located below the villages, accessed by precarious foot path.

2.5.2 Economy

The Economy of the study area is dominantly agrarian. The agriculture sector is dependent on traditional farming practice; its contribution to regional development is very limited. There is very little small scale irrigation practice in the catchment. The agriculture sector is highly dependent on rainfall, the variability of the rainfall makes the major part the area is vulnerable to drought and food insecurity problem.

Industry in the catchment is found at low level of development and its contribution to regional economy is insignificant.

2.6 Soils, Land Use and Land Cover

2.6.1 Soil

The soils in most of the Gilgel Abay catchment are derived from the weathered basalt profiles, and are highly variable. In low lying parts of Gilgel Abay, soils have been developed on alluvial sediment (SMEC, 2008). The major soil groups in the catchment are Eutric Fluvisols, Haplic Alisols, Lithic Leptosols, Chromic Luvisols and Eutric Vertisols.

Table 2.1 Soil properties for the Gilgel Abay catchment (after SMEC, 2007)

Major soil group	**Soil texture**	**Drainage condition**	**Infiltration category**
Haplic luvisols	Clay to Silty clay	Well drained	B
Haplic Alisols	Clay	Favorable drainage	C
Chromic Luvisols	Clay	Moderately well to well drained	B
Lithic Leptosols	Loam to clay loam	Moderately deep to deep	D
Eutric fluvisols	Silty clay	Moderately well drained	B

The variation in soil infiltration capacity implies that the major part of the land area of the catchment comprises moderately drained (category B) soils with moderately low runoff potential (SMEC, 2007).

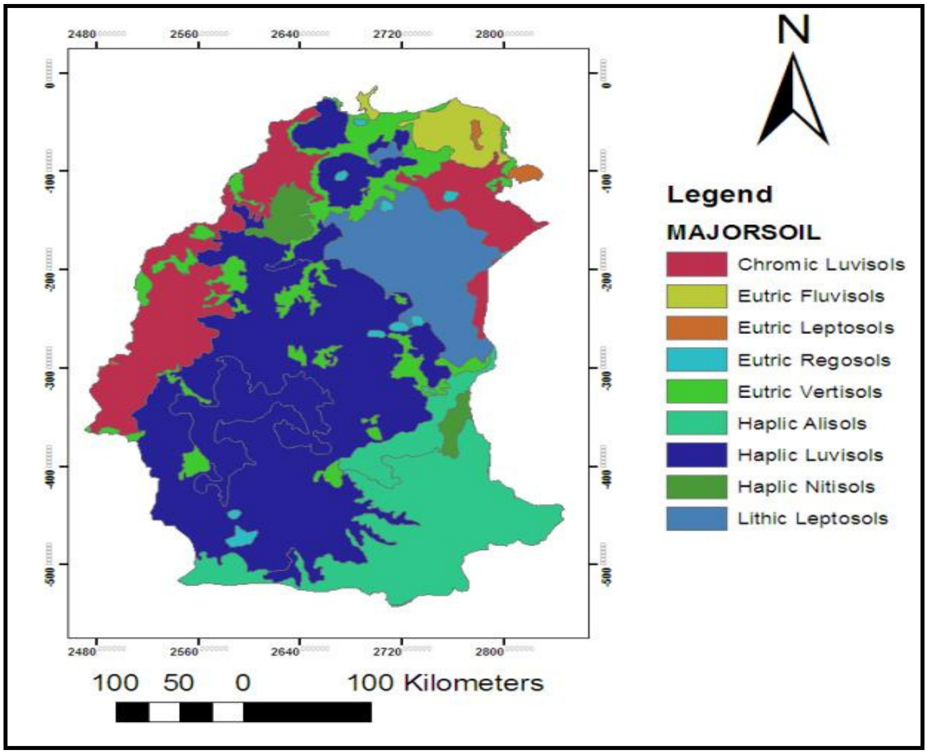


Fig 2.4 Major soil group in the Gilgel Abay catchment

2.6.2 Land use and Land cover

The land use pattern of the Gilgel Abay catchment ranges mainly from dominantly cultivated crop land to only few areas of shrub lands. The majority of the catchment is cultivated land. Figure 2.2 and table 2.2 describes the land cover type of the Gilgel Abay catchment.

Table 2-2: Types of land cover units in the catchment

Class	Land cover type	Description
1	Dominantly cultivated	Areas utilized for crops production extensively
2	Cultivated land	Areas utilized for crops production moderately
3	Shrubs lands	Characterized by small and widely spaced trees
4	Forest	Characterized by densely grown trees

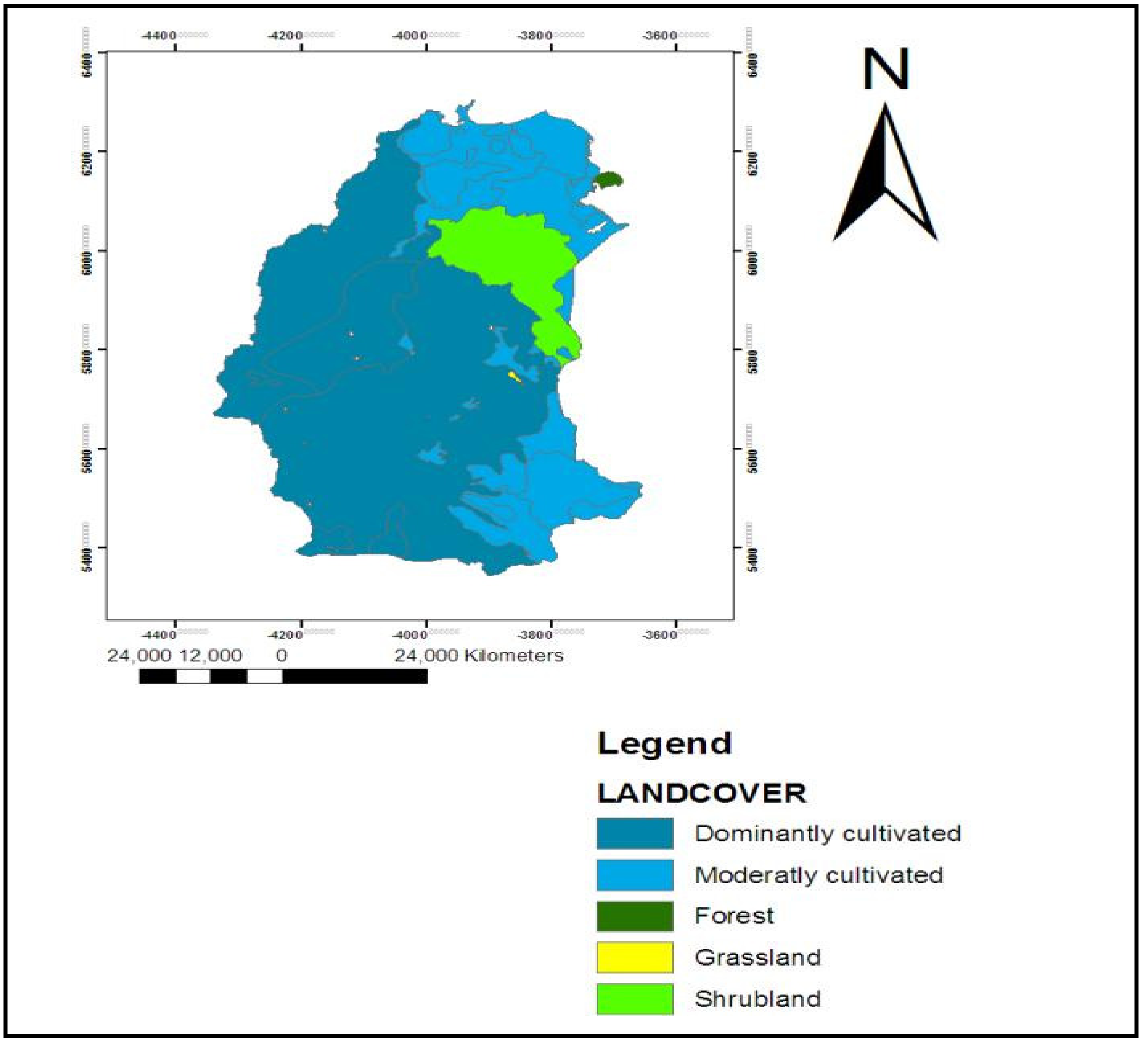


Fig 2.5 Land covers of the Gilgel Abay catchment

2.7 GEOLOGY

2.7.1 Regional Geology

The Ethiopian volcanic province is composed of Tertiary (Trap series) and Quaternary (Aden series) basaltic succession (Mohr, 1962) with thicknesses varying from 700m to 2000m at the plateau-rift margins (Berhe et al., 1987) and about 300000 km^3 size(Mohr,1962;Hart et al.,1989;Tefera et al.,1996).The volcanic province is sub divided into three major geographical and geomorphological parts: the Ethiopian plateaus(northwestern, southwestern and southeastern),the Main Ethiopian Rift(MER) and the Afar Rift(Kazmin,1979;Berhe et al.,1987;Hart et al.,1989). Although the post-rift volcanism has been concentrated mainly along the axis of MER, it also occurred in the Tana graben (Kazmin, 1972, 1979) and along the Yere-Tulu Wellel volcano-tectonic lineaments between northwestern and southwestern plateaus.

The Blue Nile basin is situated in the Northwestern Ethiopian plateau. The basin contains approximately 1400m thick section of Mesozoic sedimentary rocks unconformably overlying Neoroproterozoic basement rocks and unconformably overlain by Early-Late Oligocene and Quaternary volcanic rocks. Several shield volcanoes, also consisting of alkali basalts and fragmental material, cover the center and the upper part of the Blue Nile basin. Over two third of the upper Blue Nile is covered by Cenozoic basalts and ashes (Kebede et al., 2006).

The geology of Lake Tana Basin comprises a basement of Precambrian bedrock, overlain by Mesozoic sediments, Tertiary volcanics and minor sediments, Quaternary volcanics and recent alluvial sediments (SMEC, 2007).Ongoing tectonic activities has controlled the distribution of the rock formation and controlled the current configuration of the basin (Chorowicz et al, 1998).

The basement rocks in the Tana Basin comprise Precambrian metamorphic and granitic rocks which occur in the sub-surface of the basin. They are overlain by extensive deposits of sedimentary rock that do not outcrop in the Tana Basin, but are observed in the Blue Nile gorge to the southeast. The areas surrounding Lake Tana are made up of Tertiary basalts and much of south of Lake Tana areas covered by Quaternary volcanics, which overlie the older tertiary volcanics (SMEC, 2007).The thickness of sediments overlying the Precambrian basement and underlain 0-250 m thick continental flood basalts averages

1.5-2 km, which is comparable to the Blue Nile stratigraphic section, south of the area (Engida et al., 2007).

The thickness of Trap Series in Northern Ethiopia averages 1000-1500m (Pik et al., 2003).The Quaternary volcanic rock overlie the older tertiary volcanic rock over much of the Gilgel Abay catchment. The Quaternary volcanics expected to be more than 100m thick. The Cenozoic is characterized by extensive faulting accompanied by widespread volcanic activity and uplift.

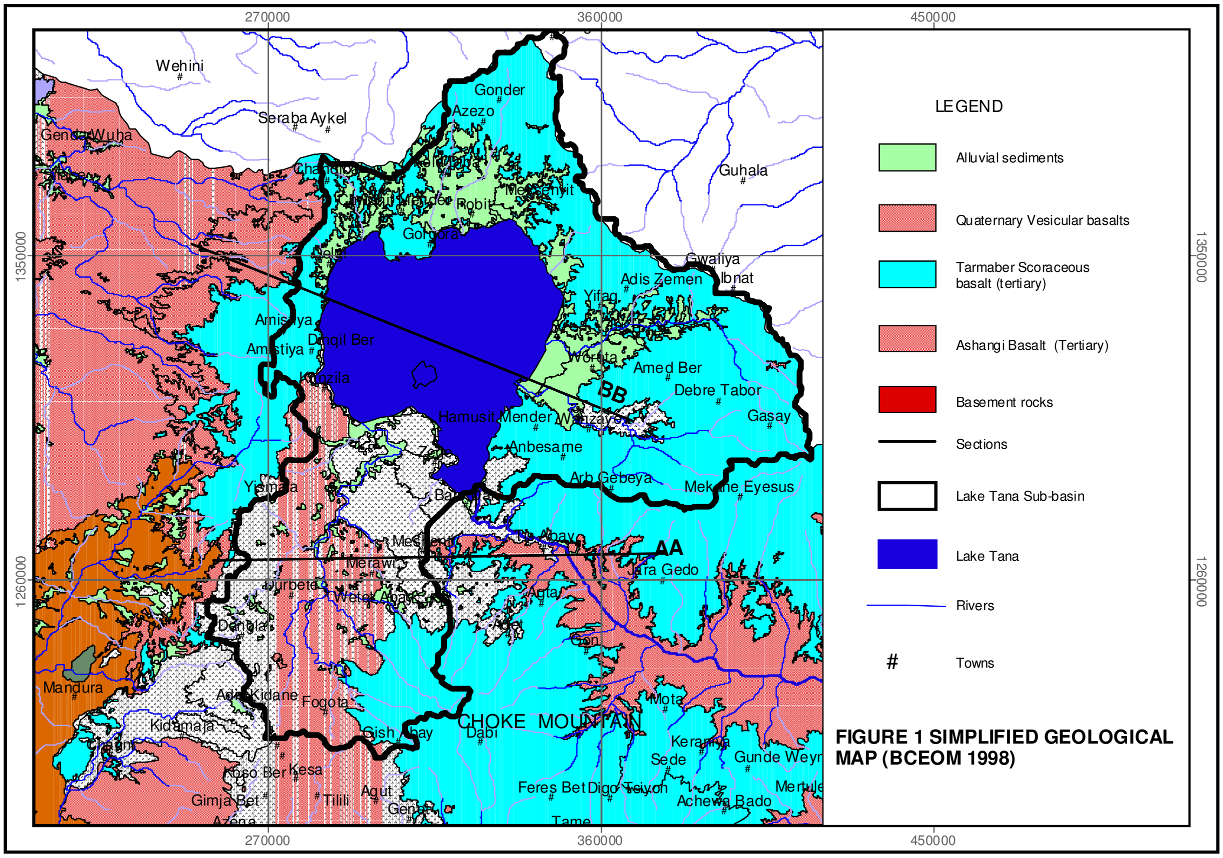


Fig 2.6 Geological map of the Tana sub-basin and surroundings (Engida et al., 2007)

2.7.2 Regional Geological Structures

The Blue Nile Basin is situated in the Northwestern Ethiopian plateau and is bounded to the East and Southeast by the tectonic escarpment of the uplifted western flanks of the Afar depression and the Main Ethiopian Rift, respectively. The North and South by the Axum-Adigrat and Ambo lineaments, respectively and in the West by the erosional Tana escarpment.

There are two prominent tectonically deformed regions on the plateau. These are the Lake Tana Graben (LTG) and the Yerer-Tullu Wellel Volcanic Lineament Zone (YTVL). The majority of geothermal springs, Quaternary volcanoes, and Quaternary basalt flows that exist in the Blue Nile basin are located in these two zones (Kebede et al., 2006). These tectonic structures play an important role in controlling groundwater flow paths and groundwater chemical evolution.

The Tana basin, Northwest Ethiopia is an uplifted dome possibly related to the Afar mantle plume (Pik et al., 2003).The basin was formed by faulting of mid -Tertiary basalt. The Tertiary basalt covers the Tana area is assumed to average 500-1500m in thickness (Jepsen and Athearn, 1961; Pik et al., 2003).The basin occupies a centre of subsidence and convergence of three grabens (Chorowicz et al., 1998)

According to Kebede et al., 2006, the LTG is a circular depression characterized by faulted blocks dipping towards Lake Tana from all direction. The faulted blocks in the western part of the lake have an average width of 1-4km and strike NNE-SSW. Gently inward-directed dips of the Tertiary basalt toward the center of the Tana basin are present to the west, north and east of the lake.

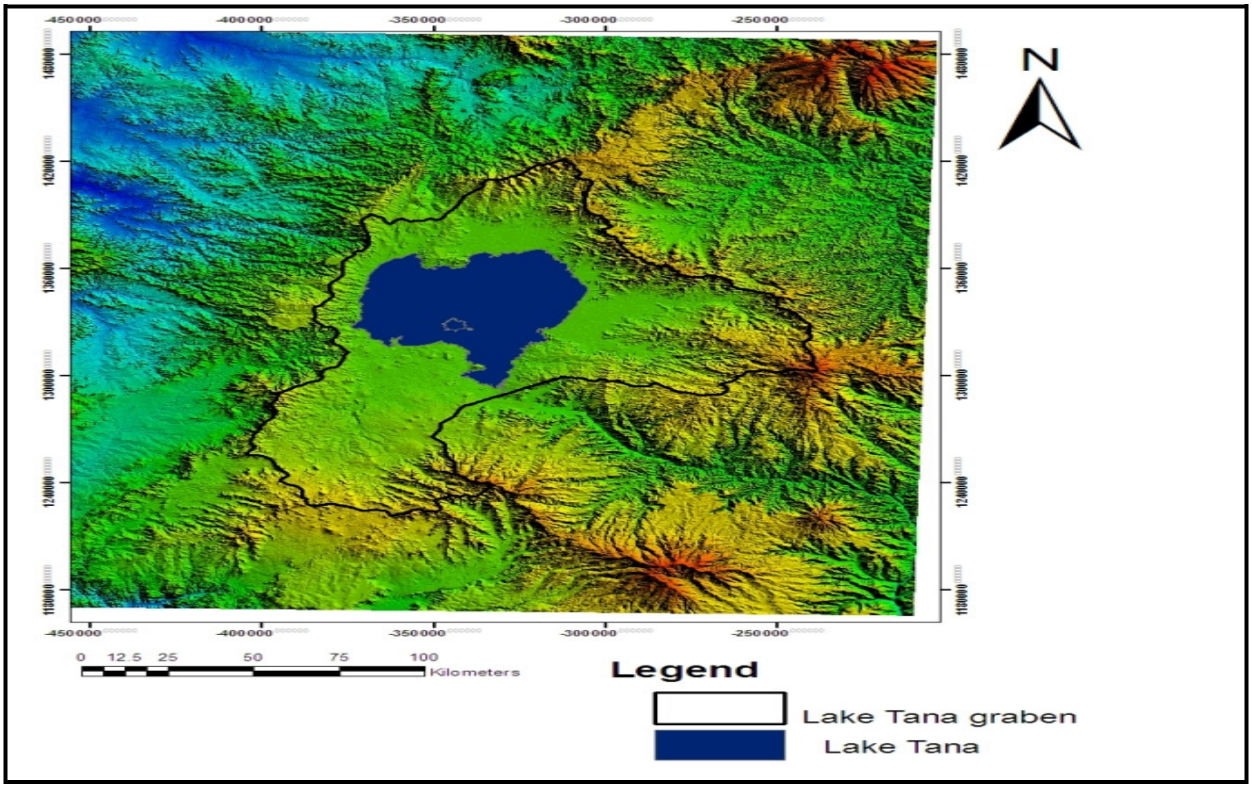


Fig 2.7 Regional geological structures

2.7.3 Geology of the Study Area

From regional geology and field check up the geology of the study area is characterized by outcrops of Tertiary, Quaternary volcanic rocks and alluvial deposits.Basement rocks in the Gilgel Abay catchment consists Precambrian metamorphic and granitic rocks. Although, they are not exposed in the study area it is believed from regional geology that occur in the catchments' subsurface.

The basement rocks are overlain by extensive deposits of Mesozoic sedimentary rocks, which are outcrop in the Blue Nile gorge in the southeast and western lowlands. These sediments are not exposed in the Gilgel Abay catchment, but from recent geophysical study by Hautot et al., 2006 in the catchment, a 1.5-2 km thick deposit of Mesozoic sediments beneath 0-250 m thick continental flood basalt have been identified.

2.7.3.1 Quaternary Volcanics

The largest part of the Gilgel Abay catchment covered with Quaternary volcanic rocks (Basalt lava flows connected to volcanic centers), extending from the north end of the catchment around Bahir Dar to south beyond the Gilgel Abay catchment boundary. Well preserved eruption points for these lavas are visible in the catchment. The Quaternary volcanic serious comprises blocky and fractured vesicular basalt with a porphyritic glassy texture, as well as some basaltic breccias and tuffs. Further south, the Quaternary volcanics are less blocky and have deeply developed soils (SMEC, 2007). This group of rocks in the study area consists of three major rock units:

1) basalts related to volcanic center 1,QCB1(Injjibara-Santil ridge)

This rock unit is found in the topographically higher part at southwestern corner of the area with patch exposure and covers very small portion of the catchment area.

2) basalts related to volcanic center 2,QCB2(Bure-Dangila lava flows)

This rock unit covers over much of the Gilgel Abay catchment from northern parts of the catchment up to south and beyond the catchment.

3) basalts related to volcanic center 3,QCB3(Chimba lava field)

This rock unit exposed in the Northeast part of the catchment, around Bahir Dar and covers 20 percent of the area of the catchment.

2.7.3.2 Tertiary Volcanics (Tarmaber basalt, 2nd event (TTB2))

Tertiary Scoracious basalt (Tarmaber basalt) represents Oligocene to Miocene basaltic shield volcanism on the Northwestern plateau. The Tarmaber shield volcanoes become progressively younger from north to south (Teferra et al., 1996). In the immediate vicinity of the Tana basin, the Trap Series basalts are overlain by the Tarmaber basalt with absolute age range from 30-13 Ma (Zanettin et al., 1974; Mohr, 1983 and Zanettin, 1988) derived from Mt.Guna and Mt.Choke shield volcanoes.

In the Gilgel Abay catchment Tarmaber basalt is overlain by the Quaternary basalt and it outcrops in the Southeast part of the catchment around Gish Abay. It has also wide distribution along the Choke mountain system. Its thickness increases from the south in the north direction with a probable maximum thickness in the Gilgel Abay River. The Tarmaber basalt can be described as superimposed basalt lava flows with intercalated tuffs, scoracious strata and typical red paleo-soils (BCEOM, 1997).

2.7.3.3 Alluvial Sediments (QALL)

Alluvial deposits have limited distribution in the catchment. Alluvial sediments exposed in the study area along the Gilgel Abay river and its tributaries. The grain size of the sediment ranges from clay to gravel and become coarser away from the lake.

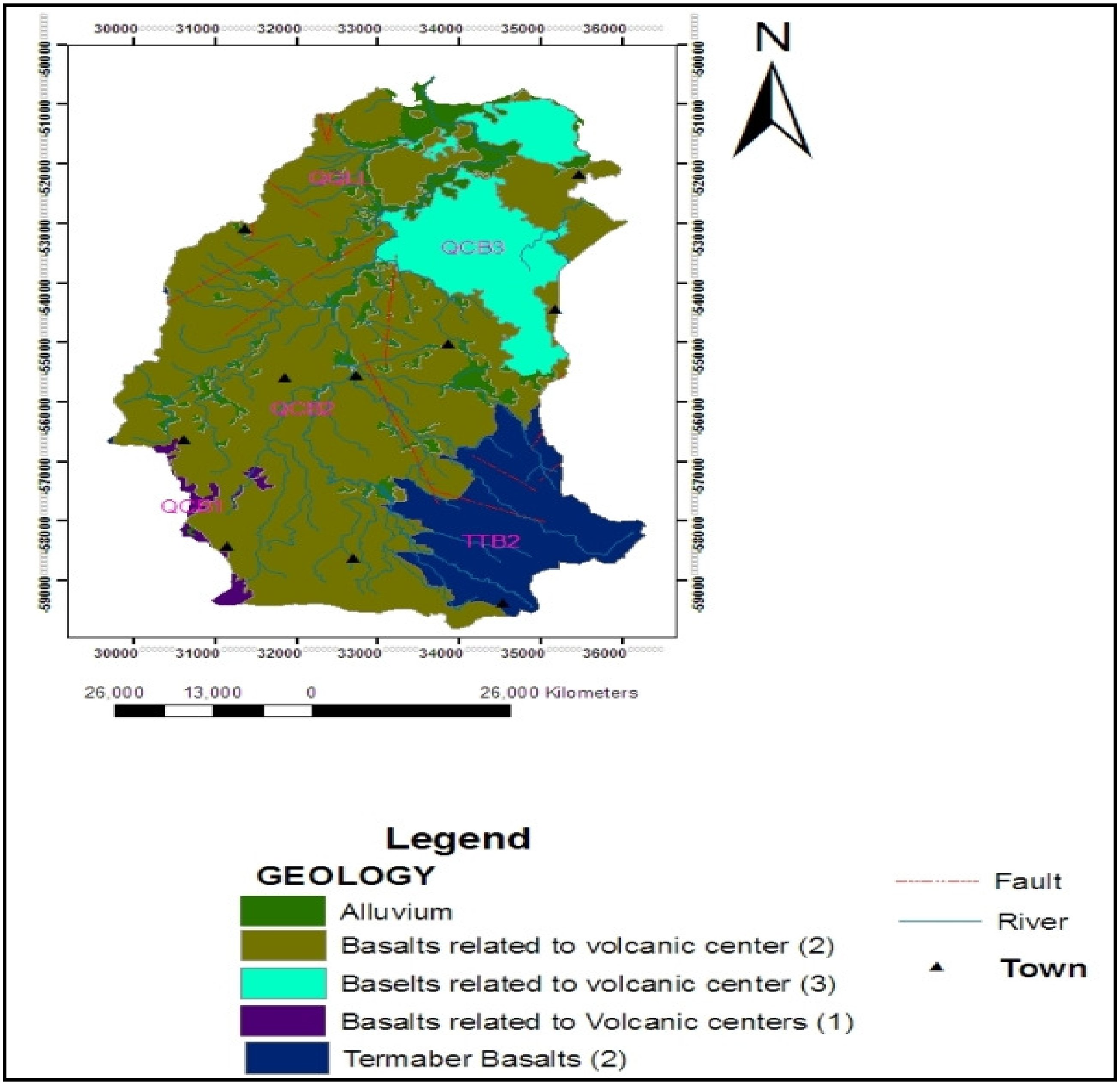


Fig 2.8 Simplified Geological Map of the Study Area

2.7.4 Geological Structure of the Study Area

The Tana basin is an uplifted dome possibly related to the Afar Mantle Plume (Pik et al., 2003).The Lake Tana basin is the junction of three grabens: the Gonder graben from North-northwest, the Dengel Ber graben from South-southwest, and Debre Tabor graben from the east (Chorowicz et al., 1988).The grabens are impressed in mid-Tertiary flood basalt pile. The basin was formed by faulting of mid- Tertiary basalts which has an average thickness 500-1500m (Jepsen and Athearn, 1961; Pik et al., 2003).Reactivation of faults occurred in the late Miocene to Quaternary, superimposing dawn-faulted north-south trending Gonder graben, which is exposed by erosion in the north of the basin, the north-south Dengel Ber, buried beneath the Quaternary volcanics in the Gilgel Abay and in the Eastern part of the basin,the East-West Debre Tabor Graben.

Faulting generally associated with large volcanic centres has resulted in very apparent lineaments (BCEOM, 1997).The main fault set directions are north-south, northwest-southeast, northeast-southwest and southeast-south.

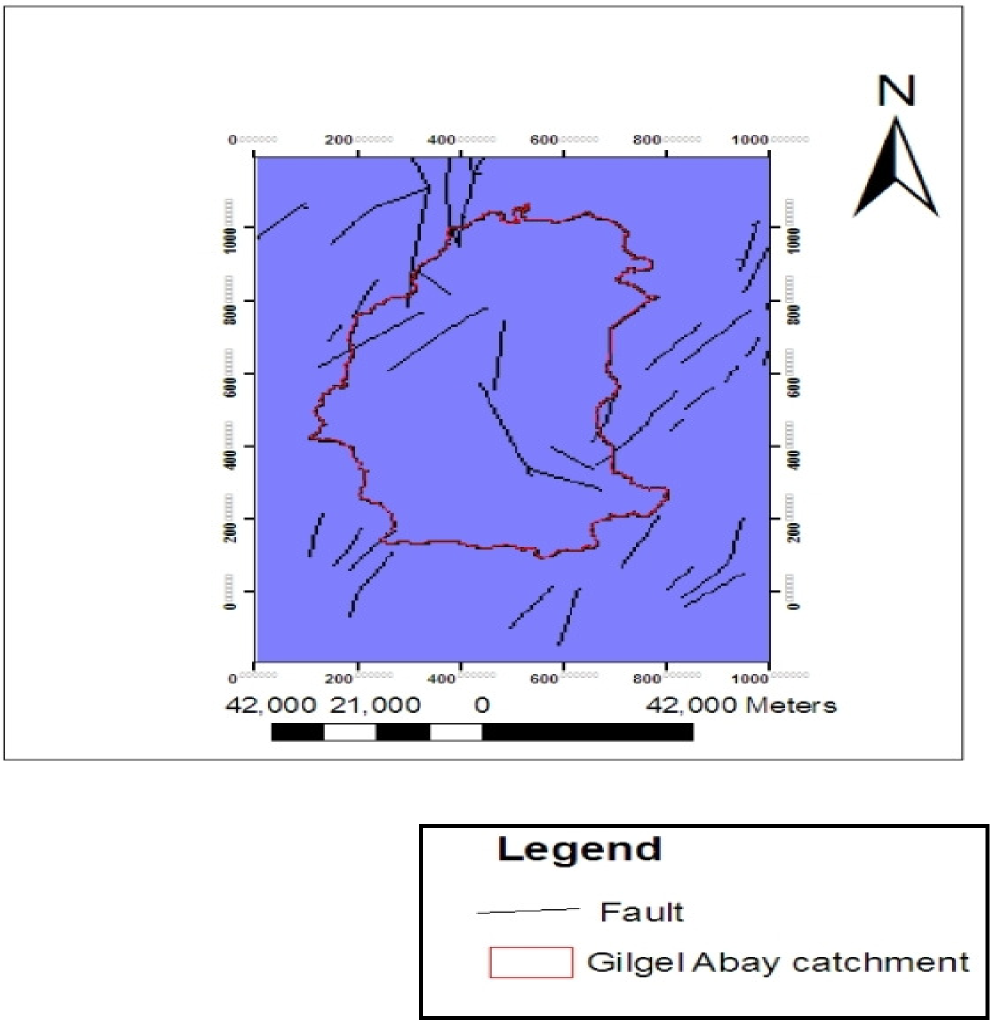


Fig 2.9 Simplified Geological Structures in the Study area

3. RECHARGE ESTIMATION

3.1 Concepts of Groundwater Recharge

Groundwater recharge may be defined as the downward flow of water reaching the water table, forming an addition to groundwater.There are two types of recharge: direct recharge and indirect recharge. Direct recharge is the process by which water added to the groundwater reservoir in excess of soil moisture deficit and evapotranspiration by direct percolation of precipitation through the unsaturated zone. Indirect recharge results from percolation to the water table following runoff and localization in joints, as ponding in low lying areas and lakes, or through the beds of surface water courses.

There are different sources of recharge to a groundwater system. These include precipitation or direct recharge, river recharge, inter-aquifer flows, irrigation losses and urban recharge. Each type of recharge can be quantified by several methods: direct measurement, water balance method, darcian approaches, tracer techniques and other empirical methods. The current study deals with direct (precipitation) recharge.

Quantitative understanding of the process of groundwater recharge is very important to the sustainable management of groundwater resources in such away that:

1) The amount of recharge dictates the amount of water that can be extracted sustainably from the aquifers

2) Recharge has great importance to assess the impact of climate changes on groundwater resources and aquifer vulnerability to contamination

3.2 Factors Affecting Recharge

Groundwater recharge can be affected by many parameters. These include:

- At the land surface – topography, precipitation (magnitude, intensity, duration, spatial distribution), runoff and ponding of water, cropping pattern, AET.
- Irrigation - nature of irrigation scheduling, losses from canals and water courses.
- Rivers - rivers flowing into and leaving out of the study area, rivers gaining water from or loosing water to the aquifer.
- Soil zone – nature of soil, depth, hydraulic parameters, variability of the soil spatially and with depth, rooting depth of the soil, and cracking of soil on drying out or swelling due to wetting

- Unsaturated zone between soil and aquifer – flow mechanism through unsaturated zones with different hydraulic conductivities
- Aquifer – ability of aquifer to accept water , variation of aquifer condition with time

In this study the recharge can be quantified by water balance method. This method estimate recharge as the residual of all the other fluxes. Hydrometeorological and hydrological data are analyzed to estimate the recharge in this method.

3.3 Hydrometeorology

Available meteorological data in the study area: rainfall, temperature, wind speed, relative humidity, and sunshine hours. The meteorological stations in and around the Gilgel Abay catchment are listed in table 4.1 below.

Table 3.1Metrological stations in and around Gilgel Abay catchment

No	Meteorological station	Latitude (North Degree)	Longitude (East Degree)	Elevation
1	Addet	11.26	37.49	2080
2	Bahidar	11.60	37.42	1770
3	Dangila	11.25	36.83	2000
4	Enjibara	10.98	36.92	2670
6	Kunzila	11.87	37.03	1800
7	Merawi	11.41	37.15	2003
8	Meshenti	11.15	35.85	2000
9	Sekela	11.00	37.22	2690

3.3.1 Precipitation

The oscillation of ITCZ north and south of the equator governs the country's seasonal rainfall variability. The catchment receives highest precipitation during rainy season (June to September) from Equatorial westerly winds from Atlantic Ocean and southerly winds from Indian Ocean. The dry months (October to May) of the catchment have little rain .Air currents that traverse Arabia during this period are North easterly trade winds and dominates the region. The study area has unimodal rainfall characteristics of peaking in July.

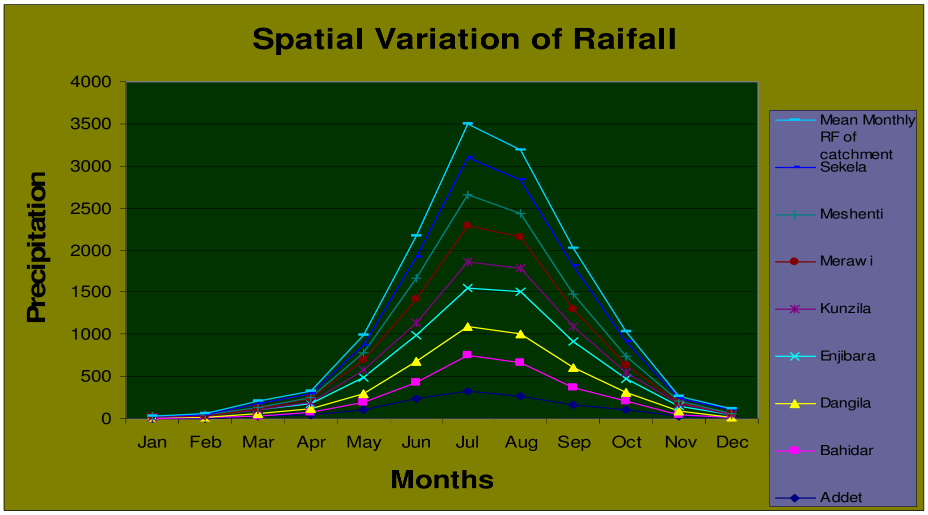


Fig 3.1 Rainfall Pattern

3.3.1.1 Determination of aerial depth of rainfall

Three different methods are used to compute aerial depth of precipitation over the catchment.

1 Arithmetic average

In this method the arithmetic mean of the amounts measured by the rain gauges with in and around the catchment is computed. The catchment under investigation has altitude variation ranges from 1770-2690m a.s.l., and the rain gauges are not evenly distributed in the study area.

$$PA = \sum P_i / n = 1544mm$$

Where PA = Average rain fall of the total area

P_i = Measured precipitation at a given station and time

n = Number of rain gauges.

Since the study area is steep and the rain gage stations are widely spaced, the result obtained from this method is unreliable.

Table 3-2: Mean monthly rainfall of seven stations in and around the Gilgel abay catchment

	Station	Months												
No	Name	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1	Addet	3	6	28	50	109	234	323	267	162	110	25	11	1327
2	Bahidar	3	2	7	24	82	188	425	391	201	93	20	3	1439
3	Dangila	3	4	24	39	110	257	349	353	236	112	42	8	1538
4	Enjibara	12	17	44	70	183	309	450	490	320	159	65	25	2145
6	Kunzila	0	4	7	9	87	146	315	278	173	77	32	0	1127
7	Merawi	3	3	14	38	123	276	430	370	211	83	15	7	1572
8	Meshenti	3	2	15	22	94	251	366	284	170	111	7	9	1335
9	Sekela	1	10	36	36	87	263	448	405	345	167	28	45	1870
	Mean Monthly RFof catchment	**3.5**	**6**	**29**	**36**	**109**	**240.5**	**388**	**355**	**201**	**114.5**	**29**	**13.5**	**1525**

2 Theissen polygon method

The method assumes that the recorded rainfall in a gauge is representative for the area halfway to the adjacent gauges. This method gives good results when the rain gauges are not evenly distributed, but it is dependant on a good network of representative rain gauges over the area in both flat and hilly terrain (Shaw, 1988). By drawing the perpendicular bisector of the line joining adjacent stations, Theissen polygons can be constructed around each station. The observed precipitation (P_i) is weighted according to the area (a_i) of the polygons associated with it.

$$P_A = (\sum P_i\, a_i)/\, A_t = 1543.8$$

Where P_A=the average depth of precipitation

P_i=the observed precipitation at $(i)^{th}$ gauge

a_i=area of polygon corresponding to gauge

A_t=total area of the catchment

The value obtained by this method is 1543.8 mm/yr.

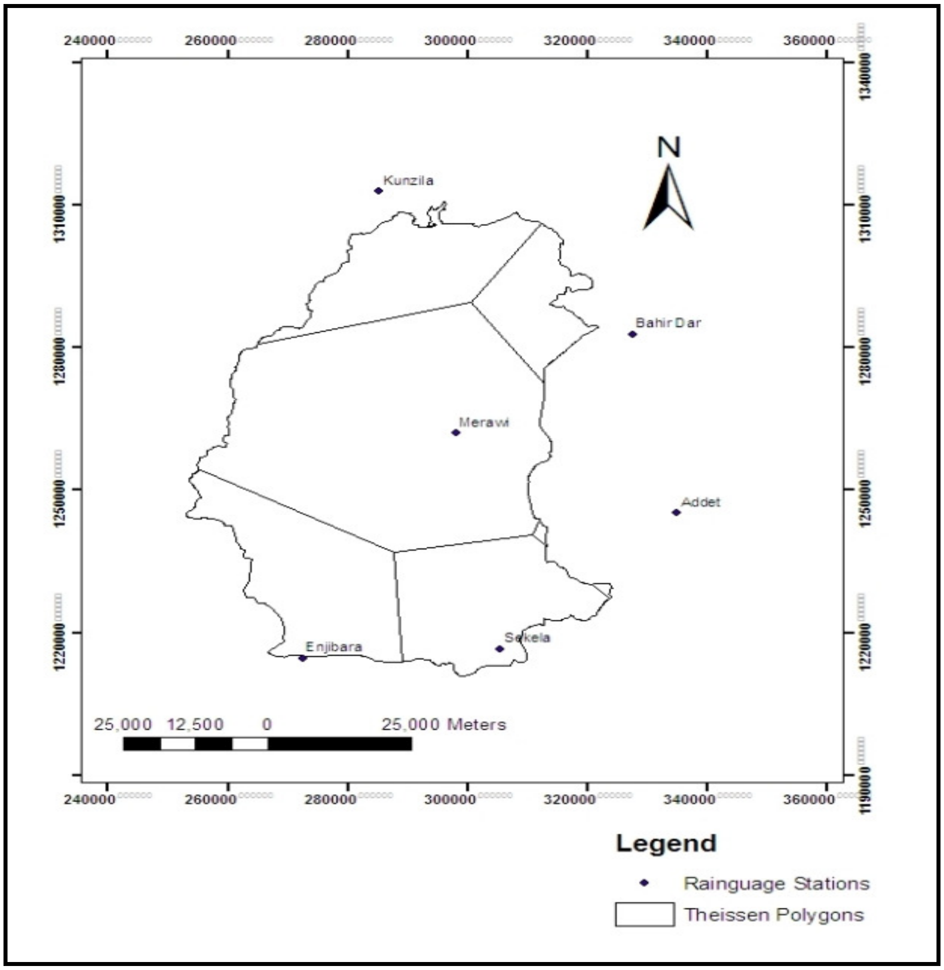


Fig 3.2 Theissen polygon

Table 3-3: Annual weighted rainfall depth using Thiessen polygon

Meteorological station	Area of influence (Km^2)	Mean RF (mm)	Weighted area %	Weighted RF (mm)
Addet	12	1327	0.3	3.5
Bahir Dar	329	1439	7.2	103.8
Dangila	947	1538	20.8	319.5
Merawi	1626	1572	35.7	560.7
Kunzila	588	1127	12.9	145.4
Sekela	688	1870	15.1	282.2
Enjibara	369	2145	8.1	173.6
Total	4559		100	**1543.8**

3 Isohytal method

In this method drawing of lines of equal rainfall depth (Isohytes) by interpolation between observed rainfalls depths at rain gauge stations were performed. In drawing the isohyets for annual rainfall over the catchment, topographic effects on the rainfall distribution are incorporated the area between successive ishohytes is calculated and multiplied by the average rainfall on that area. The average rainfall is the average value of the two adjacent isohohytes.

$$Pa = \frac{p_{12}a_{12} + p_{23}a_{23} + ... + P_{n-1,n}a_{n-1,n}}{A_T}$$

Where P_{12} - Rainfall depth between isohytes1 and 2

a_{12} - Area enclosed by successive isohytes1 and 2

A_T - total Area

Using this method, aerial depth of rainfall of the study area is **1561**mm/yr**.** The estimated rainfall by this method is taken to represent the rainfall of the catchment.

Table 3.4 Isohytal Mean Depth

Precipitation	Area(km2)	Pi(Average)	a/A	(a/A)P_i
1100-1200	10	1150	0.002	2.3
1200-1300	403	1250	0.089	111.25
1300-1400	706	1350	0.156	210.6
1400-1500	835	1450	0.184	266.8
1500-1600	997	1550	0.220	341
1600-1700	614	1650	0.135	222.75
1700-1800	358	1750	0.079	138.25
1800-1900	288	1850	0.064	118.4
1900-2000	193	1950	0.043	83.85
2000-2100	111	2050	0.024	49.2
2100-2200	17	2150	0.004	8.6

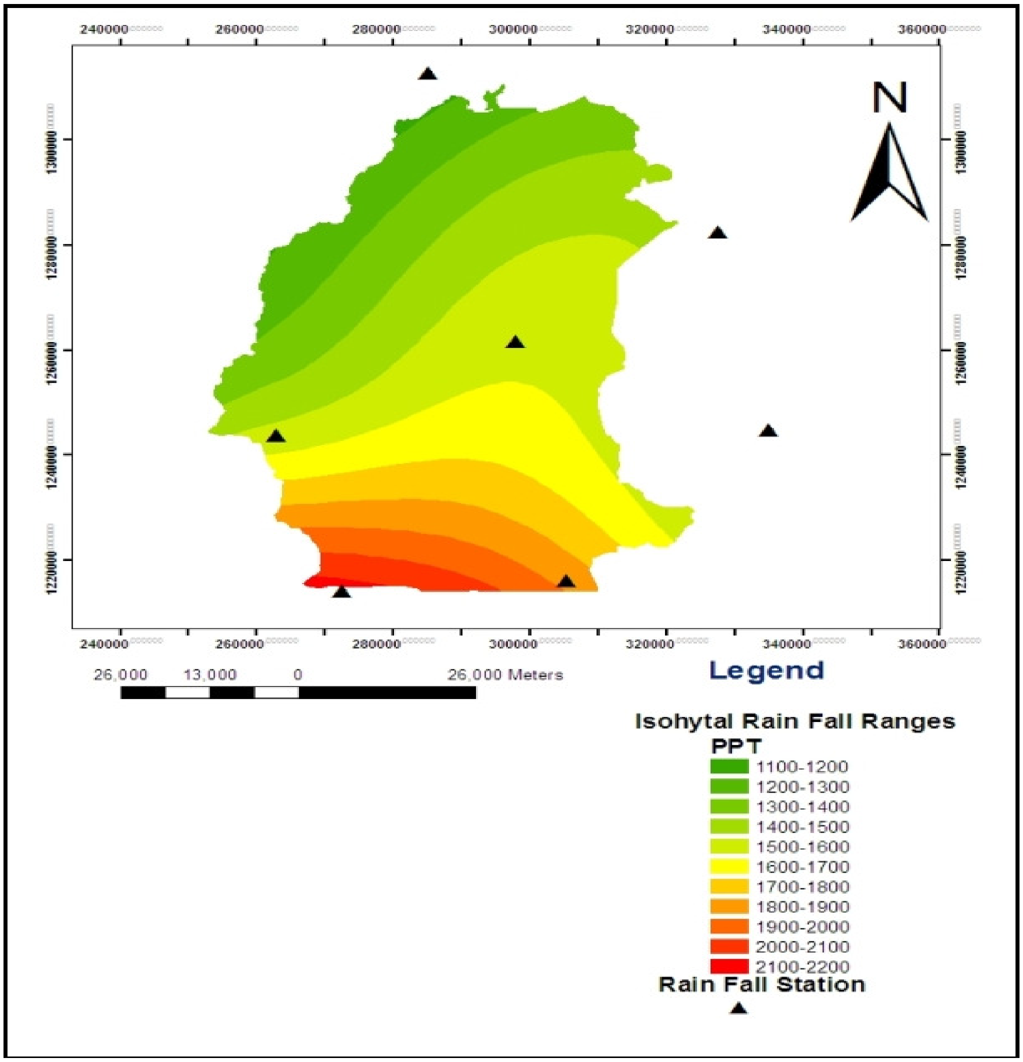


Fig 3.3 Isohytal Map of the Study Area

3.3.1.2 Spatial and temporal variation of rainfall

a) Variation of rainfall with elevation

There are many factors affecting the amount and distribution rainfall in a given region, these are: geographic position with respect to air and moisture circulation pattern, climate factors, orographic influence, distance from moisture source, and latitude. Among different factors, surface elevation is the major parameter controlling the depth of precipitation.Variation of rainfall with surface elevation in the catchment shows positive relation.

No	Metrological stations	Elevation	Rainfall (mm)
1	Addet	2080	1327
2	Bahir Dar	1770	1439
3	Dangila	2000	1538
4	Enjibara	2670	2145
5	Kunzila	1800	1127
6	Merawi	2003	1572
7	Meshenti	2000	1335
8	Sekela	2690	1870

Table 3.5 Rain fall with elevation

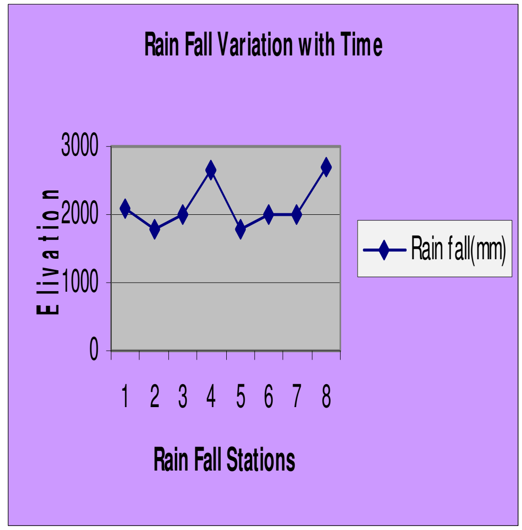


Fig 3.4 Variation of rainfall with elevation

b) Temporal variation of rainfall

The variation of rainfall with time can be explained by looking at the plot of rainfall versus time for stations.

Rainfall(mm)	Year
19	1991
1325	1992
1715.6	1993
1319.5	1994
1185.2	1995
1654.7	1996
1667.2	1997
1256.5	1998
1961.4	1999
1895.7	2000
1411.1	2001
1349.8	2002
1369.4	2003
1628.4	2004
1409.4	2005
1846.1	2006

Table 3.6 Rainfall in different years at Dangila

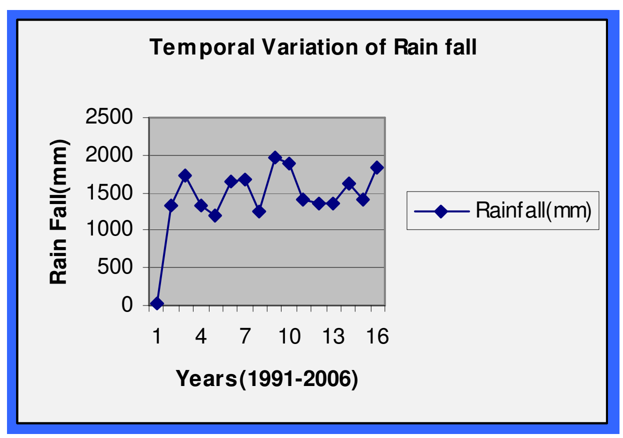


Fig 3.5 Temporal variation of rain fall with time

3.3.2 Evapotranspiration

Evapotranspiration can be defined as a natural process by which water can be transferred from both the land surface and vegetation surface by evaporation and transpiration processes.

There are different meteorological factors affecting evapotranspiration these include: water and air temperature, soil moisture content, wind speed, solar radiation, relative humidity, and hygrometric deficit.

3.3.2.1 Temperature

The rate of evaporation is dependent on the temperature at the evaporating surface and atmospheric air .The amount of water vapor in the atmosphere is directly related to the temperature. The higher the air temperature, the more vapor it can hold, and similarly if temperature of evaporating water is high, it can more readily vaporize (Shaw, 1994).

Mean monthly minimum, maximum and mean annual temperature of the catchment is listed below in Table3-7.

Table 3-7 Mean Monthly Temperature of Gilgel Abay catchment(o_C)

No	Temperature in (°c)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual airTemp
1	**Mean Max**	27.4	29.3	30	30.4	28.5	26.6	24	24	25.4	26	26.6	27	29.4
2	**Mean Min**	6.8	8.4	10.7	13.2	13.9	13.3	13.8	13.7	13	12.5	8.5	7.7	11.8
	Mean Monthly air temperature	**17.1**	**18.9**	**20.4**	**21.8**	**21.2**	**20**	**19**	**18.9**	**19.2**	**19.3**	**17.6**	**17.4**	

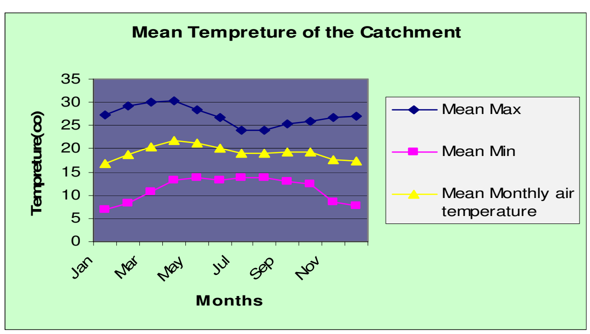


Fig 3.6 Mean Monthly Temperature of Gilgel Abay catchment(o_C)

3.3.2.2 Wind Speed

Wind speed can increase the rate of evaporation by removing vapor from evaporating surface, the saturated air above the evaporating surface replaced by dry air. This movement of air and moisture depends on wind speed and it enables evaporation to proceed. Thus, wind speed is a key factor in controlling the rate of evaporation.

The mean monthly wind speed of the study area varies from 0.7m/s to 1.2m/s with average value of 1m/s.

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean AnnWs
1	Addet	1.0	1.2	1.3	1.4	1.3	1.3	1.1	1.0	1.0	0.9	0.9	0.9	1.2
2	BahirDar	0.5	0.7	0.7	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.6
3	Dangila	1.0	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.7	0.9	0.8	0.8	1.2
4	Mean Monthly Ws	0.8	1	1	1.2	1.1	1.1	1	0.9	1.1	0.8	0.7	0.7	1

Table 3-8: Mean Monthly and mean annual Wind speed (m/s) of Gilgel Abay catchment

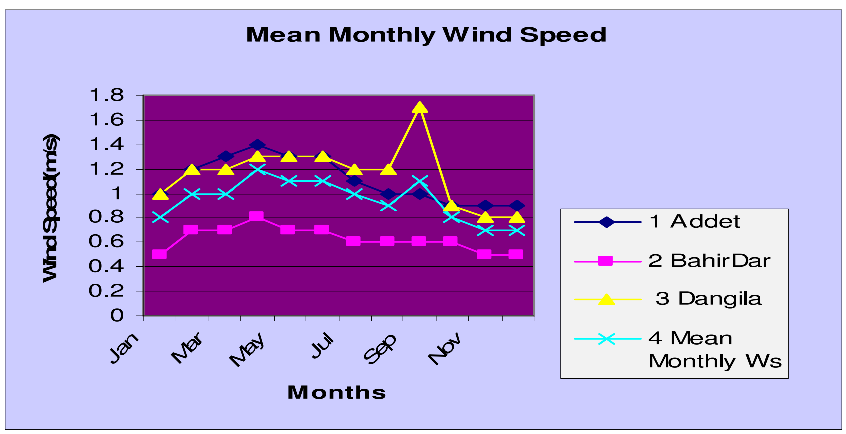


Figure 3-7: Mean Monthly Wind speed (m/s) of Gilgel Abay catchment

3.3.2.3 Relative Humidity

The relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature is defined as relative humidity. The higher the relative humidity the lower will be the rate of evaporation (Shaw, 1985). Higher values of relative humidity indicate the air close to saturation point and lower values indicate less water vapor in the atmosphere.The maximum relative humidity is found in Rainy months (June-September) 77.2% and the minimum in dry months (October-May) 56.4%.

Table3-9: Mean monthly Relative humidity (%) of Gilgel Abay catchment

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual RH
1	Addet	53.4	50.0	49.4	49.6	56.5	69.6	80.9	82.5	75.9	71.3	63.2	58.0	63.3
2	Bahir Dar	56.3	50.1	46.9	46.8	56.5	70.3	78.9	80.3	76.3	68.1	63.2	59.3	62.7
3	Dangila	62.4	55.0	53.5	55	66.2	80.4	86.5	87.1	83.6	81.1	74.9	67.1	71.1
4	Mean Monthly RH	57.3	51.7	49.9	50.5	59.7	73.4	82.1	83.3	78.6	73.5	67.1	61.5	65.7

Only two year data used

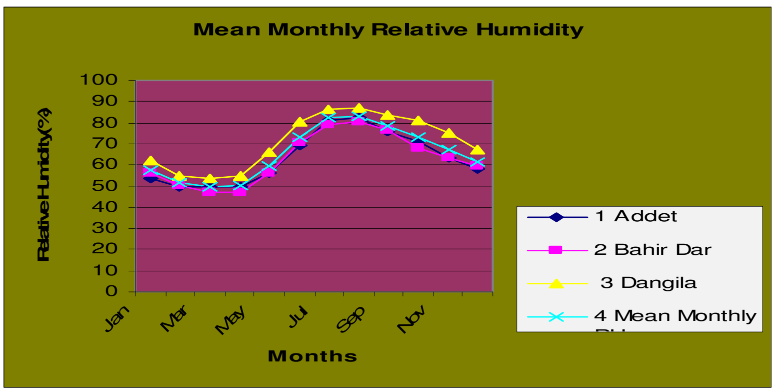


Figure3-8: Mean monthly Relative humidity (%) of Gilgel Abay catchment

3.3.2.4 Sunshine Hours

Evaporation to takes place energy inputs is very important. Solar energy is the major Input of energy for evaporation to takes place. Thus, sunshine hours play significant role in controlling the rate of evaporation.

Table 3-10: Mean monthly sunshine hours (hrs)

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual
1	Addet	8.3	8.1	8.4	7.7	7.8	6.3	4.6	5.4	7.2	8.3	8.3	6.7	7.2
2	Bahi Dar	9.7	9.7	9.0	9.2	8.3	7.0	5.2	4.7	6.7	8.6	9.5	9.7	8.1
3	Dangila	9.3	9.3	8.3	8.7	8.0	6.0	4.4	4.7	6.2	6.9	8.6	8.6	7.4
4	Mean Monthly	9.1	9	8.6	8.5	8	6.4	4.7	4.9	6.7	7.9	8.8	8.3	7.6

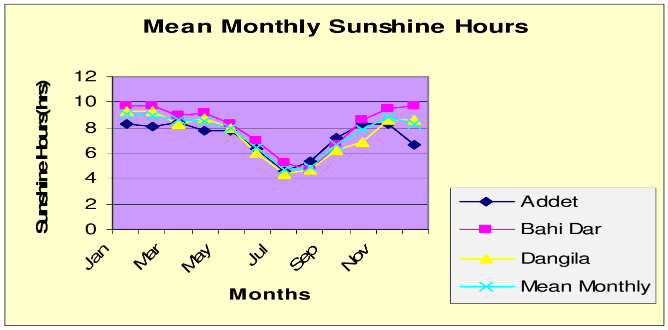


Figure 3-9: Mean monthly sunshine hours (hrs)

3.3.2.5 Estimation of Evapotranspiration

There are two types of evaporation: evaporation from an open water surface and evaporation from the transpiration process. Evaporation from an open water surface Eo, is the direct transfer of water from lakes, reservoirs and rivers to the atmosphere. The second form of evaporation, evaporation from the transpiration process from vegetation, Et (Shaw, 1988).Thus, evapotranspiration can be defined as the transfer of water vapor by direct evaporation from the land surface and vegetation and by transpiration process from the plant surface.

Evapotranspiration is a very difficult and complex task and it is hard to measure, its value varies according to the type of vegetation, its ability to transpire and to the availability of water in the soil.

1. Potential Evapotranspiration (PET)

The PET can be defined as the evapotranspiration from a vegetated surface under no moisture deficiency.

a) Thornthwaite Approach

Thornthwaite method is based upon the assumption that potential evapotranspiration is dependent only on meteorological conditions and ignores the effect of vegetation density and maturity. However the method is still practical. The formula based on temperature with an adjustment being made for the number of daylight hours (Shaw, 1988).

PET_m, calculated on a monthly basis is given by: $PET_m = 16N_m\,(10t/I)^a$ mm

Where: m: months

$N_{m:}$ is monthly adjustment factor depending on latitude and season

t: mean monthly temperature

I: annual heat index obtained by adding monthly heat index (i_m) of 12 months.

$i_m = (t/5)^{1.5}$

$a=6.7x10^{-7} I^3 -7.7 x10^{-5} I^2 + 1.8x10^{-2}I+0.49$

The mean annual Potential evapotranspiration of the study area using the above mentioned method is 776.57**mm/year.**

Table3-11: Potential evapotranspiration of Gilgel Abay river Catchment (mm) using Thornthwaite method

Element	Months												Annual
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
T_m (°C)	17.1	18.9	20.4	21.8	21.2	20	19	18.9	19.2	19.3	17.6	17.4	
N	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
Nm	0.97	0.98	1	1.03	1.05	1.06	1.05	1.03	1.01	0.98	0.97	0.96	
im	6.32	7.35	8.24	9.1	8.73	8	7.40	7.35	7.52	7.58	6.60	6.5	
I	90.7												
a	2.0												
PETm	55.4	69.15	81	94.9	92.1	83.1	73.4	70.87	72.7	71.19	58.36	56.68	878.9

N- Mean daily duration of maximum possible sunshine hrs.

b) Penman combination method

This method combines the two physical principles, the mass transfer method and the energy budget method, used to calculate evaporation .The basic equations are modified and rearranged to use metrological constants and measurement of variables made regularly at climatological stations (Shaw, 1988). The method uses many meteorological parameters.

$$PET_m = \frac{(\Delta/\gamma)H_T + E_{at}}{\Delta/\gamma + 1}$$

H_T is the available heat and is calculated from the formula given by;

$$H_T = R_I (1-r)-R_0,$$

Where r is the average albedo of the area based on land cover type.

R_I and R_0 are incoming and out going radiation respectively.

The empirical formulas take the form:

$$R_I (1-r) = 0.75 R_a f_a (n/N)$$

R_I is a function of R_a, the solar radiation (fixed by latitude and season) modulated by a function of the ratio, n/N, of measured to maximum possible sunshine duration. And “n” is bright sunshine hours over the same period, h/day. N=mean daily duration of maximum possible sunshine hours, north Latitude of 10^{o} for the study area.

f_a (n/N) is calculated as:

$$f_a(n/N) = (0.16+0.62\ n/N) \text{ for latitudes south of } (54\ 1/2)^{o}\ N$$

The empirical formula of the out going radiation takes the formula,

$$Ro = eTa^4\ (0.47-0.75(e_d)\ ½)\ (0.17+0.83n/N)$$

Where: eTa^4 is the theoretical black body radiation at $T_{a,}$ which is then modified by functions of the humidity of the air (e_d) and the cloudiness (n/N), temperature in ^{o}c.

The parameters e_a saturated vapor pressure at air temperature.

e= the Stephan Boltzman constant

Ta=mean air temperature for a month, ^{o}c. is obtained from standard table of air temperature and saturation as:

$$e_a(T_a) = 6.11 \exp (17.3\ T_a /T_a+ 273.3)$$

Relative humidity (RH) in % used to calculate the value of actual Vapor pressure($e_{d)}$ as :

$$e_d = ea\ RH\%.$$

The energy for evaporation E_{at} is given by

$$E_{at}= 0.35\ (0.5+ u_2 /100)\ (ea- e_d)$$

Where - ea =the saturated vapor pressure at air temperature, Ta

e_d =the saturated vapor pressure at the dew point = ea*Hr/100

(u_2)= mean wind speed in m/s was converted to mile/ day

The value Δ/γ is found from weighing factor Δ/γ versus temperature from Shaw, 1994.

Where - Δ = the slope of the curve of saturated vapor pressure plotted versus temperature

γ = the hygrometric constant.

The annual Potential evapotranspiration of the study area computed using the above mentioned method is1135.27 mm/year.

Table 3-12: Potential Evapotranspiration of Gilgel Abay river Catchment (mm) using Penman combination method

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
PET(mm/day)	2.95	3.40	3.79	4.48	3.52	2.91	2.38	2.45	2.72	3.19	3.16	2.70	
PET(mm/month)	91.45	95.2	117.5	134.4	105.6	87.3	73.78	71.05	81.6	98.89	94.8	83.7	

Penman combination method of computing PET is more applicable than other methods because it considers many climatic parameters which govern the rate of Evapotranspiration.

2. Actual Evapotranspiration (AET)

After calculating the potential evapotranspiration of the area the actual evapotranspiration of the catchment is calculated. The term actual evapotranspiration is used to describe the amount of water loss that occurs under moisture deficiency, existing condition.

a) Empirical formula to calculate AET

Turc

A widely used formula to estimate annual values of AET over a catchment area was developed by Turc (1954, 1955).The formula relates mean annual precipitation and mean annual temperature of the catchment.

$AET = P/[0.9+ (P/L)^2]^{½}$ mm per annum

Where: p = mean annual precipitation (mm)

$l = 300+25T + 0.05T^3$

T = mean annual temperature (^{0}c)

Actual evapotranspiration of the study area using this method is found to be 833.3mm/year.

b) Soil-water balance (Thornthwaite and Mather) method of estimating AET

This method is introduced by Thornthwaite in the early 1940's estimates actual evapotranspiration using precipitation and soil moisture. Actual evapotranspiration is the amount of evaporation that occurs when soil moisture is limiting. When moisture conditions are suitable, the actual rate of avapotranspiration is equal to the potential rate. Soil moisture budget can be made on a monthly basis for various types of vegetation classified. Thus, the catchment area has been classified in to two groups of soil texture (silt clay to clay and loam clay) and moderately deep rooted cereals and deep rooted shrubs grown on them.

Based on the soil texture and the land cover type in the catchment, the actual evapotranspiration is estimated using Thornthwaite and Mather soil moisture balance model. To evaluate actual evapotranspiration over a catchment area, the proportions of different types of vegetation covering the basin must be known. The values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation (Shaw, 1994).

In the model, accumulated potential water loss, which indicates the severity of water shortage, is obtained by cumulating of the negative values of the differences between monthly precipitation and potentional evapotranspiration for dry season only; and the summation begins with the first month of dry season.

The soil moisture during the dry moths is then obtained from the following formula:

$$S_m = W \exp\left[-\frac{(La_m)}{W}\right]$$

Where, Sm: Soil moisture during the month M (mm)

La_m: Accumulated potential water loss at month M (mm).

W: Available water capacity of the root zone (mm)

The soil moisture for each wet month is obtained by adding the excess of rain of the current month to the soil moisture of the month before. However, this value may not exceed the water capacity and excess is documented as moisture surplus. PET value competed using Thornthwaite method is taken up in the calculation of AET; because, it is important to use the same method.

The monthly actual evapotranspiration, AET_m, is then found as:

$AET = PET$ if $P_m > PET_m$

Otherwise,

$AET_m = P_m - DS_m$

Where, AET is actual evapotranspiration, PET , Potential evapotranspiration, P is aerial precipitation, DS_m are soil moisture during the month m-1 and m respectively.

Accordingly, the annual actual evapotranspiration of Gilgel Abay river catchment using Soil-Water balance (Thornthwaite & Mather. 1957) method is **713**mm.

Table 3-13: Average monthly Soil-Water balance method of estimating AET, for a soil with an available water capacity of 160mm and clay to loam clay soil (Thornthwaite & Mather. 1957)

mm	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
P_m	3.5	6	29	36	109	240.5	388	355	201	114.5	29	13.5	1525
PETm	55.4	69.15	81	94.9	92.1	83.1	73.4	70.87	72.7	71.19	58.36	56.68	878.9
P_m- PETm	-51.9	-63.15	-52	-45	16.9	157.4	314.6	284.13	128.3	43.31	-29.36	-43.18	
Acc. Pot.W l(La_m)	-124.44	187.59	-239.59	-284.59							-29.36	-72.54	
Sm	73.39	49.69	35.71	27.03	43.93	160	160	160	160	160	133.3	101.9	
DSm	-28.51	-23.37	-13.98	-8.68	16.9	116.07	0	0	0	0	-26.7	-31.4	
AETm	32.01	29.37	42.98	44.68	92.1	83.1	73.4	70.87	72.7	71.19	55.7	44.9	713
D	23.39	39.78	38.02	50.22	0	0	0	0	0	0	2.66	11.78	165.85
S	0	0	0	0	0	1.33	314.6	284.13	128.3	43.31	0	0	771.67
AWCR(W)	160mm												

AWCR = ACCUMULATED WATER CAPACITY OF ROOT ZONE:

90% moderately deep rooted crops, and 10% Deep rooted shrubs grown on silty clay to clay and clay loam soils respectively.

From Table developed by Thornthwaite and Mather, 1957, the total Available Water Capacity of the Root zone (AWCR) for the above mentioned land covers and soil is calculated to be

90% (150mm) + 10% (250) = 160mm

P_m = Mean Monthly Precipitation, mm

PET_m = Potential Evapotranspiration, mm

AET_m = Actual Evapotranspiration, mm

Acc. Pot.Wl =Accumulated Potential Water Loss, mm

S_m = Soil Moisture, mm

DS_m = Change in Soil Moisture, mm

D = Soil Moisture Deficit, mm

S = Soil Moisture Surplus, mm

3.3.3 Runoff

3.3.3.1 Mean Monthly and Annual Flows.

Gigel Abay River is the main feeding river to the Lake Tana that originate from the Gish Abay an altitude of 2728m a.b.s.l and decreases to1789m a.b.s.l at its northern end around Lake Tana. The Gilgel Abay itself has many small tributaries. It mainly drained by river Koga around merawi and Kiliti before draining in to the Lake. Based on discharge data of the past 16years (1990 -2006) record, the mean annual discharge of the river is 712.49mm. Peak discharge occurs at the month of August; and often dries during extreme dry season from December to February.

No	River	Recording. Period	Discharge (m3/s)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Gigel Abay at Merawi	1990-2006	4.49	3.03	2.54	2.81	9.10	53.33	155.39	198.60	147.90	66.53	23.1	11.53	678.35

Table 3-14: Mean monthly discharge of Gilgel Abay River.

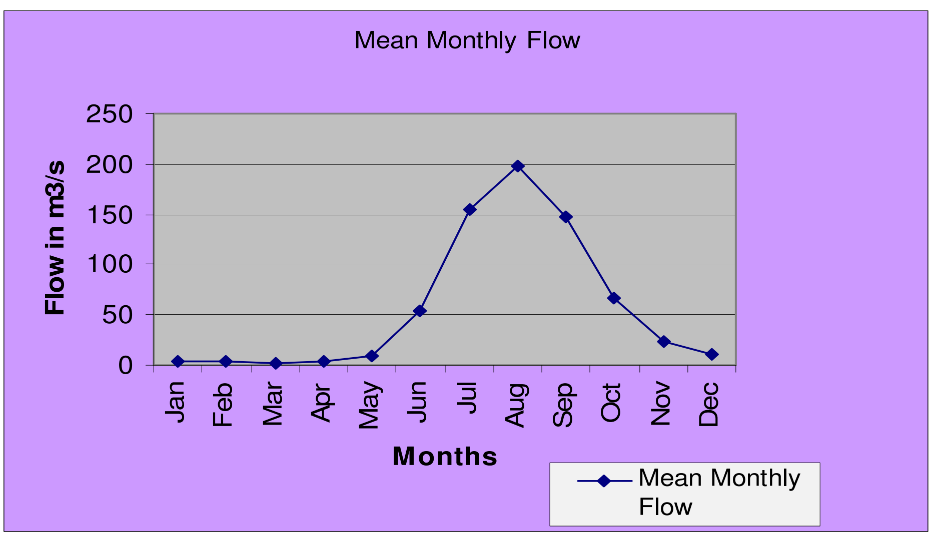


Fig 3.10 Mean Monthly Discharge of Gilgel Abay River

Estimating runoff or discharge from rainfall measurements is very much dependent on the time scale being considered. For short durations (hours) the complex interrelationship between rainfall and runoff is not easily defined, but for prolonged time the connection becomes simpler until, on an annual basis, straight line correlation may be obtained (Shaw, 1988)

Table 3-15: Rainfall-Runoff relationships at Gilgel Abay river catchment

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly RF(mm)	3.5	6	29	36	109	240.5	388	355	201	114.5	29	13.5
Mean Monthly Ro(mm)	7.22	4.42	4.09	4.38	14.6	83.08	250.1	319.65	229.94	107.08	35.98	18.56

Where RF is rainfall and RO is run off

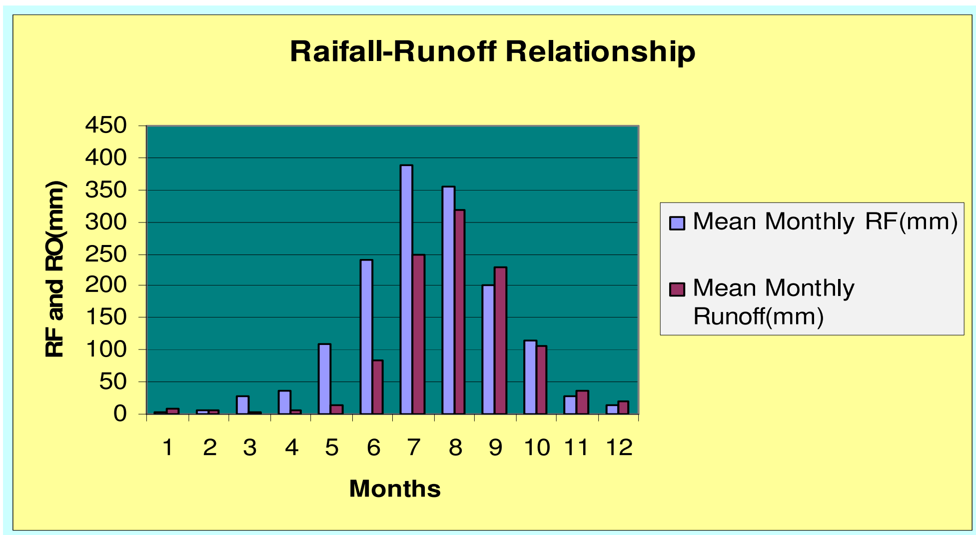


Fig3.11 Rain fall-runoff relationship

3.3.3.2 Hydrograph Analysis

The components of hydrograph are surface runoff, overland flow, interflow, direct precipitation and base flow. Figure 3.12 shows the components of a hydrograph

In this study, TIMEPLOT software was used for hydrograph analysis. Accordingly, the hydrograph separation of the Gilgel Abay river is performed by a time plot soft ware shows components of hydrograph. The obtained base flow by base flow separation method is 359mm.

Table 3-16: Base flow separation of Gilgel Abay River Catchment

Unit	Total flow	Base flow	Runoff
m^3/s	41.290	22.530	18.76

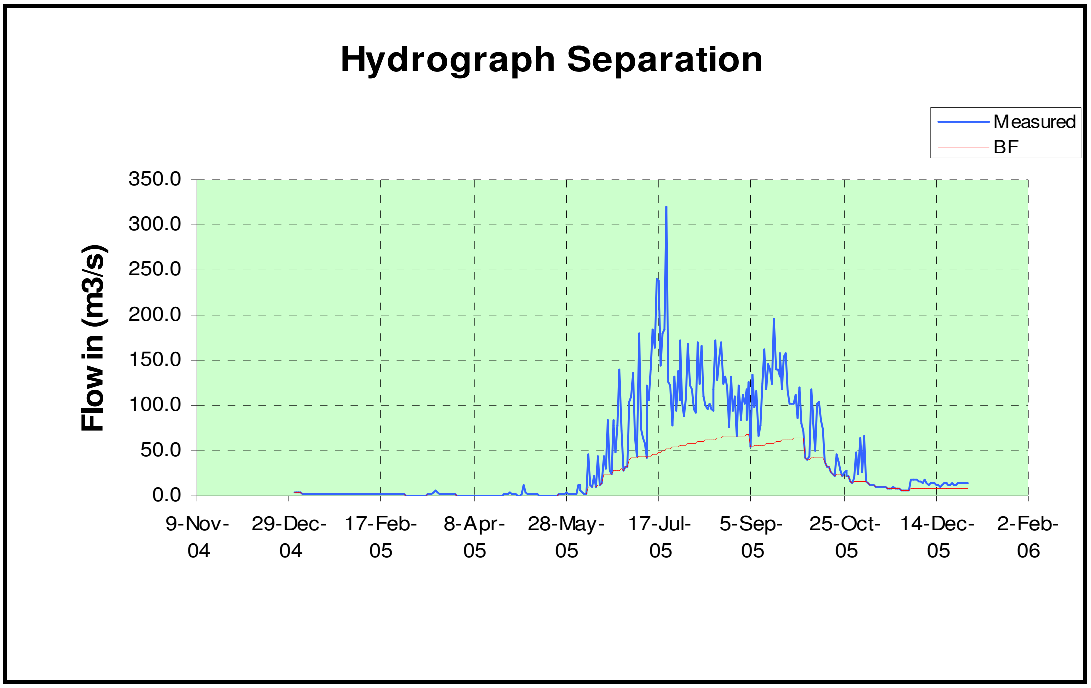


Fig 3.12 Hydrograph Separation

3.4 Recharge Estimation

There can be several sources of recharge to a groundwater system. These include precipitation recharge, river recharge, inter-aquifer flows, irrigation losses and urban recharge.

Each type of recharge can be quantified by different methods, direct measurement, water balance methods, Darcian approaches, tracer techniques and other empirical methods.

3.4.1 Recharge Estimation Using Water Balance Method

Water balance is the balance between the income of water from precipitation and snow melt and the out flow of water by evapotranspiration, groundwater recharge, and stream flow (Thornthwaite, 1957).The budget can be computed for a reservoir, soil profile, and aquifer drainage basin over a specific period of time.

General water balance equation form

Inflow= outflow $\pm$ change in storage

The following assumptions are made to derive the water balance equation of the study area:

- Surface water divide coincides with ground water divide. Hence the groundwater in the basin is in a closed system.
- The change in storage on annual basis is assumed to be zero
- The catchment is bounded by both surface water divide and groundwater divide, except at the mouth of the river where groundwater flow as a base flow
- There is no groundwater inflow
- The water balance is on annual basis

Based on the above assumptions, the water balance of the catchment is represented by the general equation.

$P=AET+RO+R\pm\Delta S$, $RO=SRO+BF$ where, SRO is over land flow and BF is base flow

$\Delta S=0$

Finally, the study area will have a water balance equation of the form:

$P=AET+RO+R$

P=precipitation (1561 mm) annually

AET=actual evapotranspiration (713mm)

RO=annual runoff out of the catchment (359mm)

R= Groundwater Recharge

$R=P-AET-RO$

From the above equation the ground water recharge of the catchment is 489mm/yr.

4 AQUIFER CHARACTERIZATIONS

4.1 Groundwater Occurrence

General

Groundwater is part of the earth's natural hydrological cycle. When rainfalls on to the land surface, some of the water will infiltrate more deeply, eventually accumulating above an impermeable bed, saturating available pore space and forming an underground reservoir. This water now called Groundwater and the rocks that store and transmit groundwater are called aquifer (Macdonald, 2005).

Ground water occurs at different depths in various geological unit of hydrogeological basin. All three classes of rocks (Igneous, sedimentary, and Metamorphic) can hold groundwater at different scale depending up on pore spaces and fractures in the rocks.

The rock properties determine how much groundwater can be stored and how productive an aquifer is. Porosity of rock related with the proportion of voids. When the pores and fractures are interconnected, the rocks are said to be permeable and water can flow easily. Volcanic rocks cover much the study area. In these rocks the occurrence of water bearing structure controlled by primary and secondary porosity which in turn related to rocks' mode of formation and modification by fractures or solution cavities respectively. Volcanic rocks have variable hydrological characteristic depending upon their mineralogy, texture, and structure. At the northern end of the catchment, along the lake margin and Gilgel Abay River and its tributaries, alluvial deposits such as sands and gravels are exposed. These sediments contain large amount of pore space between the grains. The water content of these aquifers exceeds 30% of their volume (Macdonald, 2005). However, the porosity will be gradually decreases both with the proportion of finer materials (clay or silt) and with consolidation.

4.2 Aquifer Systems

Based on the geologic units, the study area comprises of two major aquifer systems: the Quaternary basalt aquifers, and Tertiary volcanic aquifers.

No borehole data in the study area indicate the presence of Mesozoic sediment in the subsurface. However recent geophysics study by Hautot et al., (2005) suggests thick Mesozoic sediment beneath the basaltic sequence.

4.3 Aquifer Characterization

Properties of Aquifer

Quaternary basalt rocks and Tertiary volcanics exhibit a wide range of water bearing properties and yield because of their mode of formation, and the secondary processes (Fractures, faults and weathering) that modify the rocks. Groundwater flow in these rocks related to fractures. The intensity of fracturing increases the rocks' water bearing capacity.

The ability of rocks to transmit groundwater is described by its hydraulic properties, hydraulic conductivity, porosity, transmissivity, thickness and storage coefficient using pumping test method.

The available pumping test data and well log data analysis in the study area used to characterize the aquifer system in the catchment.

Well name	Well depth	Transmissivity
Bair Dar _Keb03/1	56	181.4
Bair Dar_ Keb03/1B		155.5
Bair Dar_ Keb03/2		82.9
Bair Dar _Keb03/2B		79.4
Bair Dar_ Keb17	50	5.53,3.7
Bair Dar _vet No2	60	6.02
Bair Dar_ MF No1	68	19.1
Bair Dar _MF No2	86	27.14
Bair Dar _MF No3	81	20.4
Bair Dar _workshop Bh1		16
Dangila D1	104	1.76,1.19
Dangila D2	57.9	7.78,7.66.7.26
Dangila D4	120	2.1083,3.96,0.78
Wetet Abay BH2	61	591

Table 4.1 Transmissivity of Quaternary basalt aquifer

4.4 Hydrogeologic Units in the Study Area

The major hydrogeologic units in the study area are Tertiary and Quaternary volcanic rocks and alluvial sediments along the Gilgel Abay river and its tributaries. Based on the variations in their mode of formation, lithology, structure, degree of weathering and fracturing, and the amount of pores and their degree of interconnection, these rocks have different water holding capacity. The main purpose of this groundwater study is to identify productive aquifers and to determine their hydraulic properties. The available pumping test data have been used to determine the range of permeability of various formations in the study area. The Quaternary volcanics and recent lava flows which are widely distributed in the Gilgel Abay catchment are grouped as extensive aquifer with fracture permeability. There exist boreholes drilled in Tertiary basalts for water supply of towns. The maximum average depth drilled in this formation is about 120 m. The water point inventory data (BCEOM,1997) shows that the average depth of boreholes drilled in this rock unit is in the order of 70-80 m and the static water level ranges from 1-8 m with a maximum discharge rate of 13 l/s (this is most likely the capacity of installed pump). Transmissivity values from pumping test results are with the interval of 6 - 27 m^2/day.

4.4.1 Quaternary Vesicular Basalt Aquifer

The Quaternary basalts in the study area extend from the northern end of the catchment around Bahir Dar and covers a wide area of the catchment even extends beyond the catchment. These formations comprise blocky and fractured vesicular basalt, with a porpyritic, glassy texture as well as some basaltic breccias and tuffs (SMEC, 2007).

Fig 4.1 Quaternary Fractured Basalt

The properties of these aquifers vary considerably and showing fractured properties. Comparing the transmissivity and specific capacity of these aquifers with Tertiary volcanic aquifers, Quaternary basalt aquifers have large values. Transmissivity values greater than20 m^2/day and up to 180 m^2/day is documented. This is consistent with the very fractured and weathered nature of aquifers at the northern end of the catchment and the most permeable zone of the catcment is this area. There are three major springs, which are the water supply source of Bahir Dar town, discharging from this aquifer. These springs are highly yielding, with discharge of 120 l/s and 60 l/s at the Areke, and Lomi and Tikur springs respectively, indicating shallow water level and high fracture porosity.

Fig 4.2 Areke and Lomi springs, Bahir Dar

From lithologic logs of this aquifer it can be inferred that, all wells in this unit tap water from weathered, fractured, and vesicular section between successive lava flows (Fig 4.3).

Borehole log of Bahir Dar kebele 14 borehole. Adapted from well completion report

(Water works construction enterprise, Nov., 2008)

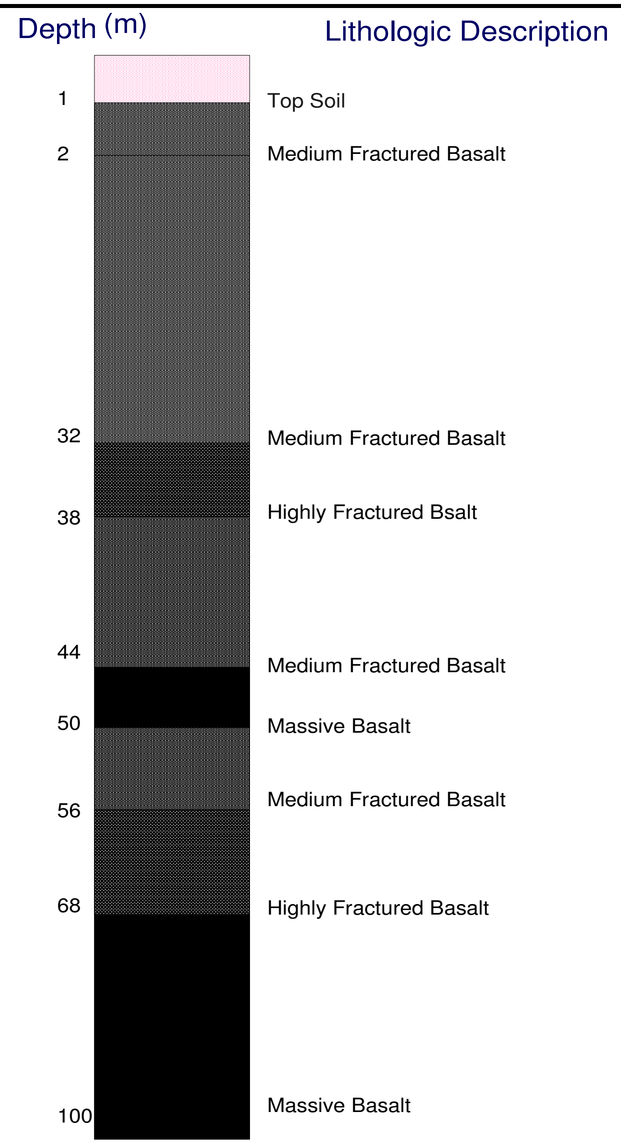


Fig 4.3 a lithologic log from Bahir Dar kebele 14 deep well

Towards south of the catchment (at Dangila) the transmissivity values is decreased and less than 10 m^2/day although one big value of 564 m^2/day at Wetet Abay recorded, this indicates the variability of the aquifers in the study area.

4.4.2 Tertiary Scoracious Basalt Aquifer

Tertiary scoracious basalt (Tarmaber basalt) outcrops in the south-east of the catchment and along the Choke mountain system and comprises basaltic lava flows, intercalated tuffs scoria and red brown paleosols. In the catchment this rock is overlain by the Quaternary basalt. Its thickness increases from the South in the North direction with a probable maximum thickness in Gilgel Abay river catchment. Although, no deep bore holes drilled in this formation where, the groundwater could be relatively deep as compared to the Quaternary basalt. The only available bore hole data at Dangla shows that this formation has high discharge 25 l/s with a drawdown of 12.5 m (CES and Tropics 2003).

4.5 Aquifer Productivity

Country wise classification of aquifer productivity and yield by (Chernet, 1993) is applied here to characterize aquifers in the catchment. Table 4.2 below shows productivity of aquifers based on specific capacity, yield and permeability.

Table 4.2.: Classes of yield and specific capacity values of aquifers

	Specific capacity in l/s/m			Estimated optimum yield in l/s (20m drawdown)		
Productivity of aquifers	Range, 80% middle values	Mean	Median	Range, 80% middle values	Mean	Median
High	0.2-7.6	3.3	2	1.8-68.4	29.7	18
Moderate	0.05-1.1	0.53	0.13	0.45-9.9	4.8	1.2
Low	0.006-3.4	0.1	0.04	0.05-4.5	0.9	0.4

The yield and specific capacity of aquifers in the catchment suggests that aquifers range from low to high productive. At the north end of the catchment around Bahir Dar highly productive aquifer with very high specific capacity and transmissivity is observed.

The major part of the surface of the catchment is covered by aquifer characterised by fracture permeability; the productivity of the aquifer formed by the volcanics productivity is considered as low to moderate; they cover of the catchment;

High productive aquifers outcrop over a restricted surface within the catchment. Most of the catchment is covered with low to moderate productivity aquifer where anticipated mean yield is about 7.1 l/s, according to the pumping test data in the area.

Table 4.3 Aquifer types and productivity in Gilgel abay catchment, from hydrogeological map of Ethiopia.

Aquifers	Extensive Aquifers, fracture permeability, volcanics
Quaternary fractured vesicular basalt	Moderate to high
Tertiary Scoracious Basalt	Low to moderate

4.6 Types of Aquifer

Types of aquifer determined by three different ways: analysis of pumping test data, description of lithologic log of bore holes, and describing seasonal fluctuation of springs and water level in hand dug wells.

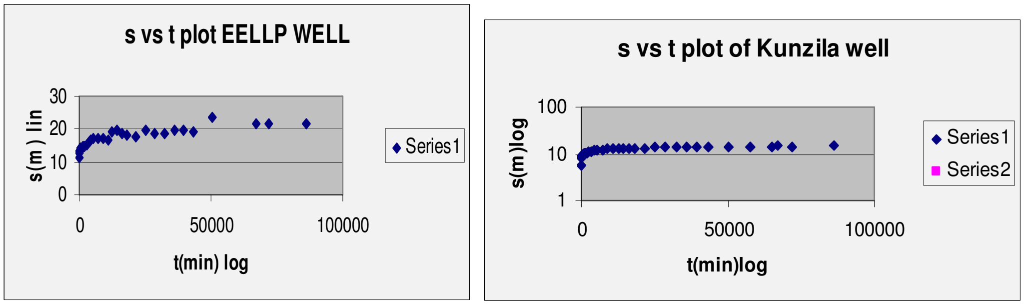
The first approach is plot of draw dawn data against time of pumping on log-log and semi-log scale for the purpose of system identification, which is based on models. The characteristics of models assumed to represent the characteristics of real aquifer system (G.P.Kruseman, 1989). Pumping test data on different aquifer systems in the study area is plotted on log-log and semi-log scale to obtain diagnostic and specialized curves respectively.

The resulting shapes obtained from the plots are used to select the appropriate model. Thus, the shapes of the curve obtained from the plots are nearly similar to the shape of the theoretical curve depicted by leaky and confined aquifer systems.

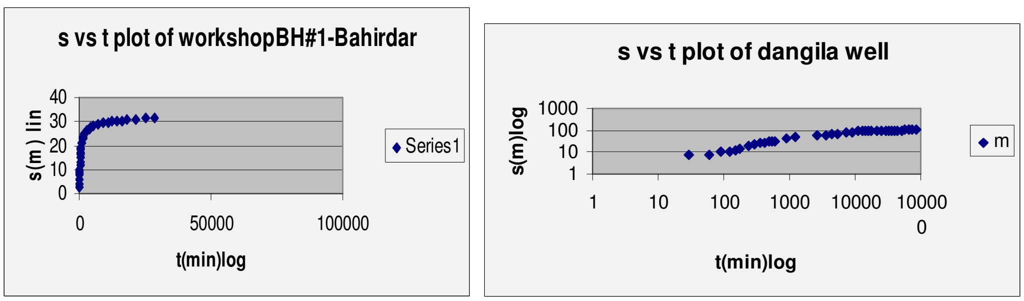
4.6.1 Interpretation of constant rate test

By plotting the collected data at the test site and by comparing the field curve with different theoretical curves the following interpretation can be done.

Fig 4.4 Diagnostic Plots and Specialized Plots



a) Confined aquifers



b) Leaky aquifers

Similarly by analyzing lithologic log in the catchment and near the catchment, the aquifer types can be inferred.

4.7 Groundwater Recharge and Discharge Areas

To map the recharge and discharge areas of the catchment Freez, 1979 explained five ways (topography, piezometric pattern, hydrochemical trends, environmental isotopes and soil and land surface features).From the above mentioned methods topography is the simplest indicator of flow direction and explained that discharge areas are topographic lows and recharge areas are topographic highs.

Therefore recharge areas in the catchment has been explained based on lithology, topography and structures in the area. Topographic high areas of the catchment in the south and south east along the Choke Mt. system considered as recharge area of the catchment.

Another way is careful looking and observation and mapping of springs and seepages in the field. At the north end of the catchment around the town of Bahir Dar there are high discharge springs and also marshy areas around Lake Tana can also indicate the zone of discharge.

The other method to indicate the recharge-discharge area of the catchment is observing hydrochemical trends. Groundwater evolves as it moves along its path (Freeze, 1979).The EC(TDS) map of the catchmenet shows an increasing trend towards the north end of the catchment showing that the area is discharging zone.

4.8 Groundwater Flow Systems

Water that enters the flow system in a given recharge area may be discharged at topographic low areas or it may be transmitted to the regional discharge area at the bottom of the major valleys (Freeze, 1979).

The water level recorded in the wells is in the range of 10m of the ground surface and shallower. The local groundwater flow system manifested by the abundance of springs mostly around the northern part of the catchment and coincidence of groundwater level with topographic relief. So, shallow groundwater operates under local flow system controlled by topographic relief. The southern part of the catchment areas is dominated by well defined topographic relief. The thickness, variability, and lateral extent of aquifer indicate the presence of deeper, regional flow system.

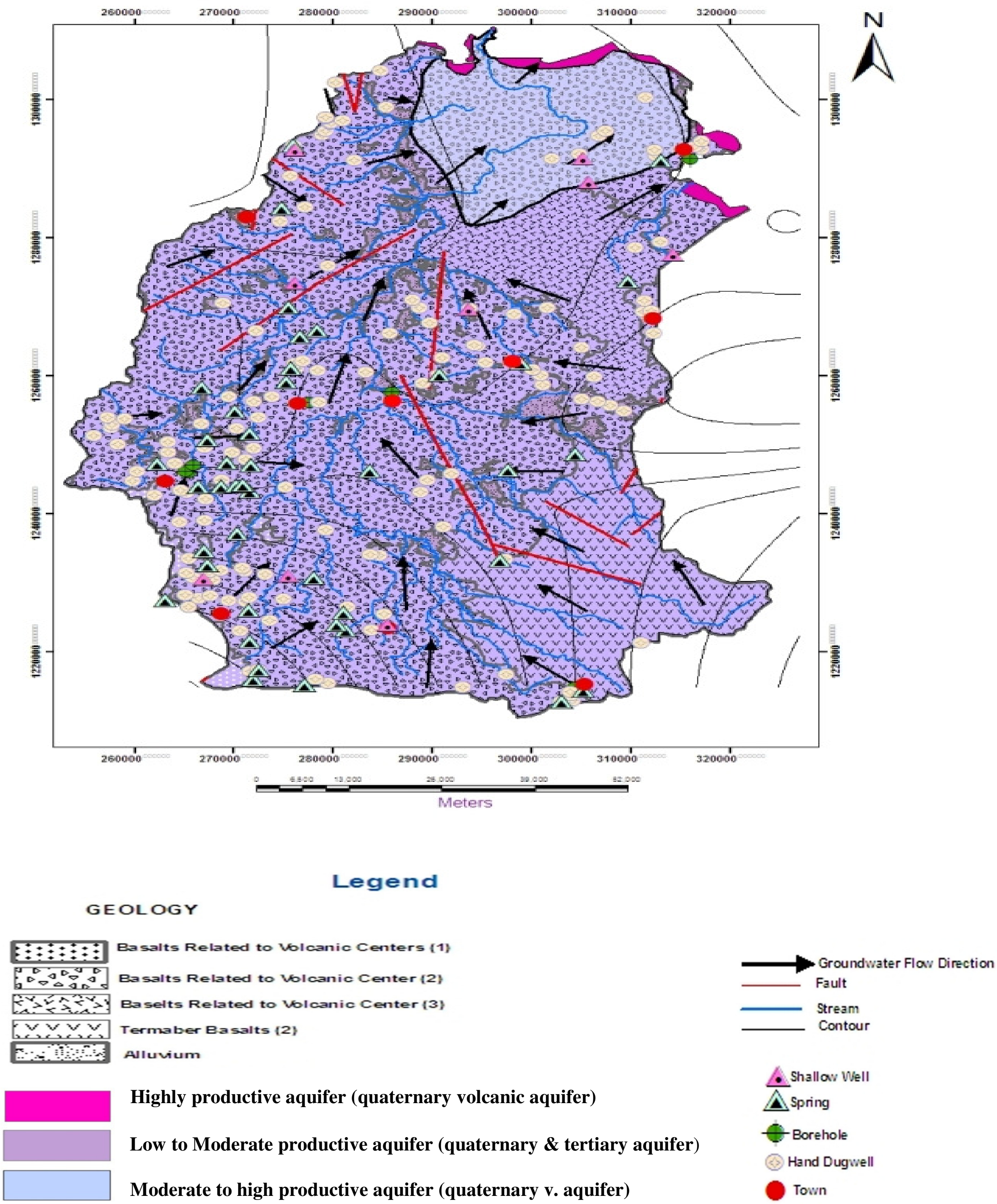
Geochemical and isotope data (Kebede et.al, 2005) supports the short flow paths of recharge water through the aquifers and low salinity groundwater dominated by Ca-Mg-HCO_3.

The deeper regional flow systems in the catchment have longer flow paths in the catchment. This had led to hydrolysis of minerals in the basaltic aquifers and in some locations enrichment by CO_2 from underlying rocks, resulting in groundwater with higher salinity dominated by Na-HCO_3 waters (Kebede et.al, 2005)

Further the EC (TDC) values of water from the wells are generally greater than for the springs. The general trend of EC shows an increase towards the north and NE direction implies that the water had traveled for a longer distance and had longer period of contact with the rocks.

In the catchment, the groundwater gradient ranges from around 0.02 in the south to around 0.005 in lower lying areas approaching Lake Tana (SMEC, 2007).

Fig 4-5 Hydrogeological map of the study area



5 HYDROCHEMISTRY

5.1 General

The primary purpose of water analysis is to determine the suitability of water for a proposed use. The water quality is determined by the type and amount of substances dissolved in the water which in turn is governed by the chemical reaction it undergoes with the environment. Thus, natural water is never pure. It always contains at least small amounts of dissolved gasses and solids. The quality of water is there for a function of many variables: geology, geomorphology, climate, physico-chemical parameters (temperature, pressure, PH, Eh, etc), biological factors, anthropogenic influence, and time. Hydrochemical information can be used to interpret the origin and mode of groundwater recharge, and provide paleo-hydrological information used to calibrate groundwater flow model.

In this study an attempts will be made, by analyzing and interpreting the chemistry of water samples to identify recharge and discharge zones, and estimating groundwater flow direction and evolution.

Samples from deep wells, hand dug wells and springs were collected and In situ tests on the parameters such as PH, EC, and temperature have been made. The results from the laboratory analysis shows suspected result on cation species and totally disregarded and an attempted is made to utilize previously analyzed water chemistry secondary data.

5.2 Evaluation of Hydrochemical Parameters

5.2.1) Insitu Test

1) PH (Hydrogen Ion Activity)

PH is the measure of the degree of acidity and alkalinity. The PH values generally vary for different water sources from 6.1 to 8.44. The minimum value is for cold springe located at (GPS location 1281517mN, 312595mE) and elevation 1770m. PH value increases towards the lowlands (discharge zone), indicating higher rock-water interaction. The maximum PH value is measured for borehole located Gordoma Gabriel, Bahirdar (GPS location 1278411mN, 312595mE) and elevation 1795m. Most of the deep wells display PH values between 7.1 and 8.44 indicating the alkaline condition. The range indicates that the carbonate equilibrium conditions of the study area favor the dissociation of bicarbonate into carbonate ions.

2) Electrical Conductivity (EC)

Electric conductivity of water is its ability to conduct electric current at specific temperature. In the study area the maximum EC value is measured at the northern tip of the catchment around Bahir Dar, Godguadit HDW (GPS location 1277444mN, 323748) and elevation 1789 its value measured as 458 µs/cm and another value at Durbete bore hole (GPS location 1255954mN, 277610mE) is closer to the above HDW, which is 445 µs/cm this higher value can be attributed to the intense weathering of basalts in the area can increase the concentration of dissolved ion, which in turn increases the conductance because TDS and EC have directly proportional. Springs found at recharge areas have relatively low EC (Gish Abay cold spring, GPS location 1215213mN, 305120mE, 68 µs/cm).The variation of EC controlled by depth and also vary laterally. Shallow boreholes located in the discharge areas show generally higher EC attributed to longer residence time of rocks and water. The relatively higher temperature around discharge area can increase the evaporation which in turn increases the TDS concentration.

In general, EC trend shows an increase towards the discharge area and also weathering processes increases the concentration of dissolved ions.

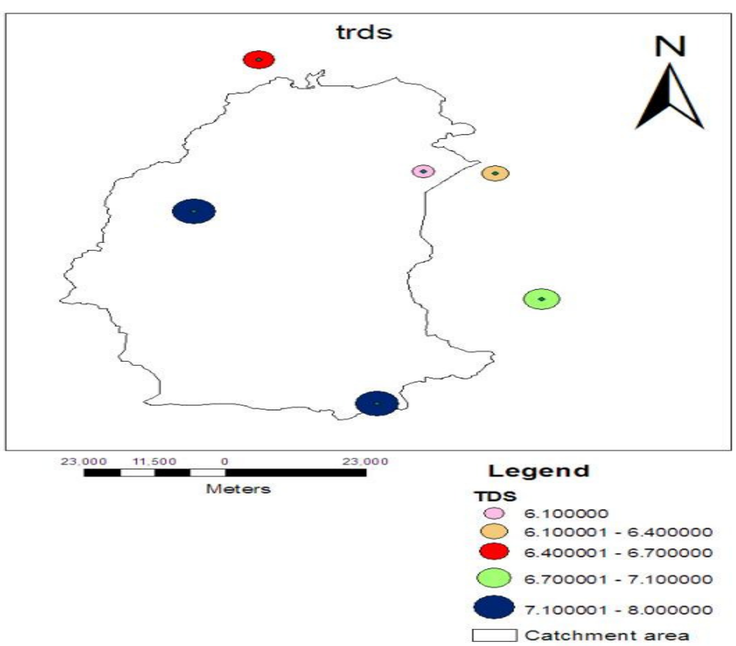


Fig 5.1 TDS map of the study area

5.2.2 Major Cations and Anions

The major cations and anions that have been identified in the catchment are Ca^{2+}, Mg^{2+}, Na^{+}, Ka^{+}, HCO_3^{-}, CO_3^{-}, SO_4^{-}, NO_3^{-}, and Cl^{-}.

The dominant cations in the water samples are Ca^{2+}, Mg^{2+}, Na^{+}, Ka^{+} and the dominant anions are bicarbonate ions $(HCO_3)^{-}$ suggesting that the water samples are from crystalline rocks(igneous). Ca^{2+} is the dominant cation followed by Mg^{2+} and Na^{+}, and $(HCO_3)^{-}$ is the dominant anions which also followed by NO_3^{-} and Cl^{-}.

5.3Classification of Water Types

Water type classification of samples from boreholes and springs is made to observe major water groups, their relationship and evolution along flow path using piper plot.

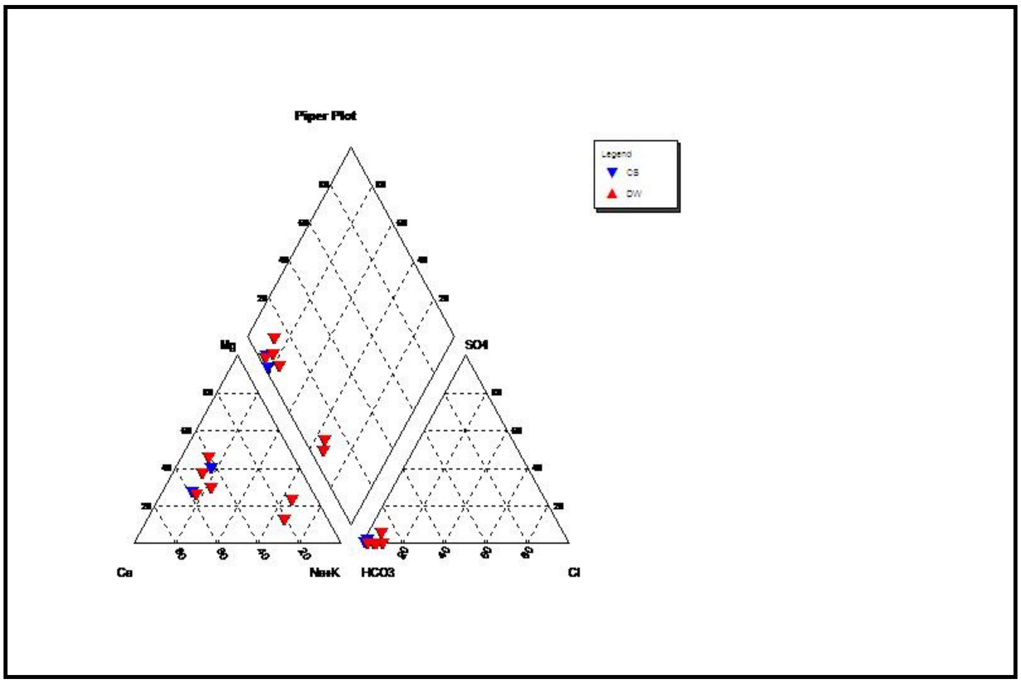


Fig 5.2 Piper plot of major ions

From the piper plot it can be observed:

- The cations plot mainly clustering around the calcium ion implies, the dominant cation is calcium ion with some samples aligned towards the sodium ion apex showing progressively increasing sodium enrichment. This shows the main controlling factor is rock-water interaction than mixing of distinct water types (Ca-type, Ca-Mg- type, Na-type).

- The anion plot exclusively clustered around the $(HCO_3)^-$ manifesting all the water samples are bicarbonate-type.
- In a central diamond shape plot, the water samples are defining a linear arrangement from $Ca\text{-}HCO_3$, $Ca\text{-}Mg\text{-}HCO_3$ progressively to $Na\text{-}HCO_3$ type water.

From the piper plot five types of waters are identified:

- ✓ $Ca\text{-}Mg\text{-}HCO_3$
- ✓ $Mg\text{-}Ca\text{-}HCO_3$
- ✓ $Ca\text{-}Mg\text{-}Na\text{-}HCO_3$
- ✓ $Na\text{-}Ca\text{-}HCO_3$
- ✓ $Na\text{-}Mg\text{-}HCO_3$

5.4 The Chemical Evolution of Groundwater

Under natural conditions groundwater flows from the highlands through fractured volcanic rocks to the discharge area. The chemistry of groundwater is affected by several factors such as, composition of rocks, the pressure-temperature condition, availability of oxygen, soil and soil forming process, composition of precipitation, anthropogenic factors, presence of bacteria, and effect of time. Based on the above mentioned factors it can be seen that the major cations are (Ca^{2+}, Mg^{2+}, Na^{+}) and the major anion is $(HCO_3)^-$ ion. The major controlling factor of ground water chemistry in the study area is lithology. Different rocks in the catchment have different composition and the water draining through these rocks have different composition. Consequently, the water evolves in the catchment area along its path from recharge to discharge areas as follows:

$Ca\text{-}(HCO_3) \rightarrow Ca\text{-}Mg\text{-}(HCO_3) \rightarrow Ca,Na\text{-}(HCO_3) \rightarrow Na\text{-}Ca\text{-}(HCO_3) \rightarrow Na\text{-}(HCO_3)$

Water from recharge area	Chemically transitional type water(mixture of $Ca\text{-}HCO_3$)	Water in discharge area

Groundwater recharge takes rapidly through fractured basalts. Groundwater flow paths are short and the waters from these areas are characterized by low TDS and Ca-Mg-HCO_3 type waters (Kebede, 2004).

5.4.1 Evolution of Major Ions

1) Mg^+ and Na^+ ions

Ca^+ ions shows generally decreasing trend from recharge to discharge area along groundwater flow path. Na^+ ions a general decrease trend following groundwater flow path.

2) Bicarbonate ions $(HCO_3)^-$

The bicarbonate ion shows an increasing trend along the flow path from recharge to discharge areas. This can be related to:

- In recharge areas, the abundant $(HCO_3)^-$ source is atmospheric CO_2 that reacts with H_2O to form dissolved CO_2 (HCO) which elevate the Bi- Carbonate ions.

$$CO_2\,(aq) + H_2O \longrightarrow HCO_3 + H \quad \text{(Freez, 1979)}$$

- As flow continues further, high $(HCO_3)^-$ content is controlled by in congruent reactions of silicate hydrolysis of feldspars of generalform

$$Rocks + H_2CO_3 \rightleftarrows Cation + H_4SiO2 + HCO_3 + Sld.$$

(Freeze, 1979)

5.5 Factors Affecting the Groundwater Chemistry

The chemistry of groundwater can be affected by different factors. Among different factors lithology is the dominant one. Groundwater chemistry is highly related to aquifer lithology. In the study area Quaternary volcanic rocks of basalt origin are the main aquifers. Compositionally these rocks composed of aluminosilcates minerals mainly quartz, feldspars (K-Feldspar, Na-feldspar), ferromagnesian minerals (Freeze, 1979). These minerals are unstable and tend to dissolve in the groundwater zone and on the surfaces of the earth. Because, they are formed at high temperature and pressure below the surface of the earth .These causes the alteration of water chemistry.

As these minerals contact with water, cations and silica are leached and leaves residue with increased Al to Si ratio. These residue usually a clay minerals such as kaolinite, illite, and montimorilonite .The cations released to the water are normally Ca^{2+},Mg^{2+},Na^{+}, and K^{+}. Another consequence of this process is an increase in PH and $(HCO_3)^-$ concentration (Freeze and Cherry, 1979)

$$\text{(Na-Feldspar) } 2NaAlSi_3O_8+9H_2O \rightleftharpoons Al_2Si_2O_5\,(OH)_4 + 2Na + 2Si\,(OH)_4$$

$$\text{(Ca-Feldspar)} CaAl_2Si_2O_8+H_2O \rightleftharpoons Al_2SiO_5\,(OH)_4\text{(Clay)} + Ca^{2+}$$

Mg^{2+} is released from dissolution of ferromagnesian olivine (foresterite).

$$5Mg_2SiO_4 + 8\,H + 2H_2O \rightleftharpoons Mg_6\,(OH)_6Si_4O_{10} + 4Mg^{2+} + H_4SiO_4$$

The abundance of these cations along the flow path is controlled by their equilibrium or solubility constant. As the cation concentration increases in the water, it precipitates from the aqueous solution (Groundwater).

The Cation exchange and precipitation process control the evolution of Ca^{2+} and Na^{+} along the flow path of groundwater in the catchment.

In the recharge area, the groundwater contains more calcium ions than sodium ions; this can be attributed to the fact that the calcium rich feldspar was first crystallized in Bowen's continuous reaction serious implies that it was formed at higher temperature and pressure than sodium rich feldspar (Albite). Therefore it is more susceptible to weathering. It dissolves easily when it is in contact with water thereby increasing calcium ion concentration in the water. As flow proceeds towards discharge areas, equilibrium will be reached and the water is saturated with respect to Ca^{2+} and precipitation starts there by reducing the concentration of Ca^{2+} towards the discharge area (Precipitation).

As flow proceeds further, residence time of water is increases and the less soluble (Albite mineral) will dissolve to raise the concentration of Na^{+} in the groundwater towards the discharge areas.

As the groundwater proceeds flowing can encounter clay minerals of soil, in the interflow lava gap. The Ca^{2+} ions are adsorbed to the surfaces of clay minerals and to the aquifer solids (Hem, 1985).

$$Na_2X + Ca^{2+} \rightleftharpoons CaX + 2Na^{+} \qquad \text{where X is clay mineral}$$

From the equation it can be seen that the sodium ions are released exchanged for calcium ions which can elevate the sodium ions concentration in the groundwater towards the discharge area.

From the above discussion, the concentration of calcium ions decreases and sodium ion increases from the Southeast and South to North of the catchment.

Consequently, the relative concentration of and evolution of Na^+, Ca^{2+}, and $(HCO_3)^-$ ions along the flow path forced the groundwater to evolve from calcium bicarbonate in the recharge area to sodium bicarbonate in the discharge area.

5.6 Water Quality

5.6.1 Drinking Water Quality

The chemical constituents of water in the study area have been evaluated and compared with WHO standards to observe the level of potability. Since the primary purpose of water analysis is to determine the suitability of water for the proposed use (Ayenew and Alemayehu, 2001).

Relative to surface water, groundwater is enriching with dissolved solids because groundwater is often occurs in association with earth materials.

For comparison World Health Organization, WHO guideline for drinking water and the ranges of concentration are supplied in the following table.

Table 5.1 comparison of water quality standards

Parameters	WHO	Obtained from field
Colour	15	Not analysed
Total dissolved solids	1000	68-461
Turbidity	5	
PH	<8	6.1-8.0
Nitrate(Mg/l)	50	0.1-58.5
Sodium(mg/l)	200	1.9-48.4
Chloride (mg/l)	250	0.6-13.6
Sulphate(mg/l)	250	0.1-5.8
Flouride(mg/l)	1.5	0.1-0.2

By comparing the measured value of major ions and some parameters from the catchment area with WHO guide for drinking water it can be seen that the parameters from the groundwater in the catchment area are well below the maximum limit value set by WHO except for nitrate which exceeds the WHO guide in excess of 8 mg/l at Addet dug wells usually indicates pollution by human or animal waste, and fertilizer run-off.

5.6.2 Irrigation Water Quality

Good quality of water permits maximum crop yields consistent with proper soil and water management. Water quality requirement for irrigation is related to several factors including salinity (which can be expressed in TDS), specific toxicity (which can be expressed by sodium, magnesium, chloride and boron) and infiltration (which can be expressed by Sodium Adsorption Ratio).

5.6.3 Sodium Adsorption Ratio

Water quality problems in irrigation include salinity and toxicity. When sodium rich water is used for irrigation, some of the sodium is taken up by clay minerals and the clay releases calcium and magnesium in exchange, in the reaction known as base-exchange reaction. Clays of montimorillonites group can expand and contract in response to changes in the composition of the adsorbed cation between the clay plates resulting in decreasing in permeability of soils. Since the major part of the catchment is covered with clay textured soil, effect of sodium on soils during irrigation should greatly be taken into consideration.

The United States salinity laboratory proposed the following relation to calculate the sodium hazard.

$$\mathbf{SAR = Na/ (\sqrt{(Ca+Mg)/2})}$$

Where SAR is defined as Sodium Adsorption Ratio expressed in mill equivalents per liter.

The United States Development of Agriculture has developed a widely accepted classification of irrigation waters based on the Sodium Adsorption Ratio as an index for sodium hazard.

Table 5-2: Suitability of natural waters for irrigation based on SAR

Water class	Alkali hazard (SAR)
Excellent	<10
Good	10-18
Medium	18-26
Bad	>26

Table 5-3: SAR values of various water samples in the catchment

No.	Woreda	Scheme ID	SAR(meq/l)
1	Bhirdar	Dw-1	30.11
2	Bahidar	CS-1	2.16
3	Kunzila	DW-3	2.1
4	Addet	DW-4	3.33
5	Yilmadensa	DW-5	4.51
6	Gishabay	CS-2	0.8
7	Dangila	DW-6	16.13

Accordingly, most of the SAR values in the study area lay less than 10; they are classified from good to excellent for their suitability for irrigation purpose. Except Bahir Dar dugwell shows high value of SAR.

6 GROUNDWATER MANAGEMENT PRACTICES

6.1 Description of the Study Area

The Gilgel Abay catchment is located in two administrative zones of Amhara region, West Gojam and Awi zone. The largest part of the catchment is located in west Gojam zone, and the remaining part found in Agew Awi zone.

There are six woredas that constitute Gilgel Abay catchment: Achefer, Bahir Dar zuria, Mecha/Merawi, Sekela, Dangila and Faggeta Lekoma. Except Mech/Merawi woreda the rest partly located in the Gilgel Abay catchment.

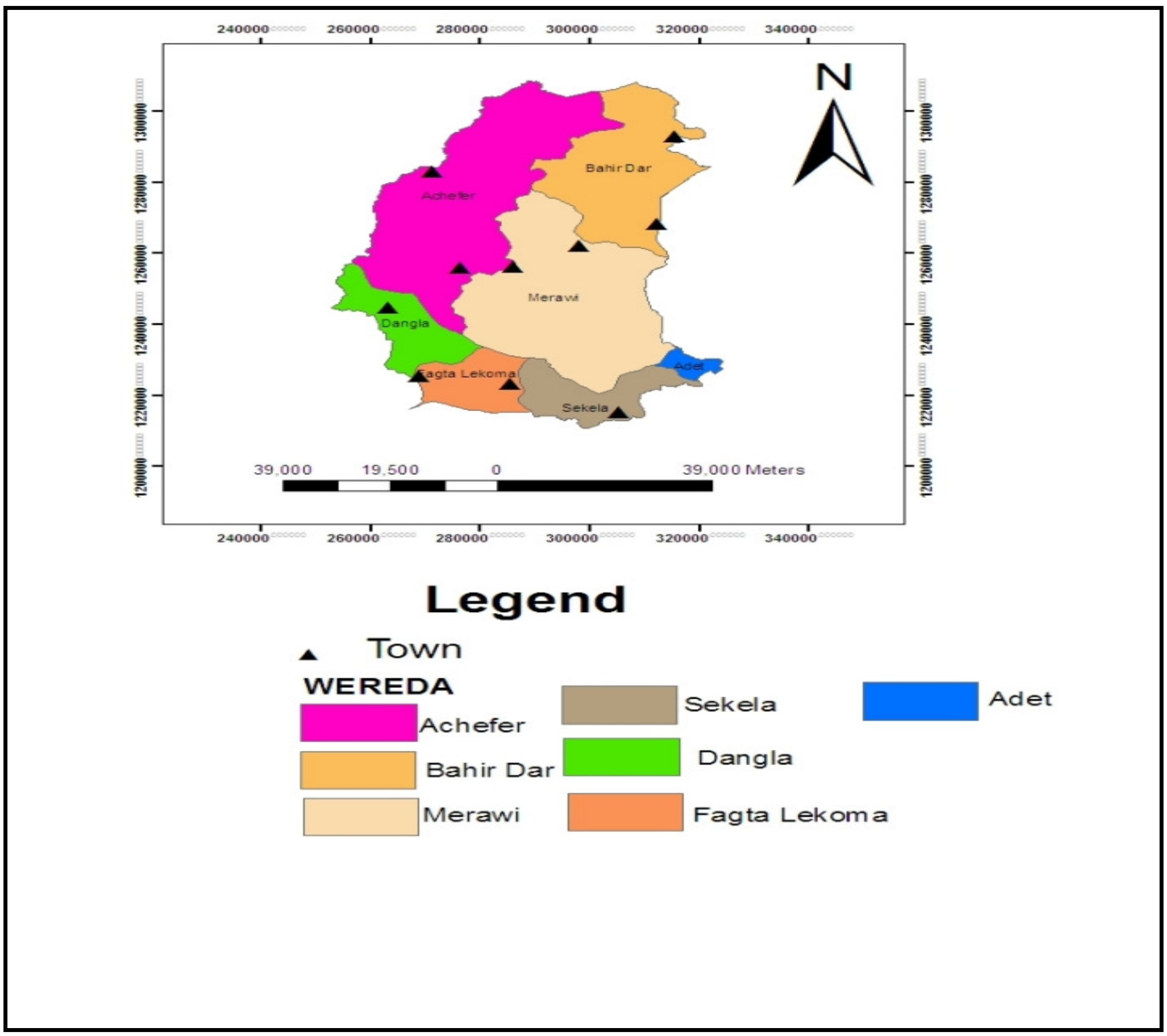


Fig 6.1 Woreda location in Gilgel Abay catchment

6.1.1 Population and demographic characteristics

According to CSA (2008) estimate of population for December 2007, which is based up on the 1994 census data, Gilgel Abay catchment is has a total population of 1,053,188.

Table 6.1 Population by sex by woreda

No	Woreda	2008 population	Male	Female
1	Achefer	155,863	78867	76996
2	Bahir Dar	182,676	93610	89066
3	Dangila	157,390	490949	77974
4	Faggeta Lekoma	126,357	62720	63637
5	Merawi	292,250	147 700	144550
6	Sekela	138,652	68989	69663

6.1.2 Socio-economic characteristics of the area

Agriculture is the mainstay of the study area economy, and it is highly dependent on rainfall. The agriculture sector in the study area dependent on traditional farming practices using backward technology, mainly by ox-plough that prevailed for thousands year with out any modification. High rain fall variability and draught makes the largest part of the study area to be more vulnerable to food insecurity problems. In the study area the agriculture sub-sector is not significantly benefiting from the technologies and practices of water management and irrigation that could improve productivity and reduce vulnerability to climate variability.

Industry in the study area is not well developed. In the urban areas there are only few large and small scale industries and their significance in terms of economic development is very limited.

6.2 Major Findings of the Study

The house hold survey was conducted in the representative woredas which can characterize the study area, and also representative Peasant associations (PA) were selected by woreda officials to implement household water economy analysis (HWEA).The survey may have lack of representativeness, except this limitation the overall survey findings are believed to be good and provide vital information to meet the proposed objectives.

Table 6.2The selected woredas and their respective PA's

Name of Woreda	Name of Peasant Association	Total No of House holds Interviewed
Achefer	Dalgai	36
	Azwa	
Bahirdar Zuria	Aste Yohannes	24
	Yeshala	
Mech/Merawi	Feresbet	42
	Hula nekura	
Dangila	Askala	38
	Dobi timirbet	
Fageta Lekoma	Banjita	22
	Azeric abo	

According to the household survey, the average house hold family size is about 5.6 persons. Man to women sex ratio is calculated approximately to be 1:1.Out the total population interviewed, 82 percent are illiterates the remaining are acquired formal education at different scale The community in all peasant association is from Amhara nation and they follow almost all Orthodox Tewahido Church.

According to the results of the survey 47% of the population is categorized under 15 age group ,while 27% is under 10 years age group. This indicates fast population growth in the near future.

Agriculture is the major activity in household economy. In terms of productivity the household age group indicates the majority of population lies in the "under 15 years ages groups". This implies, in terms of productivity, majority of household members are economically productive, even though it contradicts to internationally accepted definition of unproductive age group (less than age 15).

6.3 Existing Water Resources Availability and Scarcity

Ground water is an important source of water supply in the study area. According to the information obtained from the respondents, groundwater is the major and the most reliable source of drinking water in the area.88% of the respondents use ground water as the main source of domestic water supply. The remaining 12% uses surface water and unprotected springs. HWEA in the area reveals, peoples currently using river water due to failures of improved water supply schemes. This implies the considerable decline in clean water supply coverage. According to information gathered and HWEA, the study area stands among high water demand and water scarce area. However, almost all respondents have great interest of getting access to safe and adequate water supply. The present household water consumption rate is low, mainly due to scarcity of water.

6.4 Groundwater use

The main uses of groundwater include: domestic, agriculture, and industry. The information obtained from respondents; show that more than 90% of the households are use groundwater for domestic purpose.

Table 6.3 groundwater use

Ground water use	Groundwater withdrawals, in percent
domestic	97
Agriculture	2
industry	1

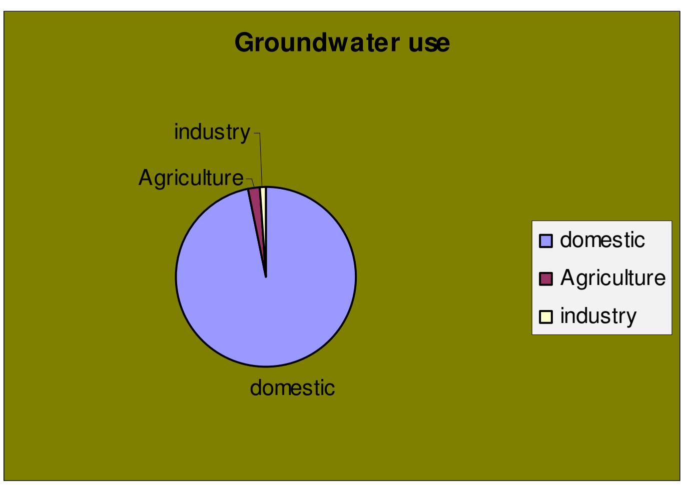


Fig 6.2 Groundwater use pattern in the study area

6.5 Water Supply Schemes

Provision of adequate water supply and sanitation services for urban and rural population is the major issues in the study area. According to the information obtained from the house hold survey, 85% of the populations do not believe on the adequacy water supply schemes and sanitation survey.

There are about 354 water points in the catchment, out of this 94 are non functional. The boreholes comprise (2.1%), hand dug wells (67.3%), springs (25.1%), others (5.6%).Hand dug wells and springs constitute 92% of the total water supply sources in the study area.

In urban areas most of the water sources are boreholes (2.1%), while in rural areas hand dug wells and springs are the main sources. Bahir dar, Merawi, and Addis Kidam towns have spring water as source.

Table 6-4: Type of Water sources in the study area

Source	**Urban**		**Rural**		**Total**	
	No.	**%**	**No**	**%**	**No**	**%**
HDW	-		228	67	228	64.4
SP	6	44	85	25	91	25.7
SHW	-		19	5.6	19	5.4
BH	9	60	7	2.1	16	4.5
Total	**15**	100	**339**	100	**354**	100

The water supply coverage of the study area is very low, particularly; the rural population of the region has limited access to improved water supply service.

Fig 6.3 Competition for limited resource

6.6 Rural Water Supply Schemes

Rural water supply schemes in the study area are characterized by: the schemes are widely distributed and it is difficult to reach the site; the schemes are small, remote, and lack infrastructure typical characteristics of rural water supply schemes.

A total of 339 water supply schemes were inventoried in the rural area of the study area. The boreholes comprise (2.1%), hand dug wells (67.3%), springs (25.1%), others (5.6%). Hand dug wells and springs constitute 92% of the total water supply sources in the study area.

6.6.1 Physical status

During the field survey, many rural water supply schemes were observed to be non-functional.

Fig 6.4 Non-functional well, Zekuskuam, near Wetet Abay (Gps location 288515mN, 1258795mE)

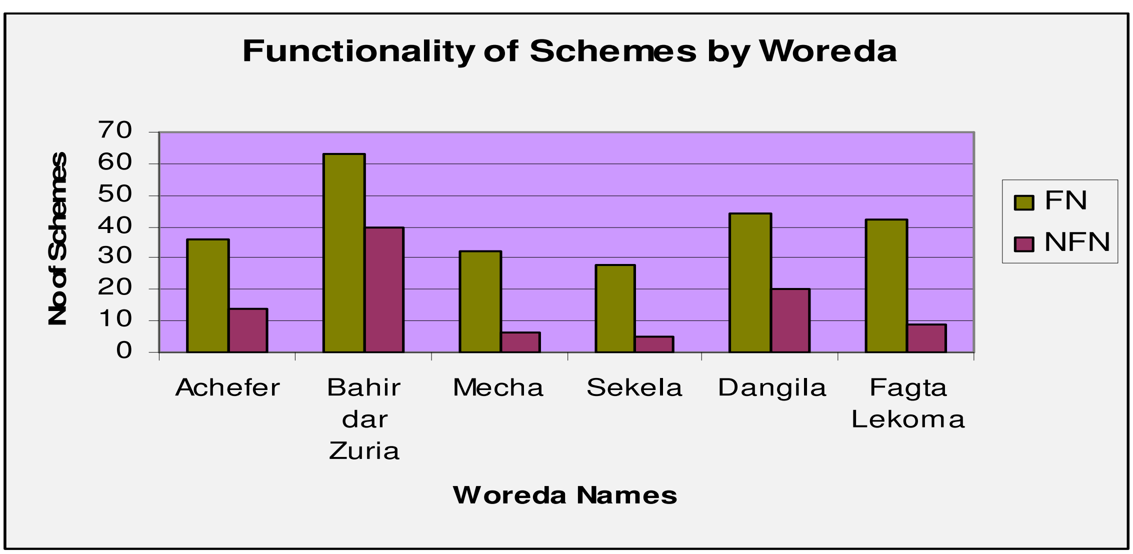
There are 245 functional and 94 non functional water supply schemes in the rural areas of the study area. Functional and non functional schemes constitute 72.3% and 26.7% of the total water supply schemes available in the rural areas of the study area.

It can be seen from the figure that a significant number of the water supply schemes are out order. This is a serious problem to be taken in to consideration concerning the water supply coverage of the area. The causes of failure in water supply schemes are: construction problem, poor management of the constructed schemes, lack of awareness at community level, spare part problems, and due to chemical contaminant.

Table 6.5 Rural Water Supply Schemes by Woreda

No of Schemes												
Woreda	HDW		SP		SHW		BH		Total			
	FN	NFN	FN	NFN	FN	NFN	FN	NFN	FN	NFN	UC
Achefer	27	10	7	3		1	2		36	14	0
Bahir Dar zuria	48	25	5	11	10	4			63	40	o
Mech/Merawi	25	6	5		1		1		32	6	0
Sekela	19	3	8	2			1		28	5	0
Dangila	30	5	12	14		1	2		44	20	0
Faggeta Lekoma	25	5	16	2	1	1		1	42	9	0

Figure 6-5 Status of Rural Water Supply Schemes by Woreda



6.6.2 Adequacy of schemes

Water supply schemes to be adequate they should be sufficient both in quantity and quality for the community. In the study area the adequacy of the water supply schemes are in question because the household members most of the time spent their time queuing up for water, this implies how limited the water supply schemes.

6.7 Water Lifting Technologies

Demand for water lifting technologies in the study area for domestic, agricultural and industrial use is high. Appropriate water lifting technologies can reduce waste and release more water for the sectors.

6.7.1 Hand pumps

Hand pumps are familiar and widely used for small scale water supply purpose, but are seldom used for irrigation. These pumps are also used pumping water from shallow hand dug or machine drilled wells, which generally vary from few meters to not more than 50 meters deep. Hand pumps use different operating principles but are commonly classified in accordance with the depth from which particular pumps draw water, namely: low, intermediate and high lift respectively.

Widely used hand pumps in the study area are, Afridev and Indian mark II.

Afridev

The Afridev hand pump has a lifting capacity of up to 45 meters and a pumping rate capacity of 0.38l/s (adequate) for low lift, 0.19 l/s (good) for medium and 0.14 l/s (good) for high lift conditions.

All the down-hole components consist of stainless steel rods and PVC riser pipes, which are resistance to corrosion. The pump has excellent VLOM potential, as it is easy to repair the pump.

Indian mark II

Afridev pump becomes unsuitable above 45 meters depth and a higher capacity hand pump must be selected. The recommended type of hand pump for use in such kind of deep well is the modified version of Indian mark II (public domain type). The modified Indian mark II though, not truly VLOM, is capable of lifting water from deep wells.

6.7.2 Motorized pumps

There are several types of motorized pump sets that use fossil fuel: mostly gasoline or diesel. Where the depth of bore hole or location of a spring do not allow the use of hand pumps or gravity flow respectively then it will be necessary to use motorized pumps for lifting the water to the convenient point. There are generally two types: surface and submersible types.

Treadle pumps and low cost motorized pumps are among the most popular technologies for water lifting and conveyance. Treadle pumps are potentially high return and high impact. Motorized pumps are few in numbers compared with springs and HDW in the study area.

6.7.3 Technologies for irrigation water application

Low cost drip irrigation kits enable the farmer to make use of limited amounts of water and fertilizer to grow high value crops. It allows the precise application of small amounts of water directly to the root zone; it reduces losses from evaporation, weeds, runoff and percolation.

Fig 6.6 Groundwater use and technology

6.8 Sustainability of Water Supply Systems

For a scheme to be sustainable good operation and maintenance must be fulfilling. In addition the presence of community management and water committee are crucial for a scheme to be sustainable for longer service.

Generally a scheme is sustainable if:

- repair is done on time,
- the scheme caretakers are trained,
- spare parts are available,
- community management is in place, and
- there is water committee.

6.9 Women's Capacity and Role in RWSS

HWEA survey indicates, in the community women and girls are main water fetchers. Collecting water is not only physically stressful but also time consuming.

Fig 6.7 queuing up for water

Women could play a major role in taking care of water supply schemes. Their participation in rural water supply schemes can reduce sustainability problems.Women are usually reputed to be competent at managing finance. In some cases women are influential in deciding the location of water sources and water points. In general there appears to be no pronounced barrier or resistances to women participation in rural water supply.Women are not fairly represented in water committees. In most of the places the combination is 70 % men and 30% women and in some places even less. More attention should be given for women's involvement in rural water supply schemes committees, there are some places in the study area that still believe that women should not be involved in such activities.

6.10 Groundwater Consumption

Based on the information gathered from respondent, 76.5% of the households' collect water once a day, the remaining 23.5% collects twice and more than twice a day. Depending on the wealth of households' water consumption also vary accordingly. The average daily house hold water consumption is about 50 liter. As stated in the previous section, the average house hold's size in the area is estimated to be around 5.6 persons, which means the per capital daily water consumption in the PAs will be around 8.9 liter. . The Groundwater consumption pattern of the area is characterized proper and reasonable water utilization pattern. According to the information obtained from the respondents, clean and scarce sources (such as spring) are exclusively used for food preparation and drinking, while river sources are used for bathing ,cloth washing , and for cattle. It can be seen the community aware how to utilize this scarce resource.

6.11 Fetching Distance

Information gathered from the respondents indicates that, the house hold members travel long distance to collect water from the available water resources. The information acquired from community members, show that more than 56% of the households are located more than 1 kilometer far from the water sources similarly, more than 47% of the households walk for more than an hour to reach at the water sources. According to information gathered from community members and officials of the woreda, in some areas, people particularly women and children who are socially water fetchers, travel up to 10 km distance especially in the dry season.

The household members not only travel a long distance to collect water but they also face queue. Queuing time is equally long for most households. The long queuing time is form lining up at the sources. The queuing time affect women and children school life because these groups of community are water fetchers. The findings of the households' survey revealed that, 80% of the households have to wait for more than an hour to collect water;

sometimes they may wait up to six hours, once they reach at the water sources. This shows how scarce the source is.

Fig 6.8 women and children travel a long distance to fetch the water

6.12 Sanitation and Hygiene Condition

The results of focus group discussions in most PA's indicate that over 90% of the household dispose garbage in their open field. Similarly, about 90% of them use the open field as the means of excreta disposal and the deification site is mostly in their back yards around their dwellings, which are also play grounds for children. Very few of them use pit latrine. This result is very similar to the regional sanitation coverage which is about 98 percent as reported by CSA, 1994. Most of them are living sharing the same room with domestic animals.

The plastic jerry cans are the most common containers in the study are used both for collection and storage of water. This practice may expose the water to contamination due to poor storage condition.

7. CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

- In the study area there are two major aquifer systems (Quaternary basalt aquifer and Tertiary scoraceous basalt aquifer).
- The main recharge area of the catchment is towards the Southern part of the catchment along the Mt. Choke system and surrounding area.
- The discharge area in the study area is located around the Northern tip of the catchment
- The Ground water along its path evolves from calcium–bicarbonate type in the recharge area to sodium-bicarbonate type in the discharge area.
- The estimated recharge of the catchment is around 489 mm/yr.

The main problems regarding the water supply schemes in the catchment area are:

- Poor planning and management practices
- Limited private sector participation
- Lack of skilled man power
- Poor coordination
- Community participation is low
- Women participation is low focus
- Government irresponsible

7.2 RECOMMENDATION

- Well compilation report should be property documented to obtain relevant information on borehole history of the catchments
- Water quality analysis or physico-chemical analysis should be included in water well drilling program.
- Inventory of available ground water abstraction points and estimation of ground water use must be made, in order to manage the available resource.
- Significant number of water supply schemes in the catchment is non functional due to various reasons. So, it is strongly recommended that the regional water resource bureau should give due attention to groundwater management issues.
- Develop public awareness of water as economic goods

- Provide financial and logistic support for water committees
- Promote community participation
- It is better to have strong involvement of local communities especially women in water administration and management practices.
- Essential to have good database on groundwater use, administration, technology and management issues.
- Designing new strategies of water supply scheme management have to be implemented to attain suitability of the water supply schemes.
- Establish appropriate monitoring and evaluation system
- Training and capacity building of water supply service staff.

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ANNEX- 1 PHOTO FROM FIELD VISIT

PHOTO-1 Focal group discussion at Wetet Abay

PHOTO-2 Gilgel Abay river

PHOTO-3 Groundwater (spring water) use Mereawi

PHOTO-4 Competition for a limited resource

PHOTO 5 In situ tests Dangila

PHOTO-6 FLOOD PLAIN AROUND DANGILA

ANNEX - 2 HYDROLOGY

A) Metrological stations in and around Gilgel Abay catchment

No	Meteorological Station	Latitude (North Degree)	Longitude (East Degree)	Annual rainfall	Elevation
1	Addet	11.26	37.49	1327	2080
2	Bahidar	11.60	37.42	1439	1770
3	Dangila	11.25	36.83	1538	2000
4	Enjibara	10.98	36.92	2145	2670
6	Kunzila	11.87	37.03	1127	1800
7	Merawi	11.41	37.15	1572	2003
8	Meshenti	11.15	35.85	1335	2000
9	Sekela	11.00	37.22	1870	2690

B) Mean monthly rainfall of seven stations in and around the Gilgel abay catchment

	Station	Months												
No	Name	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1	Addet	3	6	28	50	109	234	323	267	162	110	25	11	1327
2	Bahidar	3	2	7	24	82	188	425	391	201	93	20	3	1439
3	Dangila	3	4	24	39	110	257	349	353	236	112	42	8	1538
4	Enjibara	12	17	44	70	183	309	450	490	320	159	65	25	2145
6	Kunzila	0	4	7	9	87	146	315	278	173	77	32	0	1127
7	Merawi	3	3	14	38	123	276	430	370	211	83	15	7	1572
8	Meshenti	3	2	15	22	94	251	366	284	170	111	7	9	1335
9	Sekela	1	10	36	36	87	263	448	405	345	167	28	45	1870
	Mean Monthly RFof catchment	**3.5**	**6**	**29**	**36**	**109**	**240.5**	**388**	**355**	**201**	**114.5**	**29**	**13.5**	**1525**

C) Soil-Water balance, AET

Root Capacity= 160mm

mm	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
P_m	3.5	6	29	36	109	240.5	388	355	201	114.5	29	13.5	1525
PETm	55.4	69.15	81	94.9	92.1	83.1	73.4	70.87	72.7	71.19	58.36	56.68	878.9
P_{m}- PETm	-51.9	-63.15	-52	-45	16.9	157.4	314.6	284.13	128.3	43.31	-29.36	-43.18	
Acc. Pot.W l(La_m)	-124.44	187.59	-239.59	-284.59							-29.36	-72.54	
Sm	73.39	49.69	35.71	27.03	43.93	160	160	160	160	160	133.3	101.9	
DSm	-28.51	-23.37	-13.98	-8.68	16.9	116.07	0	0	0	0	-26.7	-31.4	
AETm	32.01	29.37	42.98	44.68	92.1	83.1	73.4	70.87	72.7	71.19	55.7	44.9	713
D	23.39	39.78	38.02	50.22	0	0	0	0	0	0	2.66	11.78	165.85
S	0	0	0	0	0	1.33	314.6	284.13	128.3	43.31	0	0	771.67
AWCR(W)	160mm												

YEAR	*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	I				8.170	11.420	74.360				224.840	65.940	32.260
1959	II				4.790	13.170	75.060			231.130	156.200	39.900	16.300
	III				2.280	2.640	4.530			115.700	42.130	16.300	8.900
	I	19.710	13.450	9.990	7.070	8.820	37.870	384.440	590.120	388.420	134.850	40.250	24.690
1960	II	9.620	6.120	4.530	3.400	5.840	62.500	22.150	300.430	218.640	99.980	21.400	12.730
	III	6.120	4.530	2.820	2.280	2.280	2.820	46.700	169.500	121.400	21.960	11.140	6.680
	I	15.010	12.580	11.940	9.660	5.280	37.690	285.800	449.340	449.490	189.090	87.440	71.400
1961	II	6.680	6.980	9.620	6.400	3.600	51.690	186.600	263.600	246.000	166.500	55.150	53.400
	II	4.790	4.280	3.400	2.460	1.490	1.630	31.420	82.200	135.200	25.530	21.400	14.500
	I	27.120	13.270	11.250	7.710	10.800	55.480	393.450	556.040	391.320	178.940	43.050	23.130
1962	II	14.050	6.980	4.530	3.600	12.300	81.120	223.920	280.560	225.700	160.550	28.090	11.900
	III	6.980	4.530	3.600	2.460	2.460	4.530	52.540	168.000	97.580	20.850	12.300	6.120
	I	12.600	7.270	5.960	6.150	20.090	78.750	416.020	508.860	364.500	98.110	94.140	53.240
1963	II	5.840	3.600	2.820	5.570	24.300	96.380	246.000	242.240	181.800	76.060	57.850	43.650
	III	3.600	2.460	1.490	1.230	1.490	6.120	90.430	150.400	79.070	18.250	18.750	11.140
	I	24.080	13.220	9.530	5.380	5.740	76.480	439.540	526.390	370.280	204.120	72.420	30.650
1964	II	12.300	6.400	4.040	2.820	8.220	76.060	284.500	244.120	231.130	106.000	45.200	15.840
	III	6.400	4.040	3.000	0.250	0.070	6.680	66.280	125.750	70.140	50.020	16.780	7.900
	I	21.580	15.370	12.720	11.200	7.060	66.440	363.600	533.170	345.530	181.300	114.630	66.410
1965	II	9.860	7.640	5.670	7.990	5.980	66.140	320.000	249.580	227.290	146.680	67.120	44.780
	III	6.960	5.670	3.970	2.500	2.050	2.270	54.120	151.140	93.690	32.360	29.750	13.690
	I	28.400	15.400	14.700	7.120	15.130	123.410	423.270	587.880	374.480	121.040	73.230	33.910
1966	II	13.690	9.090	8.350	4.500	14.150	100.780	242.000	283.240	238.270	72.090	38.000	19.730
	III	8.720	5.370	3.270	1.390	1.610	8.720	77.200	179.560	53.250	33.030	19.730	9.090
	I	18.780	11.480	12.870	6.670	9.100	563.500	387.760	479.910	419.110	210.240	62.480	41.320
1967	II	9.090	5.670	9.090	3.710	9.860	72.090	223.700	220.130	218.360	187.840	33.710	27.280
	III	5.670	3.710	3.210	2.050	1.610	2.970	82.480	137.980	104.470	29.750	20.280	9.860
	I	21.150	12.080	8.980	6.000	16.720	122.740	441.280	507.560	327.640	147.280	44.450	26.120
1968	II	9.860	6.300	4.230	2.970	16.000	125.180	243.320	266.990	216.090	128.880	22.550	13.690
	III	6.300	3.970	2.970	1.610	1.390	10.260	80.560	134.090	82.480	23.130	14.150	7.640
	I	18.320	11.250	11.100	6.280	9.520	43.220	356.040	625.790	308.010	82.070	33.040	19.640
1969	II	8.350	5.670	6.630	4.500	9.860	42.600	221.320	379.400	171.380	50.700	16.570	9.470
	III	5.670	3.970	3.210	1.610	1.610	2.970	64.280	169.770	56.770	17.080	9.860	5.370
	I								480.730	304.040	191.150	66.950	29.630
1970	II								279.160	216.600	125.470	57.670	15.100
	III								71.090	54.120	41.030	14.150	8.720
	I	17.200	10.680	9.070	7.080	12.750	51.780	411.600	641.730	426.020	125.580	61.050	26.080
1971	II	8.130	5.040	3.650	3.450	12.180	57.000	260.400	452.000	319.200	110.700	45.930	13.920
	III	5.040	3.650	3.060	2.390	2.550	3.650	52.050	139.800	75.600	27.520	14.380	7.200
	I	16.990	11.090	8.380	7.230	10.280	48.230	254.870	454.200	360.900	94.290	44.100	20.940
1972	II	7.810	5.040	3.650	3.450	11.370	64.600	179.000	279.000	284.000	82.400	31.630	10.600
	III	5.040	3.650	2.880	2.390	2.550	3.250	43.400	94.600	62.400	15.810	10.980	5.810
	I	13.510	9.650	8.050	7.770	23.800	82.180	258.400	532.100	381.600	188.470	49.080	23.350
1973	II	5.970	4.290	3.480	3.290	17.650	85.200	175.600	287.000	211.300	175.600	33.680	11.370
	III	4.080	3.680	2.780	2.780	3.290	10.600	44.700	93.900	69.000	26.310	11.370	7.300
	I	16.640	10.380	9.560	6.370	40.400	148.510	475.800	512.800	407.800	112.480	36.710	20.440
1974	II	7.300	4.740	4.290	2.780	51.000	122.800	294.500	262.600	255.400	113.400	21.160	9.180
	III	4.740	3.680	2.940	2.350	2.350	16.690	122.800	134.000	87.600	21.160	9.520	6.230

1975	I	11.370	8.890	8.420	6.740	7.830	61.630	456.000	628.560	461.850	154.270	64.560	36.310
	II	4.740	4.290	3.290	2.780	7.300	91.300	380.900	322.800	312.400	111.900	45.600	18.130
	III	3.680	3.290	2.780	2.350	2.210	3.480	73.400	124.400	92.600	27.560	16.210	9.520
1976	I	19.020	12.270	10.550	9.340	19.400	129.760	396.600	597.500	357.900	96.840	72.520	27.560
	II	8.850	5.460	4.740	6.490	27.560	150.000	223.200	341.500	217.900	78.000	78.000	14.340
	III	5.460	4.290	3.110	2.780	2.780	5.710	93.900	129.200	734.000	18.610	14.800	7.300
1977	I	16.500	10.860	10.760	7.390	15.360	109.370	467.460	545.720	369.840	182.890	61.860	28.420
	II	7.300	5.210	4.970	3.880	23.360	107.400	346.900	269.800	197.000	101.700	53.800	13.890
	III	5.210	4.080	3.680	2.350	2.070	8.520	67.900	158.900	92.600	37.430	12.600	7.300
1978	I	16.230	10.540	10.370	9.130	10.240	59.970	337.960	505.200	508.390	206.940	50.890	29.330
	II	7.300	4.510	4.080	6.750	9.520	58.800	201.000	312.400	309.800	248.200	28.850	15.730
	III	4.510	4.080	3.680	2.350	2.940	3.110	58.800	100.400	146.800	22.800	14.800	7.890
1979	I	18.540	10.150	7.700	6.640	11.760	75.320	357.790	515.260	422.960	164.330	58.690	30.290
	II	8.520	5.710	3.110	2.780	10.230	78.000	279.500	267.400	248.200	108.900	39.000	13.890
	III	5.710	3.110	2.490	2.120	2.780	2.780	43.800	132.400	99.100	39.800	13.450	9.180
1980	I	18.820	13.320	10.200	12.270	13.240	106.460	500.200	631.300	365.900	123.300	39.040	21.510
	II	8.850	5.970	6.230	10.230	11.770	84.000	409.600	320.200	299.500	92.600	22.800	10.230
	III	5.970	4.290	3.110	2.940	3.290	16.210	60.800	181.300	41.400	23.360	10.230	5.710
1981	I	14.160	8.880	7.400	6.600	19.190	60.990	606.550	574.000	427.200	143.320	35.480	19.550
	II	6.230	5.710	3.110	3.880	21.160	49.200	513.000	328.000	238.600	169.900	19.100	9.870
	III	4.510	3.110	2.490	2.210	2.210	5.210	26.930	168.000	92.600	19.600	10.230	5.460
1982	I	15.570	11.850	13.840	8.070	12.510	82.020	426.430	524.620	341.370	153.840	34.410	19.970
	II	6.490	5.710	8.520	3.880	8.850	63.800	320.200	282.000	229.000	103.000	18.130	10.980
	III	5.210	4.290	3.880	2.630	2.940	9.180	58.800	118.000	57.800	18.610	9.870	5.710
1983	I	13.090	8.230	6.720	4.640	10.810	47.950	272.480	568.500	336.540	178.850	57.640	20.210
	II	5.710	4.080	2.780	1.930	12.180	60.800	248.200	322.800	183.200	100.400	42.200	10.600
	III	3.880	2.780	2.070	1.510	1.510	4.510	22.800	160.700	104.400	44.700	10.600	5.710
1984	I	13.220	8.330	7.290	5.270	15.470	162.150	414.600	521.700	546.800	105.090	31.280	18.030
	II	5.710	4.080	3.110	2.490	56.800	150.000	267.400	328.000	262.600	138.800	17.170	9.180
	III	4.080	2.940	2.350	1.650	1.650	11.370	56.800	135.600	60.800	18.130	8.200	4.978
1985	I	11.070	6.990	6.870	7.820	26.600	94.190	438.000	617.710	404.180	99.120	26.200	17.900
	II	4.970	3.480	3.880	6.750	42.200	90.000	650.000	312.400	253.000	116.400	13.450	9.180
	III	3.480	2.490	2.210	######	1.930	7.300	29.510	150.000	53.800	14.340	7.590	4.970
1986	I			7.750	5.170	5.120	67.920	337.000	382.300	327.800	128.200	29.810	19.080
	II			4.970	2.780	3.880	62.800	241.000	229.000	177.500	142.000	16.690	9.520
	III			1.650	1.650	1.510	2.070	35.900	67.900	42.200	17.170	8.520	5.420
1987	I	10.770	7.330	6.950	5.910	32.140	142.800	356.000	430.400	325.100	169.000	51.980	24.940
	II	5.210	3.680	6.230	4.510	37.430	143.600	253.000	233.800	233.800	96.500	43.000	12.600
	III	3.480	2.630	1.930	1.650	1.930	28.850	44.700	93.900	65.800	32.250	10.980	7.590
1988	I	15.710	10.620	7.390	5.120	11.090	74.760	414.000	559.500	395.900	191.400	51.300	22.540
	II	7.590	0.210	3.480	2.210	9.870	61.800	248.200	277.000	217.900	124.400	35.150	11.370
	III	4.290	3.480	2.210	1.790	1.650	4.080	32.960	160.700	97.800	30.860	11.370	6.750
1989	I	13.260	7.450	8.830	7.930	19.530	102.300	518.600	613.400	359.100	118.500	33.730	23.110
	II	6.750	3.480	4.970	4.740	17.650	87.600	403.200	436.300	233.600	124.400	26.310	15.260
	III	3.480	2.740	2.630	2.490	2.210	3.680	69.000	153.500	73.400	21.700	8.850	6.230
1990	I	13.690	8.780	7.150	5.365	7.993	36.264	272.131	473.515	341.870	109.900	25.350	14.670
	II	6.750	4.740	2.940	2.490	7.890	90.648	248.767	387.943	227.261	121.200	14.340	7.020
	III	4.290	2.780	2.350	1.930	1.650	2.210	21.700	60.800	73.726	14.800	7.020	4.290
1991	I	9.990	6.210	5.750	11.520	23.890	142.970	507.780	577.800	419.640	112.600	28.770	17.020
	II	4.290	3.110	2.350	13.890	14.340	209.100	302.000	338.800	349.600	100.400	26.310	8.200

	III	2.940	2.110	1.650	1.650	2.780	14.800	65.800	135.600	50.100	21.600	5.710	4.970
	I	11.351	7.483	6.325	9.950	17.854	79.268	332.912	518.261	368.884	239.216	76.375	29.366
1992	II	4.740	3.480	3.110	18.130	21.160	80.400	229.000	409.600	243.400	150.000	85.200	19.600
	III	3.480	2.490	1.930	1.650	2.780	2.780	43.800	114.900	63.800	38.210	15.730	7.300
	I	14.880	9.221	8.620	13.098	24.223	193.447	509.632	477.187	398.606	239.800	59.620	22.029
1993	II	7.300	4.290	6.750	9.870	49.200	140.400	360.200	312.400	377.800	199.000	40.600	12.180
	III	4.290	3.110	2.630	2.780	2.630	23.360	8.520	151.700	74.500	34.410	12.180	5.710
	I	13.000	8.250	6.730	5.680	19.320	157.440	393.310	472.880	305.740	62.670	27.200	17.140
1994	II	5.710	4.080	3.480	2.780	39.000	191.000	226.700	279.500	262.600	44.700	19.100	11.370
	III	3.880	3.110	2.070	1.790	2.940	6.750	84.000	113.400	46.500	12.180	8.200	4.290
	I	9.662	6.248	5.233	5.468	29.840	142.990	246.960	529.630	339.880	68.750	20.590	15.253
1995	II	4.080	3.110	2.940	4.080	66.800	130.800	187.000	964.000	289.500	51.000	21.700	7.020
	III	3.110	2.210	1.650	1.240	1.650	9.180	32.960	82.800	51.900	13.450	6.230	4.740
	III												
	I	9.680	5.850	10.980	10.230	52.840	220.161	527.920	595.360	365.256	227.970	175.600	128.257
1996	II	4.740	3.110	30.860	20.630	100.400	189.000	360.400	352.300	253.000	146.800	96.500	58.800
	III	3.110	1.650	1.010	1.010	2.490	14.480	74.200	138.200	80.400	26.930	9.870	42.200
	I	7.990	4.850	4.830	4.400	43.330	157.870	428.190	523.890	322.410	161.820	92.560	28.320
1997	II	3.880	2.630	2.780	4.290	78.000	142.000	257.800	355.000	201.000	157.100	74.500	43.800
	III	2.490	1.650	1.120	1.010	1.930	20.630	31.550	87.600	55.800	24.510	17.650	6.230
1998	I	12.130	6.270	5.160	3.320	27.190	166.030	379.810	491.560	396.130	256.280	47.720	17.610
	II	6.230	3.480	2.490	1.930	100.400	205.000	274.600	297.000	241.000	220.100	47.400	9.870
	III	3.480	2.210	1.510	0.910	2.070	12.180	56.800	97.800	81.600	31.550	9.180	4.510
1999	I	9.958	5.173	3.839	4.427	23.864	149.670	436.688	500.474	329.393	328.166	50.965	20.353
	II	4.466	2.733	1.716	7.291	33.020	174.812	285.225	298.031	190.377	234.997	40.613	12.112
	III	2.733	1.716	1.153	1.056	2.263	12.512	65.885	121.692	72.490	37.465	10.588	4.690
2000	I	9.171	5.077	3.988	8.026	16.281	127.124	391.131	544.307	347.755	340.097	95.151	23.979
	II	4.920	2.571	1.593	8.524	33.738	134.328	223.872	381.915	223.872	251.107	104.096	13.335
	III	2.571	1.593	1.255	1.153	1.475	9.183	58.642	80.668	56.664	66.960	13.758	5.400
2001	I	10.259	5.630	4.829	4.643	16.083	174.093	404.200	551.493	333.585	110.315	35.928	14.429
	II	5.157	2.733	2.571	3.635	21.057	190.377	303.247	295.444	244.126	89.363	33.020	7.893
	III	3.076	1.978	1.593	1.255	1.056	12.112	61.686	129.504	39.020	20.514	7.893	3.442
2002	I	8.259	4.337	3.767	2.669	2.707	99.079	388.142	450.923	258.420	77.531	26.299	11.209
	II	3.833	2.263	1.844	1.593	3.833	124.783	263.000	303.247	186.413	71.363	19.451	6.170
	III	2.263	1.475	1.153	0.716	0.643	3.256	42.243	90.648	47.361	14.627	6.170	2.901
2003	I	5.955	3.639	3.191	1.727	2.381	112.719	477.915	493.426	450.447	87.636	26.406	10.790
	II	2.901	1.844	1.844	0.964	5.650	147.702	319.212	400.169	378.921	117.142	28.246	6.717
	III	1.844	1.255	0.876	0.511	0.511	1.255	71.363	60.661	85.573	11.720	5.157	2.733
2004	I	6.184	3.486	2.495	5.867	3.073	71.148	367.998	444.521	356.829	171.432	29.593	13.643
	II	3.076	1.716	1.362	12.112	3.076	69.141	287.760	253.460	335.660	248.767	16.938	9.183
	III	1.716	1.153	0.794	0.643	0.575	1.844	47.361	59.647	58.642	17.424	7.291	3.442

ANNEX- 3 BOREHOLE DATA

Shallow wells

Zone Name	Wereda	Kebele	Peasant Association	Date of Inventory	Easting	Northing	Elevation (M)
WEST GOJAM	BAHIR DAR ZURIA	Leta Anba	Askarie		322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Yigodi Tentela	Yigodi	7 /31/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Maji Debre Nigist	Mendel	8 /9 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Yibab chencher	Agita	8 /4 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Yibab chencher	School	8 /4 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Maji Debre Nigist	Tis Abay Gocha	8 /9 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Zenzelima	Girarma	7 /29/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Major Debre Nigist (Huletu Egoma)	Egoma gorgies (Andasa)	8 /2 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Sebetamit	Kibushet	8 /2 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Sebetamit	School	8 /2 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Dishet Abaraj	Godigadit	8 /2 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Yibab chencher	Yibab	8 /6 /2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Maji Debre Nigist	Yeshemel	8 /9 /2004	322547	1282800	1781

WEST GOJAM	BAHIR DAR ZURIA	Major Debre Nigist (Huletu Egoma)	Andasa Town	8 /2 /2004	322547	1282800	1781
WEST GOJAM	MERAWI	Amarit	Mamna	7 /16/2004	293535	1269543	1901
WEST GOJAM	MERAWI	Barakat	Brakat	7 /14/2004	314598	1252024	2083
AWI	DANIGL A	Chara 01	Chara 01	10/5 /2004	255470	1238449	2011
AWI	DANIGL A	Gisa Bolegzabi her	Gisa Chereka	10/5 /2004	245633	1237680	1860
AWI	FAGITA LEKOMA	Aswa - Finzit	Banja - Slassie	5 /31/2004	275456	1230927	2265
AWI	FAGITA LEKOMA	Ashewa - Afra	Koshni	5 /30/2004	266885	1230662	2365
AWI	FAGITA LEKOMA	Fagta Tuji	Fagta	3 /6 /2004	286138	1223788	2329

Springs

Zone Name	Wereda	kebele	Peasant Association	Date of Inventory	Easting	Northing	Elevation (M)
AWI	DANIGLA	Dubi	Dubi Mender No 3	5 /14/2004	260104	1239467	2089
AWI	DANIGLA	Kab Abo	Workmeda Ketema	5 /15/2004	243029	1257159	1298
AWI	DANIGLA	Argabo	Argabo No 1	5 /15/2004	226646	1280548	1219
AWI	DANIGLA	Argabo	Argabo No 2	5 /15/2004	226646	1280548	1219

AWI	DANIGLA	Argabo	Argabo No 3	5 /15/2004	226646	1280548	1219
AWI	DANIGLA	Addisweyin	Addisweyin No 1	5 /15/2004	225955	1280639	1192
AWI	DANIGLA	Addisweyin	Addisweyin No 2	5 /15/2004	225955	1280639	1192
AWI	DANIGLA	Girarge Warkit	Dengeshta Mender No 2	5 /17/2004	267179	1250700	2073
AWI	FAGITA LEKOMA	Sigla Banbl	Banjita	3 /6 /2004	281295	1223247	2453
AWI	FAGITA LEKOMA	Ashewa Afra & Shenga	Abu - Gush	5 /30/2004	266953	1234735	2272
AWI	FAGITA LEKOMA	Azerik - Abo	Azerik - Abo	4 /6 /2004	263002	1227533	2402
AWI	FAGITA LEKOMA	Azmach - Gula	Banjita	1 /6 /2004	271406	1226203	2419
AWI	FAGITA LEKOMA	Ende - Weha	Esa	5 /31/2004	273532	1217690	2570
AWI	FAGITA LEKOMA	Amsha - Shokuri	Jigrti	4 /6 /2004	264467	1225846	2419
AWI	FAGITA LEKOMA	Amesha - Znbiri	Zinta	4 /6 /2004	264441	1222824	2412
AWI	FAGITA LEKOMA	Aswa - Finzit	Tekuta	5 /31/2004	277878	1230883	2237
AWI	FAGITA LEKOMA	Dmama - Manguda	Danguri	4 /6 /2004	259754	1230185	2372
AWI	FAGITA LEKOMA	Sigla Banbl	Anzeba	3 /6 /2004	280859	1225497	2400
AWI	FAGITA LEKOMA	Dafera	Wahsa	5 /31/2004	271681	1221532	2525
AWI	FAGITA LEKOMA	Dmama - Maguda	Bashir	4 /6 /2004	263497	1230560	2394
AWI	FAGITA LEKOMA	Sigla - Banbl	Dbuki	3 /6 /2004	280386	1224002	2455
AWI	FAGITA LEKOMA	Ashewa - Abla	Kes Mender	5 /30/2004	267415	1232556	2359

WEST GOJAM	BAHIR DAR ZURIA	Kenbaba	Weji (Agamuwha)	8 /10/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Kenbaba	Weji (Tikurit)	8 /10/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Kenbaba	Jakira	8 /10/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Kenbaba	Dagosima	8 /10/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Robit	Weine wuha Ras	8 /11/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Yisela Dirdera	Yisela	8 /12/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Allohay	Atseye Yohannes	8 /14/2004	322547	1282800	1781
WEST GOJAM	MERAWI	Rim	Rim	9 /7 /2004	304507	1250161	2083
WEST GOJAM	MERAWI	Brhan - Chora	Feres - Bet	9 /7 /2004	297582	1246508	2026
WEST GOJAM	MERAWI	Amba - Mesk	Hula Nekura	7 /15/2004	290683	1260243	1950
WEST GOJAM	MERAWI	Enamrt	Malog	7 /16/2004	298828	1261967	1988
WEST GOJAM	MERAWI	Tatk - Lesra	Wer - wenti	8 /7 /2004	283680	1246400	1977
WEST GOJAM	KESELA	Gish Abay	Bereket	8 /24/1996		1214111	2731

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Hand dug wells

Zone Name	Wereda	kebele	Date of Inventory	East	North	Elevation (M)
WEST GOJAM	BAHIR DAR ZURIA	Tenta Laguna	7 /28/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Tenta Laguna	7 /28/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Tenta Laguna	7 /28/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Tenta Cherkos	7 /29/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Tenta Cherkos	7 /29/2004	322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Tenta Cherkos		322547	1282800	1781
WEST GOJAM	BAHIR DAR ZURIA	Zenzelima	7 /29/2004	322547	1282800	1781
WEST GOJAM	MERAWI	Idget Behbre	7 /19/2004	288743	1269985	1898
WEST GOJAM	MERAWI	Andnet	7 /20/2004	298253	1269014	1890
WEST GOJAM	MERAWI	Kurt Bahr	7 /17/2004	305034	1256742	2041
WEST GOJAM	MERAWI	Enamrt	7 /15/2004	290683	1260241	2016
WEST GOJAM	MERAWI	Tatk - Geberia	7 /18/2004	315449	1257257	2051
WEST GOJAM	MERAWI	Inashenfalen	7 /17/2004	306302	1259946	2036
WEST GOJAM	MERAWI	Tatk - Geberia	7 /18/2004	313793	1257566	2051

WEST GOJA M	MERAWI	Inguti	7 /16/2004	295515	1261949	1986
AWI	DANIGLA	Kab Abo	5 /15/2004	243029	1257159	1298
AWI	DANIGLA	Dekwork Hager	5 /15/2004	227193	1240734	1318
AWI	DANIGLA	Zelesa Simalta	5 /14/2004	265244	1243145	2134
AWI	DANIGLA	Zelesa Simalta	5 /14/2004	264667	1243276	2149
AWI	DANIGLA	Zibura Kwandisha	5 /14/2004	262059	1242742	2165
AWI	DANIGLA	Dubi	5 /14/2004	258739	1239597	2053
AWI	DANIGLA	Kwancha Kwakurta	5 /14/2004	256292	1240419	2012
AWI	DANIGLA	Kwancha Kwakurta	5 /14/2004	254434	1242904	2050
AWI	DANIGLA	Kwancha Kwakurta	5 /14/2004	255406	1242436	2050
AWI	DANIGLA	Bacha Dimsa	12/5 /2004	264114	1247457	2096
AWI	DANIGLA	Ziguda Guilt	11/5 /2004	269717	1249003	2061
AWI	FAGITA LEKOMA	Azmach - Gula	2 /6 /2004	266414	1227927	2375
AWI	FAGITA LEKOMA	Azmach - Gula	1 /6 /2004	271310	1227279	2400
AWI	FAGITA LEKOMA	Gezahar	2 /6 /2004	263874	1219838	2569
AWI	FAGITA LEKOMA	Azmach - Gula	4 /6 /2004	265547	1226612	2404
AWI	FAGITA LEKOMA	Ende - Weha	5 /31/2004	273532	1217690	2570
AWI	FAGITA LEKOMA	Gafera - Ateta	4 /6 /2004	270698	1223102	2532
AWI	FAGITA LEKOMA	Sgla Yohans	3 /6 /2004	281492	1226512	2390
AWI	FAGITA LEKOMA	Ashewa - Afra	3 /6 /2004	265518	1233572	2398

Boreholes

Zone Name	Wereda	Type	Easting	Northing	Elevation (m):	Status
AWI	DANIGLA	Motorized Bore hole	265135	1246144	2097	Functional
AWI	DANIGLA	Motorized Bore hole	265507	1246041	2104	Functional
AWI	DANIGLA	Motorized Bore hole	266026	1247062	2109	Functional
AWI	DANIGLA	Non Motorized Bore hole	230657	1239902	1341	Functional
WEST GOJAM	ACHEFER	Motorized Spring	273294	1282576	2045	Functional
WEST GOJAM	ACHEFER	Motorized Bore hole	284898	1313852	1794	Functional
WEST GOJAM	ACHEFER	Motorized Bore hole	277687	1256155	1952	Functional
WEST GOJAM	BAHIR DAR ZURIA	Motorized Spring	348249	1269083	1626	Functional
WEST GOJAM	BAHIR DAR ZURIA	Motorized Spring	313502	1268062	1956	Functional
WEST GOJAM	BAHIR DAR ZURIA	Motorized Bore hole	315968	1291412	1781	Functional
WEST GOJAM	BAHIR DAR ZURIA	Non Motorized Bore hole	313439	1268106	1952	Functional
WEST GOJAM	YILMANA DENSA	Motorized Bore hole	335592	1244119	2201	Functional
WEST GOJAM	YILMANA DENSA	Motorized Bore hole	334884	1247026	2183	Functional
WEST GOJAM	MERAWI	Motorized Bore hole	286043	1257594	1880	Functional
WEST GOJAM	MERAWI	Motorized Spring	298430	1262569	2004	Functional

Well name	Kebele	Woreda	Water Strike Depth(m)	Total screen	Depth(m)	Well status	SWL(m)	Estimated yield
Jutie No 1		Achefer	18,34	11.4	40	productive	5.00	6.00
Tadura		Achefer	8.65,24.65	17.1	48.60	productive	2.00	8.00
Guber	Ahurie Keltafa	Achefer	5,30,48	14.25	54.60	productive	5.00	4.00
Tach Afer Fida	Abchelkie Zuria	Achefer		14.25	61.40	productive	8.00	0.50
Dalegie	Debre Tsion	Achefer		19.95	63.60	productive	16.00	3.00
Koga China Camp Well No 1		Achefer	62	34.4	80.0	productive	24.0	1.50
Deber Gedema	Gedeme Mariam	Achefer	12	14.25	38.20	productive	8.00	8.00
Debekan	Bido Abaye	Achefer	45,15	25.65	56.50	productive	4.0	2.00
Sanikera no 1	Sankikera	Achefer	15,18,42, 60,68,80	40.25	103	productive	Over flowing Artesian	5.00
Achfi	Lata	Bahir Dar	6,28	17.1	40.40	productive	6.0	4.00
Abay Sargib well no 1	Tanta Laguna	Bahir Dar	13,23		64.00	productive	12.00	3.00
Abay Sargib well no 2		Bahir Dar	18		37.00		18.0	0.80
Chincha Mender	Meshente	Bahir Dar Zuria	21,43	20.3	52.40	productive	15.0	3.0
Delshet	Delshet	Bahir Dar Zuria		15	58.0	productive	10.0	1.50
Zelema no 2	Wonjita	Bahir Dar Zuria	22	8.55	27.0	productive	14.50	3.00
Gonbat	Gonbat	Bahir Dar Zuria			32.0	Abondone		
Debre Genet	Lata	Bahir Dar Zuria	15,27,37	19.95	52.40	productive	6.00	2.00
Tenta Laguna	Tenta Laguna	Bahir Dar Zuria		Open well	57.45	productive	3.50	2.00
Charma no 1	Wogersa	Bahir Dar Zuria	13		64.40	productive	13.00	0.40

Galadula no 1	Yigoda and Tentela	Bahir Dar Zuria	12,50	22.8	64.40	productive	12.00	1.20
Gulit	Egodi	Bahir Dar Zuria	13	28.25	67.40	productive	0.60	0.60
Yibab Eyesus	Gonbat	Bahir Dar Zuria		34.87	96.55	productive	27.00	2.00
Sewatamp no 1	Sewatamp	Dngila	6,34	Open well	46.0	productive	3.00	5.00
Sewatamp no 2	Sewatamp	Dngila	3	Open well	42.0	productive	2.00	8.00
Sewatamp no 3	Sewatamp	Dngila	9	Open well	27.0	productive	1.00	1.20
Sewatamp no 4	Sewatamp	Dngila	2.5,5.5,13	14.25	30.0	productive	1.00	4.00
Sewatamp no 5	Sewatamp	Dngila	7.5,11	Open well	25.0	productive	1.00	10.0
Sewatamp no 6	Sewatamp	Dngila	8.5	11.4	22	productive	3.50	2.00
Merawi-Bchema		Mecha	12,90,105,117	22.96	126	productive	38.80	5

Insitu measured parametres

No	Site name	Source	Easting	Northing	Elevation (m)	EC	PH	T
1	Burka	spring	298317	1262352	1900	190	7.85	21.5
2	Adis kidam	spring	267740	1226808	2409	170.3	7.60	18.5
3	Dangila	borehole	266735	1247056	2068	304	8.16	21.5
4	Durbete	borehole	277610	1255954	1981	445	6.90	23.0
5	Cherechera	borehole	327040	1284098	1786	396	7.05	24.1
6	Gordoma Gebriel	borehole	323768	1278411	1795	410	8.47	25.5
7	Gudobahir Medhanialem	borehole	320519	1280562	1801	287	8.10	24.7
8	Godguadit	hand dug well	323748	1277444	1789	458	7.30	24.0

Hydraulic parameter

Locality	Easting	Northing	Aquifer	Depth	SWL	DWL	Max yield	Safe yield	Specific Capacity	T(m2/day	Hydraulic Conductivity
Bahir dar zuria	323600	1282200	Quaternary volcanics	64	1		4				
				68			2.5				
				56	3.6		7.78		1.30	13.1	0.73
					7.86		2			82.9	
					2.71		6.94		0.24	16	
				80			3.2				
				58			3.5				
			Alluvials over basalt	60	7.75		2.8			6.02	0.50
Dangila	265416	1245820	Quaternary volcanics	104	3.77	30.61		0.9	0.03	1.76,1.19	0.07
	264953	1246292		57.9		40		3.3	0.08	7.78,9.66, 9.26	0.32
	265082	1245943		122				3			
				120				3.5		3.3,3.96,0.78	
				132	3.2			1			

Secondary water quality analysis data obtained from different sources

No	Site Name	Source	*UTM E*	*UTM N*	$\delta^{18}O$	Na	K	Mg	Ca	δD	*PCO2*	HCO_3	SO_4	Cl	F	NO_3
1	Kunzila	Dw	285598	1313579	-2.1	10.1	1.1	14.8	31.2	-0.8	0.039	200.0	0.8	3.6	0.2	
2	Bahir Dar	Cs	312595	1281517	-2.2	8.4	1.2	10.8	18.6	1.9	0.111	130.0	0.8	1.0		8.9
3	Bahir Dar	Dw	324500	1281000	-2.7	5.9	0.4	11.3	16.6	-3.8	6.4	98.0	5.0	4.4	0.0	9.6
4	Adet town	Dw	332000	1245100	-2.3	21.6	1.6	18.3	65.7	-5.0	0.024	281.0	0.1	13.6		58.8
5	GishAbay	Cs	305120	1215213	-2.3	1.9	1.0	2.5	8.6	0.4	0.001	45	0.9	0.6		7.1
6	Yilmandensa	Dw	328472	1230922		25.5	1.1	17.5	46.5		0.008	244	0.1	11.3	0.4	49.0
7	Dangila	Dw	275060	1270131		48.4	1.4	4.9	13.2		0.002	183	0.1	7.1	0.1	0.1
8	BahrDar	Dw	324990	1281000		160.5	7.3	31.1	25.7		0.010	634.4	2.8	0.1	24.1	0.5

Transmissivity data in the Gilgel Abay catchment

Well name	Well depth	Transmissivity
Bair Dar _Keb03/1	56	181.4
Bair Dar_ Keb03/1B		155.5
Bair Dar_ Keb03/2		82.9
Bair Dar _Keb03/2B		79.4
Bair Dar_ Keb17	50	5.53,3.7
Bair Dar _vet No2	60	6.02
Bair Dar_ MF No1	68	19.1
Bair Dar _MF No2	86	27.14
Bair Dar _MF No3	81	20.4
Bair Dar _workshop Bh1		16
Dangila D1	104	1.76,1.19
Dangila D2	57.9	7.78,7.66.7.26
Dangila D4	120	2.1083,3.96,0.78
Wetet Abay BH2	61	591

ANNEX-4 WATER SUPPLY SCHEMES

ereda	No.of schemes															Rural WS Coverage	Urb Co
	HDW			SP			SHW			BH			Total				
	FN	NFN	UC	FN	NFN	UC	FN	NFN	UC	FN	NFN	UC	FN	N/FN	U/C		
jam Zone	**323**	**87**	**23**	**100**	**38**	**0**	**16**	**8**	**0**	**11**	**2**	**0**	**450**	**135**	**23**	**7.05**	
Wereda	27	10		7	3			1		2			36	14	0	5.52	
r Zuria	48	25		5	11		10	4					63	40	0	5.19	
Denesa	79	13	15	9	3					1	2		89	18	15	7.44	
lerawi	25	6		5			1			1			32	6	0	5.3	
Vereda	19	3		8	2					1			28	5	0	4.59	
ereda	34	2		13	1					1			48	3	0	9.91	
mot	58	6	6	9	1								67	7	6	9.25	
na Wereda	13	8		3	8		1			2			19	16	0	9.55	
an Wereda	10	7	1	14			4	3		2			30	10	1	7.89	
ereda	4	5		16	4					1			21	9	0	9.38	
ama	6	2	1	11	5								17	7	1	6.85	
wi Zone	**159**	**44**	**0**	**90**	**26**	**0**	**3**	**5**	**0**	**3**	**1**	**0**	**255**	**76**	**0**	**8.63**	
Wereda	30	5		12	14			1		2			44	20	0	6.04	
n Wereda	33	6		18	7		1	2		1			53	15	0	11.42	
gusa	23	3		32	3			1					55	7	0	8.91	
a Wereda	48	25		12			1						61	25	0	8.51	
Lekoma	25	5		16	2		1	1			1		42	9	0	8.83	

ANNEX-5 HOUSE HOLD SURVEY

Water-Supply Sustainability Problems of Gilgel Abay Cachments

(Source Netsannet Kasa, 2008)

House hold survey questionnaire

Survey area: Region________Zone________Woreda:______

Date of interview: ____________ Name of interviewer: ___________

Name of head of house hold__________________________ Age ______Sex_______

Respondent's Name (if different from the head):________________ Age:__ Sex____

1. What type of source do you use for domestic water supply?
   a. Surface water source
   b. Groundwater source
   c. Both sources

2. What is your source of water for agricultural use?
   a. Surface water source
   b. Groundwater source
   c. Both sources

3 What is your source of water for industrial use?
   a. Surface water source
   b. Groundwater source
   c. Both sources

4. If your answer is surface water, what type of surface water?
   a. River b. Lake c. Ponds d. Dams e. All
   f. Other, specify____

5. If your answer is groundwater, what type of groundwater?
   a. Hand dug well b. Spring c. Bore hole d. Wind mill
   e. Other, specify____
   Purpose specify____

6. Is the source you are using at present healthy potable? Yes______ No______

7. If it is not healthy, what are specific problems?

a. Physical contaminants b. Chemical contaminants c. Biological contaminants d. a&b e. b&c f. a&c g. all

8. Are there members of the family who are victims of dental fluorosis?

a. Yes b. No

9. If yes state in number___________________________________

10. Is there any failed water supply scheme in your area?

a. Yes b. No

9. When did you observe the problem? (Year, months, weeks, days)

a. weeks_________ b. months__________ c. years___________

e. Others, specify____

10. Did you take any measure? a.Yes___________ b.No_____________

11. If not why?

a. It is costly b. high labor demanding c. I don't know how to participate

d. other reason (specify) ____

12. What are the water supply development activities undertaken by you and your family traditionally?

a. dug wells b. springs c. ponds

d. Others specify___________________________

13. Who else worked on water supply development activities?

a. Governmental organizations, b. NGOs, c. local institutions? d. others

Mention the names____

14. Have you ever participated in any water supply development activities initiated by the above mentioned agents? Yes___________, No_____________

15. What is the extent of community participation in deciding the site and design of the water supply scheme projects?
    a. involved in site selection b. involved in planning
    c. involved in implementation d. involved in administration and management
    e. others, specify__________________________

16. What type of participation did you have during the water supply scheme development?
    a. Cash b. Labor c. local materials d. idea e. Other_____

17. Do you get training at a household level?
    a. Yes b. No

18. Do you need new water points?
    a. Yes b. No

19. Who organizes the water supply scheme management?
    a. water committee b. professionals c. community d. administrators
    e. others, specify____________________________________

20. How can you justify the acceptance of the water management committee by the community?
    a. not accepted b. accepted c. well accepted d. extremely accepted
    e. other, specify____

21. What is the participation of women in water supply scheme management and development?
    a. water committee and water use management
    b. main fetchers c. guards d. technical workers
    e. Other specify____

22. Do you think representation of more women in the water committee is good for the society?

a. Yes b. No

23. Do you discuss about water supply problems with your neighbors, Local authorities, or other community members? a. Yes b. No

24. What major natural disasters occurred in your Woreda that affects sustainability of the water supply scheme?

a. drought b. flooding c. conflict over water resources

d. water born diseases e. presence of hazardous chemical constituents

f. other, specify____

25. What are the causes of groundwater development failures?

a. Quality problem

b. Quantity problem

c. Financial problem

d. Conflict

e. Institutional problem

f. Lack of proper investigation

g. Management problem

h. Others specify_______________________________________

26. What are the causes for the delay of water supply scheme projects?

a. Financial problem

b. Conflict

c. Management problem

d. Policy

e. Political instability

f. Institutional structure problem

g. Lack of proper investigation

h. others specify____

27. What kind of measures should be taken to minimize the current water supply development failures?

a. improving institutional structure

b. prevention of the resource from contamination

c. investing on knowledge of professionals

d. revisiting policy

e. improving awareness about the resource to the water management committees and administrators

g. Other specify____

28. Are there any conflicts that arise from competition over water resources? Yes___ No_

If there are any, when? ______________ With whom? ______________________

What types of damages occurred? (In number)

a. deaths__________ b. injuries__________ c. property damage______________

d. others, specify____

29. Do you believe that the sustainability of developed water supply schemes have the potential to improve productivity. a. Yes b. No

30. What are the major benefits of water supply scheme development for the community?

a. improves health b. reduces conflict over resources

c. improves productivity d. safe, adequate and clean water for domestic supply

e. other, specify____

31. What are your Main recommendations regarding water supply Sustainability problems?

____

Technical expert's questionnaire prepared to understand water supply sustainability problems of Gilgel Abay catchment

Water -Supply Sustainability Problems of Gilgel Abay Catchment

Questionnaire Survey

A. Experts and technical persons survey questionnaire

Survey area: Region________Zone________Woreda:______

Date of interview: ____________ **Name of interviewer**: _____________________

Respondent's Name:_____________________________ Age: _______Sex_______

1. Describe the most important water supply development activities carried out in the past till to date through government /or other organizations support, Discuss what is working well and what not, including suggestion for improvement and change:____
____
____
____

2. What are the major water supply sustainability problems in order of importance?
   i. Quality ii. Quantity iii .Skill iv. Policy v. institutional structure
   vi. Hydrogeological knowledge vii water use management
   vii. Others, specify ____

3. What is the role of women on domestic water supply development activities?
   a. water committee and water use management
   b. main fetchers c. guards d. technical workers
   e. Other specify_______________________________________

4. How can Water supply sustainability problems be minimized?
   a. improving institutional structure
   b. prevention of the resource from contamination
   c. investing on knowledge of professionals

d. revisiting policy

e. improving awareness of the resource to the water management committees and administrators

f. understanding the resource

g. Other specify____

5. What major natural disasters have occurred in your Woreda that affects sustainability of the water supply scheme?

a. drought b. flooding c. conflict over water resources

d. water born diseases e. presence of hazardous chemical constituents

f. other, specify____

6. What prevalent problems encountered in the developed water supply schemes?

a. imbalance between supply and demand b. poor administration

c. conflict over water resources d. failure of developed schemes

e. No problem

f. other, specify____

7. Do you have legal frameworks for promoting participation of various stakeholders?

Yes__________ No____________

8. What are the major benefits of sustainable water supply schemes for your community?

a. improved health b. reduced conflict over resources

c. improved productivity d. safe, adequate and clean water for domestic supply

e. other, specify____

9. What criteria's are considered when planning sites for water supply development schemes?

a. Settlement

b. transport accessibility.

c. hydrogeological feasibility

d. policy makers decision

e. others, specify ____

10. Is there continuous supervision during water supply scheme development?

a. Yes b. No c. intermittent supervision

11. Is there any monitoring system after development of water supply schemes?

a. Yes b. No

12. What is the extent of community participation in deciding the site and design of the water supply scheme projects?

a. involved in site selection b. involved in planning

c. involved in implementation d. involved in administration and management

e. others, specify____

13. What is the average distance to the water point?

a. <1km b. 1km-2km c. 2km-3km d. 3km-5km e. >5km

14. Out of the developed groundwater sources, how many are failed to meet their objectives? (In percent)

Bore holes__________

Shallow wells____________________

Springs___________________

Wind mills_____________________

15. How many water supply development scheme projects are delayed than the planned time? (In percent)

Ground water development scheme projects____________

Surface water development scheme projects______________

16. What are the causes of ground water development failures? (Put in order of importance)

a. Quality problem

b. Quantity problem

c. Financial problem

d. Conflict

e. Institutional structure problem

g Lack of proper investigation

h. Management problem

i. policy

j. Others specify____

17. What are the causes for the delay of water supply project schemes?

a. Financial problem

b. Conflict

c. Management problem

d. Policy

e. others specify____

18. Who organizes the water supply scheme management?

a. water committee b. professionals c. community d. administrators

e. others, specify____

19. Are there any conflicts that arise from competition over water resources?

a. Yes b. No

If there are any, when? _________________________, with whom? _____________

What types of damages occurred? (In number)

a. deaths___________ b. injuries___________ c. property damage_________

d. others, specify____

20. Does the existing education and staff mobility policies allow professionals to improve their skills? Yes________________ No______________________

21. Do you think staff is enough and capable?

a. Yes b. No

22. Do you train village level operators?

a. Yes b. No

23. Do you give training to house holds and water committee?

a. yes b. No

24. Do you have Zone-level/Woreda level organization(s) for management of multiple water resources? a. Yes b. No

25. What are the possible solutions to improve water supply sustainability in your woreda?

____

____

____

26**.** What are your Main recommendations regarding water supply Sustainability problems?