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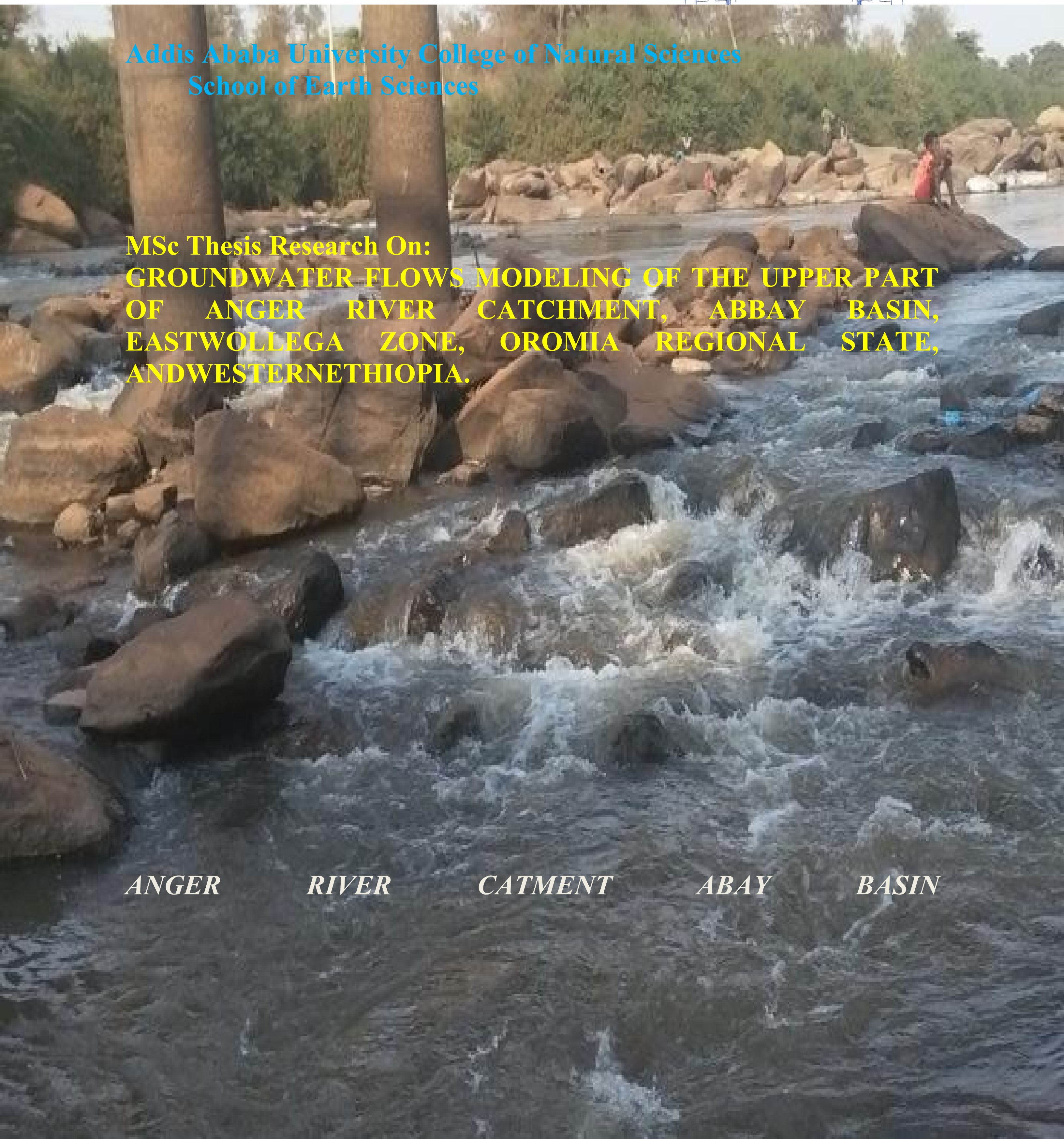

Addis Ababa University College of Natural Sciences

School of Earth Sciences

MSc Thesis Research On:

GROUNDWATER FLOWS MODELING OF THE UPPER PART OF ANGER RIVER CATCHMENT, ABBAY BASIN, EASTWOLLEGA ZONE, OROMIA REGIONAL STATE, ANDWESTERNETHIOPIA.

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GROUNDWATER FLOWS MODELING OF THE UPPER PART OF ANGER RIVER CATCHMENT, ABBAY BASIN, EASTWOLLEGA ZONE, OROMIA REGIONAL STATE, AND WESTERN ETHIOPIA.

THEISIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDISABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMEMTS FOR THE DEGREE OF MASTER OF SCIENCE IN HYDROGEOLOGY.

BY ASNAKECH GOSHUU
STREAM: HYDROGEOLOGY

ADVISOR: PROFESOR TENALEM AYENEW
CO-ADVISOR: GADDISSA DAYASSA (PHD)

ADDIS ABABA **MAY 2019**

Declaration

I would like to declare that this thesis is my original work that means not done or presented by other person and all sources of data used for this thesis accordingly acknowledge. Also complies with as the rule and regulation of the university with respect to the originality.

Asnakech Goshuu

Signature_________________.

School of graduate studies

May 2019

Addis Ababa University

School of Graduate Studies

This is to certify that the thesis prepared by Asnakech Goshuu entitled Groundwater Flow Modeling of the Upper part of Anger River Catchment Abbay Basin. Submitted in partial fulfillment of the requirements for Degree of Master of science (Hydrogeology) complies with the regulations of the University and meets the accepted standards with respect to Originality and quality.

Signed by Examining Committee.

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ABSTRACT

The problematic area selected is finding in the East Wollega Zone, Western Ethiopia called upper Anger River Catchment of Abay Basin. The total surface area of the catchment is 7159.21 Km^2. The purpose of this study has to understand the Regional Groundwater flow and the response of groundwater system to different scenarios with the help of numerical groundwater flow modeling. One layer and unconfined Aquifer system simulated under steady state flow condition by using MODFLOW.

The boundary of the study area delineated from ASTR DEM with the 30m resolution by using Arc SWAT (Soil Water Assessment tool) software. The input parameters for the model gathered from the well completion reports. SWAT software used to calculate the regional recharge rate of the upper Anger River Catchment. Annual recharge to the deep and shallow aquifer calculated by the model is 388.84 mm/year.

The general Groundwater flow direction is from the north- east to south- west by following the topographical trend and structural orientation. The model calibrated by Trial and Error method using groundwater contours produced from different heads collected from 7 observation wells. The calibration shows that about 97.75% of the simulated heads with the calibration targets and the overall water of the simulated model result show 8889163.3130. Model sensitivity analyses conducted with changing of the hydraulic conductivity and recharge the model is more sensitive to them. Change in the hydraulic head by 20%, 30%, 40%, 50% result for the RMSE changes in the head from the calibrated value. In addition, the same change happens in the recharge like the difference in hydraulic head.

The result of the numerical simulations indicates while increasing well withdrawals by 25%, 50%, 75% and 100% respectively it also resulted to the change of RMSE heads by 8%. Water Budget results of the model shows that the reviled groundwater recharge comprise by 0.5% and 97.75% by river leakage of the total water input for the total study area. The spatial distribution of groundwater decline is limited towards the river. However, there is hydraulic connection between the sediment bed and Anger River.

Keywords: Anger catchment, Agro ecological zone, Water balance, Nekemte, Ethiopia.

1. INTRODUCTION

1.1 Background

To satisfy the needs of all lives on the Earth, Groundwater stored in the aquifer extracted through well and use for different purposes, such that for domestic, Industrial and Agricultural continuously. This means water is an essential ingredient for all life forms on Earth. According to Seifu Kebede , (2013) Groundwater is paramount importance for the supplement of available surface water resources in providing drinking water to population and for socio economic development (agriculture, livestock, industry, tourism). Groundwater occurs in a wide range of rock types and usually requires little or no treatment; therefore, it is often consider as the cheapest and simplest water supply option (Thangarajan, 2007).Groundwater defined as down ward flow of water reaching the water table following an addition of groundwater.

In fact, groundwater is simply the subsurface water that fully saturates pores or cracks in soils and rocks. Most groundwater is contained in and moves through the pore spaces between rock particles or in rock fractures and fissures. When the pore spaces in sand and gravel became saturate with water, the water is call groundwater. Groundwater has replenished by precipitation and depending on the local climate and geology, unevenly distributed in both quantity and quality.

When it rains, some of the water runs off to streams, some evaporates, and some recharges aquifers .Groundwater occurs nearly everywhere in the world at depths ranging from land surface to about 2000ft below the land surface. Below that depth, most pores and cracks are close because of the weight of over lying rocks. Most groundwater is present within 300ft of the land surface. After the water requirements for plants and soil satisfied, any excess water will infiltrate the water table, which is top of the zone below which the openings in rocks saturated. Below the water table, all the openings in the rocks are full of water that moves through the aquifer to streams, springs or well and Groundwater stored and transmitted by aquifer (Moore,*et al.,* 2002).

Regardless of the economic and political develop, three major themes are common everywhere: (1) competition for groundwater resource between Agriculture (farmers), growing urban population, and industry, (2) depletion of these resources by all three; and (3) contamination of the resources by all three (William, 2009). Groundwater systems affected by natural and human activity; require targeted and ongoing management to maintain the condition of groundwater system within acceptable limits while providing desired economic and social benefit (Barnett *et al*., 2012).The over development of groundwater resources leads to the decline of water level because of this socio-economic and environmental degradation come. It is imperative to manage the groundwater in an optimal manner. Management schemes can evolve, only if ground water potential is assess in more realistic manner.

Effective groundwater management requires, firstly, a good understanding of the aquifer system, secondly, practical measures to control abstraction, thirdly increase groundwater resource through artificial recharge. It is therefore essential to quantify the response of aquifer under the study of different input output stresses (Thangarajan, 2007). The most important ground water flow source and sink system are pumping or injection wells (i.e., point source / sinks).These are considered internal flow of water (fluxes). Pumping lower the hydraulic potential at the well and in its immediate vicinity, creating cone of depression and the result of decreasing in hydraulic potential toward the well is the flow of water to the well. Injection does result in flow away from the well (kramer, 1990).

According to National Water Commission Groundwater is easily extracted through wells and how much can be extracted depends on the water level (NWC 2005). Groundwater management and policy decisions must based on the knowledge of past and present behavior of the groundwater system. Proper understanding of natural recharge and groundwater flow system through groundwater flow modeling is important for understanding the effect of pumping in the area and groundwater management by measuring water levels in the subsurface, the direction of groundwater flow can be determined (Barnett *et al.,* 2012). The groundwater flow system for the upper Anger River Catchment Abbey Basin has not explored and simulated and there is no much guidance on how to deal with the complicated geological conditions, boundaries and the relationship between the groundwater and rivers. Groundwater simulation modeling is a powerful management tools for study such problematic areas. Most of the present investigations related to groundwater modeling are carrying out by MODFLOW.

1.2 Statements of the Problem

The sustainable use and management of groundwater resources is now a great challenge for many countries of the world. Recently groundwater modeling has been an effective way to address this challenge. Although in the proposed study area (Upper Anger River catchment) which find in the East Wollega Zone, the consumption of groundwater is growing continuously and increasing being as the main source of water supply for urban and rural community. Generally groundwater development and management needs knowledge of groundwater Potential and flow system. However, for the proposed study area (upper Anger River catchment) previously groundwater flow system has not been explored, simulated, and there is no control or management of groundwater resources. Therefore, developing groundwater model is essential to promote sustainable groundwater resource development and management scheme in the proposed study area (Upper Anger River Catchment) east Wollega Zone.

1.3 Objective

1.3.1 General Objective

The Major objective of the study is to have detail understanding of regional Groundwater Flow system in the upper Anger River Catchment Abay Basin and develop groundwater management schemes through simulation of regional groundwater flow model in the aquifer as one layer system in the East Wollega Zone, Oromia Regional State, and Western Ethiopia.

Concerning to the General objective the paper, will intend to deal with the following specific objective:

- To understand the Hydrodynamic properties under the steady state flow model.
- To evaluate the water budget of the catchment in identified boundary condition.
- To understand groundwater flow direction in the catchment by mode flow.
- To evaluate the response of the aquifer system for different possible scenario of groundwater consumption and altered Groundwater recharge in the study area.
- To identify the effect of future stress on groundwater resource and make prediction under various abstraction scenario for selected study area.
- To calibrate steady flow model by using observed water level points and map of the study area.

1.4 Significance of the Study Area

The area selected for this work is essential to describe groundwater flow system for the selected catchment; it will contribute good understanding about Groundwater flow system and its response of future stress in changing of environmental condition. Also used as reference for Governmental organization, nongovernmental organization and for students who have interested to do around this area. Furthermore, it will give future ideal input for groundwater resource development and management processes and will set the basic strategies, which can be use for the environment and socioeconomic development.

1.5. Approaches and Methodology

1.5.1 Approaches

The study will be progressed in different phases; in order to come up with the proposed objective of the study, the following three approaches helps; at this stage, all data collection process will be complete. Firstly Desk study or pre fieldwork; Review of previous work, Literature review related to the principles of groundwater flow modeling and other works. Reports of the study area were review to get insight about the problem and define the direction of the research Collection and organization of different relevant data such as (hydro geological, geological, topographic maps, Meteorological data, and hydrological data) and Acquisition of necessary equipment for fieldwork.

Secondly, Fieldwork during this fieldwork, clearly understand what the condition of the field looks like for the development of the conceptual models. Collect primary data from the field such as measuring different groundwater level using deep meter, Understanding the hydro geological and geological setup, Collection of well completion and pump test data, taking the readings of borehole locations and elevation using GPS and Field verification of the study area and determination of physical boundaries. Thirdly, select the appropriate computer code (MODFLOW); systematically analyze the conceptual model to develop the ground water flow model. Designing the gird, selecting time steps, setting boundary and initial conditions, and inputting reasonable aquifer parameters, Interpretation of field collected hydro geological, meteorological and hydrometric data to estimate model input parameters (estimation of recharge and hydraulic conductivity),Data processing, analysis, Model development and interpretation of the main activity.

1.5.2. Methodology

Two models shall be use to achieve the above-proposed objective; these are SWAT and Modflow.

i. MODFLOW(modular finite-difference groundwater flow model).

MODFLOW is computer program developed for U.S. Geological survey. This is versatile code to simulate groundwater flow in multi-layer porous aquifer. In MOD FLOW, cells used to simulate boundary conditions are group into two categories-"constant head "cells and "no-flow" cells. Constant-head cells are those for which the head is specify for each time, and the head value does not change because of solving the flow equations (Harbaugh, 2005). MODFLOW works on many different computer systems ranging from personal computers to supercomputers, for purpose of understanding the characteristics of groundwater flow and the aquifer storage. The input files for MODFLOW may vary depending up on the version of the model, on the model set up and user's preference. The common ASCII files use for MODFLOW recharge, Initial head and prescribe, boundary condition, Transmissivity (hydraulic and layer thickness) Top layer, Bottom layer, River (drains) and Wells. Modules categorized into packages, each packages deal with specific future of hydrologic system that is to be simulate, division of MODFLOW into modules permits the user to examine specific hydrologic features of the model independently (Kumar, 2014).

ii. SWAT (Soil and Water Assessment Tool)

SWAT (Soil and water Assessment Tool) is catchment or river basin scale model developed for the USDA Agricultural Research Service (ARS) (Neisch *et al.,* 2001). It is physically based model able to estimate the impact of land management practices on water, sediment and agricultural chemicals on a sub-catchment and land use unit scale over long periods. SWAT is a popular model among many watershed hydrologist who are interested in studying the impact of agricultural activities and land use management in the overall watershed health including stream flow and water quality.

One of the most essential components of an efficient groundwater model is the accuracy of recharge rates within input data. Groundwater recharge rates show spatial-temporal variability due climatic condition, land use, soil characteristics and hydro geological heterogeneity. HRUs are use to describe the spatial heterogeneity in a watershed Soil and Water Assessment Tool (SWAT) was used for discharge estimation for the catchments. SWAT requires four main data files to simulate the discharge; these are Digital elevation Model (DEM) data, land use data, soil data and weather data. The main objective of Hydrological model using SWAT is to quantify the groundwater recharge of the study area.

In general, Groundwater flow modeling protocol and the following general methodology was used to fulfill the above proposed objective and the simulation processes in this work are summarized in figure **1.1.**The protocol for modeling includes build conceptual model, formulate mathematical model and select modeling code, model design, calibration, sensitivity analysis, and finally forecasting and report preparation. In developing a conceptual model, Hydro geological data was organized, analyzed, and synthesized with the help of a database tool i.e. GIS. The model was design, which involves translating the conceptual model into a numerical groundwater flow model by designing the grid/mesh, setting boundaries, assigning values of aquifer parameters, and hydrologic stresses. Model fit was assessing through history matching with field-collected data.

The purpose of calibration has established to compare model results with the field-measured heads. It was due by trial-and-error adjustment of parameters. Forecasting simulations used the calibrated model to forecast the response to future events. Estimates of anticipated future hydrologic conditions (recharge rates and pumping rates) were use to perform the forecast. In this work, the model was limited to steady state numerical groundwater, forecasting change of the head with time has not made.

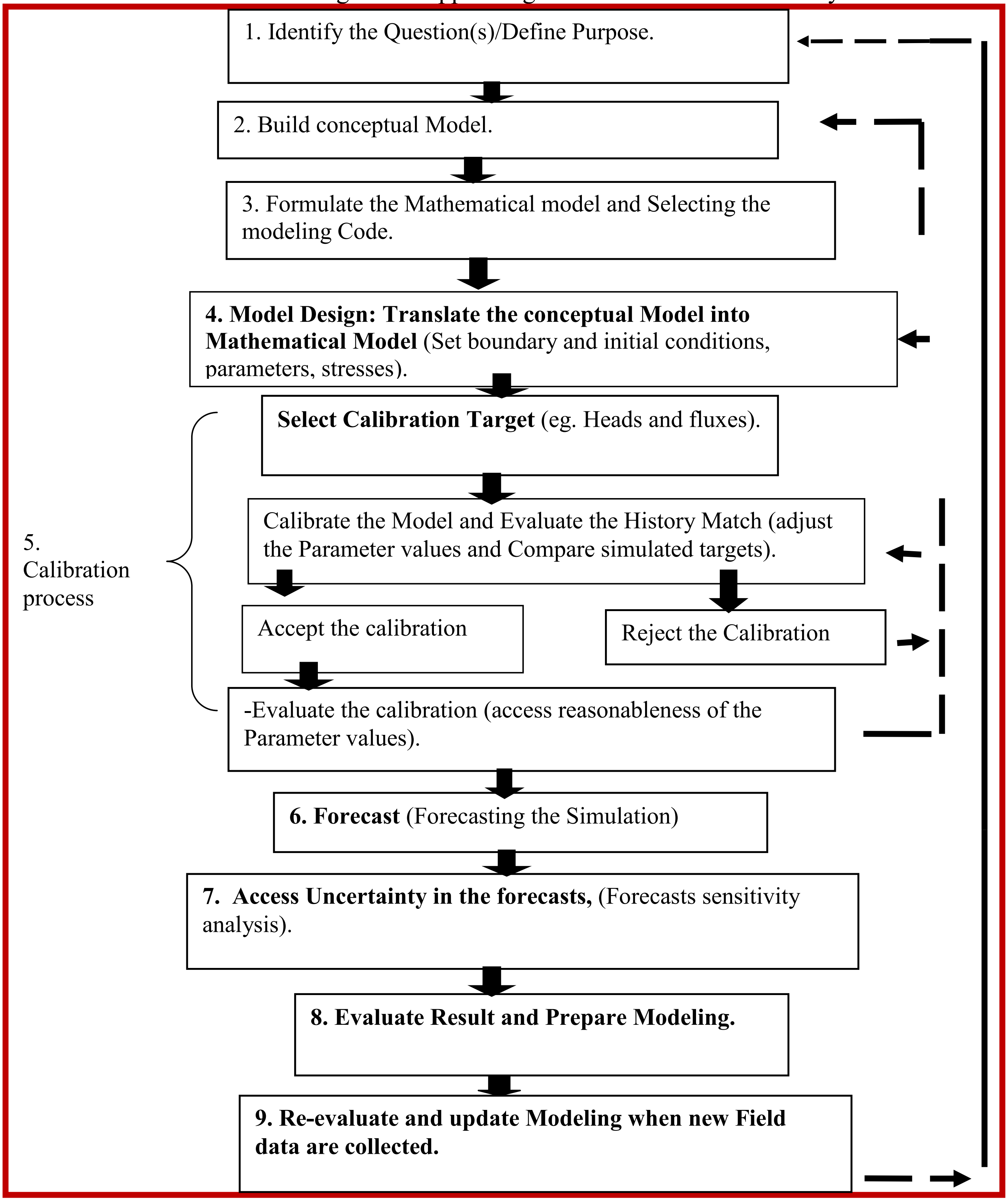


Figure 1:1 Work flow for groundwater flow modeling (adopted from; Anderson, *et, al*., 2015

1.5.3. Material

There are different materials, which are use for the research activity. Those materials are required to achieve proposed goal.

Deep meter measure the water level of representative well in the study area to know water level.

Geological and Hydro geological map, with available and necessary scale,which are important for the study area hydro geological information.

GPS will be used to locate specific location of well.

SRTM DEM and Google earth, which help to identify the study area boundary and conceptualize the groundwater boundary condition.

Various computer software such as :-(MODFLOW, Arc GIS 10.5, Google Earth, Arc SWAT, Envi, Global Mapper17, Rockworks, Geomantic 2018).

2. LITERATURE REVIEW

Groundwater models are the simplified representation of the subsurface aquifer systems. Groundwater flow in the aquifer may be simulated as confined, unconfined or the combination of both. A model is any device that represents an approximation of afield situation. Physical models such as laboratory sand tanks simulate groundwater flow directly. Whereas mathematical model simulates groundwater flow indirectly by means of a governing equation throughout representing the physical processes that occur in the system and together with the equations that describe heads or flows along the boundaries of the model or boundary conditions (Anderson and Woessner.2002). Groundwater Models are valuable tools, which use to understand the movement of water and chemicals in the subsurface.

The purpose of modeling in this study is to investigate the patterns of flow in both Shallow and deep aquifers designed to answer specific question or set of question commonly performed, to forecast the effects of some future action or hydrologic condition. Faurthely models are also use to recreate past conditions (hind casting) and as interpretive tools. The powerful groundwater model is one that quantitatively represents heads in space and time in simplified representation of the complex hydro geologic conditions in the subsurface. All process-based on models of groundwater flow are derived from the two basic principles; conversation of mass, which states that water is not created or destroyed, and Darcy', which states that groundwater flows from higher to low potential energy (Anderson *et,.al* 2015).

Properly applied groundwater model result, can help in decision making about the site condition. Model results can be used to supplement knowledge of site conditions but cannot be replace the decision making process. Reilly and Harbaugh (2004) identify five broad classes of problems that may initiate a hydrology study involving groundwater modeling: basic understanding groundwater systems; estimation of aquifer properties; understanding the present; understanding the past; and forecasting the future.

Groundwater models provide additional insight into the complex system behavior and can assist in developing conceptual understanding. Furthermore, once they have been demonstrate reasonably to reproduce the past behavior, they can forecast the outcome of future groundwater behavior, support decision making and allow the exploration of alternative management approaches. Groundwater flow model simulates hydraulic heads and ground water flow rates within and across the boundaries of the system under consideration and it can provide estimates of water balance and travel time along flow paths (Kumar, 2013).Groundwater resource issues involving primarily water quantity are largely addresses by groundwater-flow models. Groundwater-flow model is a necessary precursor to the development of a ground water-transport model. In MODFLOW, the heads computed for the end of each time step are use is initial trial values of head for the succeeding time step (Harbaugh , 2005).

Groundwater flow models used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface. Fate and transport models estimate the concentration of a chemical in groundwater beginning at its point of introduction to the environment to the location down gradient the source. Fate and transport models require the development of calibrated groundwater flow model of at a minimum an accurate determination of the velocity and direction of groundwater flow that has based on field data. Models are conceptual description or approximations that describe physical systems using mathematical equations; they are not exact description of physical system or processes (Richler *et.,al* 2002).

Models have become an essential tool in the modern world of water management. It use extensively and play an important auxiliary role in fulfilling the core tasks of water management, in policy preparation, operational water management and research, and in the collection of basic data. The standard water framework is intend to provide water managers with an integrated system in which models and other information systems can easily couple or decouple, depending on the type of problem requiring attention. However, when model develop in the flexible manner, also increase the risk of expert use. This may the result of errors in the software or careless treatment of input data, insufficient calibration and validation, working outside the scope of model, in accurate model hypothesis, this can have far-reaching consequences, certainly when considering the important role played by models in modern-day water management (R.H. van Waveren *et.al*., 1999).

SWAT (soil and water Assessment Tool) is catchment or river basin scale model developed for the USDA Agricultural Research Service (ARS) (Neitschet al., 2001).inputs for the Land Phase of the hydrologic cycle, Climate: Daily Precipitation, Solar Radiation, Wind Speed, Max /Min Air Temperature and Relative Humidity (from observed data or generated using "Weather Generator"),

Previously the study area has been a major interest for local and foreign researcher and organization, thus a number of essential works carried out over the hydrology, Hydrologeology, climate, geological structure, and land use of the basin. However, in the study area there is no work done regarding to groundwater flow model, as result of lack for public awareness and profession about sustainable groundwater resource use and management schemes, this make gap in groundwater resource development and management skill. Hydrogeology and Geological structure of the east Wollege zone (NC37-9) was studied by; (Shayaq,*et.,al* 2015) Geologic structures are formed by the rock deformation at contraction and non-contraction are responsible for groundwater occurrences.

The deformation events leading to the deformation distinct to the deformation of generation geologic structures are resulted from different tectonic forces acting on the rock resulted for groundwater formation. The displaced people have mostly moved to available areas within the watershed, and have often taken up agricultural activities on steep and marginal areas within the watershed (Sterk,**et al**., 2008).

Kasahunabera, (2008) study recharge estimation for the highlands and lowland parts of Diddessa catchment separately using the soil moisture balance, base flow separation and water balance methods. The results of the study are 380mm, 312mm, and 336mm respectively. According to (Mengesh *et al,* 1996) Western highlands, early basaltic flows represented by mokononen basalt and late flows are Jimmavolcanic. According toTeklu Erkossa and Gezahn Ayale,(2003) the Major cause of land degradation and nutrient depletion are soil erosion, intensive Tillage, exhaustion of nutrients by crops and deforestation.

3. GENERAL OVER VIEW OF THE STUDY AREA AND HYDROLOGY

3.1. Location and Accessibility

The study area selected for this research is Administratively Located in East wollega zone Oromia Regional state, of Western Ethiopia at distance of 399km, from Addis Ababa. And can be reached from Addis-Holeta- Ambo-Bako-Nekemte on the main asphalt road and divert to the North along weathered gravel road and pass through uke town and go straight forward to see the specific location of study area.

The area characterized by subtropical (Weina-Dega) climatic zone and found in the highland part of Ethiopia. Geographically, the study area is bounded between 9°0'00" to 10°0'00"N Latitude and 36°15'00" to 37°15'00"E Longitude. The Elevation varies from 3215m.a.s.l to 942m.a.s.l at the western. The total surface area of the catchment is about 7159.21 Km².There is so many tributaries flowing from highland to low lands. They are following the dendertic pattern. Most of the streams drained from the center of the area to the surrounding.

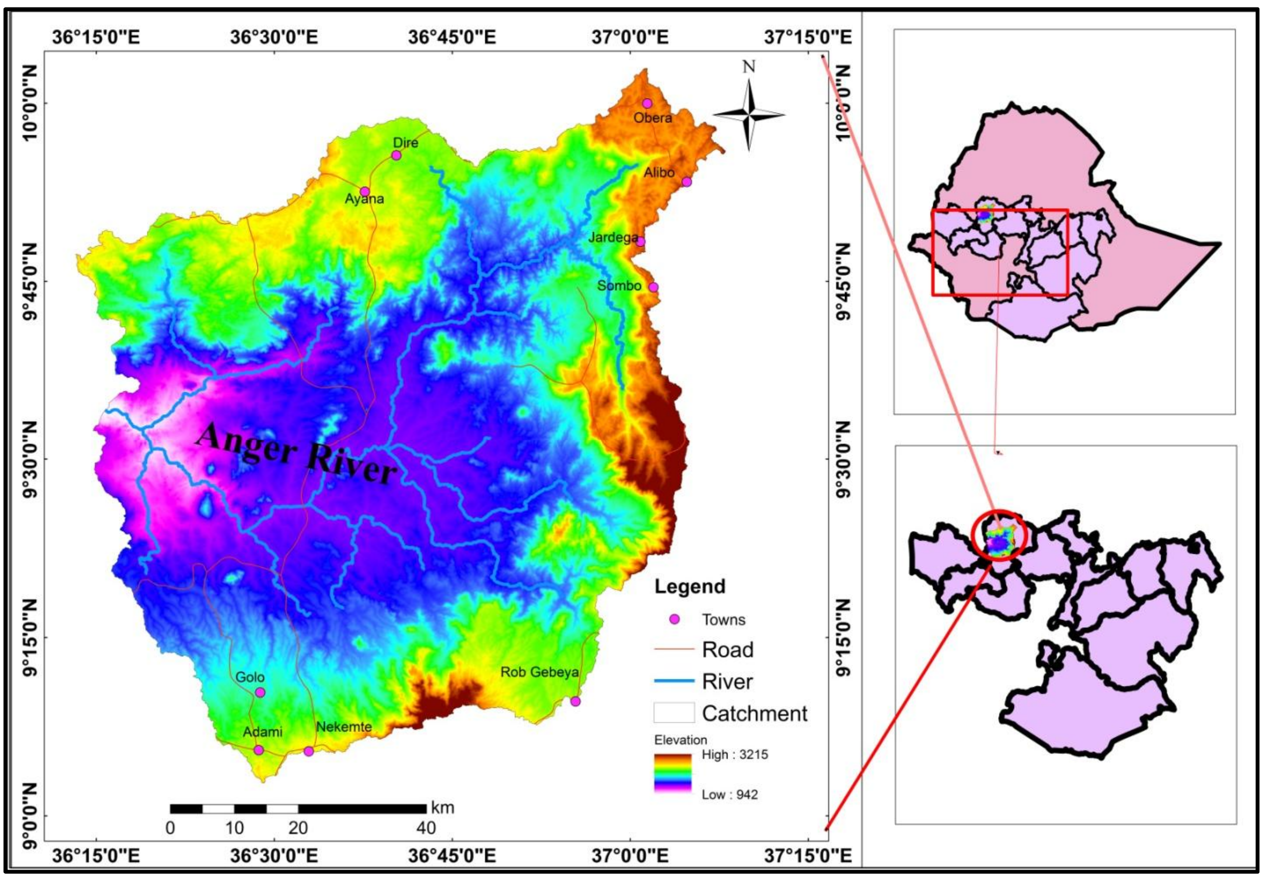


Figure:3.1. Location Map of Study Area.

3.2. Physiographic and Drainage Features of the Study Area

There are two drainage systems in the study area through the Abay (Blue Nile) drainage system in the north and Gibe river drainage system in the south. Rivers like Gibe, Dedessa, Anger and Fincha-a are perennial and mainly used for irrigation. The catchment find in the study area lies in the Abay and Omo river Basin. It is characterize by many flows down streams from the major fault, which is at high elevation (3215m.asl) and at low elevation (942m.asl), found the area with flat topography, and join the in the area where tributaries complete. It has dendrites drainage pattern, which resulted from the structure and volcanic activity.

The study area has a distinct physiographic feature bounded north, south and east by highlands, which forms part of the central highland in the area. The physiographic land features of the study area formed by different activities, such as by depossional processes, volcanic activities, erosion and the underlying geology affected by the structure, found within the area. Mountain Chains characterize the highland regions with steep slope, Komto and Geddo Kara Belbela mountain chain, which extend from the southeastern part of the area to northwest, is the most prominent physiographic feature for good recharge zone in the area .And the valley with gentle slope that show flat land.

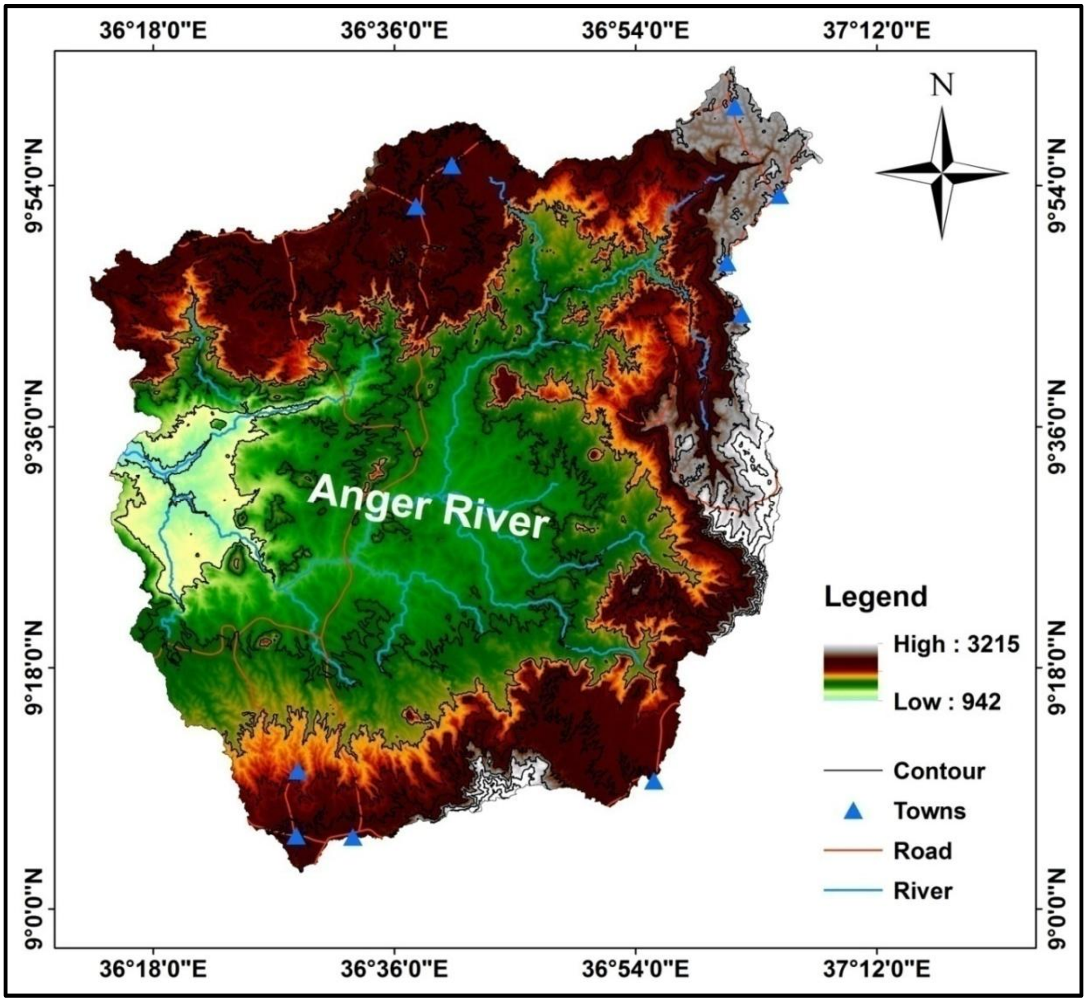


Figure: 2.2.Physiographic and Drainage map of the study area.

3.3. Soil Type of the Study Area

Soil reflects the basic climatic conditions of the area as well as stores the rainwater in its pores before it infiltrates to the grater depths and recharges the aquifer system. Soil waters evaporates in the upper layer is evaporates directly, soil water that is stored in deeper layers absorbed by vegetation roots then transpires to leaves where it is evaporated. The amount of evapotranspiration from soil is control by soil attributes such assoil texture, soil structure and soil moisture content. Therefore, the ability of soil to store and transport water is different for every soil type. The deeper soil has maximum soil moisture than shallow soil moisture, which can supply more water to evaporate. The formation of soil different depends on the parent material and transporting agent. The hydrology of soil determine by the texture of rocks and degree of weathering.

The soil classes used for the soil water balance and ground water recharge evaluation, based on the hydrological property. However, the Anger graben 11% covered by quaternary soil. These soil consists of three types of sediments: black cotton soil, reddish sandy soil and fluvial soil since these sediments are occur mixed with one another , it is impossible to map separately. The black cotton soil is locating mainly on the marshy area around Lake Chomen and on the plain south of Bako town. It is black to dark brown, fine-grained and has clay texture. This type of soil has 25 to 30m thickness, covered by elephant grass. Reddish sandy soil mainly located on the Anger graben. The soil is loose and fine to medium grained. It composes from angular grains of quartz and feldspar. More than six soil types are cover in the study area; however, most of them are finding in the location.

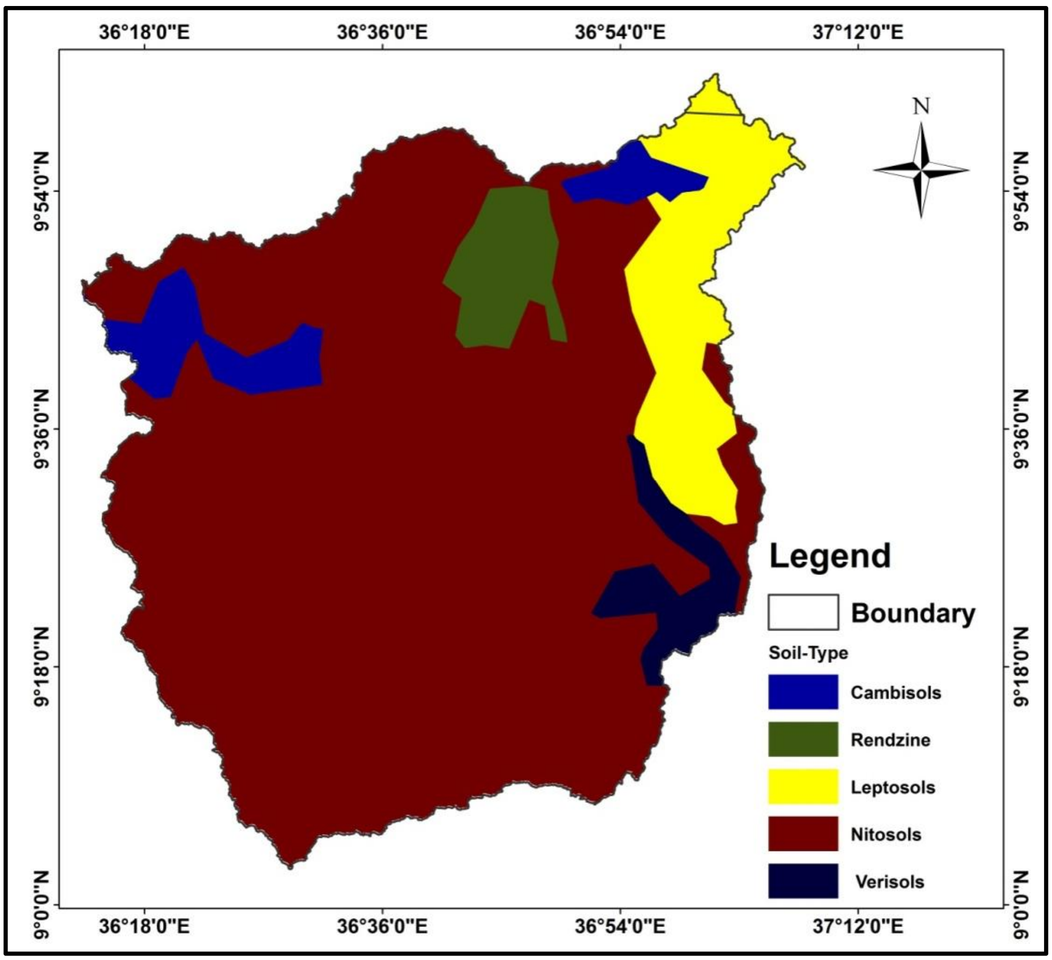


Figure: 3.3. soil type of the study area (FAO 2013).

Cambisols; are found on very steep slopes mainly in association to Nitosols and arcisols. They occur in the humid high rainfall areas. Generally, they have texture of loamy, very fine sand show that the evidence of alteration. This alteration can be in the form of oxidation-reduction process or some evidence of removal of carbonates. Due to their topographical position of cambisols are often shallow and stony. On flatter lands of the area, cambisols can be deep. these types of soil cover wide range of the catchment area .the soil chararacterized by dark to reddish brown clay, fine angular blocky aggregates; non plastic and has well developed fine structures, porous and are well drained. Find in high to medium gentle slope with high rainfall area.

Nitosols: occur in gentle slope lands, flat land. They are clayey, reddish brown to red soils with deep, stable angular to sub angular blocky structure, shiny pad surfaces and very porous. Have stable structure and high water storage capacity. Nitosols are the most inherently fertile of the tropical soils because of their high nutrient content and deep permeable structure. They can exploit for plantation agriculture.

Rendzinas; it is dark, grayish-brown to humus rich. It is one of the soils most closely associated with bedrock type and an example of the initial stage of soil development. The soil of this type contains significant amount of gravel and stones .I t has usually developed beneath grassland formed by weathering of soft rock types: such as carbonate rocks, (dolomite, limestone, marl chalk) but occasionally sulfate rocks (gypsum).

Vertisols: Vertisols known as black cotton soil containing steatite clay characterized by the sticky nature, high water holding capacity and low infiltration. It become hard in the dry season and are sticky in the wet season. These vertisols are finding in the catchment area on colluvial slopes and side slopes and side slopes of volcanoes, on the colluvial slopes and alluvial plains.Generly has dark, montmorillonitic clay soils, which expand and contract with changes in moisture content and consequently show wide vertical carks when dry. Has low permeability.

Leptosols; leptosols are mineral soils less than 10cm thick developed over hard rock. These soils have no agricultural value. They are often referred to as “skeletal soils” because of their extreme shallowness and steepness and steepness’ consequently their high erosion hazard. However, in the study area there is no much of this soil type. It is found in very little amount.

3.4. Land Use and Land Cover classes of the Study Area.

Land use land cover of selected area for this research has greater role in controlling the groundwater recharge. In the study area land use land cover, is categorized depends on certain parameters such as physiographic, climate, Ecological conditions and the interest of the people who live in that area. The area is highly vegetated relative to the other part of the country. The most dominant land use and its coverage is woodland dense, woodland open, Forest, Moderately cultivated, Bush land, State farm, Grassland, Urban and dominantly cultivated. In addition, the scattered Bushes and savanna grasses cover lowland areas; while the escarpment areas covered by thick and long trees like Zigba, Wanza and Tide. However, the land cover has changing from time to time Because of number of population increasing; they need land for the purpose of Agricultural, irrigation and for charcoal. Generally, land use and its coverage have an effect on Groundwater recharge.

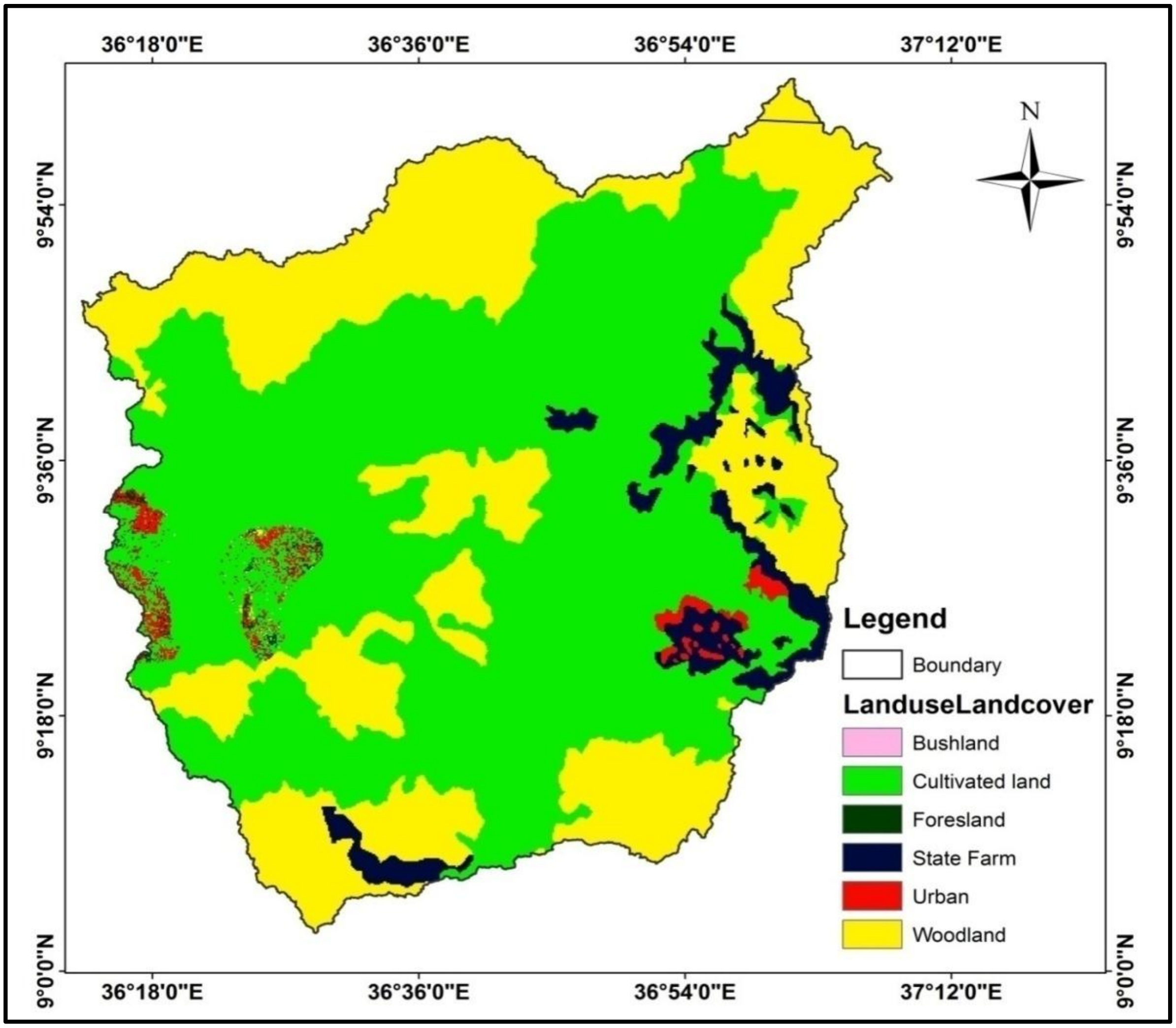


Figure:3.4. land use/Landover map of the study area (modified from Ethiopian Water Resource).

Table 3.1. areal distribution of Land use unit.

Land use/land cover	Bush Land	Dominantly cultivatited	Moderately cultivated	State Farm	urban	Woodland
Area coverage(km²)	254.325	6684.341	4252.227	5793.127	3752.365	4589.761
Area (%)	4.588	33.819	42.312	22.486	32.1587	42.6324

3.5. Slope of the Study Area

Slope is the measure of steepness. The study area covered with erratic topography that makes most part of the area under sloping condition. Eastern, northern, western and some other parts of the study area covered with higher altitude Mountains, such as Komtosilase, Tulu Cali mountain result for the steep slope land surface. Slope of the catchment Developed from the digital elevation model (DEM) of study area, (30m Resolution).

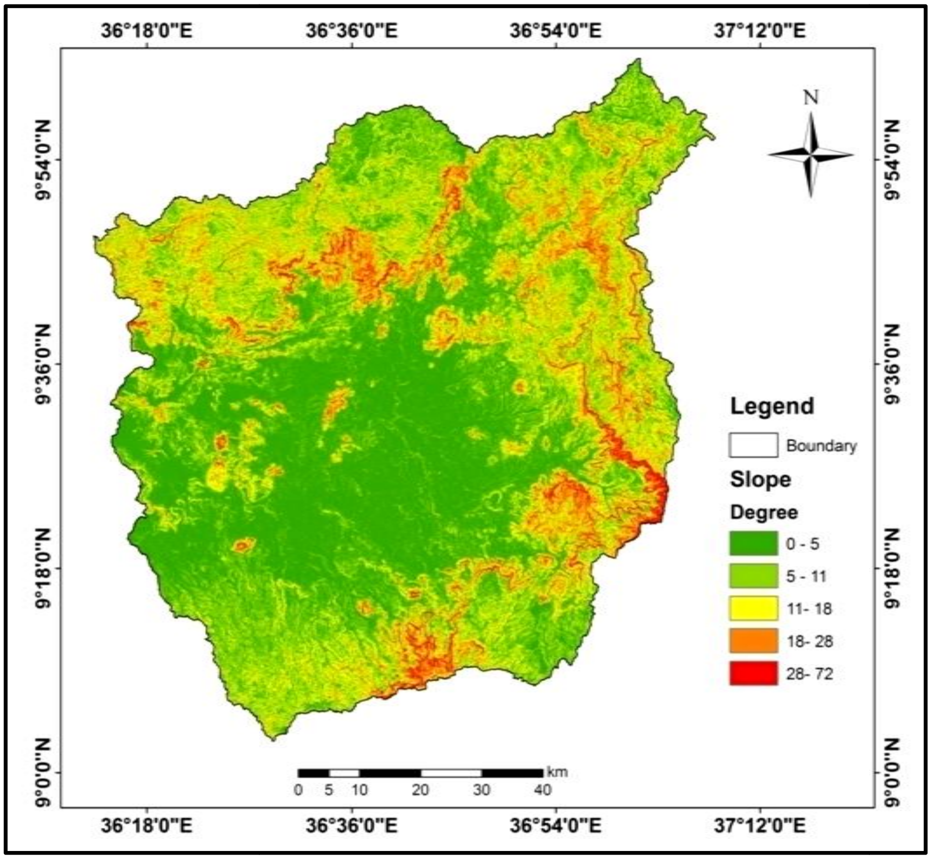


Figure: 3.5. Slope map of the study area.

3.6. Hydrochemistry

The primary purpose of water analyses is to determine the sustainability of water for the proposed use (Tenalem Ayenew and Tamiru Alemayehu, 2001). The Hydro chemical composition of water refers to the quantities of substances present in the given water making up its chemistry. which affect the water from the time it begin as dilute rainfall, infiltrate to the soil above the water table, and pass into the aquifer during groundwater recharge travel, some times over great depth and distance. Water acquires small quantities of solutes from the dust and gases at the time of it falls through the atmosphere as precipitation.

However, it acquires the majority of solutes during it reaches of the land surface. Solutes present in the water increase in concentration because of transpiration and evaporation process. As water, infiltrates through the soil zone, tends to dissolve carbon dioxide (CO_2) gas that exist within the soil, which has large quantities as compared to the atmosphere. Moreover, this carbon dioxide (CO_2) dissolves with the water in the soil zone and from weak acid. This acid promotes the dissolution of minerals present in the soil and rocks. In most of groundwater, only seven solutes calcium (Ca), Magnesium (Mg), Sodium (Na), sulfates (SO_4), potassium (K), Chloride (Cl) and Bicarbonate (HCO_3), make nearly 95% of all water solutes.

In general, the mineralogy of aquifers divided into two groups, these are aquifers that contain reactive mineral rocks like (limestone, dolomite, gypsum, halite, and organic matter) isotopic composition changed significantly with distance along groundwater flow path, reflecting extensive chemical reaction and UN reactive minerals. In the aquifers composed of mostly UN reactive material, like sand and gravel from the chemical and mechanical breakdown of silicate rocks and minerals, solute concentrations change slightly with distance down a flow path.

Water chemistry differs depending on the source of water, the degree to which it has been evaporate, Rocks and minerals dissolve in water to form ion. Positively charged elements dissolve in water (Ca^{2+},Mg^{2+},Na^{+},NH_4^{+},K^{+},Sr^{2+},$Mn^{1+,2+,4+}$,Fe^{2+},Fe^{3+},H^{+}) are called cat ions negatively charged element called anions. these are dissolved in water (HCO_3^{-},CO_3^{2-},SO_4^{2-},Cl^{-},Br^{-},NO_3^{-},NO_2^{-},OH^{-}) .there is also species which dissolve as non-ionic or uncharged molecules (CO_2,O_2,H_2, and N_2).other species dissolve in water are find as colloidal suspension(Si, Al, Fe, organic matter, etc.) .knowing geochemistry of groundwater is important to understand geochemical process of the aquifer. To define the pathway of chemical evolution, to identify source of water recharge, differentiate mixing and interconnection of groundwater and surface water. Generally, the Hydro chemical information can used to interpret the origin and mode of groundwater recharge and provide pale hydrological information used to calibrate groundwater flow model.

3.6.1. Water Quality of Study Area

The water quality determined by the type and amount of substances dissolved in the water, which in turn governed by the chemical reaction undergoes with the environment. Thus natural water is never pure, always contains at least small amount of dissolved gases and solids. Therefore, the quality of water is the function of different variables, such as geology, geomorphology, climatic physio-chemical parameters (temperature, pressure, PH, EC) and biological factors, anthropogenic influence and time. Due to the difference in mineralogy, texture, structure of volcanic rocks, the water bearing quality and potentials are varying.

As the results of water quality analysis of the Upper part of Anger River catchment data taken from the well completion report shows that the water type is Ca-Mg-HCO3 type. The quality of the water meets WHO standards Physic-chemically.the concentration of nitrate and fluoride ranges from 0.01705meq/l to 9.87meql/l and 0.0105meq/l to 9.84meq/l respectively. Sodium and bicarbonates are the dominant cat ions and anions of water chemistry of boreholes with dominant Mg-Ca-HCO3 followed equally by Ca-Mg-Na-HCO3 and Ca-Mg-Na-HCO3-NO3 water types.

3.7 Hydro Metrology

3.7.1. Climatic Characteristic

There are certain parameters, which are use to understand the climate of an interesting area, those are precipitation, Temperature, wind speed, and sunshine in hour and humidity are key point to identify the climatic behavior of one area. Even though there are, more than six Metrological stations are use in and around the study area to identify the climatic condition of the Upper Anger watershed catchment. However, the study area has characterized by highland subtropical climatic conditions with higher elevation, which ranges from3252m.a.s.l.to 954m.a.s.l. and the average mean annual temperature ranges between (17.6951to22.4457) °C. Although February and March are, the warmest month while June and July are the coldest month. It has one of the highest rainfall regions in Ethiopia in short time. With the value which ranges from (1905.7to1435.83) mm per year.

3.7.2. Precipitation

The spatial and temporal variation of rainfall in Ethiopia is controlled by the movement of position of the Inter Tropical Convergence Zone (ITCZ), (Tenalem Ayenew and Tamiru Alemayehu, 2001).according to their main rainy season from June to September controlled by the ITCZ which lies to north of Ethiopia in these months. Southwest wind brings rains from the Atlantic Ocean and the study area receives most of the rainfall in those months.

The whole area has summer season starting from June to September and dry seasons starting from October to February when the ITCZ lies to the southern of the country. Figure 3.5 below show that the spatial distribution of rainfall station data that obtained from the National Metrological Agency (NMA).as the map below show from the station find in the Upper Anger River catchment, Nekemte gates the highest rains throughout the year while Anger station gates lowest value as compare with other station. However, the study area has main rainy and dry season from June to September and between Octobers to February respectively.

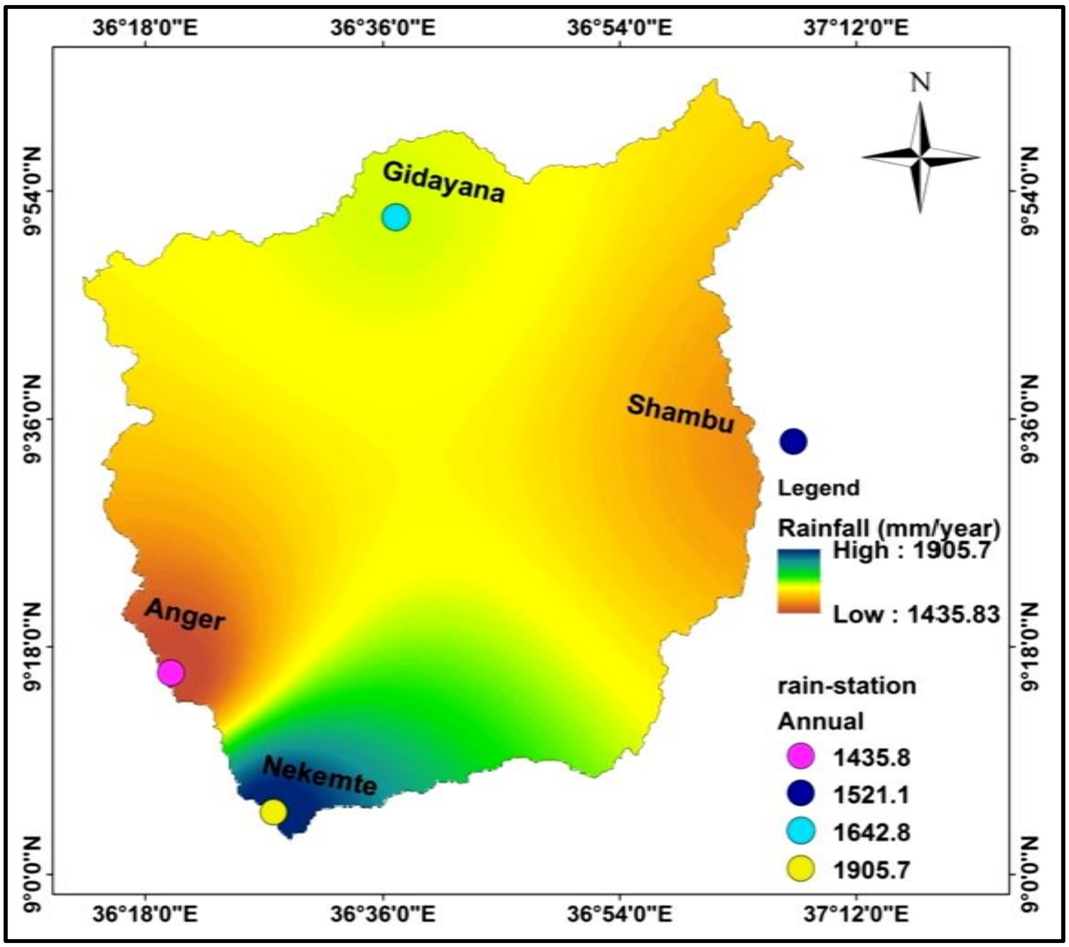


Figure:3.6**.** Spatial distribution of rainfall (source NMA 1987-2017).

From the six observed station the maximum rainfall recorded at Arjo and Nekemte stations with monthly peak rainfall (393.2 and 392.3) mm respectively. The records from Dedessa and Shambu stations show the minimum rainfall. The lowest average monthly rainfall occurs in

January. The maximum annual rainfall 2214.1mm at Arjo gauging Station and the minimum annual rainfall is 1515.6mm at Dedessa gauging station as observed from the figure 3.6 and table 3.2 below.

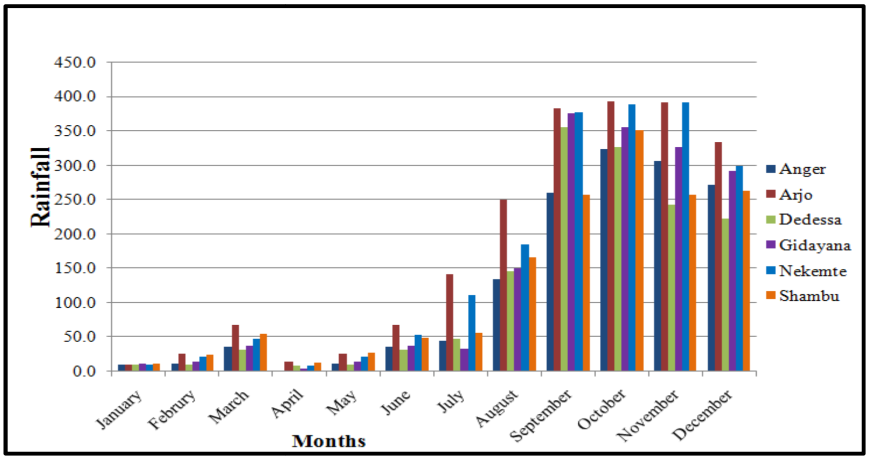


Figure: 3.7.Long terms mean monthly Rainfall Distribution of Study Area (1987-2017).

Table 3.2.Mean monthly rainfall for six stations found in the study area and near Anger watershed (1987-2017).

Stations	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Anger	0.2	9.7	34.6	44.1	133.6	259.6	323.3	306.1	271.0	114.5	22.7	9.3	1528.7
Arjo	12.6	25.2	66.9	141.1	249.0	383.7	393.2	392.5	334.3	132.9	52.6	30.4	2214.1
Dedessa	6.8	8.7	30.3	47.1	145.6	355.6	326.0	241.9	222.1	86.8	28.2	16.7	1515.6
Gidayana	2.8	13.1	36.6	31.4	149.8	376.4	355.0	326.8	291.2	101.3	45.0	4.9	1734.1
Nekemte	7.5	20.3	46.3	100.6	222.8	392.9	395.5	384.1	306.8	153.7	43.4	7.9	1879.5
Shambu	13.3	23.35	53.7	49.3	158.9	258.9	356.9	265.2	261.2	50.9	17.7	15.3	1524.5

3.7.3 .Temperature

The Temperature of Upper Anger watershed catchment depends on the altitude and environmental Condition. However, the value of Temperature varies from place to place, even with the same station characterized by different value with significant rate. The mean annual average, maximum and minimum temperatures are different. As shown on the figure 3.8 below the highest value of mean annual temperature find with Anger station with 22.4457°C and the lowest value of the mean annual Temperature find with Shambu Station with 17.6951°C. Generally, the temperature of the study Area (Upper Anger watershed) ranges from 22.4457 °C to 17.6951°C.

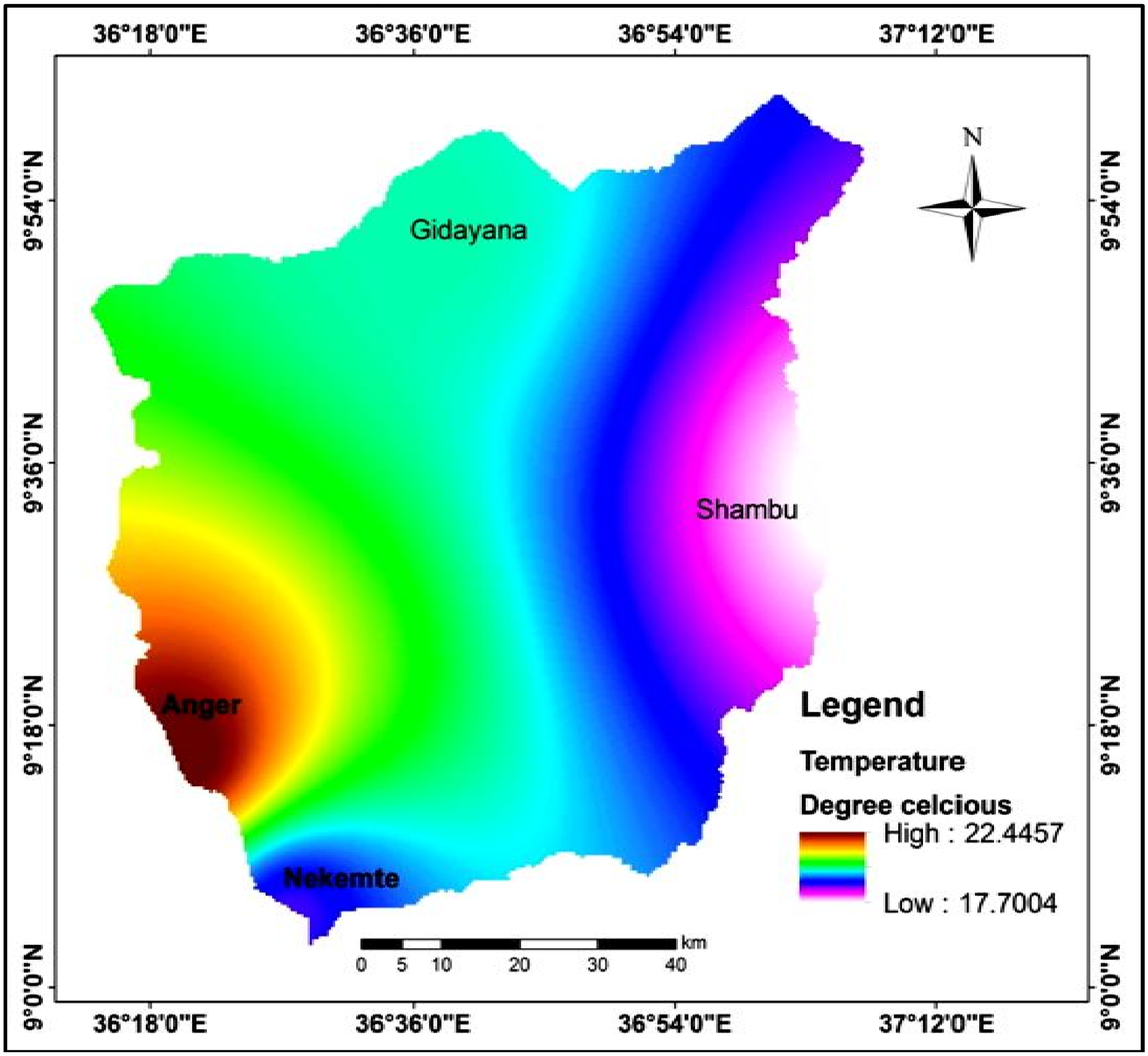


Figure: 3.8.mean Annual Spatial Distribution of Temperature within the gagging station of study area (source NMA 1987-2017).

Table 3.3.The Generalized Minimum,Maximum and Mean Temperature (°C) of the Stations that find within and around the Upper Anger River Catchment (1987-2017).

Station		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Anger	Minimum	14	15.1	14.9	15	14.5	14.7	13.7	13.2	12.8	14.7	14.2	13.3
	Maximum	31	33.4	34.1	33.6	30.7	28.9	26.9	28.1	29	32	30.8	30.1
	Mean	22.5	24.25	24.5	24.3	22.6	21.8	20.3	20.65	20.9	23.35	22.5	21.7
Gidayana	Minimum	12.4	13.9	14.6	15.3	14.6	13.4	12.8	13.2	12.9	13.3	13.2	12.1
	Maximum	26.8	28.5	28.6	28.8	29.4	26.1	23.4	34	24.1	25.1	25.5	25.9
	Mean	19.6	21.2	21.6	22.05	22	19.75	18.1	18.6	18.5	19.2	19.35	19
Nekemte	Minimum	11.3	12.2	13.8	13	12.4	12.1	11.9	12.6	12.4	12.3	12.1	10.9
	maximum	26.7	29.6	28.8	27.7	28	23.5	22.2	21.9	22.9	24.7	25.3	25.7
	Mean	19	20.9	21.3	20.35	20.2	17.8	17.05	17.25	17.65	18.5	18.7	18.3
Shambu	Minimum	10.2	11.5	12.3	12.7	12.2	11.4	10.9	10.8	10.9	9.9	10	9.8
	Maximum	25.2	27	26.2	26.8	27.6	22.5	21.2	20.4	21.2	22.7	23.9	24.4
	Mean	17.7	19.25	19.3	20.8	19.9	16.95	16.1	15.6	16.1	16.3	16.95	17.1

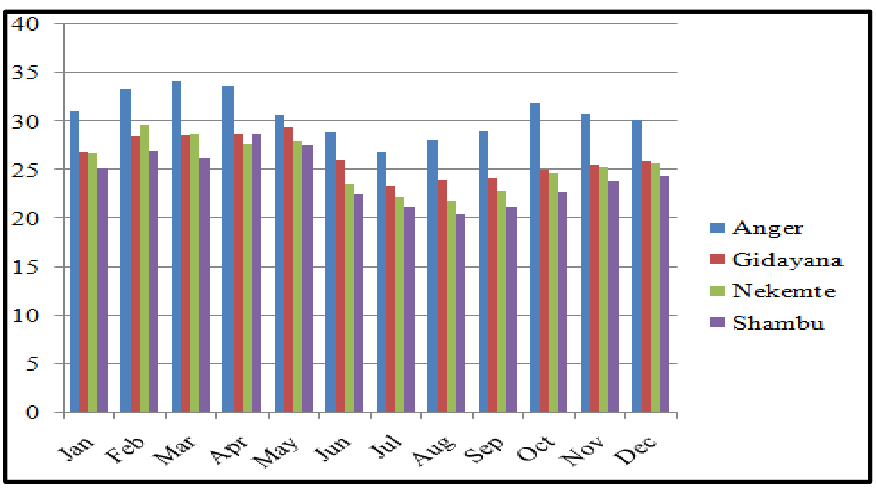
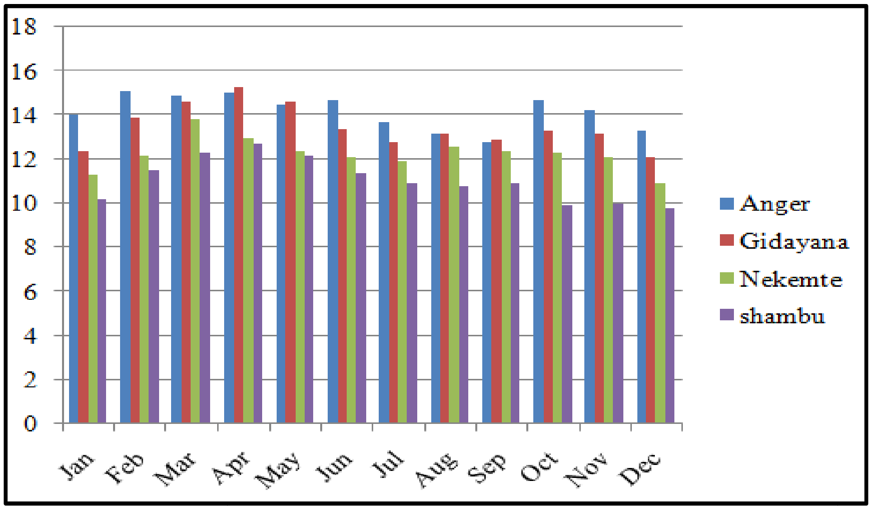


Figure:3.9. Mean Maximum Monthly Air Temperatures.



Source National Metrological Agency (NMA) (1987-2017).

Figure:3.10.Mean minimum monthly air Temperature.

As illustrated in the figure 3.9 below the mean monthly air temperature for the stations, find within the Anger watershed varies between 20°C to 24°C.

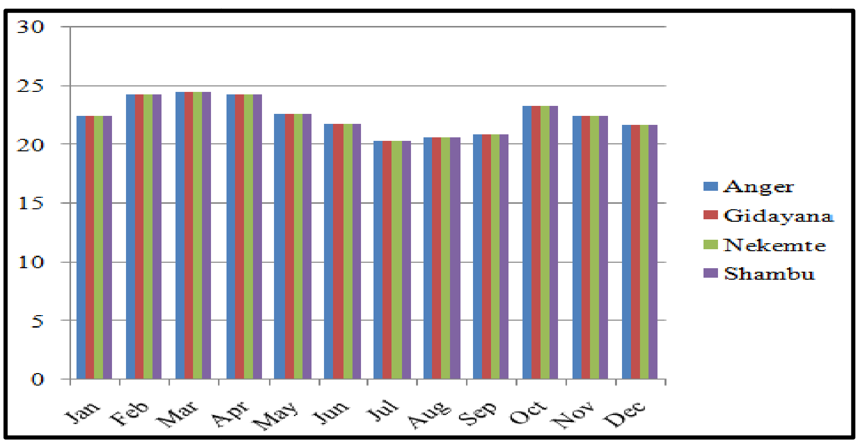


Figure: 3.11.Mean monthly air temperature.

However, the weather data obtained from National Metrological Agency has not been sufficient and sparsely distributed to calculate the water Balance of Anger watershed by using SWAT. Therefore, another weather data are required, from National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) website (http://globalweather.tamu.edu/).The Geographic coordinate system of the weather data that are used to calculate water balance by using SWAT in the upper Anger watershed catchment are list in the table below.

Table 3.4. Geographic coordinate system of weather data used to calculate balance water.

S/N	Station	WLATITUDE	WLONGITUDE	WELEVATION
1	92366	9.21075	36.5625	15090
2	923669	9.21075	36.875	1856
3	95366	9.52298	36.5625	1510
4	953669	9.52298	36.875	1522
5	98366	9.83521	36.5625	2100
6	98369	9.83521	36.875	1787

Source (http:globalweather.tamu.edu/).

3.7.4. Wind Speed

Mean monthly wind speed on average (1998-2012) from six stations are analyzed and use for evaluating water balance in the hydrological model. Wind speed is one of the input parameter to calculate the recharge of an area by using SWAT model. Since penman- monteinth, method has selected to calculate potential Evapotranspiration.

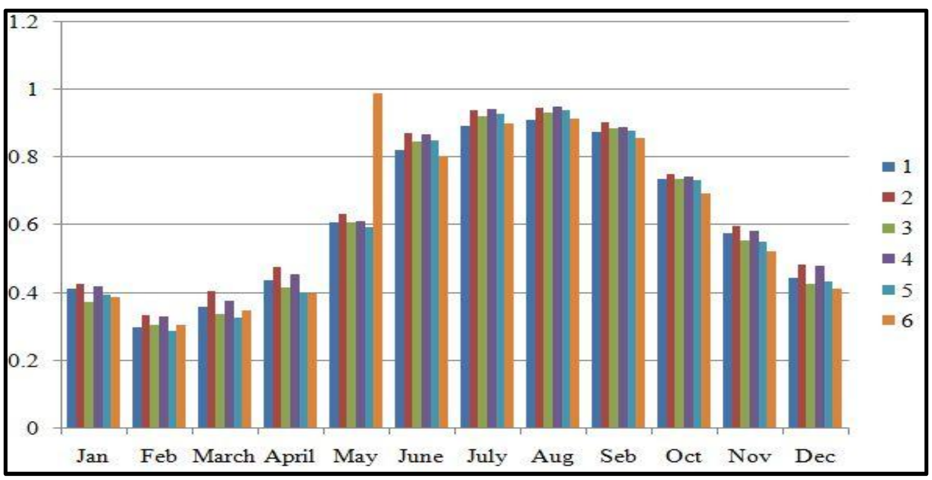


Figure:3.12. The Graphical plot of wind speed (m/s). (Source, NCEP)

3.7.5. Solar Radiation

Solar radiation governs the rate of evaporation by changing large quantities of liquid water into water vapor.consiquently the evapotranspiration process is determined by the amount of energy available to vaporize water. Mean monthly solar radiation on the average (1987-2017) from the six stations that are use for calculating the recharge amount of an area by using SWAT model.

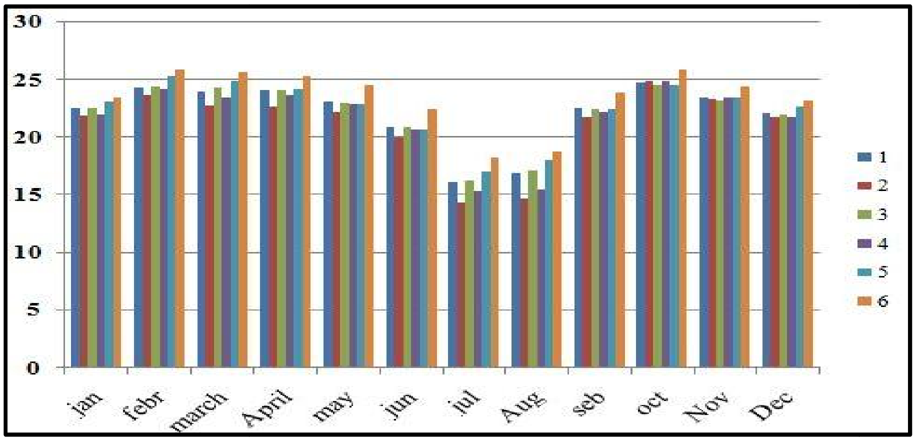


Figure:3.13.The Graphical plot of Solar Radiation (MJ/m²). (Source, NCEP).

3.7.6. Relative Humidity

Mean monthly relative humidity on the Average of (1998-2012) from the six stations that are analysis and used for the hydrological model for evaluating water balance. Relative humidity used to estimate evapotransipiration of one area in hydrologic water balance that helps to calculate recharge of selected area. The amount of water vapor in the air at any given time is usually less than the time required to saturate the air.

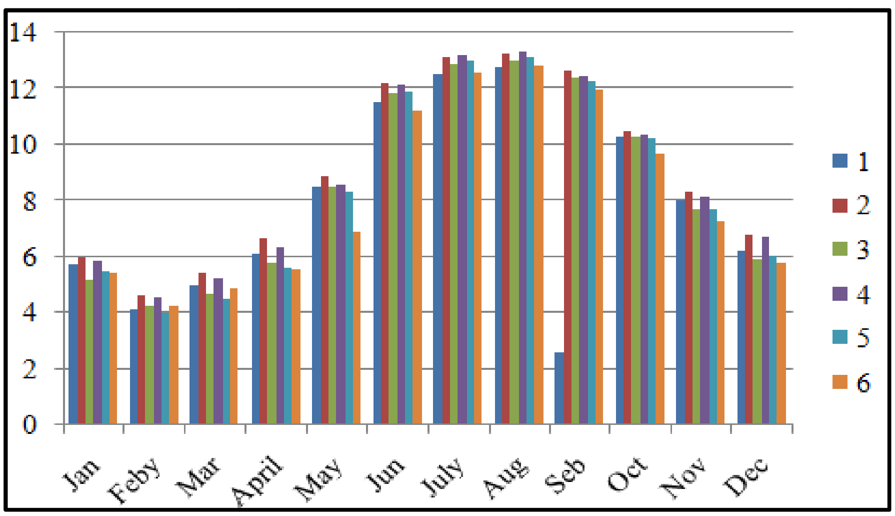


Figure:3.14.Show the graphical plot Relative Humidity (source, NCEP).

4. HYDROLOGICAL MODEL AND ESTIMATION OF WATER BALANCE USING SWAT MODEL.

Knowledge of water Balance and water yield of river basin is the first requirement for the sustainable management of water resource. The parameters of water Balance influenced by the climate and Physical characteristics the catchment like morphology, land use land cover and soil. Therefore, by giving consideration for the relationship between these physical parameter and hydrologic components important to understand the hydrologic response to the climate and land use land cover difference in determining of water availability.

The hydrologic processes are very complex watershed models, which are use for the comprehension of water balance parameters. The watershed model divides the rainfall into different hydrological processes; base flow, lateral flow, evapotranspiration, percolation, and surface runoff, by considering all the water entering to the catchment, storing in the catchment and leaving from the catchment. SWAT allows the division of the watershed into 5 sub-basins (watershed) and further subdivided into 132 hydrological response units (HRU) based on the land use, slope characteristic and soil distribution. The hydrological response units (HRU) are use to describe spatial heterogeneity in terms of land cover, Soil type and slope class within watershed. Therefore, SWAT is a physically based model, which uses the water balance equation in the simulation of hydrology, applied to quantify the water Balance of the Upper Anger River Catchment Basin, which found in the East Wollega zone.

4.1. Inputs of the Model

Weather Data used to run the SWAT taken from the different gauge station, which are finding within and close to the upper Anger River Catchment. Daily Rainfall data and daily Maximum and minimum temperature obtained from the National Metrological Agency (NMA) starting from 1987-2017.However, in the area there is lack of Metrological data of gauge Stations the data obtained from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) website (http://globalweather.tamu.edu). During the time of simulation all, the sub-basins are link to the nearest weather station. The land cover and soil data obtained from the Minister of Water Resource of Ethiopia are use for parameter zing the SWAT model. SWAT use different input data in order to do the water balance. Such input data has different phase.

The first input parameter data are DEM. This DEM prepared as suit for the SWAT from the ASTR DEM.

Land use map for SWAT input used for regional water balance estimation in the raster format.

Soil map input for SWAT in raster format for the purpose of regional water balance estimation.

Slope class prepared from ASTR DEM use as input for SWAT to estimate the regional water balance.

Weather data

the weather data includes the following parameters; Daily Rainfall data from 1987to2017, Maximum and minimum Temperature data of six gauge station starting from 1987to 2017 taken from National Metrological Agency in order to determine the regional water balance. Solar radiation, wind speed, and Relative humidity data obtained from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) website (http://globalweather.tamu.edu/).

Table 4.2: SWAT average Monthly Basin output.

Mon	Rain (MM)	Snow fall (MM)	SURFQ (MM)	LATQ (MM)	WATER YEILD (MM)	ET (MM)	SEDYIELD (T/HA)	PET (MM)
1	7.80	0.00	0.18	0.54	6.20	11.47	0.04	102.11
2	9.07	0.00	0.30	0.73	2.45	11.89	0.07	107.18
3	40.47	0.00	1.22	4.00	6.21	38.24	0.09	148.61
4	67.15	0.00	3.99	7.85	13.14	47.48	0.13	135.85
5	175.75	0.00	22.63	31.42	58.57	61.75	0.87	106.10
6	249.92	0.00	41.69	55.57	118.80	65.72	1.81	83.38
7	293.11	0.00	59.62	69.59	180.51	69.07	2.88	83.44
8	277.29	0.00	54.91	67.37	195.43	64.90	3.36	81.06
9	196.94	0.00	30.61	46.51	153.35	59.94	2.25	78.86
10	86.02	0.00	13.64	17.35	97.93	47.26	1.25	108.37
11	30.61	0.00	3.10	4.07	47.94	28.33	0.38	105.56
12	11.37	0.00	1.03	1.03	21.23	15.76	0.15	99.16

Hint SURFQ=Surface flow discharge, LATQ=Lateral soil discharge, ET=Evapotranspiration, SEDYIELD=Sediment yield and PET=Potential Evapotranspiration.

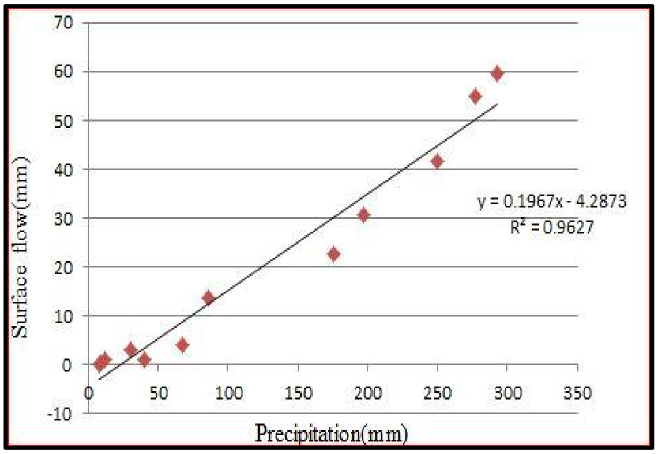


Figure:4.1.correlation of precipitation versus surface flow.

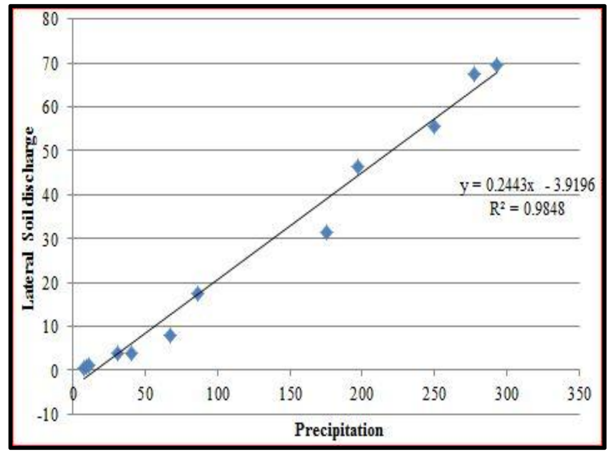


Figure :4.2.Correlation of precipitation versus lateral soil discharge.

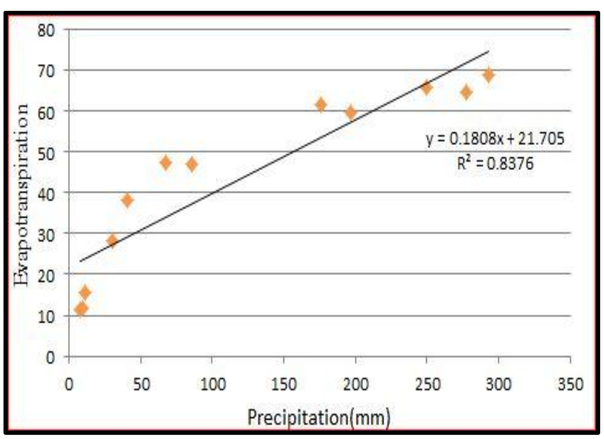
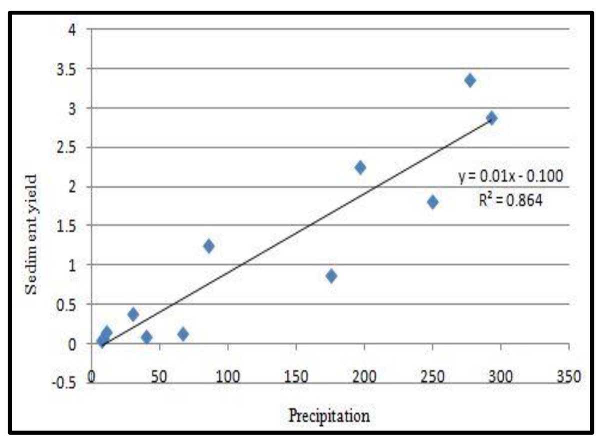


Figure:4.3.Correlation of precipitation versus Evapotranspiration.



4.4. Correlation of precipitation versus sediment yield.

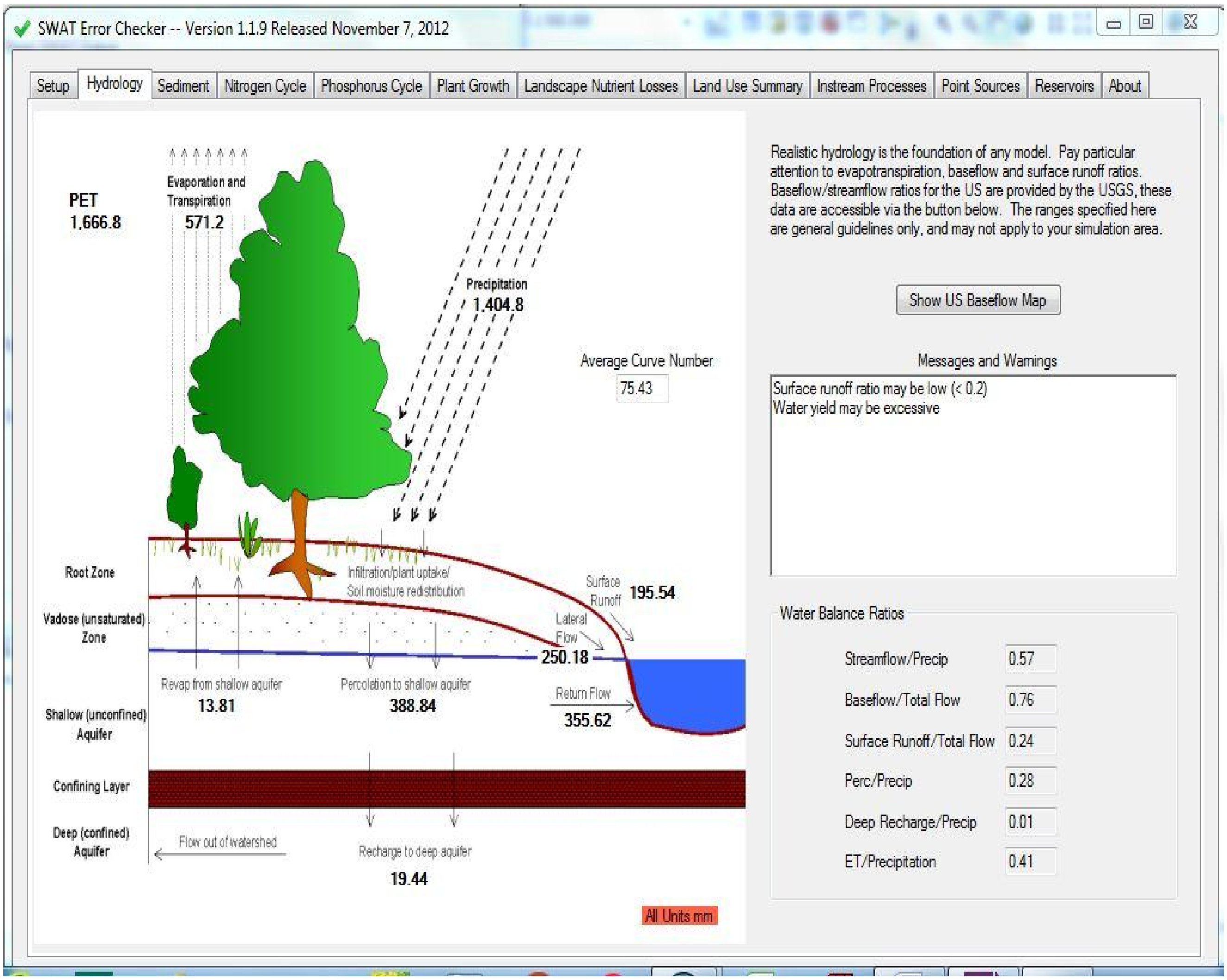


Figure: 4.5. Hydrological water Balance representation of the basin.

4.2.1. Hydrological Response Units (Hru)

A hydrological response unit (HRU) divides the Basin watershed into 5sub-basins.

Again, the sub-basin further subdivided into 401 HRUS by over lying Land use, Soil map and slope class. .

Generally, Soil Water Assessment Tools (SWAT) helps to have knowledge about hydrologic information on the land use, soil, slope and weather data property (precipitation, temperature, solar radiation, wind speed and Relative humidity).

4.2.2. Water Balance Components

Precipitation is uniformly distributed and the potential evapotranspiration (PET) use the penman-montieth, daily rainfall or Runoff Estimated by curve number method. Daily Stream Routing determined by variable storage Routing method and channel dimension remain constant. All SWAT output water balance component exist with each watershed and find with annual, monthly and daily time steps. Average annual rainfall=1404.8mm, Average annual ET=571.2mm/year, Average annual PET=166.8mm/year, average annual Surface Runoff Q=195.54mm/year, average annual Lateral Soil Q=250.18mm/year and annual deep groundwater recharge 19.44 mm/year and percolation to the shallow aquifer 388.84mm/year. However, the general result of water Balance components come from the Combination of both Land resource (Land use, soil and slope (geomorphology)) and climatic data. Agro- Ecological zone (AEZ) these contain both land resource and climatic data.

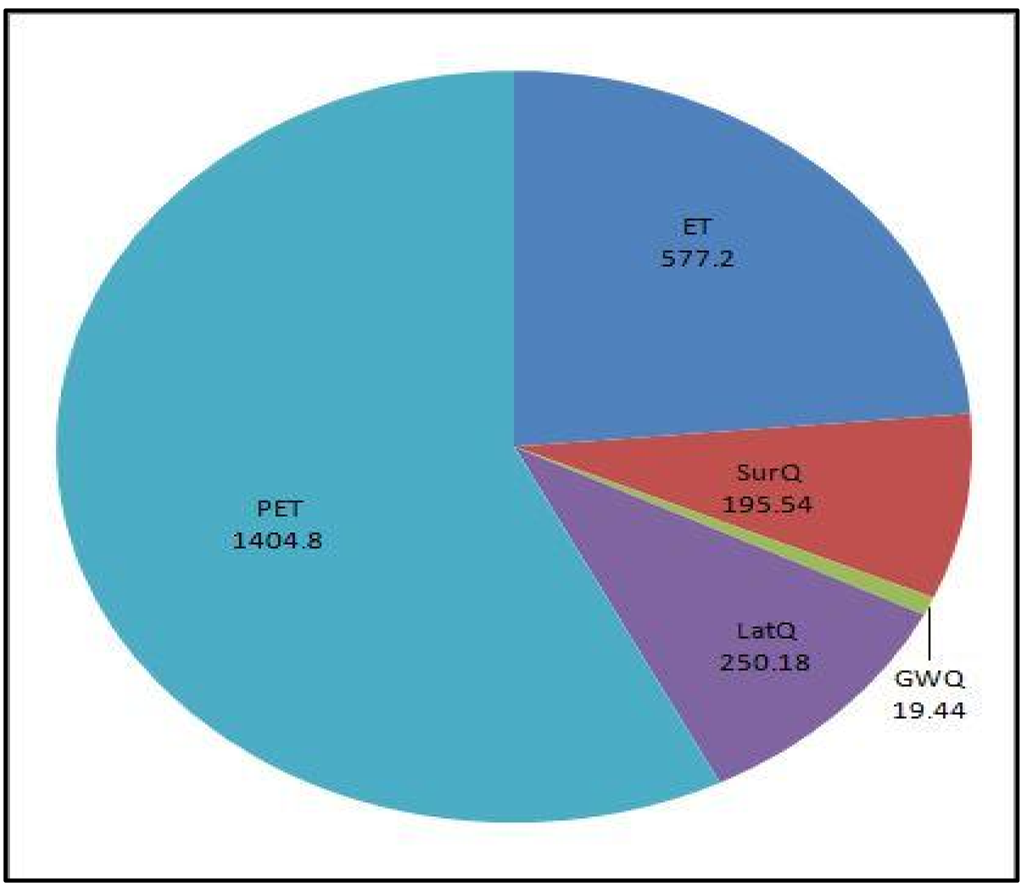


Figure:4.6.Pie diagram show the water Balance components of SWAT output.

5. GEOLOGY AND HYDROGEOLOGY

5.1. Regional Geology

The metamorphic basement rocks of Nekemte map sheet is part of Proterozoic rocks of the western Ethiopian Shield, which is assumed to be the southern extension of the Arabian-Nubian shield(A.NS)(Ayalew et al.,1990).According to Kazmin(1978),The Western Ethiopian shield consists the Lower and Upper Complex rocks. Precambrian rocks of western Ethiopia classified into three, The Western high-grade gneisses, Central volcano sedimentary belt and eastern high-grade belt. The Low- grade volcano-sedimentary belt has bounded by both, the east and west high-grade gneisses. Western Ethiopian shield constitute high-grade gneisses and low-grade Met volcano-sedimentary rocks that include the northern and southern continuation of the Mozambique Belt (MB) and Arabian Nubian shield (ANS), respectively and the pre-tectonic plutonic rocks and post-tectonic granites intrude these rocks (EGS, 2006).

In Ethiopia, sedimentary history began with the development of rifts, which form northeasterly and northwesterly trending trough. In Late Jurassic, the transgressive sea covered most part of Ethiopian landmass. Towards the ends of the Jurrassic, uplifting of the landmass initiated a regression of the water mass(Getaneh Assefa,1991).the outcrops of Paleozoic to Mesozoic sedimentary rocks in Tigray, Abay River Basin and large areas of the southeastern plateau reveal the extent of sedimentation in the country. The Sedimentary succession of the Abay River Basin (Western Ethiopia) consists of lower sandstone (Ad grate sandstone), transitional beds (Abay beds or Gohatsion formation), Antalo limestone and upper sandstone (Ambaradam orDebreLibanos Formation).

Table 5:1.in western Centeral Ethiopia formation of Sedimentary thickness (After Getaneh Assefa, 1991).

	DebreLibanos Thickness in (m)	Gohatsion Formation thickness in (m)	Fincha-a thickness in (m)
Upper sandstone	172	0	0
Antalo-Limestone	Not exposed	400	0
Transitional beds	Not Exposed	500	30
Lower sandstone	Not Exposed	>300	1100

The sedimentary rocks of Nekemte sheet are the southwestern extension of the western central Ethiopian sedimentary succession (EGS, 2006). It consists of thick lower sandstone succession that overlain by thin remnants of transitional beds (Table 5.1).According to the Geological map of Nekemte sheet (EGS, 2011) columnar basalt unit is exposed in the area along NE-SW running fault line that runs up to the foot of Komto ridges. Irregular to prefect columnar joint characterizes these rocks.

5.2. Local Geological Set Up and Stratigraphy

In all groundwater study, the geological history of the basin must known, for the resulting, of the geological structure largely controls the occurrence and movement of groundwater. The number and typing of water bearing formations, their depth, interconnections, hydraulic properties, and outcrop patterns are all the result of the basin's geological history.

5.2.1 Meta-Gabbro

Meta-gabbro outcrops find in the central and western part of the map sheet covering about 3.5% of the map area. It characterized by the blocky outcrops forming prominent ridges and hills but rarely with low-lying ridges mostly covered by soil. Meta-gabbro is mainly fine to medium grained but rarely, coarse grained greenish grey to dark grey on fresh outcrops. Weathered surface of the rock shows brownish grey color. The rock is jointed and massive which has weakly foliate. In some areas, meta-gabbro has thinly banded and the bands are result of the mineral alignments of fine to medium-grained dark and light minerals.

5.2.2. Mesozoic Sandstone

This subunit has exposed at lower part of Mesozoic sandstone succession. It covers 8% of the total mapped area. Stratigraphically, it bounded by Paleozoic sandstone and tertiary volcanic rocks and overlie by few erosion remnants of Mesozoic siltstone. It has maximum thickness of 390meters around Beda Sire and uncomfortably underlain by the Paleozoic sandstone without clear unconformity. However, in the study area, these rocks have lateral variation in composition and facies from east to the west. All the section taken at eastern side (Beda Sire, Gute and Fincha-a) began with 40to 150meter thick mudstone, shale and siltstone layers followed by 200 to 240 meter thick clastics.

Generally, the Lower sandstone section consists of sandstone, mudstone, conglomerate and siltstone/shale. The first layer, which exposed in the lower sandstone section has a maximum thickness of one meter and located between two siltstone/ shale layers. Due to its resistance to weathering and erosion, the ironstone layer has exposed as cliff forming. Upward in the succession 220-meter thick yellowish and light yellowish gray sandstone is exposed at Beda Sire section. The graded bedded sandstone is light to gray, well sorted and mature. This sandstone grades from conglomeratic sandstone at the base to siltstone and mudstone at top. This sandstone is matrix supported, poorly to moderately sorted, mature to immature, friable and weathers to brown. At the base sandstone, is cross-bedded and weakly developed cross beds throughout the subunit. Locally it is massive and cliff forming. A mud crack has observed at varying scale in the sandstone unit and upper sandstone underline by lower sandstone and unconformable overlain by the tertiary volcanic rocks. In the study area the upper sandstone covered by middle Mesozoic siltstone/shale, around Gute area (Solomon Gerra and Mulugeta Haile/mariam 2000).

5.2.3. Paleozoic Sandstone

This unit exposed in the northeastern central to northwestern part of Nekemte map sheet. It covers 4.8% of the total mapped area. The sediments of this unit deposited in N-S trending series of graben basins and syn-forms. The Paleozoic sandstone unit consists of different layers, such as sandstone (80%), siltstone (10%), conglomerate (5%), limestone (3%) and mudstone (2%). the rocks have variegated colors (red, pink, violet, light gray) on fresh out crops and weathers has the color of brownish or yellowish. The sandstone is fine to coarse grained, cross-bedded and shows graded bedding at varying scale. Compositionally varies from well-sorted and matured Quartz arenite to poor sort and immature lithic wack. In some cases, have sharp boundaries and easily split apart in to different bands during hammering. At places, the bands may not be evident, individual band show mineralogical and textural differences (EGS, 2006).

5.2.4. Lower Basalt

The lower basalt unit is the most abundant unit of volcanic rocks in the mapped area. It rest uncomfortably over the Precambrian basement rocks at the western part and over Paleozoic-Mesozoic sedimentary rocks at the eastern part of the map sheet. At the southeastern comer, it rests over the lower pyroclastic rocks, unit lower basalts. This rock unit consists of the 35%

augite phyric basalt, which are 75 meter and 150meter thick respectively. Further, up in the succession, the unit becomes one-meter thick lateritic paleosoil at the base and fifty-meter thick baked soil at the top respectively around Ijaji. The aphanitic basalt is grey to dark to black when fresh and weathers to yellowish or reddish brown.

Around Sheboka area, it varies gradually from the aphanitic, layered at the bottom to fine grained, augit phyric, and columnar jointed at the top. Generally, the rock is composed of 75% microcrystalline and glassy matrix 15% augit, 5% opaque minerals, 4% olivine and 1% biotitic. These minerals are occurring as microphenocrysts with in microcrystalline and glassy matrix. It has characterized by subophilitic texture.

The amagdaloil basalt has exposed near the base of the section. It has a total thickness of 100meter.The rock is dark to dark grey and composed of secondary minerals (Zeolite, amorphous silica and calcite) in fine grained cryptocrystalline and glass matrix of Olivine ,pyroxene and plagioclase minerals. The secondary minerals comprise about 10% of the total volume of the rock. The olivine –augite phyric basalt has exposed near the middle of the lower basalt section of sheboka area. Generally, the lower basalt rock Aphanatic and columnar jointed dark green, locally. This rock has composed 35% plagioclase, 30%olivine, 20% augit and 5% opaque minerals. These minerals occur as phenocrysts within the cryptocrystalline to glassy groundmass (EGS, 2006).

Figure:5.1.Vesicular Basalt which filled by secondary mineral.

5.2.5 Gutin Granites

The major outcrop of this unit is near and around Gutin Village and hence named as Gutin granite.

It is located in the central part of the map sheet forming NE-SW and NNE-SSW running spectacular ridges standing against the low-lying Anger graben covers about 2% of the area. The ridges are parallel to the regional foliation and form moderately too highly rugged topography. This rocks lies out in the west and in the east under Tertiary volcanic rock and Paleozoic sandstone, respectively. Numerous southeast and west draining perennial and intermittent streams have dissected the unit in the Gutin granite is medium to coarse grained, light grey, pink to pinkishgrey with dark and whitish spots. The weathered surface is dull grey to buff. The Gutin granite has subjected to the Gutin shearing event and developed Foliation. In the central part of the shear zone, foliation is intense whereas away from the center, this foliation progressively decreases and became poorly foliated, especially towards the northeastern margin of the unit. Big grains of the quartz and feldspar minerals that has subjected to shearing were modify and later developed (symmetric and asymmetric) clastics.

(Tasfaye et, al.2000), named the Gutin granite as megacrystic granite. According to this author, crystals are mostly symmetric, but rarely asymmetric that is set in a matrix of fine quartz and feldspar minerals. To the east and northeast part of the Gutin, shear zone, the Gutin granite grades to a course grained poorly deformed to massive granite of similar composition. This rock type occurs as huge jointed blocks of porphyritic granite with the quartz phenocrysts showing random orientation. The Gutin granite is composed of 30-40%microcline, 25-30% plagioclase (oligoclase to andesine), 20-25% quartz and 7-10% biotitic. Minor opaque, carbonate, hornblende, arginine, chlorite, epidotic, sericite and muscovite have observed (EGS, 2006).

5.2.6. Quartzo-Fieldspatic Gneiss

Quartzo- feldspatic gneiss has the light grey, medium to coarse-grained and weak to strong foliate. Weathered weakly and has buff color. Quartzo-feldspathic gneiss composed of the 30-40% plagioclase, 25-35% quartz, 15-25% microcline, 3-7% biotite and minor muscovite, chlorite, sericite, orthoclase and calcite, sillimanite and opaque. Locally the orthoclase and muscovite observed. Porphyroclasts of quartz and feldspar comprise by fine matrixes of the same minerals. Most of the feldspars shattered and often replaced by secondary white mica along twin lamellae and cleavage traces. Biotite is greenish because of the incipient chloritization. It also altered to epidote and quartz feldspar porphyroclasts (EGS, 2006).

5.2.7. Quaternary Sediment

Quaternary sediment formed extensively in the central part of Nekemte map sheet. This unit mainly covers the Anger graben. Approximately cover 11% of the total mapped area. it has three types of the sediment. Black cotton, sandy soil, reddish sandy soil and fluvial sandy soil are the type of quaternary sediment. These sediments are form one mixed with the other, it is impossible to map separately.

The black cotton soil is located around the marshy area, which located in the Lake Chomen and on the plain south Bako town. It is black to dark brown, fine grained and has clay texture. The black cotton sand soil is mainly cover by extensive elephant grass of the Chomen Lake. Reddish sand soil mainly located in the Anger graben. This soil is the loose and fine to medium grained. It is composed of the angular grains of quartz and feldspar. The other sediment type is fluvial sediment occurs along the banks of the Anger, Fincha and Gibe rivers. Some of the sand type is unmappable. Fluvial sand soil is deposits also occur along the bank of Didessa River. The fluvial sediment mainly consist mixture of coarse to fine sandy sediments

5.2.8. Biotitic Gneiss

This unit is about 3.5%of the map area. Crops out western, central and eastern parts of the area forming N-S low lying valleys and moderately high standing rigdes. In western part of the mapped area, this unit disappears under Cenozoic basalt cover. The major rock type of this unit is banded biotite gneiss; hence, it mapped as biotite gneiss. Minor intercalations include undifferentiated meta-volcanic and meta-sedimentary schist's which consist less than 5% of the unit. Generally fine to medium grained but locally there are coarse-grained varieties. It is grey to dark grey on weathered outcrops and greenish black in fresh outcrops. Compositionally the felsic mineral is greater than the mafic minerals. The unit shows the characteristics of folded and layered migmatite structure.

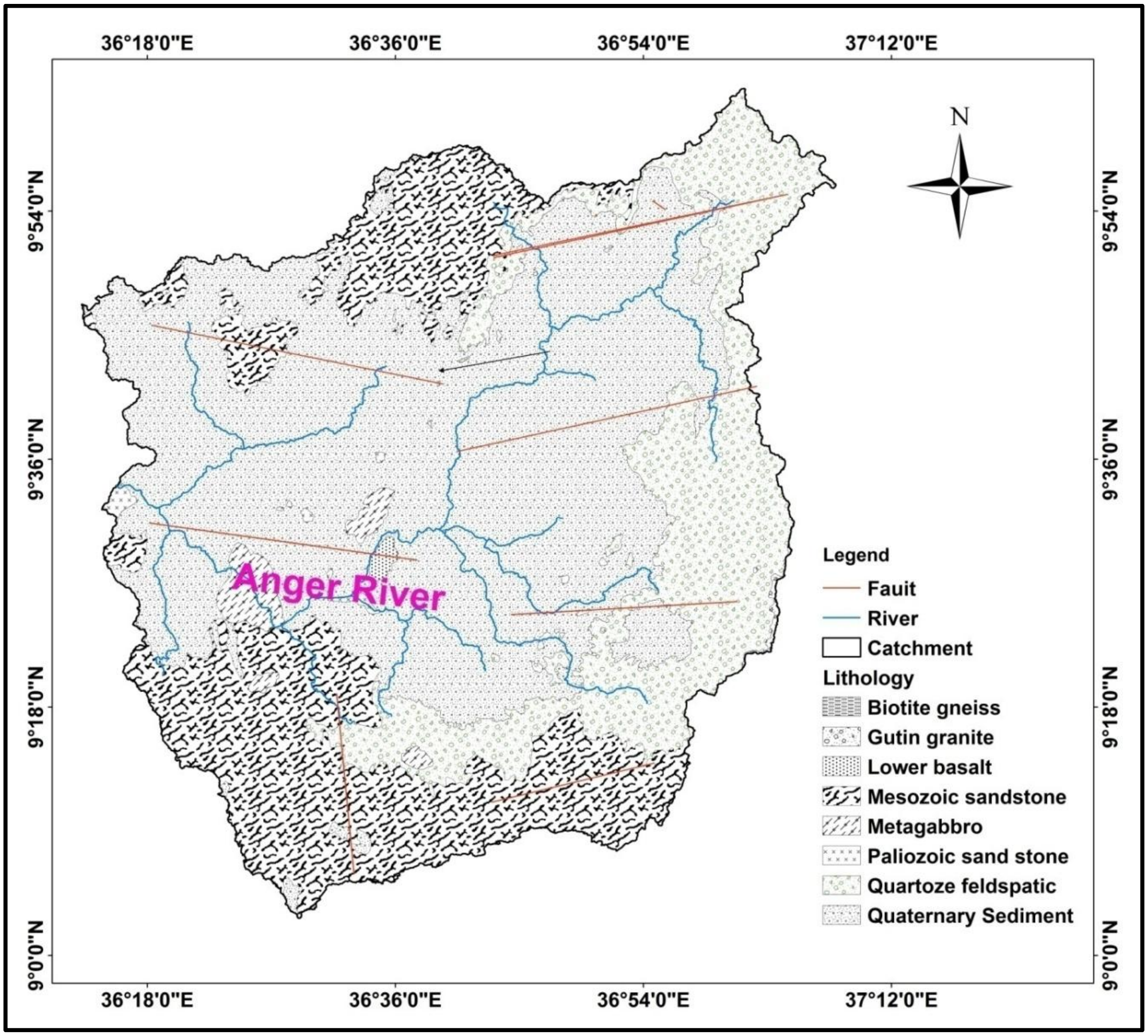


Figure: 5.2. Geological map the study area. Source, EWR and EM.

5.3. Geological Structures

Different workers have outlined a poly phase deformation events for the structural evolution of the crystalline basement rocks of the Western Ethiopia. Kazmin et al., 1979 give more emphasis to folding events, and Ayalew et al., 1990 focused on the Ocean culture and associate with organic movements. Deformation style, foliation trend and fold attitude, presume the Precambrian rock subject to deformation events. Therefore, during the deformation events placement of existing tectonic fabrics, such as foliation, lineation folds and the others to the particular deformation occurrence give Impression that the structures of different classes have been develop during structural events. However, the specific study are has characterized by different structural features; these are joint set and Lineaments. The existence of different water source (spring and stream) indicates that the availability of geological structure. Volcanic tertiary rocks and the variation in the mode of formation, Litho logy, structure, degree of weathering and amount of interaction results for the formation with high capacity of water holding, mainly cover the study.

5.3.1. Joint

Joints observe at local scale with volcanic rock units and play great role in the Groundwater occurrences. The major set of joints with general trending orientation NNW -SSW and NNE direction. Volcanic rock units are prominently subject to the columnar joint as the fig. below 5.3(a) show.

Figure: 5.3 (a). The Columnar Joint map of the study area.

5.3.2. Lineaments

Identification of lineament features has performed by preliminary interpretation of Satellite image. The Satellite Image data for the study area overlay then proceed by using PCI Geomantic Software to gate the Lineament pattern using line algorithm. Lineament is a linear feature in the landscape, which is an expression of an underlying geological structure. Lineament will locate as fault-aligned valley, series fold or fault aligned hills and straight coastline. The linear features are the result of weak zones or structural displacement inside the earth's Crust**.** The features have the NNW, NE, NNE, and NW and there is less EW trending linear features dominate the catchment. Lineaments are the controlling factors of groundwater base flow and recharge condition of the area. In addition, the fractures affect the litho logic units in the area out of which they are in the basaltic rock. The occurrence of ground water varies depends on the litho logical fractures. Fracture controls the litho logy for water bearing capacity. The study area has high lineament feature shown figure (5 :3b).

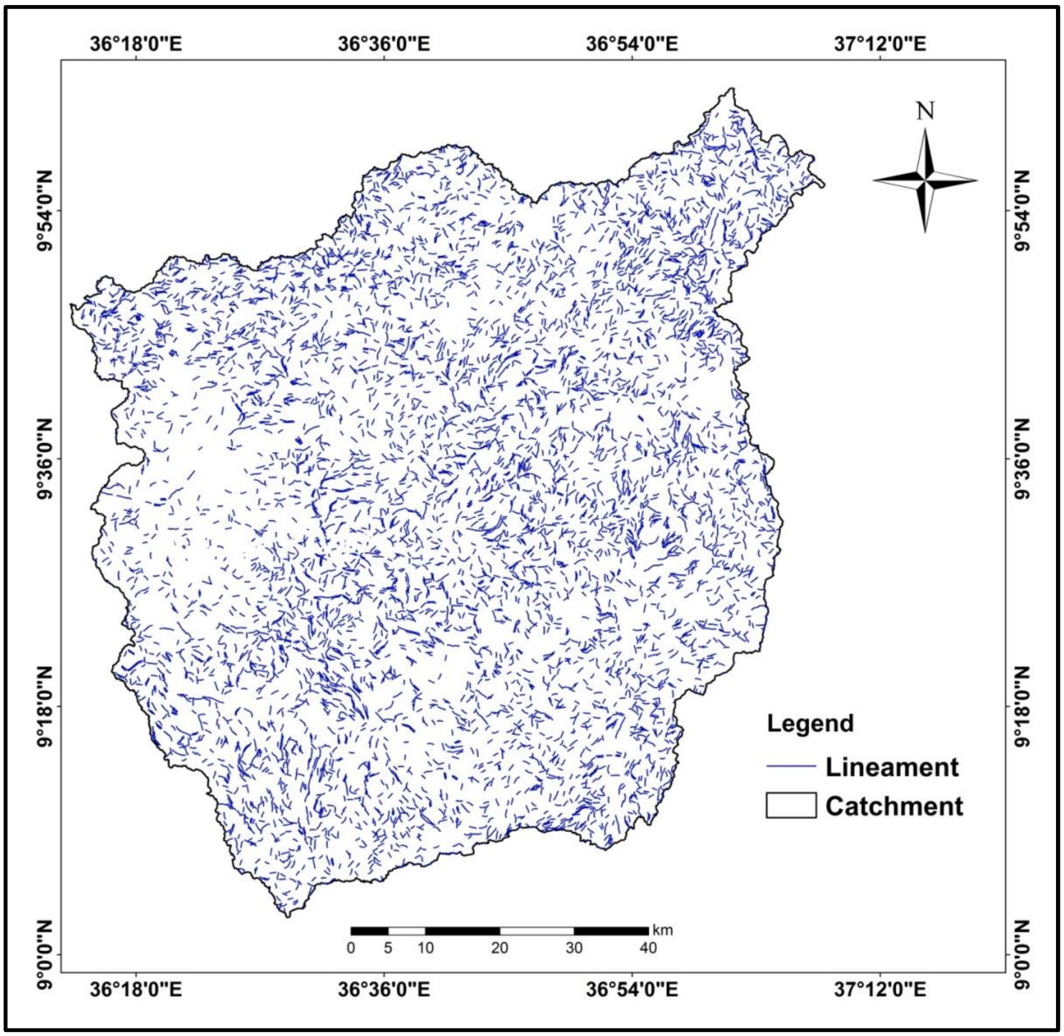


Figure:5.3(b). lineament map of the study area.

5.3.3. Rose Diagram

The rose diagram is circular histogram plot, which displays directional (azimuthally) data and frequency of each class. In structural geology, the rose diagrams are use to plot the orientation of joint and dykes (https://earthscience.Stackexchange.com/---/). The lineament show that the orientations are steeply dipping to the vertical. This shows that the direction of lineament features follow the way the way through which of river flow. That means the Dimension and direction of lineament feature have relation with catchment activity. Fig (5:3c) below shown that the lineament set trends NE-SW, NNE-SSW, NNW-SSE AND E-W. The most trends of lineament orientation NNE-SSW, NE-EW and E-W by both Azimuth and Geographic. From the following Rose Diagram the minor Lineament Orientation NNNW-SSE, NW-SE.

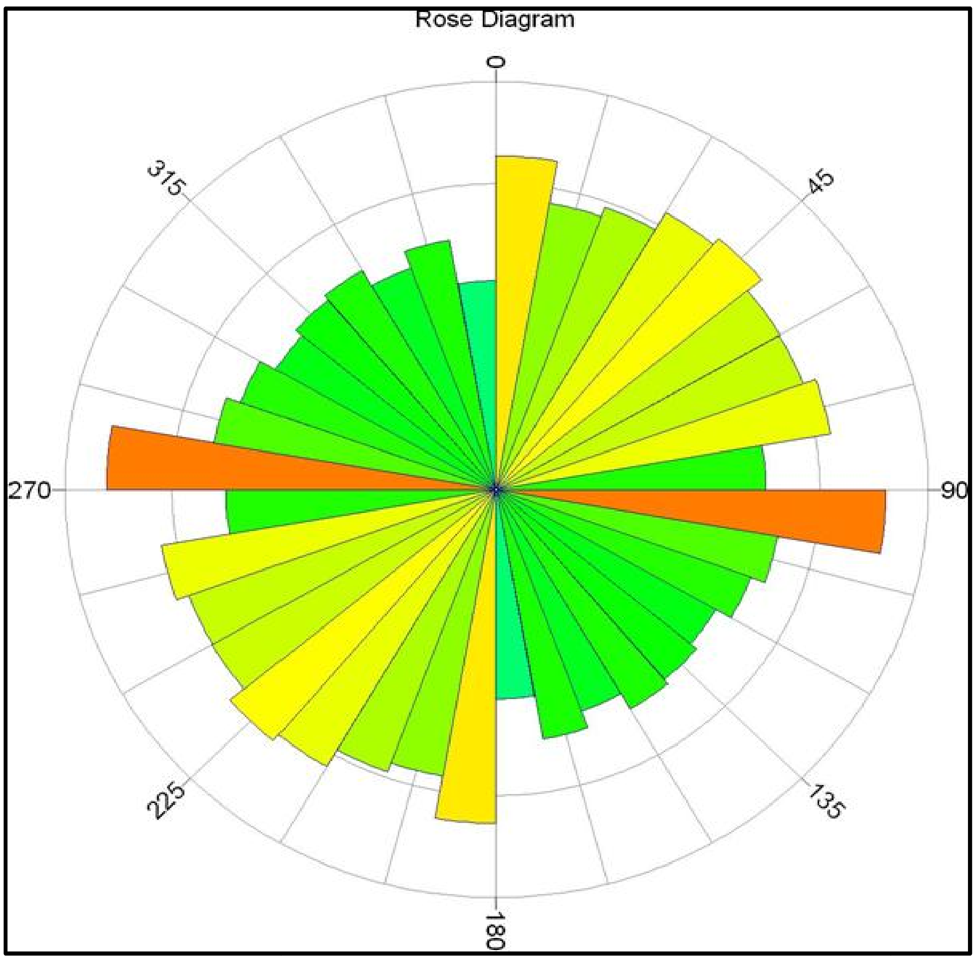


Figure 5:3(c) Rose Diagram map show the Lineament Orientations.

Generally, the major lineament trending direction is oriented from NE-SW, while the minor lineament orientation shows NW-SW (fig 5:3c).This shows the flow direction of rivers and streams networks are following the general lineament orientation.

5.3.4. Lineament Density

Lineament density of an area can indirectly reveal groundwater potential, since the presence of lineaments usually denotes a permeable zone. Areas with high lineament density are good for groundwater potential zones (Haridas et al., 1998). Springs occurred within massive basalt, highly fractured and through the joints.

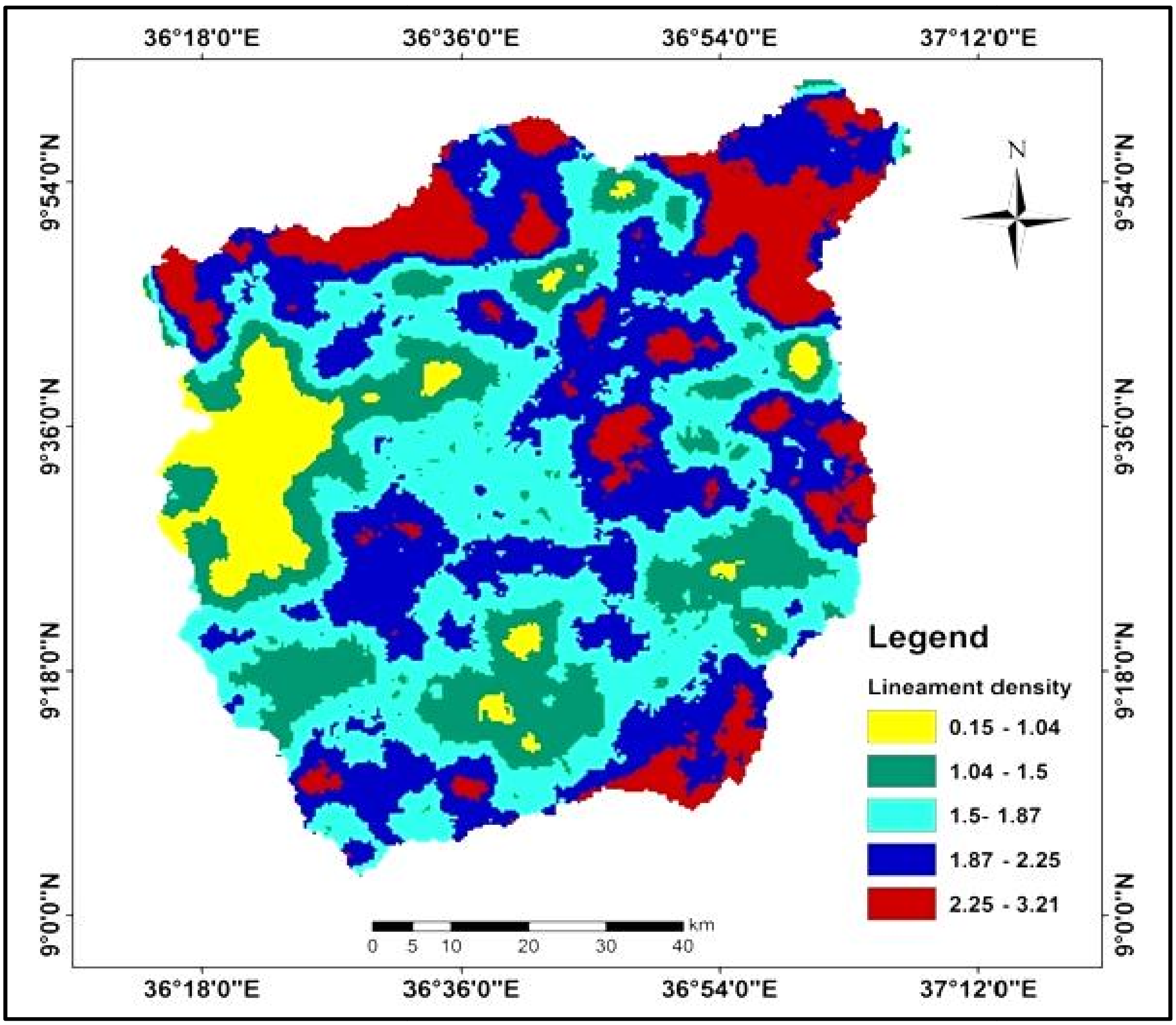


Figure: 5.3. (d) Lineament map show density of fractures in the study area.

5.4. Hydrogeology

Study of the subsurface geology is required to find the type of materials that make up the groundwater basin, their depositional environment, age and their structural deformation. Exploration of ground water resource requires detail understanding of hydro geological properties that form the aquifer system. Groundwater occurs at different depth in varies geological unit of hydro geological basin. All the three classes of rocks (Igneous, Sedimentary and Metamorphic) can hold water at different scale based on the pores space and the composition constituents there in.

Properties of rock determines how much groundwater can be stored and how much productive an aquifer .when the features are interconnected in the rock s called permeable and fluid can flow through it easily. The important features for the groundwater occurrences in the crystalline rocks are weathered zones (regolith) and fractured zones. The weathered layer, called regolith developed on intact volcanic and sedimentary rock is necessary for the groundwater source, for the urban and rural water supply source in the study area. Generally in the study area alluvium and volcanic rock unit poor in primary porosity which limit the capacity to preserve groundwater. From the geological data recorded during the drilled boreholes, the basalt lack with the primary porosity has high secondary porosity due to intense weathering and fracturing through which the rainfall percolates and mixing with the composition of rock outcrops.

The vesicular basalt has high primary and secondary porosity hence high permeability for the groundwater movement and reserve as high groundwater potential.Springs are also an important source of hydrologic information. They occur because of the hydraulic head in the aquifer system intersect the land surface. By giving consideration for their distribution, flow characteristics, and water qualities, valuable information gathered without drilling well. Impervious Rock Springs (fracture springs) are recorded from the gentle slope of Nekemte highland.

They are finding in massive basalt, which is highly fractured and joint the water moves through the fractures and springs formed where these fractures intersect the land surface at low elevations. There are different boreholes inventoried in addition to the 32 boreholes. However, there is no full information relevant data for hydro geological and hydro chemical analysis.

There is no enough data information regarding to the transimissivity, hydraulic conductivity, depth, static water level, etc. as information gathered from the available data source the major aquifers are highly fractured and weathered layers, slightly fractured and weathered layer. The PH values of boreholes ranges between6.59 to 9.15.

Table :5.2. Hydraulic characteristic recorded from the well report data.

No	Site Name	Location(m)			Depth (m)	SWL(m)2	Q l/s	T(m²/d)	K(m/d)	Sc(m/d/m)	Aquifer formation
		Easting (m)	Northing (m)	Elevation (mbgl)							
1	Nekemte1	232006	999156	1938	160	12.75	6.2	15.41	0.33	16.76	Basalt
2	Nekemte2	231781	999520	1942	134	23.85	27.82	164.16	3.91	90.00	Basalt
3	Nekemte3	231936	1000096	1945	166	23.05	7.83	71.28	1.32	57.00	Basalt
4	Sire1	266656	996573	1736	101.5	38.33	21.65	513.86	17.6	80.92	Basalt
5	Sire2	266632	997181	1740	104.5	9.5	9.34	50.47	1.42	20.04	Basalt
6	Sanbatdure	223088	1015565	1725	82.45	21.83	45.27	0.63	14.3	12.53	Basalt
7	Tsige	226118	1016499	1685	90.55	20.85	4.53	12.96	0.38	12.57	Basalt
8	Shambu#1	287604	1053587	2729	340	1.19					Basalt
9	Shambu#2	288412	1053724	2740	370	6.5					"
10	Shambu#3	292848	1061504	2362	287	27.24	30l/s				Basalt
11	Kiramu#1	261631	1099396	1983	150						Basalt
12	Kiramu#2	261393	1099274	1975	55						"
13	Dipo site	223915	1035395	1360	59.8						"
14	Mandar14 sit	238986	1055201	1342	105	1.85	5.6				"
15	Dhagajigii	245493	1069159		67.8	7.8	2	3.45			"
16	Laku	26159	995287	1593	224	3.02	15.7	15.1			"
17	Gabasenbat	218125	1016938	1678	146						"

18	Sinaguso	343424	1083808	2292	203	34.9	2.8				Basalt
19	Bikila	318354	1026323	2233	230	41.3	5				Basalt
20	Aga/guda	321372	1035677	2218	120	2	5				Basalt
21	Abdatscho ol	230682	993678	1944	54.8						“
22	Godahara	278930	1016447	1963	60						“

Source, of data gathered from well completion Report. Remark (Zone:37.UTM. Adindain).

SWL-Static water level, Q-Discharge, T-Transimissivity, K-Hydraulic Conductivity, Sc-Specific Capacity.

From the above table most of the wells have nearly small drawdown as compared to their static water level and depth. This result is due to the low capacity of pumps for pumping test. Therefore, the safe yield of these wells will be much higher than the pumping rate. The permeability and transimissivity of volcanic rock in the Anger River Catchment Basin vary see (table 5.2).The Hydraulic parameter of the Aquifer system not similar this occur because of the difference in the distribution and orientation of fractures. For example from the above table wells, which find in Nekemte located in the same area which far not more than two Kilometers (2km), the hydraulic conductivity varies from 0.3 to 3.9m/day.

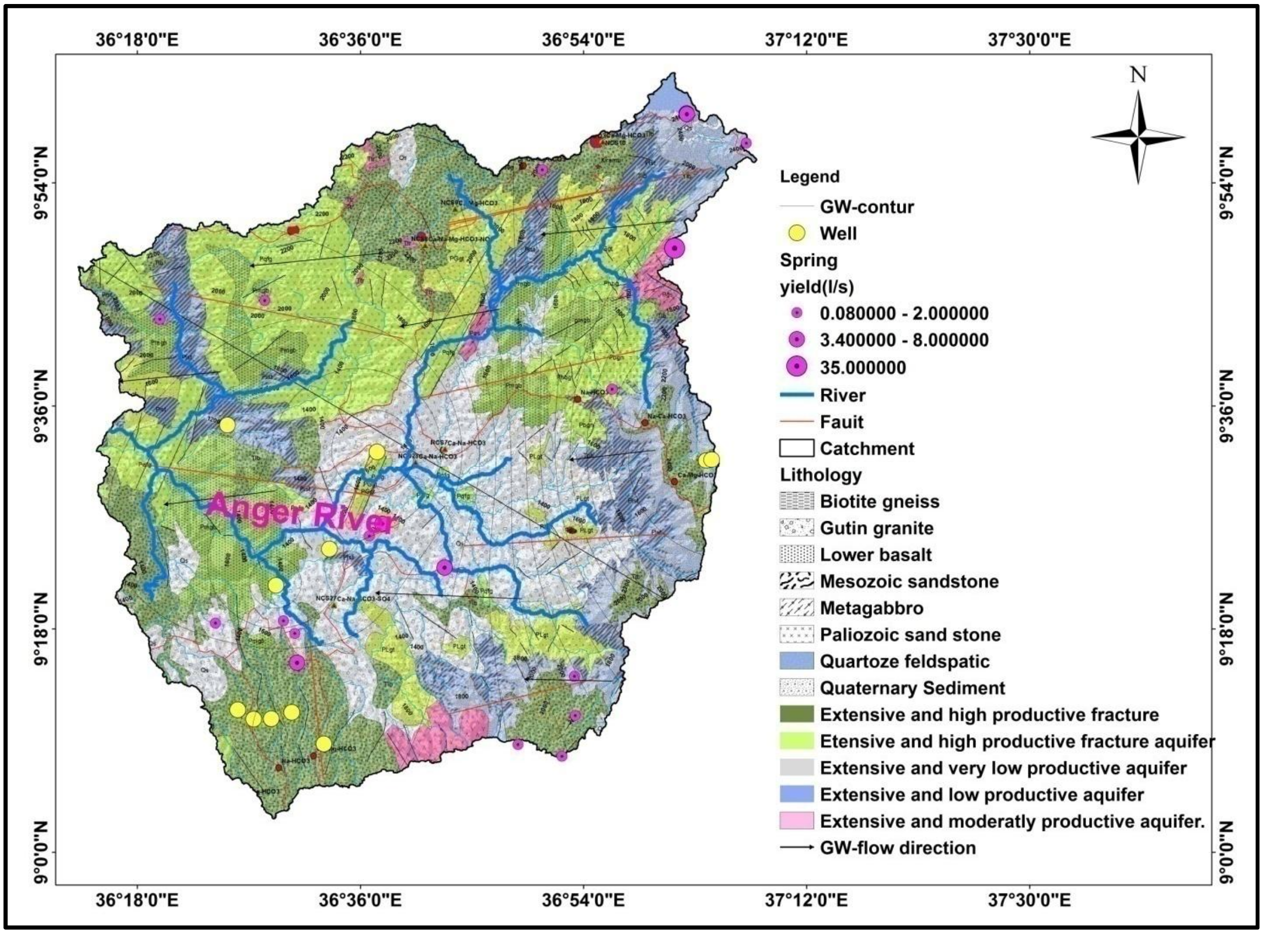


Figure: 5.4. Hydro geological map of study area (Modified from EGS, 2011).

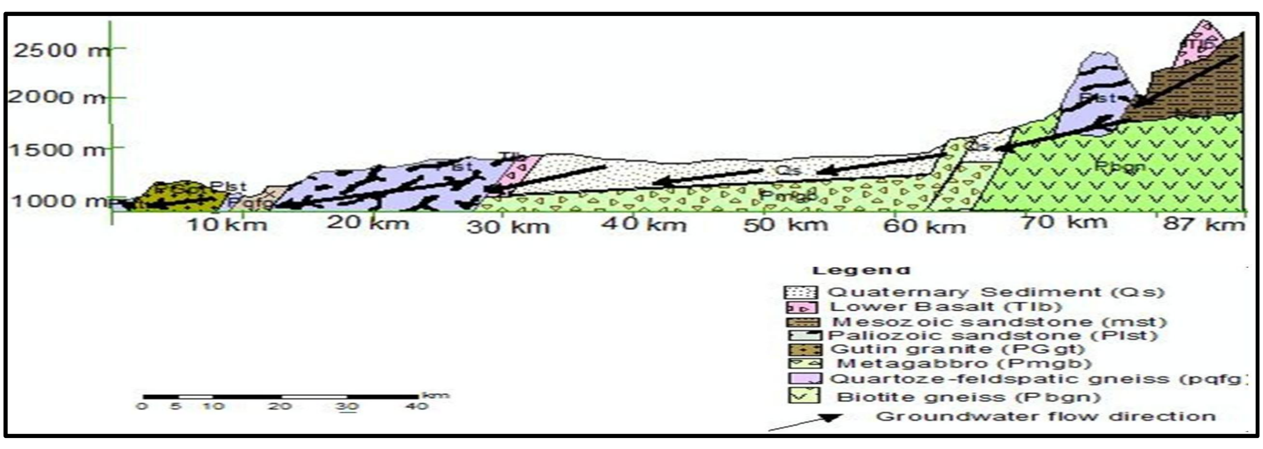


Figure: 5.5 Figure Hydro geological Cross-section of the study area along NE-SW profile**.**

However, this hydro geological stratigraphic cross-section not scaled systematically, but this sequence use to show the litho logical stratigraphic sequence of the study area.

5.4.1. Spring

Springs has formed due to the intersection of hydraulic head in the aquifer system with the land surface. It is the major source of water supply for the Community in the study area. They can access in rugged topography easily as compared to the boreholes drilled by machines. Cold springs mostly emerge along the fracture and weathered layers of basalt due to Topographic breaks or slope breaks.

The yield of spring varies from place to place depending on the geology, geological structure, precipitation, and topographic setting of the area. However, the lineament density in (fig5.3d) varies from place to place and the spring has closely related with the structure of the area. Spring discharge from the lower basalt and Mesozoic sandstone have relatively high yield (0.08-34.93)l/s.(fig.5.4) below that show the spatial distribution of spring yield. The map is the results of spring yield.

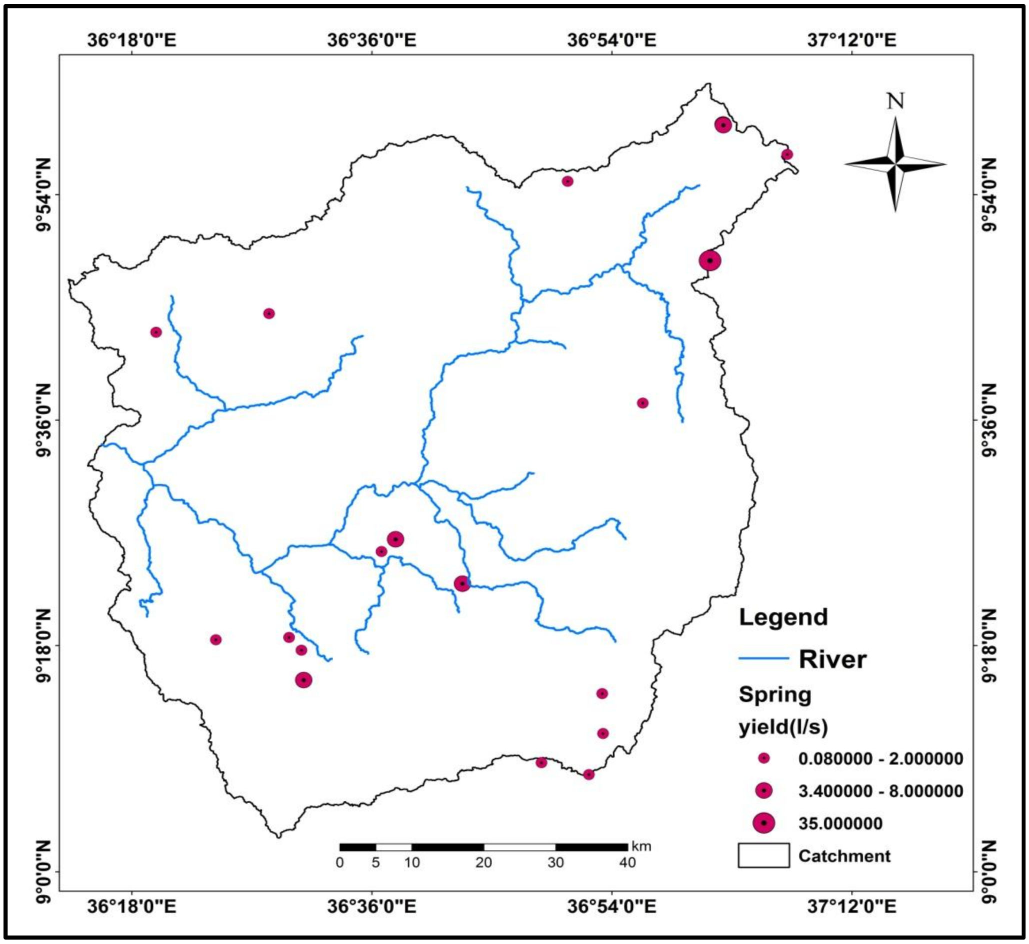


Figure: 5.6. The spatial distribution of spring yield in the study area (Source; OWWDSE).

Table 5.3. Springs Find in the Upper Anger River Catchment (source OWWDSE).

No.	Name(Locality)	Easting(X)	Northing(Y)	Elevation	Yield (l/s)
1	Gashusspringamuru town	285067	1105115	229	3.4
2	Talo	266044	1009710	208	0.08
3	Bujira	268029	1015728	197	2
4	Doboo	267952	1021582	193	0.12
5	Horro	239707	1044411	133	7
6	Agro. Camp	237770	1042624	133	0.4
7	Loko	248860	1037839	139	8
8	Warka	226663	1028211	140	0.6
9	Ambilta	226954	1023839	154	5
10	Badessa	259538	1011485	217	0.9
11	Sankor	207068	1075179	157	0.32
12	Sagiro	222250	1077810	195	0.75
13	Nachino	263669	1096980	203	0.37
14	Hoda gudina	214936	1029838	143	0.21
15	Laga hare	224989	1030099	139	0.41
16	Laga Abba moro	273770	1064282	231	0.247
17	Jardega	283129	1085213	247	35
18	Oftanan	293738	1100759	240	0.124
19	Gassas	285023	1105224	230	5

Remark (Zone; 37, UTM, Adindian)

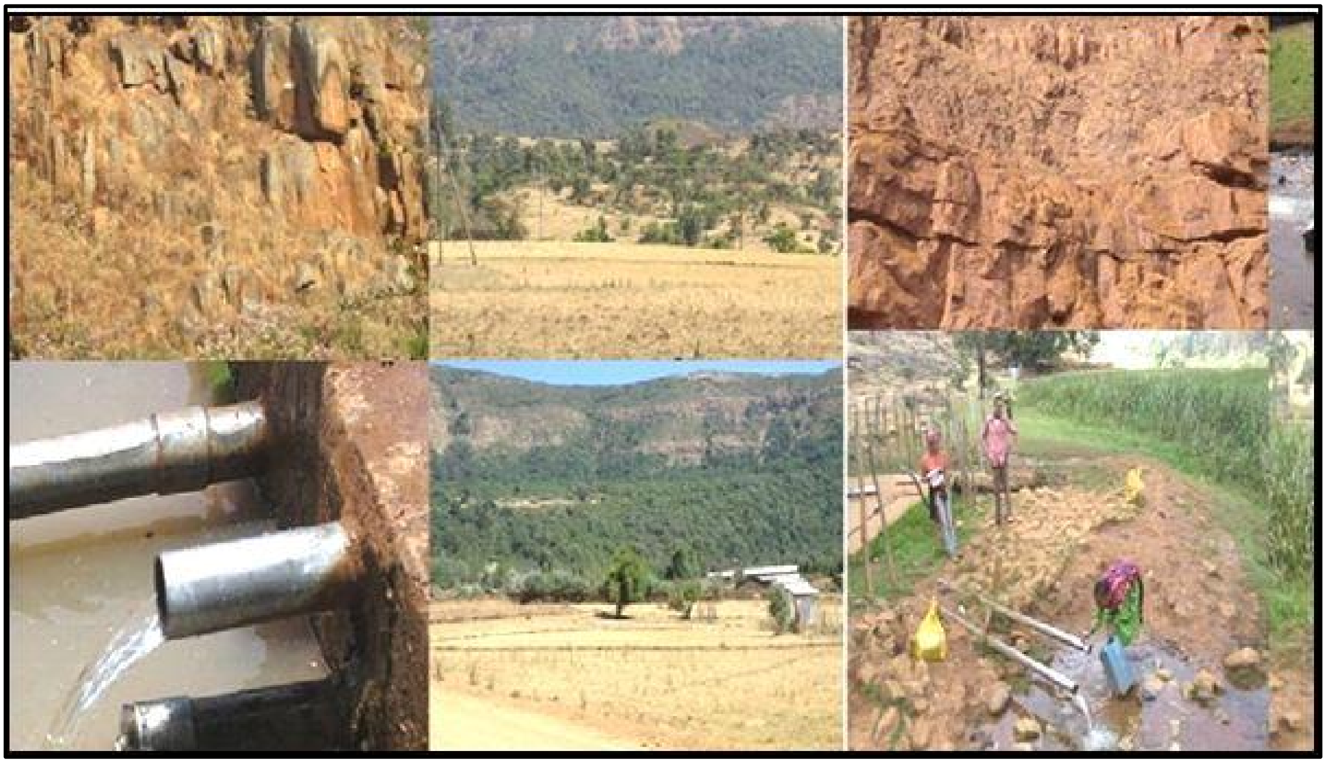


Figure: 5.7.springs find in the study area, with high yield.

6. GROUNDWATER FLOW MODELING

6.1. Conceptual Model Development

Conceptual model (model concept); describes the field conditions assembled in systematic way to describe the groundwater flow and contaminant transport processes at a site. Conceptual model helps in determining the modeling approach and which model software use (Mandle, 2002). Conceptual model describe functional relationships between components with which the system will simplified to model, text or mathematical equation this may supported by means of drawing graphs or diagrams.

Conceptual model is a mental construct or hypothesis that simplifies and summaries what known about the hydrogeology in the form of written text, flow charts, cross sections, and block diagram, and tables. Conceptual model is an expression of the past and current state of the system based on field information from the site and knowledge available from similar sites (Andorsen et al., 2015). Conceptual groundwater flow system is an interpretation of the groundwater flow system, and idealization of real world that summaries the current situation of site conditions and how the groundwater system works frequently.

The structure of the model must, be recorded in the conceptual model. Structure shows the net work of components from which the model is built and the relationships between the components. Concerning with the following components: Input variables (interpolated input data), State the variables and other variables. Choose the type of model, in this step the independent variables must first choose. After deter independent variables, the type of model must selected if space and time are the independent variables, the model can be 1D, 2D or 3D.Define relationship between variables, the relationships show which variables, affect one or more other variables. These may be state variables, input variables or other variables. So this has taken place record must be made here how the relationship is defined mathematically or textually.

Establish the assumption, Evaluation of the success or failure of modeling project will not work without the opportunity to use the supposition hypotheses in the concept in order to interpret the results. A list of all assumptions must set, with a note of why this assumption was set or why it is justified. Verify the conceptual model, if there is a conceptual model; consider whether this concept is the best one, for the given problem, the objective of the model and the available data techniques. Compare a number of concepts with one another in an experimental manner (make and analyze the model in accordance with the various concepts and then compare the results).Therefore the conceptual model should be properly designed to reduce the spent of time and effort.

6.1.1. Hydro Stratigraphic Units

Hydro stratigraphy forms the framework of conceptual model. Hydrologic information used to conceptualize the movement of groundwater through the system (Anderson and Woessner , 1992). Characterizations of the hydro stratigraphic unit conditions are important in the in order to understand the relevant flow or solute transport processes and use to define the number of layers that control the groundwater flow in the aquifer. For the hydro geological investigations, geologic layers or formations often classified into hydro stratigraphic units. A hydro stratigraphic unit consists of the geological units of similar hydro geological properties. Litho logical logs show variable aquifer Litho logy with different degrees of the fracturing and weathering. The aquifer system of the area composed of different volcanic rocks. However due to their permeability hydro stratigraphic units are interconnected hydraulically. Therefore, these hydro stratigraphic units considered as one layer aquifer. Based on the pumping test data and Litho logical logs the aquifer system behaves as an unconfined aquifer system. The hydro geological stratigraphic sequence cross-section looks like (Figure 5.5).

6.1.2 Groundwater Flow Conceptualization

Groundwater contained in and moves through the pore spaces between rock particles in fractures and fissures in rocks. Intrinsic permeability of rocks controls the movement of groundwater. The intrinsic permeability of rocks are due to the primary openings (porosity) formed with the rocks and secondary openings created after rock formed. When the pore spaces in sand and gravel came saturated with water, the water called groundwater (Moore et al., 2002).

Generalized potentiometric surface of the upper Anger river catchment Estimated from the observed wells of water levels in the aquifer. The potentiometric surfaces indicate that the generalized flows of groundwater is from southwestern direction and slightly following the topography of the area. Generally, groundwater flows from areas of high topography (recharge area) to low area of topography (discharge area) through the base flow or stream. However, the general groundwater flow direction of the Anger river catchment is from the northeast to the south west towards the Abay River Basin. The flow line is perpendicular to equipotential line.

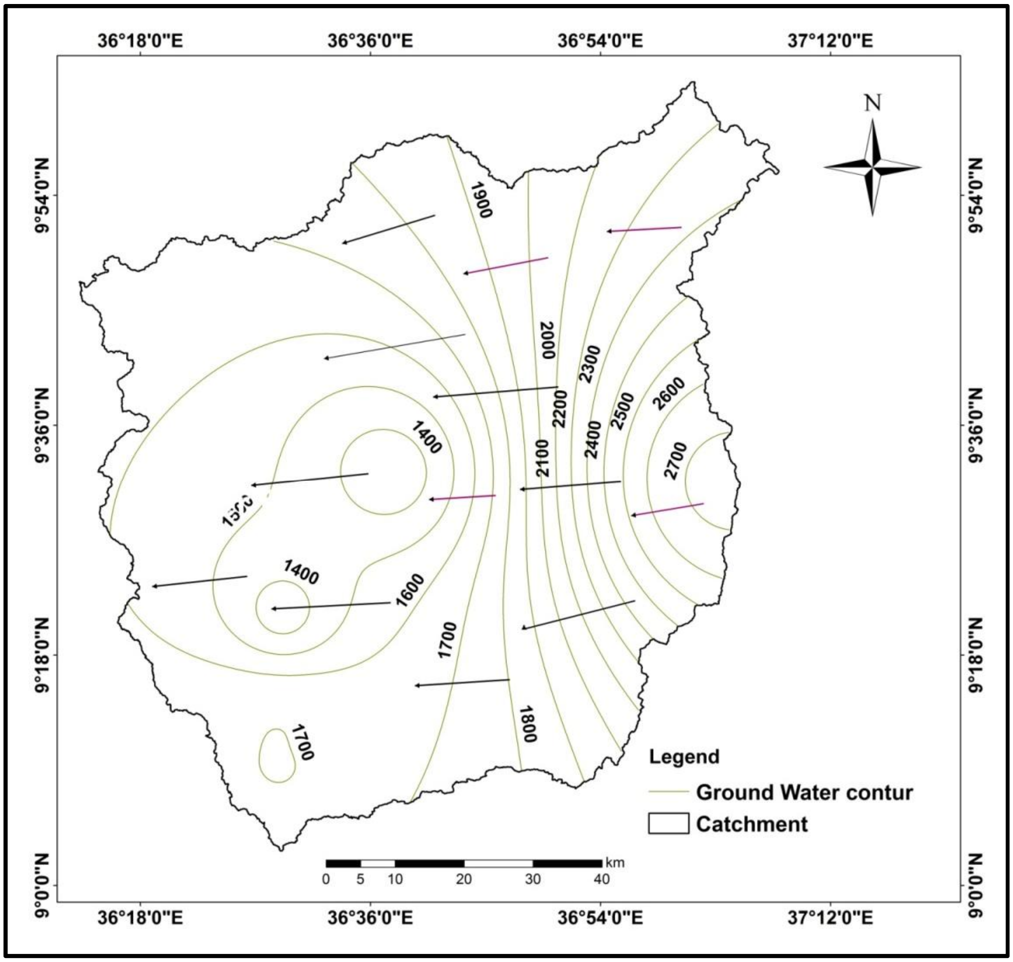


Figure: 6.1.Groundwater level contour map of the upper Anger river catchment.

6.1.3. Boundary Condition

Boundaries identified from potentiometric, topographic and geologic maps of the region and site. The system boundary is the dividing line between the system and the environment. It may often suffice to define the system boundary, preferably in such manner that is the dividing line between the system and environment characterized by clear transition from processes inherent to the system processes not inherent to the system (Anderson et al., 2015).

Specified head boundaries (constant head boundary); specified head boundaries are best used to represent large bodies of water (major rivers, lakes, reservoirs, and oceans)not affected by stress in the system, such as pumping and changes in recharge rate. Commonly specified head boundary condition used to solve for associated discharge in a pumping well. Specified head condition allows the head in the well fixed at the desired elevation for problems involving dewatering without the need to know the pumping rate that will produce that head. h=is constant and q determined by the model. Specified head boundary is implemented by fixing head values at the nodes along the boundary; hence the specified head do not change in response to hydrologic stresses. In steady state models, specified boundary heads are invariant but most codes allow the user to input a time series of heads to update boundary values during transient simulations (Anderson et al., 2015).

Specified flow boundary (Specified flux boundary); specified flow boundary is realized by setting the flow at boundary. Then heads at boundary calculated by the code and can change as the simulation progresses in time. Conceptually, the same hydraulic effect achieved by using either specified head or specified flow conditions. However, it is usually preferable to specify flow rather than head. A specified head boundary fixes the head at the boundary so that flow across the boundary is dependent on the head gradient, which calculated by the model; hence, the calculated flow may not be representative of field conditions. Specified flow boundary, on the other way maintains a constant realistic flow of water into or out of the model, as designated by modeler. q Constant h determined by model.

Head Dependent boundary (Cauchy conditions);-flow across the boundary calculated from Darcy's law using a gradient and calculated as the difference between specified head outside the boundary and the head computed by the model at the node located on or near the boundary. This type of boundary condition sometimes called mixed boundary condition because it relates a boundary head to a boundary flow. Based on Geologic, Topographic, Potentiometric and hydro geological map of the selected site for this activity the boundary conditions identified for the study area. The direction of General Head boundary identified which run from south to western boundary of the aquifer system. Specified flow boundary (no flow boundary) is assigned for the remaining all boundaries.

6.1.4. Groundwater Recharge

Groundwater in unconfined aquifers moves from topographically high areas (recharge) to topographically low areas (discharge). In the recharge area, the potential energy decreases with depth, this results in the downward movement of water from high elevation to lowest one. The SWAT Model used for recharge quantification and variability values. SWAT model give the specific value of the recharge in the study area by considering the Land Cover, Soil type, topography (Slope class) and distribution of precipitation. The total groundwater recharge to the shallow aquifer estimated by using the SWAT Model 338.41(mm/year) and deep Groundwater recharge of deep aquifer 19.44(mm/Year). However, the total annual recharge of the Aquifer for the basin shallow and deep aquifer is 388.92mm/Year (0.010416m/day).As the result in the above figure (4.5) indicate that precipitation is the main source of recharge for the aquifer in the basin.

6.1.5 Groundwater Discharge

Groundwater discharge in the study area occurred through discharging the stream, subsurface outflow, and well withdrawals. Discharge to the stream happen as flow from the spring, seepage and base flow where the aquifers connected hydraulically to the streams (river leakage).All discharge from springs and seepages was assumed to reach stream and contribute to base flow. Well withdrawals are for public and domestic water supplies.

6.1.6 Hydraulic Conductivity

Hydraulic conductivity is one of the most important input parameter used in developing numerical groundwater modeling under steady state simulation. hydraulic conductivity measure the volume of water that move through a porous medium in unit time under a unit hydraulic gradient through a unit measured depends largely on the density of fracture and the width of their apertures. Hydraulic conductivity measure the ability to transfer groundwater from one point to another through its interconnected pores, fractures, conduits and other open discontinuities. It is the function of both fluid and medium.

Assuming a laminar flow, the specific discharge (q), the hydraulic gradient (J) and the hydraulic conductivity (k) are interrelated. linear relationship discoversed in the 1856 by the french engineer Henry philibert Gaspard Darcy and bears his name as darcy's law. it gives acalar quantity, i.e,azero order tensor, for homogenous and isotropic pervious media. the spatial distribution of hydraulic conductivity is known through Lithiologic log of the area these used for understanding the hydraulic Conductive Zone. however the pumping data obtained from the Mineral, Energy and Water Barue of EastWollega zone,Horro Guduru Wollega Zone and OWWDSE used for the interpolation of the hydraulic conductivity aquiufer.To understand the spatial distribution of the aquifer parameter hydraulic condutivity the result classified into six from the existing pump test data analysis 0.381491 to 1.6908470(m/day).

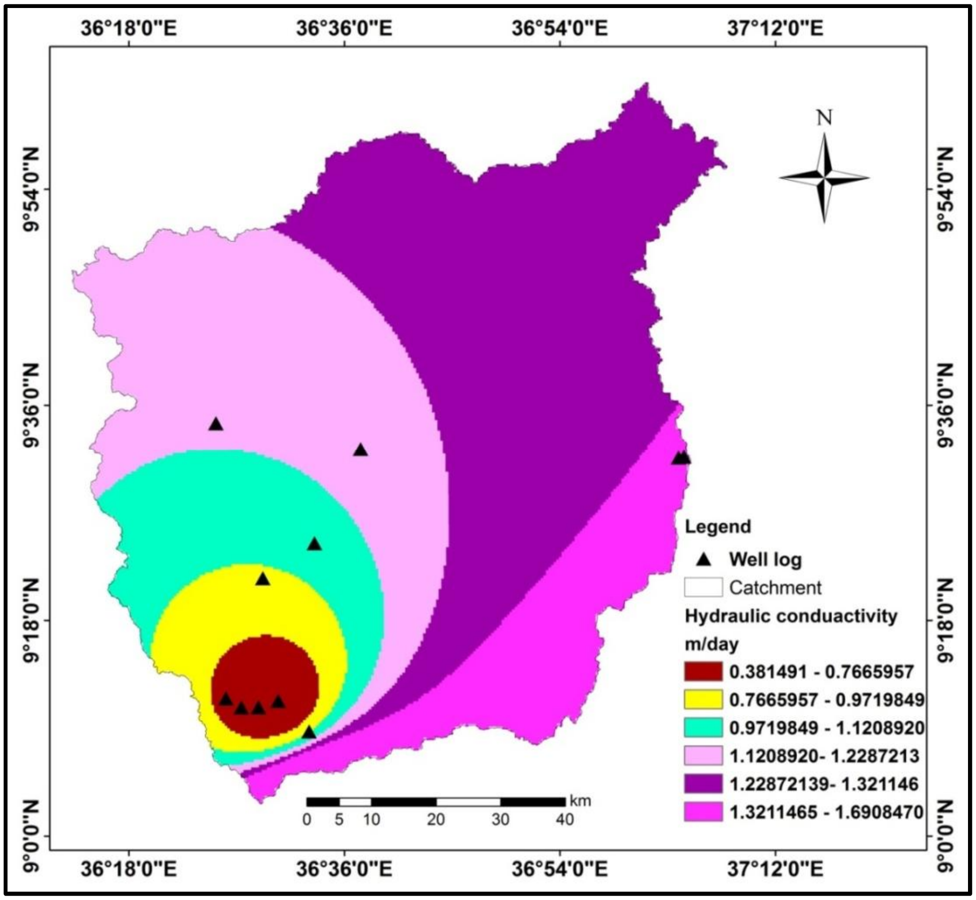


Figure: 6.2.Classification of the hydraulic conductivity (m/day).

6.2 Numerical Groundwater Flow Modeling

6.2.1 General Over View

Groundwater flow models are simplified representation of groundwater system with mathematical equations solved by computer program, yet the simplification based on logical assumptions and without compromise reasonable representation of complex hydrological dynamics. The selection of steady state simulation is, therefore never random selection (Behailu Berehanu et al., 2017).

For this reason groundwater, flow modeling is necessary and powerful tool of groundwater resource management, groundwater protection and remediation.

6.2.2 Governing Differential Equation

The governing Equation for groundwater flow model derived from the principles of conservation mass or water balance, states that water neither created nor destroyed; and Darcy's law, which states that groundwater flows from high to low potential energy. The Mathematical model groundwater flow consist the governing equation that represents the processes within the problem domain, boundary conditions that represent processes along the boundaries, for transient problems and initial conditions that specify values of head at the time of start simulation. The model development based on the well-known three-dimensional flow equation given below;

$$K_x \frac{\partial^2 h}{\partial x^2} + K_y \frac{\partial^2 h}{\partial y^2} + K_z \frac{\partial^2 h}{\partial z^2} = 0$$ ....Eqn.6.1.

Where h is the head, Kx, Ky and Kz are the components of hydraulic conductivity in x, y and z directions respectively.

6.2.3. Model Grid Design

Groundwater flow models require the model domain to be subdivided (discretized) into a grid (mesh)that defines the locations of the points which referred to as nodes at which heads or solute concentrations are calculated and geometry of cells (elements) that controls the circulation of the volumetric or mass flow rate of water and solute(Barnett et al.,2012). The extent of model in the north south to east west is 127000m and 122500m respectively. The total area of the catchment is 7159.21km^2. The lateral dimension of cell is 500m by 500m on each side with 245row and 256 columns in single layer.

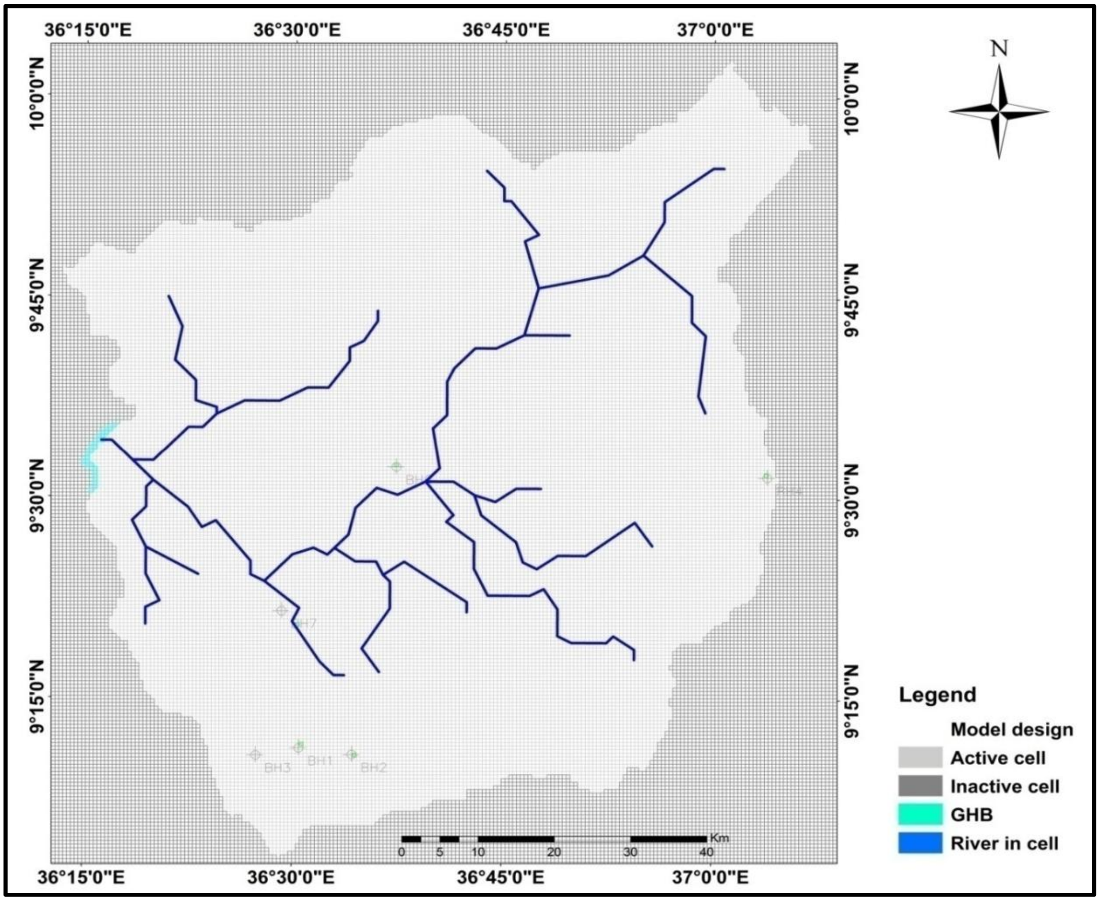


Figure : 6.3. Model grid design.

6.2.4. Top of the Model

The proposed model was single layer and unconfined aquifer system. The top layer of the aquifer assumed elevation of the surface. The 30-meter resolution SRTM used to generate the DEM and converted to the GRD 6Surfare text (grd) for the development of top elevation. After this activity, load the prepared data in grid format to MODFLOW top layer package.

6.2.5. Bottom of the Model

Bottom elevation of the model generated from the top elevation by subtracting certain amount from the top layer. During this time aquifer, have different thickness rather than constant head throughout the proposed model. However, in the selected study area, the aquifer thickness lies between 55to 370m and relatively high amounts of aquifer thickness given to the fractured lower volcanoes.

6.2.6. Initial and Prescribed Hydraulic Head

MODFLOW requires initial hydraulic heads and constant heads at the beginning of flow simulation. Initial hydraulic heads at constant head cells used as specified head values for those cells and remain constant throughout the simulation processes (example. Anger River given constant head through the simulation).The initial head generated by reducing the average of static water level of all the available well data found in the area.

6.3. Modflow/Flow Packages

6.3.1. General-Head Boundary

The General-Head Boundary (GHB) package used to simulate head-dependent flow boundaries (Cauchy boundary condition), where flow into or out of a GHB-cell from an external source is provided in proportion to the difference between the head in the cell and the head assigned to the external source. User specifies the reference head and constant of proportionality called boundary conductance. Linear relation flow into the cell and head in the cell established (Harbaugh, 2005).

$$QB_n=CB_n\ (HB_n-h_{i,j,k})$$ Eqn.6.2

Where n is a boundary number.

QB_n is flow into cell i, j, k from the boundary (L^3T^{-1});

CB_n is boundary conductance (L^2T^{-1});

HB_n Head assigned to external source (L); and

hi,j,k is the head in i,j,k cell (L).

However, in the study, area the heads at or outside the boundary is less than the head in the aquifer. This results in loss of water from the system. Heads with the boundary approximated by the water level altitude of upper Anger River Catchment and the head in the aquifer determined by simulation.

6.3.2. River

The purpose of river package is to simulate the effect of flow between groundwater system and surface water features such as rivers, lakes, or reservoirs. RIV does not simulate surface water flow only the /aquifer seepage (Harbaugh, 2005). In the River package, two elevations specify. That is the lowermost of the riverbed and the bottom of the riverbed. If the head in the cell connected to the river drops below the bottom of the riverbed, the leakage rate QRIV from the river to the aquifer calculated by eq.6.2. If the head is above the bottom of the river, the water flows from the aquifer into the river and is removed from the groundwater system and calculated as Eq.6.2.river bed conductance (Criv) is multiply by the difference between the head in the cell and the head in the river to determine the flux.

$$Qriv=Criv\ (hriv-h)\ \text{if}\ h>Briv \qquad \text{Eq.6.3}$$

$$Qriv=Criv\ (hriv-Briv)\ \text{if}\ h<Briv \qquad \text{Eq.6.4}$$

Where: Qriv, Flow rate between the river and groundwater

hriv= Head in the river

h= head in the aquifer or the model

Briv=elevation of bottom of the riverbed.

Criv=hydraulic conductance of the riverbed.

Kriv=hydraulic conductivity of the riverbed.

L=of the river within the cell.

Generally, the study area Anger River and its tributaries, uke and tato maintain their dry period of flow with contribution of the groundwater. Depending on the collected data from fieldwork activity and estimation, riverbed sediment thickness has range between 0.25 to 1m. River width ranges from 3 to 18m.

$$C_{riv} = \frac{K_{riv} \cdot L \cdot W_{riv}}{M_{riv}} \qquad \text{.........Eq.6.5}$$

Where; Criv= is the hydraulic conductance of the riverbed [L2T-1].

Kriv=hydraulic conductance of the riverbed material [LT-1].

L=Length of the river within a cell [L].

Wriv=Width of the river within a cell [L].

Mriv=Thickness of the riverbed [L].

6.3.3. Recharge

The Recharge package simulates the spatial distribution of recharge amount of groundwater system within the designed model. In the selected study area, the recharging source of Groundwater is only precipitation, except precipitation there is no other recharging well or other artificial recharge processes depending on the result discussed in section 4 above. Aquifer recharge in the catchment is directly from precipitation during intensive rainy season. The Recharge package designed to simulate distributed recharge to the groundwater system and defined by assigning the following data to each vertical column of cells (Chiang, 2005).

Recharge Flux IR [LT-1]

Layer Indicator IRCH [-]

Parameter Number [-]

MODFLOW uses IR to calculate the recharge flow rate (QR [L3T-1]) applied to the model cell;

QR=IRDELR.DECLC...Eqn6.6.

Where: DELR.DELC is map of model of a model cell,

IR is recharge flux.

In MODFLOW, the recharge rate QR applied to a single cell with in the vertical column of cell.

6.3.4. Well Package

The well package that used in this model is the result of analyzed value from the yield of borehole and the average pumping hours. Abstraction of groundwater simulated by using well package and defined by using cell-by-cell method. The sum of pumping or an injection rate of the well is independent of the cell area and hydraulic in the cell

6.4. Model Calibration and Sensitivity Analysis

6.4.1. Calibration

Calibration of a flow model refers to the demonstration that the model is capable of producing field-measured heads and flows from the accomplished set of parameters, such as boundary conditions and stresses that produce simulated heads and fluxes that show how the field measured values match with the per-established range of error (Anderson et al .,2015).

Calibration process involves adjusting of the input (hydro geological) parameters until the field observation of head and fluxes match with the pre-established ranges of error.

However, there are two way of finding model parameter to achieve the calibration target: Manual trial and error calibration and automated calibration using computer software (Anderson et al., 2015). While automated calibration using computer software has available for decades and considered as it increase the reproducibility of calibration process compared to trial- and -error calibration (Barnett et al.,2012).model run by using initial estimation of all model parameter, for the period of time during which historical data exist. The measured head and fluxes compared with the standard model value, numerically, either spatially on map or graphically.

6.4.2. Manual Trial And Error Calibration

Groundwater flow model calibrated by using manual Trial and Error method in order to achieve the actual estimation of the Aquifer properties (Hydraulic conductivity and recharge) until the model run matches the simulated head to calibration target. History matching considered as a hard knowledge of model performance because field measurement directly compared with simulated values. The following figure 6.4below show the general workflow of the manual Trial and Error matching history of calibration.

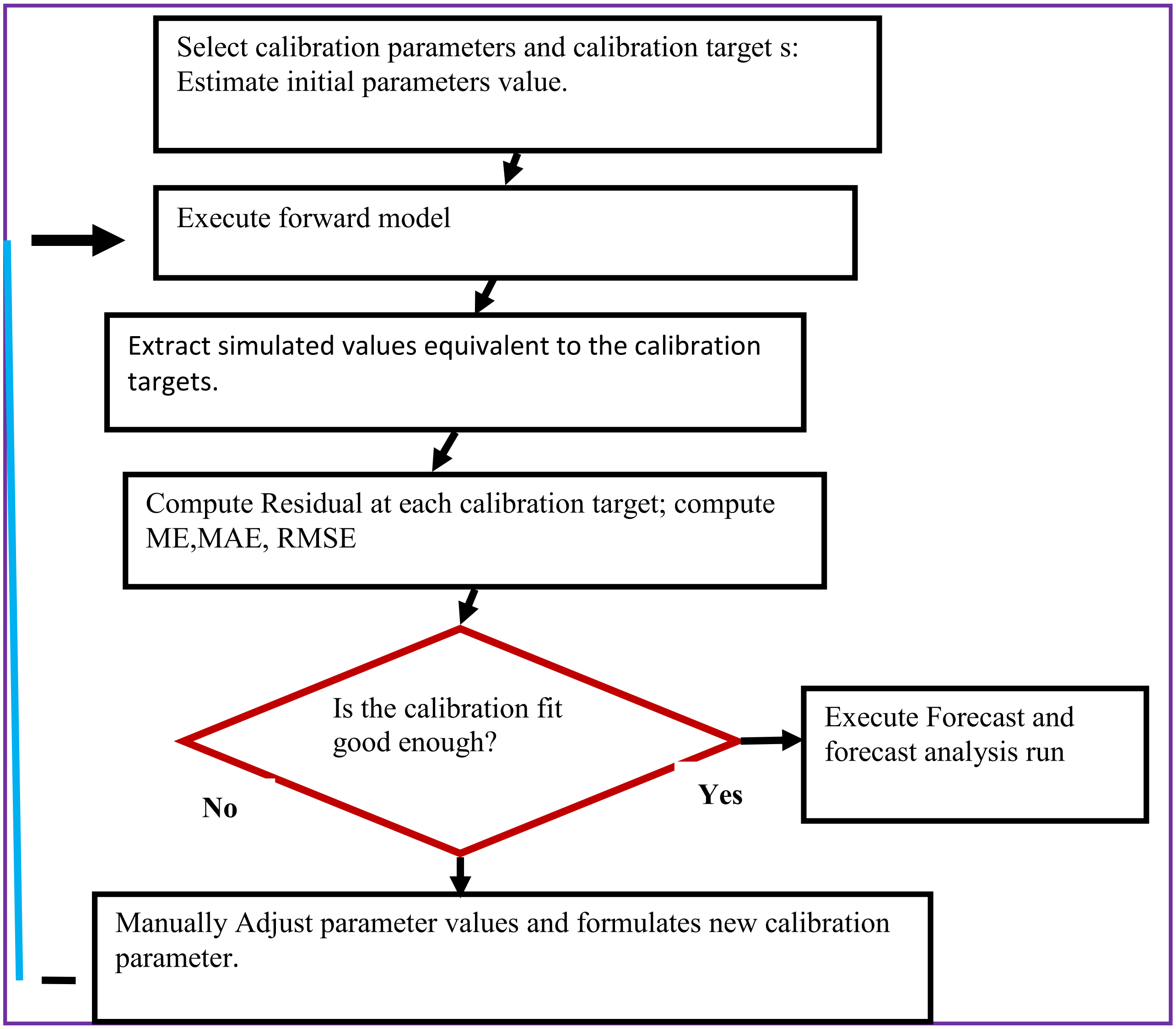


Figure: 6.4 general workflow for manual Trial and Error first phase of history Matching.

a model intended for forecasting (ME, mean error, MAE, mean absolute error; RMSE,root mean squared error)(Adopted from the (Anderson,et al., 2015).

6.4.3. Data Use for Calibration

The Groundwater flow model calibrated by, using the measured water level. The observational data taken from, pumping test used for calibration purpose. However, the water level data (head information) gathered from the pumping test reports while direct measurement of water level is impossible**.** Generally seven water levels or heads used for head observation at the time of model calibration.

6.4.4. Evaluation and Calibration Result

In this model, calibration values evaluated by using visual examination of scatter diagram plots. Scatter diagram plots of Fig 6.5 below show all of predicted heads on the vertical side and the corresponding measured heads on the horizontal side. Generally, the data find along the straight line by overlapping with the origin of slope.

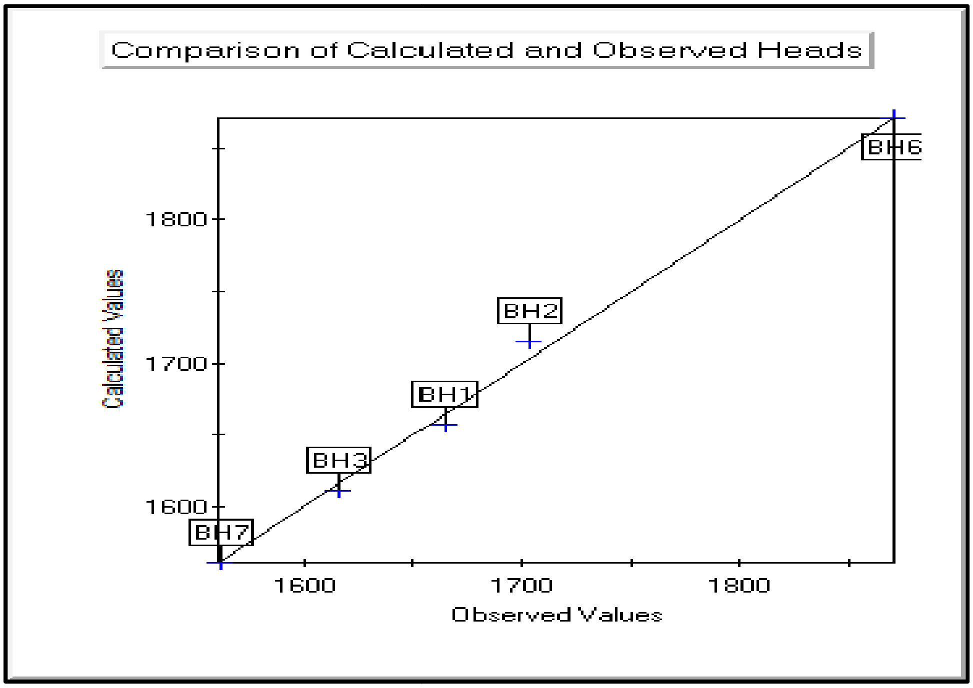


Figure: 6.5.Scatter plots of head Distribution of Calibrated Model.

However, in addition to the visual examination of scatter diagram plots statistical has calculated to measure the goodness fit. Quantities of the statistical summary indicate that statistical lumped sum description of average difference of residuals between measured and simulated heads, in the ways of;

1. Mean Error (ME): is the mean difference of the residual errors (measured heads and simulated head).

$$ME = \frac{1}{n}\sum_{i=1}^{n}(hm - hs)i \qquad \text{Eq.6.7}$$

2. Mean absolute error (MAE); is the mean absolute values of the difference between the measured heads and simulated heads (residual).

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |hm - hs|i$$

Eqn6.8

3. Root Mean Squared Error (RMSE): is the square root of averages of squared difference between the measured heads and simulated heads (average of squared residual).

$$RMSE = \sqrt{\left[\frac{1}{n}\sum_{i=1}^{n}(hm - hs)^2 i\right]}$$

Eqn6.9

Where n= is number of targets.

hm=is the measured head.

hs=calculated head and n= is number of head measurement.

Table:6.1 Summary of Calibration statistics.

No	Statistical Parameter	Error
1.	Mean Error (ME)	-0.3388
2.	Mean Absolute Error.	5.2476
3.	Root Mean Squared Error.	6.7673

6.4.5. Sensitivity Analysis

Model is more sensitive for the increasing of recharge and decreasing of hydraulic head. In the simulation of groundwater flow modeling there are two sources of uncertainty. The first one is the uncertainty associated with the model itself and the second is uncertainty associated with the accurate specification of feature conditions. The first source of uncertainty from the assumptions made in conceptual model measurement error in observations used to calibrate the model, simplifications required by calibration and simplification error result resulting from defects in the parameterization of the model selected. The next source of uncertainty arises when forecasts needed to estimate feature stresses and properties.

Examples of uncertain parameters are the future recharge rates, future pumping schedules and locations of future source and sinks, as well as related to the non-hydro geological factors (Anderson et al., 2015). In general, the purpose of uncertainty is to quantify the uncertainty in the calibrated model caused by uncertainty in the estimates of aquifer parameter, stresses and boundary conditions, which performed by systematically changing the calibrated values (Anderson et al., 2015).

In this study of groundwater flow model, sensitivity analysis progressed by changing the parameter values. While changing the parameter the model shows different inclinations. This aquifer parameter like; recharge, hydraulic conductivity and pumping well by decreasing and increasing by fixed amount the calibrated model. Sensitivity graph produced by the absolute value of mean residual water level against changes from the calibrated value in percent shows, the model is more sensitive for hydraulic conductivity, and recharge. While both the hydraulic conductivity and recharge increased by 20%, 30%, and 40% from the calibrated value. In addition, recharge is more sensitive than hydraulic conductivity when it multiplied by 1.25,1.4, and 1.6 of the calibrated value there is a change. Pumping well sensitivity is constant throughout the sensitivity values. In general, the sensitivity analysis shows that recharge and hydraulic conductivity are more sensitive. The figure below show model sensitivity to both recharge and hydraulic conductivity.

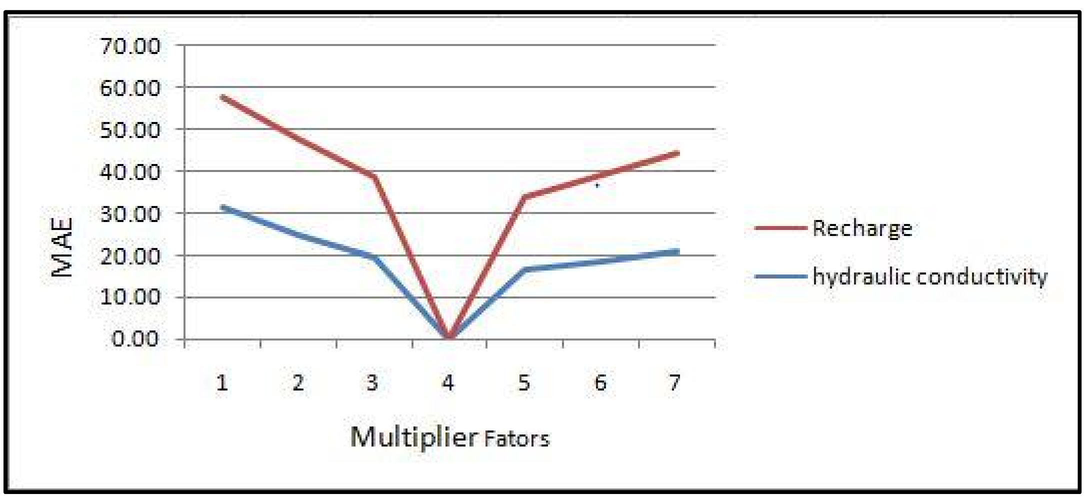


Figure :6.6.Sensetivity Analysis test on the recharge and hydraulic conductivity.

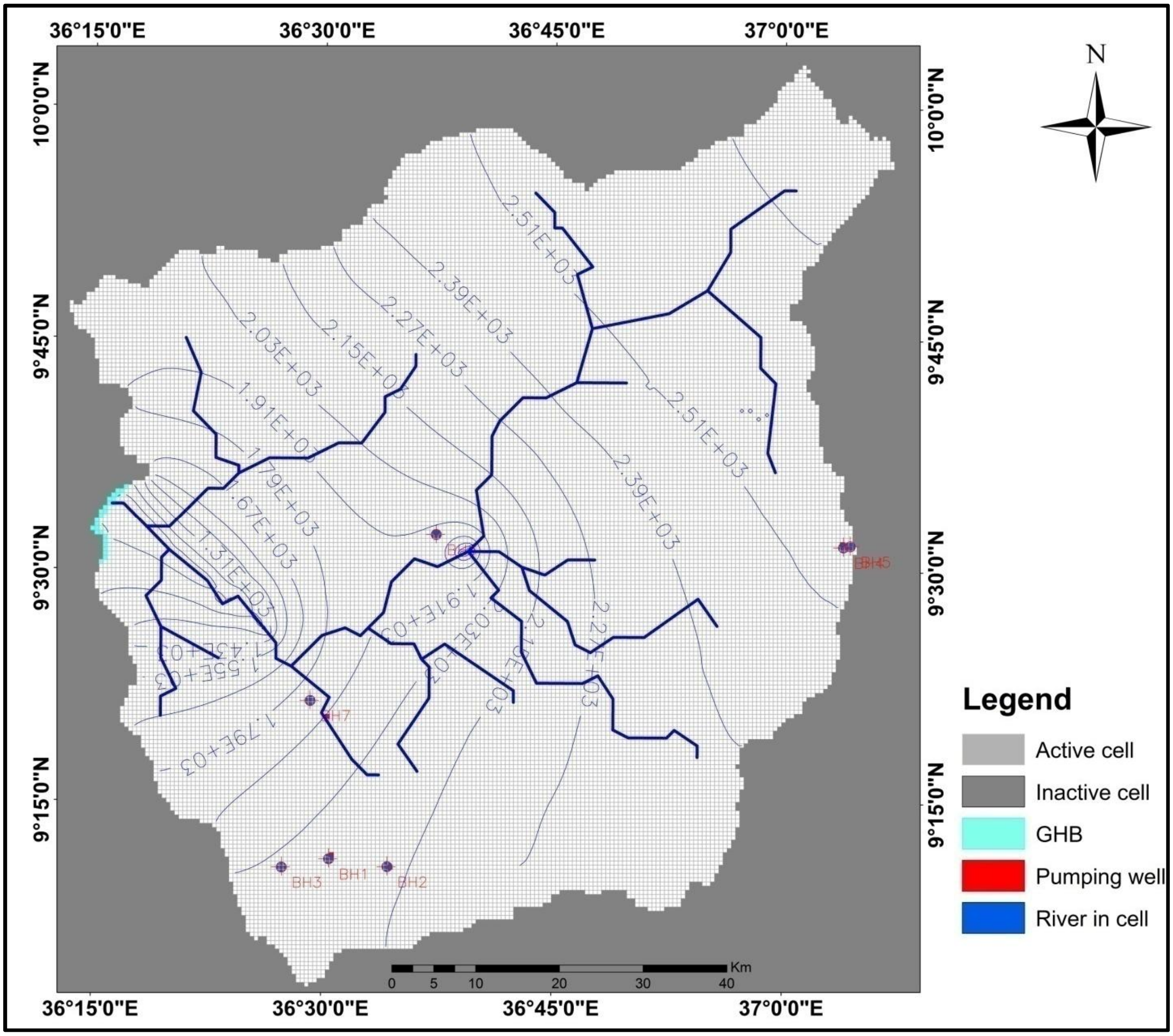


Figure: 6.7. Simulated groundwater contour map.

6.4.6. Pumping Scenario Analysis

The response of Groundwater system estimated under different groundwater abstraction rates and pumping scenarios function. The response of groundwater system compared with the change in the water level (drawdown) and groundwater out flow from the model domain. However, there is no excess data the recorded about groundwater abstraction information. For scenario analysis, production boreholes assign with different pumping rate. In the pumping scenario model the abstraction rate increased by 25%, 50, 75%, 100% and 200% based on the need of groundwater consumption. The average of groundwater decline when the withdrawal of 25%, 50%, 75%, 100% and 200% is 1.58, 1.87, 2.33, 3.04 and 4.69 respectively. The general pumping scenarios executes and result for the changes of groundwater balance components summarized in the table below.

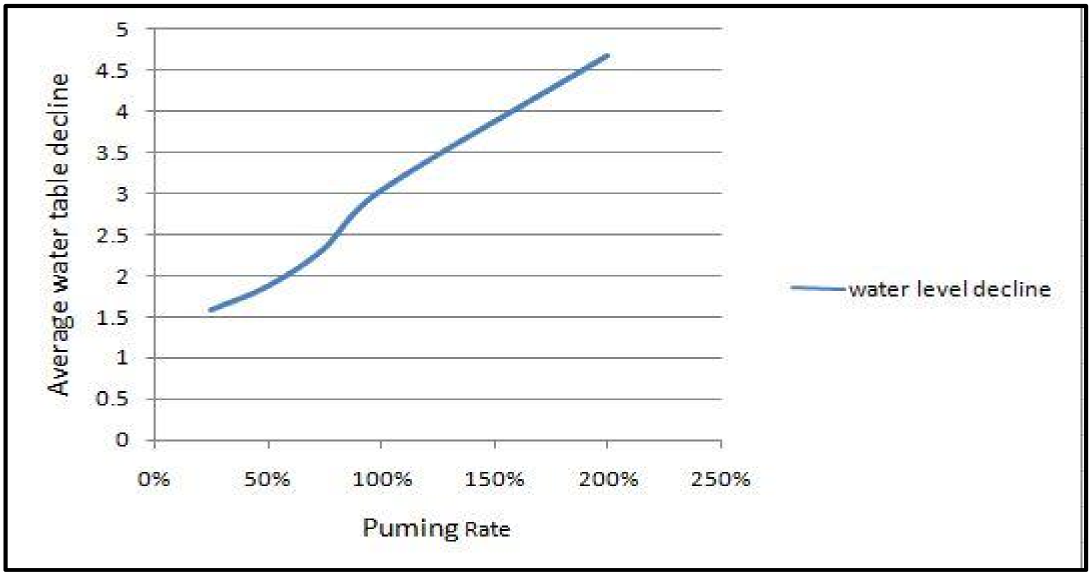


Figure: 6.8 Aquifer response for the increased ground water withdrawal.

Table. 6.2. Result of pumping scenario Analysis.

Scenario	Flow component	IN (m^3/day)	OUT (m^3/day)	Difference with respect to base model (Outflow)	Change in out flow with respect to the base model (%)
Scenario 1 Increasing pumping by 25%	Well	0	1.2035520E+03	- 1.2035520E+03	-25
	Recharge	7.0798162E+05	0		
	River Leakage	8.0121438E+04	8.8795988E+05	-4189.87	2.062055
	Head dependent boundary	1.0073366E+05	0	1.0073366E+05	
Scenario 2 pumping Increasing by 50%	Well	0	1.9811520E+03	- 1.9811520E+03	-50
	Recharge				
	River Leakage	5.8961234E+04	2.3610768E+06	- 2.3021155E+06	3.095525
	Head dependent boundary	1.7955469E+05	2.8534934E+03	1.7670119E+05	0.145302
Scenario 3 pumping increased by 75%	Well	0	1.9811520E+03	- 1.9811520E+03	-75
	Recharge	1.4113422E+11	0	1.4113422E+11	0.001
	River Leakage	0	3.9050199E+13	- 3.9050199E+13	1.753
	Head dependent boundary	0	8.7786848E+11	-8.7786848E+1	1.007
Scenario 4 pumping increased by 100	Well	0	1.2035520E+03	- 1.2035520E+03	-100
	Recharge	7.0798162E+05	0	7.0798162E+05	0.136
	River Leakage	8.0121438E+04	8.8795988E+05	- 8.0783844E+05	0.001052
	Head dependent boundary	1.0073366E+05	0	1.0073366E+05	0.546234

6.4.7. Water Budget of the Model Domain Result

Water budget is the result of the model output, in the form of outflow and inflow from parts of the enter array model domain in head dependent boundary. The outflow includes, wells, river leakage, and heads dependent boundary condition. Whereas the inflow model domain consist the regional recharge and head dependent boundary condition.

Depends on the modeling, result the relationship between the inflow and outflow model domain is strong because of the foot lines of the Gedo Kara balbala and Komto silase mountain, find in the northeast part of the study area. The flow direction toward the river is different due to the interaction of stream-aquifer and groundwater withdrawals. The model domain water Budget result shown in Table 6.1 below the groundwater input data comprised by 0.3% of the total input water in the entire model domain of the study area.

The water budget of the model domain used to quantify and determine all flows in and out of the Aquifer structure. The water budgets of the model area quantitatively evaluate the amount of Groundwater through the Aquifer system. However, the inflow and outflow components of groundwater system is impossible to determine directly both components since computed by the computed by model. Model calibration progressed through Trial-and Error approach until the simulated head fit the observed head values.

The hydraulic conductivity values for the Upper Anger River Catchment of Abbey Basin obtained from the pump test data analysis. These pump test data used for the evaluation of well properties rather than aquifer properties and the result obtained from the model is in accurate to represent the whole area of the model. The hydraulic conductivity values taken from the pumping test data analysis indicate high spatial variation throughout the region of the study area. The whole model domain classified into to three sub-basin in order to understand water budget of the basin differently.

Table 6.Water Budget summary for sub region under steady state problem calculated by MODFLOW.

Sub region		Daily (m^3/d)		
	Flow term	IN	OUT	IN-OUT
Subregion1	Wells	0.0000000E+00	5.6419202E+02	-5.6419202E+02
	Recharge	1.5201000E+06	0.0000	1.5201000E+06
	River Leakage	3.5500000E+03	8.1642710E+06	-8.1607210E+06
	Head dependent boundary	3.8898918E+04	1.2084652E+05	-8.1947594E+04
Sub region 2	Well	0.0000	6.3935999E+02	-6.3935999E+02
	Recharge	1.4465250E+06	0.0000	1.4465250E+06
	River Leakage	0.0000000E+00	0.0000000E+00	0.0000000E+00
	Head dependent boundary	0.0000000E+00	0.0000000E+00	0.0000000E+00
Sub region 3	Well	0.0000000E+00	7.7759998E+02	-7.7759998E+02
	Recharge	5.2780250E+06	0.0000000E+00	5.2780250E+06
	River Leakage	0.0000000E+00	0.0000000E+00	0.0000000E+00
	Head dependent Boundary	0.0000000E+00	0.0000000E+00	0.0000000E+00
	Sum	8.2870990E+06	8.2870985E+06	2.5036621E-01
	Discrepancy [%] 0.00			

6.4.8. Model Limitations

Groundwater flow management and policy decision making based on the knowledge of past and present behavior of the groundwater system. The accuracy of the groundwater model results depends on the input parameter either spatially or temporally. However, the model input parameters are estimated by approximation of field situation and the model is calibrated under steady state condition; it may not use for the interpretation. Nevertheless, it gives more detail information to understand the response of the aquifer system under different hydro geological parameters. Generally, due to the lack of well-documented hydrological and hydro geological data the uncertainty is high. Moreover, the model is not use for groundwater management purpose. The hydro geological data limit the quality of model.

7. CONCLUSION AND RECOMENDATION

7.1. Conclusion

Groundwater is the major source of water supply in the upper part of Anger river catchment. In fact, groundwater is simply the subsurface water that fully saturates pores or cracks in soils and rocks. Most groundwater is contained in and moves through the pore space between rock particles or in rock fractures and fissures, because of this groundwater management and policy decision making require detail understanding of groundwater potential and development.

In the study area one layer and unconfined aquifer system simulated under steady flow condition by using the MODFLOW software. The upper part of Anger River Catchment Basin delineated from ASTR DEM with 30m resolution by using Soil Water Assessment Tool (SWAT). Well completion reports gathered from office to determine the Regional groundwater flow system and the response of Aquifer for different Scenarios. Annual recharge of the deep and shallow Aquifer of the catchment calculated by using SWAT soft ware, and 388.84mm/year are the result of the SWAT.

As determined from the water level points the Groundwater flows from the Northeast to South-West by following the topographical variation and structural orientations. The boundary of the study area represented cell by cell, each cell size has 500 by 500m and grouped into 245 rows and 254 columns. Model used to study the response hydrologic system, two scenarios increased withdrawals used to understand the system. The model calibrated by Trial-and-Error method using groundwater contours produced from different head in 12 observation wells. The calibration shows that the hydraulic conductivity and recharge are more sensitive during history matching of the measured head with model standard.

The effects of groundwater determined with respect to the changes on the stream leakage, subsurface out flow and groundwater heads as compared to the steady state simulated result. Calibration result determined by using visual examination of scatter graph and quantitative summary statistics. The model calibrate to mean error (-m); absolute mean error (m) and root mean squared error (m).

The model calibration result show the good fit between groundwater level observation and simulated heads. Model parameter of Sensitivity determined during the calibration activity. Depends on the calibration process, the model is more sensitive to decreasing change in recharge than hydraulic conductivity. Scenario modeling executed, by different groundwater abstraction rates. Decreasing and increasing aquifer recharge as part of the forecast. The system response compared with the resulting change in water level and groundwater outflow from the model.

For pumping scenarios analysis, production of boreholes ordered with different pumping rate. Based on the need of future water consumption, four stages of pumping scenarios model run with increased abstraction rates under steady-state condition. In the scenarios-model, the abstraction has increased by 20%, 40%, 60% and 80%. Increased the steady-state well discharges by these rates resulted in irrelevant declines in groundwater levels in most cases of the model domain.

The model scenarios of the rainfall inputs of SWAT result has changed to evaluate the impacts of variable rainfall on groundwater recharge. Aquifer system response to different parameter to decrease and increase groundwater recharge rate evaluated by using heads of the calibrated model baseline and compared with the resulting values in the water table elevation in the new scenario simulation. The difference of the aquifer recharge play great role in changing the water level and fluxes. Model simulation result of the regional water budget of the model domain is varying with the model parameter.

7.2. Recommendation

I would like recommend the following points:

- Model should verify to improve the overall reliability and usability of the model. It is important to re-evaluate and update the model when new field data are collected.
- MODFLOW soft ware used as the monitoring tool for the development and management of groundwater system.
- Hydrogeology and geology of the valley should study in detail through further data collection for the future development of groundwater resource, since groundwater is the main source of water supply in the area.

- Water supply well data should be record and reported time to time in the data base to determine (understand) variation of seasonal and annual borehole condition.
- Use the SWAT to represent the system in realistic situation, and classify the aquifer system into different layers and evaluate their hydrologic response unit (HRU).
- The model results can use as input parameter for contaminant transport modeling studies to determine the effects future land- use variation particles or diffuse pollution scenarios.

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ANNEX:I. Thesis Originality Test Report.

NAME OF STUDENT	ASNAKECH GOSHUU OLIKA.
ID NO	GSR/2726/10
STREAM	Hydrogeology
THESIS TITLE	Groundwater Flow Modeling in the Upper part Anger River Catchment.

	Particulars	Test I		Test II		Test III		Test V		Average					
1	**Abstract**	Originality%	Plagiarism%	Originality	Plagiarism %	Originality	Plagiarism %	Originality	Plagiarism %	Originality	Plagiarism%				
2	**Chapter 1**	100	0							100	0				
3	**Chapter 2**	100	0	100	0					100	0				
4	**Chapter 3**	100	0							100	0				
5	**Chapter 4**	100	0	100	0					100	0				
6	**Chapter 5**	100	0							100	0				
7	**Chapter 6**	100	0	100	0	100	0	100	0	100	0				
8	**Chapter 7**	100	0							100	0				
Over all Thesis										100	0				

	Name	Signature	Date
Student	Asnakech Goshuu		
Advisor	Prof-Tenalem Ayenew		

Signature _________________________ Date______________________

School of Earth Science

May, 2019

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ANNEX:II. Regional lineament density

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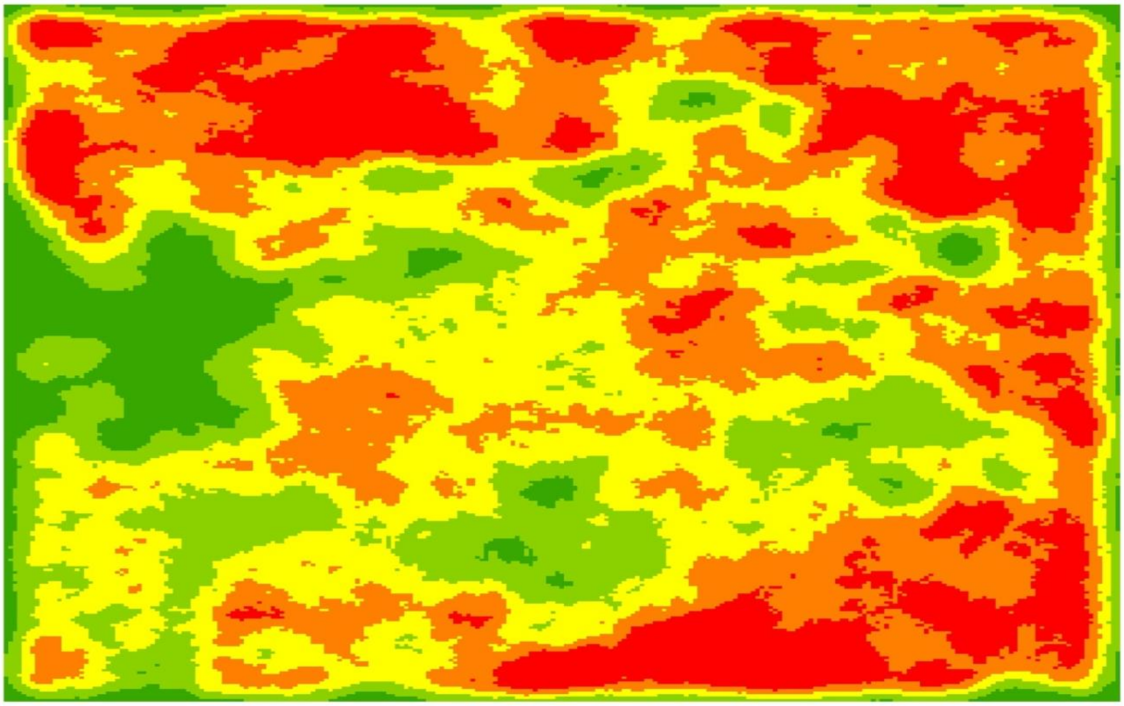
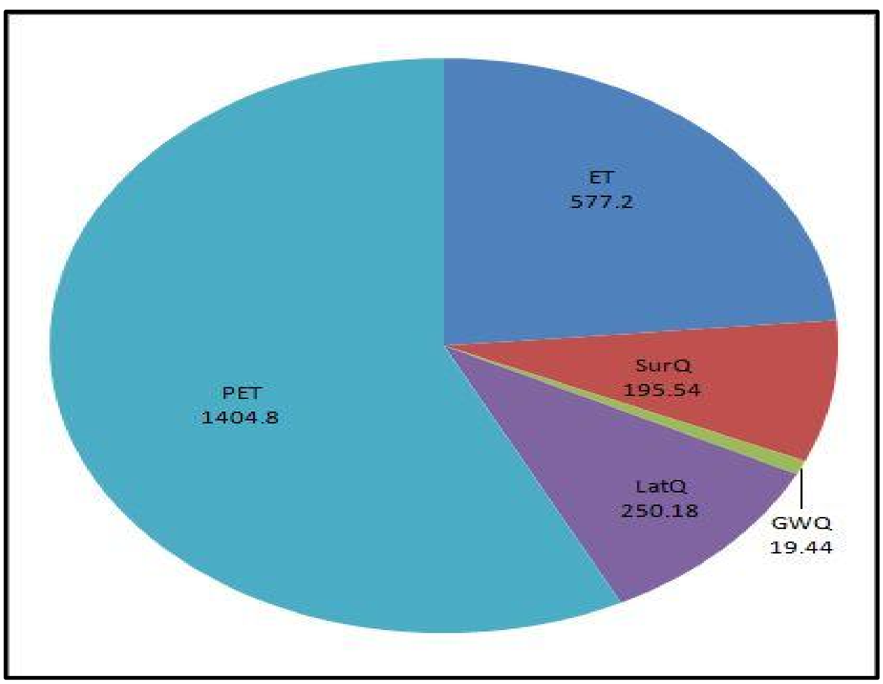


ANNEXIV: Pie diagram shows the water balance components of SWAT result



No	Site Name	Location(m)			Depth (m)	SWL(m)2	Q l/s	T(m²/d)	K(m/ d)	Sc(m/d/ m)	Aquifer formation
		Easting (m)	Northing (m)	Elevation (mbgl)							
1	Nekemte1	232006	999156	1938	160	12.75	6.2	15.41	0.33	16.76	Basalt
2	Nekemte2	231781	999520	1942	134	23.85	27.82	164.16	3.91	90.00	Basalt
3	Nekemte3	231936	1000096	1945	166	23.05	7.83	71.28	1.32	57.00	Basalt
4	Sire1	266656	996573	1736	101.5	38.33	21.65	513.86	17.6	80.92	Basalt
5	Sire2	266632	997181	1740	104.5	9.5	9.34	50.47	1.42	20.04	Basalt
6	Sanbatdure	223088	1015565	1725	82.45	21.83	45.27	0.63	14.3	12.53	Basalt
7	Tsige	226118	1016499	1685	90.55	20.85	4.53	12.96	0.38	12.57	Basalt
8	Shambu#1	287604	1053587	2729	340	1.19					Basalt
9	Shambu#2	288412	1053724	2740	370	6.5					"
10	Shambu#3	292848	1061504	2362	287	27.24	30l/s				Basalt
11	Kiramu#1	261631	1099396	1983	150						Basalt
12	Kiramu#2	261393	1099274	1975	55						"
13	Dipo site	223915	1035395	1360	59.8						"
14	Mandar14 sit	238986	1055201	1342	105	1.85	5.6				"
15	Dhagajigii	245493	1069159		67.8	7.8	2	3.45			"
16	Laku	26159	995287	1593	224	3.02	15.7	15.1			"
17	Gabasenbat	218125	1016938	1678	146						"
18	Sinaguso	343424	1083808	2292	203	34.9	2.8				Basalt
19	Bikila	318354	1026323	2233	230	41.3	5				Basalt
20	Aga/guda	321372	1035677	2218	120	2	5				Basalt
21	Abdatschool	230682	993678	1944	54.8						"

22	Godahara	278930	1016447	1963	60						“

Annex: V, table Well completion report data.