JIMMA UNIVERSTIY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF HYDRAULIC AND WATER RESOURCE ENGINEERING

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Assessment of Ground Water Potential Zones in Megech River Catchment in North Gondar, Ethiopia

By

Beyenech Mandefro Aragaw

A Thesis submitted to Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Hydraulic Engineering Chair in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering

June, 2019 G.C

Jimma, Ethiopia

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Main advisor: Dr:-Ing. Fekadu fufa

Co advisor: Mr. Andualem shigutie(MSC)

June, 2019 G.C

Jimma, Ethiopia

APPROVAL PAGE

This thesis entitled with "Assessment of Groundwater Potential Zones in Megech River Catchment in North Gondar, Ethiopia" has been approved by the following examiners for partial fulfilment of the requirement for the degree of Master of Science in Hydraulic Engineering.

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DECLARATION

This research is my original work and has not been presented for a degree in any other university.

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Approval of the advisors

This thesis has been submitted for examination with my approval as University advisors.

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ABSTRACT

This study focused on the assessment of groundwater potential zones in Megech River Catchment. The area is found in the North Gondar Zone of the Amhara Regional State in the Northern portion of Lake Tana sub basin. The current water supply system of the Gondar city was designed to have two water sources that are Angereb reservoirs and boreholes. These sources all together cover only 47% of the water requirement of the city. This indicates that the water supply coverage of the city is very low which is due to low capacity of exciting system. So it is important to assess the Ground water potential condition for the area.The metrological data, geological data and hydrogeological data's have had an input for the determination of groundwater potential for this area. To get the average rainfall over the area arithmetic method has been used. Other meteorological data such as temperature, relative humidity, sunshine hour, wind speed have been organized in a way suitable for analysis. They have been put into penman modified method for calculation of potential evapotranspiration (PET). The actual evapotranspiration (AET) which uses rainfall and PET as an input is calculated by Thornthwaite and mather soilwater balance model. The annual average recharge of catchment has been estimated by water balance method. The collected data on geological map, land use land cover map, lineaments map, drainage map, and slope map combined with Hydro-geological data analysis have been integrated using GIS 10.3 and related software to make rational interpretations that meets the objectives of the research. The catchment receives the mean annual rainfall of 1123 mm; the actual evapotranspiration is 890.32 mm; the mean annual surface runoff that leaves the catchment is 109 million cubic meter of water and the amount of annual recharge is 133 million cubic meter. The groundwater potential zone map shows that the downstream of the river near Lake Tana has high potential zone because of high infiltration rates by agricultural land use.

Key words: *Geographic information system, Groundwater Potential zone, Metrological characteristics, recharge estimation, Water balance*

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CHAPTER ONE

INTRODUCTION

1.1. Background

Water is necessary for all forms of human, animal and plant life. It is essential for overall human well-being and supports all aspects of human livelihoods. Furthermore, It is indispensable for domestic and is of vital importance in the development of agriculture and industries. It can also be used to generate electrical energy in case where a large quantity of surface water exists. Generally it plays a very significant role in every aspect of human life. The need for water is strongly ascending from time to time as it is fundamental for all development activities. Any development is directly or indirectly dependent upon utilization of water resources (Sophocleous, 2000). Persistent drought and population growth together with the need for water to domestic, irrigation and industrial development brings high demand in water resources. With time due to population expansion, higher per capital demand and pollution, water resources become scarce.

Water covers three fourth of the planet Earth. About ninety seven percent of water on the planet is salty and two percent of the water is in the form of ice and glaciers whereas only one percent is fresh and potable water which is vital to sustain life, sensitive to domestic uses, irrigation and industrialization purposes (Oki and Kanae, 2006). The global water demand will primarily grow due to population and economic growth, rapid urbanization and the increasing demand for food and energy (Tesema, 2010).

Groundwater is generally the most abundant fresh water source in the globe next to glaciers and ice capes. Estimates of global water supply show that groundwater represents about 0.6% of the world's total water (Postel et al., 1996). Integration of remote sensing data and the geographical information system (GIS) for the exploration of groundwater resources has become a breakthrough in the field of groundwater research, which assists in assessing, monitoring, and conserving groundwater resources(Sander et al., 1996). The various thematic maps prepared for delineating groundwater potential zones are lineament density, drainage density, digital elevation model (DEM), slope map and land use/land cover (LULC) (Gupta and Srivastava, 2005). Since much of groundwater below a depth of 0.8 Km is saline or costs too much to develop with present technology and economic conditions, the total volume of readily available groundwater is about $4.2x10^6$ km^3, much more than the $0.126x10^6$ km^3 fresh water stored in lakes and streams (Beddows et al., 2007). Ground water may be fetched through simple hand dug wells, shallow wells, deep wells, developed springs and the like. Groundwater is the only reliable sources of water compared to surface water though there is temporal and spatial variation in quality and quantity (MacDonald et al., 2009).

In Africa, groundwater is the major source of drinking water and its use for irrigation is forecast to increase substantially to combat growing food insecurity. estimate total groundwater storage in Africa to be 0.66 million km^3 (0.36–1.75 million km^3) (MacDonald et al., 2011). Across equatorial Africa, increasing demand for groundwater has raised concerns about resource sustainability and has highlighted the need for reliable estimates of groundwater recharge(Taylor and Howard, 1996). Compared to many countries of sub-Saharan Africa, Ethiopia is endowed with abundant water resources. The annual flow from the 12 major river basins the country has is estimated at 124 (BCM) billion meter cube (Woldeamlak et al., 2015). As compared to surface water resource, Ethiopia has lower ground water potential. However, by many countries standard the total exploitable ground water potential is high. Based on scanty knowledge available on ground water resource, the potential is estimated to be about 2.6 BCM (Billion Metric Cube) annually rechargeable resources (Awulachew et al., 2007). In the northern part of the country, the study revealed that there are large groundwater reserves within the valley floor's Quaternary alluvial sediments and underlying Tertiary fractured volcanic rocks (Ayenew et al., 2013)

Over 70% of Ethiopia's water supply comes from groundwater, and only 34% of the population has access to an improved water supply. Groundwater investigation is, therefore, indispensable for ensuring sustainable and judicious use of water resources. Isotope hydrology has become a standard tool in the country's strategy for future water resource development, as contained in the national master plan, in the Ethiopian Groundwater Resources Assessment Programme (EGRAP). EGRAP has been incorporated into the national Water Sector Strategic Development Programme and has been submitted to the Ministry of Finance and Economic Development (MFED) for funding (EGRAP, 2013). Such high demand of water urges different researchers to conduct research work so as to identify potential sites for further development activities (Kifle, 2012).

In the Megech River basin groundwater is exploited by different industries and institutions, in addition to wells that are operated by Gondar Water Supply and used for public services(Tsegaye, 2015). In N/Gondar town, the water supply for domestic and industrial purposes is mainly from Angereb River but there is a problem of shortage of water. Therefore, assessing groundwater potential zones is important.

1.2. Statement of the problem

The global demand for water has been increasing at a rate of about 1% per year over the past decades as a function of population growth, economic development and changing consumption pattern, among other factor, and it will continue to grow significantly over the foreseeable future (UN, 2018). Industrial and domestic demand for water will increase much faster than agricultural demand, although agriculture will remain the largest user overall. The vast majority of the growth in demand for water will occur in countries with developing or emerging economics.

The demand for water supply in Gondar town is obviously increasing. This is due to increase in population in the town such that in the Universities and population increment in the surrounding and also there is high rate of sedimentation in the Angereb reservoir which is the main source of water supply in the town. Thus this increases the water demand. As a part of filling the gap, the present study may use to minimize water scarcity in the town, by assessing and identifying groundwater potential zones in the area. This study presents the well identified recharge and discharge zones within the catchment. Not only this but the present work also estimate the annual groundwater recharge using water balance method. Therefore, the main aim of this study is to identify the groundwater potential zones in Megech river catchment.

1.3. Objectives of the study

1.3.1. General objective

The main objective of this study is to identify the ground water potential zones in Megech River Catchment in North Gondar Zone.

1.3.2. Specific objectives

The specific objectives of the study are:

- to assess the hydro-metrological characteristics of the area;
- to estimate the annual recharge of the catchment;

- to determine groundwater flow direction**;** and
- To delineate potential sites for further development activities.

1.4. Research questions

1. What is the hydro-metrological characteristic of the Megech river catchment?
2. What would be the annual recharge of catchment?
3. To which direction the ground water is flowing in the aquifer?
4. Where is the ground water potential site in the area?

1.5. Justification of the study

The current water supply system of the city was designed to have two water sources that are Angereb reservoirs and boreholes. According to the design, Angereb reservoir serves as the primary source while additional boreholes serve as supplementary sources.

The current combined average production capacity of the dam and the operational wells are 10,500 m3/day while the current water demand of the town is estimated to be 22,400 m^3/day. The current sources all together cover only 47% of the water requirement of the city (GTWSSS, 2017). This critical shortage of water constrained investment works, tourist resorts and other socio-economic development of the city. This indicates that the water supply coverage of the city is very low and far from sufficiency which is due to low capacity of exciting system. To reduce the problem it is essential to assess the condition of ground water potential for the area so that better alternative way is to be implied.

1.6. The scope of the study

The study is undertaken in north Gondar zone of Amhara Regional State in the Northern portion of Lake Tana sub basin, Megech river catchment. In order to do the gathered data effectively and maintain the objective of the research the study is conducted on this river catchment which the outlet point is taken at Lake tana with an elevation of 1776 m.

1.7. Limitation of the study

Metrological stations does not have fully recorded data and lack of discharge measurements of the springs, boreholes and hand dug wells for a complete hydrological year limits quantifying the amount of water abstracted from the catchment.

1.8. Organization of the thesis

The study has been formulated in to five chapters. The first chapter is an introduction part which includes background of the study, statement of the problem, the objective of the study, the research questions, justification of the study, the scope of the study, limitation of the study and the organization of the thesis. The second chapter presents literature review which includes Groundwater potential and recharge zone, groundwater recharge estimation, role of GIS in determining groundwater potential zone and groundwater in Ethiopia. The third chapter presents the materials and methods of the research which includes description of the study area; climate and vegetation, Land use land cover and soils, geology, types of data used and data analysis. The fourth chapter presents results and discussions of the research. Finally conclusions and recommendations drawn from the analysis of the data are given in the fifth chapter.

CHAPTER TWO

LITERATURE REVIEW

This chapter discusses and presents relevant and related literatures on the title. The selected readings from the broad range of literatures are expected to serve as a base for formulating the conceptual frame work of this research

2.1. Definition of Groundwater potential and Recharge zone

Groundwater is the water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers (Schmidt and Hahn, 2012). Groundwater recharge is usually considered a process of water movement downward through the saturated zone under the forces of gravity or in a direction determined by the hydraulic conditions (Simmers, 2013). A recharge area can be defined as that portion of a drainage basin in which the net saturated flow of groundwater is directed away from the water table. In a recharge area the water table usually lies at some depth. A discharge area can be defined as that portion of the drainage basin in which the net saturated flow of groundwater is directed towards the water table. In a discharge area the water table usually lies at or very near to the surface

2.2. Groundwater Recharge estimation

Groundwater recharge is one of the most important limiting factors for groundwater withdrawal and determines the groundwater development potential of an area. Groundwater recharge connects atmospheric, surface and subsurface components of the water balance and is sensitive to both climatic and anthropogenic factors (Finch, 1998). Various studies have employed different methods to estimate groundwater recharge including tracer methods, water table fluctuation methods, lysimeter methods, model, base flow separation method and simple water balance techniques (Ali and Mubarak, 2017). The water balance method is a book keeping procedure which estimates the balance between the inflow and outflow of water of the system. This method was developed Thornthwaite in 1848 and revised by himself and Mather in 1955.This method helps in identifying and estimating the natural water surplus and water deficit months of an area (Fowe et al., 2015).

Evaporation and evapotranspiration are two of the most important and most complicated phases of the hydrologic cycle. These phases redistribute heat energy between the surface and the atmosphere. Estimations of evaporation and evapotranspiration are required in the design of many water resource projects, irrigation systems, scheduling the frequency of irrigation and water balance and simulation studies (Subramanian, 1994). Evaporation is the process by which water from liquid or solid state passes in to water pour state and is diffused into the atmosphere. The nature of evaporating surface affects evaporation by modifying the wind pattern (Chaw, 1998). Evapotranspiration is a result of two phenomena evaporation and transpiration. However, in field conditions it is impossible to separate the two processes. Instead their combined effect, evapotranspiration is usually considered. Among the many phases of the hydrologic cycle, evapotranspiration is one of the most difficult to quantify. Both evaporation and transpiration are affected by condition such as solar radiation, temperature of the evaporating surface and the air above it, wind speed, atmospheric pressure, and vapour holding capacity of air.

Potential evapotranspiration is the water loss if at no time there is a deficit of water in the soil for the use of vegetation or the amount of evaporation that would occur if a sufficient water source were available (Thornthwaite, 1944). Several methods have been developed to estimate potential evapotranspiration such as using pan evapotranspiration up to empirical formulas. Due to lack of pan evaporation data, empirical formulas that use different meteorological data are used to calculate potential evapotranspiration. These methods include Thornthwaite method which is based on monthly air temperature (T), latitude and month (Almorox et al., 2015); Linacre method which depends on elevation above sea level, latitude, average dew point temperature and average temperature; Blaney-Criddle which depends on average temperature latitude, coefficient depend on the vegetation type, location and season; Kharrufa method which depends on average temperature and latitude: Haragreaves method wehich depends on latitude, average minimum and maximum temperature, average temperature; Hamon method which depends on average temperature and latitude; Remanenko method which depends on average temperature and average relative humidty of air; Turic method which depends on temperature of air, relative humidty of air, and net solar radiation; Makkink method which depends on temperature of air, elevation above mean sea level and net solar radiation; Jensen-Haise method which depends on temperature of air and net solar radiation; Doorenbos and Pruitt method which depends on temperature of air, net solar radiation, average relative humidity of air and average daily wind speed; McGuinness and Bordne which depends on temperature of air and net solar radiation; Abtew method which depends on temperature of air, net solar radiation and dimensionless coefficient; Priestley and Taylor method which depends on temperature of air and net solar radiation; Penman-Monteith method which depends on net solar radiation, relative humidity of air, temperature of air, wind speed, elevation above sea level and latitude (Poyen et al., 2016). Using potential evapotranspiration (PET) to estimate crop actual evapotranspiration (AET) is a critical approach in hydrological models (Li et al., 2016). Water surplus and water deficit months have been found based on precipitation, potential evapotranspiration, and actual evapotranspiration.

2.3. Role of GIS in determining groundwater potential zone

World over geographic information system (GIS) technological applications has now become the common place for the utilities, land information and planning. GIS can be an effective tool in the design and monitoring of groundwater development and its uses. GIS has found a role in the analysis and management of all such areas where 'variations in local and micro-elements influence the patterns'. There are a vast potential in GIS applications by using remotely sensed data (images) to evaluate the potentiality of groundwater resources for agriculture and sustainable development (Selvam et al., 2016).

Lithology, land use land cover, lineaments, drainage, and slope as the five significant factors affecting groundwater recharge potential. This factors influencing groundwater recharge potential are lithology which categorize Rock type, weathering character, joints and fractures; Land use land cover which categorize type, areal extent and associated vegetation; lineaments which categorize lineament –density value; drainage which categorize drainage density value; And slope which categorize slope gradient.

2.4. Groundwater in Ethiopia

Water, as a basic necessity to life, is a substance highly demanded. Every living thing wants it at different scales and for different needs. Human beings need water for their domestic, agricultural or industrial purposes. This water is obtained from different sources of the hydrosphere – mainly from surface and subsurface (underground) sources. The water on the surface is accessible but usually needs extra treatment before use. The subsurface waters are potable in most instances but are not easily accessible. However, most of water supply for domestic purposes in the world comes from underground storages due to its abundance and potablity without excessive treatments (Woldeamlak et al., 2015). There are also places where GW is used largely for irrigation and industrial consumptions. Most of the towns and villages in Ethiopia get their water supply from underground sources due to the better potential of GW in the country, unavailability and good inaccessibility, need of extra treatment and high investment in infrastructure set up for surface water sources.

Ethiopia has a complex topography, diversified climate, and immense water resources. The spatiotemporal variability of the water resources is characterized by multi-weather systems rainfall of the country. Most of the river courses become full and flood their surroundings during the three main rainy months (June–August). West-flowing rivers Abay, Baro-Akobo, Omo-Gibe, and Tekeze receive much rainfall unlike the northeast- (Awash) and east-flowing rivers Wabishebele and Genale-Dawa which receive normal to low rainfall. Although it needs further detailed investigation, according to the current knowledge, the country has about 124.4 billion cubic meter (BCM) river water, 70 BCM lake water, and 3 BCM groundwater resources. It has a potential to develop 3.8 million ha of irrigation and 45,000 MW hydropower production(Berhanu et al., 2015). All the four major categories of rocks hold groundwater at different specific capacities. Owing to their stratigraphic position volcanic rocks from the most accessible aquifers in central Ethiopia. Sedimentary rock forms aquifers in areas where they are exhumed by erosion of the volcanic caps(such as in the Blue Nile basin, the Mekelle Outlier) or where the volcanic rocks didn’t exist initially (such as the Ogaden lowlands) (Kebede, 2012)

There were different major sources of water supply to the city of Gondar in the past. Of those sources, the first source was koremrem spring. This was constructed during the Italian acceptation. It was the main sources of water supply until Angereb Dam is constructed. 15 boreholes constructed at different periods are not presently functioning. Angereb Dam stated its full service during 2002, is now the major source of urban water supply. Kereberb spring and other non-function-especially the six reserves bore holes-could boost production capacity of the city however, these sources have not been well rehabilitated and monthly average production is 84 thousand m^3. Water production from dam is 5000 m^3 to 7000 m^3 a day. On average 6400 m^3

of water is produces. However, the dam is located at a foot hill where silt deposit is a major problem. Erosion from hillside and siltation in the dam will continue there will be water problem in the Gondar city. Furthermore the present water supply does not provide more water for industrial demand and other uses. Gondar Population is likely to increase by two fold in the coming decade(Singh, 2005).

The study area, Megech river catchment is part of upper Blue Nile basin has studied previously by different scholars as well as non-governmental and governmental organizations. Review and Study of Ground Water Potential for Borehole Sitting, Contract Administration and Supervision of Drilling and Associated Civil Works (2012): conducted a study on Groundwater basins and surface water may not have geographic relationship and the basins may not coincide. The whole groundwater basin needs to be considered to estimate recharge of a groundwater. The magnitude of the groundwater study in this project does not include the whole groundwater basin which is not known or delineated unpublished Report.

Beruke, (2010): Conducted Ground Water Resource Evaluation and Management Practices in Gilgel Abay Catchment, Tana Basin published M.sc Thesis. He has investigated groundwater recharge may be defined as the downward flow of water reaching the water table, forming in addition to groundwater. He also considers that 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. He has also conducted the 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.

Nigussie, (2010): Focused on numerical groundwater flow modeling of thenorthern river catchment of the Lake Tana in his M.sc Thesis, Addis Ababa University. He has investigated that the rate of replenishment of the water table in aquifers (mainly by rainfall) is known as groundwater recharge rate. He had conducted that groundwater recharge is one of the difficult input data to quantify and distribute spatially in precision. He also said, the flow is highly governed with precipitation (not lost by evapotranspiration and run off), vertical hydraulic conductivity that determines the quantity of water joining the saturated zone and water moving ability of the aquifer and hydraulic gradient.

Getachew, (2010): Focused on Base flow Analysis of Rivers in Lake Tana sub basin published M.sc Thesis. According to his investigation recharge has been defined as the water added to the saturated groundwater body; in the context of river recharge it is the water that leaves a river and crosses the water table and also recharge comprises the processes involved in the absorption and addition of water to the zone of saturation. He has also conducted the recharge estimation of the Lake Tana sub basin which was carried out based on the principle of base flow separation. He has recognized that the base flow results for the catchments show; that large amount of groundwater contribution found in the south part of the Lake Tana sub basin however, Megech catchment contributes 14.1% of the total runoff and 5.72% of the mean annual rainfall which is attributed to less amount of rainfall in the north side of the basin.

Sileshi, (2015): Focused on Integrated Hydrological and Hydrogeological System Analysis of the Lake Tana Basin, North-western Ethiopia, published PhD Thesis. According to his investigation, recharge is the downward movement of water to the water table that adds water to the groundwater reservoir; he also considers recharge can be direct from precipitation and irrigation and indirect from streams and localized surface ponds. Besides this, he has also recognized that several methods to directly calculate the groundwater recharge and the most reliable ones are to measure directly with lysimeter or to use tank model, and by monitoring the movement of water through the vadose zone with tensiometers. However, these methods give local information and are difficult to regionalize. The actual methods he has been used to estimate recharge depend on the scale and accuracy required, in humid areas like the Tana basin, base flow separation and soil water balance methods are appropriate, these methods together with chloride mass balance have been used here to estimate the recharge (Asrie and Sebhat, 2016).

Andarge, (2002): Focused on Integrated Approach for Hydrogeological Investigation of Megech River Catchment, Northwestern Ethiopia published M.sc Thesis, and Addis Ababa University. He has investigated recharge estimation using base flow separation and water balance.

According to his investigation, from base flow separation result of Megech River, the surface runoff component is very high whereas the base flow component is small. This may be due to the fact that the Megech catchment is characterized by rugged topography, steep slopes and absence of vegetation covers which all facilitates runoff than infiltration.

Almost all previous studies within the catchment were focused on groundwater potential evaluation and recharge estimation towards alleviating the acute shortage of water for the inhabitants of Gondar town. Piped water supply scheme from springs in the town was established during the Italian invasion in late 1930's (Zavadskas et al., 2018). As the population, urbanization and industrialization increases, the water supply became inadequate. To solve the problem several studies and extended works on the existing water supply system were carried out over the years. All the studies and extended work were unable to solve the problem. As a result, consultants were employed to carry out feasibility studies. Hydrogeological and geophysical explorations were conducted to identify groundwater fields in Azezo-Gondar area by Amhara National Regional State and water, mines and energy resources development Bureau.

All these studies concentrate in the vicinity of Gondar, which represents only a small portion of the upper and downstream of Megech catchment. Based on these studies, ground water wells were drilled but most of them were abandoned due to absence and/or low yield. The productive wells are also inconsistent in yield; they show significant water level fluctuations. The hydrology, hydrogeology and geology of Megech river catchment as a whole were not studied separately and in detail, the area is even not fully covered by the 1:50,000 scale topographic map prepared by the Ethiopian Mapping Authority. In the lower reach of Megech River basin, groundwater is exploited by different industries and institutions (Kola Diba town, Gondar town, Dashen Brewery and Dashen malt factory). In long terms, extended and uncontrolled withdrawals may result in water declines, which cause imbalances among hydrologic stresses.

Generally, groundwater in the catchment would be inadequate resource for large scale, sustainable groundwater supply and irrigation development. the gauged part of the Megech sub-basin is only the upper part of the catchment enclosing an area of 462 km^2.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location and accessibility

The study area, Megech river catchment is found in the North Gondar Zone of the Amhara region. This catchment is located about 748km from Addis Ababa. Geographically it is suited between at coordinates of 12^0 17'00" N 12^0 42' 30'' N latitudes and longitudes of 37^0 19' 00''E 37^0 36'00''E with an approximate altitude range 1776m to 2921m above mean sea level. The catchment covers an area of 630.6km^2

Semen Gondar (or north Gondar) is a zone in the Ethiopian Amhara region. This zone is named for the city of Gondar, the capital of Ethiopia until the mid-19^{th} century province of begemder. Semin Gondar is bordered on the south by lake tana, Mirab (West) Gojam, AgewAwi and BenishanguleGumuz Region, on the west by sudan, on the north by tigray region, on the East by Waghemra and on the southeast by Debub Gondar.The city of Gondar; Founded by Emperor Faisledas in 1636 A.D is also the current capital of the Administrative Zone. It was once the capital of Ethiopia for more than 100 years. The main highway connects Addis Ababa with Gondar via Bahir Dar (Tadesse and Kumie, 2007).

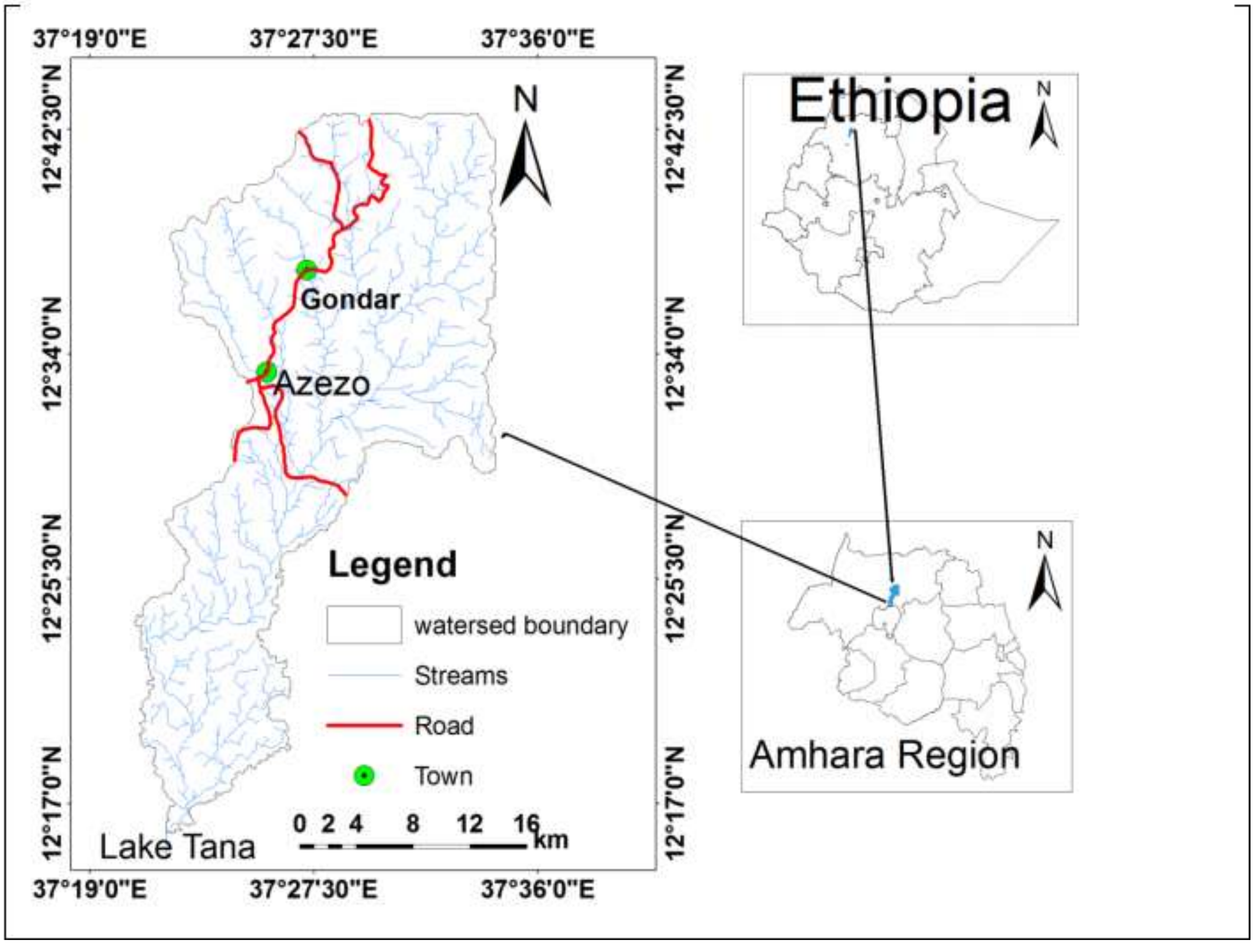

Figure3. 1 location of study area

3.1.2. Population and Socio-economic activity

Based on the 2007 census conducted by the Centeral Statistical Agency of Ethiopia (CSA), this zone has a total population of 2,929,628, an increase of 40.26% over the 1994 census with an area of 45,944.63 square kilometers. The same study of socio-economic section shows that the population distribution was not even, thus some area have highly pressure while others are with fewer burdens. Most of the areas are used for cultivation. Also from aspect of land suitability, steep slopes carry more than their capability. Most of the inhabitants live on the hill and mountainsides and the houses are moderately scattered all over the watershed.

High population density and land degradation problems have resulted in land shortages. Consequently, cultivable land is no longer put fallow, and marginal lands on very steep slopes are cultivated without proper conservation measures.

The major crops grown in the area are barely, teff, wheat, maize, sorghum, bean, peas, dagussa and nug. The current vegetation is dominated by eucalyptus and there are also sparse indigenous trees like" Dokima", "Sholla", "Wanza", "Weyra", "Bisana", "Girar" and related bushes and shrubs. Dense settlements are in the town of Gondar and some rural areas (Woleka, Shenbekit, Wizaba, Ambober, Ayba Iyesu) and scattered settlements are mostly in the rest of the rural community (Ayehu, 2010).

3.1.3. Climate

The climate of Ethiopia ranges from equatorial desert to hot and cool steppe, and from tropical savannah and rain forest to warm temperate, from hot lowland to cool highlands (Alemayehu, 2006). Similar to the other parts of the region, the rainfall of the catchment area is erratic. According to the general classification of Agro- climate zone (on the bases of annual rainfall, temperature, length of growing period and plant types) used in Ethiopia the study area is located within "Moist Weyina Dega" zone. The amount of rainfall in Ethiopia is influenced by the location of the place relative to the source of moisture, the direction of winds and topographical relief (Yitbarek, 2002).

Based on the rainfall, the climate of the area can be categorized in to two broad seasons; the dry season (winter) which covers the period from October to May and wet season (summer) extends from Jun to September, with slightly rainfall during Autumn and Spring. The annually mean maximum, mean, and mean minimum temperatures are 24.68, 18.09, and 11.5 ^{0}C respectively.

3.1.4. Topography and drainage

The topography of the area is predominantly hilly. The slope classes in the watershed encompasses very steep to gentle topography. There is a large elevation difference within the watershed. Elevations range from 1776m at the outlet to 2921m (northern extreme of the catchment, kosoye village) above mean sea level (a.m.s.l). High rates of soil erosion and low crop production (mainly due to land degradation) are attributable to the rugged topographic conditions of the catchment. In the northern part of the catchment, which is characterized by dense drainage pattern, there is high runoff with little infiltration. This is due to the fact that the northern part of the catchment is characterized by steeper slopes and very thin and/or absent weathered mantle.

The drainage of an area is affected by numerous factors among which, rainfall, slope, rock type and tectonic activity, vegetation, soil type and thickness, infiltration capacity etc. In the northern part of the catchment the drainage forms relatively steep narrow gorges that can attributed to high rainfall, small depth soil and high topographic elevation. Where there are volcanic ridges, drainage radiates in all directions forming radial or parallel system. It is known that area with high permeability have lower drainage density that intern may decrease the surface runoff (Ayehu, 2010).

The main streams in the catchment that has well developed drainage system and which are tributaries of Megech River are Wizaba, Gilgel Megech, Angereb, Keha, Shinta and Dimaza. During the first field visit all the tributaries were with floods. In the second field visit (February 19 to March 15), all the rivers decrease their discharge. In some of these rivers such as Shinta, Dimaza and Keha patches of small ponds on the riverbed were observed. Megech River flows out of the catchment after gauged at the southern end of the catchment at Megech Bridge on the Gondar-Bahir Dar highway. All the tributaries join with each other (Wizaba with Gilgel Megech, Angereb with Keha, Shinta with Dimaza) and finally all join the river Megech upstream of the gauging station (the bridge). Hence the contribution of all the tributaries is measured as total discharge before the river gets exit to Lake Tana.

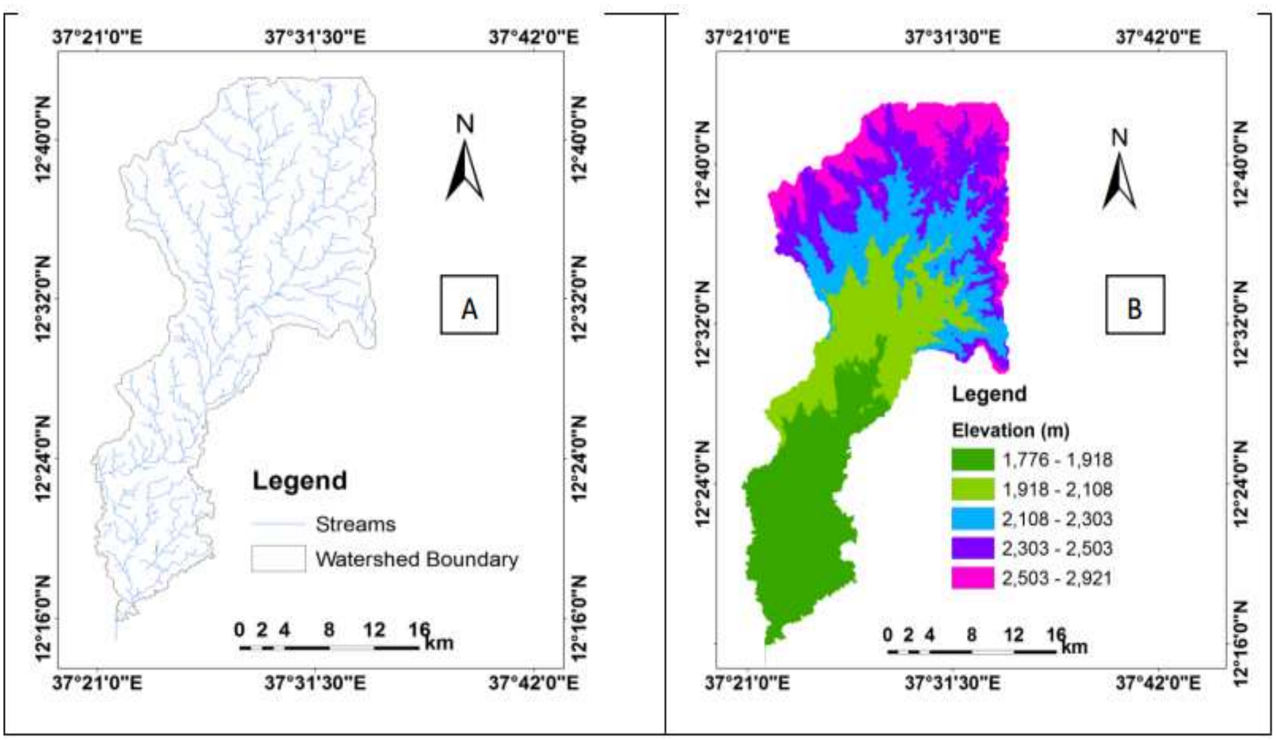

Figure3. 2 drainage (A) and Elevation of the area (B)

3.1.5. Land use land cover

Every parcel of land on the Earth's surface is unique in the cover it possesses. Land use and land cover are distinct yet closely linked characteristics of the Earth's surface. It is the manner in which human beings employ the land and its resources. Landuse is important in the hydrological and groundwater studies, because it is a prominent factor affecting the recharge (Getaneh, 2010).

In most of the northern part of the catchment, the soils are shallow Leptosols underline by Unconsolidated medium sized gravels with loose joints, which in turn underline by watertight rocky layers. These layers are easily visible in some healing gullies and steeper part of the river beds (DEVECON, 1992)

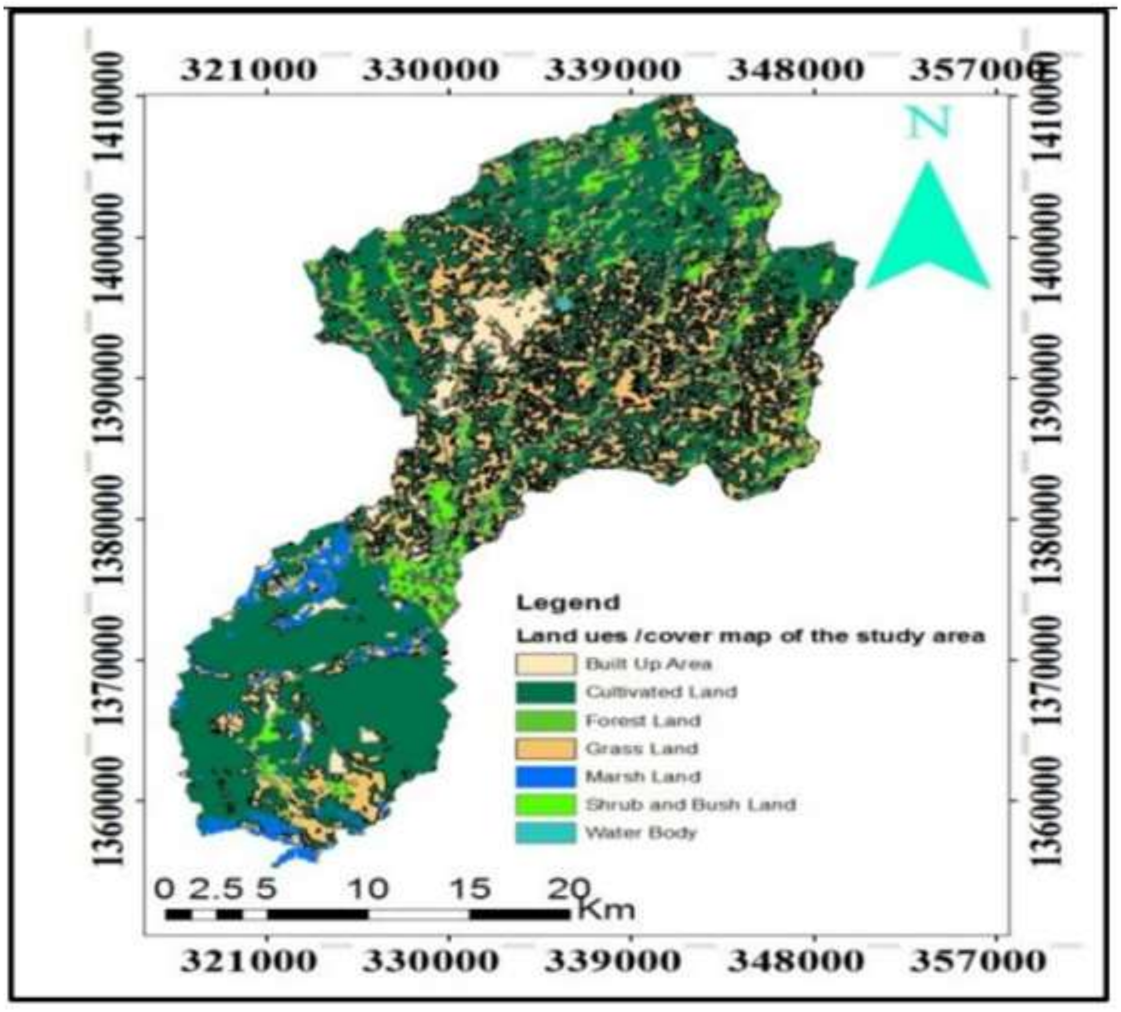

Figure3. 3 Land use/cover map of the study area

Table3. 1 land use land cover map of megech river catchment

NO.	Landuse land cover type	Areal coverage (km^2)	Areal Proportion (%)
1	Built up area	15	2.4
2	Cultivationed land	384.6	61
3	Forest land	87	13.8
4	Grass land	87.91	13.9
5	Marsh land	30.9	4.9
6	UrbanShrub and Bush land	15	2.4
7	Water body	10.2	1.6

3.1.6. Soils

Soil is one of the main factors for the percolation of water into the ground. Based on FAO soil class (2010) the texture of soils in the area is classified in to five major categories as listed below.

Chromic Luvisols is dark brown over yellowish brown clay, moderately to well drained and deep to very deep. It covers an area of 67.56 km^2 (9.47% of the catchment). Eutric Fluvisols is dark olive brown over black clay, moderately well to imperfectly drained, very deep, firm to friable when moist, and sticky and plastic when wet. It is clay loam. It covers 7.73 km^2 areas (1.08% of the area). Eutric Leptosols is dark brown clay, excessively drained, hard when dry, firm to friable when moist and sticky and plastic when wet. It covers an area of 469.4 km^2 (65.8% of the area). Eutric Vertisols is very deep, imperfectly to poorly drained, very dark grey to reddish brown clay. It has an area of 236.1 km^2 (33.1% of the area). Haplic Nitisols is moderately well drained silty clay to clay soil (SMEC, 2007), which occupies 0.1 km^2 area (0.014% of the area).

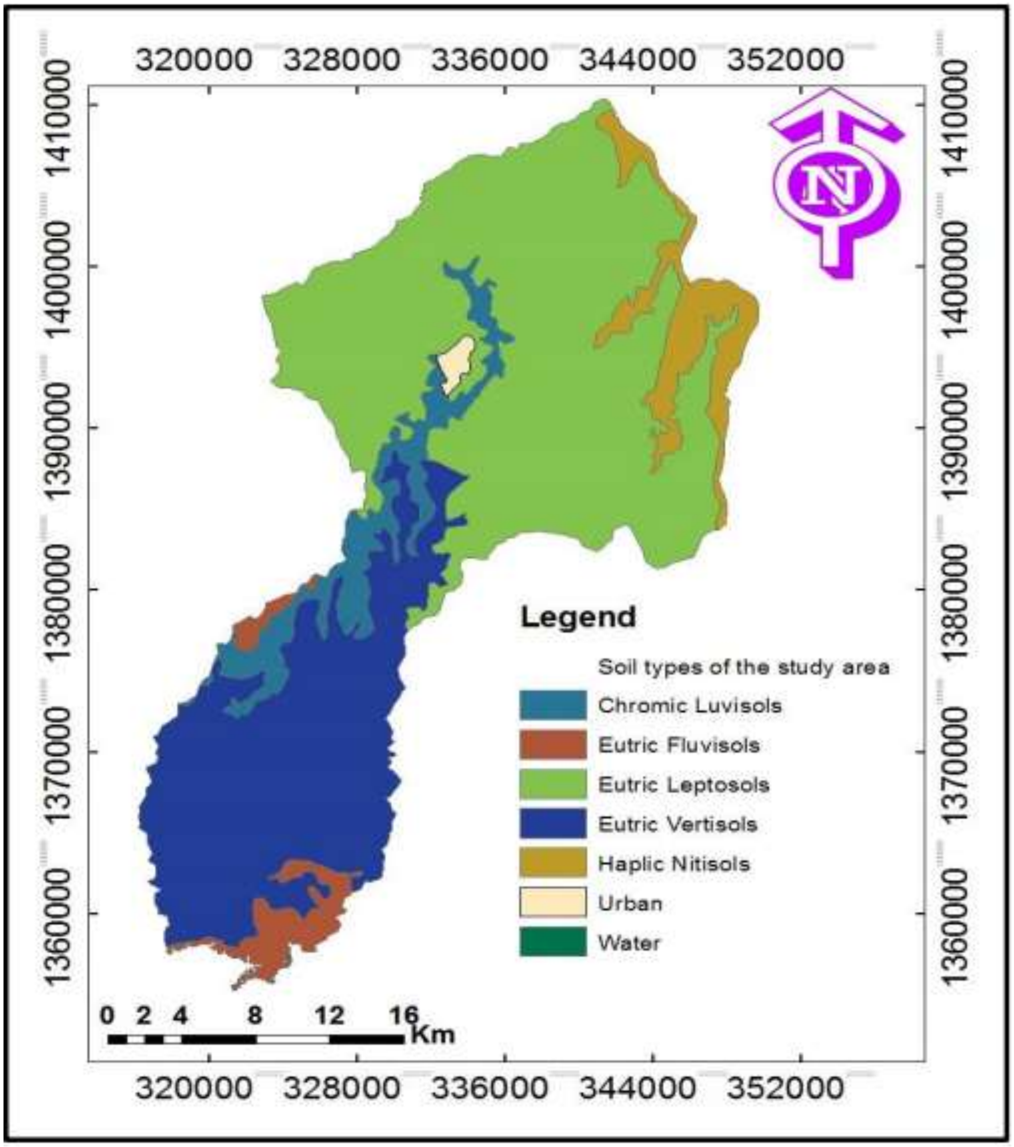

Figure3. 4 Major group Soil map of the study area

3.1.7. Geology

Geological structure of fractures, joints, faults, folds and lineaments and physiography affects hydrological process of an area (Abdalla, 2012).

The Megech river catchment is characterized by the uniform exposure of basaltic lava flows with occasionally very thin trachytic flow at higher elevations. The basalts in the study area consist of amygdaloidal basalt, weathered vesicular basalt, and massive olivine basalt. A common Field feature, in respect to the massive lava flows (olivine basalt), is the columnar (usually hexagonal) shrinkage jointing and the spheroidal weathering whereas the vesicular basalts in various stages of decomposition tend to disintegrate creating a debris flow like features.

Lateralization is also taking place; pure laterite horizons have been seen in places like Weleka where these soils are used for making different household goods such as pots. South of the catchment the hilly terrain grades to a wide flat valley covered by lacustrine and alluvial deposits that has been an ancient extension of Lake Tana.

Figure3. 5 Upper basalt of the study area

3.2. Data sources

In order to conduct this study two major data collection method were used. These data collection methods have been described below.

3.2.1. Primary data collection

To conduct the study primary data collection processes were conducted by both observation and field survey. Observations of the study area were geological structures and dam sites using digital camera. Data from field survey such as Universal Transvers Mercator (UTM) locations of borehole, springs and wells have been collected by using Geographical Positioning System (GPS Garmin 72).

3.2.2. Secondary data collection

Secondary data have been collected from the different organization. Long term meteorological data have been taken from Amhara Region Meteorological Service Bureau(ARMSB). The river discharge data on the other hand is taken from Amhara water bureau. Borehole data have been collected from Amhara Water Works Construction Enterprise (AWWCE). GIS data such that DEM 30, soil and land use land cover data have been taken from FAO. Geological map of the area found from Amhara design bureau.

3.3. Methodology

3.3.1. Materials

The materials that have been used in the field include GPS and digital camera. The materials used at office level are toposheets of topographic maps and geological maps, GIS software, excel spreadsheets.

3.3.2. Methods

To compute the average rainfall over the catchment arithmetic method has been used. Other metrological data such as temperature, relative humidity, sunshine hour, wind speed have been organized in a way suitable for analysis. They have been put into penman modified method for calculation of potential evapotranspiration (PET). The actual evapotranspiration (AET) which uses rainfall and PET as an input is calculated by Thornthwaite and mather soilwater balance model. The annual average of the runoff of catchment on the other hand has been estimated by general water balance method.

The hydrogeology of the area has been evaluated using qualitative and quantitative parameters. Physical observation and description of the nature of geologic materials, degree of weathering/ fracturing, porosities, discharge conditions, sustainability of water points, well data etc are some of the sources of important qualitative parameters. Generally the collected data (both primary and secondary) have been analyzed using GIS 10.3. Digital elevation maps, topographic, use land cover map , drainage map, and geological maps, combined with primary data acquired from field investigation analysis have been integrated under GIS 10.3 environment to make rational interpretations that meets the objectives of the research.

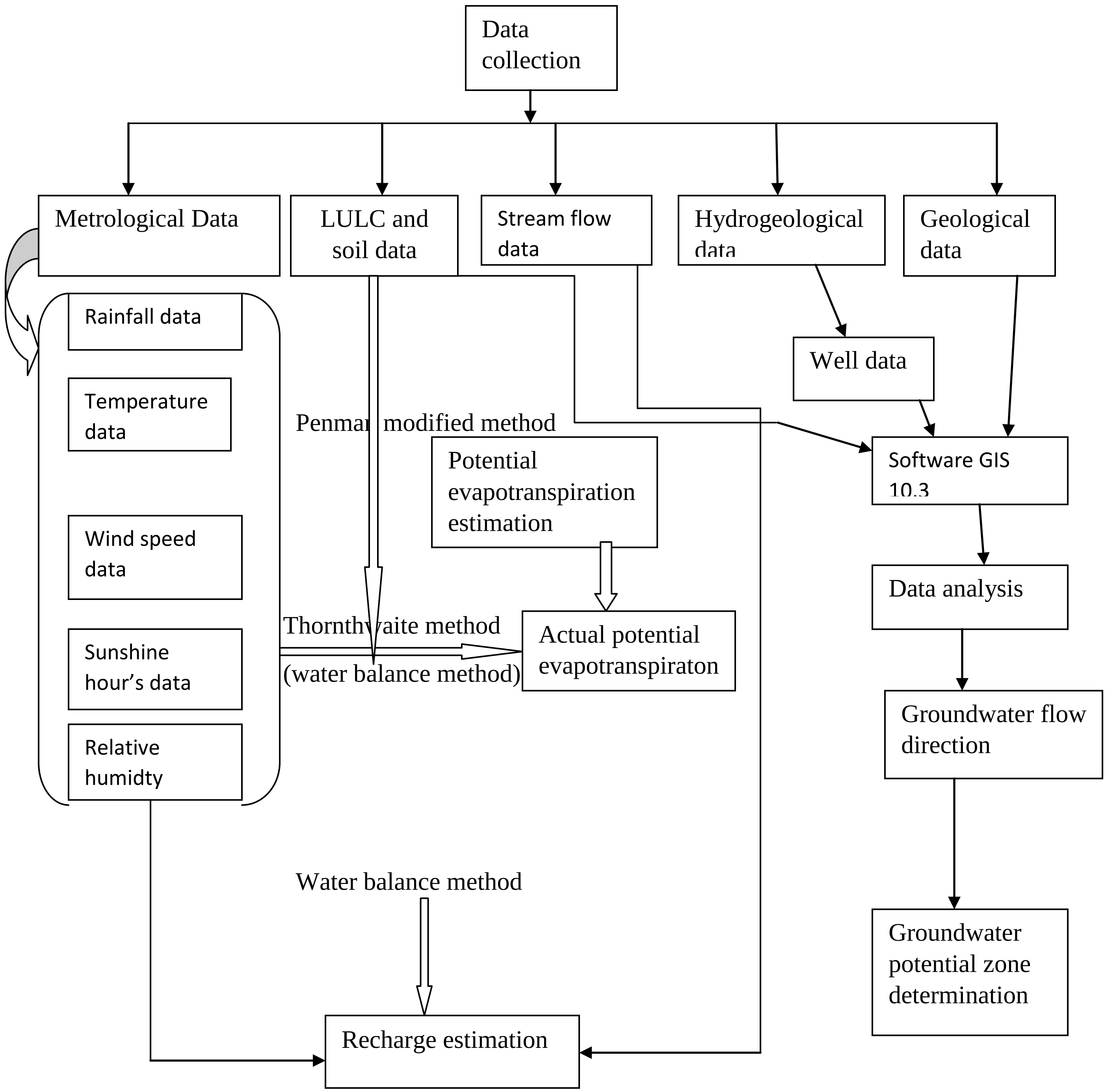

Figure3. 6 General methodology

3.4. Data analysis

3.4.1. Metrological data analysis

Long term measurements of Meteorological parameters such as precipitation, temperature, wind speed, relative humidity, sunshine hours, evaporation, atmospheric pressure and radiation are essential to understand the atmospheric phenomena. Though it is generally difficult to make short term weather prediction, observation over a period of time would render long term prediction on statistics basis. To analyze various hydrologic cycle components, The meteorological station within the study area and the vicinity is displayed in the table 4.1 and all the stations are active at the moment. Meteorological data are taken from five stations based on their availability within the recording year. However, long term records of values of meteorological parameters are enough for the purpose of this study.

Table3. 2 Location of Meteorological Stations and data recording years

Meteorological Stations and Data recording Years					
		Location in decimal degree			
NO.	Station	Northing	Easting	Altitude (m)	Recording year
1	Gondar	12.521	37.432	1973	1980-2016
2	Ambagiworgis	12.77	37.619	2948	1984-2016
3	Maksegnit	12.388	37.555	1912	1987-2016
4	Aykel	12.48	37.03	2150	1987-2016
5	Tikildingay	12.746	37.416	2035	2005-2016

3.4.1.1. Precipitation

Of all the components of the hydrologic cycle, precipitation is the most commonly measured. The rainfall obtained from a single rain gauge station is the point rainfall or station rainfall. Precipitation for given duration over a particular area rarely produces uniform depth over entire area. In areas where more than one rain gauge is established three methods may be employed to compute the average rain fall. These are Arithmetic average method, Weight mean method or Thiessen polygon method and Isohytal method. Among them, Arithmetic mean method have been used for this work because it is the simplest of the three methods and the result is obtained by dividing the sum of the rainfall amounts recorded at all the rain gauge stations which are located within and around the area under consideration by the number of station.

$$PA = \frac{P1 + P2 + P3 + P4 + P5}{n} \qquad \text{Eq. (1)}$$

Where PA is the average depth of precipitation of the area, n the number of station and P_1, P_2, P_3,P_4 and P_5 are the rainfall records at the stations 1,2,3,4,and 5.

Table3. 3 Mean monthly precipitation of the stations in and around the catchment

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Gondar	3.0	3.4	17.3	34.2	89.0	154.5	289.2	266.6	108.7	76.5	20.5	6.9	1069.8
Ambagiworgis	0.5	3.1	19.7	43.6	75.4	125.8	296.4	294.0	85.0	38.7	17.7	3.8	1003.9
Maksegnit	1.4	0.7	16.1	31.3	70.0	144.1	304.9	300.8	90.3	38.1	20.3	4.2	1022.3
Ayikel	1.5	1.4	14.0	40.3	105.3	188.3	285.6	257.3	152.6	94.5	18.4	3.3	1162.4
Tikildingay	1.8	3.2	17.3	29.2	171.0	314.0	553.9	741.2	367.1	133.5	23.7	3.0	2358.8

3.4.1.2. Temprature

Temperature data is available in four stations such as Gondar, Maksegnit, Ambagiworgis and Ayikel. The mean temperature of the four stations is used for the whole catchment in the evapotranspiration quantification and in the evaluation of the water balance of the catchment.

Table3. 4 Monthly variability of temperature at Gondar

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean max	27.91	29.37	29.65	30.10	28.65	25.57	22.96	23.07	25.13	26.69	27.44	27.48
Mean mean	11.74	13.36	14.36	15.86	15.74	14.37	13.65	13.51	13.07	13.03	12.41	12.05
Mean	19.82	21.36	22.00	22.98	22.19	19.97	18.30	18.29	19.10	19.86	19.93	19.77

Table3. 5 Monthly Variability of temperature at Maksegnt

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean max	25.73	27.25	31.75	31.28	30.32	27.537	24.39	24.68	26.63	28.16	28.6	26.4
Mean min	11.16	13.22	15.22	15.81	15.7	14.704	14.34	14.17	13.68	13.24	12.7	11.5
Mean	18.44	20.24	23.49	23.54	23.01	21.121	19.36	19.43	20.16	20.7	20.7	19

Table3. 6 Monthly variability of temperature at Ambagiworgis

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean max	18.65	20.93	21.91	22.05	21.8	20.468	18.74	18.9	17.95	19.01	18.8	19.2
Mean min	6.608	7.95	8.828	9.239	9.425	9.5023	8.826	8.891	9.001	8.018	6.51	5.76
Mean	12.63	14.44	15.37	15.64	15.61	14.985	13.78	13.9	13.48	13.51	12.7	12.5

Table3. 7 Monthly variability of temperature at Ayikel

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean max	25	26.59	27.78	27.96	25.67	22.508	20.13	20.57	21.72	22.71	24.2	24.6
Mean min	12.96	14.32	15.32	15.8	14.98	13.182	12.28	12.24	12.7	13.02	13.1	12.9
Mean	18.98	20.46	21.55	21.88	20.33	17.845	16.2	16.41	17.21	17.87	18.6	18.8

Table3. 8 the mean monthly Temperature of the four stations

Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	19.82	21.36	22	22.98	22.19	19.972	18.3	18.29	19.1	19.86	19.9	19.77
Maksegnit	18.44	20.24	23.49	23.54	23.01	21.121	19.36	19.43	20.16	20.7	20.7	18.96
Ambagiworgis	12.63	14.44	15.37	15.64	15.61	14.985	13.78	13.9	13.48	13.51	12.7	12.48
Ayikel	18.98	20.46	21.55	21.88	20.33	17.845	16.2	16.41	17.21	17.87	18.6	18.75
Average	17.47	19.12	20.6	21.01	20.29	18.481	16.91	17	17.49	17.99	18	17.49

3.4.1.3. Relative humidity

Available data of relative humidity are taken from Gondar and Aykel stations. These data are used for evapotranspiration calculations.

Table3. 9 Mean monthly relative humidity

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	36.59	30.83	31.51	34.17	45.76	66.05	76.34	77.10	68.42	54.88	46.42	40.10
Ayikel	39.78	31.82	35.91	34.47	61.29	61.37	85.41	87.12	84.25	75.92	55.58	46.34
Average	38.19	31.33	33.71	34.32	53.52	63.71	80.87	82.11	76.33	65.40	51.00	43.22

3.4.1.4. Wind speed

Wind speed in the study area and nearby stations is measured at 2m above the surface of the ground.

Table3. 10 Mean monthly wind speed

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	1.30	1.43	1.44	1.49	1.57	1.58	1.10	1.09	1.13	1.06	1.08	1.16
Ayikel	2.46	2.67	2.80	2.69	2.61	2.53	2.20	2.08	1.97	1.88	1.93	2.15
Average	1.88	2.05	2.12	2.09	2.09	2.05	1.65	1.58	1.55	1.47	1.51	1.65

3.4.1.5. Sunshine hours

Sunshine hour refers to the duration of sunshine in a day. The area consists of two sunshine hour recording stations which is Gondar and Aykel.

Table3. 11 Mean monthly sunshine hour

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	9.18	8.96	7.65	7.75	6.93	4.28	4.14	4.80	6.43	7.50	8.63	8.56
Ayikel	9.32	9.17	8.25	8.09	6.84	4.91	3.13	3.44	4.69	6.73	8.73	8.52
Average	9.25	9.07	7.95	7.92	6.89	4.59	3.63	4.12	5.56	7.12	8.68	8.54

3.4.1.6. Potential Evapotranspiration

Potential evapotranspiration is the upper limit of evapotranspiration for a crop in a given climate.

Penman method or combination method

The most general and widely used equation for calculating PET is the penman equation. The penman monteith variation is recommended by the food and agriculture organization. This equation uses climatic data such as vapour pressure, sunshine hours, net radiation, wind speed and mean temperature. Penman (1948 and 1956) devised a method combines two approaches to evaporation calculation: the mass transfer method and energy budget method (Tegos et al., 2017). The basic equation are modified and rearranged to use meteorological components and measurement of variables made regularly at climatological stations.

$H=E_O+Q$ simplified energy balance method Eq. (2)

$E_O= f(u)(es-ed)$ mass transfer method. Eq. (3)

Where: H is available heat, Q-energy for evaporation, E_O- energy for evaporation or rate of evaporation, es- saturatedvapour pressure of air at the water surface (saturated), ed- saturated vapour pressure of air above the water surface (actual), es-ed –saturation deficit and f(u) is a function of wind speed

After rearranging the different parameters based on the above two methods, penman arrive this basic equation to calculate potential evapotranspiration, PETm is

$$PET_m= (\frac{\Delta/\Upsilon)HT+Eat}{(\frac{\Delta}{\Upsilon}+1)} \quad \text{Eq. (4)}$$

Where, Eat = energy for evapotranspiration (mm/day), Δ=slope of saturated vapour pressure plotted against temperature, (Malamos et al., 2015) it can be obtained from approximate equation,

$$\Delta=\frac{4098\,ea}{(237.3+T)2} \quad \text{Eq. (5)}$$

ϒ=the hygrometric constant (0.4859 mmHg/0c), PET = potential evapotranspiration (mm/month), HT is the available heat and is calculated from the formula given by;

HT= RI (1-r)-R0 Eq. (6)

Where: r is the average albedo of the area based on land cover type. RI and R0 are incoming and outgoing radiation respectively and their empirical formulas take the form:

RI (1-r)= 0.95 Rafa(n/N) Eq. (7)

RI is a function of Ra, 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.

Since the study area is located south of $(54.5)^0$N, fa (n/N) is calculated as:

Fa(n/N)=(0.16+0.62 n/N) Eq. (8)

The empirical formula of the outgoing radiation takes the formula,

$R_O = \sigma T^4 (0.47-0.75ed^{½}) (0.17+0.83n/N)$ Eq. (9)

Where: σT4 is the theoretical black body radiation at Ta, which is then modified by functions of the humidity of the air (ed) and the cloudness (n/N).temperature in ^{o}k is converted result of temperature in oc. The parameters ea saturated vapor pressure at air temperature.

T is from the calculated air temperature in ^{o}C and saturation as:

$ea= e^o (T) = 0.611 \exp(17.27 Ta/Ta +273.3)$ Eq. (10)

ea in kpa. Hence, 1 mmHg=0.1333kpa, Relative humidity (HR) in % used to calculate the value of actual vapour pressure (ed) in mmHg as:

ed = ea RH % Eq. (11)

Eat =0.35(0.5+u2/100) (ea-ed) Eq. (12)

Where ea =saturated vapour pressure (mmHg), ed= actual vapour pressure (mmHg), RH=relative humidity (%), U2=wind speed (mile/day), Eat=energy for evapotranspiration (mm/day).

Table3. 12 Mean monthly saturation and actual vapour pressure in mmHg

Month	Jun	Feb	Mar	April	May	Jun	July	Aug	Sep	Oct	Nov	Dec
T	17.47	19.12	20.6	21	20.29	18.5	16.91	17	17.5	18	18	17.5
ed	5.73	5.16	6.10	6.40	9.23	10.18	11.76	11.94	11.45	10.13	7.90	6.48
ea	15.00	16.48	18.09	18.66	17.25	15.98	14.54	14.54	15.00	15.48	15.48	15.00
RH%	38.19	31.33	33.7	34.3	53.52	63.7	80.87	82.1	76.3	65.4	51	43.2

Table3. 13 potential evapotranspiration of megech river using penman modified method

Month	JUN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP.	OCT.	NOV.	DEC.
T	17.47	19.12	20.60	21.01	20.29	18.48	16.91	17.00	17.49	17.99	17.97	17.49
ea	15.00	16.48	18.09	18.66	17.25	15.98	14.54	14.54	15.00	15.48	15.48	15.00
RH%	0.38	0.31	0.34	0.34	0.54	0.64	0.81	0.82	0.76	0.65	0.51	0.43
ed	5.73	5.16	6.10	6.40	9.23	10.18	11.76	11.94	11.45	10.13	7.90	6.48
U2(m/s)	1.88	2.05	2.12	2.09	2.09	2.05	1.65	1.58	1.55	1.47	1.51	1.65
U2(mile/day)	100.93	110.06	113.82	112.20	112.20	110.06	88.58	84.82	83.21	78.92	81.07	88.58
Tk	290.63	292.28	293.76	294.17	293.45	291.64	290.07	290.16	290.65	291.15	291.13	290.65
n	9.25	9.07	7.95	7.92	6.89	4.59	3.63	4.12	5.56	7.12	8.68	8.54
N	11.40	11.60	11.90	12.30	12.60	12.70	12.60	12.40	12.10	11.70	11.40	11.30
n/N	0.81	0.78	0.67	0.64	0.55	0.36	0.29	0.33	0.46	0.61	0.76	0.76
fa(n/N)	0.66	0.64	0.57	0.56	0.50	0.38	0.34	0.37	0.44	0.54	0.63	0.63
Ra	12.61	13.80	14.90	15.51	15.51	15.35	15.35	15.43	15.06	14.08	12.86	12.24
RI(1-r)	7.94	8.45	8.13	8.24	7.35	5.60	4.94	5.36	6.37	7.19	7.72	7.31
σTa4	14.28	14.58	14.88	14.98	14.82	14.48	14.17	14.18	14.28	14.38	14.38	14.28
Ro	3.50	3.58	3.07	2.96	2.24	1.57	1.23	1.33	1.70	2.25	2.99	3.18
Ht	4.45	4.87	5.06	5.28	5.11	4.03	3.70	4.03	4.66	4.94	4.73	4.13
Eat	4.90	6.34	6.88	6.96	4.55	3.25	1.35	1.23	1.66	2.42	3.48	4.13
Δ/Ƴ	1.95	2.11	2.29	2.36	2.19	2.06	1.90	1.90	1.95	2.00	2.00	1.95
PET	137.98	160.34	168.27	173.43	148.15	113.23	86.72	91.89	109.30	123.03	129.42	124.02

RH=relative humidity (%), U2=wind speed (mile/day), n= daily mean bright hour (hr/day), N=Max. possible sunshine hour determined by latitude and season (12^0) in case of Megech fa=function of sunshine hour, Ra=solar radiation dependent latitude and season (mm/day), RI= incoming solar radiation (mm/day), r=albedo reflection coefficient for incoming radiation σ= stephphanboltzman constant =5.67x10-8xWm-2T4, T=temperature(0c), Tk= temperature in Kelvin, R_O=outgoing solar radiation (mm/day), H=available heat(mm/day), σTa4= theoretical black body radiation (mm/day), Δ=slope of saturated vapour pressure plotted against temperature, PET= potential evapotranspiration (mm/month)

3.4.1.7. Actual evapotranspiration estimation

Using potential evapotranspiration (PET) to estimate crop actual evapotranspiration (AET) is a critical approach in hydrological models (Li et al., 2016). Actual evapotranspiration refers to the evaporation from vegetable cover under given or natural condition of supply of moisture. It helps to describe the amount of evaporation that occurs under filed condition and depends on the availability of water to meet the atmospheric demand. When the vegetation is unable to abstract water from the soil, then the actual evapotranspiration becomes less then potential. Thus the relation between the potential evapotranspiration and the actual evapotranspiration depends up on the soil moisture contents (Chaw, 1998). The methods by which AET is calculated are:

Thornthwaite method (water balance method):

This method calculates actual evapotranspiration using precipitation and soil moisture deficit values. Always actual evapotranspiration is less or equal to potential evapotranspiration. When the soil is saturated, it will hold no more water. In this condition, actual evapotranspiration is equal to potential evapotranspiration. Given the fact that the values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation, during times when there is no rain to replenish the water supply, the soil moisture gradually becomes, depleted by the demand of vegetation to produce a soil moisture deficit (SMD). As a result the actual evapotranspiration becomes less than the potential evapotranspiration. A soil moisture budget can be made on the monthly basis for various types of vegetation classified according to their root constants which define the amount of moisture that can be extracted without difficulty by given vegetation. Therefore to evaluate the actual evapotranspiration over the catchment area, the proportion of different types of vegetation and soil covering the catchment are identified from soil, land use land/land cover maps.

Accordingly the study area has been classified three soil textures with their corresponding vegetation cover. Based on these categories and meteorological data the actual evapotranspiration of the catchment is calculated using thornthwaite and Mather soil water balance model. Since there are different land use/land cover categories and soil texture in the study area, the model provides different independent results.

If Pm>PETm the value of soil moisture at the end of that month Sm is given as:

S_m=W*exp ($-\frac{APWL}{W}$) Eq. (13)

If for a given month Pm<PETm: a soil moisture deficit develops or increase, the soil moisture for this case is given as:

Sm=min (((Pm-PETm)+S_{m-1}),Smax) Eq. (14)

Soil moisture values for each wet month are obtained by adding the excess rain of the current month to the soil moisture of the month before. But, the sum may or may not exceed the available water capacity. If the soil moisture value exceeds the available water capacity of the root zone, the excess moisture is recorded as moisture surplus; W is the available water capacity of the root zone (mm).

AET is the actual evapotranspiration. AET =PET if P of that month is greater than the respective PET. Otherwise;

AETm=Pm+S_{m-1}-Sm Eq. (15)

Where m stands for month and S_{m-l} and Sm are soil moisture during the month m-1(earlier month) and m (current Month) respectively (Rajasivaranjan, 2015).

P = the mean rainfall of the catchment; PET =the potential evapotranspiration calculated from penman modified method; P-PET is the difference between precipitation and potential evapotranspiration. Positive values are indicatives of the addition of moisture to the soil while the negative values are showing the monthly demand of moisture by the vegetation which is not satisfied by the monthly rainfall; Sm is the soil moisture. Accumulated potential water loss is used to calculate Sm for the dry months using the following relation; APWL= accumulated potential water loss, which is obtained by cumulating the negative values of the differences between monthly precipitation and evapotranspiration; SMD is the soil moisture deficit obtained by deducting AET from PET; S is the soil moisture surplus which is in excess of soil moisture values (Sm) especially in wet season; TARO refers to the total amount of water available for runoff. The value is determined staring from the first month of the water surplus period. It is simply equal to the amount of soil moisture surplus for the first month (TRO =S) in the month of July in case of Megech river catchment but the value for consecutive coming months is obtained by adding the surplus of the month and the detained amount of water in the preceding month as this detained water is thought to be readily available for run off for the coming month. According to Thornthwaite and Mather assumption, 50% of the surplus is detained (D) in sub soil, ground water, channels of the catchment and available for run of for the next month and the remaining 50% is the run off (RO) that is as river discharge. The available water capacity of soil for three different land uses is obtained from a table developed by Thornwaite and Mather, 1957. The analysis of the model will be described in the table 14, table 15 and 16 respectively. **(**All units are mm)

Table3. 14 Calculated AET using soil water balance model for clay loam soil covered with shallow rooted crops and available water capacity of the root zone 100mm

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
p	1.65	2.35	16.89	35.72	102.14	185.34	346.00	371.98	160.77	76.26	20.09	4.24
PET	137.98	160.34	168.27	173.43	148.15	113.23	86.72	91.89	109.30	123.03	129.42	124.02
P-PET	-136.33	-157.98	-151.38	-137.71	-46.01	72.11	259.29	280.08	51.46	-46.78	-109.33	-119.78
APWL	-412.21	-570.20	-721.58	-859.29	-905.30					-46.78	-156.11	-275.88
SM	1.62	0.33	0.07	0.02	0.01	72.11	100.00	100.00	100.00	62.64	20.99	6.34
ΔSM	-4.72	-1.29	-0.26	-0.05	-0.01	72.10	27.89	0.00	0.00	-37.36	-41.65	-14.66
AET	6.37	3.64	17.15	35.77	102.15	113.24	87.00	92.00	109.00	113.62	61.74	18.90
SMD	131.61	156.70	151.12	137.65	46.00	-0.01	-0.28	-0.11	0.30	9.42	67.68	105.12
S	0.00	0.00	0.00	0.00	0.00	0.01	231.40	280.08	51.46	0.00	0.00	0.00
TARO	15.58	7.79	3.89	1.95	0.97	0.50	231.00	395.58	249.25	124.63	62.31	31.16
RO	7.79	3.89	1.95	0.97	0.49	0.25	115.50	197.79	124.63	62.31	31.16	15.58
D	7.79	3.89	1.95	0.97	0.49	0.25	115.50	197.79	124.63	62.31	31.16	15.58

Table3. 15 Calculated AET using soil water balance model for clay soil covered with moderately deep rooted crops and available water capacity of the root zone 200 mm

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
p	1.6515	2.352	16.89	35.719	102.14	185.34	346	371.977	160.77	76.26	20.093	4.2427
PET	137.98	160.34	168.27	173.43	148.15	113.23	86.716	91.8925	109.3	123	129.42	124.02
P-PET	-136.3	-157.98	-151.38	-137.7	-46.01	72.11	259.29	280.084	51.462	-46.78	-109.3	-119.8
APWL	-412.2	-570.2	-721.58	-859.3	-905.3					-46.78	-156.1	-275.9

SM	25.464	11.558	5.4217	2.7234	2.1637	72	200	200	153.22	121.3	70.202	38.571
ΔSM	-13.57	-13.906	-6.1358	-2.698	-0.56	69.836	128	0	-46.78	-31.95	-51.07	-31.63
AET	53.793	16.258	23.026	38.418	102.7	113	87	92	109	108.2	71.16	35.874
SMD	84.187	144.08	145.25	135.01	45.449	0.2286	-0.284	-0.10745	0.3036	14.82	58.259	88.145
S	0	0	0	0	0	2.2734	131.29	280.084	98.239	0	0	0
TARO	16.96	8.4798	4.2399	2.1199	1.06	2	132.29	346.228	271.35	135.7	67.838	33.919
RO	8.4798	4.2399	2.1199	1.06	0.53	1	66.144	173.114	135.68	67.84	33.919	16.96
D	8.4798	4.2399	2.1199	1.06	0.53	1	66.144	173.114	135.68	67.84	33.919	16.96

Table3. 16 Calculated AET using soil water balance model for sandy loam soil covered with moderately deep rooted crops and available water capacity of the root zone 300mm

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
p	1.6515	2.352	16.89	35.719	102.14	185.34	346	371.977	160.77	76.26	20.093	4.2427
PET	137.98	160.34	168.27	173.43	148.15	113.23	86.716	91.8925	109.3	123	129.42	124.02
P-PET	-136.3	-157.98	-151.38	-137.7	-46.01	72.11	259.29	280.084	51.462	-46.78	-109.3	-119.8
APWL	-412.2	-570.2	-721.58	-859.3	-905.3					-46.78	-156.1	-275.9
SM	75.925	44.841	27.072	17.107	14.675	72	300	300	253.22	216.7	150.49	100.95
ΔSM	-25.03	-31.084	-17.769	-9.965	-2.432	57.325	228	0	-46.78	-36.56	-66.17	-49.54
AET	26.681	33.436	34.659	45.685	104.58	113	87	92	109	112.8	86.262	53.783
SMD	111.3	126.9	133.62	127.74	43.576	0.2286	-0.284	-0.10745	0.3036	10.22	43.157	70.237
S	0	0	0	0	0	14.784	31.288	280.084	98.239	0	0	0
TARO	15.499	7.7493	3.8747	1.9373	0.9687	15	38.788	299.478	247.98	124	61.995	30.997
RO	7.7493	3.8747	1.9373	0.9687	0.4843	7.5	19.394	149.739	123.99	61.99	30.997	15.499
D	7.7493	3.8747	1.9373	0.9687	0.4843	7.5	19.394	149.739	123.99	61.99	30.997	15.499

3.4.2. Recharge estimation analysis

Water balance represents the hydrogeological gains and losses of a given system over a specific period of time. Water balance model were developed by Thornthwaite 1948 and revised by Thornthwaite and Mather 1955. This method is essential procedure, which estimates the balance between the inflow and outflow of water.

Generally water balance has the following form:

Inflow=Outflow + change in storage

The general form of the water balance of a given basin or catchment can be given by:

$$P+ Gi=RO+ AET+ I+ Go\pm \Delta S \quad \text{Eq. (16)}$$

Where; P=annual precipitation; Gi= groundwater inflow; RO= annual surface runoff; AET= actual evapotranspiration; I=groundwater recharge; Go= groundwater outflow; ΔS= change in water storage.

The main purpose of this computation is to make a quantitative evaluation of the amount of water that percolates in to the ground to recharge the groundwater circulation occurring in the study area. Therefore basic assumptions made to drive the water balance equation for the study area: the surface water divides coincides with the subsurface drainage basin so groundwater inflow and outflow are equal and the change in storage (ΔS) of groundwater in annual basis is negligible. As a result of the above assumption equation 16 is simplified and rearranged to:

$$I=P-AET-RO \quad \text{Eq. (17)}$$

Where: I= groundwater recharge; P= annual precipitation; AET= actual evapotranspiration; RO= annual surface runoff.

3.4.2.1. River Discharge Data

The Megech River has a drainage area of about 630.6 km^2 and an average annual 80.1million cubic meter. The table 3.17 and the figure 3.4 show an average twenty eight years hydrological summary table and hydrograph respectively.

Table3. 17 the minimum, maximum and mean of the gauged stream

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.06	0.89	0.94	1.06	1.51	4.06	15.98	34.40	13.15	3.89	1.87	1.30
Max.	6.34	5.00	5.10	5.90	9.16	26.07	46.74	75.40	34.15	12.37	7.86	6.41
Min.	0.00	0.00	0.00	0.00	0.00	0.00	1.21	13.82	3.58	0.00	0.00	0.00

In megech river catchment the gauging station found at the dam it measures 462km^2 of the catchment which is 73.26% of the total catchment area. The rest 26.73% is ungauged and which is determined by the following formula (Liyew, 2009).

$$Q_{mouth}=(A_2/A_1)Q_{gauged} \quad \text{Eq. (18)}$$

Where A1= the area of gauging station which is 462km2; A2= the total area of the megech catchment which is 630.6 km2; Q_{mouth}= the stream flow at the outlet taken; Qgauged=the stream flow in the gauged catchment

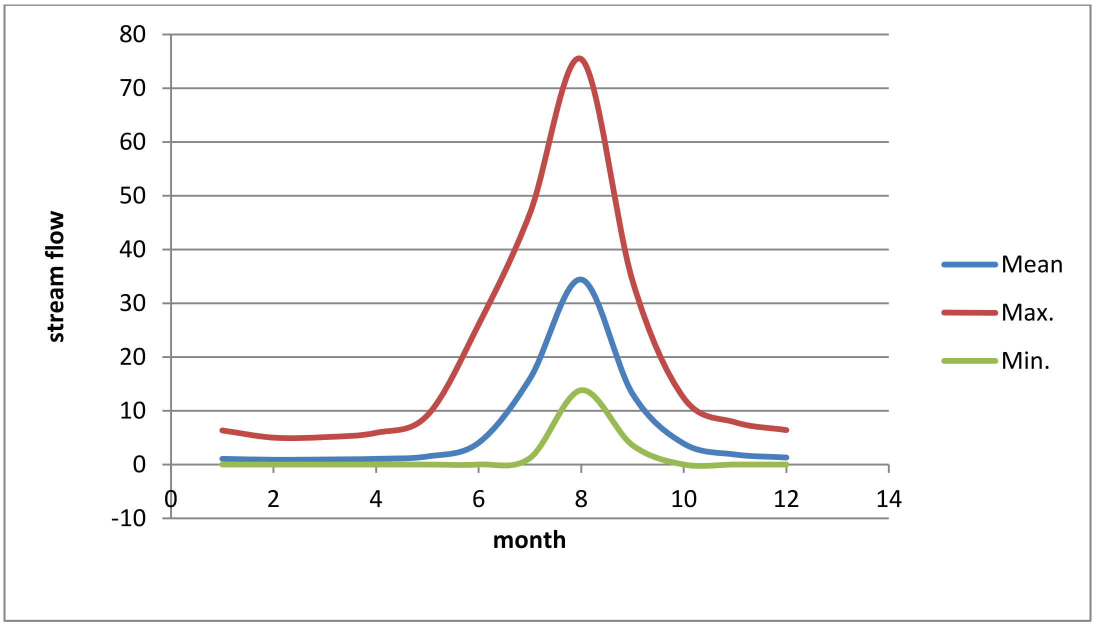

Figure3. 7 River discharge in years

3.4.3. Hydrogeological data

Secondary data on springs, hand dag wells and boreholes have taken from different organizations.

3.4.3.1. Boreholes

All the boreholes are drilled for the water supply system of Gondar town and are also located in the vicinity of the town in four well fields (Angereb, Keha, Shinta and Koladiba).

3.4.3.1.1. Angereb vally well field

The angereb vally is located on the eastern side of Gondar town. The Angereb River forms the valley, which is one of the major tributaries of Megech River. A total of fourteen boreholes were drilled in this valley very near to the river bank in two phase, the seven old Angereb wells (OAI-0A7) drilled from 1982 to 1992 and the seven new Angereb wells (NA1-NA7) drilled in 1998. The distances between the boreholes are approximately 500-700m. All the wells are located on the left bank of the river.

3.4.3.1.2. keha vally well field

The keha well field is situated in the valley of keha River on the western side of Gondar town. A total of five wells (C1-C4 and Y1) were drilled along the bank of the river. The lithologic logs in Angereb, shinta and Azezo boreholes are all record only basaltic rocks. There is no structural or strait graphic evidence for the existence of tuff or pyroclastic in the keha valley, alone.

3.4.3.1.3. shinta and Azezo well field

The third area of well field around Gondar is the shinta and Azezo well field. This is formed by the small the streams of shinta and Dimaza flowing in N-S direction through the town of Azezo. The two streams join just east of Azezo and drain in to Megach River. More than fifteen wells were drilled in these valleys. Water wells drilled with few hundred meters distance along Shinta valley had different yield capacity and some are abandoned as totally dry.

3.4.3.1.4. Koladiba well feild

The fourth area of well field far from Gondar is Koladiba well field. This is formed by lacustrine sediment that is flat area towards Tana Lake. The wells found within the flood plain of Dembia. More than twelve wells were drilled in these areas. Water wells drilled around Koladiba flood plain had different yield capacity and some are abandoned as totally dry. The new boreholes in the plain area south of Kola Diba are five in number and are estimated to provide more than 120 l/s. Three other boreholes to the east of Kola Diba towards Megech have not been successful since they yield little or no water.

Table 3. 1 Location of Boreholes in Kola Diba Area

Number	Borehole name	Easting	Northing
1	Wonfela BH	319011	1371677
2	Muncipality BH	318437	1374599
3	S of Wonfela	319357	1370951
4	TPW 4	318855	1371152
5	TPW 6 (No. 6)	318242	1370980
6	TWP 5	318108	1371661
7	No, 3	318942	1370592
8	TPLl -Minichir Gebriel	327753	1377650
9	TPL 2	327035	1372836
10	Well 3 AWWC	326420	1372609

The pump test data indicates that the three wells of the factory (TW-1/no.1, TW-2/no.2 and TW-4/no.3) are tested for twenty- four hours with constant discharge of 10, 10 and 9 l/sec respectively. From the data sheet the drawdown of the three wells is not stabilized at the end of the test. With this data on hand the aquifer parameters are calculated and the design yield of the wells is recommended to be 9.9, 9 and 10 l/sec respectively. Based on the recommended yield the factory starts pumping the wells and at peak dry periods, peak production season of the factory, the wells run out of water in less than four hours pumping and are unable to satisfy the needs of the factory, as a result the factory is currently sharing the town supply from the dam.

Generally, the potential of the well fields in the vicinity of Gondar is not properly known due to improper pumping test and some other reasons. In some wells high capacity pumps are installed due to over estimation of the well yield during pumping test, in some other low capacity pumps are installed such that the water level in the well never decreases in twenty-four-hour pumping.

Therefore, no pumping test data of any of the wells is used in this work. But the potential of the well fields and the properties of the aquifer should be known through appropriate pumping test for sustained supply and future planning. As of September 2010, the Gondar water supply totally depends on water from Angereb dam and Koladiba wells.

3.4.3.2. Hand Dug Wells

Both the rural and urban community in the catchment is using a number of hand –dug wells. Most of the wells have depths 6-9m. Almost all the wells tap the weathered mantle and/or the alluvial and colluvial deposit. All of the privately owned dug wells both in urban and rural areas are poorly protected and are centers of contamination. Three hand dug wells which are properly constructed, two in the rural areas and one in Gondar town.

3.4.3.3. Springs

A number of low discharge (commonly less than 11/sec) are emanating in the catchment. More than 22 springs were identified and mapped in the catchment. Two exceptional springs with a relatively higher discharge are, Shollaye spring with an estimated discharge of 51/sec and used for the Azezo military camp supply, and Korebreb spring with an estimated discharge of 41/sec and used for Gondar water supply. The tow springs are believed to be controlled by the NNW-SSW trending lineaments (Yitbarek, 2002). The Italians developed both springs in the 1930s.

Angereb dam: This dam is constructed in the Angereb valley. The dam site is located 5 km south from the bridge of the Debark highway. The drainage area of the Angereb river at the dam site is 68.1 km2(DEVECON, 1992). There is a gauging station located 200m downstream from the highway bridge. At this site, the drainage area is 50.3km^2. Thus the area increases by 35% between the station and the dam site. The station has been in operation since 1983. The mean annual flow is 33.1 million cubic meters (mcm). The Angereb dam is earth dam constructed by the Ethiopian water works construction Authority (EWWCA) from 1987- 1994. The construction was first designed to be completed in three years time, but due to several reasons it took a total of seven years for completion.the dam is 35m high 425m long with a reservoir capacity of 5.286mcm. this is the volume of the reservoir at the level of 1909m. The capacity of the spillway is 60m^3/sec and that of the diversion conduit is 15m^3/sec. The mean annual sediment inflow to the reservoir is estimated to be 0.068mcm. thus the half –life of the reservoir would be about 40 years (DEVECON, 1992). The life time of the reservoir could be extended by using the diversion conduit to release extra sediment inflow instead of using the spillway particularly at the beginning of the rainy season. Soil conservation measures should be performed to reduce the sedimentation rate in the Angereb basin so as to increase the life of the dam. The activity is started by the Amhara Development Association (ADA), but there is a lot to do to conserve the highly rugged bare catchment of Angereb River. In addition to its use as source for for water supply, from the geomorphology, geology and topographic characteristics of the area, the dam might serve as recharging site for wells located downstream of the dam(Yitbarek, 2002).

Megech dam: this dam site area is found in north Gonder zone of Amhara regional state in the northern portion of Lake Tana sub basin. The dam site is located close to the Azezo air strip upstream from the bridge along the Bahir-Dar Gondar road. The location of the river bed at the center of the dam axis (in UTM) is E= 332 646 and N= 1 382 648. The left abutment of the dam axis is found centering at the geog. grid ref. 0333013 m E & 1382143m N UTM, at an altitude of 1965 m.a.s.l. The right abutment is centered at the geographic grid ref. 0332485 m E & 1382866 m N UTM, at an altitude of 1972 m.a.s.l. The dam site is characterized by broad and flat flood plains, old bench forming terrace and low to high relief basaltic hills of steep to gently sloping.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Hydro-metrological characteristics of Megech River catchment

4.1.1. Percipitation

Based on equation 1 the arithmetic average precipitation of the five stations within and around the catchment gives 1323.4 mm.

According to the table 3.2 and table 3.3 the rainfall distribution in the study area ranges from 1003.86mm to 2358.84mm. The highest rainfall is recorded in Tikildingay highland area and the lowest rainfall is from Maksegnit. As it is seen table 3.3 mean monthly precipitation of the stations, the mean maximum rainfall is recorded in the month of August and the mean minimum in the month of January.

Table 4. 1 Monthly percentage contribution of rainfall

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Rainfall (mm)	1.65	2.35	16.9	35.72	102.14	185.34	346	371.98	160.77	76.26	20.09	4.24
Contribution in %	0.12	0.18	1.28	2.699	7.7181	14.004	26.14	28.107	12.148	5.762	1.518	0.32

The majority of rainfall in the catchment is concentrated during Ethiopian wet season (Kiremt). 80.4% of the mean annual rainfall is covered in July to September with maximum monthly mean value reaching more than 741.22mm in the month of August.

In many areas of the world, rainfall uniformly increases with altitude. However, this increase of rainfall with altitude in the area is valid for the stations Maksegit and Gondar. Whereas the lowering of rainfall in Ambagiorgis, while it is at higher elevation than Gondar, it may be related to orograpic effect.

4.1.2. Temperature

Based on table 3.8 the maximum temperature is recorded in the month of April for all the four stations and the minimum temperature records in the month of December, January and Augest. According to table 3.2 and table 3.8 figure 4.2 was constructed to show the relation between temperature and altitude.

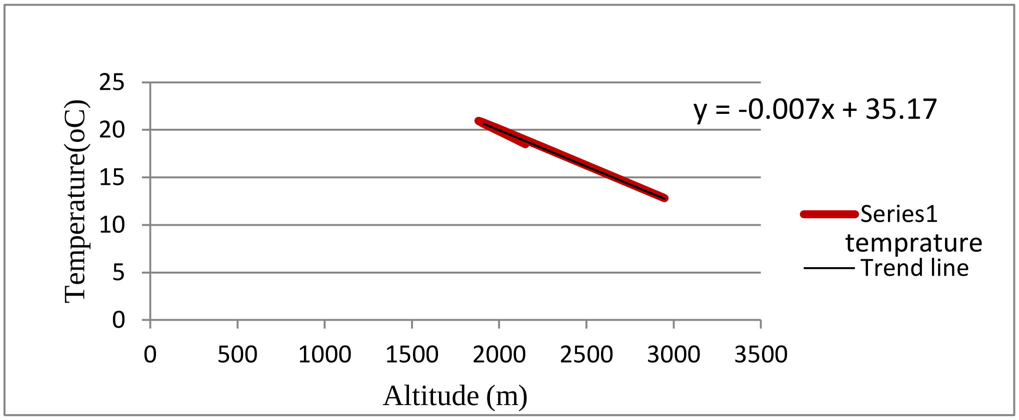

Figure4. 1 the relation between temperature with altitude

The figure 4.2 shows the temperature decreases with increase in altitude.

4.1.3. Relative humidty

Based on table 3.9 the maximum and minimum values of relative humidity exist in August and February: and this is attributed to rainy and dry season of Ethiopia.

4.1.4. Wind speed

According to table 3.10 the mean monthly wind speed of the area varies from 1.47 to 2.0: And maximum values obtained in the months of April and May and minimum values were observed in the months of October.

4.1.5. Sunshine hours

According to table 3.11 the average values of monthly sunshine hour ranges from 3.63 to 9.25. The maximum sunshine hour corresponds to the minimum cloud cover in the dry months (January to February) and minimum to the rainy months, which are most of the day covered with clouds.

4.1.6. Potential Evapotranspiration

According to penman equastion (equastion 4) and table 3.13, potential evapotranspiration of megech river using penman modified method the potential evapotranspiration of the catchment is found 1565 mm per year which is the summation of the potential evapotranspiration of the twelve months. PET tends to increase as temperature, sunshine, wind speed increases and as humidity decreases.

4.1.7. Actual evapotranspiration estimation

Based on table 3.14, 3.15 and 3.16 the following table 4.3 was constructed.

Table 4. 2 the relationship between soil type, actual evapotranspiration and Moisture surplus

Soil type	Avaliable water capacity (mm)	Area(km2)	AET(mm)	surples(mm)
clay loam	100	4.9	761	563
clay	200	98.9	850	512
sandy loam	300	526.7	899	424
Weghted Average			890.32	499.67

The actual evapotranspiration obtained for the Megech river catchment as a weighted sum of the areal proportion of each soil and vegetation type is 890.32 mm, which is 67.27% of the mean annual rainfall of the catchment with a surplus of 499.67 mm annually, that occur in the months of June, July, August and September.

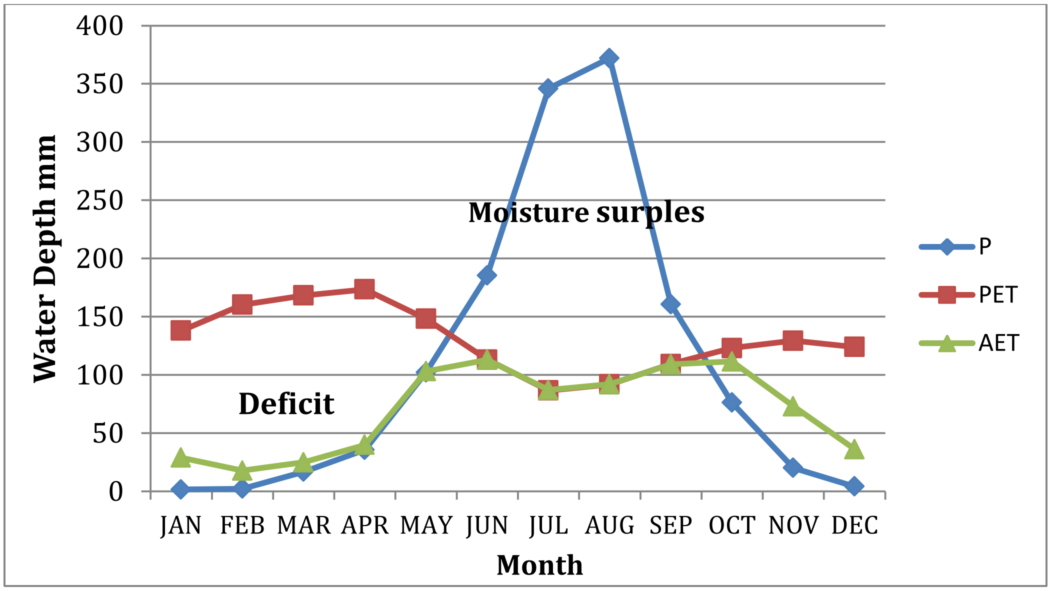

Figure4. 2 Graph of Annual Soil Water Balance in Megech River Catchment

The graphical representation of Thornthwaite water balance components especially the relationship between precipitation, potential evapotranspiration, actual evapotranspiration as well as the respective moisture surplus and deficit of Megech river catchment is shown in the figure 4.3.

4.2. Recharge

4.2.1. River Discharge

Based on equation 18 the Runoff of the whole catchment is 630.6 km2/462km2*80.1 million m^3 = 109.33million cubic meter=173.4mm.

The water balance is computed for the entire Megech river catchment . Lack of discharge measurements of the springs, boreholes and hand dug wells for a complete hydrological year limits quantifying the amount of water abstracted from the catchment. As a result the abstraction amount is excluded in the water balance analysis.

Based on equation 17 the annual recharge amount of megech river catchment is 259.68mm or 133.5 million cubic meter where: P= perciptation (1323.4mm); AET= actual evapotranspiration (890.32mm); RO= Surface water out flow (173.4mm).

The water balance indicates that the groundwater recharge over the catchment 19.6 percent of the total rainfall. The actual evapotranspiration is about 67.3 percent of the total rainfall; about 13.1 percent is the surface runoff.

4.3. Ground water flow direction

On the basis of the potentiometer head distribution from various deep wells drilled in the aquifer system, Potentiometer contour map has been constructed to show the groundwater flow direction. The groundwater level of the area was found by subtracting the static water level from surface ground elevation. Based on this the groundwater level map of the area was developed and the flow direction was indicated. The groundwater level map of the study area below shows that the levels of groundwater depth getting vary from place to place. The flow direction indicator shows that the groundwater flows towards the Lake Tana.

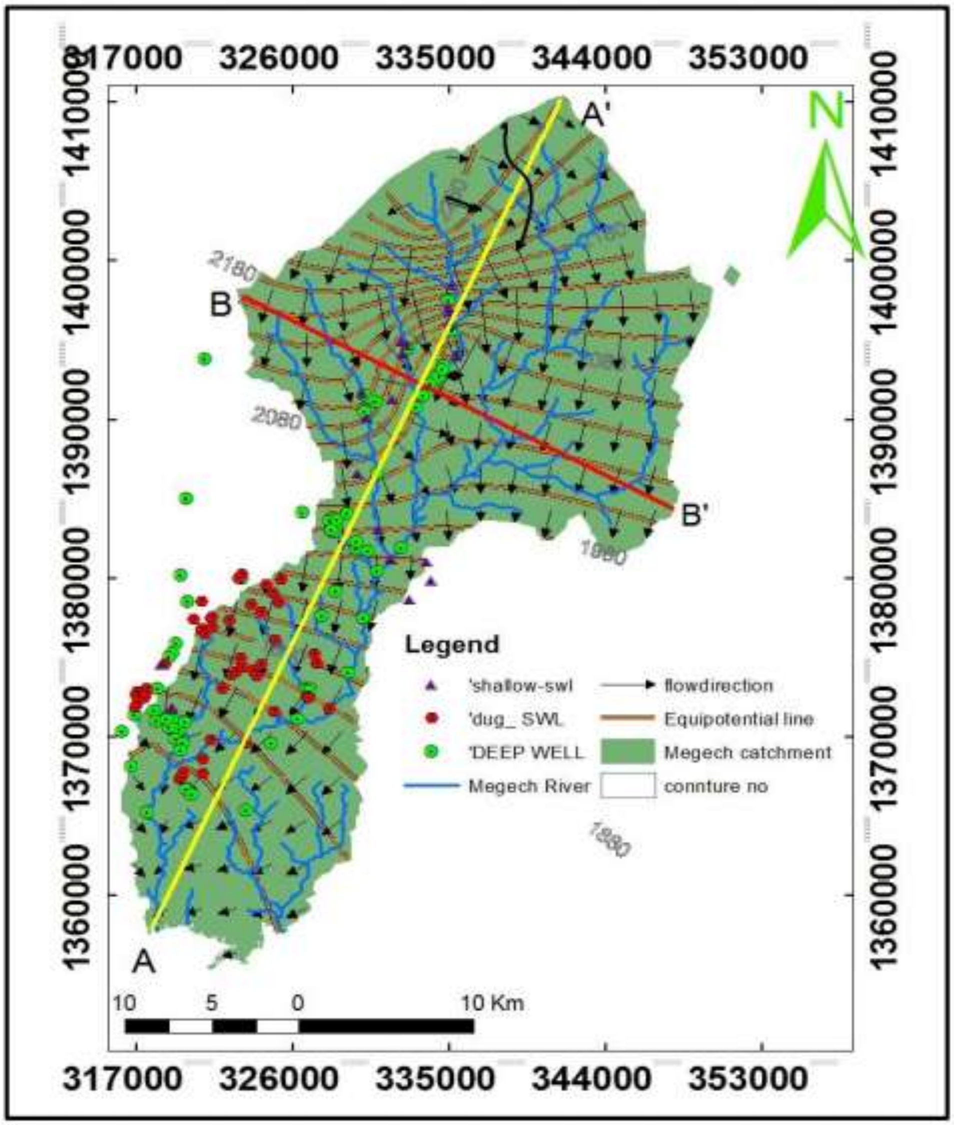

Figure4. 3 Groundwater flow direction of Megech catchment

4.4. Groundwater potential zones

Generally in the studied catchment recharge areas occupy topographically elevated areas which is covered by deeply weathered, fractured and friable basalt, whereas discharge areas which is groundwater potential zones are located on the topographic lows comprising the major river valleys, lines of seepage, springs, sites of hand dug wells and boreholes that is lacustrine deposites toward Lake Tana. Alluvial, riverbed and colluvial deposits cover most of the transition areas. In Megech river catchment it is common to get low discharge springs at topographic highs. Some springs are also located near or at the water divide where most of them are the starting point of the major valleys, (Angereb, Shinta Keha, and Dimaza). The high potential zones correspond to alluvial plains, lacustrine sediments, the fracture valleys, and valley fills, which coincide with the low slope and high lineaments density areas. The low zones mainly comprise structural hills and escarpments which contributes high runoff. Poor groundwater potential zones are present in the mountain peaks, plateaus and escarpments with steep cliff, where low fractured rocks.

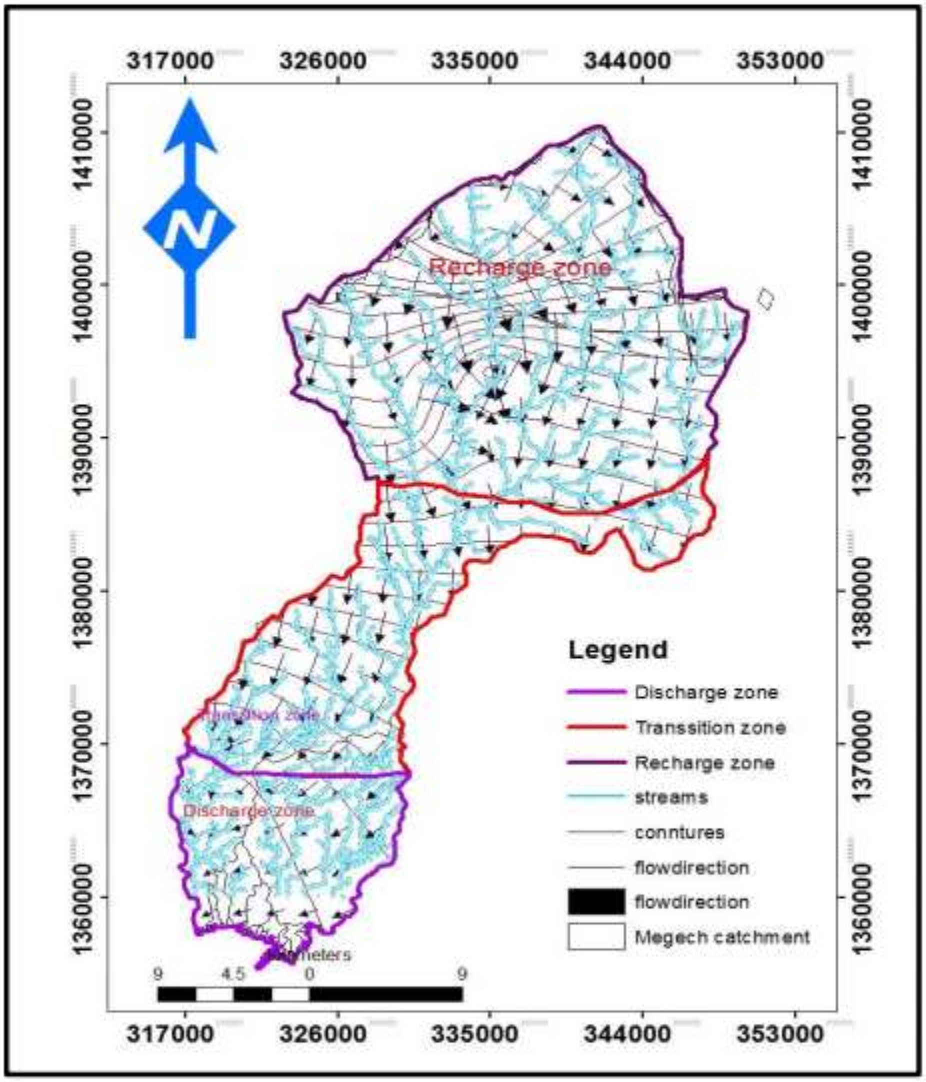

Figure4. 4 Recharge and discharge zones of the study area

CHAPTER FIVE

CONCLUSSIONS AND RECOMMENDATIONS

5.1. Conclusions

This research was conducted to determine groundwater potential zone determination and recharge estimation of megech river catchment. It was found that the annually mean maximum, mean, and mean minimum temperatures of the Megech River catchment are 24.68, 18.09, and 11.5 ^{0}C respectively. The long term mean annual precipitation calculating by using arithmetic method which result is 1323.4mm. The majority of rainfall in the catchment is concentrated during Ethiopian wet season (Kiremt). 80.4% of the mean annual rainfall is covered in July to September with maximum monthly mean value reaching more than 741.22mm in the month of August. Maximum and minimum values of relative humidity exist in August and February: and this is attributed to rainy and dry season of Ethiopia. Wind speed in the study area and nearby stations is measured at 2m above the surface of the ground. The mean monthly wind speed of the area varies from 1.47 to 2.0: And maximum values obtained in the months of April and May and minimum values were observed in the months of October. Average values of monthly sunshine hour ranges from 3.63 to 9.25. The maximum sunshine hour corresponds to the minimum cloud cover in the dry months (January to February) and minimum to the rainy months, which are most of the day covered with clouds (July and August). Potential evapotranspiration is estimated by using penman modified method which results 1565 mm per year. The acual evapotranspiration is calculated by Thornthwhatie method (water balance method) is 890.32 mm per year.

Annual ground water recharge estimated though water balance method is 259.68mm which is 19.6 % of mean annual precipitation of the catchment.

The shallow groundwater of the study area is dependent on the inclination of the topography of the area. Both the groundwater level and groundwater head contour map show that the local groundwater flow direction in Megech area is tends to be towards Lake Tana.

The ground water recharge and discharge condition of the area is controlled by the topography, the prevailing geologic set up especially the existence of weathered and fractured geologic materials. The high potential zones correspond to alluvial plains, lacustrine sediments, the fracture valleys, which coincide with the low slope and high lineaments density areas. The low zones mainly comprise structural hills and escarpments which contributes high runoff. Poor groundwater potential zones are present in the mountain peaks, plateaus and escarpments with steep cliff, where low fractured rocks. In the study area high groundwater potential zones found at downstream of Megech river catchment near Lake Tana.

4.5. Recommendations

- The metrological data are important for hydrological study therefore all the stations should have complete information on metrological element such as rainfall, tempreture, wind speed, relative humidity, sunshine hours
- Proper soil and water conservation should be developed to enhance the ground water recharge, to increase the yield of water wells and to minimize siltation of Angereb dam, on the proposed Megech dam and Lake Tana.
- For further validation, complete discharge measurements of the springs, boreholes and hand dug wells of the catchment sites are recommended.

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APPENDCIES

Appendix 1 Rainfall data at Gondar station

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	0	5.2	31.7	123.4	47.9	177.2	352	298.5	128.6	89.1	57.3	0
1981	4	0	11.4	60.9	96	97	260.3	156.3	88.6	27.6	4.3	0.5
1982	14.6	0	21.2	20.9	41.8	52	214.2	218.2	76.6	36.4	24	0
1983	0	0	0	5.3	100.1	155.6	263.9	201.2	91.9	69	19.3	0
1984	0	0	4.6	7	93.1	214.3	253.9	238.3	151.5	13.2	25.1	21.7
1985	0	0	56.4	61.8	81.3	80.3	179.7	334	122.2	64.4	42.2	16
1986	0	0	6.9	33.3	10.5	159	322.7	278.1	85.7	79.3	20.2	3.2
1987	12.8	0	2.1	36.5	210.6	207.5	232.6	195.2	125.1	90.6	17.4	3.7
1988	0	32.6	0	12.2	62.2	190.5	306.6	304.1	92.1	83.3	7.7	0.7
1989	0	1.4	38.7	32.4	59.7	206.4	269.1	279.7	108.1	34.5	7	11.9
1990	4.2	0	6.5	29.7	18	59.4	361.1	235.2	127.1	1.4	1.2	0
1991	0	9.3	2.3	19.5	52	35.9	285.9	269.9	67.5	64.9	35.9	0
1992	0	0	2.7	51.7	80.7	86.8	249.5	218.2	117.6	79.6	11.9	21.6
1993	0	3.5	30.8	78.5	104.2	166.6	305.4	201.9	136.6	86.7	16.5	0.5
1994	0	1	0	7.8	84.5	156	289.4	265.9	125	37.9	20	2.8
1995	0	0	34.5	23.9	99.3	105.9	283	307.1	91.8	11.9	0.9	19.8
1996	0	4.4	22.2	83.6	183.8	194.7	249.3	290	75.8	67.7	23.2	0.4
1997	0	1.8	28.4	42.8	124.2	176.8	239.9	230.4	33.1	200	40.2	13.7
1998	0	0	10	3.7	88.5	169.2	241.3	359.5	79	79.6	3	0
1999	22.2	0	0	26.4	80.1	92.5	285.4	242.5	133.4	240	7.1	33.1
2000	0	1.4	2.6	46	38.4	229.5	284.7	232.6	105.5	169	1.2	0
2001	0	0.6	2.1	29.4	56	254.8	358.5	310.4	74.5	91.6	10	0
2002	*	*	0	16.6	87.1	197.4	312.7	247.6	76.8	45.2	5.8	4.2
2003	0	22.1	11.1	0	37.9	244.2	318.7	280.7	134.9	21.7	0	0
2004	1.6	3.7	5.9	37.6	1.4	181.4	378.3	312.3	112.4	67.6	65.7	0
2005	0	11.2	60.8	12.1	24.2	137.5	304.1	274.2	169.3	42.8	17.4	0
2006	0	0	10.8	27.8	152.6	98.7	291.5	305.3	192.5	87.4	29.9	35
2007	4.8	0	15.8	45.1	101.6	162.2	340.7	355.1	126.6	96.2	10.6	0
2008	1.7	0	0	63.5	104.7	228.5	365.6	301.5	106.6	15.7	17.9	15.1
2009	1.8	12.5	2.7	56	195.2	303.5	341.4	39.2	56	1.2	0	**
2010	19.7	0	23.8	45.4	145.9	105.4	266.6	325	71.7	37.4	14.6	0
2011	2.5	0	19.9	23.8	104.7	172	230.9	268	103.5	52.3	46.6	0
2012	9.8	0	8.9	0	31.2	117.3	381.5	354.4	135.2	43.9	51.1	11.1
2013	0	0	2.6	8.1	69.8	154.6	244.4	309.5	63.3	62.8	43.6	0
2014	9.2	8.1	85	77.1	111.8	96.9	230.3	333.8	158.5	40.8	17.6	20.1
2015	0	0	20.7	2.5	130.4	121.6	236.2	247.3	123.2	25.4		

2016	0	0	25.2	20.2	144.7	126.9	369.2	242.3	102.3	397	0	

Appendix 2 Rainfall data at Ambagiworgis station

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1984	*	*	0	8.1	88.1	186.5	168.8	195.9	98.4	2.7	5.2	9.8
1985	*	0	1.2	7.5	75.6	173	160.3	1806	80.2	1.5	11.5	*
1986	*	*	2	7.5	72	12.28	150.3	145.6	82.1	12.1	0	*
1987	0	0	1.6	12	65.7	10.3	120.6	140.5	75.2	13	11.5	0
1988	*	0.6	0.8	13.3	60.2	55	100.3	155.3	70.3	6.5	13	0
1989	0	0.2	0.9	12	32	65.2	104.5	188	77.1	5.4	25	0
1990	*	0	0	14	55	100.3	120.7	150.3	65.2	10	13.1	0
1991	0	0	12.8	15.3	20.6	50.8	140.3	200.1	123	15	0	0
1992	*	*	14.8	74	81.7	43.2	147.5	267.3	130.1	172.9	58.6	0
1993	9.2	3	15.3	36.3	81.9	108.3	240	162.9	101.5	57.3	7.8	2.5
1994	0	8.6	0	24.1	82	134	310.5	310	56.9	3.1	1.5	0
1995	0	0	44.6	74.1	37.7	70.1	416.4	220.2	21.2	0	0	28
1996	0	0	18.8	62.7	157.2	265	163.5	242	36.4	0	68.7	0
1997	0	0	22.6	53	107	78.7	272.6	221.7	33.1	109.3	71	0
1998	0	0	1.6	3.5	68.1	145.9	356.9	286.9	66.7	0	0	0
1999	0	0	0	27.8	55.6	142.5	334.6	315.6	81.8	98.7	14.5	6
2000	0	0	0	75.7	26.1	76.4	222.5	187.9	90	120.7	1.3	0
2001	0	2.3	11.6	32.2	59.3	175.8	372.3	356.3	32.8	60.4	8.1	16.2
2002	0	0	10.7	25.5	28.5	159.2	438.5	171.1	31.9	3.2	0	8.5
2003	0	21.6	19.8	0	21.8	114.9	448.2	515.5	139	0	18.3	0
2004	0	11.3	13	82	8	173.7	280	209.7	35	48.4	47.2	0
2005	*	*	92.6	145.9	43.7	150.9	264.5	200.9	32	50	14	*
2006	0	0	16.3	49.8	131.9	88.1	310	400.2	40.2	45.5	0	0
2007	0	0	103.2	33.8	114	178.7	338.7	384.5	116.6	10.9	27.9	0
2008	3.4	2.5	0	49.1	111.8	148.6	283.9	314.2	114.6	57.2	0	2.8
2009	0	2.3	17.5	0	0	46.6	322.7	150.4	69.2	42	7.7	0
2010	0	0	36.5	114.6	48.2	116.5	248.9	486.2	0	0	19.3	0
2011	0	0	*	17.7	125.7	285.3	534.6	357.1	257.3	105.6	0	0
2012	0	0	12	15	100.9	200	259	300.1	142	12	0	0
2013	*	*	0	11	15	249.4	389.6	383.9	155.9	13.8	29.3	0
2014	0	0	0	29.3	137.5	18.2	274.3	318	210.2	46.1	10.9	0
2015	0	9.4	6.7	4.6	104	0	104.8	348.4	65.1	7	35.75	21.8
2016	0	9.4	47	54	216.1	73.8	357.3	357.3	65.1	12	5.9	0

Appendix 3 Rainfall data at Maksegnit station

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1984	*	0	0	8.1	88.1	186.5	168.8	195.9	98.4	2.7	5.2	9.8
1985	*	0	1.9	5	58	120	142	150	88	6	3	0
1986	*	2	5	8	57	122	130	140	55	12.1	0	*
1987	0	3.2	9	36	55	110.6	120.6	150	72	12	10	0
1988	*	0	0.8	13.3	55	72	105	190	66	10	2	0
1989	*	12	1.5	22	32	65.2	104.5	188	77.1	5.4	25	0
1990	0	0	12	40	45	52	100	178.2	88.3	10	13.1	0
1991	0	12	15	37	47	50	98.2	200.6	120.1	26	0	*
1992	*	11	14.8	74	81.7	43.2	147.5	267.3	130.1	172.9	58.6	0
1993	9.2	3	15.3	36.3	81.9	108.3	240	162.9	101.5	57.3	7.8	2.5
1994	0	8.6	0	24.1	82	134	310.5	310	56.9	3.1	1.5	0
1995	0	0	44.6	74.1	37.7	70.1	416.4	220.2	21.2	0	0	28
1996	0	0	18.8	62.7	157.2	265	163.5	242	36.4	0	68.7	0
1997	0	0	22.6	53	107	78.7	272.6	221.7	33.1	109.3	71	0
1998	0	0	1.6	3.5	68.1	145.9	356.9	286.9	66.7	0	0	0
1999	0	0	0	27.8	55.6	142.5	334.6	315.6	81.8	98.7	14.5	6
2000	0	0	0	75.7	26.1	76.4	222.5	187.9	90	120.7	1.3	0
2001	0	2.3	11.6	32.2	59.3	175.8	372.3	356.3	32.8	60.4	8.1	16.2
2002	0	0	10.7	25.5	28.5	159.2	438.5	171.1	31.9	3.2	0	8.5
2003	0	21.6	19.8	0	21.8	114.9	448.2	515.5	139	0	18.3	0
2004	0	11.3	13	82	8	173.7	280	209.7	35	48.4	47.2	0
2005	*	*	92.6	145.9	43.7	156	264.5	159	33	22	11	*
2006	0	0	16.3	49.8	131.9	88.1	310	400.2	40.2	45.5	0	0
2007	0	0	103.2	33.8	114	178.7	338.7	384.5	116.6	10.9	27.9	0
2008	3.4	2.5	0	49.1	111.8	148.6	283.9	314.2	114.6	57.2	0	2.8
2009	0	2.3	17.5	0	0	46.6	322.7	150.4	69.2	42	7.7	0
2010	0	0	36.5	114.6	48.2	116.5	248.9	486.2	0	0	19.3	0
2011	0	0	*	17.7	125.7	285.3	534.6	357.1	257.3	105.6	0	0
2012	0	0	0	15	59	100	200.9	226.1	69	36	22	*
2013	*	*	11	19	0	249.4	389.6	383.9	155.9	13.8	29.3	0
2014	0	0	0	29.3	137.5	18.2	274.3	318	210.2	46.1	10.9	0
2015	0	9.4	6.7	4.6	104	0	104.8	348.4	65.1	7	35.75	21.8
2016	0	9.4	47	54	216.1	73.8	357.3	357.3	65.1	12	5.9	

Appendix 4 Rainfall data at Ayikel station

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1987	*	*	*	27.4	*	168.7	210.4	207.8	91.9	195	4.3	0
1988	0	11.5	0.5	2.9	153.7	153.1	355.7	243.5	138.6	177	29	0
1989	0	0	16.9	87.8	135.2	154.8	320.2	246	135.3	82.2	10.4	0
1990	3.9	0	1.3	32.3	52.2	153.3	257.3	207.7	237.2	59.4	0	0
1991	0	0	1.2	20.3	45	113	195.8	250.3	149.8	139	2.9	2.8
1992	0	0	0	49.5	0	140.3	163.9	200	120	86	23	0
1993	0	1.9	5.1	143.3	112.5	109.3	320.1	232.5	292.9	118	4.2	*
1994	*	1.2	2.6	12.1	50.3	281	214.4	272.5	215.5	42.4	3.7	14.1
1995	0	0	57.9	33.8	111.5	155.9	300.6	319.9	121.6	41	6.8	0.2
1996	0	6.9	37.8	62.4	72.8	269.3	204.8	196.1	166.6	30.8	28.3	0
1997	0	0.5	6.1	95.4	156.6	203.4	208.1	194.7	134.2	227	75.6	0
1998	0	0	17.4	2.7	92.7	235.8	311	326.4	117.4	125	1.6	0
1999	0	0	0	27.7	120.8	157.4	391	273.8	189.1	154	0	4.4
2000	0	0	4.2	81.5	100.7	137.3	268.8	244	202	203	45.9	0
2001	0	3.6	2	29.5	144.8	267.3	307.6	290.2	104.3	121	0	0
2002	0	0	0	1	100.7	185	238.4	323	174.6	69.7	0	0
2003	0	6.9	0.3	2.5	34.7	143.1	225.3	223.3	221	54.8	0	0
2004	0	0	11	50.9	2.5	185.6	320.7	207.5	138.7	90.8	23.2	0
2005	*	*	36.8	18.6	40.6	234.8	261.5	193.3	152.3	27.3	5.6	0
2006	2.6	0	2.3	21.2	219.5	115.9	364.6	284	231.2	156	0	0
2007	1.5	0	5.5	77.9	184.5	277.9	232.9	281.3	155.9	55.8	25.3	0
2008	21.8	0	0	82.7	136.6	206.8	308.1	274.3	142.5	23.9	33.8	0
2009	0	5.7	35.8	58.5	0	250	282.4	325.6	0	45	7.7	58.9
2010	9.5	0	12.1	26.7	87.2	278.6	279.5	217.1	78.7	10.3	0	9.7
2011	0	0	0.5	10.1	154.2	122.5	308.6	312.9	135.9	61.7	21.7	0
2012	0	0	2.5	0	121.9	252.4	315.8	291.9	115	65.8	114	5.3
2013	0	0	3.7	5.4	6.7	166.7	397.7	269	100.5	127	11.2	0
2014	0	0	44.2	87.9	182.1	138.8	278.5	217.3	195.2	69.5	14	0
2015	0	0	41.6	15.8	169.1	102.8	246	277.3	207.5	71.2	46.3	0
2016	0	0	31.8	20.3	204.1	165.4	356.2	257.1	81.1	98.7	17.3	0

Appendix 5 Rainfall data at Tikildingay station

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2005	0	5	41.5	17	98.7	311	409.7	528	388.4	77.1	28.7	0
2006	0	0	0	37.9	206.9	430.1	560.8	617	485.9	277.3	0	*
2007	*	0	13.9	49.5	200.8	429.7	549.1	1004.3	260.5	194	3.6	0
2008	18.1	0	0	116.5	174.4	434.1	611.1	500.3	342.4	31.9	4	*
2009	0	0	5.3	68	132	117.1	614.5	601.4	502.6	60.9	0	0
2010	0	0	7.7	0	65.6	340.4	689.5	742.5	341.5	97.7	9	0.1
2011	0	0	22.3	19.2	277.3	263.9	448.1	702.2	234.8	151.9	37.8	*
2012	0	0	6	0	114	392.8	785.4	840.8	367.5	114.2	61.6	16.7
2013	0	0	8.1	7.1	62.3	332.7	524.5	564.8	364.6	252	27.7	0
2014	0	30.5	48.2	58.2	304.7	154.7	353.8	945.1	529.4	255	13.1	0
2015	0	0	15	15.5	154.5	253.1	347.8	913.3	222.8	89.5	89.2	10
2016	0	0	28	0	221.7	307.9	752.9	694	364.6	0	9.4	0

Appendix 6 Temperature, Relative Humidity, Wind Speed and Sunshine hour

Maximum Minimum and Average Monthly Temperature of the stations													
station	Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	Max	27.9	29.4	29.6	30.1	28.65	25.57	22.96	23.07	25.13	26.7	27.4	27.5
	Min	11.7	13.4	14.4	15.86	15.74	14.37	13.65	13.51	13.07	13	12.4	12.1
	Mean	19.8	21.4	22	22.98	22.19	19.97	18.3	18.29	19.1	19.9	19.9	19.8
Ambag iworgis	Max	18.6	20.9	21.9	22.05	21.8	20.47	18.74	18.9	17.95	19	18.8	19.2
	Min	6.61	7.95	8.83	9.239	9.425	9.502	8.826	8.891	9.001	8.02	6.51	5.76
	Mean	12.6	14.4	15.4	15.64	15.61	14.99	13.78	13.9	13.48	13.5	12.7	12.5
Maksegnit	Max	25.7	27.2	31.8	31.28	30.32	27.54	24.39	24.68	26.63	28.2	28.6	26.4
	Min	11.2	13.2	15.2	15.81	15.7	14.7	14.34	14.17	13.68	13.2	12.7	11.5
	Mean	18.4	20.2	23.5	23.54	23.01	21.12	19.36	19.43	20.16	20.7	20.7	19
Aykel	Max	25	26.6	27.8	27.96	25.67	22.51	20.13	20.57	21.72	22.7	24.2	24.6
	Min	13	14.3	15.3	15.8	14.98	13.18	12.28	12.24	12.7	13	13.1	12.9
	Mean	19	20.5	21.6	21.88	20.33	17.84	16.2	16.41	17.21	17.9	18.6	18.8

Relative Humidity												
Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	36.59	30.83	31.51	34.17	45.76	66.05	76.34	77.10	68.42	54.88	46.42	40.10
Aykel	39.78	31.82	35.91	34.47	61.29	61.37	85.41	87.12	84.25	75.92	55.58	46.34
Avg.	38.19	31.33	33.71	34.32	53.52	63.71	80.87	82.11	76.33	65.40	51.00	43.22

Wind speed												
Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	1.3048	1.435	1.44	1.49	1.573	1.578	1.102	1.088	1.128	1.064	1.08	1.16
Aykel	2.4597	2.669	2.8	2.69	2.605	2.526	2.202	2.079	1.97	1.878	1.93	2.15
Avg.	1.8822	2.052	2.12	2.09	2.089	2.052	1.652	1.583	1.549	1.471	1.51	1.65

Sunshine hour												
Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Gondar	9.1774	8.962	7.65	7.75	6.934	4.281	4.137	4.796	6.432	7.503	8.63	8.56

Aykel	9.3224	9.171	8.25	8.09	6.837	4.906	3.126	3.443	4.692	6.729	8.73	8.52
Avg.	9.2499	9.066	7.95	7.92	6.885	4.594	3.632	4.119	5.562	7.116	8.68	8.54

Appendix 7 Stream flow data

Montly runoff data of Megech River in million m3													
year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	0.06	0.08	0.05	0.16	0.12	1.14	23.55	36.72	26.52	3.11	1.08	0.72	93.31
1981	0.42	0.27	0.25	0.40	0.71	0.62	7.44	49.53	7.57	1.04	0.71	0.35	69.30
1982	0.23	0.12	0.12	0.05	0.17	0.24	1.21	15.94	5.44	0.70	0.32	0.17	24.70
1983	0.09	0.12	0.05	0.11	0.41	1.09	5.44	22.89	14.46	1.55	0.84	0.54	47.58
1984	0.13	0.05	0.02	0.03	0.18	4.81	10.16	14.64	6.66	0.85	0.29	0.00	37.81
1985	0.07	0.05	0.03	0.11	0.31	0.23	5.61	28.45	10.30	1.34	0.58	0.14	47.22
1986	0.07	0.06	0.04	0.05	0.05	2.51	18.34	34.61	10.99	2.54	0.92	0.53	70.70
1987	0.27	0.12	0.07	0.06	0.93	2.41	4.21	17.82	4.05	1.17	0.59	0.18	31.87
1988	0.08	0.10	0.03	0.02	0.06	0.32	24.21	36.99	10.11	4.30	1.74	0.51	78.46
1989	0.26	0.09	0.15	0.17	0.60	2.11	4.41	16.17	3.58	0.04	0.12	0.04	27.75
1990	0.12	0.06	0.03	0.03	0.11	0.60	11.05	13.82	7.36	1.17	0.42	0.26	35.04
1991	0.13	0.09	0.12	0.21	0.10	2.74	4.46	19.04	4.07	1.35	0.41	0.08	32.80
1992	0.10	0.06	0.10	0.41	0.25	0.41	7.69	19.51	14.98	2.53	1.27	0.45	47.75
1993	0.31	0.25	0.25	0.29	0.80	3.44	8.92	24.22	13.86	4.40	1.24	0.30	58.28
1994	0.32	0.15	0.09	0.09	0.39	2.53	11.71	39.96	12.52	1.53	0.88	0.47	70.64
1995	0.25	0.17	0.16	0.15	0.93	3.50	12.02	43.84	6.57	0.47	0.16	0.09	68.29
1996	0.03	0.01	0.01	0.19	1.49	11.53	15.27	33.23	7.82	2.06	0.99	0.48	73.11
1997	0.30	0.20	0.19	0.19	1.08	6.01	22.80	19.33	4.30	2.88	1.59	0.51	59.37
1998	0.20	0.15	0.22	0.19	0.38	2.09	24.88	44.74	15.50	5.78	1.07	2.04	97.24
1999	1.77	1.45	1.39	1.50	3.03	2.85	11.99	35.81	18.19	10.79	6.17	4.63	99.57
2000	3.80	2.68	2.83	4.01	3.79	5.20	12.71	26.66	12.41	8.79	4.66	3.65	91.19
2001	3.09	3.25	4.45	4.55	5.51	2.58	22.06	43.07	9.56	2.74	1.46	0.56	102.86
2002	0.37	0.22	0.22	0.14	0.28	1.31	17.91	18.92	7.32	2.66	2.09	1.66	53.10
2003	1.32	1.31	1.25	1.12	1.08	6.50	16.76	38.88	11.78	4.84	2.84	2.35	90.04
2004	1.59	1.52	1.41	2.09	1.42	4.03	20.81	33.92	9.10	6.05	3.66	2.96	88.56
2005	2.54	2.34	2.76	2.39	2.44	16.10	14.57	32.81	18.83	8.00	5.01	3.63	111.41
2006	3.12	2.93	2.81	2.86	4.24	2.18	23.81	58.73	24.04	10.51	7.06	5.31	147.60
2007	4.51	3.86	4.05	4.47	5.13	6.57	34.51	75.40	31.58	11.08	7.86	6.41	195.43
2008	6.34	5.00	5.10	5.90	9.16	26.07	34.17	74.44	30.85	12.37	0.00	0.00	209.41

2009	0	0	0	0	0	0	46.7	62	34.1	0	0	0	142.9

Appendix 8 Ground Water source inventory Data

WELL Name	Easting	Northing	Elevation	SWL	SWL elv.	DWL	Depth
China well 1	332300	1394139	2107	6.3	2100.70	36.4	69.5
Chian well 2	332461	1394631	2113	7.4	2105.60	89.3	120
China well 4	332597	1394758	2121	5.97	2115.03	36.5	90
Angereb 1	335026	1397495	2170	10.77	2159.23	28	108
Angereb 2	334986	1397091	2161	17.05	2143.95	61.6	86
Angereb 3	335144	1395982	2134	6.05	2127.95	53	65
Angereb4	335236	1395580	2127	0.8	2126.20	149	174
Angereb 5	334934	1396639	2150	18.8	2131.20	23.2	72
Angereb 6	335160	1398499	2198	13.8	2184.20	24.8	56
Angereb 7	334673	1393121	2061	0	2061.00	18	120
Y-1 Keha Val.	332240	1394903	2128	13	2115.00	74	92
Shinta 1	330233	1390128	2070	3.6	2066.40	32.3	54
Shinta 2 /GTW 3	330279	1391160	2095	6.8	2088.20	88	140
Shinta 3	329980	1391692	2112	3	2109.00	18.6	80.9
Azezo 6	330233	1390128	1946	3.9	1942.10	32.3	54
Azezo 7	329725	1386589	1952	5.4	1946.60	35	58
Angereb EW 1	335045	1396219	2143	5.4	2137.60	33.2	53
Angereb NW1	333085	1391110	2023	8.4	2014.60	119.6	141
Angereb NW2	333566	1391524	2029	0	2029.00	49.39	164
Angereb NW3	333846	1391778	2035	12.5	2022.50	49.39	173
Angereb NW4	333995	1392223	2044	9.89	2034.11	133.1	172
Angereb NW5	334483	1392668	2074	42.7	2031.30	75.12	172
Angereb NW6	334785	1393410	2072	73	1999.00	90.62	172
Azezo TW 1	328605	1383715	1978	24	1954.00	76.47	107
Azezo TW 2	329204	1384103	1972	12.5	1959.50	133.5	150
Azezo TW 3	330914	1386610	1980	10	1970.00	98.6	150
Azezo TW 4	328216	1383658	1979	24.5	1954.50	65.8	100.7
Angereb TW5	334274	1392754	2057	48	2009.00	51	109
Angereb TW6	335444	1394001	2089	37.8	2051.20	39.77	95
DBW 5	328279	1383057	1953	31.8	1921.20	77.3	188
DBW 6	328399	1382893	1946	26.5	1919.50	179.6	210
DBW 7	328253	1383050	1952	8.8	1943.20	109.9	175
DBW 8	328278	1382579	1964	13.6	1950.40	143.9	180
Tikildingay1	334114	1402016	2288	24.2	2263.80	143.05	168
Tikildingay2	333989	1402312	2315	15.25	2299.75	46.82	157
Tikildingay3	334517	1401409	2268	9	2259.00	147.1	182

NB1	333010	1382150	1965	2.6	1962.40		90
NB2	332724	1382496	1978	2.6	1975.40		80.15
NB3	332650	1382650	1887	4.25	1882.75		85