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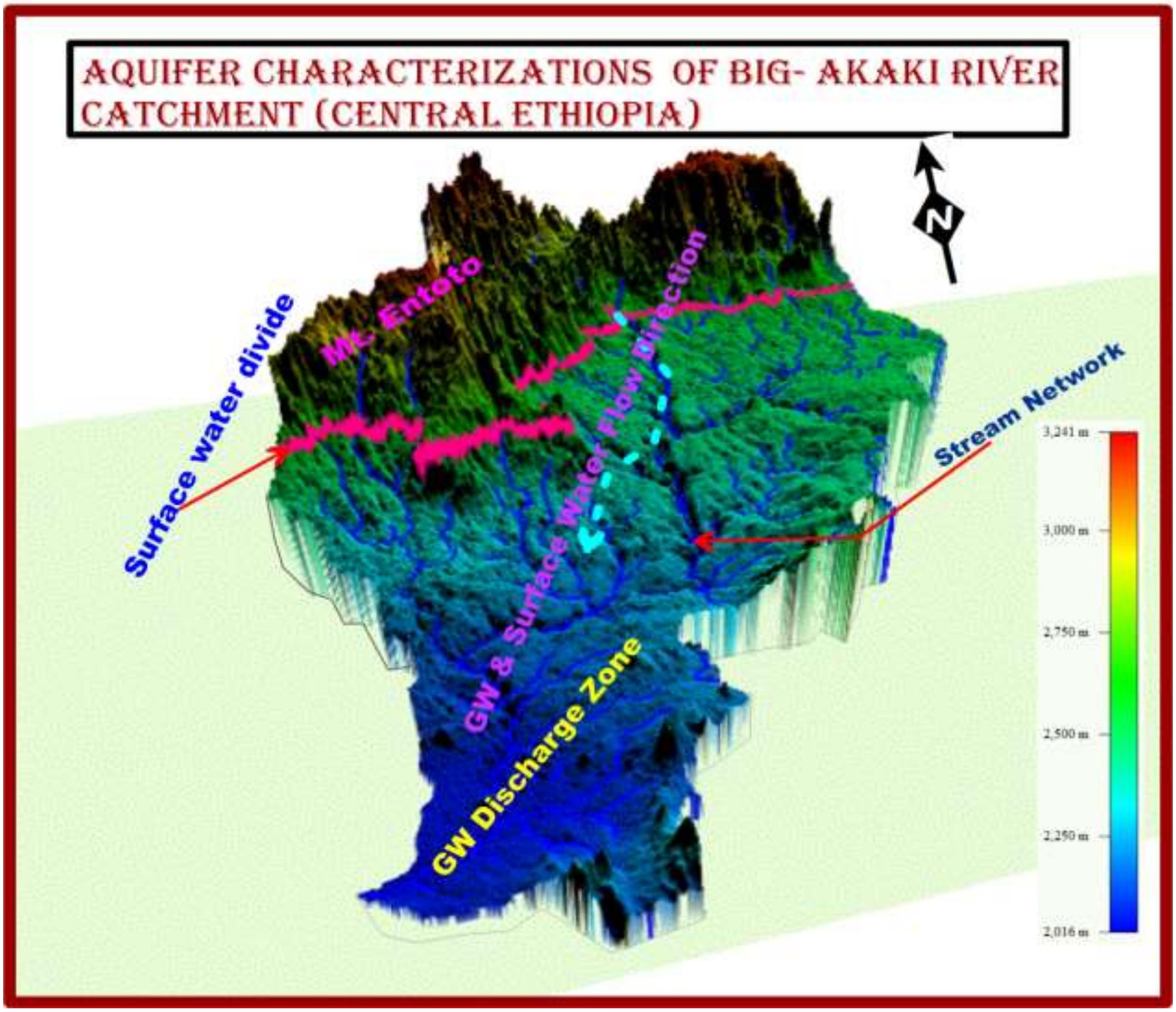

JUNE 2022

ADDIS ABABA UNIVERSITY
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AQUIFER CHARACTERIZATIONS OF BIG- AKAKI RIVER CATCHMENT (CENTRAL ETHIOPIA)

A THESIS SUBMITED TO THE SCHOOL OF GRADUATE STUDIES ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF SIENCE IN HYDROGEOLOGY

BY

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Advisor: DR. TELAHUN AZAGEGN

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By; Wasihun Kibret

A Thesis Submitted To the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydrogeology

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List of Acronyms

AET	Actual Evapotranspiration
BFS	Base Flow Separation
DEM	Digital Elevation Model
M/s	Meter per second
FAO	Food and Agriculture Organization
GPS	Global Positioning System
M2/d	Meter square per day
m.a.s.l.	meters above sea level
m3/s	meter cubic per second
MA	Meteorological Agency
MER	Main Ethiopian Rift
mg/l	Milligram per litre
MoWIE	Ministry of Water, Irrigation and Energy
PET	Potential Evapotranspiration
R	Runoff
RAP	River Analysis Package
SSH	Sun shine Hour
SWL	Static Water Level
TDS	Total Dissolved Substances
GW	Groundwater
WWDSE	Water work design and supervision enterprise

ABSTRACT

The study area covers (big akaki) that situated in upper awash basins and it is part of sub- akaki river catchment, akaki catchment has massive drainage system mainly composed of Big and Small Akaki River. The two rivers meet at the man- made reservoir called Aba Samuel reservoir. The Akaki River gauged at Akaki Bridge and flows to Awash River. The study asses the Groundwater system of big akaki catchment using different approaches by estimating groundwater recharge, characterizing the groundwater system based on the hydraulic properties, ground water occurrence and hydro geochemical signature. The precipitation conditions of the area show bimodal rainfall type.

The groundwater system and aquifer characterized based on hydraulic parameters and pump testing results (transmissivity, hydraulic properties, specific capacity, safe yield, water level, drawdown, depth variation and aquifer thickness to evaluate aquifer system of the investigation area. Hence, the transmissivity and hydraulic conductivity is maximum at akaki and legetafo well fields while lower or minimum at central western of the catchment. Additionally groundwater occurrence of the catchment classifying based on intergranular and fissured aquifer. Highly productive intergranular aquifer contains chefe donsa phyroclastic and alluvial sediments while fissured aquifer unit is mostly Addis Ababa basalt , Addis Ababa ignimbrite and entoto becho rhyolitic rock units. The aquifer system also classified based on productivity nature in which highly productive, moderate and low productive zones of the aquifer catchment identified. The hydrochemical signature of the catchment characterized based on spatial variations of anions and cations, hydrochemical facies, water type and chemical evolution entire catchment.

Aquifer characterization described as the process of evaluating the transport characteristics and chemistry of aquifers. The study area is part of rift volcanic margin and covered by different geological sequence especially volcanic rocks like basalt, rhyolites, ignimbrite, tracky basalt and volcanic deposition. These above listed lithologies mainly occurred as on both the surface out crop and forming subsurface volcanic strata and used as ground water reservoir of subsurface aquifer. Dominantly the ground water system of the study area may transmitted through interconnected spaces that make the regional ground water flow, this is due to the highly porous and permeable formations and structures found (fault, joints, lineaments and fractures) .That the area is part of the rift system, which is tectonically active to produce different geological structure.

CHAPTER ONE:

1. INTRODUCTION

1.2 BACKGROUND

Water is the most precious resource and abundant compound on earth's surface, covering more than 70 percent of the planet. The role of water in many human activities including agriculture, industry, domestic uses, power generation, transport and recreation makes it priceless commodity (*Abebe et, el. 2011*). Moreover, know a day's water resources demand has been increasing rapidly in alarming rate accompanied with the issue of supplying adequate water to meet social needs as the most significant challenge. The growth of population and the expansion of the different industries, agricultural sectors and different economical purpose have significantly increased the demand for water resources this case will expected in the study area (big-akaki river catchment). The problems arise when the water is insufficient to meet the demand or polluted. Extensive development in various sectors has resulted in certain impacts on the high demand of clean water in some areas In addition, climate change may be a contributor to the water supply problem as it changes the availability, quantity, and quality of water resources, thereby influencing the entire cycle of water supply. Groundwater is a good source of fresh water that used to fulfill basic population needs.

The study area big-akaki river catchment is part of whole akaki catchment and upper awash basin that has a high contributor of groundwater supply sources for the towns, villages and others that found in this basin and surrounding localities. Additionally the area is located in the central Ethiopian highlands at the western edge of the Main Ethiopian Rift (MER), *(Ayenew, 2008).*

In the study area, the rift volcanic rocks basalt, rhyolite, trachyte and volcano clastic deposits (pyroclastic materials, tuff material, volcanic ashes, and ignimbrites) are dominantly occurring. The volcanic lava flow (basaltic materials) is mainly occurring at and near the study area. Volcanic rocks are igneous rocks originating from magma that has erupted at earth surface. Magma flowing over and crystallizing at land surface called lava.

In many part of the study area lava flows and volcanic domes (scoriaceous domes) are exhibited as a surface lateral and vertically extended layers and have variable thickness.

The other part of the volcanic rocks especially basalt covers most part of the study area and it is jointed, fractured and weathered type of rock whereas the akaki and Gelan condominium scoria domes (caldera) contains void which filled by air and porous basic rock which covers large area, Although the soil profiles are visible.

Groundwater occurs in geological formations with sediments and rocks in effect forming a subsurface reservoir or aquifer in which groundwater can be accumulated and transmitted. The hydrogeological properties, porosity and permeability, of geological layers and their spatial distribution vary for many reasons, the type of rocks or sediments, cracks and fissures within the rocks and the depth of burial. The availability of groundwater depends on hydrogeological setting, which may be very variable, even within a single lithology. Because groundwater usually an important source of surface water.

Additionally Groundwater occurs in openings in rock materials in the form of pores, or voids, or fractures that constitute the porosity of the material. Nearly all rocks, whatever type, origin or age, possess some degree of porosity.

Therefore, groundwater can be finding in all geological environments. If 'useful' groundwater occurs in rock material, then this called an aquifer. Usually Aquifer referred to as an underground layer or bodies of saturated rocks or geological formations through which volumes of water find their way (permeability) into wells and springs. (An aquifer is defined as a geological formation (or sometimes part of a formation or a group of formations) that contains saturated material of sufficient permeability to yield 'useful' quantities of water to wells (*C.W. Fetter, 1994*).

1.3 Objective of the work

1.3.1 General Objective of the work

The main purpose of this work is to characterize aquifers in the big Akaki catchment based on groundwater occurrence, hydraulic properties of aquifers and hydro chemical signature.

1.3.1.1 Specific objective of the study

- ✓ Develop conceptual hydrogeological model from geological description and borehole lithology
- ✓ Recharge estimation from hydrometeorological data
- ✓ Characterize aquifer and hydraulic features based on pump test data
- ✓ Hydro chemical Characterizations of Groundwater

1.4 APPROACHS AND METHODS

1.4.1 General Approach

The study assesses the Groundwater system of big - akaki catchment with different approaches these are estimating groundwater recharge using meteorological data analysis, Groundwater occurrence based on lithological, structural, ground water flow direction interpretation, and characterizing the aquifer system using hydraulic parameters of pump test data and developing spatial analysis (transmissivity, hydraulic conductivity, specific capacity's, etc.)

Hydro geologic logs that leads to recognizing the aquifer system properties. Moreover, classifying the aquifers based on the productivity nature using hydrogeological units, developing a conceptual model. Finally, hydro geochemical spatial Analysis anions and cations of big akaki catchment made identifying the water type.

Generally, converging evidences from hydrology, geology and hydrogeology with that of the Hydrochemistry data the relationship between the groundwater systems of the catchment can be study. The work methodologies listed as pre fieldwork, Field observations and post fieldwork applied. Under each methodological steps detail description of the study take place. Collecting of secondary data (reports, maps, etc.), primary data measurement (qualitative hydrogeological features, identifications of exposures, measuring water level and insitu parameters) and finally organizing and analyzing of the data obtained also conclusion and recommendations.

1.4.2 Detailed Methodology

The methodologies of the research will involve the following;

1.4.2.1PRE-FIELD WORK

In starting phase, (pre fieldwork) different works was prepared. Like Literature review of all existing researches conducted on the study area to assess the gap and get useful data for the study, collected different secondary data such as pumping test data, borehole logs from reports, and meteorological data collected from AAWSA and river flow data obtained from ministry of water. Collect, modify and develop maps such as; topographic maps, geologic maps, satellite images etc. Additionally delineating watershed and define the boundary of the catchment using digital elevation model.

1.4.2.2 FIELD WORK

Field observations and measurements or primary data undertaken from the study area this includes, Recording Existing well locations, Measuring Water level and measuring of physical parameters of groundwater chemistry (TDS, EC and PH), Qualitative evaluation of hydrogeological features and description of geology, topography, and location of recharge and discharge areas. Although, field observations and descriptions of geological Structures. Taking photographs of exposures and structures.

1.4.1.3 POST FIELD WORK

After field observations, data organizing, processing and analyzing all collected data. The assembled data well organize and analyze for successful outcome investigation. Water balances estimate using different parameters of hydrologic condition includes; (precipitation, temperature, wind speed, relative humidity and sunshine hours) used to calculate the PET and AET.

Hydrograph separation from river gauging station data interpreted, regional and local geological evidences was collected from different literatures and reports and organizations that has contributions for the hydrogeological conditions of big akaki catchment.

In addition, the hydrogeology of the area designated as using detail characterizing of aquifer units, which are found in the area and model them to represents and having contribution for the overall aquifer system of the area, this aquifer units also characterized by diagrammatical model representations that constructed using existing borehole data with help of software analyses.

by utilizing different software applications includes; *ArcGIS (Esri)10.3* software is widely used to analyze DEM, creating shape files and analyzing satellite imageries. The processing of Dem is using to develop topographical and stream network, analyzing shape files like roads, towns, land uses, geological and hydrogeological maps. Also analyzing and produce different spatial maps like (transmissivity, hydraulic conductivity, safe yield, specific capacity, Tds, ph., Ec, cations and anions). Geo-statistical analysis tools develop these spatial distributions. In addition, conceptual model (cross sections) developed by Arc GIs, Global mapper and excels software's in combination; in which well lithological and pump test especially ground water level used as an input.

To fulfill this study basic and significant detail hydrogeological data also collected are includes; transmissivity, hydraulic conductivity, discharge, water level, draw down, well lithology and depth of existing wells are widely used. Also hydro geochemical data includes; physical parameters (ph., EC and TDS), measure Cations (Na, Mg, K, Ca) and anions (COH3, NH4-, S04-, I, Fe, etc.*)* are used and evaluated all map.

Additionally *surfer software* used to visualize 3D view surface topography, *Microsoft Excel 2010*, to, develop graphs, to organize and analyses different raw data including; meteorological, hydrogeological and hydro geochemical. *Shlumberger Aquitest, 14.0* used to analyze pump testing raw data to produce pump test diagrams for classifying hydraulic parameters easily. *RAP 3.0.8.0* version software (River analysis package) software used to estimate the recharge and analyses base flow separation graph. *Shlumberger Aquachem, 14.2software* categorize water types and plot diagrams and charts like piper (for water type analysis) and wil cox (for salinity and SAR) analysis.

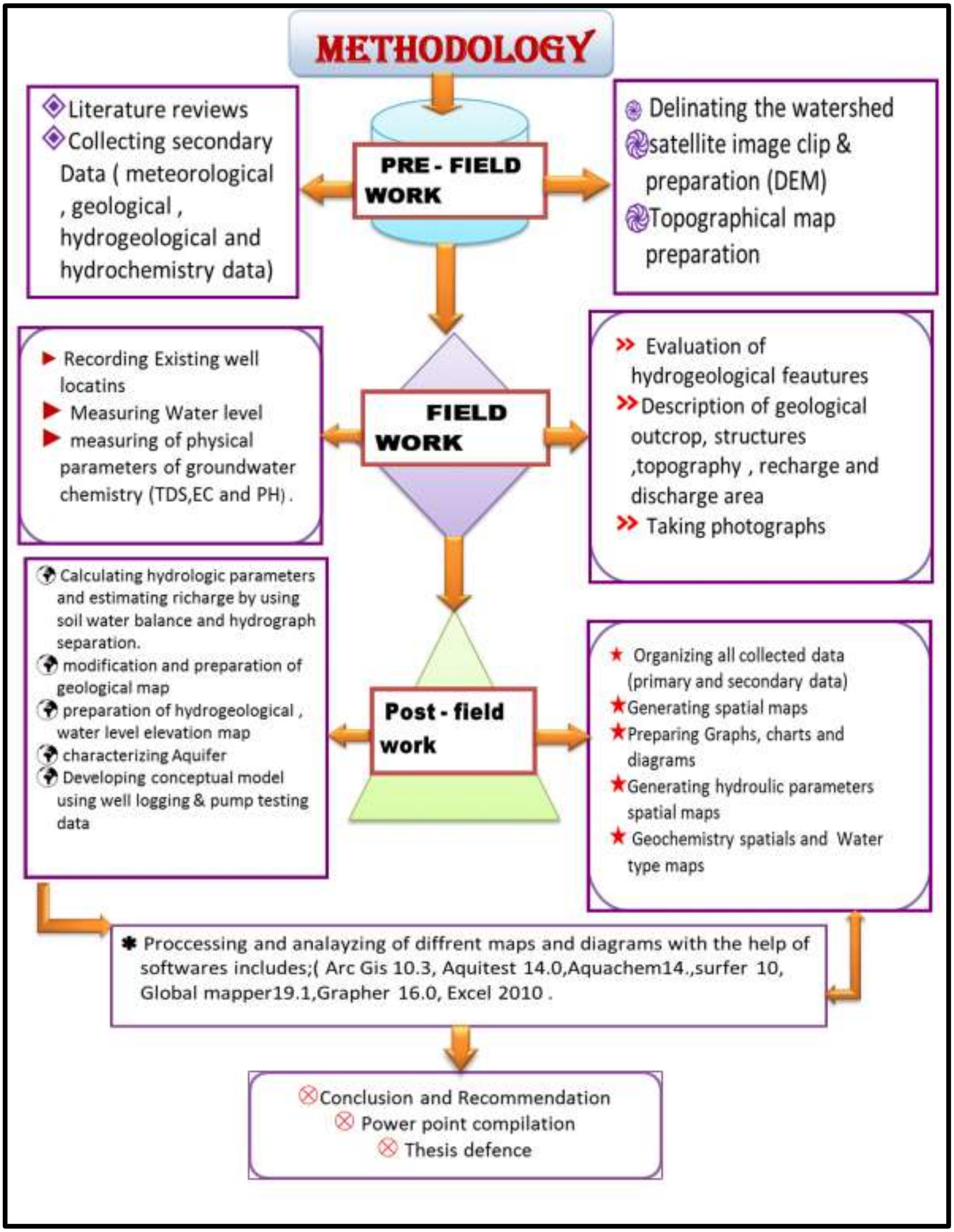


Figure 1; Flow chart shows the general methodological overview of the whole study

1.2 Literature Reviews

An aquifer is a saturated geologic unit that is permeable enough to yield economic quantity of water to well *(Kruse and Rider, 1990)*. In addition, aquifer a given geologic media is largely a function degree of weathering, fracturing and faulting, the nature of geologic material, sediment grain size, degree of sorting and packing. Although lateral and vertical extent, distribution of geological formation play a great role /in characterizing the aquifer of a given area (*Hussein, 2006)*,

Recharge estimate for the Upper Awash basin ranges from 51.5 to 157 mm/year and the two southern left-bank sub-basins of the Middle Blue Nile basin, (Mugher and Jema) ranges from 86 to 239 mm/year according to (*Berehanu1, 2017.*)

In addition, the significant flux joining the Upper Awash groundwater system from part of the Middle Blue Nile basin, which is almost 37% of the total annual recharge to the Upper Awash basin, makes this part of the Middle Blue Nile basin an important recharge zone for the Upper Awash groundwater. a conceptual model should consist of the source of water as well as the expected flow directions and exit points (*Ebasa, 2006*).

Type and extent of water bearing zone, aquifer hydraulic parameters, system boundary, flow system (groundwater levels), fluxes (recharge), sources (addition) and sinks (abstraction), initial conditions(*Kassa, 2015*). Proper utilization of the groundwater, the water beneath the surface of the earth, becomes increasingly more important all over the world as a sustainable method managing water resources (*Foster et al., 2003*) The presence of permeable geological formation, Bottom confining beds and lateral confining beds (barriers) are important for the storage of ground water (*Freez and Cherry, 1979*).

Groundwater has long-been used as a community water supply in the Akaki catchment including The Addis Ababa city, currently approximately over 25 percent of the water supply to the city comes from groundwater, particularly from the Akaki well field located in the southern part of the catchment (*Demlie 2007*). Future population growth and industrialization would make the case more pressing (*Alema, 2009*).

The borehole logs show variable lithology and degrees of fracturing the pumping test data indicates that the catchment is consider as unconfined aquifer with varying specific yield (*Efrem, 2010*).

Generally, by using Different techniques and approaches for developing groundwater models of upper awash and surrounding basins was studied by numerous researchers, this includes;

Application of Numerical Modeling for Groundwater Flow System Analysis in the Akaki Catchment, Central Ethiopia by (*Tenalem. A et.al, 2007*), Groundwater Dynamics in the Left Bank Catchments of the Middle Blue Nile and the Upper Awash River Basins, Central Ethiopia by (*Telahun A. 2014*) ,Water chemistry and groundwater of akaki catchment interaction sekelo basin (*Ayenalem , 1999*), Steady state groundwater flow contaminant transport modeling of akaki well field and surrounding catchment (*Alema, 2009*), Aquifer characterization of Addis Ababa and adjacent highlands *(Fanuel seyoum, 2007),* Aquifer characterization of akaki Debre-zeyt volcanic rocks *(Assefa, 2007),*

Physico-chemical pollution pattern in Akaki River basin, Addis Ababa, Ethiopia (*Ferezer, 2012),* Analysis of Subsurface Contaminant Transport in Akaki Well Field and surrounding *areas, Central* Ethiopia *(Guddisa, 2007),* Characterization of aquifers and hydrochemistry in volcanic terrain of central ethiopia *(Mekdes .N, 2012)*

Numerical Groundwater Flow and Nitrate Transport Modeling for the Prediction of Impacts of Land Use Changes on Water Quality in Akaki Catchment by *(Ayinalem, 2015*), numerical groundwater flow modeling of akaki river catchment by *(Ebbasa,2006),* A study on the hydrochemical and environmental investigation of Addis Ababa region (the Akaki catchment) was done by Birhanu (*Gizaw, 2002*).

Impact natural and anthropogenic stresses on surface and groundwater supply sources of the Upper Awash Sub-Basin, Central Ethiopia (*Birhanu et.al, 2021*), Litho-structural control on inter-basin groundwater transfer in central Ethiopia by (*Azagegn, et. al 2014)* integrated Groundwater Modeling and Hydrochemical Study in Addis Ababa Area by (*Tenalem, et. al 2007*). Those enable determination, evaluation and model of the ground water system of upper awash basin. The overall study that was carried out in this basin was very applicable. However, mostly the previous studies concentrated on small scale or wide area coverage these leads to hide the concerning part of an area. Additionally since due to these detail aquifer characterizations for catchment or watersheds is vital for groundwater management system.

The increasing of population and expansion of town has an impact in groundwater system of an area these problems happen in the study area particularly in akaki catchment and surrounding localities.

The increasing of GW exploitation, abstraction, demand and the problem of water resources for community has in unbalanced circumstance. In these scenarios, the government exploits GW for community and private sectors for their own purpose exploit GW in un-appropriate way, where us the water supply problem in community is very concerning case and relation to this the GW level depleted through time. What solution takes in to consideration?, High abstraction of ground water leads high demand of water, the populations of the area mostly using groundwater source or water supply directly for various proposes like drinking, for industries, agricultures and for different constructions.

Additionally the expansions provide problems directly or in directly to the groundwater system by increases the runoff during high or low intensity precipitation because particularly the Addis Abeba town now a days have paved floor due to different foundations and asphalt roads these may leads to the restricting or controlling local recharges.

Particularly in the Akaki, well field the number of wells are highly increasing through time new boreholes are adding year to year. Hence the previous wells are mostly shallow wells that are ranges (from 10 – 200m) depth that has tap water from shallow aquifer units and has good yields during earlier. Generally characterizing the aquifer of this catchment has a vital role in understanding the groundwater system and used as an input for the groundwater management.

1.6 Statement of the Problem

In most part of our country the aquifer miss-management is a series case these is because populations and organizations have no good awareness and information how to manage and wise use of groundwater resource this issue indicates to future ground water scarcity and aquifer expose. .

In our country aquifer, characterization mostly done on large scale while there exist significantly different types of lithologies at different locations (sub water sheds). Therefore, characterization and classification of aquifers is of paramount importance systematically classifying aquifers based on groundwater occurrence, hydraulic parameters, and mechanisms of recharge and hydrochemical signature of an area. Many functional boreholes exist in the area and ground water exploitation trend is highly increasing due to rapidly growing population size, industrialization, irrigation and subsequent rise in water demand.

The abstraction of groundwater resource in well fields of Akaki catchment currently not based on understanding of drawdown levels and available potential groundwater resources in the area. Meanwhile, this mismanagement of groundwater resource and over exploitation in the Akaki catchment has caused continuous decline of groundwater level. Topographically most part of the study area is wet land this makes the area suitable for urban expansion and agriculture.

Land use land cover of the study area lacks incorporating potential ground water exploitation areas (well fields) and rather using them for other constructions like real states.

During rainy season the high runoff may occurring particularly at towns this is due to the topographic variation and population expansion forming the surface paved by asphalt roads, by different constructed buildings and by recreational centers this may reduce the water that infiltrates to subsurface (reduce local recharge) and structural infilling may occur.

1.7 Significance of the study

There is different findings/output/from this research. The following are some of it

- The aquifer characterization mainly has importance in understanding property of aquifer and productivity nature of different lithological formations or units and sediments using geological and hydrogeological setting.
- Aquifer characterization provides the foundation for groundwater modeling and a way of evaluating aquifers. Therefore, aquifer characterization assists in developing of conceptual model on which groundwater flow modeling based for future researches. Furthermore, the result of aquifer characterization can used as input parameters for groundwater flow modeling to obtain dependable result, which enhance decision-making.
- The aquifer characterization study also provides insight into the hydro geologic units of the area and it helps to ensure proper drilling (full penetrations of aquifers) and ground water exploitation
- Aquifer characterization is a vital tool for a detail understanding of aquifer nature and system for the ground water investigation.
- Describing and understanding ground water or aquifer geochemical evolution of the study area.
- Input for ground water management system and wise use of aquifer.
- It provides information on the spatial variation about the hydraulic parameters vary in the big akaki catchment.
- The government water supply organizations take in to account how aquifer works concerning a given well abstraction e.g. (AAWSA).
- Detail understanding what the aquifer of the study area looks like using geological, hydrogeological and hydro chemical parameter analysis before goes to further modeling.

CHAPTER TWO:

2. GENERAL OVERVIEW OF THE STUDY AREA

2.1 Location of the study area

The study area is located in the central part of Oromia Regional Government, particularly semi-part of Addis Abeba (capital of Ethiopia) and neighboring towns in the eastern and northern direction. It is part of sub-akaki river catchment (Big-akaki river catchment).

Geographically the area lies in between 9°01'28.80'' to 9°9'7.3''N latitude and 38°44'14.39'' to 39°1.401'E longitude. Totally, the area covers greater than 900km^2.

The study area bounded to the north by the **Entoto ridge**, to the west by Menagesha including the Wechacha volcanic range, to the south western and Mt. furi, and to the east by the Mt Yerer volcanic center.

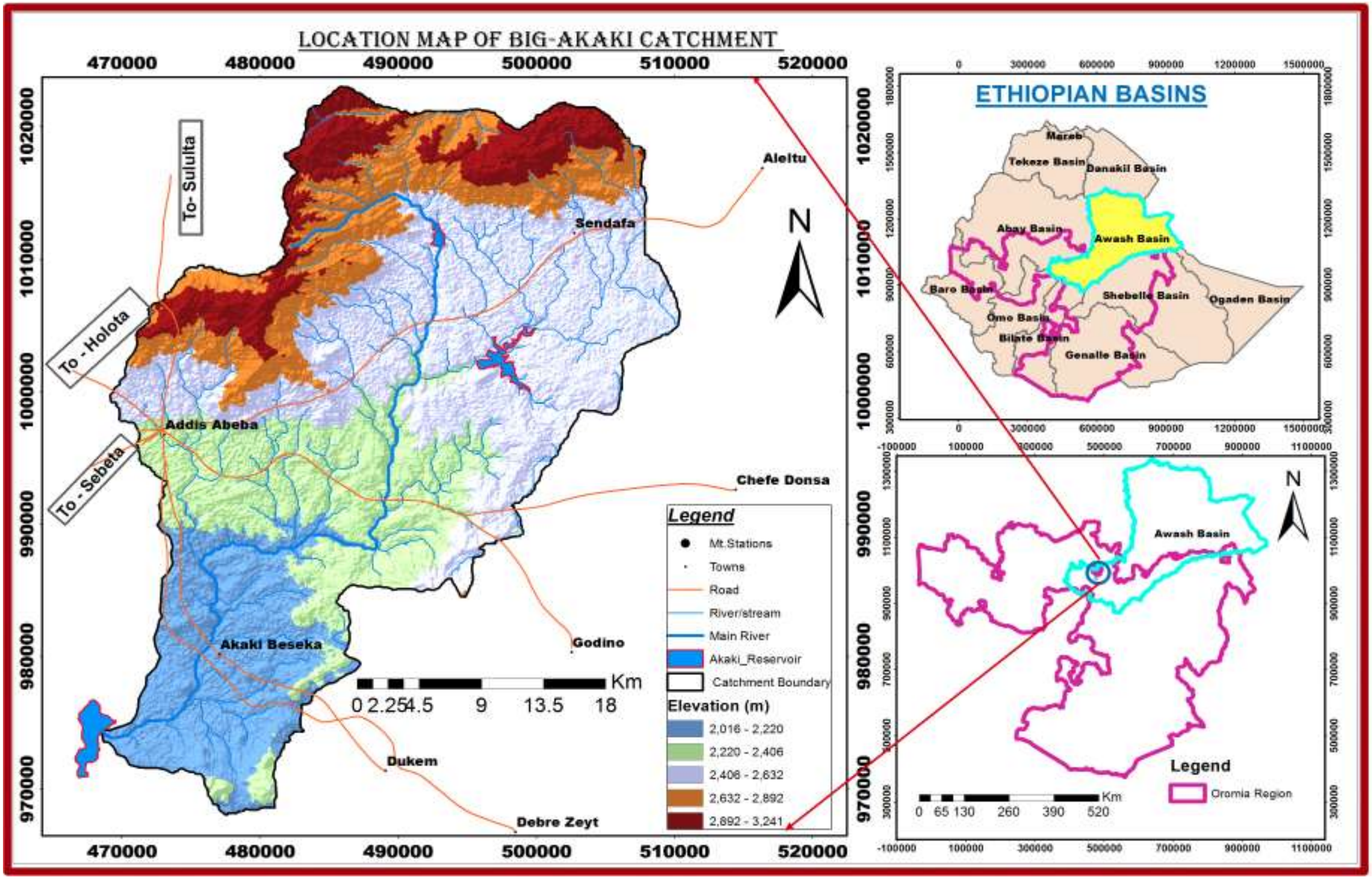


Figure 2: Location map of Big-Akaki River Catchment

2.2; Topography and Drainage

Big-Akakii River catchment is located partly in the central Ethiopian highlands and western margin of the Rift Valley floor. Moreover, the area has featured by distinctive and variable topographic features and ranging by low land to rugged or highly elevated topography. The Area catchment is surrounded by various volcanic ridges includes from northern by Mt. Entoto(3200m) and mango (2660m), from west by Wechacha (3391m), Menagesha(2932m) and Mt. Mogle (3241m), at SE by Yerer (3099m) and Bushu (2346m), SW Mt. Furi (2839m) and Mt. Guji (2475m) are high topographic ranges and which may mostly volcanic forming mountains.

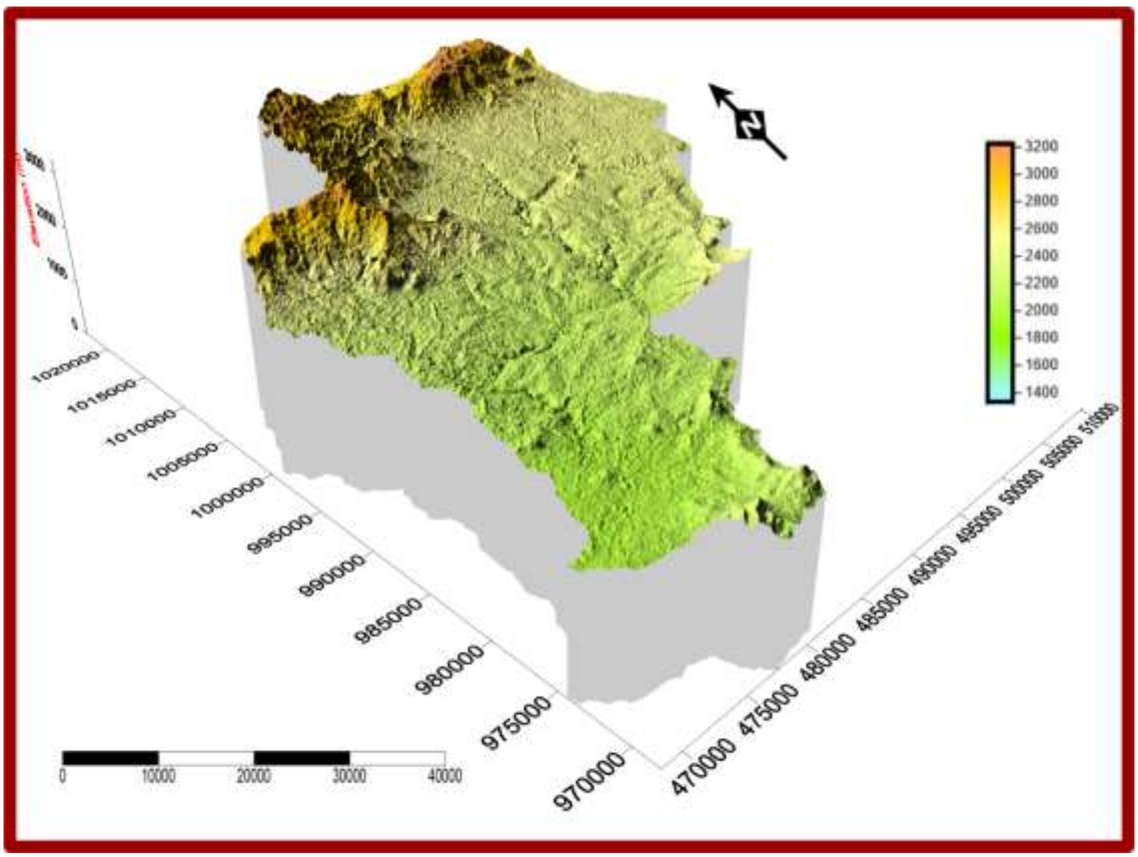


Figure 3: Topographic Variation Map of the study area

Digital Elevation Model (DEM) of 30m resolution is mostly used for the displaying of the landscape and Topographic variation of the study area (watershed) is derived from DEM and is shown in figure;2. DEMs are used in different water resource study to identify drainage related features such as watershed divides, valley bottoms, channel networks and surface drainage patterns, and to quantify sub catchment and channel properties such as size, length, slopes etc. The DEMs have proved to be very efficient in extracting the characteristics of a watershed for modeling purposes. DEMs are potentially valuable tool for the topographic parameterization of hydrological models especially for drainage analysis, hill slope hydrology, watersheds, groundwater flow and geological structures delineation etc. The accuracy of these topographic parameters is a function of both the quality and resolution of the DEM used in the extraction.

Accordingly as the information obtained from DEM, the elevation of the study area varies from 2016 m (lowland) to 3241m.a.s.l. (highland), and has an approximate surface area of 1250km2 and boundary length of above 190 km$^{2.}$

The capital city, Addis Ababa and other small towns includes; Akakii, legatafo legadadi, Sendafa, and smaller villages found in this catchment. The study area accessed, in every direction by highways from the capital that is, by the major roads extending to Wollega, Awasa (sidama), Jimma, Wallo, Harar and Gojjam. Although, other minor or weathered roads found in the catchment and these used for pass through between villages.

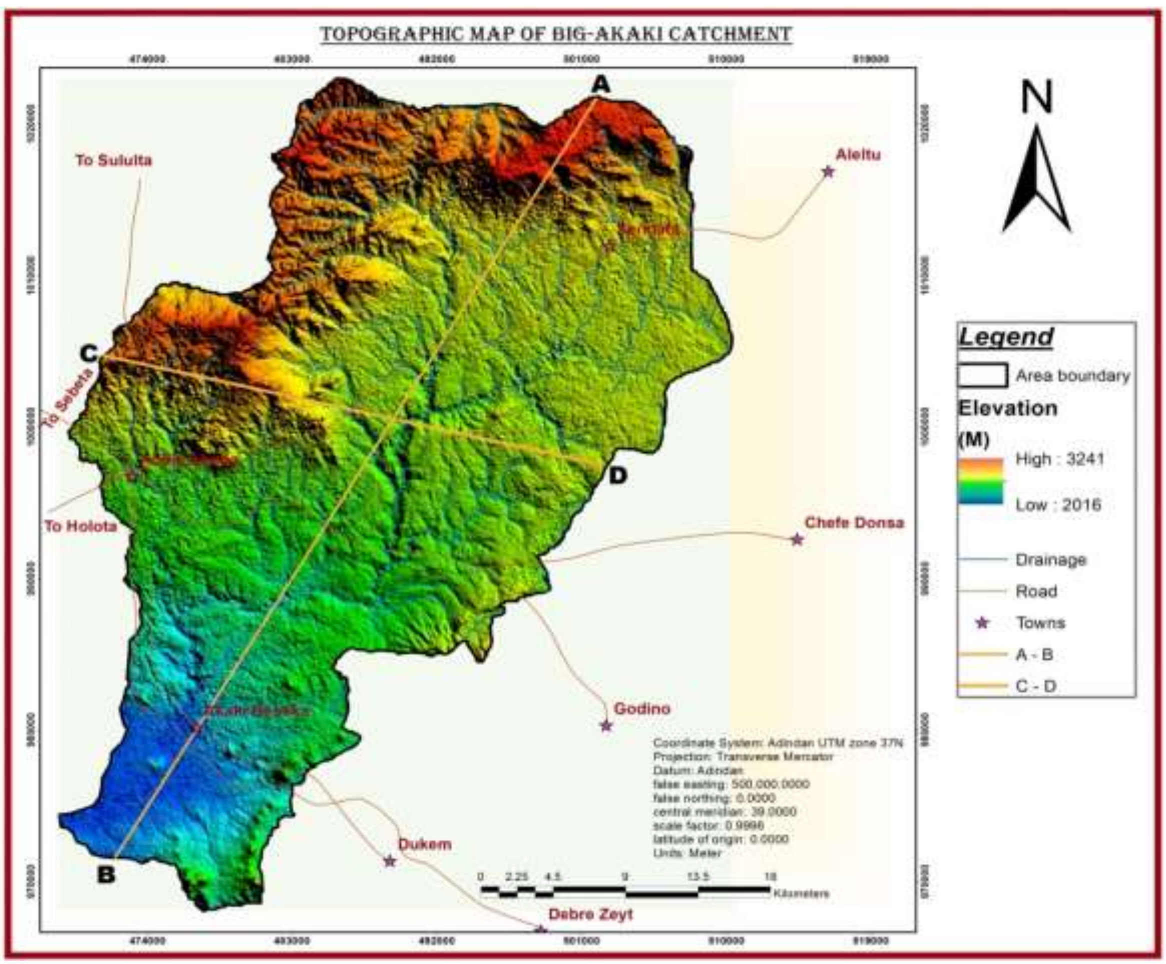
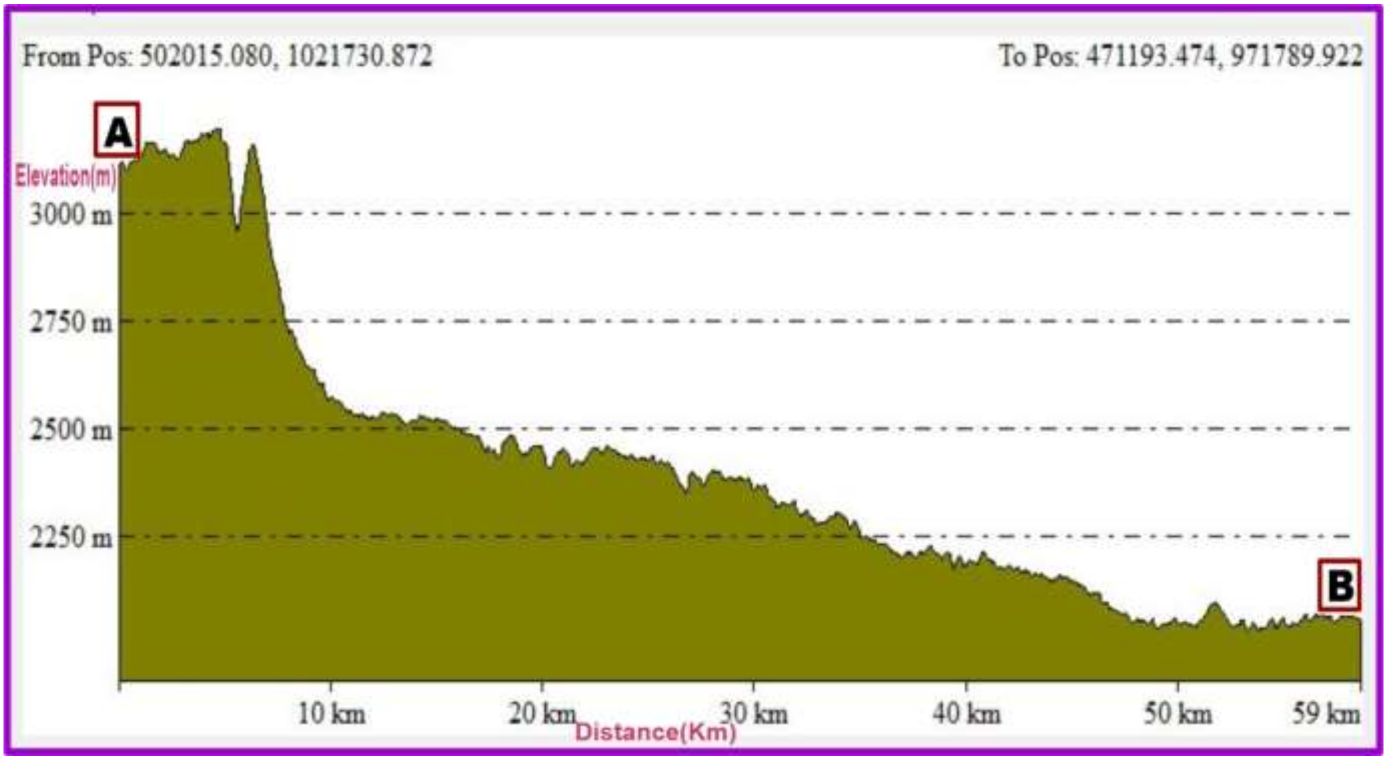


Figure 4; topography and drainage map of the catchment



a) Cross sections of the study area along the line A-B on the DEM

b) Cross sections of the study area along the line C- D on the DEM

The drainage pattern of given watershed generated by stream erosion over time that reveals characteristics of the kind of rocks and geologic structures in a landscape region drained by streams. Although Drainage pattern the pattern formed by streams, rivers, and lakes in a particular watershed or drainage basin.

A main drainage arrangement in the area is dendritic and sub parallel drainage patterns that are oriented from north(Intoto) to south lowland (akaki well fields). Also the river akaki is governed by a smaller tributeries which flows from northern and north western towards the main stream and it finally meets the small akaki river at akaki before they get into abba samuel reservoir. The drainage pattern conditions of a given area define the structural nature of an area or an indicative for structures formed. Almost all parts of the study areas are governed by regional structures such as normal fault , local fractures and liniments. These structures are a conduit for the ground water occurrences and movement.

According to the AWSA The boreholes existed in the study area are classified as well fields and phases includes; legetafo legedadi well field (LLA), Ayat fenta well fields (SANF) , Pocket area well field ,Koye feche /Tullu dimtu well field(WF-PW) and Akaka well fields (SL-PW and SWAWF). Each well fields has binds many well distributions in the catchment.

The existing boreholes have variable depth, diameter, yield, hydraulic parameters and the overall well histories are different. Type of well and depth are shallow, deep, dug well and springs with a variable discharge are located in the area. Hence, relatively the wells are denser at the discharge zone this may highly elevated at the recharge zones and low elevation at the discharge zones of the catchment. The hydraulic parameters of the existing boreholes are mainly significant in aquifer characterization. Most of the wells of this catchment are good to very good yields and hydraulic properties especially transmissivity are relatively low, medium, high and very high results recorded.

The wells are distributed in the volcanic formations (basaltic, vesicular basalt, and pyroclastic materials includes ignimbrites, tuffs and pumice. There are denser at some part of an area and sparsely distributed as some other parts. The average denser wells distance from each other may estimate about 1 to 6km away.

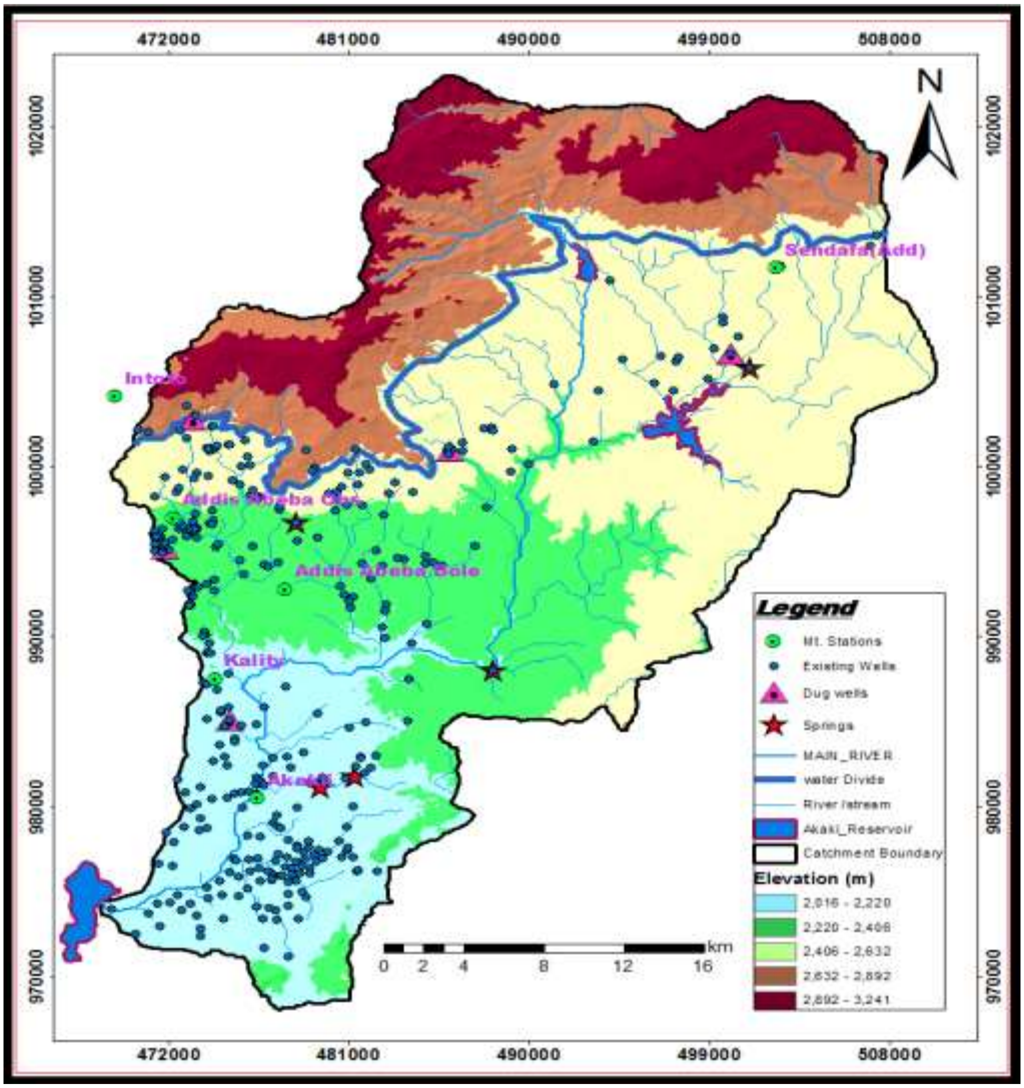


Figure 5 Locations of boreholes and Meteo. Stations entire catchment relative to elevation variation

2.2 Climate

2.2.1 General Descriptions

Climate conditions of an area described by two distinct seasonal patterns. That meant as bimodal type of rainfall weight. The main wet season, extends from June to September called 'Kiremt'. A minor rainy season, locally known as 'Belg', contributes moisture to the region from mid-march to May *(Daniel, 1977)*.

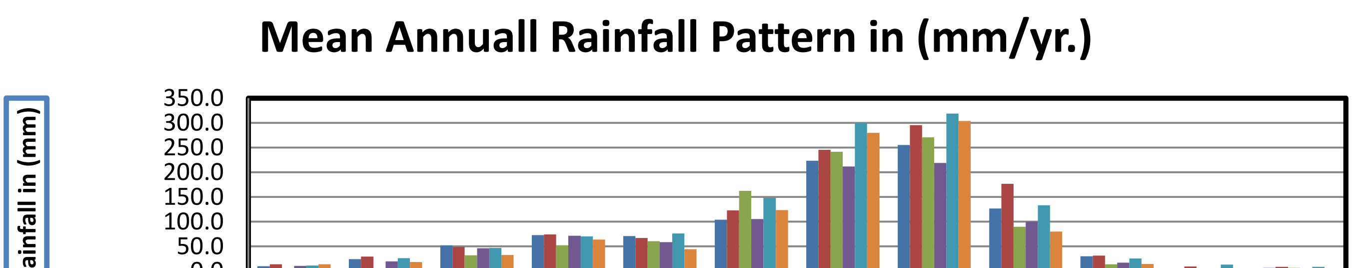
Additionally the area lying in tropical classified as wet, humid region with a mean annual rainfall of 1000 – 1400 mm per year according to (Ethiopian Meteorological Authority, 1981).

For the discussion of climate and hydrology, the records from active Addis Ababa and surrounding Observatory that are; Addis Ababa Bole, Addis Ababa observatory, Kality, akaki beseka, Sendafa (Add) and intoto stations utilized from NMA. Data set. Relatively the highest rainfall peak observed in August and extremely low precipitation recorded in December.

2.2.2 Rain fall

The explanation of the seasonal rainfall distribution with in the Awash River basin lies in the annual migration of the Inter Tropical convergence Zone (ITCZ) across the basin. The ITCZ starts its advance across the Awash basin from the south in March, bringing the spring rains. In the month of June and July the ITCZ reaches it's most northerly location beyond the basin, which then experiences the heavy, or summer rains thought. During September and October, the ITCZ returns southwards, restoring a drier, easterly air stream which prevail until the ITCZ resumes its northward migration in March (HALCROW, 1988/1989).

Rainfall records in the study area available from seven (6) stations (figure;6). Study area characterized by bi-modal rainfall pattern. According to *(Tenalem and Tamiru, 2001)*, it is expected to receive rainfall during summer and spring with maximum rainfall is evidently experienced in summer.



	jan.	feb.	mar.	apr.	may.	jun.	july.	aug.	sept.	oct.	nov.	dec.
Addis Ababa Bole	10.0	24.4	51.8	73.1	71.0	104.0	223.2	255.4	126.9	30.0	4.6	6.7
Addis Ababa Obs	13.7	29.3	49.2	74.0	67.2	122.7	245.0	295.4	176.6	31.5	9.5	8.7
Kality	3.1	4.4	32.3	52.1	60.4	162.6	241.7	270.7	89.5	14.1	5.4	6.5
Akaki	10.4	19.8	46.0	71.5	58.8	105.0	211.4	219.1	99.9	17.0	5.9	5.1
Intoto	11.6	26.4	47.2	70.3	76.1	147.9	299.0	318.8	133.0	25.6	13.5	8.4
Sendafa (Add)	13.9	18.7	32.5	63.8	44.0	123.6	279.8	304.0	80.1	14.8	4.1	2.7

Figure 6 Annual Rainfall distributions of big akaki catchment

2.2.3 Temperature

Temperature is a very significant component in hydrological interpretation and recharge estimation .The temperature record of the study area collected from Ethiopian National Meteorological Agency data source. In addition, there are three temperature data stations are used in the study area that is because the data recording for other stations are very limited like (sendafa, Kotebe akaki and Yekatit 23 school) they has only one year recording. Due to these only three stations are designated which was recorded at different duration. These includes; Addis Abeba bole (1989-2019), Addis Abeba Observatory (1989 - 2019), and Kality (2007 – 2015). The annual maximum, minimum and mean temperature records used for analysis and they are labeled as, at Addis Abeba bole station is 23.08-˚C, 6.55-˚C and 16.81c˚ respectively. At Addis Abeba observatory- station, they are 25.27 ˚c, 8.07 and 18.09˚c respectively and for the Kality station are 21.32˚c , 2.49 and 14.64 ˚C respectively.

Station	Type	Jan.	Feb.	Mar.	Apr.	May.	Jun.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
A.A Bole	Min	7.56	8.36	10.13	10.59	10.54	10.89	11.2	11.19	10.92	8.8	6.56	6.55	9.44
	Max	20.96	20.43	22.49	21.31	23.08	20.03	20.03	20.44	20.68	21.83	20.4	20.36	21
	Mean	**14.26**	**14.39**	**16.31**	**15.95**	**16.81**	**15.46**	**15.61**	**15.82**	**15.8**	**15.31**	**13.48**	**13.45**	**15.22**
A.A Obs	Min	9.1	10.27	11.31	11.6	11.77	11.32	11.18	11.71	11.4	9.72	8.53	8.07	10.5
	Max	24.19	25.27	24.86	23.48	22.85	22.13	20.55	20.88	21.98	21.64	22.66	22.7	22.77
	Mean	**16.64**	**17.77**	**18.09**	**17.54**	**17.31**	**16.72**	**15.86**	**16.3**	**16.69**	**15.68**	**15.59**	**15.38**	**16.63**
Kality	Min	5.19	4.46	5.91	6.49	7.55	6.18	9.97	7.29	7	5.18	2.49	3.21	5.91
	Max	17.03	12.06	15.37	15.42	21.32	17.72	19.3	12.78	13.14	13.44	8.06	8.3	14.5
	Mean	**11.11**	**8.26**	**10.64**	**10.96**	**14.44**	**11.95**	**14.64**	**10.03**	**10.07**	**9.31**	**5.27**	**5.76**	**10.2**

Table 1; Mean monthly air Temprature (c) in different stations.

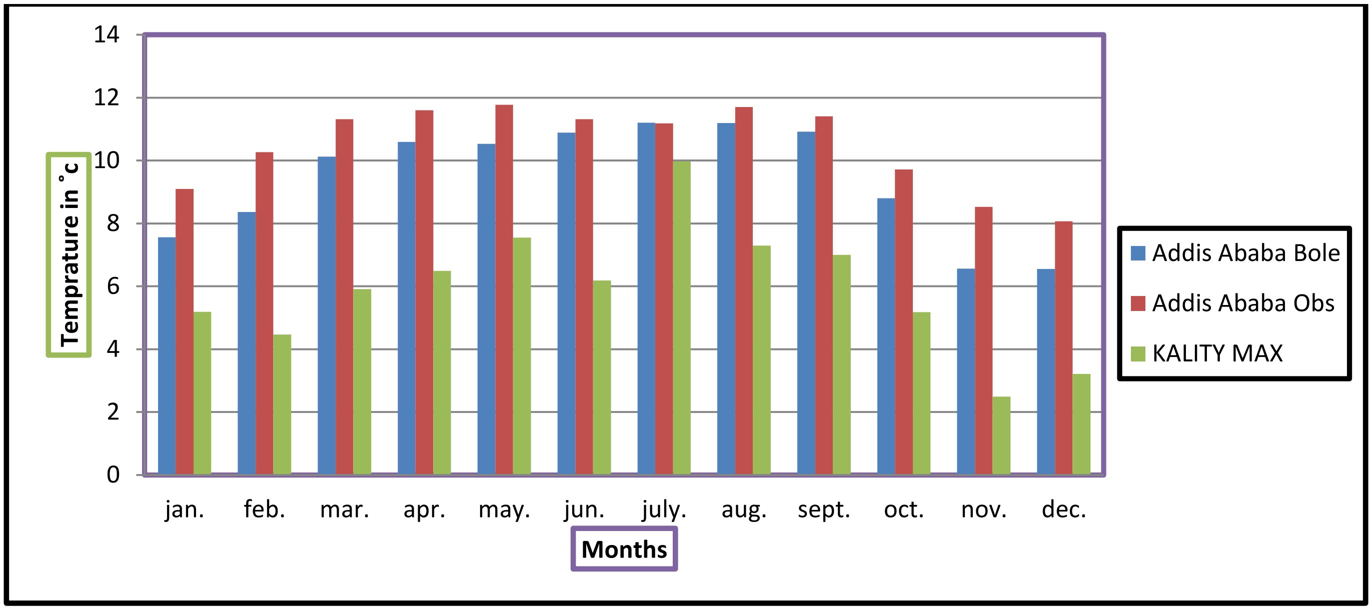


Figure 7mean minimum air temperature in different stations

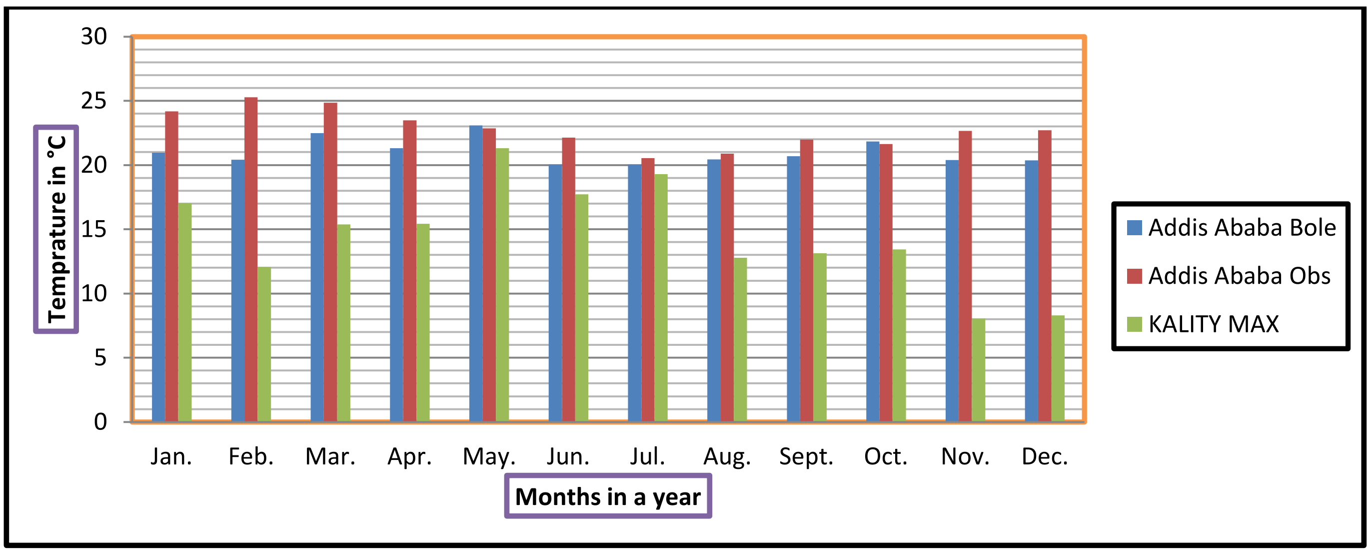
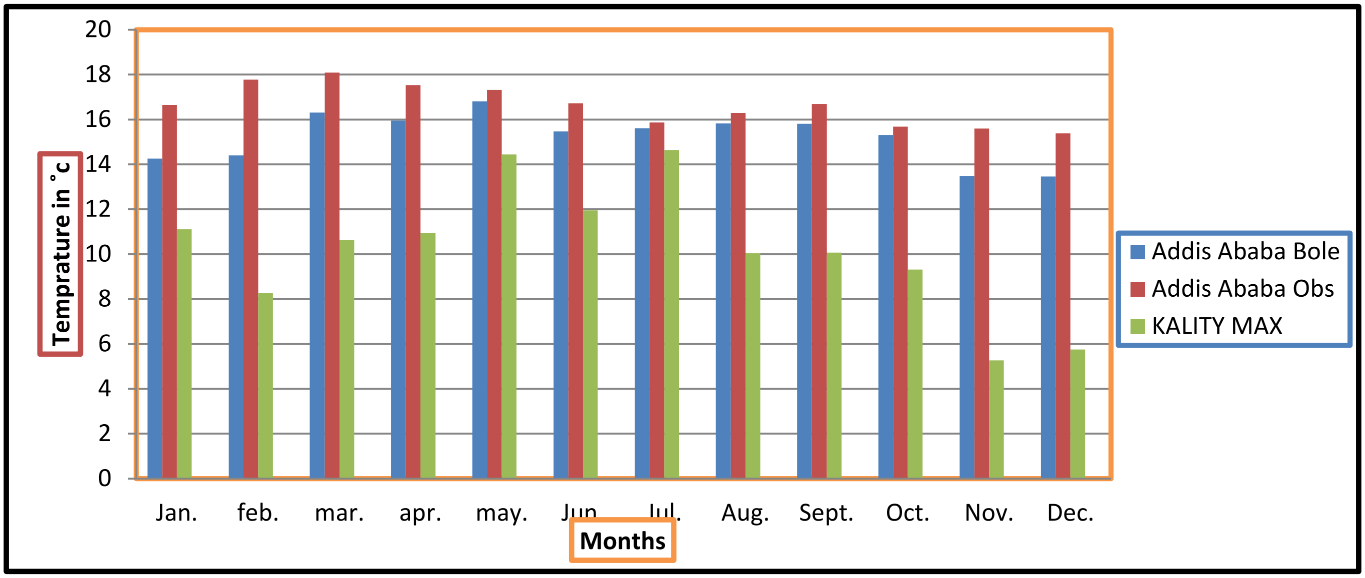


Figure 8 mean maximum air temperature in different stations

Figure 9 Average mean minimum maximum temperature of the stations



2.3 Land Use Land Cover (LULC)

The LULC of an area is one of the most important determinant factors for the water resource potential of an area. In groundwater recharge, it controls areas of rainfall percolation and runoff generating areas. The LULC data of the area found from 20m resolution Sentinel-2 LULC map of Ethiopia.

Based on the LULC map, the watershed divided into eight land cover classes: Cropland, Shrub covers areas, Grassland, Tree cover areas, Aquatic or regularly flooded Vegetation, Built up areas, Bare areas and Open water. The main crops grown in the region include barley, wheat, beans, field peas, and lentils. Farming is almost entirely rain-fed, and is dependent on weather conditions. The chart below shows the percentage distribution of each land cover class in the watershed.

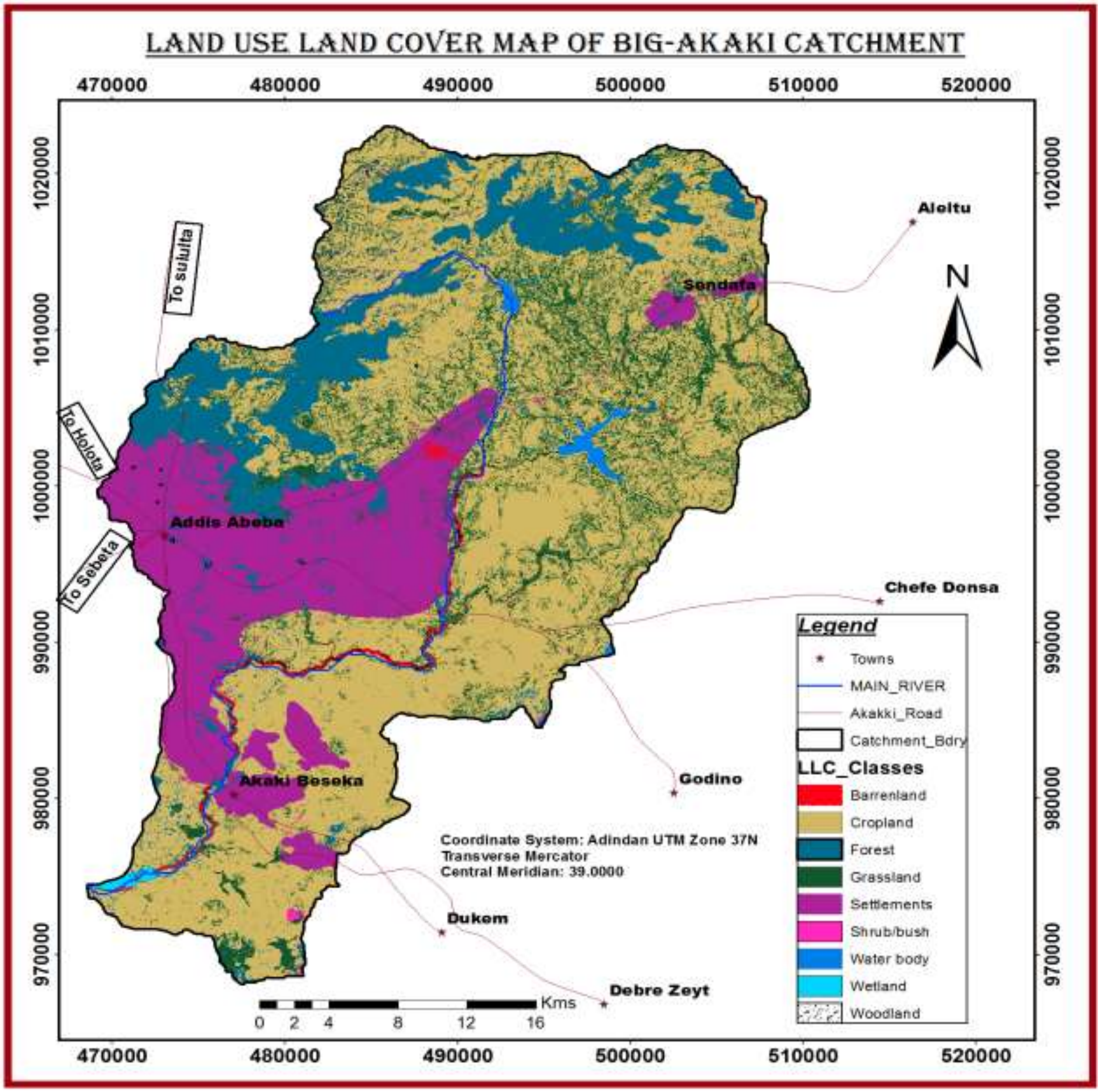


Figure 10 Land use Land cover of the catchment from Landsat 2020 WLRC.

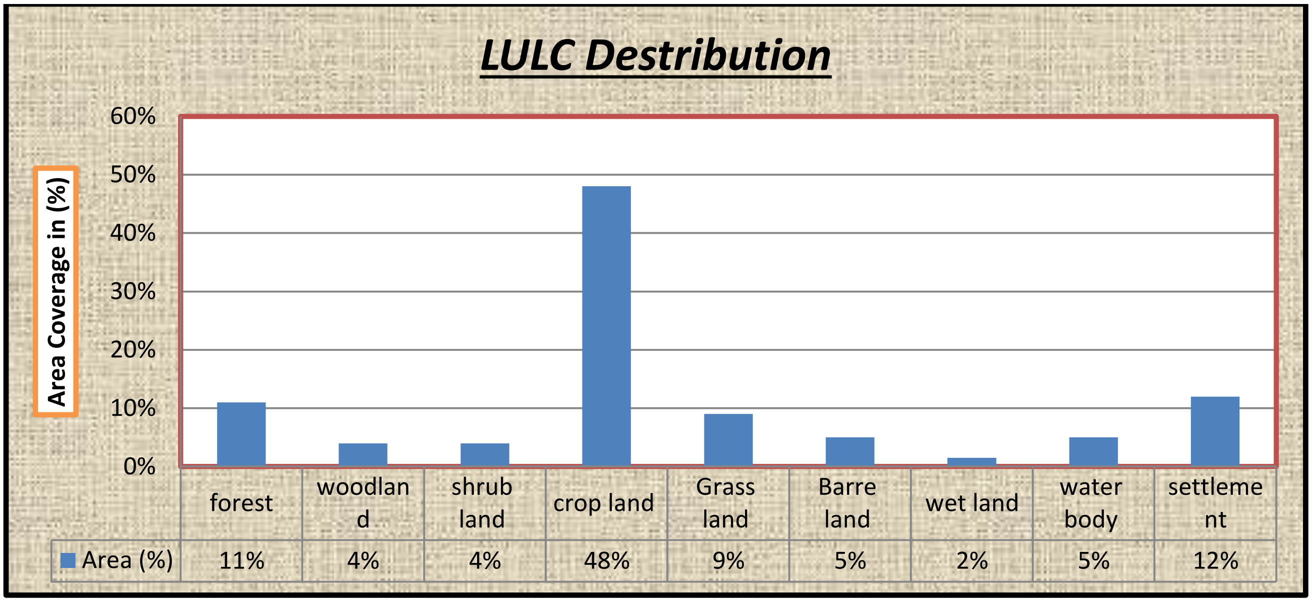


Figure 11; Graph shows land use land cover distribution entire the catchment

2.4 SOIL

The soils found in most of the study area catchment are derived from the weathered volcanic rocks specially basalt and residual pyroclastic deposit, and are highly variable in thickness and lateral extension. The Major Soil Groups, characterized Based on (*Yohannes , 2007*), are classified as calcic zero sols, chromic cambisols, chromic luvisols, chromic vertisols, eutric nitisols, leptosols, orthic solonchaks, pellic vertisols and vertic cambi sols. Although over seventy percent of an area covered by pellic vertisols (clay soil).

Pellic Vertisols is the first most covers of large are and characterized by their extensive cracking from the surface to depths of 50 cm or more with seasonal drying and subsoil showing slicker-sides or spheroid structures as evidence of seasonal expansion and contraction (*Probert et al, 1987*).

In the central highlands of Ethiopia, the main soil parent material is olivine basalt of tertiary age.

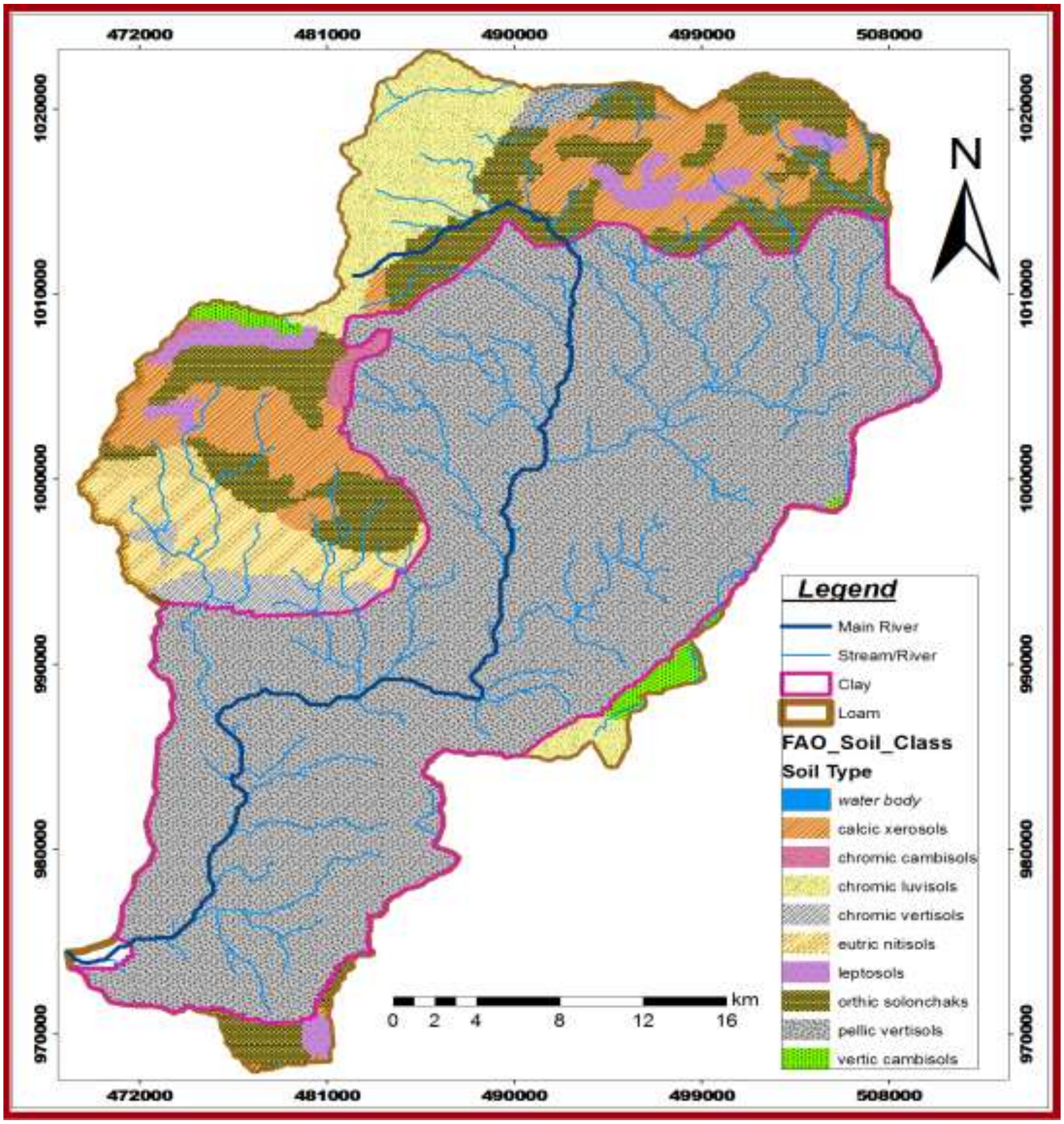


Figure 12; soil classification in the catchment (modified from FAO, 1984)

Generally have a weak horizon differentiation. According to (IUSS Working Group WRB 2014. 2014. World Reference Base for Soil Resources 2014), Orthic solonchaks Soil Group includes soils that have a high concentration of 'soluble salts' at some time in the year. Solonchaks largely confined to the arid and semi-arid climatic zones and to coastal regions in all climates. Common international names are 'saline soils' and 'salt-affected soils.

Generally, pellic vertisoils covering larger area (70%) of the catchment and composed of the clay soil texture. Where the other soil types of the catchment are collectively composed of Loam soil texture

CHAPTER THREE;

3.1 GEOLOGY

1.3.1 Overview of Regional geology

The volcanic rocks that covers most part of Ethiopia have been subdivided into five major province which are Volcanoes of northern plateau , volcanoes of southern plateau, vulcanizes of Somali plateau , Afar vulcanite and Main Ethiopian rift Volcanites on the bases of their lithological development, types of activities, frequency of volcanic center and age effusion (*Abbate and Sagri ,1980*).

The afar and the main Ethiopian rift volcanizes filling two mega structure related to neogene continental fragmentation, have a more limited extension and were referred to as Aden series (Mohr ,1962) .The Northern Ethiopia flood basalts are classified into four groups based on their age from older to younger. These are Ashange, Aiba, Alage and Termaber formation. (*Mohr, 1983*).

The Ashange basalt represents the oldest fissures flood basalt volcanism on the northwestern plateaus. Ashange formation is the oldest (>35Ma) and cover large area in the North Western Ethiopia. The Aiba basalt is the major part of the Ethiopian flood basalt sequence. It is composed of massive flood basalt flows with or without intervening agglomerate bed.

3.1.1.1 Ashange formation

The Ashange basalt represents the oldest fissures flood basalt volcanism on the north -western plateaus. Ashange formation is the oldest (>35Ma) and cover large area in the North Western Ethiopia. Most of the Ethiopian plateaus are covered by basalts & very little is known about felsic composition. It is silicic volcanic rocks which consists mainly of Oligocene and subordinately Miocene ignimbrites forming a thick sequence overlaying the flood basalts

It composed of pre-dominantly alkaline basalt with inter-bedded pyro lasts and rare rhyolites erupted from fissure. The basalts and ignimbrites form typical plateaus topography that often extensively eroded and dissected by deep groups. The maximum thickness of the plateau ignimbrite is extremely variable.

Three regionally distinct Oligocene rhyolite units are recognized. The Lema limo rhyolites in the north west plateau forming several beds capping low –Ti basalt floods, the wegeltela rhyolites to the east corresponding to very thick ignimbrite overlaying high Ti flood basalts and the jima rhyolite located on the south western plateau overlaying high Ti flood basalt. The Miocene rhyolite is located in the Molale Debrebirhan area close to the rift margin and overlay Miocene low Ti flood basalt.

Dolerite sills, acidic dykes and gabbroic intrusions commonly eject the formation. The upper part of the Ashange formation is more tuffaceous contains lacustrine deposits including lignite seams and acidic volcanic. Locally it overlies the older part of the group with angular unconformities. This formation is un-conformable over lain by the Aiba basalt (*Merlaetal, 1979*) which gives age of 30-35Ma. The Ashange formation probably has a Paleocene to Miocene age range (*Kazmin, 1975*).

3.1.1.2 Aiba formation

The Aiba basalt is the major part of the Ethiopian flood basalt sequence. It is composed of massive flood basalt flows with or without intervening agglomerate bed and generally, dense dark color, fine grain olivine, pyroxene basalt and rock fragment, commonly columnar jointed. The olivine basalt consists of porphyritic basalt. In addition, in this formation it contains some inter-beds of felsic pyroclastic rocks. Pyroclastic rock classified based on grain size (tuff <2mm, lapilli 2 – 64 mm, bomb > 64 mm) and strength (unwelded, moderately welded &welded ignimbrite). The thickness of pyroclastic beds sparsely developed between 5 m to 6 m flow that together comprise the Aiba formation (*Kazmin, 1975*).

In Aiba basalt formation, the second major processes of fissured volcanism taken place on the north- western plateau. They are typically transitional basalts and unconformable overlie the Ashange formation and contain a thickness of 200 m – 600 m. The absolute age of the Aiba basalt ranges from 34 to 28 Ma layering in the Oligocene period *(Zanettin et al., 1980; Kazmin 1979).* Aiba formation is preserved

3.1.1.3 Alage Formation

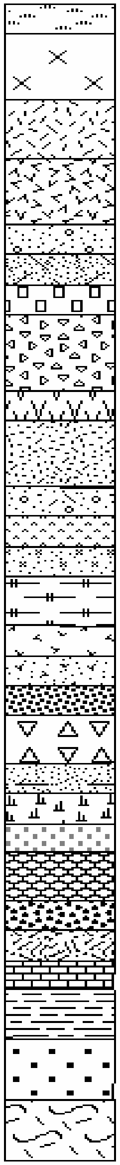
Alage formation is a type of Ethiopia continental flood basalt that is predominantly younger than Aiba formation. Alage formation is abundant within the Ethiopia rift and on the adjoining plateau and conformably overlay the Aiba basalt. Both are in Cenozoic era and have age between 36 Ma. To 13 Ma. Its tectonic setting is within the intra-plate or hotspot. Basaltic rock units which are capped by Alage ignimbrite formation have about 500 m thickness.. It is dominantly by acidic rock including tuff, ignimbrite, rhyolite, and trachytes. Inter bedded basalt flows are common and other pyroclastic rocks. Especially, it formed in range from 36 to 13ma (*Kazmin 1980; Zanetinn 1992*).

3.1.1.4 Termaber Formation

It is the youngest Cenozoic Ethiopia continentals flood basalt. The name Termaber is given from the shield volcanoes of the northern central Ethiopia plateaus with an absolute age range of 26 Ma to 16 Ma (*Kazmin, 1979*). The Termaber formation formed due to volcanism built up large shield volcanoes decreasing in age from North to South. This formation form large, shield up to 10 of Km in diameter and it is composed of mafic flood basalts that fed from focused groups of sub parallel fissures. It is dominantly composed of mafic flood basalt but pyroclastic sequences are common in some places. The types of mafic basalt are scoria and amygdaloidal porphyritic varieties of basalt including olivine- pyroxene. It is types of central volcano that represented by Termaber formation and it forms large shield volcano with decreasing in age from north to south. These not easily distinguished in the field on basis of lithology alone. These in the present and absence of areal field studies, correlation across Ethiopian provinces are provisional. The alkaline basalt of Termaber formation comprises about forty shields like pile on the Ethiopian and Harar plateaus (Mohr and Wood 1976). Among these shields, considerable physical, lithological and chemical varieties exhibited. Their elevation above sea level can reach to as much as 4000 m and volumes are generally in the range of 500-1000 km^3. Mapping on the sole basis of lithology and geochemistry can lead in Ethiopia to matching of rock units of every diver's age. Radioactive method summarized that Termaber type volcanism largely over lapped in time in the north and for this reason the division of the Termaber formation (*Zanettin and Justinvisenin, 1974*) into an early Miocene Termaber-gussa and middle Miocene meghezez formation.

3.1.1.5 Nazeret Unit

This unit is mainly exposed in the southeastern part of the area mapped area and forms rift floor. It consists of a sequence of welded per alkaline rhyolitic ignimbrite. The unit comprises numerous rhyolitic and trachytic domes. Rock fragments and crystals, generally broken, are abundant; alkali feldspars, quartz and amphiboles are the most common crystals. The age of this unit is 5.4 to 3.11 Ma (*Morton et al. 1979*).



	Lithology	Description	Abebe et al., 2005		
			Age (Ma)	Category	Lithologic unit
> 0.5		Alluvium: reworked materials of volcanic origin	Holocene		Alluvial Cover
10		Lacustrine sediments: sand, silt, clay, diatomites, limestone, and beach sand	< 0.5		Lacustrine Sediments
		Basaltic lava flows: porphyritic to aphyric alkali- and/or olivine basalts	< 1.6		Wonji Basalts
		Scoria cones and fallout deposits: reddish or black in color			
60		Phreatomagmatic deposits: maar deposits intercalated with lacustrine sediments and distal silicic volcanic ashes			
200		Phyroclastic and pumice fall deposits: pumice falls with intercalation of fine ash and lacustrine	< 0.9	Main Rift	Bora Bericha Rhyolites
50		Rhyolitic domes with obsidian lava flows:			
		Zikwala trachytes: dark gray, porphyritic trachytes with intercalation of pyroclastic material	1.28-0.85		Zikwala Trachytes
5		Phyric basaltic flows: pyroxene and olivine -phyric basalts with microcrysts of plagioclase and	2.9-2.0		Akaki Basalts
		Scoria fallouts:			
40		Chefe Donsa pyroclastic deposits: unwelded to poorly welded, fine volcanic ash flow and fall deposits	2.54-1.7		Chefe Donsa pyroclastic deposits
		Wechacha trachytes: short, thick trachytic lava flows and domes with minor pyroclastic materials	4.6-3.3		Wechacha trachytes
		Guder Basalt: aphanitic basalt with coumnar joint	?		?
		Gash Megal rhyolites: fine-grained to alkali-feldspar phyric lava flows with interbedded basaltic lava	<5	Main Rift	Gash Megal Rhyolites
50		Rhyolitic and trachytic lava domes: rhyolitic and trachytic quartz, sanidine, anorthoclase-phyric lava domes	5.2-2.6	Syn-Rift	Nazret Pyroclastic Rocks
700		Welded to partially welded pyroclastic flows: ignimbrite			
150		Welded pyroclastic flows: ignimbrite with minor intercalated basaltic lava flows			
60		Addis Ababa basalts: fine grained to olivine phyric alkali basalts, olivine basalt and trachybasalt lava	7.5-5	Pre-Rift	Addis Ababa Basalts
300		Guraghe-Anchar basalts:aphyric to plagioclase and pyroxene phyric basalts intercalated with	10.6-8.3		Guraghe-Anchar Basalts
		Tarmaber-Megezez Formation: transitional alkaline basalt	M. Miocene		?
		Makonnen basalts: flood basalt	Oligo-Mio.		?
150		Aiba-Alaje basalts: weakly altered, tilted basalt with intercalation of pyroclstic rocks	32-29		Aiba-Alaje Basalts
		Jimma upper basalts: rhyolite, trachyte and tuffs with minor basalt	L.Eocene - L.Oli		?
		Jimma lower basalts: flood basalt with minor salic flows			?
25		Antalo Limestone :yellowish gray fossiliferous	Jurassic		Antalo-Adigrat Sedimentary Rocks
30		Shales and marls: interbedded marl and shale			
[illegible]		[illegible]	[illegible]		
150		Biotite gneiss: strongly weathered, yellowish, coarse grained often cut by pegmatite veins	Precambria	Pre-Rift	Kella Metamorphic Rocks

Table 2; regional stratigraphic sequence (source Tsegaye A. et.al, 2005)

3.1.2 Geology of the Study Area

3.1.2.1 Akaki Basalt

This unit also contains two types of volcanic products namely, Phyric basalt lava flows (NakB) and scoria fallout/cones (*Tsegaye A.et al., 2005) and (Efrem, 2010*). It is exposed in central to southern parts of the study area on the western rift shoulder south of Addis Ababa at around Akaki Bridge extends to Tulu dimtu it found at the road cut and it consists of coarse grained moderate to highly weathered and fractured light black color basalt and which is oriented west to east direction. It is vesicular basalt. It is consisting of scoria with associated lava flows. Both the basalt and scoria extracted and used as a selected (filling) material for road and bridge construction of akaki and for surrounding area. Although the joint structure is visible which is void space none filling with other materials the vertical and horizontal thickness of this unit estimated as 10m and above 500m respectively. The age of the Akaki basalt is 2.9-2.0 Ma (*Chernet et al. 1998) and (Morton et al, 1979)*.

Figure 13; picture the akaki basalt lava flows

Akaki scoria comprises of a huge mountain forming scoria cone (dome) found at around both tulludimtu and at akaki Kality specifically Gelan condominium (salogora area). It exposed as a quarry site, although This unit has large area coverage, thick, reddish, porphyritic, poorly sorted highly void vesiculated and weathered scoria. Usually it forms irregularly distributed cinder cones sometimes broad-based gently sloping circular to elliptical hills. (***Tsegaye A. et al, 2005***) differentiated this rock from the coeval rift floor Bofa basalts since it represents a volcanic episode composed of monogenic scoria cones and associated lava flows. Phyric basaltic lava flows (NakB):- dark color fine grained with main composition of plagioclase pyroxene and opaque minerals characterized this rock. (***Efrem B, 2010***). Usually it is fresh and compact. In addition, shows vesicular cavity filled with or without secondary material.

Additionally the outcrop used as a selective material source for road construction purpose. The thickness of this exposure estimated vertically at around 30m above the ground surface. The upper exposed part is highly affected by temperature and highly weathered while the bottom is nearly fresh rock.

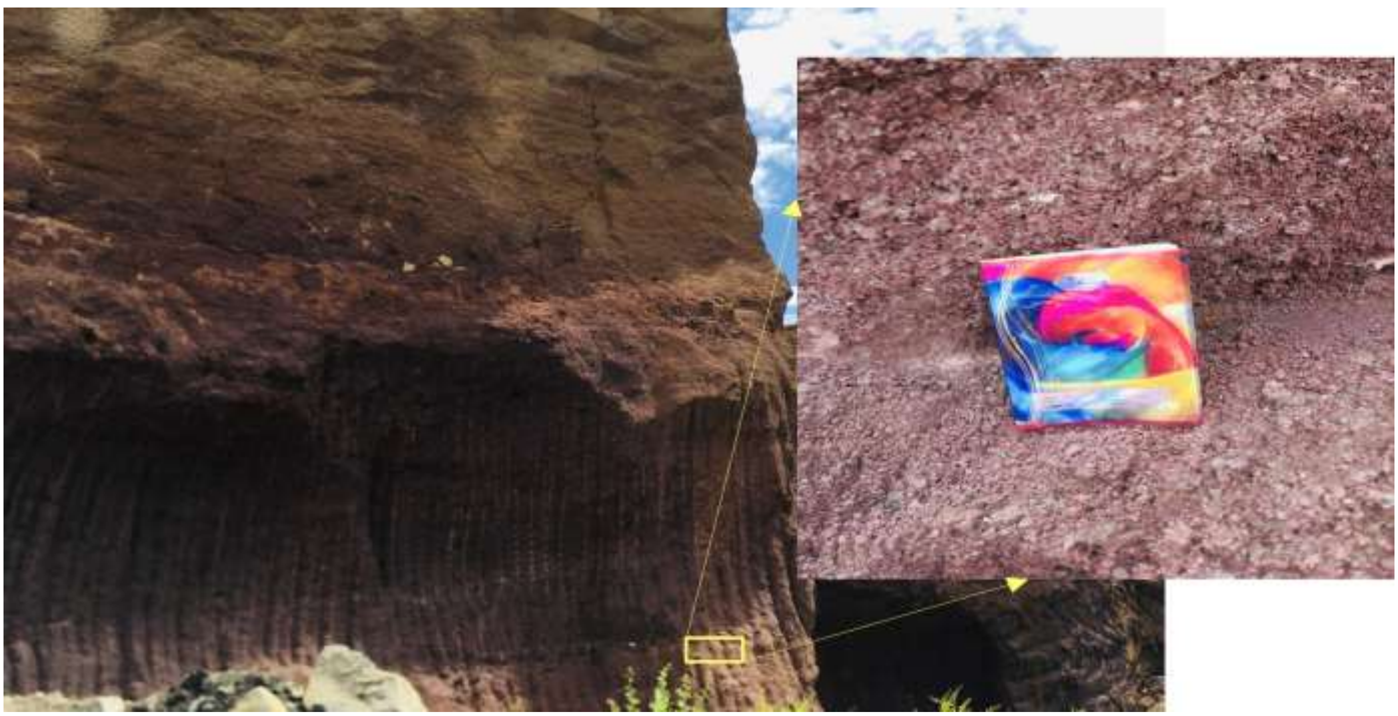


Figure 14; the Scoria spatter cone rock unit at the field (tullu dimtu quarry site)

3.1.2.2 Addis Ababa Basalt

This formation is outcropped to the central northwest part of the map area (figure3.3) below, localized around Addis Ababa area along the valleys of Akaki and kebena rivers. According to *(Abebe et al. 2005*) this unit mainly consists of fine grained to oliven-pyric alkaline basalt, olivine basalt and trachybasalt (NadB). In most places it is compact and fine grained rock but in places, it shows vesicular cavity filled with or without secondary mineral

This unit mapped by (*Kebede and Taddese 1990*) at 1:25,000 scales and the basalts area classified in to different units based on their texture and compositions. For the purpose of the present mapping scale, they mapped as one unit. This unit is fine to coarse-grained basalt composed of olivine and plagioclase phenocrysts. In most part of the outcropped area, it is relatively thin (20m) lava flow overlying the ignimbrite. The age of the Addis Ababa basalt is 7.5-4.5 Ma (*Chernet et al. 1998) and (Morton et al. 1979*).

Additionally it is dark color fine-grained rock mainly composed of plagioclase, pyroxene and opaques. Generally, it is fresh, compact fine-grained rock, but in places, it shows vesicular cavity filled with or without secondary minerals of zeolite (?) and /or calcite. Microscopically, it is composed of 60% plagioclase, 30% pyroxene, 8% opaques and 2% olivine with intergranular and intersertal textures..

3.1.2.3 Addis Ababa Ignimbrite

This Ignimbrite (Nadl) is outcropped in most part of the plane area around Addis Ababa and the Becho plane including lege tafo lege dadi area and sendafa town. it covers over 40 percent of an area, It is composed of welded tuff (ignimbrite) and non-welded phyroclastic fall (Ash and tuff)(figure 3.2). It is grayish to white color and when welded it exhibits sharp textures, elongated rock fragments of various color. Around the Legedadi plane and melka kunture area the thickness of this unit reaches up to 200m (exploration drill data). In the Becho plane, area it covered by thin 5-7m thick residual soil developed from the same rock. The age of this unit is 5.11-3.26 Ma *(Morton et al. 1979)*.

3.1.2.4 Entoto Becho Rhyolite

The Entoto mixed rocks are found in the northwestern part of map area (figure; 3.3). This unit constitutes rhyolite, trachyte, pyroclastic rocks and sediments (NebRy). It also contains obsidian reach formation; all the rocks are highly weathered and jointed with few layers of agglomerate at some places. There is a red backed soil development at the contact with the under lying basalt. This lithological unit is highly affected by joints trending E-W and N. Also fault aligned from NE – SE and NE – SE ,It forms high mountain chain called Entoto trending E-W (*Assiged, 2007*).

This formation exposed also in south western and southeastern outside part of the map area. It is found over lying tertiary basalt marked by a thick paleosols and it occurred by forming big mountains such as Furi, wechecha and Yerer. It has aphanitic to medium grained texture with vesicular varieties mostly at it is lower part. Mostly the trachyte and the trachy basalt found alternatively layered with the trachyte being dominant. At its lower part, it shows columnar jointing and affected by two sets of joints (*Assiged, 2007*).

Figu15; weathered rhyolitic unit exposed at ridge and road cut (Entoto plain)

3.1.2.5 Chefe Donsa Unit (NQcdpc)

The Chefe-Donsa volcanic rocks units are outcropped at the east, northeast, south and west extreme parts of Debre-zeyt. They are consisting of fall deposits (ash, tuff and pumice) and poorly welded ignimbrites of rhyolitic composition. At places in the Dukem and Mojo river valleys, they observed under the lacustrine deposit. The age of this unit ranges 2.24 to 1.71 Ma (Morton et al. 1979).

This unit covered by patches of Quaternary olivine basalt. This unit exposed in the central east and northeastern parts of the mapped area. The rock is fine-grained poorly welded volcanic ash flow and fall deposits with lithic fragments with associated pumice and rhyolic lava flows. *(Efrem B, 2010)* and (*Tsegaye A. et al. 2005*) mapped this unit as pyroclastic deposits overlying the Nazareth pyroclastic rocks and very often the Bofa Basalts. The Chefa Donsa pyroclastic deposits differentiated from those

Nazareth group (generally strongly welded) by their poorly welded surfaces. The exposed thickness of this unit varies from place to place.

3.1.2.6. Tarmaber-Megezez Formation (E3tm)

This unit is occured in the central west and northern portion of the map (Enclosure 1) area. It is dark grey in fresh samples but reddish-brown in weathered specimens. It is a fine-grained volcanic rock composed of plagioclase, pyroxene, and opaque minerals.

Generally, the geology of the area is listed according to their increasing age is as follows;

Lithology	**Lithological Description**	**Age (Ma)**	**Category**
	Entoto Becho Rhyolitic and trachytic lava ; Rhyolitic and trachytic quartz, sanidine, anorthoclase-phyric lava domes	(< 0.90)	Main Rift
	Chefe Donsa pyroclastic deposits; unwelded to poorly welded, fine volcanic ash flow and fall deposits	(1.7 - 2.54)	Main Rift
	Akakii basalts; pyroxene and olivine -phyric basalts with microcrysts of plagioclase and opaque minerals	(2 – 2.9)	Main Rift
	Addis Ababa ignimbrite ; Welded to partially welded pyroclastic flows	(2.6 – 5.2)	Syn Rift
	Wechacha trachytes; short, thick trachytic lava flows and domes with minor pyroclastic materials	(3.3 - 4.6)	Main Rift
	Addis Ababa basalts; fine grained to olivine phyric alkali basalts, olivine basalt and trachybasalt lava flows	(4 – 7.5)	Pre Rift
	Tarmaber-Megezez Formation; transitional alkaline basalt	(5 – 23)	Pre Rift

Table 3; stratigraphic sequence of the study area source Tsegaye abebe et al, 2005

Addis Ababa ignimbrite is dominated over the catchment which is estimated around 40% , Tarmaber basalt covers about 21% and chefe donsa phyroclastic has minimum about 0.24%. (Table)

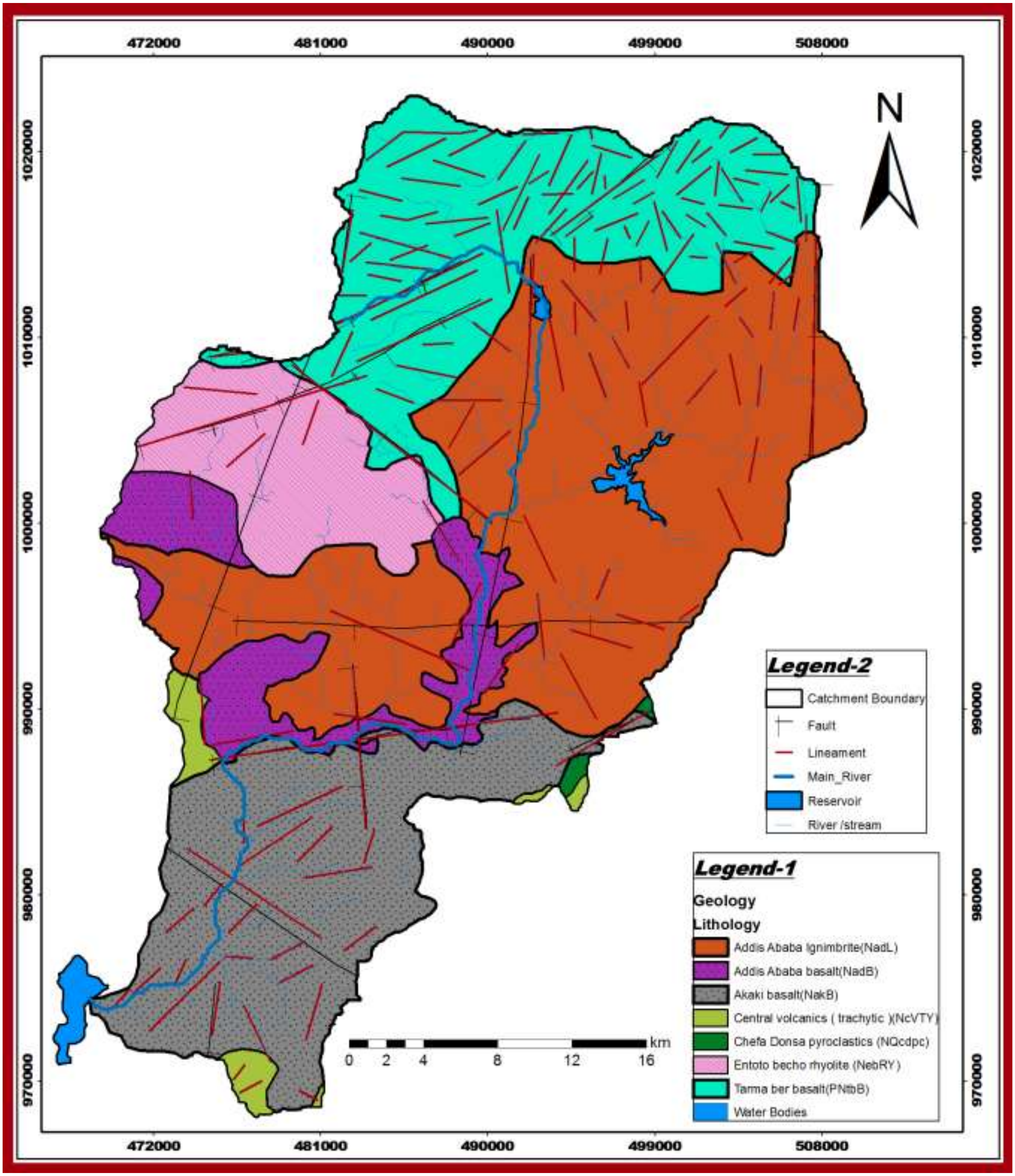


Figure 16; geological map of the catchment (modified from geologicalmapof WWDSE,2005)

No.	Geology	Area coverage(km²)	Coverage percent (%)
1	Termaber basalt	266	21.28
2	A.A ignimbrite	501	40.08
3	Entoto becho rhyolite	112	8.96
4	A.A basalt	95	7.6
5	Central volcanics of wechecha	18	1.44
6	Chefe.d phyroclastic	3	0.24
7	Akaki basalt	255	20.4
	Total	1250	100

Table 4; Lithological area coverage in the catchment in square kilometer and percentage (%)

3.1.2 Geological structures

In general, three sets of faults trending NE-SW, NW-SE and N-S observed in the study area. Every type of faults occurred in a particular part of the sheet are prominent. The NE-SW faults are part of the Main Ethiopian Rift (MER) faults and are younger structures developed with the association of Tertiary basalts, at the northwest corner of the area. In addition, these faults are the same age category as of Wanji Fault-Belt. In this part of the area, such faults expressed forming continuous cliffs (in the mountain range), fault blocks, and abrupt lithological changes. According to *(Bekele et al. 1992),*

Some of the fault (normal fault) orientation follows and parallel the main stream line which runs from the N - S direction of the study area. While other fault line oriented perpendicular or cutting the main stream. Generally, the structure density is higher to the northern to eastern western direction.

The localize Lineament structures occurred and follow the streamline that forms linear trending. As defined on map It was produced by using ArcGIS 10.3 software delineating the DEM file as hill shade to determine and visualize clear structural orientation or trend (figure;3.3). In addition, they extended lower than the regional fault sloping from the NE – SW and NW-SE direction.

CHAPTER FOUR

4. HYDROMETEOROLOGY AND RICHARGE ESTIMATION

Hydrometeorology deals with the circulation of water within the earth and atmospheres or hydrologic cycle, the water budget, and the rainfall statistics of storm. Although it is significant to processes both precipitation and evapotranspiration, *(Shaw 1988).*

This chapter describes the overview of hydro-meteorological attempt for the study area, Hydrometeorology data are essential to characterize the climatic conditions and determine the water balance of a certain basin or catchment for developing and managing its water resources. Due to this data obtained from the National Meteorological Agency (NMA) of Ethiopia databases.

4.1 Hydrometeorological Stations and components

The most useful hydro meteorological elements are precipitation, evapotranspiration, sunshine hours, air temperature, and relative humidity, soil moisture and stream discharge (runoff), etc. There are around six meteorological stations are available within the upper, middle and lower catchment which are situated and characterized at different localities of the study area watershed. These stations selected from their geographical distributions point of view. The overall meteorological parameters obtained from these stations in the study area are; rainfall (precipitation), maximum and minimum temperatures, Relative .humidity, wind speed and sunshine hours.

no.	station	Temprature	Rel.Hum	Sun hrs	Wind speed	precipitation
1	Addis Ababa Bole	18yrs(1988 - 2006)	20yrs(1998 - 2019)	12yrs (2006 - 2018)		30yrs(1988 - 2018)
2	Addis Ababa Obs	30yrs(1988 - 2018)	24yrs (1988 - 2014)	12yrs (2006 - 2018)	24yrs(1988 - 2012)	30yrs(1988 - 2018)
3	Kality	9yrs(2007 - 2016)	24yrs (1988 - 2014)			10yrs(1988 - 1998)
4	Akaki					30yrs(1988 - 2018)
5	Kotebe		24yrs (1988 - 2014)			21yrs(1990 - 2011)
6	Sendafa (Add)	12yrs(2007 - 2019)				29yrs(1990 - 2019)
7	Yekatit 23 School					21yrs(1990 - 2011)

Table 5; Types of hydro meteorological basis and measured years

4.2 Hydro meteorological Components

4.2.1 Precipitation

Precipitation is the most important part of the atmospheric conditions in the hydrologic cycle that falls on the earth surface in the form of water droplets and its amount is one of the most important factors to determine the density and distribution of vegetation.

The rainfall in Ethiopia varies from less than 200mm in arid zones to 2000mm in the southwest part of the country. This is due to altitude variations over the country from about 120m below sea level in dallol depression to peaks of more than 1000m sea level.

To show this rainfall data analyzed and the graphs of the total mean monthly rainfalls for the study area have been drawn .From these graphs we can see that the area has two-rainfall seasons and dry seasons. The rainy seasons include months June to September (summer), March and May (Belg). Whereas, the rest months belongs dry seasons with small rainfall.

According to the assessment of rainfall meteorology data from all stations, the study area also receives the maximum values of rainfall in July and September months. In general it can be concluded that the rainfall in the area varies from a mean annual rainfall of 869.9mm at akaki to a mean annual rainfall of 1,122.73mm at entoto (figure;17) .Therefore, the distribution and amount of rainfall in the area is largely dependent on geographical position with respect to the climatologic elements and orographic factor.

Station	Jan.	Feb.	Mar.	Apr.	May.	jun.	Jul.	aug.	Sept.	oct.	Nov.	Dec.	M A. Rf	Altitude(m)
Addis Ababa Bole	10.0	24.4	51.8	73.1	71.0	104.0	223.2	255.4	126.9	30.0	4.6	6.7	981.2	2354
Addis Ababa Obs	13.7	29.3	49.2	74.0	67.2	122.7	245.0	295.4	176.6	31.5	9.5	8.7	1122.7	2386
Kality	3.1	4.4	32.3	52.1	60.4	162.6	241.7	270.7	89.5	14.1	5.4	6.5	942.7	2186
Akaki	10.4	19.8	46.0	71.5	58.8	105.0	211.4	219.1	99.9	17.0	5.9	5.1	869.9	2057
Intoto	11.6	26.4	47.2	70.3	76.1	147.9	299.0	318.8	133.0	25.6	13.5	8.4	1177.7	2903
Sendafa (Add)	13.9	18.7	32.5	63.8	44.0	123.6	279.8	304.0	80.1	14.8	4.1	2.7	982.0	2569
Average	10.4	20.5	43.2	67.5	62.9	127.6	250.0	277.2	117.7	22.2	7.2	6.3	1012.7	

Table 6; mean monthly rainfall at gauging stations of the catchment

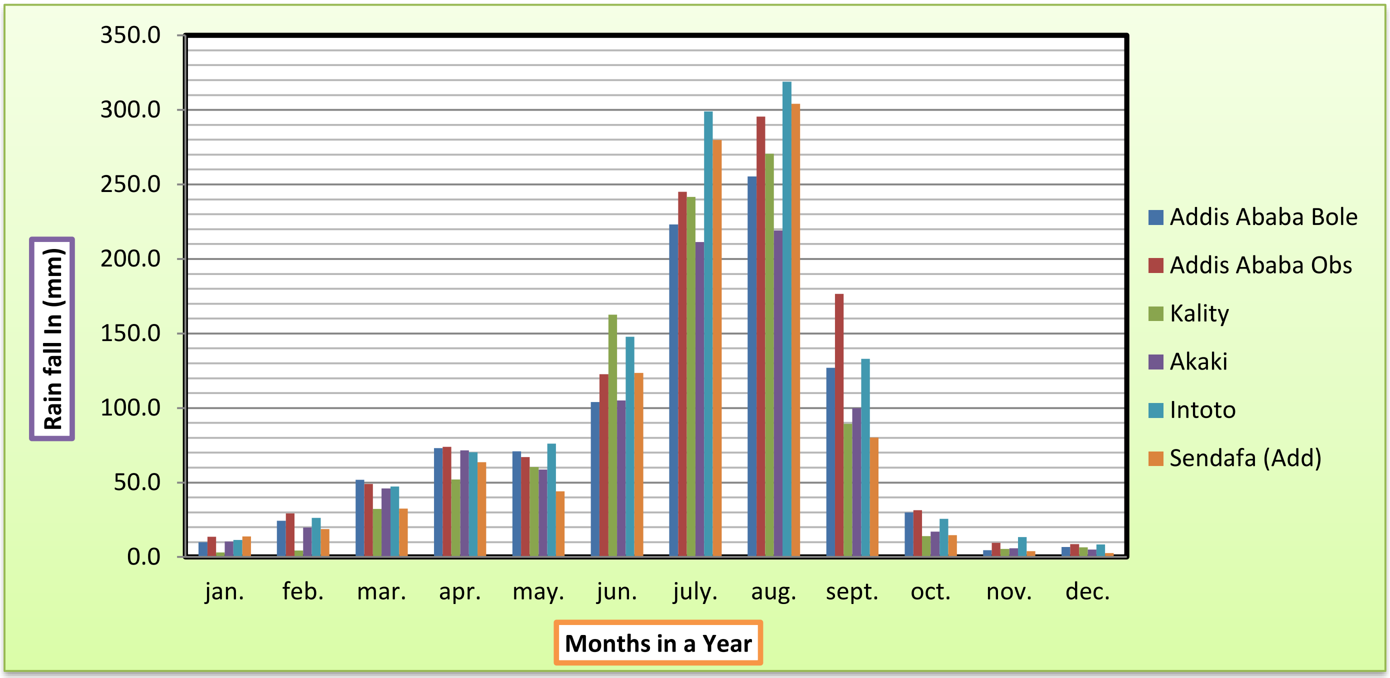


Figure 17; Annual rainfall distribution in the big akaki catchment

4.2.1.1 Relation between altitude and precipitation

Generally, known that there is a correlation between annual rainfall and altitude (Table7) and scatter diagram figure 17, does show some correlation in the study area. The variation of period of the data and quality meteorology of data collection has an effect on the correlation. The relation between mean annual rainfall x (mm) and elevation of the stations Y (m) is Y= -2.53, X=20 and R2 = -5.854

NO	Station	Altitude (m)	Precipitation (mm/Year)	Duration
1	Addis Ababa Bole	2354	981.25	30yrs
2	Addis Ababa Obs	2386	1,122.73	30yrs
3	Kality	2186	942.7	10yrs
4	Akaki	2057	869.91	30yrs
5	Intoto	2903	1177.7	21yrs
6	Sendafa (Add)	2569	982.02	29yrs

Table 7; Relation between altitude and precipitation

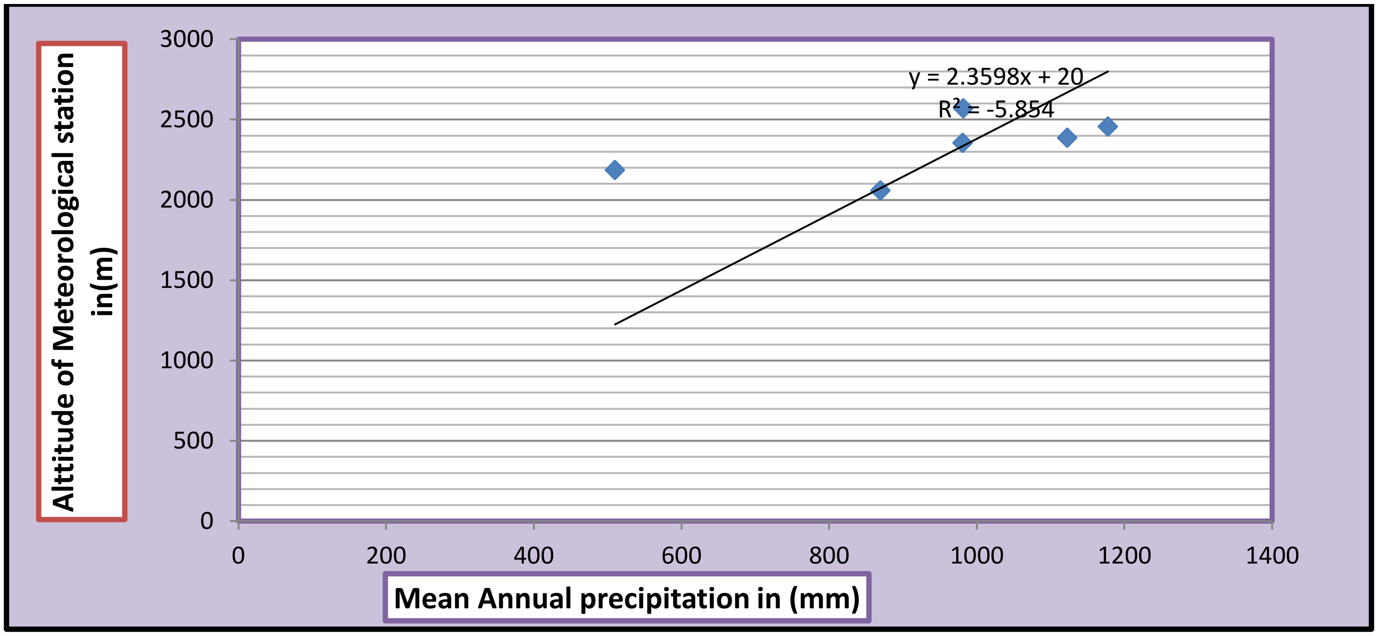


Figure 18; Correlation between annual rainfall (mm/yr.) and Altitude (m)

4.2.1.2 Rainfall coefficient for Monthly Distribution of rainfall

The distribution of rainfall in year can evaluate by rainfall coefficient method. This explained by Daniel G. from publication on Awash River basin (UnFAO, 1965) on his book entitled Aspects of climate and water Balance in Ethiopia. In order to have a complete understand of months of rainfall distribution, rainfall coefficient has calculated for rainfall stations, which is a ratio between mean monthly rainfall depth and one twelfth of the mean yearly rainfall. It given by the formula,

RC = pm/ (**py**/12**) Equation**

Where, **RC**= rainfall coefficient,

Pm = mean monthly rainfall depth

Py = mean yearly rainfall depth.

A month is considered“rainy” when the corresponding monthly rainfall coefficient reaches 0.6 and distinctly rainy when it exceeds 0.8. Extremely rainy months may have a coefficient of more than 1 (*Daniel 1977*). In the area, the rainfall coefficient has a variable value falling with in a range of 0.13 to 3.05. The following shows the rainfall coefficients for the weighted mean of precipitation of the study area. Py = 1122.7 mm, Py/12 = 24.63

Calculated rainfall coefficient indicates that months in the rainy and dry months can classified in the area as follows.

i) **Dry months**: October, November, December, January and February

ii) **Rainy months**: April May, June, July, August, and September

4.2.2 Relative Humidity

Relative humidity is the relative measure of the water vapor content or amount of moisture in the air or to the amount needed to saturate the air at the same temperature (Shaw, 1988). It varies from time to time, depending on variation in rainfall and air temperature. Relative Humidity is strongly proportional to the temperature and highly sensitive to the temperature changes. As the relative humidity rises, proportionately fewer of the water vapor molecules leaving the evaporating surface can retained in the air, and so the total number of molecules leaving minus the total number of molecules returning gradually reduced. Available relative humidity data obtained from Kality, Addis Abeba obs. Kotebe and A.A Bole stations that has 20, 24, 24 and 24 years data respectively and the average used for the calculation.

In the area the relative humidity attains its maximum is from June to September and minimum values in the months of February to April, (Table4.2).

Station-id	Jan	Feb	Mar	april	may	Jun	Jul	Aug	sept	oct	nov	dec
Kality	40.23	39.87	33.42	25.06	34.90	47.42	52.19	58.45	53.39	37.55	42.35	40.52
A.A obs	53.80	54.05	52.34	59.10	50.29	64.20	77.15	77.24	70.12	52.32	50.51	50.59
kotebe	48.5	42.8	49.6	51.5	51.3	63.2	65.0	73.8	66.6	52.8	46.4	47.4
A.A Bole	34.8	26.7	32.7	29.4	50.4	58.9	68.8	72.8	64.6	30.4	38.3	38.5
Average	**59.1**	**54.5**	**56.0**	**55.0**	**62.3**	**77.9**	**87.7**	**94.1**	**84.9**	**57.7**	**59.2**	**59.0**

Table 8; mean monthly relative humidity of the catchment

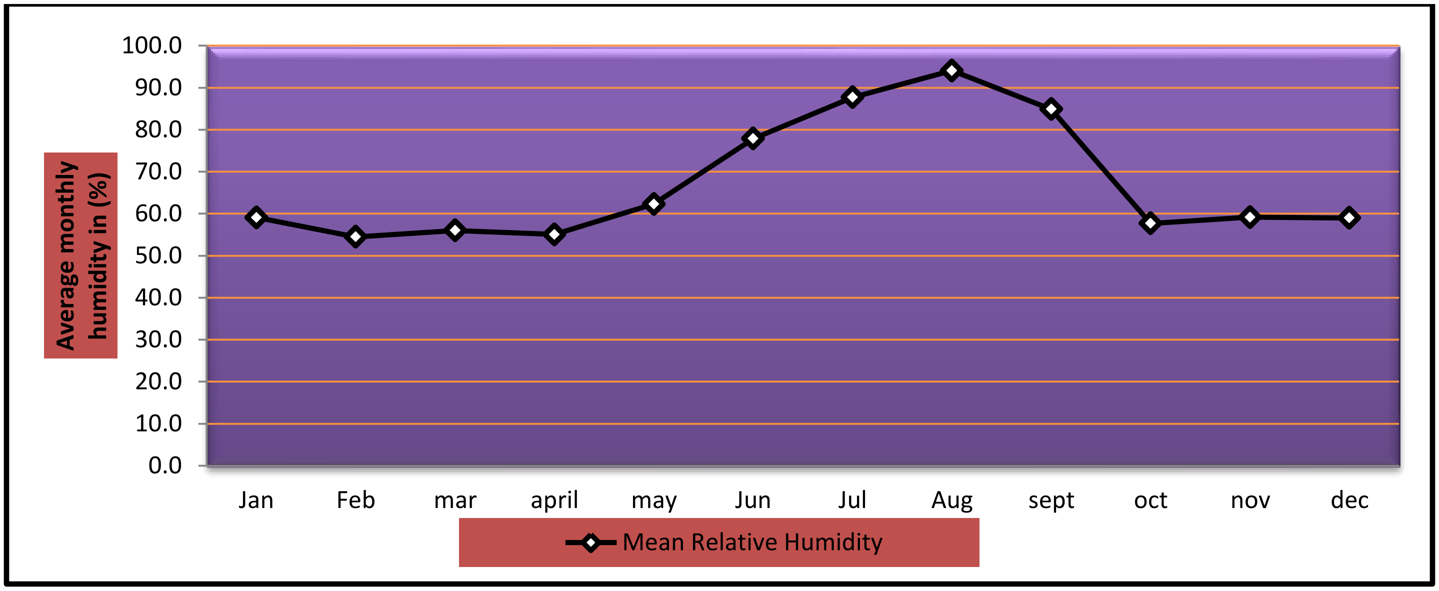


Figure 19; monthly mean relative humidity distributions of the catchment

4.2.3 Sunshine hours

Sunshine duration or sunshine hour is a climatological indicator for measuring duration of sunshine in a given period (usually, a day or a year) for a given location. Although it's one of the variable characteristics among the metrological elements. It plays an important role for evaporation and has a direct relationship with it. In addition, the variation in sunshine hour is important factor for evapotranspiration *(Telahun A, 2014)* According to the assessment and analysis result of sunshine hour the data collected at Addis Abeba observatory and Addis Abeba bole for the last 13, and 12 years respectively.

The study area experiences the mean annual total sunshine hours ranging from 72.1 hours at Addis Abeba observatory to 76.24 hours at Addis Abeba bole.

The sunshine hour is starts to decline or minimized from February to July and extremely low at July, which is lowered to one (1). Additionally started rise from July to December. For quick visual understanding, graphs for the two stations drawn using mean monthly sunshine (hours) versus months.

Station-id	Jan	Feb	mar	April	may	Jun	Jul	Aug	Sept.	Oct.	Nov.	Dec.
Addis Ababa Bole	8.61	7.00	7.01	5.50	6.66	5.27	3.32	3.78	5.52	7.90	7.79	7.88
Addis Ababa Obs.	8.82	8.32	6.78	6.04	5.42	4.41	2.04	2.84	4.09	6.64	7.88	8.82
Average	4.41	4.16	3.39	3.02	2.71	2.20	1.02	1.42	2.05	3.32	3.94	4.41

Table 9; average monthly mean sunshine hour (hour) of the catchment

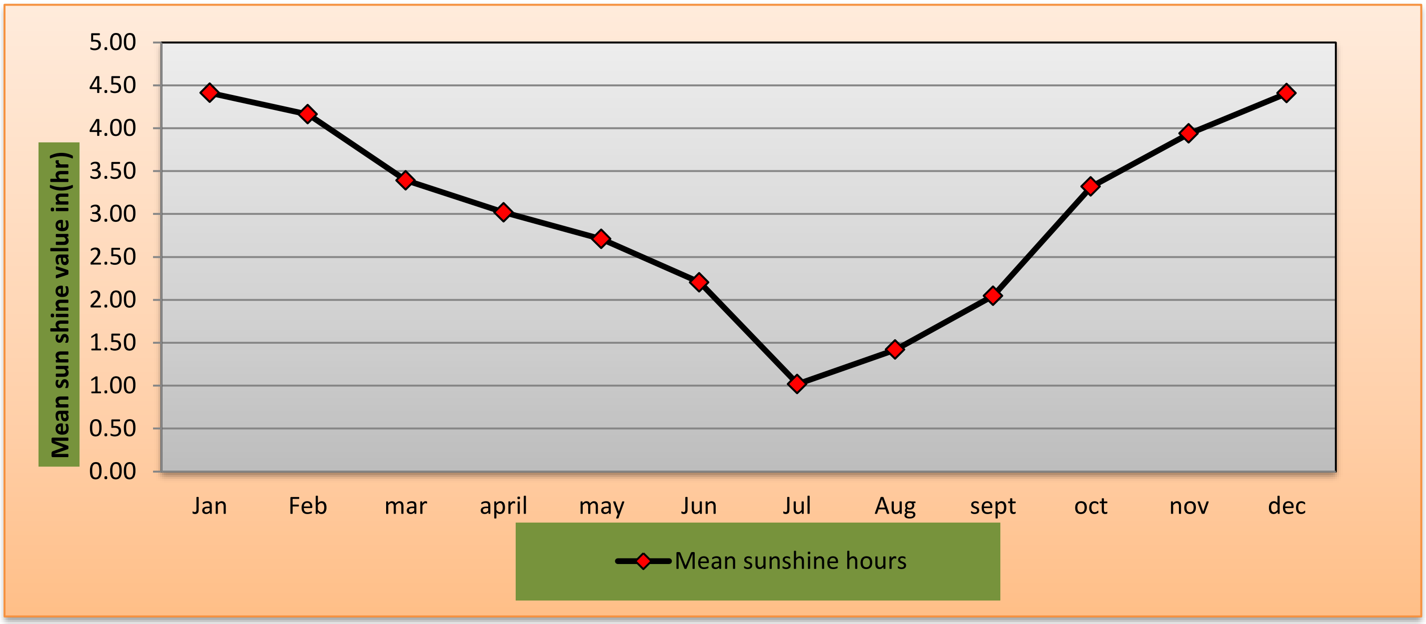


Figure 20; mean sunshine hours of the catchment

4.2.4 Wind Speed

According to the assessment of wind speed data collected by NMA, more stations or wind speed data not obtained or having a limited data due to these only one station or Addis Abeba observatory year from 1988 to 2012 has attained and analysis was made using 24 years average data. Similarly from this there is no wind speed data exist year, 2006 to 2012.The monthly mean wind speed at Addis Abeba obs. area lies in the range of **7.8 m/s to 16m/s .**

Some sort of air movement is necessary mixing the air and to remove the lowest moist layers in contact with the water surface and to mix them with the upper drier layers. Data on wind velocity is required in the evaporation studies. Because most of the time the rate of evaporation and evapotranspiration is directly influenced to some extent by (wind speed) air movement. The higher the wind speed takes away the moisture in the air which assists evaporation if its movement is turbulent than laminar. Wind speed varies with the height above the ground.

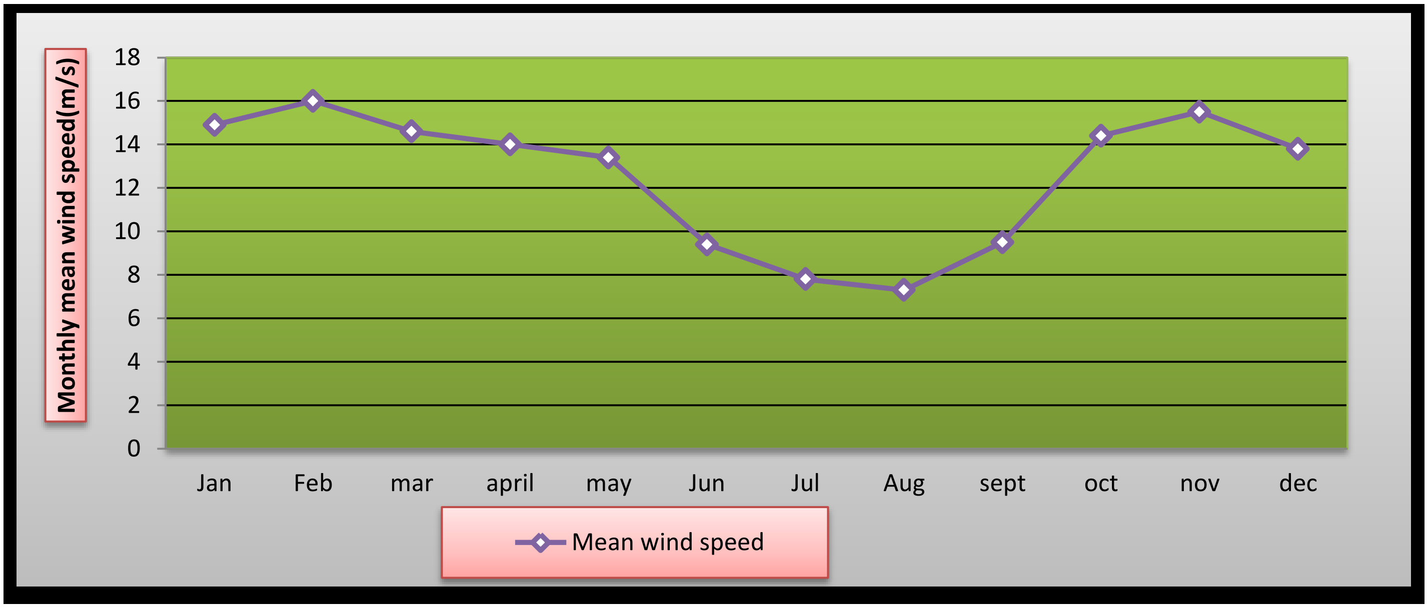


Figure 21; mean monthly wind speed (m/s) of the catchment

4.3 Annual Effective aerial depth of Precipitation

In water budget studies, it is necessary to know the average depth of precipitation over a drainage basin. Based on the available rainfall data taken from 6 (six) stations analysis should be done to obtain the effective uniform depth of precipitation for the catchment to get a more reliable & representative result. The average depth of rainfall is also known as effective uniform depth of rainfall (*Jayarami, 1996*).The three methods are the following to obtain the effective uniform depth of rainfall over the drainage basin:

- Arithmetic mean method
- Theissen polygon method
- Isoheytal method.

4.3.1 Arithmetic mean method

If the rain gauge network is of uniform density, flat area, and the variation of individual gauge records from the mean is not too large then a simple arithmetic average of the point – rainfall data for each station is sufficient to determine the average depth of rainfall over an area (*Shaw, 1988) and (Jayerami, 1996*). It is the simplest of the three methods and the result is obtained by dividing the sum of the rainfall amounts recorded at all the rain gauge stations which are located within the area under consideration by the number of stations (*Wilson ,1983*).

$$\text{i.e: } p = \frac{P1 + P2 + \text{---} Pn}{n}$$

Where,

P is the average depth of rainfall & P1, P2, --- Pn are the rainfalls recorded at stations 1, 2, ---etc. and n is the number of rain gauge stations within the area. Based on this method the average depth of rainfall of the area, P = 1012.731mm (Table 4.4).

4.3.1.1 Theissen polygon method

This method attempts to adjust for non-uniform gauge distribution by weighing the record of each gauge in proportion to the area that is closer to that gauge than to any other gauge (Figure 4.2). It produced using ArcGIS 10.3 software. Also calculates the weighted average of each precipitation station in and near by the catchment based on the following relationship.

That is $$p = \frac{A1P1 + A2P2 + \text{---}AnPn}{\Sigma Ai}$$

Where,

P = Average aerial depth of rainfall

P1, P2, --- Pn = mean annual rainfalls recorded at each rain gauge stations.

A1, A2, --- An = polygonal areas around each stations.

i refers to the i th precipitation gauge and n is the number of the Theissen polygons. The result obtained by using this method is 985.87mm (Table 4.8).

Station	Jan.	Feb.	Mar.	Apr.	May.	jun.	Jul.	aug.	Sept.	oct.	Nov.	dec.	M A. Rf
Addis Ababa Bole	10.00	24.40	51.80	73.10	71.00	104.00	223.20	255.40	126.90	30.00	4.60	6.70	981.20
Area of influence(KM2)	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Weighted Rainfall in(mm)	2.64	6.44	13.66	19.28	18.73	27.43	58.88	67.37	33.47	7.91	1.21	1.77	258.83
Addis Ababa Obs	13.70	29.30	49.20	74.00	67.20	122.70	245.00	295.40	176.60	31.50	9.50	8.70	1122.70
Area of influence(KM2)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
weighted Rainfall in(mm)	0.69	1.48	2.48	3.73	3.38	6.18	12.34	14.88	8.89	1.59	0.48	0.44	56.54
Kality	3.10	4.40	32.30	52.10	60.40	162.60	241.70	270.70	89.50	14.10	5.40	6.50	942.70
Area of influence(KM2)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
weighted Rainfall in(mm)	0.10	0.14	1.06	1.71	1.98	5.33	7.92	8.87	2.93	0.46	0.18	0.21	30.90
Akaki	10.40	19.80	46.00	71.50	58.80	105.00	211.40	219.10	99.90	17.00	5.90	5.10	869.90
Area of influence(KM2)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
weighted Rainfall in(mm)	1.60	3.04	7.06	10.97	9.02	16.12	32.45	33.63	15.33	2.61	0.91	0.78	133.51
Intoto	11.60	26.40	47.20	70.30	76.10	147.90	299.00	318.80	133.00	25.60	13.50	8.40	1177.70
Area of influence(KM2)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
weighted Rainfall in(mm)	0.92	2.09	3.74	5.56	6.02	11.70	23.66	25.23	10.53	2.03	1.07	0.66	93.20
Sendafa (Add)	13.90	18.70	32.50	63.80	44.00	123.60	279.80	304.00	80.10	14.80	4.10	2.70	982.00

Area of influence(KM2)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
weighted Rainfall in(mm)	5.84	7.86	13.67	26.83	18.50	51.97	117.65	127.82	33.68	6.22	1.72	1.14	412.90

Table 10; Theissen polygon method to calculate annual rainfall of the catchment

The Theissen polygon approach is a geometric method for assigning areal weights to each gauge based on a nearest neighbor approach, Theissen polygons constructed by:

(1) Connecting each gauge in a triangulated network

(2) Intersecting each triangle edge by a perpendicular bisector

(3) Deriving polygons from the bisector edges and watershed boundary

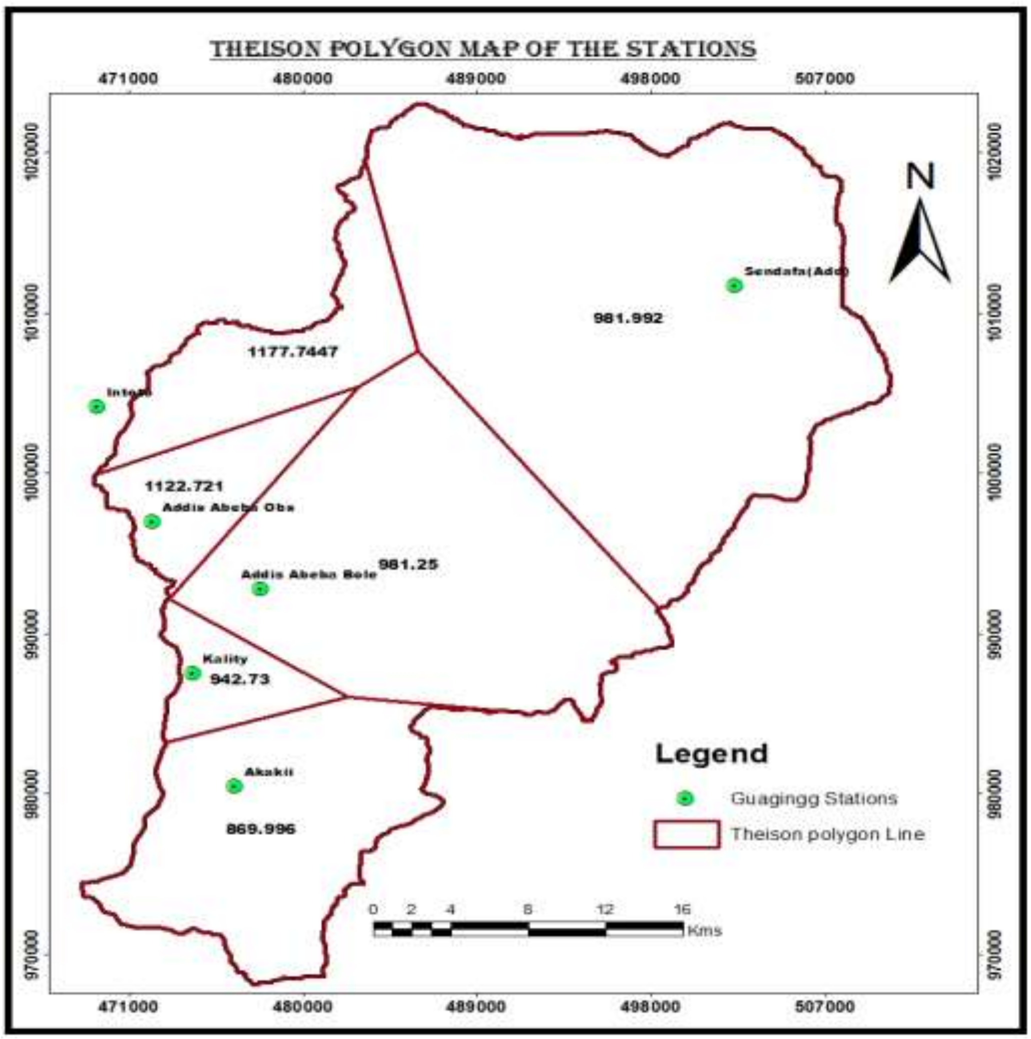


Figure 22; Theissen polygon map of the big akaki river catchment

4.3.1.2 The Isoheytal method

This method allows the influence of physiographic parameters such as elevation, distance from the coast, slop, and exposure to rain bearing winds (Shaw, 1988) to be taken in to account and is the most accurate method of computing the average depth of rainfall. It employed by plotting isoheytal map on a suitable chart by drawing contours of equal rainfall. That means isohyets are lines joining points of equal precipitation. According to this method, the mean annual precipitation of the study area is equals *1012.6mm*

LC	HC	Pi	Ai (km)	At	Ai/At	Ai/At*Pi
800	850	825	38	1250	0.0096	7.92
850	875	862.5	104	1250	0.0832	77.76
875	900	887.5	174	1250	0.1392	123.54
900	950	925	118	1250	0.0944	89.32
950	1000	975	438	1250	0.3504	341.64
1000	1050	1025	161	1250	0.1288	136.02
1050	1100	1075	117	1250	0.0936	100.62
1100	1150	1125	95	1250	0.076	85.2
1150	1200	1175	48	1250	0.0248	37.14

Table 11; isoheytal methods of calculating annual rainfall in the catchment

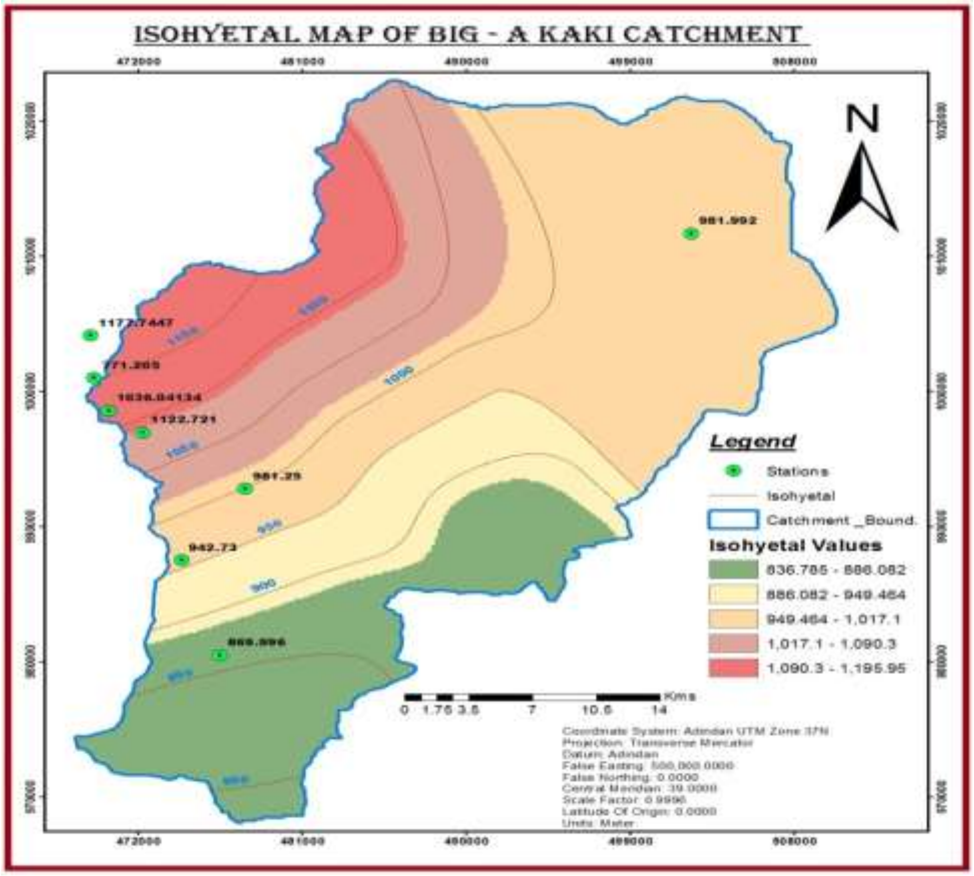


Figure 23; Isoheytal map of the catchment

The above two methods result is more or less similar. Therefore the, Theissen polygon and isoheytal methods are averaged to fit best for the study area and hence the mean annual precipitation of the catchment is equal to 999.16 mm. In general, the analysis of the rainfall data obtained over a long period in the past would help to make reasonable estimates of rainfall used in various development activities. The rainfall distribution in the study area is not uniform which ranges from 500mm to 1020mm. The highest rainfall is recorded in A.A observatory which is located southeast part of the study area and the lowest rainfall record is in akaki.

From precipitation, bar graph (Figure 4.9) it is possible to see that the maximum rainfall recorded in the month of August and the minimum rainfall recorded in the month of December.

Majority of the rainfall in the study area obtained during the summer time (Kiremt) during July, August and September that covers over 58.2% of the total annual rainfall (Table 4.9). The minimum records are in the months of November, December, January and February.

4.2 Estimation of Evapotranspiration

Evapotranspiration is the conversion of water to vapor by evaporation and transpiration and enter from the watershed surface to the atmosphere (*Axon, 1982*). Although, the total loss by both evaporation and transpiration from a land surface and its vegetation. Quantitative assessments of water resources and the effects of climate and land use change on those resources need a quantitative understanding of evaporation.

Evapotranspiration refers to evaporation and transpiration. Evaporation is the process whereby solar energy releases water molecules directly from water bodies like lakes, rivers, ponds etc. The process happens when the water molecules have absorbed enough energy to escape from the surface tension that holds them in the liquid or solid state. It can occur at land surface in soil hold water consisting of silt , clay and other sort of sand.

Transpiration is the process whereby the transformation of water in to water vapor taken place through the vegetation at land surface. Water taken up by the root of plants, trees and transported to their leaves. As result of the physical properties of the vegetation itself and the supply of solar energy, the water at the leaves can be able in to the atmosphere as water Vapor.

Evapotranspiration controlled by Metrological conditions, the type of vegetation, and the supply of water. For a given set of metrological conditions, evapotranspiration rates reach maximum values if the supply of water is unlimited. We call this maximum rate of potential evapotranspiration. This is nearly always true for open water bodies like large lakes, rivers, etc. For the upper part of the soil, the amount of water available for evapotranspiration depends on the soil moisture content. Generally, the evapotranspiration affected by change in the physical nature consisting of like geomorphology, geological, land use land cover of the area, soil, etc.

4.2.1. Potential Evapotranspiration (PET)

According to Thornthwaite (1948), PET refers to the rate at which evapotranspiration would occur from an area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water and without heat storage effects. Potential evapotranspiration has to use for hydrogeological assessments determined by various methods: These methods classified on basis of their data requirements (Jensen et.al., 1990).also

It is used with precipitation data to calculate water balances ,the calculation are useful in calculating plant water requirements and also the losses of water to evaporation from the areas such as irrigated fields and reservoirs. The PET is one of a component that used in the analysis of water balance method due to this the Thornthwaite method used to calculate potential evapotranspiration.

4.2.1.1 Thornthwaite Method (1948)

An empirical formula of Thornthwaite, which used to calculate potential evapotranspiration, PEm, based mainly on temperature with an adjustment made for the number of day light hours. In this approach an estimate of the PE m, calculated on a monthly basis, given by a formula:

$$\boxed{PE\ m=16Nm\ (10Tm/\ I)\ a\ mm}$$

Where m is the months 1, 2, 3…12,

Nm is the monthly adjustment factor related to hours of day light (Day light factor),

PEm = potential evapotranspiration (mm)

Tm = the monthly mean temperature oC

a=6.7x10-7I3-7.7x10-5I2+1.8 x10-2I+0.49 (to 2 significant figures)

The Heat index of the year given by:

$I=\Sigma\ im= \Sigma(Tm/5)^{1.5}$, for m=1….12

Where, I=Heat index of the year

I=Heat index of the Month

Thornthwaite computation has a dominant effect in the summer months with the high temperatures. Based on this empirical formula, the weighted mean annual PET over the study area indicated on table below (table)

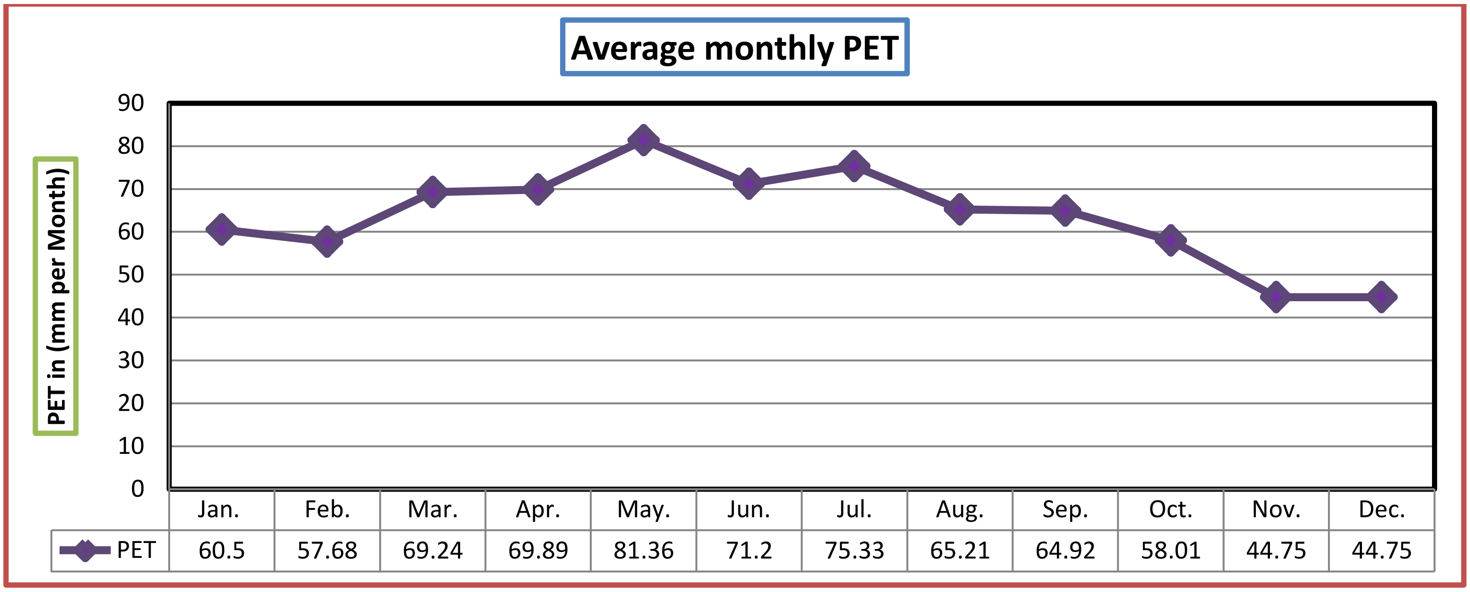


Figure 24; Average monthly potential evapotranspiration

4.2.2. Actual evapotranspiration (AET)

The most popular method of computing actual evapotranspiration is through the calculation of potential evapotranspiration. Soil moisture budgets calculation has carried out to evaluate AET values of the sub-basins. The values of soil moisture deficit and AET vary with soil type and vegetation (Shaw, 1994). During the months in which the rainfall exceeds the potential evapotranspiration the actual evapotranspiration will be set equal to the potential evapotranspiration. During the dry months the AET exist of the sum of the rainfall of the current month and the amount of the water extracted from the soil (the soil moisture utilization). The soil moisture during the dry month obtained using the following formula.

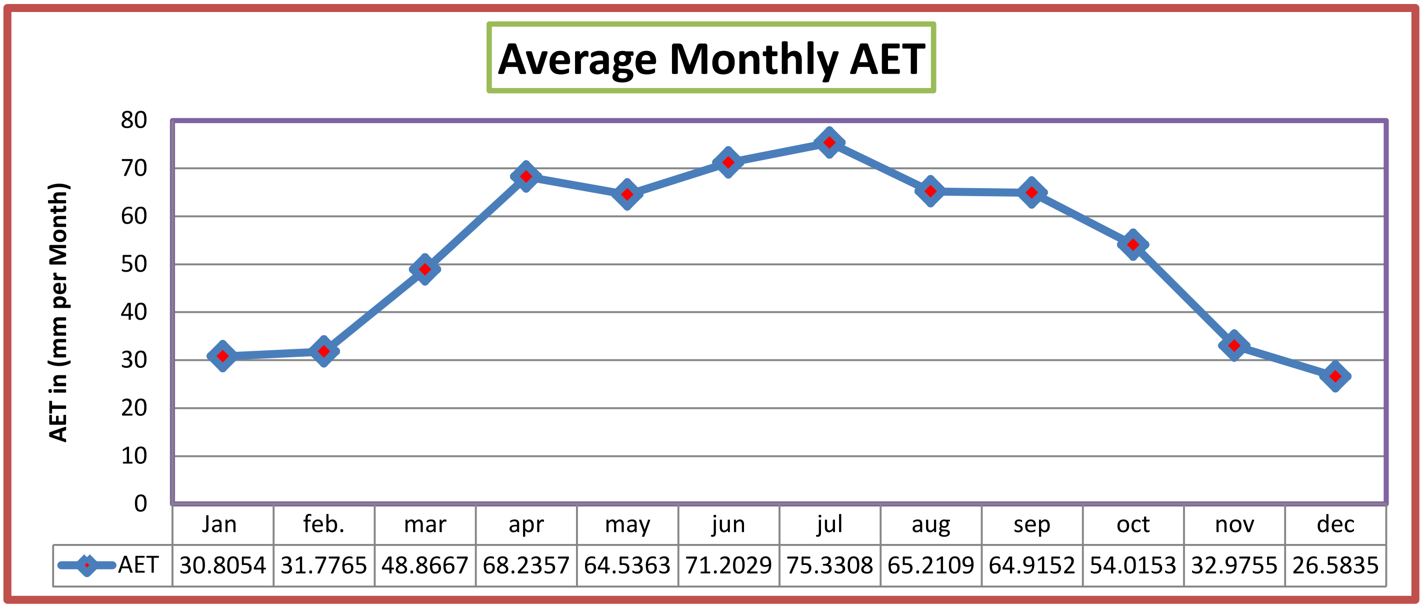
$$SM = 10^{\left[\log MAWC - \left(\left(0.525/\left(MAWC^{1.0371}\right)\right) * ACPWL\right)\right]}$$

Where: SM: soil moisture during month (mm)

MAWC, Maximum available water capacity

ACPWL, accumulate potential water loss

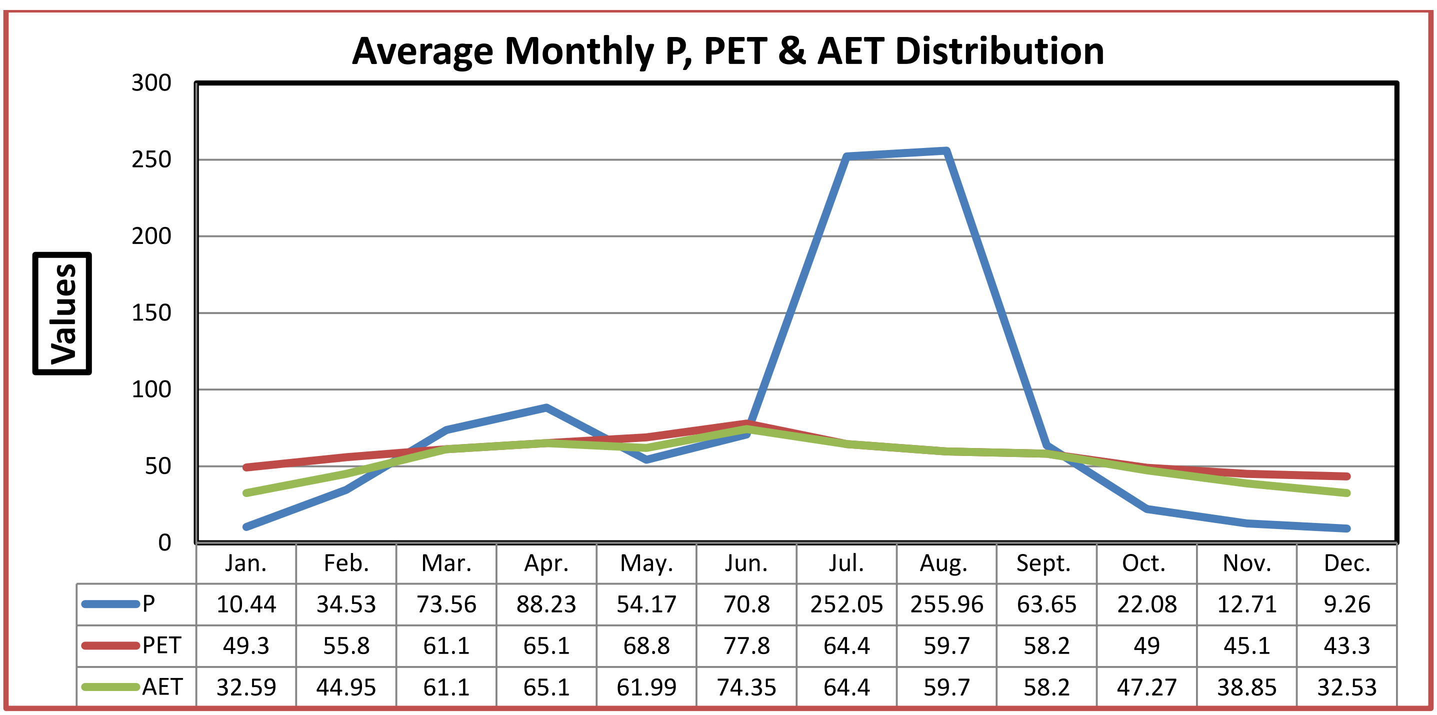
The source water balance calculation of the Thornthwaite ,user manual , 1948 for moderately deep rooted crops /corn and cereals /clay ,clay loam soil textures available water capacity of root zone(mm) is (W = 150).



	Jan	feb.	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
AET	30.8054	31.7765	48.8667	68.2357	64.5363	71.2029	75.3308	65.2109	64.9152	54.0153	32.9755	26.5835

Figure 25; Average monthly actual evapotranspiration

As described and mentioned on the above graph, the highest average monthly actual evapotranspiration under the available soil moisture condition occurs on July. This is shows on this month the temperature that drives evapotranspiration is may be higher. In another case, the lowest average monthly actual evapotranspiration occurs in December, January and February since there is soil moisture deficit in these months.



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
P	10.44	34.53	73.56	88.23	54.17	70.8	252.05	255.96	63.65	22.08	12.71	9.26
PET	49.3	55.8	61.1	65.1	68.8	77.8	64.4	59.7	58.2	49	45.1	43.3
AET	32.59	44.95	61.1	65.1	61.99	74.35	64.4	59.7	58.2	47.27	38.85	32.53

Figure 26; the relationship between precipitation, potential and actual evapotranspiration

4.3 Runoff Analysis and Estimation

Runoff is the movement of an element of stream water under the force of gravity through well Defined channels or over the land in undefined channels that generates from precipitation in a Catchment or basin. The runoff process is strongly influenced by the intensity of precipitation and the rate of infiltration .Also The main controlling factors of runoff over an area are climate, geology, vegetation, topography, Soils, Drainage network, size and average height of catchments, land use and human factors such as urbanization that decreases infiltration etc.

In general, the relationship between Runoff, stream flow and precipitation expressed in terms of continues circulation of water through the hydrologic cycle. In order to analyze and estimate runoff conditions from a catchments area, existing discharge records of akaki station where obtained from MOWR (period 1988-2016).

The out flow of the Catchment River during the dry season is limited to the base flow. Although the base flow component of a stream is less than the total surface flow, the total discharge of the stream may fluctuate greatly through the year. The difference is due to the variable nature of precipitation intensity events that contribute over land flow (Runoff), inter flow and direct precipitation

The maximum peak flow (Runoff) that occurred over the past 28 years (1988 – 2016) reaches 693.10m3/s in September for the upper part of the area.

In the study area there is a recorded study of flooding, however there were flooding in the area some times during the biggest discharge period at time of large storms in the months of September, July and August. Overland flow (*Kirkbay, 1978*) is the dominant producer of the storm runoff in the study area. In general, the amount of runoff in the area is generally medium to large and can contribute by intense rain events.

The computed high evapotranspiration rate of the area also indicates that it contributes to the small amount of runoff. Besides, in some parts of the study area, there is high drainage density and this is an indication of the presence of a corresponding high runoff volume. By taking this in to consideration, the runoff coefficient of the area suggested for runoff calculation of the study area and the runoff over the study area is calculated using curve number method, the result includes 0.38mm. The rainfall of the entire study area is 999.16mm and to estimate the runoff of the lower part of the study area is as follows:

Runoff is calculated using; a formula,

$$Q = \frac{(P - 0.2S)^2}{(P - 0.8S)}, \qquad S = \frac{1000}{CN} - 10$$

Where; CN is known as curve number as sugested by American Soil Conservation Service (SCS)

Q is volume of runoff in inches ,P is rainfall depth in inches ,S = potential maximum retention after runoff begins

Parameter	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
RF.	62.6	123.0	259.2	404.9	377.4	765.8	1500.2	1663.4	706.1	133.0	42.9	38.0
R.Dicharge	94.2	87.3	100.1	122.8	115.4	156.4	784.1	1739.4	790.9	161.5	105.7	99.8

Table 12; Rainfall - discharge (1988 -2016)

The catchment has high amount of storm water, since there is a natural outlet for storm water runoff. All storm water that comes from highland produce high runoff and accumulates in the depression or downstream of the catchment boundary and eventually drowns to the subsurface. It is possible to drain the sewage by gravity towards a lower site as this site will regularly be flooded with a good percolation.

4.4. Recharge Estimation

Recharging water is mostly source of Precipitation that contributes moisture in soil and subsurface materials. In addition, water that percolates, pass upper unsaturated materials meets the water table infiltrate or added as a recharge to the groundwater system.

The amount of recharge to the aquifer system depends upon the rate and duration of precipitation, topography, soil texture and moisture conditions, depth to the water table and underlying litho-structural setting (*Shaw, 1994*).

4.4.1 Soil water balance

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc.) over a specific period *(Tenalem and Tamiru, 2001)*. Water balance is extremely important for studies of the hydrologic cycle. Based on the water balance approach it is possible to make a quantitative evaluation of water resources and their change under the influence of man's activities. Besides, water balance studies help to make an indirect investigation of an unknown water balance component from the difference between the known components. For natural drainage basin, measurement of the precipitation, transported water, reservoir evaporation and river discharge made satisfactorily with some degree of precision. However, groundwater inflow, outflow, and change in storage computed from the hydraulic aquifer characteristics and measured potentiometric data. The measurement of groundwater movements into or out of the drainage area cannot make easily. The water balance for any water body and at any time interval in its general form represented by the general equation as follows:

Inflow = Out flow + Change in storage

Here, inflow includes precipitation and groundwater inflow whereas out flow includes surface runoff, groundwater out flow, evaporation, evapotranspiration, withdrawal and change in storage.

The soil-water balance model uses a simple accounting scheme to predict soil- water storage, evaporation and water surplus. This method helps to quantify the annual AET of the area based on the potential evapotranspiration already computed by Thornthwaite. The following table shows values of the major components of the soil water balance. Table: 9 Long-term average monthly Soil-water balance Method of estimating AET (Thornthwaite), for a soil with available soil water storage capacity of the root zone is 150 mm. The soil is assuming a uniform land cover of clay loam and over 70% moderately deep rooted vegetation's with available water capacity from 25 – 30% volume and rooting depth 0.50 and 1m respectively. The Estimated AET prepared by below steps; Actual evapotranspiration calculated from potential evapotranspiration by the following procedures (*Kolka & Wolf, 1998*):

Step 1: PET- potential evapotranspiration calculated with the Thornthwaite equation.

Step 2: P-PET- precipitation less the potential Evapotranspiration

Step 3: Accumulated Potential Water Loss (ACPWL) - accumulated potential water loss, which is the amount of soil water lost when PET exceeds P; i.e., there is less precipitation than potential evapotranspiration. In the calculation of AET, ACPWL is not a factor until P-PET becomes negative. To determine the ACPWL for a particular month, the previous month's ACPWL and the current month's P-PET summed. In the original program, ACPWL becomes 0 after a month in which PET< P.

Step 4: Soil moisture- soil storage is the maximum soil storage at field capacity (ACPWL =0). When below field capacity (ACPWL < 0), soil moisture is a function of both maximum soil storage and ACPWL.

Step 5: Delta (change in soil moisture), the difference between soil storage in successive months when it is less than maximum. When DELTA is negative, then AET < PET i.e., soil moisture is limiting evapotranspiration. When delta is positive, then AET = PET.

Step 6: Actual Evapotranspiration (AET) - actual evapotranspiration is the sum of available precipitation for the month the change in soil moisture. When Delta is positive, AET = PET. When delta is negative, AET= Precipitation for the month plus the absolute value of delta.

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
P	11.12	20.77	42.41	67.77	60.28	123.18	251.45	277.51	111.25	21.51	6.37	5.68
PET	60.50	57.68	69.24	69.89	81.36	71.20	75.33	65.21	64.92	58.01	44.75	44.75
P-PET	-49.38	-36.91	-26.82	-2.12	-21.09	51.98	176.12	212.30	46.34	-36.52	-38.38	-39.07
Acc. Pot WL	-163.35	-200.26	-227.08	-229.21	-250.29					-36.52	-74.90	-113.97
AWC	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00
Log MAC	1.70	1.59	1.52	1.51	1.45	2.18	2.18	2.18	2.18	2.07	1.96	1.84
SM Retained	50.27	39.27	32.82	32.36	28.10	150.00	150.00	150.00	150.00	117.48	90.87	69.96
ΔSM	-19.69	-11.00	-6.45	-0.46	-4.26					-32.52	-26.61	-20.91
AET	30.81	31.78	48.87	68.24	64.54	71.20	75.33	65.21	64.92	54.02	32.98	26.58

Table 13; step- by step or systematic calculation of actual evapotranspiration

Where,P = Mean monthly precipitation, mm

PET = Potential evapotranspiration, mm

AET = Actual evapotranspiration, mm

Ac. PWL = Accumulated potential water loss, mm

Sm = Soil Moisture retained, mm

ΔSM = change in soil moisture, mm

D = soil moisture deficit, mm

S = Soil moisture surplus, mm.

Estimation and description approaches of each of the main components that influence the Soil - water balance presented precisely in the following way. The mean monthly precipitation (p) values obtained from the average of Theissen and Arithmetic Methods presented in row 1 of the table. The value and result mean monthly precipitation and potential evapotranspiration presented in row 2. The accumulated potential water loss that obtained by adding the negative values of P – PET of a consecutive months are listed in row 3. The amount of water retained by the soil, the soil moisture listed in row 4. The change in soil moisture, which obtained by deducing the soil moisture of the month under consideration from the soil moisture of the preceding month, is listed in row 5. The retained soil moisture is indicted in row 7, The AET is listed in row 9. The AET = PET during the months when mean monthly precipitation exceeds PET.

When PET exceeds P, the AET will be equal to the sum of mean monthly precipitation and the amount of soil moisture withdrawn from the storage. The soil moisture deficit calculated easily by deducting the AET from values of PET and listed in row 8. Moisture surplus that is available for infiltration and runoff computed to be zero and listed in row 7. Once a moisture deficit developed, it reduced when excess precipitation is stored in the soil at the beginning of wet season. When soil moisture attains its field capacity, further precipitation must leave the soil as runoff.

Amount of water that cannot be stored in the soil known as moisture surplus. Surplus does not evaporate or remain in soil storage and includes both surface and subsurface runoff. If the drainage basin is large, about 50% of the moisture surplus estimated as runoff. According to Soil-water balance result, in the study area the moisture surplus is zero.

This implies there is no runoff from precipitation that fall in the area. Since the area has subtropical highland climate, the PET value of Thornthwaite method & its AET tend to be mostly lower than precipitation in the region. The soil–water balance includes storm runoff that usually is a source of runoff in subtropical highland zones.

According to *(David. 1990)* soil moisture, budgeting developed for humid climates and has less validity in arid and semi-arid zones. This model works best for the seasonal patterns of recharge, well-developed soil that do not dry completely and in conditions when PET and AET are similar and precipitation relatively uniform.

4.4.1.1 Groundwater Recharge Estimation

The quantitative analysis and estimation of a groundwater that will recharge the drainage basin evaluated from the components of the hydrological cycle. The main objectives of balancing hydrologic components that prevail in the study area lie in identifying the annual groundwater recharge and the AET of the area. Before making a balance among the components, defining the water balance equation applied in the study area followed by estimating and computing each of the components is crucial.

Determining annual groundwater recharge follows the general water balance equation that introduces the main components that are prevailing and omits those that are of less effect in the balance. Allowing for changes of storage within the system input must be equal to output under steady estate. However, for most natural conditions this is not true due to certain topographic situation and geological structures.

The natural recharge to an undeveloped aquifer may determine by a water- budget analysis of the recharge area: Groundwater recharge = (Precipitation + surface-water inflow + imported water + groundwater inflow) – (Actual evapotranspiration + reservoir evaporation + surface water outflow + exported water + groundwater out flow) + changes in surface water storage.

This equation can account for groundwater recharge not only from precipitation, but also from losing streams, irrigation water, unlined canals, etc. Water used for many purposes may be recharged to the groundwater reservoir such as excess irrigation water, surface reservoir and water used for domestic and industrial purposes.

The determination of such additional groundwater recharge is often more complicated than an analysis of the basic amount of recharge. This is because an accurate accounting of this type of recharge involves long and tedious inventory analysis. In the study, area the area boundary based on surface water divide that may coincides with groundwater divide.

At a regional scale, a unique groundwater flow pattern indicative of inter basin groundwater flow from the Blue Nile to the Upper Awash basin as *(Azagegn, 2014)*.The long term water balance calculation based on different approaches may the groundwater recharge from precipitation is almost good. Therefore, the groundwater storage is mainly groundwater inflows from external basins contribute to the Basin catchment. , the water balance of the study area is:

$$\Delta G = P - AET - RO - W$$

Where, p = Mean precipitation = 999.30 mm

AET = Actual evapotranspiration = 634.45mm

PET = Potential Evapotranspiration = 762.84mm

Ro = a runoff from over the study area = 38mm

ΔG = Groundwater recharge.

ΔG = (P + Gi) – AET - RO -W finally the recharge is calculated and result of recharge is 326.85mm/yr.

Authors	Estimated Recharge /Upper Awash	Year of study
Molla Demlie	105.4mm/yr.	2015
Dr. Tilehun Azagegn	82.6mm/yr.	2014
Prof.Tenalem Ayenaw	51.5 to 157mm/yr.	2014

Table 14; previous works on recharge estimations of upper awash by different authors

4.2.2 Base flow separation

Estimation and separation of base flow and direct runoff is very significant to understand the hydrologic properties of the watershed .There have been various methods and software's which are used to analyses and separate the runoff from base flow, this are BFi+, Time plot , RAP ,etc. Accordingly, the recharge computed by computing using a RAP (river analyses package) (version 3.0.8.0).

The base flow models can used to calculate long-term average recharge and base flow. Base-flow separation methods used to identify the base flow component of stream flow at a number of currently operated and discontinued stream flow gaging-station locations.

Base flow is also one way of the calculating and estimating the recharge or has used as an approximation of recharge with the acknowledgement that it is probably less than the amount recharging the groundwater system (*Daniel, 1996*). Generally, the base flow estimated from three river packages that characterized the catchment includes, Akaki River found at akaki, Mutincha River nearby legedadi dam and kessem at beke. The station akaki is located at the out late of the catchment and is a main river that covers an enclosed area (884.4 sq.km) of whereas mutincha (172.5 sq.km) and kessem (50.0 sq.km) are a station where the upper of intermittent river.

	Coordinate		Year Of Rec.		Enclosed Area(sq.km)	Recharge in(mm)
Station Name	UTME	UTMN	From	To		
Akakii @ Akakii	476178	981961	1988	2016	884.4	137.61
Mutincha @ Legedadi	490842	1000381	1988	2006	172.5	241.50
Kessem @ Beke	507324	1013279	1988	2017	50	91.85

Table 15; Base flow along river gauge stations location and enclosed area

Base flow separation method used to separate and calculate part of the stream flow hydrograph attributed to groundwater discharge. Daily river discharge records over 28 years from three stations (akaki, Mutincha and Kessem river gauging stations) was used for the analysis. The discharge and Base flow result is calculated by the software is using coefficient value 0.930 rather than the default. The average weighted base flow of the three stations, which is representative of catchment obtained and is around 156.99mm.

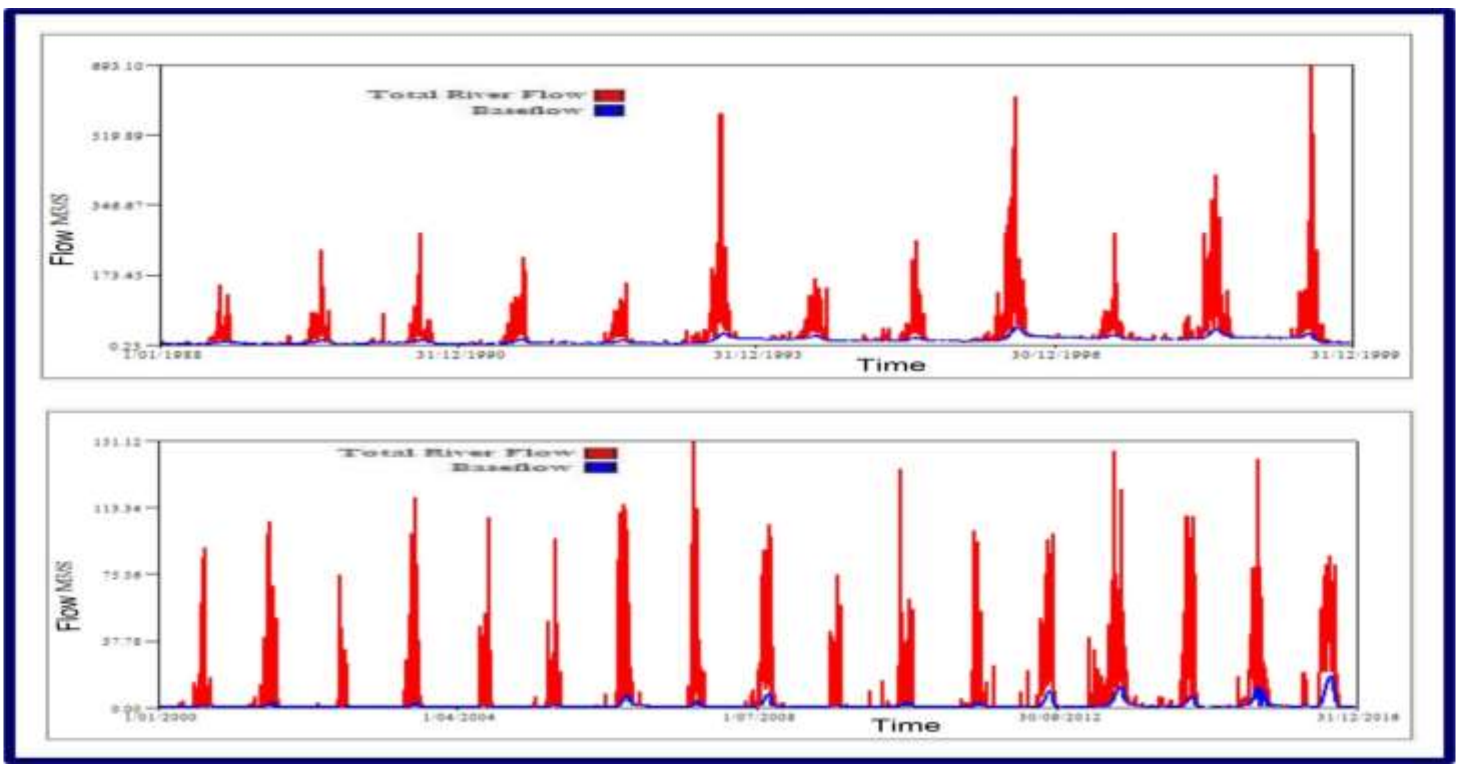


Figure 27; Hydrograph analysis of main Akaki River at akaki catchment using RAP. Software

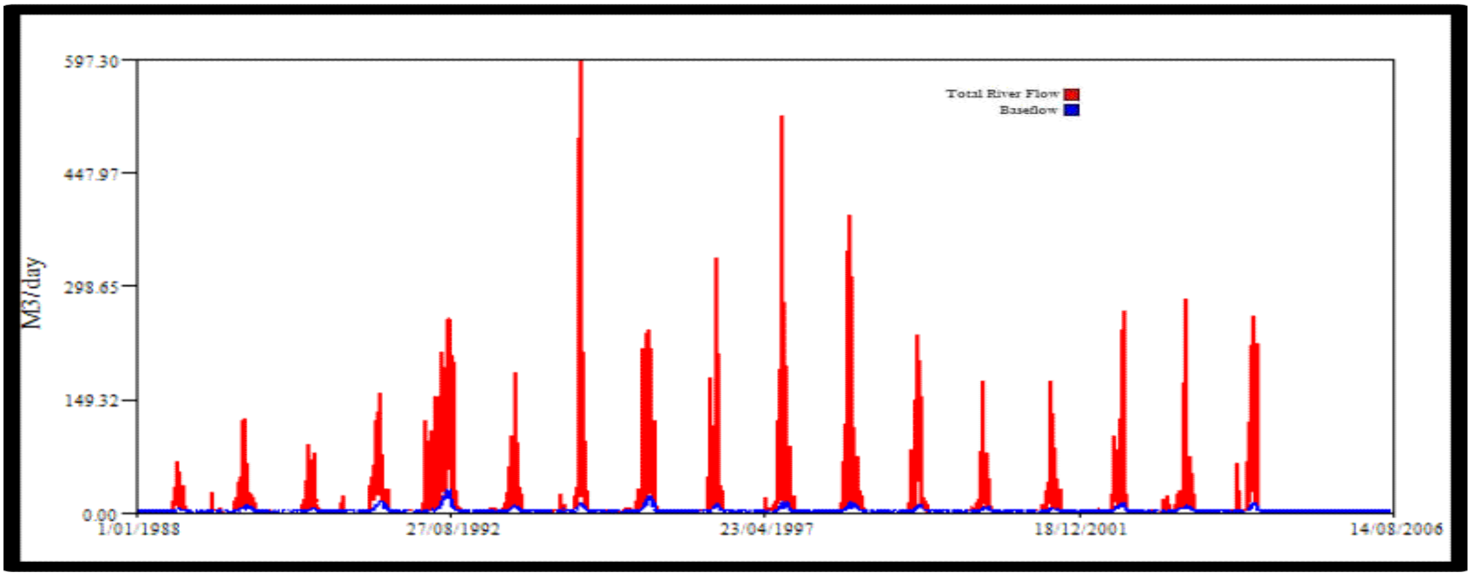


Figure 28; hydrograph separation analysis of mutincha river @akaki river catchment

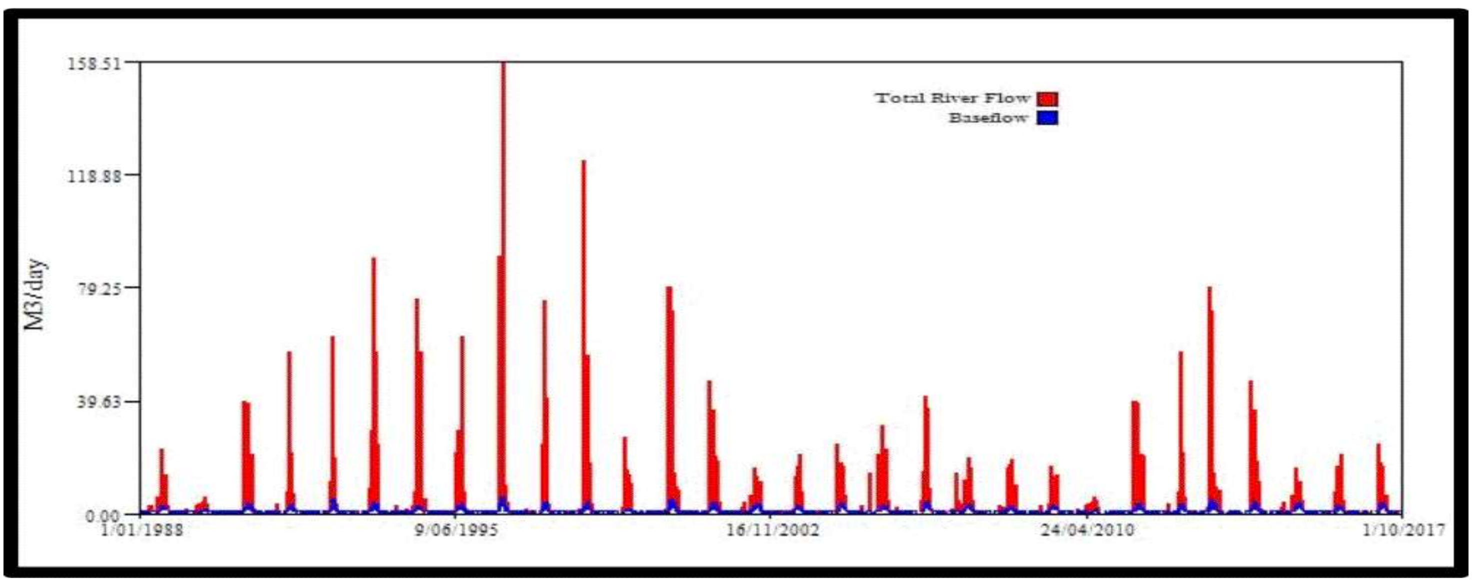


Figure 29; hydrograph separation analysis of Kessem @beke in akaki river catchment

4.3 Surface water

Surface water resource in the study area includes the tributaries of the catchment that mostly flow orientations from the North (Intoto ridge) to South (Akaki well fields). Although the man- made reservoirs found within and nearby to the study area those are Abba Samuel reservoir, Gefersa, legedadi and dire reservoir.

The main surface water (River) in study area comprised Akaki River is perennial and intermittent streams. This tributaries are covers most localities of the catchment and flows to the main river (Akaki) from different direction follows the surface structure. The river at a place has local term lege Dadi River that has this name before meets the Akaki River.

As described at the first chapter the overall drainage system in both study areas characterized by dendritic and sub parallel flowing patterns. These drainage patterns might develop on the northern part of the area, trending fractures and openings formed due to tectonic activities. The streams in semi-arid area are decreasing during dry season. During rainy season surface runoff recharge through soil, infiltration and forming intermittent stream channels and Perennial River in the basin drainage system. The stream/river distribution network and reservoir found in the catchment defined or located on map (Table: 4)

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CHAPTER FIVE

5. HYDROGEOLOGY

5.1 Hydrogeology of the study area

Hydrogeology is the study of the occurrences, lateral and vertical distributions and sub-surface movements of water. It (hydrogeology) also outlines the relationships of physical and chemical properties of the sub-surface water against the geological materials that are naturally occurring along the path from the inflow (Recharge area) to the out flow (Storage area) *(Sen., 1995).*

The complex hydro stratigraphy and aquifer materials that are distributed at the surface and subsurface of the area are composed of volcanic flows, phyroclastic and river deposits. As the inventory data that collected from field (32) and different reports over (500) well data obtained for detail analysis and (Annexed to this thesis report). From the area and major lithological description of existing wells, indicate that the majority of wells penetrated through basalt, rhyolite, trachyte and pyroclastic materials, pumacious materials, ignimbrite, unwelded tuffs and making up the aquifer system of the well field.

The groundwater circulation depends on the hydrogeological characteristics of the material more specifically hydraulic properties such as porosity and permeability. They are the principal hydro geologic properties of rocks to control the entrance of water in the aquifers at the recharge areas of the Sub basin and controls water leaving the aquifer at the out flow area.

The porosities of volcanic formations in the area vary considerable. Rock porosity refers to the open space in the various rock types. The groundwater origin, distribution and flow controlled by the type of lithology, distribution, thickness and structure of hydrogeological units through which it moves.

The exposed formation of the study area has both primary (can be porous at horizontals with gas holes or vesicles, lava tubes, and secondary porosity at sections of the formation occurred as a joining or fracturing example of this primary and secondary porosity's are vesiculated basalt (scoria) and fractured (basalt, rhyolite, tracky basalt and ignimbrite) respectively. It also discussed below in detail.

The primary porosity formed during the crystallization of magma that erupted from the interior of the earth and exposed to the surface as either a flow or ejection (pyroclastic) and cavity. While secondary porosity generated after the crystallizations of rocks by the tectonic effect or by the mechanisms of pressure and temperature.

Structural features of rocks such as secondary porosities, the geometrical properties of the geological system produced by deformation or crystallization (*Freeze, 1979*), may provide secondary hydro geological properties to the various rock types.

In volcanic rocks, the porosity depends on the size of the individual fractures, joints and cavity. Besides, the density of these openings in the rock mass is a determining factor. For instance, the porosity of highly fractured basalt may be as mostly higher. In particular, in dense un fractured and un jointed volcanic rock the porosities will be very low.

The capacities of rock transmit water through it known as permeability. Permeability of volcanic rocks determine by the size of the fractures and joints, vesicles, and other openings. The inter connection between the openings also play an important role. Due to the uneven distribution of the openings, the permeability may vary significantly within the lava flows and pyroclastic materials.

High permeability mostly found in unconsolidated deposits composed of large rounded grains that well sorted. As mentioned in previous sections, the study area dominantly covered by volcanic rocks, which shows greater variations in their hydro geological properties.

Volcanic rocks in the area include material having a wide range of hydrologic properties such as basic, acidic and pyroclastic rocks. Basic volcanic rocks such as vesicular basalt are generally rich in cavities due to rapid cooling and escape of gases, cooling joints and bubble like pore space.

As a result, they are highly permeable. Whereas acidic volcanic rocks may or may not contain groundwater even though they generally possess pore spaces. Pyroclastic rocks associated with lava flows are generally porous but their permeability varies depending on the degree of inter connection of the interstices ***(Davis et al, 1966).***

Large fractures in volcanic rocks are usually few in number, produced by sub-surface earth stresses, and may extend to great depth; and small near surface fractures may occur in great numbers (***Nockoldset, et.al 1979***).

Generally, volcanic rocks are basic, with low silica content (basalt and basalt like rocks), some are rich in plagioclase and other may be rich in olivine (alkaline basalts). High silica content is find in acidic rocks, such as rhyolites and little in ignimbrite.

From hydro geological point of view, the most important GW sources are volcanic formations in the study area are scoriaceous basalt, lava flows, ignimbrites, highly fractured rhyolites and other deposits such as tuff with minimum contributions.

Specific yield (drainable porosity) is small for fine grain pyroclastic formations, ash and weathered rocks. In any hard rocks the ground water movement is restricted to fractures, fissures and cracks by mechanical stresses and the groundwater flow velocities range from less than 1m/day and may be high but the velocity is generally decreasing with depth. Most ground water is stored in the bulk of the volcanic formulations as slowly flowing water.

The more the pore spaces occurring in the rocks, the more is the ground water storage. The other factors that control the amount of ground water in the volcanic rocks and unconsolidated deposits are precipitation, topographic features, and runoff distribution, and irrigation, hydraulic properties of lithological units and boundaries of aquifers.

5.1.1 Aspects of Groundwater Recharge

5.1.1.1 Groundwater Recharge

The groundwater recharge in the study area mainly from direct precipitation depending on its intensity and annual distribution, topographical gradient of the area, lithological composition of aquifers and their tectonic disturbance. The groundwater of the higher areas generally recharged from direct precipitation. The recharge condition in the akaki catchment is characterized by three sources of water; precipitation recharge, riverbed infiltration and seepage from Aba Samuel and legedadi lakes (***Alema Tesfaye. 2009***).

The rainfall pattern of the area has two seasons (bimodal type) which is from January to May and July to September. This may supply significant amount of recharge to localized aquifers from most of the Tributaries as well as the main streams after the Kiremt rains when the level of stream is above the groundwater level Aquifers along the river recharged by the surface water of streams as the flow of the stream controlled by structures. This type of recharge is important in the downstream lowland where evapotranspiration is higher and precipitation is lower than in the highland.

The Vertical recharge that occurs is concentrated along the major valleys, especially in their superficial deposits and in fault valleys that are structurally controlled. In the mountains and foothills, erosion is so deep that recharged water soon finds its way towards valley axes, to become stream or subsurface wide gravel flow (***Had win et al. 1979***)

Horizontal recharge provides the most dependable groundwater resources. Highland rain infiltrates vertically and laterally into the exposed fractured and jointed basalt and ignimbrite of the lower parts of the succession, and moves southeastwards beneath the younger formations. The secondary porosity of aquifer materials of hydrogeological terrain in which the surface water and ground water regimes are highly interconnected and often constitute a single, dynamic flow system (***White, 1993***).

In a favorable geologic and structural context, most of the rainfalls quantities on the highlands, upstream the big akaki watershed, are immediately swallowed by fractures and absorbed underground vertically and conveyed laterally to the discharge areas. Such a scenario repeated for million years can contribute to the storage of very important freshwater quantities available downstream, within the main basalt and pyroclastic flow aquifers.

5.2 Ground water Occurrence And Hydrogeological Units

5.2.1 Classifications of aquifer units

The importance and classifications of aquifer units based on ground water occurrence depends on the lithological units against their porosity and permeability. Additionally the aquifer characterization based on the hydrogeological features of various rock types using well inventory data specially the well yields and transmissivity analysis results considered. Lithological units classified into groups with dominant porous and permeability includes; (high, moderate and low) productive for both Porous inter granular aquifer and fissured aquifer units.

Since the quantitative data such as transmissivity, permeability, aquifer thickness and yield are adequate or distributed enough to make a detailed quantitative potential classification. Hence, the hydrogeological characterization of the study area reveals the following aquifer/ Aquitard system.

5.2.1.1 Porous intergranular aquifers

Productive intergranular aquifers represented in the study area are chefe donsa pyroclastic and alluvial sediment.

5.2.1.1.1 Chefe donsa phyroclastic

Chefe donsa phyroclastic rocks composed of unwelded to poorly welded, fine volcanic ash flow and fall deposits. The groundwater hosting part of this unit is the primary permeability resulted from the availability of primary effective porosity. The ground water availability is highly dependent on the grain size, distribution as well as sorting. The grain size on this aquifer varies from low to medium sometimes fine with poorly sorting pattern and hence decreases the transmissivity of the aquifer. This aquifer gets its recharge directly from precipitation and the adjacent plateau volcanics. In this area transmissivity ranges also low to moderate that is from 32 – 650m2/d and the thickness of this aquifer unit is low 10 – 20m from report. Moreover, the overall depth of the saturated and unsaturated aquifer is from shallow to deep aquifer that includes from 10 – 300m. Generally, type of aquifer unit categorized under low to moderate porous aquifer unit.

5.2.1.1.2 Alluvial sediment deposits

Alluvial deposit is a Material deposited by rivers. It consists of silt, sand, clay, and gravel, as well as much organic matter. Alluvial deposits are usually most extensive in the lower part of a river course, forming floodplains and deltas, but they may form at any point where the river overflows its banks or where the flow of a river is checked (*Adam, 2018*).

The thickness of this unit more than 10 to 15 meters. The grain size shows great variation ranging from clay and silt to sand and gravel. This unit is one of the most important sources of shallow groundwater. From these unit the groundwater is tapped from shallow aquifers and their yield is varies from 2 to 10 L/s information obtained from the AAWSA completion reports.

Additionally it has moderate permeability and productivity with sand to gravel size as well as with some fine undifferentiated grains. In some places the grains of the sediment show poor sorting ranging from clay to boulder resulting in a very low permeability and water bearing capacity and this aquifer gets mostly its recharge from perennial and intermittent streams *(Bereket F. Mihret M, EGS. 2011).*

5.2.1.2 High productive Fissured aquifers

5.2.1.2.1 Akaki Basalt Unit

Akaki basalt is the most highly productive aquifer zone and the outcropping of this formation covers Around 255 sq.km (20.4%) from study area (Table; 4). Additionally it has large extension formation to all direction, and it is the most important potential aquifer of the whole region. Especially this rock unit (akaki basalt) covers the akaki well fields and tulle dimtu or koyefeche well fields, which stretched to the pocket area, well fields.

Its thickness varies between 100 to 350 meters in the southern and 380 to 600m to the south central to ayat fenta well fields. This formation shows relatively high porosity and permeability, especially near the surface where it has been leached (***Had win et al. 1973***). Based on the vertical extensions of the lithology of the akaki well fields and tullu dimtu well, the average expected thickness of this rock unit is around 600m; the potential of this formation relative to its yield increased due to well exposed to fractures and topographic nature, which improve the recharge process and enlarge rock porosity and conductivity. In any case, the recharge capacity is linked to rainfalls intensity, but the cumulative process working years after years is most likely creating huge opportunities downstream we fields.

All the boreholes drilled in the southern part of the study area (akaki well fields) have apparently targeted the discharge zone of akaki basalt of fractured and weathered aquifer. These aquifer formation yields water at depths ranging from 100 to 380 m (akaki we fields) and > 380m (tulludimtu we fields), reaching the static water level from Artesian(0+1) to a depth of 80m. The yields range to 100 l/sec.

In some places, including akaki well field's basalt intercalated with trachyte forming trachy-basalt, which is moderately saturated zone. In the volcanic rock units, the water accumulated in its weathered, fractured horizons and holes of large cavities and fissures forming secondary porosity. Wide holes aquifer is which water flows very long distances with very high discharge like an underground river. This condition happens especially in basalt formation.

5.2.1.2 .2 Addis Ababa Ignimbrite unit

The Addis Ababa pyroclastic encompasses (Ignimbrite, unwelded tuff and pumice) .Ignimbrite rocks exposed at the Addis Ababa, Lege tafo and surrounding areas have a very good potential aquifer. The lateral formations surface area coverage is around 501 square kilometer, which is 40 percent of the area (table; 4). From the obtainable well data information point of view the pyroclastic flow specially ignimbrite (welded tuff) degree of fracturing and weathering is varies from low to high ranges, high and low degree of weathering and fracturing, has highly saturated zone and low saturated zone respectively and in between This intermediate saturated zone(aquifer) exists.

Average layer thickness of this formation extends over 70 meter, and water level depth ranges of 0 to 80m with the aquifer depth of 70 to 550m. Moreover, Around the Legadadi plane area the thickness of this unit reaches up to 200m (exploration drill data). This geological Outcrop extends to northern part of Addis Ababa, lege tafo .Sendafa and Becho plane. Abundant fresh water has encountered in many boreholes in outcrop areas (***Shaac, 2010***).

The Upper ignimbrite one of the major water bearing formations next to lower units of basalt formation represents major water bearing formation of the area this formation represents highly productive and most potable water zones next to the akaki basalt. For this reason the structures like joints, lineaments and fractures plays a significant role to groundwater flow to the subsurface reservoir.

According to borehole data collected and analyzed overall depth vary from (70 to >550 m), the static groundwater level varies from Artesian to 80m, transmissivity varies from 32 m2/day to > 10,000m^2/d and the potential aquifer yield is ranges to 120 l/s.
Boreholes drilled in this formation have good yield as in the case of well field that supplies water to the Addis Abeba and legato legedadi town.

5.2.1.3 Moderate productive fissured aquifers

Relatively moderate productive formations represented by Addis Abeba basalt rocks and expressed in the hydrogeological map.

5.3.2.1 Addis Ababa Basalt Rock Unit

Addis Ababa basal unit exposed in the western and central portion of the study area in which it is part of Entoto ridge in western direction from geological map on (Figure;15). The overall thickness of these aquifer units is from (50 – 480m) depth and the saturated zone of the aquifer is around 100m thick. The transmissivity range of this area is recorded (32 – 2800m2/d) and the aquifer yield is varies from (2 - 60l/s). In these rock units, also, the groundwater accumulated or stored through the fracture openings, weathered parts, fractures and joints of the hard rock, which may closed at depth hindering deeper groundwater circulation and storage. Therefore, because of the topographical, structural discontinuity's fracturing and jointing, density's and permeable nature of the rock (fractured rock), they have relatively high prospect of having sufficient water conduit to be good regional and discharge zone aquifers.

Generally Due to the topographic variation and presence of regional structural prevalence the rock out crops found in this area are commonly the Addis Ababa basalt and Tarmaber basalt are supply the overall groundwater source as a recharge zone for the catchment. This observed and inferred as the recharge area of the catchment has high structural discontinuity particularly normal fault and high lineament density distribution (figure; 29) that contributes high groundwater source to convey to discharge zones.

5.2.1.4 Low Productive Fissured aquifer

5.2.1.4.1 Rhyolite and Wechacha trachyte unit

The Intoto becho Rhyolitic is also the other source of recharge for the area with little to moderate contributions the lineament density in this rock unit is ranges (0.36 – 1.25km.sq.km) which indicates moderate to high structural density (lineament) (figure;29). The degree of weathering may be shallow or continue to certain depths. Also this formation affected by N-SW and NW-SW stretching lineaments and faults. Fractures play very important role in the movement and drainage of groundwater. They are fragmented and form high openings and therefore, can easily infiltrate water if there is adequate precipitation. From field observation, boreholes are finding in this unit along fractured or deeply weathered zones. Boreholes drilled in the study area have shown as shallow, medium and deep aquifer of the rock units. Moreover, their transmissivity (32 -100m2/d) and the aquifer yield ranges to (20l/s).

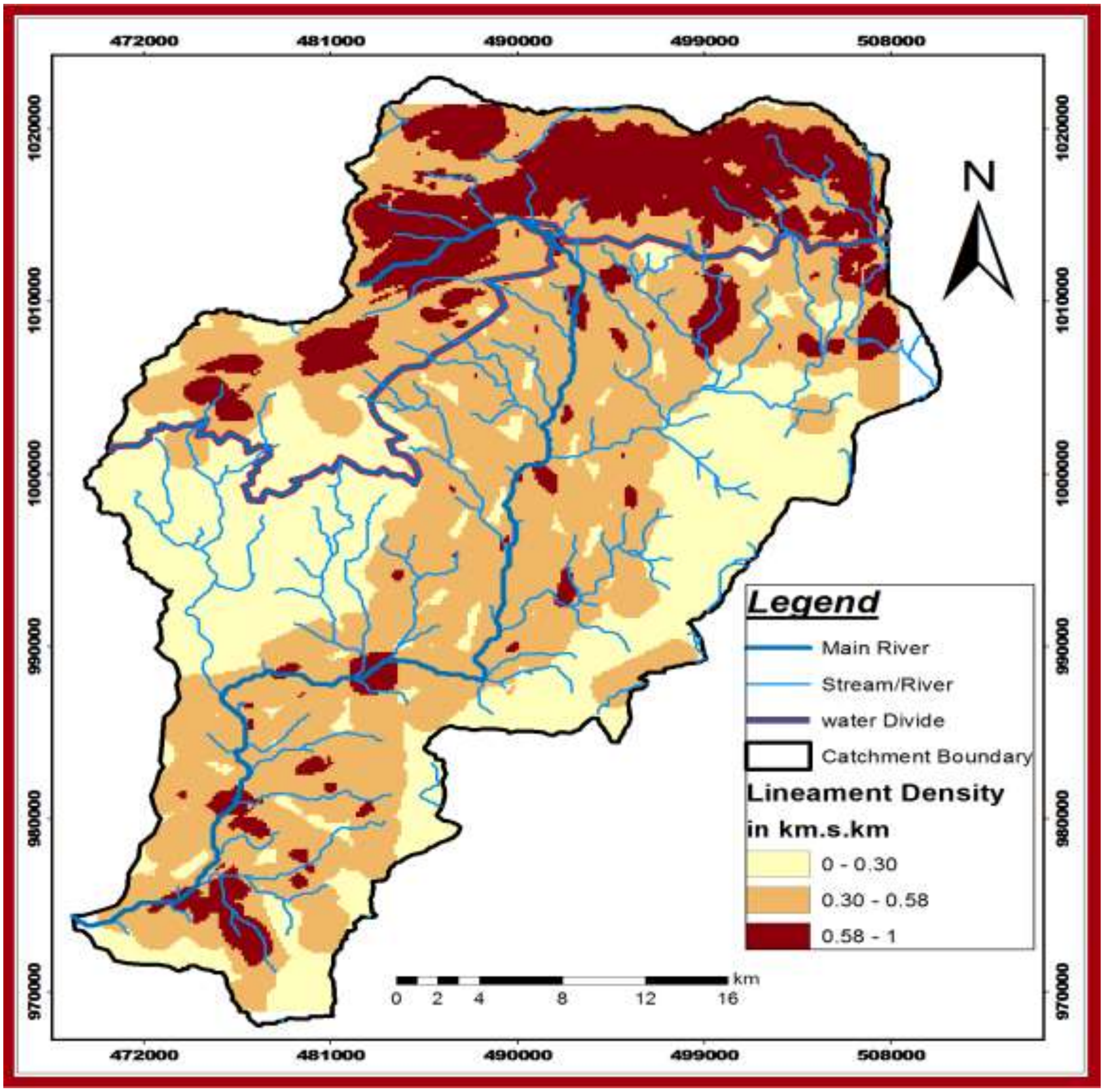


Figure 30; Lineament density distribution and groundwater flow direction map of big akaki river catchment

The lineament density is maximum (0.58 – 1) at the recharge zone which revealing the ground water occurrence and movement in the catchment. Additionally the lineament density is also moderate (0.30 – 0.58) and finally minimum lineament density (zero – 0.30 Km. s.km) at the discharge zones. High lineament density implies high recharge and low lineament density may or may not have low recharge.

5.3.4 Aquifer zones (Groundwater zones)

The zonation of groundwater aquifers in big akaki watershed is classified in to three parts; high permeability zones, moderate and low permeability zones, based on available pumping test(transmissivity , yield and specific capacity) , lithological logs, topography.

5.3.4.1 High permeability zone (Zone 1)

Based on the pumping test data Transmissivity value of this zone is greater than 4,000m2/day and the altitude ranges from 2000 - 2400 m.a.s.l. The main aquifer zone of this area is akaki basalt and Addis Ababa ignimbrite (fractured ignimbrite) under lain by Tarmaber basalt.

The overland flow that retained at the discharge zone from the recharge area may normally contribute groundwater recharge and supplied by Akaki River for akaki well fields and Dadhi River for lege-tafo legedadi well fields in addition to the direct recharge from precipitation. Boreholes drilled in this zone have a yield is greater than moderate to very high discharge.

5.3.4.2 Moderate Permeability zone (Zone 2)

Based on the available pumping test data the moderately permeable zone recognized and in this zone transmissivity value ranging 1000m2/day - 4000 m2/day exhibited. Borehole yield in this zone ranges 40 - 70 l/s. The topography of this zone ranges 1000-1500 m.a.s.l and little bit higher than zone 3.

5.3.4.3 Low permeability zone (Zone 3)

The zone has relatively lower Transmissivity ranges to 1000 and yield range 2 - 30 l/s. The zone characterized by higher elevation (2400 – 2700m A.m.s.l) and compacted lithology. As this zone is also part of the area watershed, its recharge mechanism is through big akaki river and from direct precipitation, as the river is in lower elevation relative to the surrounding topography all precipitation runs off towards the river, retained, and infiltrated to meet the ground water system.

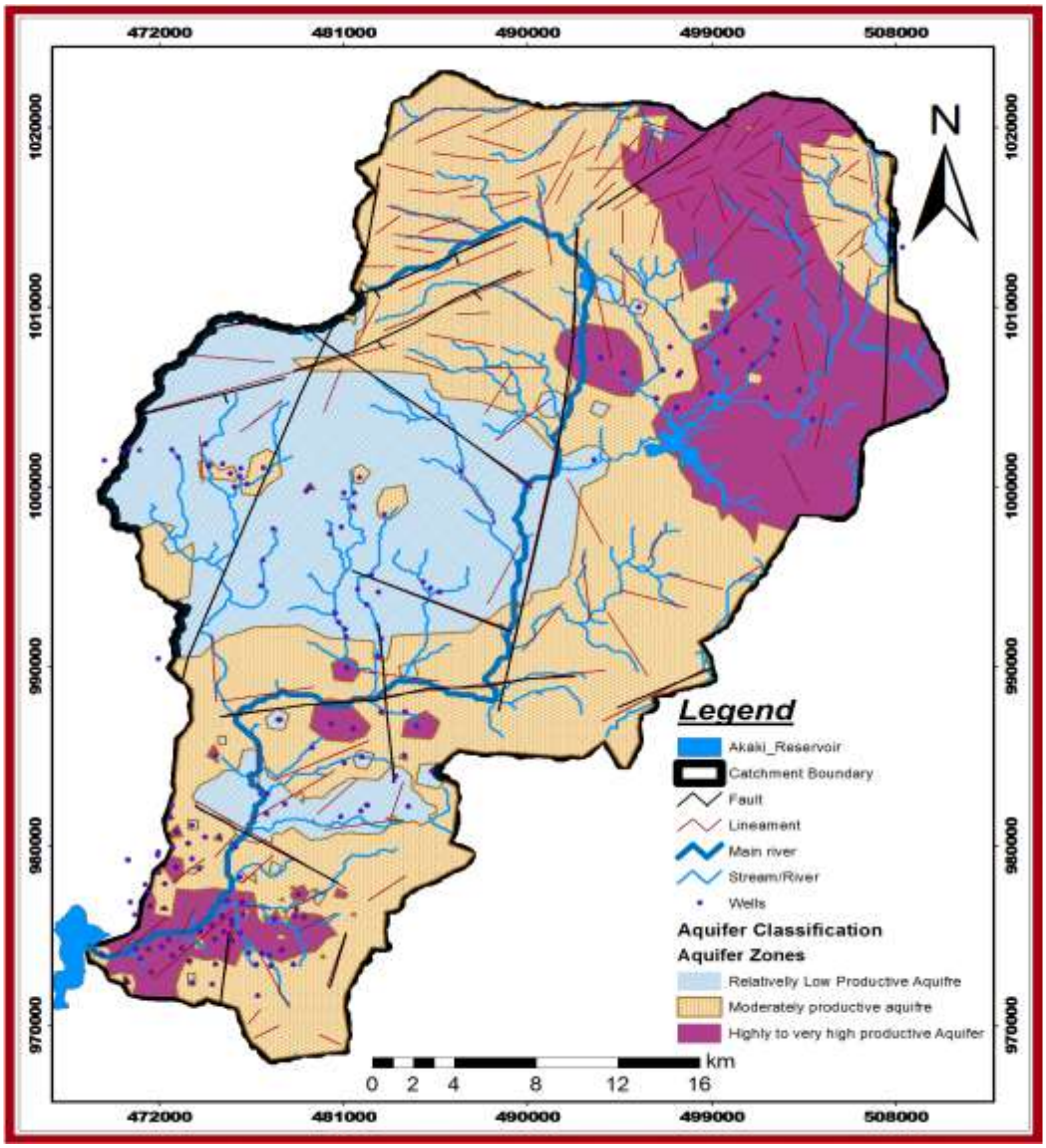


Figure 31; Aquifer classification map of the catchment based on productivity/Transmissivity and aquifer yields

5.4.2 Well Discharge and Aquifer Yield

A discharge zone or area can defined as, that portion of the drainage basin in which the net saturated flow of the groundwater directed toward the water table.. In daily and annual abstraction basis from the aquifer in the Upper Awash groundwater basin estimated and annually, about 256 Mm^3 water is being pumped out, which is equivalent to 29 mm/year over the basin (*Berehanu1 ,2017*)

In the study area the general topographic and structure, controls play a major role for the occurrence of groundwater discharge zone in various ways in the area. As topographic highs like the mountain range in the north and northwest of the study area are the recharge zone, the topographic lows or the valley bottom of the study area such as the southeastern part of downstream (akaki) considered a groundwater discharge zone. The general groundwater aquifer discharge spatial distribution map generated from pump testing result to contrast and evaluate the overall catchment groundwater system. So the ground water harvest is characterized by the well yield existed in the area and also categorized relatively as low (2 – 20L/S), moderate (20 – 40L/S), high (40 – 80L/S) and very high >80 or (80-125L/s).

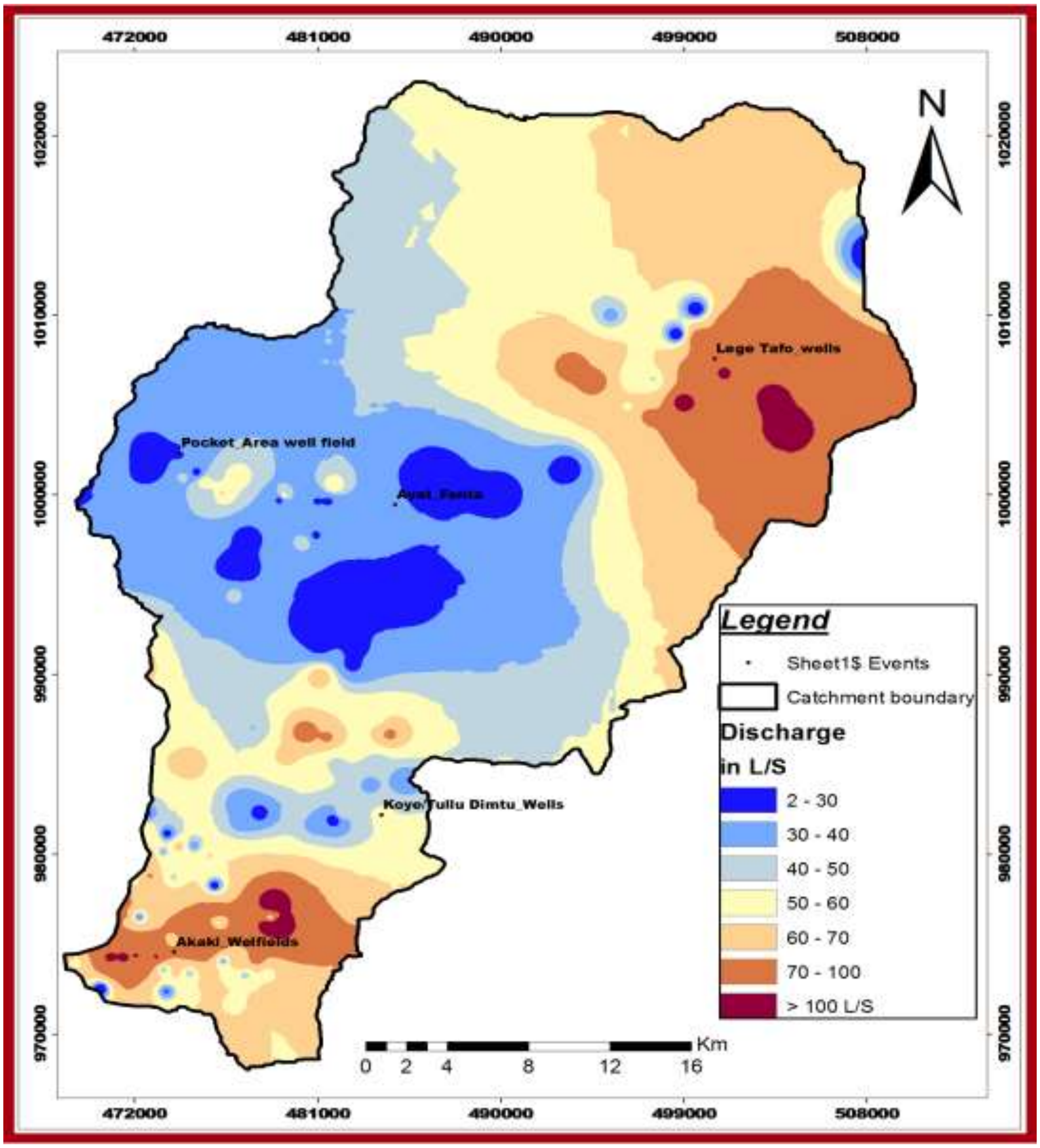


Figure 32; well Discharge (yield) spatial variation distribution of Big-akaki catchment measured from point data

5.5 Characterization of Groundwater systems based on depth

Characterization of properties and chemistry of aquifers evaluated. Aquifer characterization provides the foundation for groundwater modeling, which commonly used to assess groundwater. Detailed aquifer characterization is particularly important where solute transport is a concern, as aquifer heterogeneity has a much greater impact on groundwater flow direction and rates than it does on aquifer heads (*Robert G. Maliva, 1992*).

5.5.1 Aquifer Systems

The major Aquifer system classifications and characterization have been prepared from the geological and hydrogeological patterns of the area for the depth of groundwater level in wells and aquifer in relation to the prevailing aquifer thickness and saturation of the groundwater. This based on the observation and analysis of all the compiled well log data and pumping test data for the existing wells in the study area.

The rocks and structures forming the hydrogeological framework for a groundwater flow system are termed hydrogeological units. Hydrogeological unit has a considerable lateral extent and has reasonably distinct hydrologic properties because of its physical (geological and structural) characteristics. An aquifer is a geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to wells (*Fetter 2001, p. 95*).

The aquifer materials, which cover the study area, are categorized as volcanic flows specially basalt, , rhyolite, trachyte, trcky- basalt, riverbed alluvial deposit (sand) and pyroclastic deposits; unwelded, ashes, pumice ,ignimbrites and tuffaceus materials.

In another way, the aquifer characterized and classified as aquifer depth variation (partial penetration and full penetration), which includes as shallow, deep and very deep aquifer system. Pump testing analysis (SWL, discharge, drawdown, and specific capacity, safe yield) and hydraulic properties (transmissivity, hydraulic conductivity’s).

5.5.1.1 Shallow aquifer system (0-100m)

Certain boreholes, which are finding in the study area, are tab water from shallow, deep and very deep aquifer system. Shallow aquifer system existed in the study area watershed consists of open dug wells ,springs and very shallow wells which has composed of fractured and weathered volcanic rocks specially vesicular (scoriaceous) basalt and gravelly material as their yield varies from very low to medium discharge. The well are drilled along the river banks like the dug wells and springs at southwestern of Addis Abeba town at akaki river where a shallow sand and gravel and vesicular basalt aquifer system are encountered at a depth of around 10-30 meters. The alluvial deposits hold shallow water that exploited by shallow hand dug wells with total depths ranging between 10 and 30 m and a static water level of around 4–23m.

Hand dug wells dug along dry streambeds where thick sand and river gravel accumulated along the banks of akaki stream and its tributaries. The alluvial deposits can yield good quality and quantity of water that can be used both for domestic and small-scale irrigation purpose. Majority of hand-dug wells in the study area are located within this aquifer.

Furthermore, the river deposits, the shallow aquifer system exists also within the gravelly materials. Such volcanic aquifers can reach a thickness of 35m maximum with good yields. Nevertheless, such aquifers can only use for the small-scale irrigation (private) and supply fresh drinking water for small communities (*Gachet.2013*). Also, shallow aquifer was encountered in the volcanic basalts in the study area observed in the akaki well fields borehole lithology 58-62m and the main water bearing strata was encountered at a depth ranging from 50 meter to greater than 100m and the water table is 17-39m depth.

5.5.1.2 Deep Aquifer system (100-250 m)-to Very deep (>250 m)

Deep aquifers and very deep aquifers are existed in the area borehole depth ranges from 250 – 623m. In the area both partial penetration and fully penetrated aquifer wells are available but most boreholes in the study area tap water from deep to very deep aquifer system i.e. basalt, ignimbrite, trachyte or rhyolite formation.

The deep aquifers of the study area are basalt (flow basalt), ignimbrite, trachyte, rhyolite and tuffs. Most of the aquifers have well to very good aquifer regards to quality and quantity due to morphological features and structural (fractures, joints, faults and lineament density).

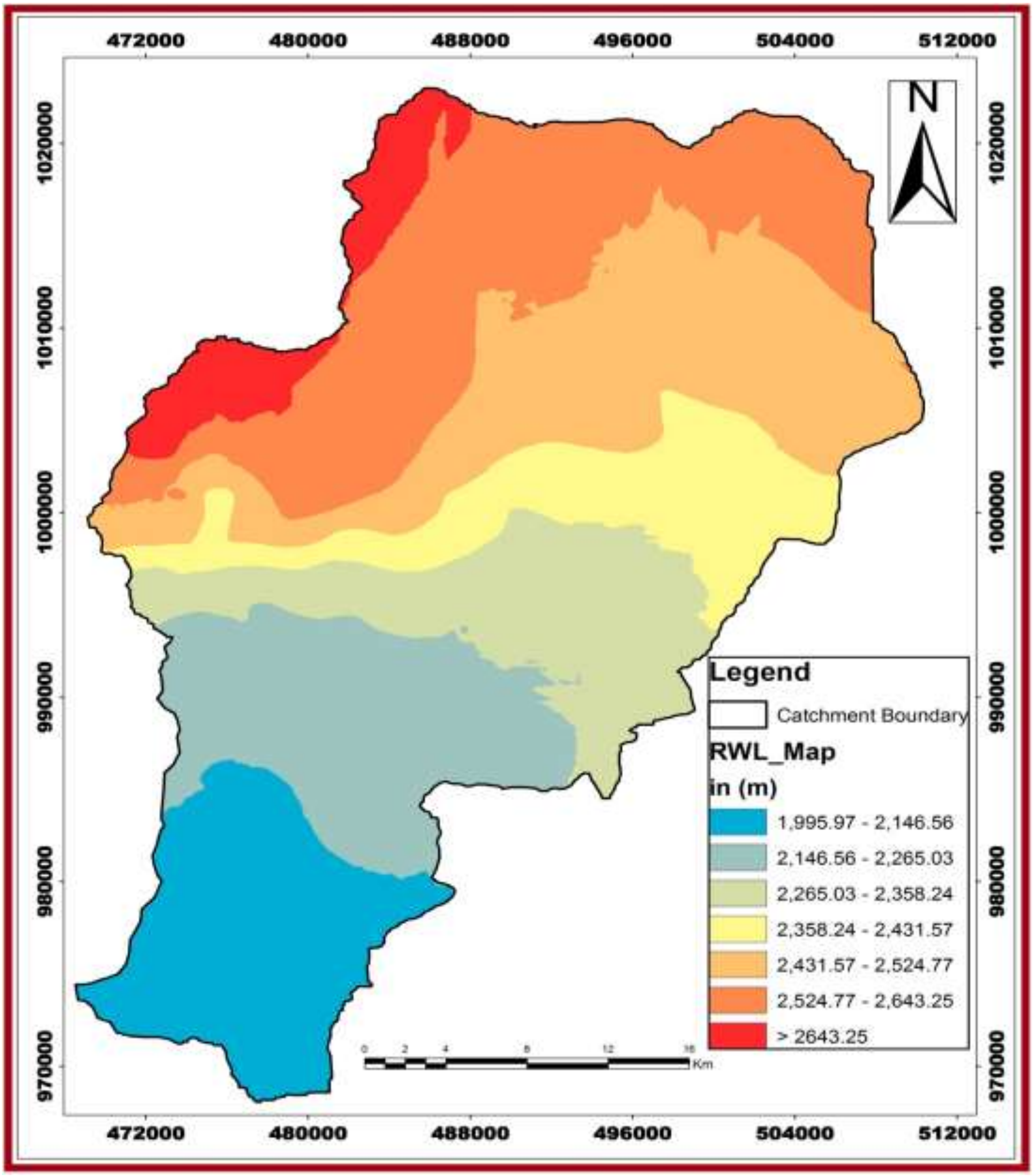


Figure 33; Groundwater level elevation map of the catchment measured from point data

The ground water level map generated using the difference of existing boreholes elevation and their static water level which results reduced water level map. Which has a hydrogeological contributions for the study area and the map elevation variation identifies the groundwater recharge and discharge zones. Therefore, recharge zone designated by the higher water level elevation (2524.77 – 2820.25m) or highlighted by (reddish color) and the discharge area indicated by relatively lowest water level elevation (1995.97 – 2146.56m).

5.6 Description of the hydrogeological framework

As described above most groundwater recharge probably originates from precipitation onto the northern volcanic highlands (northern Addis Abeba). It then runs off on the relatively permeable and moderately permeable layers of volcanic rocks and enters surface exposures of the basalt and phyroclastic flow Formations.

The general Groundwater flow of the area is from the northern to southwestern direction to the akaki basalt. The rocks of the pocket area and ayat fenta area are seems relatively low to moderately permeable in the upper and middle of the area.

5.6.1 Determination of Groundwater Flow Direction

The groundwater flow direction of the area follows the surface water flow and this is exceedingly depends on the geomorphology, geological structures and rainfall intensity. Because of there are sufficient groundwater level data that can represent the sub basin, it was possible to produce the map of pizeometric surface (Figure; 30) and able to determine the general direction of groundwater flow.

This was through utilizing the static water level elevations of previously drilled wells .The Groundwater-level altitudes lowers to the south ranges to (2000m). And higher at northern and north- western direction to (2700m) which may implies that groundwater-flow direction trending from North-West-South-East and from North-East to South that exactly follows the geological structures and surface hydrologic flow direction(Figure:30).

Generally, the overall subsurface and surface movement of water resembles and finally joins the River Akakii and akaki well fields and meets artificial reservoir called Abba Samuel Lake (Figure-33). The static water elevations descriptions table annexed that utilized to determine the direction of the groundwater.

5.7 Conceptual Hydrogeological Model

A conceptual model is a pictorial representation of the groundwater flow system, frequently in the form of a block diagram or hydro geologic cross-section (*Anderson and Woessner, 1992*). The Conceptualization of the water originates in groundwater flow system and how leaves system. In addition, the hydrogeological conceptual model is outcome of the combination of (the lithology, soils, geological structures, Groundwater level, etc.) (*Anderson and Woessner, 1992*). Hence, the model is develop using drilling and pumps testing data. In developing a conceptual model, the extent of the model lateral and vertical characterized and determined by the distributions of existing boreholes and their depth.

The Inflow for the groundwater of the study area is the groundwater recharge from precipitation. Outflow includes withdrawals from catchment town's water supply and irrigation wells and subsurface outflow at southern part of the study area.

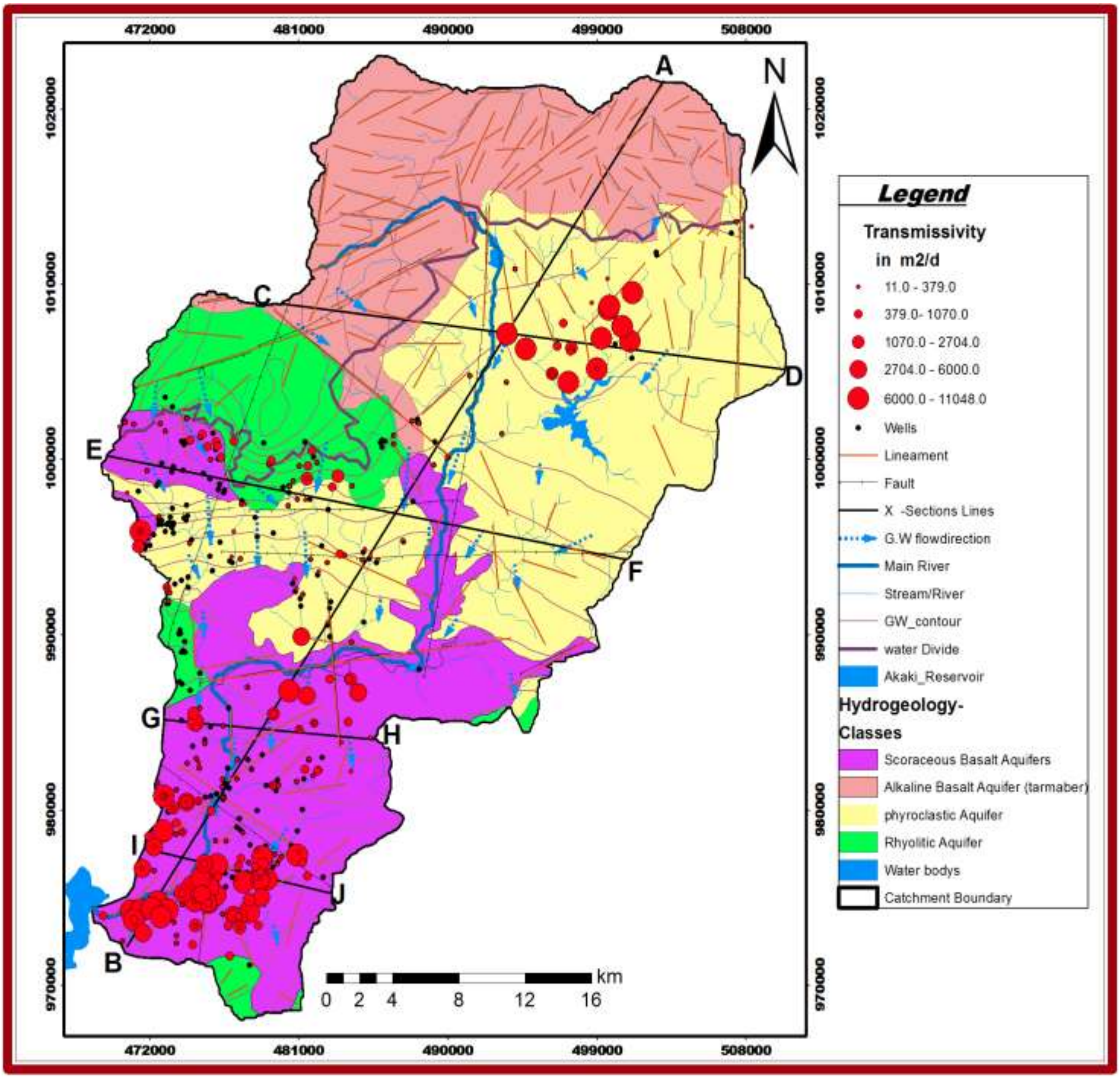


Figure 34; Hydrogeological map of big akaki river catchment

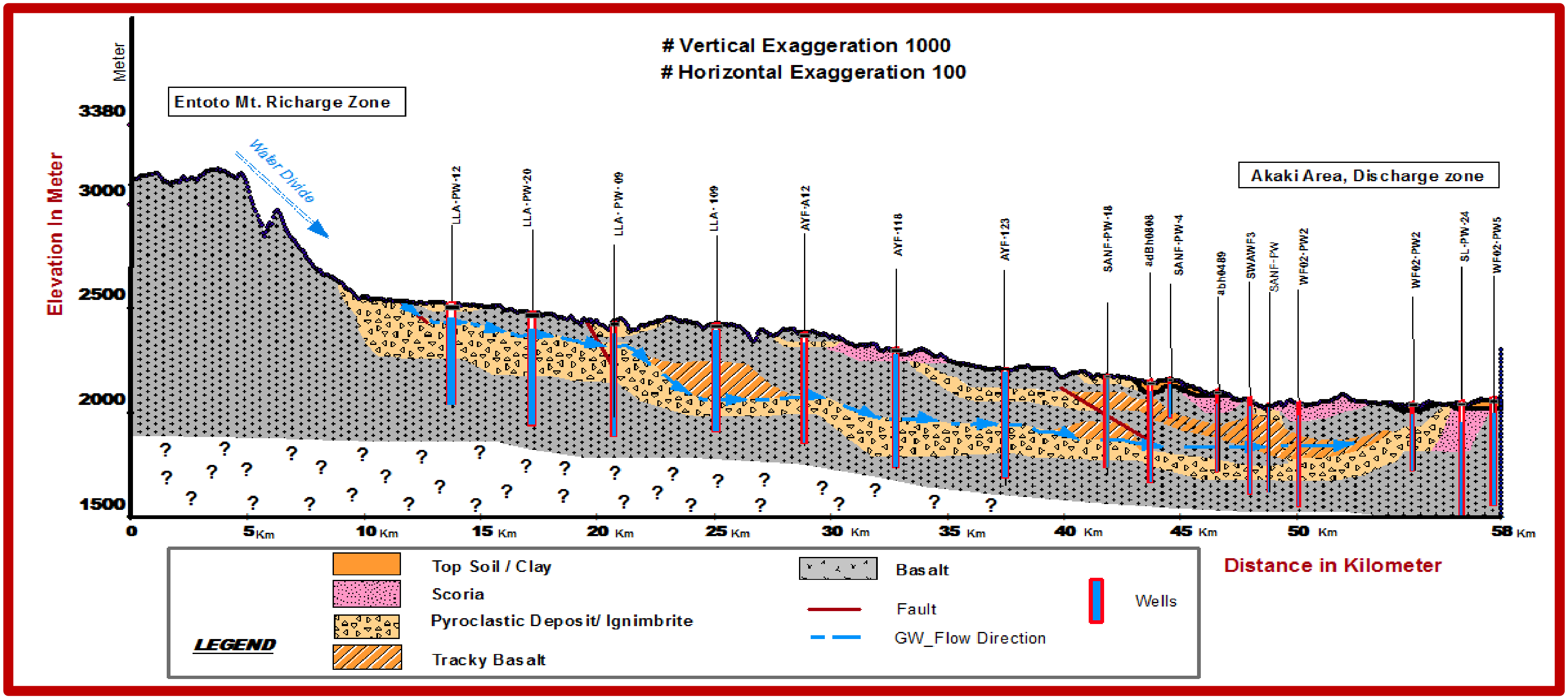


Figure 35; schematic conceptual model of groundwater level at big-akaki catchment (using deep well logging, depth and pump testing data) construct cross-section along (A - B section).

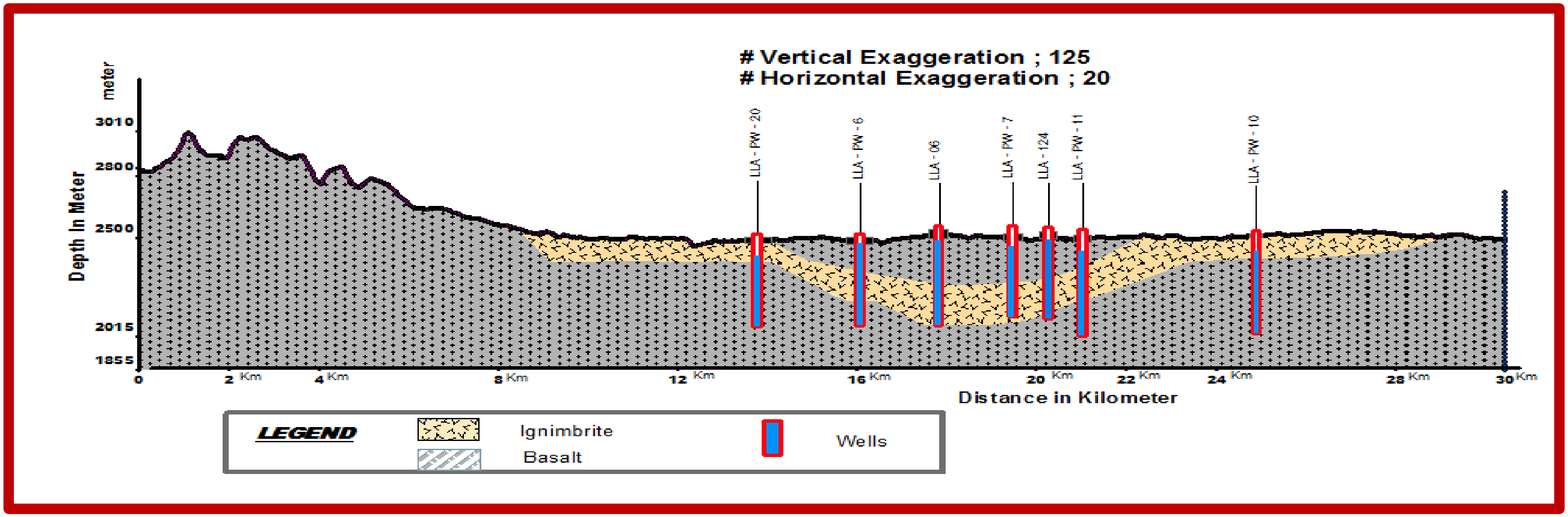


Figure 36; schematic conceptual model of groundwater level of big akaki catchment (using deep well logging, depth and pump testing data) to construct the cross-section along (C- D sections).

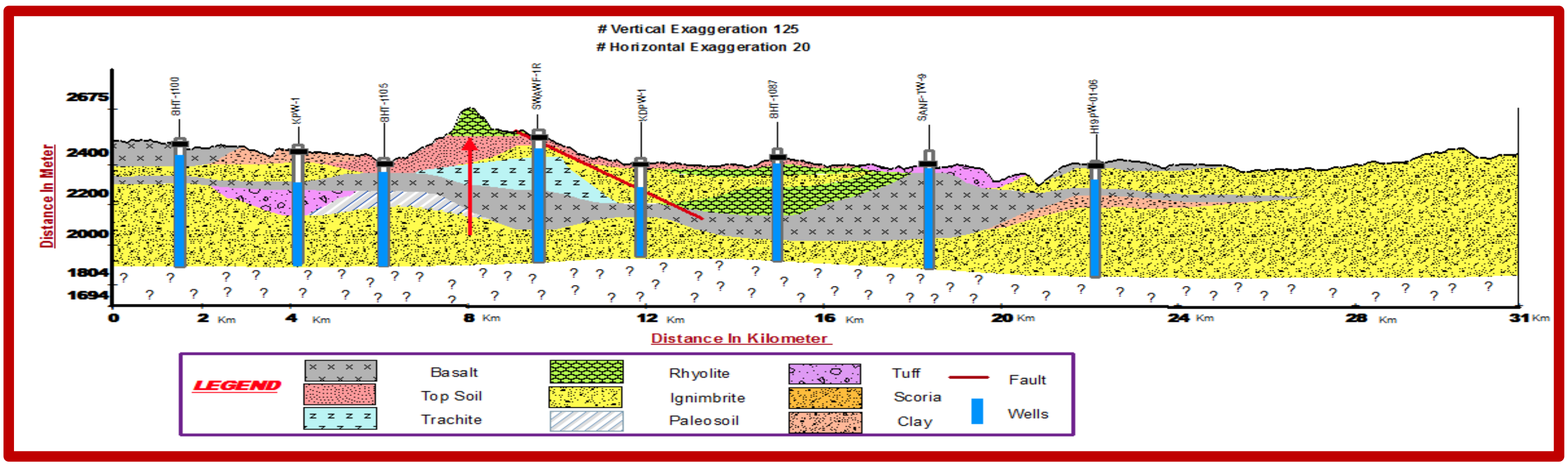


Figure 37; schematic conceptual model of groundwater level of big-akaki catchment (using deep well logging, depth and pumping testing data) to construct the cross-section along (E-F section)

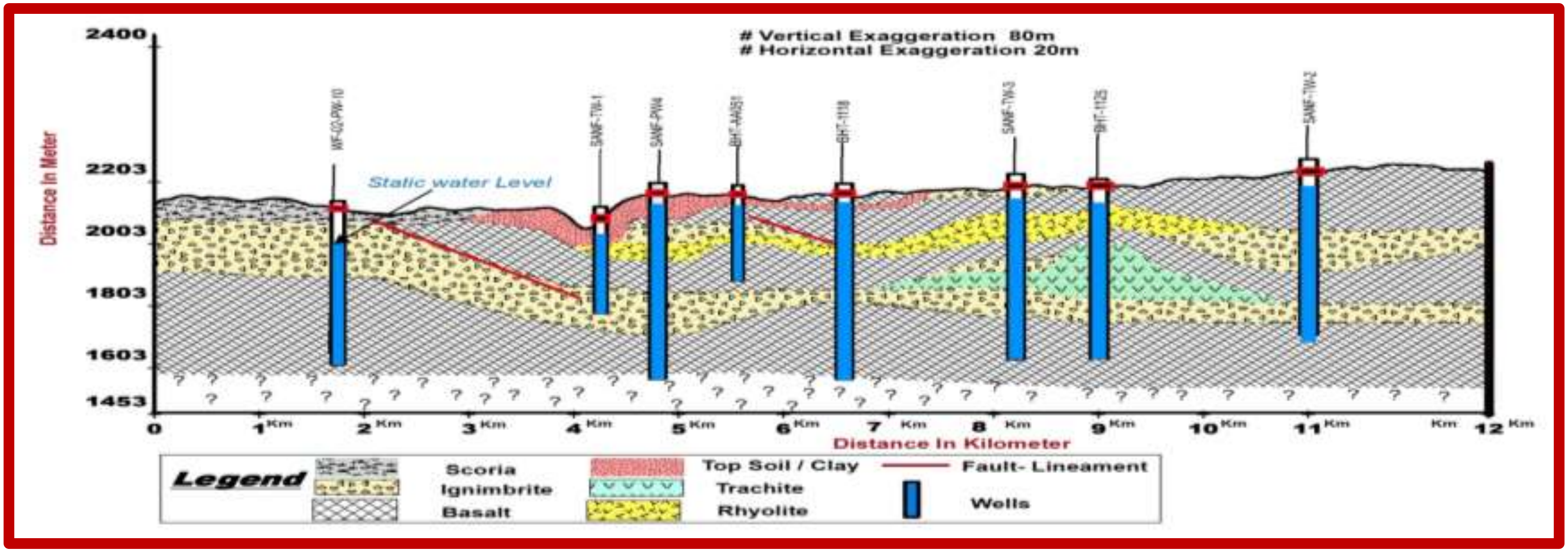


Figure 38; schematic conceptual model of groundwater level of big-akaki catchment (using deep well logging ,depth,and pumping testing data) to construct cross-section along (G -H section)

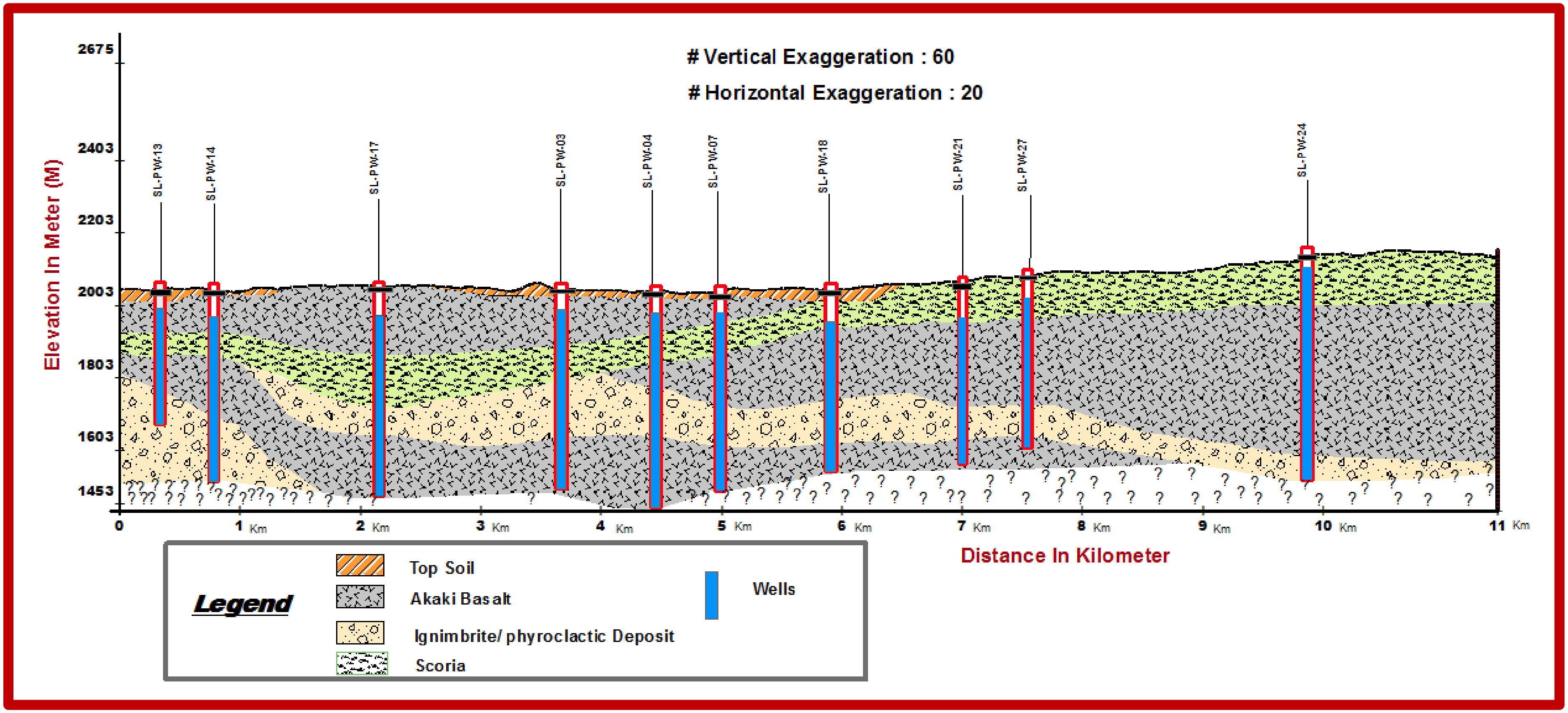


Figure 39; schematic conceptual model of groundwater level of big-akaki catchment (using deep well logging, depth and pump testing data) to construct the cross-section along (I-J section)

5.8 Hydraulic Parameters and Spatial Analysis

5.8.1 Transmissivity

Transmissivity (T) of an aquifer measures how much water may be transmitting horizontally. It is the product of the hydraulic conductivity times the thickness of the aquifer (*Driscoll, 1986*). Transmissivity (T) is a hydraulic parameter of an aquifer that known & employed in most groundwater flow equations to understand the flow dynamics and generally estimated from pumping tests (*Freeze & Cherry*, 1979.

For characterization of rocks as a water conductivity media, transmissivity is a major property (*Fatoba, 2014*). It can infer that groundwater flow potential increases as transmissivity and permeability (Hydraulic conductivity) increases. In order to categorize the potential of groundwater for different use the transmissivity value of aquifer employed by (*Krasny, 1993*).

$$\boxed{T = bk}$$

Where, T; Transmissivity, b; is thickness and K; Hydraulic conductivity

T (m2/day)	Designation	Discharge
>1000	Very high	>25
>100 – 1000	High	5-25
>10 – 100	Intermediate	2-5
>1 – 10	Low	0.5 - 2
> 0.1 – 1	Very low	0.05 – 0.5
< 0.1	Imperceptible	< 0.5

Table 16; standard transmissivity, (after krasny, 1993) designated for groundwater supply

To classify the aquifer based on transmissivity occurring in different aquifer, the whole range of possible transmissivity values separated into six (6) classes representing the orders of transmissivity magnitude (Figure;40).

Transmissivity spatial variation of the area classified and undertaken by using the values of the aquifer-pumping test) analyzed result. These Models for the interpretation of pumping test data initiated under constant pumping test rate and equilibrium conditions for confined and unconfined aquifers.

This transmissivity spatial variation and distribution map is prepared and Classified by using ArcGIS (10.3) software in which to evaluate the properties of aquifer regarding with the use of different well fields existed in the area. The aquifer transmissivity also evaluated as using the geological materials having the sufficient and potential occurrence of water under a given abstraction. The geologic materials having sufficient degree of fracturing, weathering and opening that is filled with sufficient water has high transmissivity and the reverse is true.

The potential energy that drives groundwater movement includes both pressure and gravity. The volcanic formation that is highly fractured water lain scoriaceous basaltic flows (With primary and Secondary Porosities) and fractured ignimbrite pyroclastic flow deposit (Secondary Porosities) and all formations are horizontally and vertically extensive and widely distributed in the area, and considered as the major aquifer unit.

In general, the values of Transmissivity for the Akaki basalt and Addis Ababa ignimbrite rocks are higher and are ranges from (2000 – 10,000m^2/d). In this case high transmissivity value indicates that the aquifer is very high productive. Additionally the yield ranges from (60 – 125l/s). The legetafo wells and akaki well fields are part of these aquifer zones of very high productive area.

Relatively the Tarmaber basalt and entoto becho rhyolites are low Transmissivity ad ranges from (32 – 1000m^2/d) which covers the pocket area wells and ayat fenta well fields.

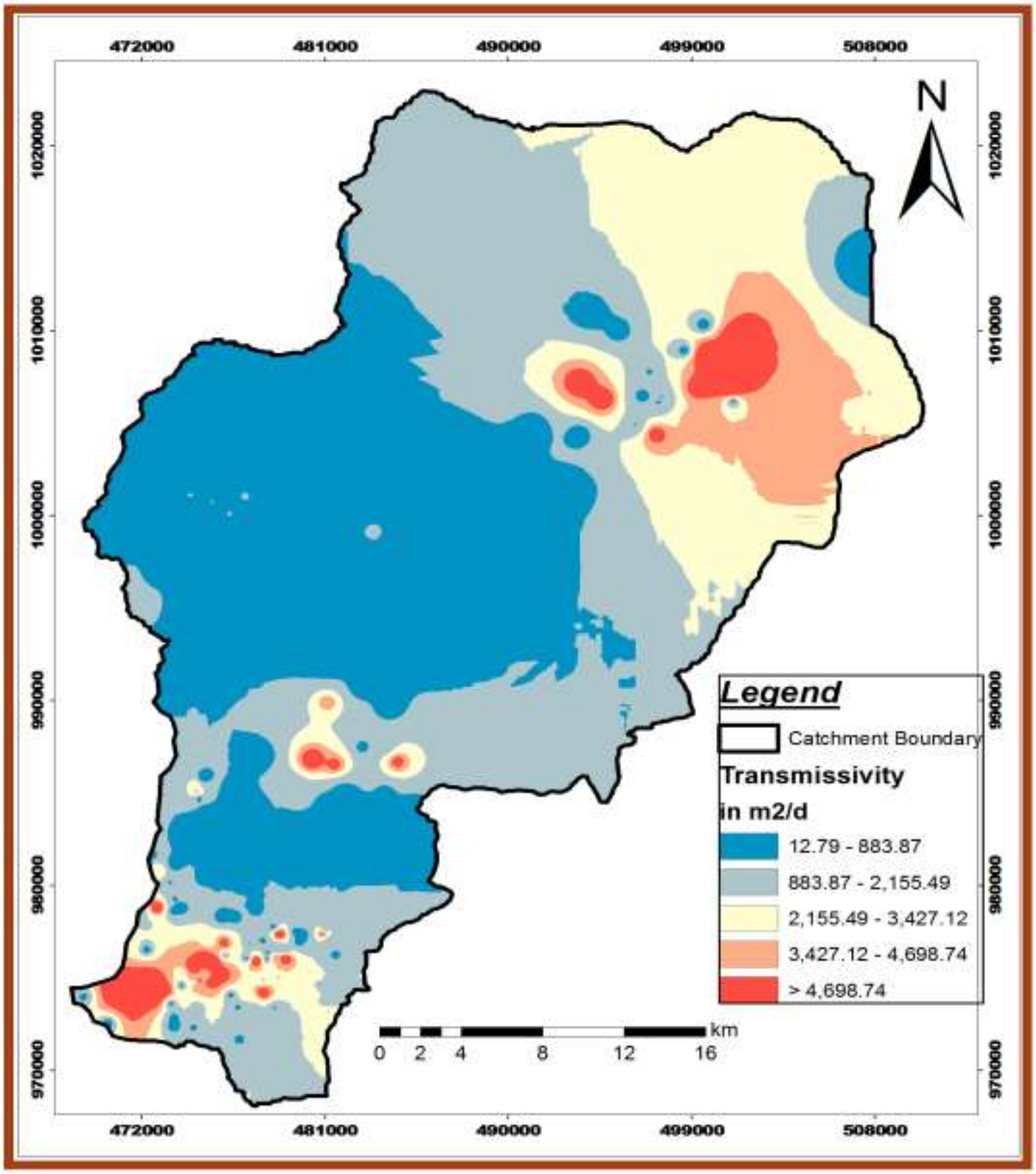


Figure 40; Transmissivity spatial variation map in big akaki river catchment

5.8.2 Hydraulic Conductivity

Hydraulic conductivity is a coefficient of proportionality describing the rate at which water can move through a permeable medium is a property of both the medium and the fluid. In addition, both density and kinematic viscosity of the water are considering in determining hydraulic conductivity.

The unit of hydraulic conductivity is m/day, indicating the hydraulic conductivity has units of velocity Determination of Hydraulic Conductivity, Hydraulic conductivity in saturated zones can be determined by a variety of techniques, including calculation from formula, laboratory methods, tracer tests, slug tests, and pumping tests of wells. Laboratory constant-head and falling-head types of parameters are simple to operate and widely employed

Hydraulic conductivity is the rate of flow under a unit hydraulic gradient through a unit cross-sectional area of aquifer. Transmissivity is the rate of flow under a unit hydraulic gradient through a unit width of aquifer of thickness (m).

Additionally it is a measure of a material's capacity to transmit water. In another way It defined as a constant of proportionality relating the specific discharge of a porous medium under a unit hydraulic gradient in Darcy's law: $v = -kv$, $v = -ki$ Where ν, is specific discharge [L/T], K is hydraulic conductivity [L/T] and i is hydraulic gradient [dimensionless]. Coefficient of permeability is another term for hydraulic conductivity.

Note that hydraulic conductivity, which is a function of water viscosity and density, is in a strict sense a function of water temperature; however, given the small range of temperature variation encountered in most groundwater systems.

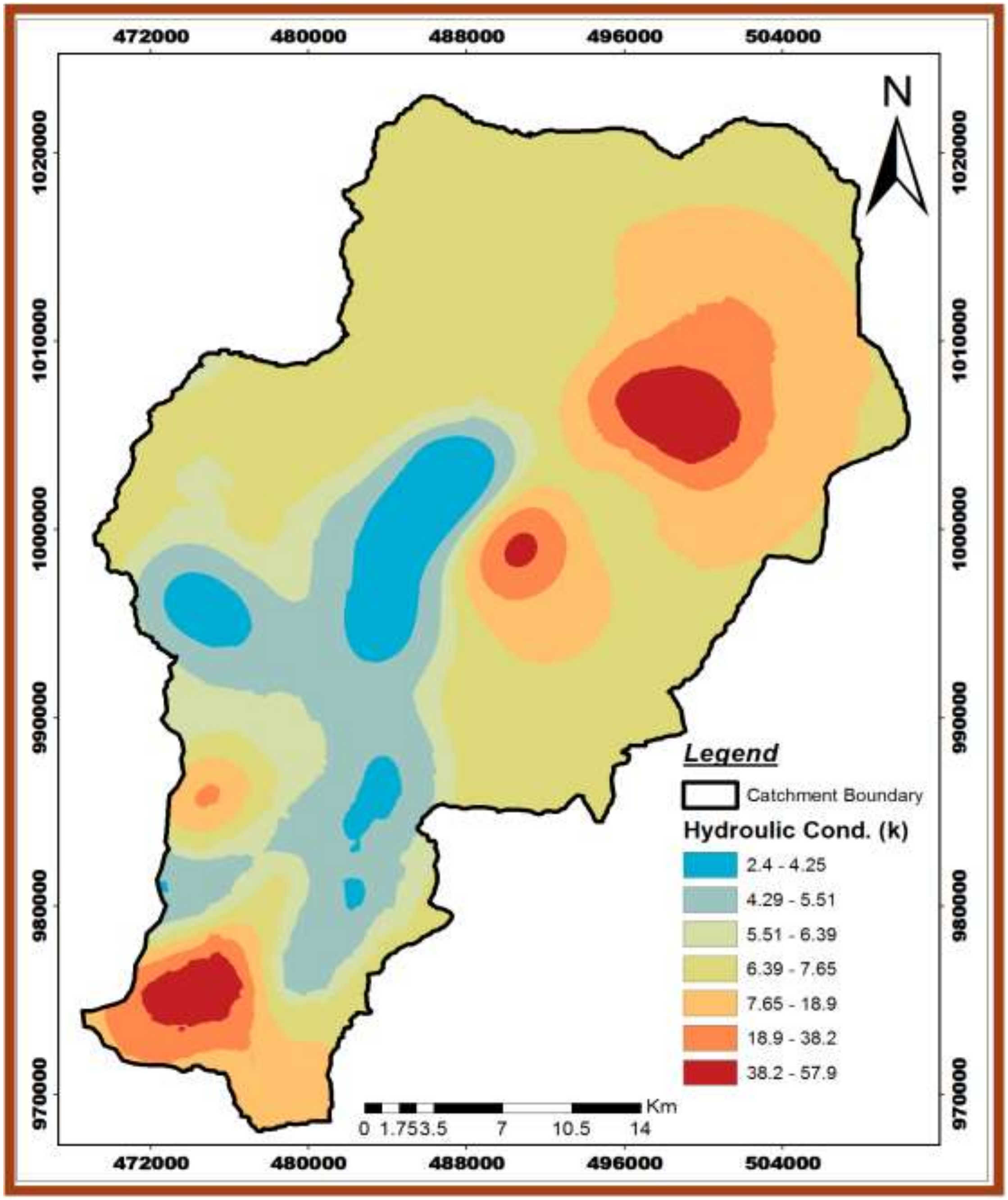


Figure 41; hydraulic conductivity spatial variation distribution map measured from point data

5.8.3 Specific capacity.

Specific capacity is its yield per unit of drawdown, usually expressed cubic meters per day per meter (m^3/day/ m) of drawdown, after a given time has elapsed, usually 24 hours. It varies with duration of pumping- as pumping time increases specific capacity decreases with a given draw down. Also Specific capacity is known as well performance test estimated by assuming the well is pumped at a constant rate long enough to establish the equilibrium drawdown; within the well, there is a combination of the decrease in hydraulic head (pressure) and a pressure loss due to well loss. Specific capacity defined as:

$$SC = Q / TDD\ w$$

Where, Sc is specific capacity, Q is the pumping rate, and TDDw is the total drawdown in the well due to both aquifer drawdown and well loss.

Well loss created by the turbulent flow of water through the well screen and into the pump intake. Specific capacity estimated by discharge on a linear x-axis and drawdown on a linear y-axis and measuring the slope of the straight line fit.

Specific capacity of the area expressed on map by their variation in depth. Therefore , specific capacity for 0 -100m depth recorded high to very high in Akaki basalt formations which ranges from (82 – 300m3/day/m) and lower (0- 23.945 m3/day/m) at central and upper part of the catchment (@ pocket area, ayat fenta and legetafo well fields) (figure.28, A)

For depth (100 – 250m) is higher at akaki and tullu dimtu well fields that ranges from (10.288 – 200m3/day), relatively moderate at some part of tullu dimtu well fields and legetafo area (1.768 – 2.940m3/day/m).

In addition, lower at pocket area, Ayat fenta and some part of legetafo legedadi and recharge zone ranges (0 – 20m3/day/m) (figure, 28. B)

Finally, for aquifer depth of (> 250m) is higher at akaki and pocket area well fields(southern and western part) of the catchment that ranges (5.738 – 98.465m3/day/m) and lowers at the legetafo and ayat fenta well field(<5.3738m3/day/m).

Generally the specific capacity is low at Intoto becho Rhyolite, Tarmaber basalt and some part of pyroclastic deposit specially ignimbrite which ranges from (0 to 10m3/day/m),the pocket area, legetafo and akaki well fields are part moderate to high and very high specific capacity.

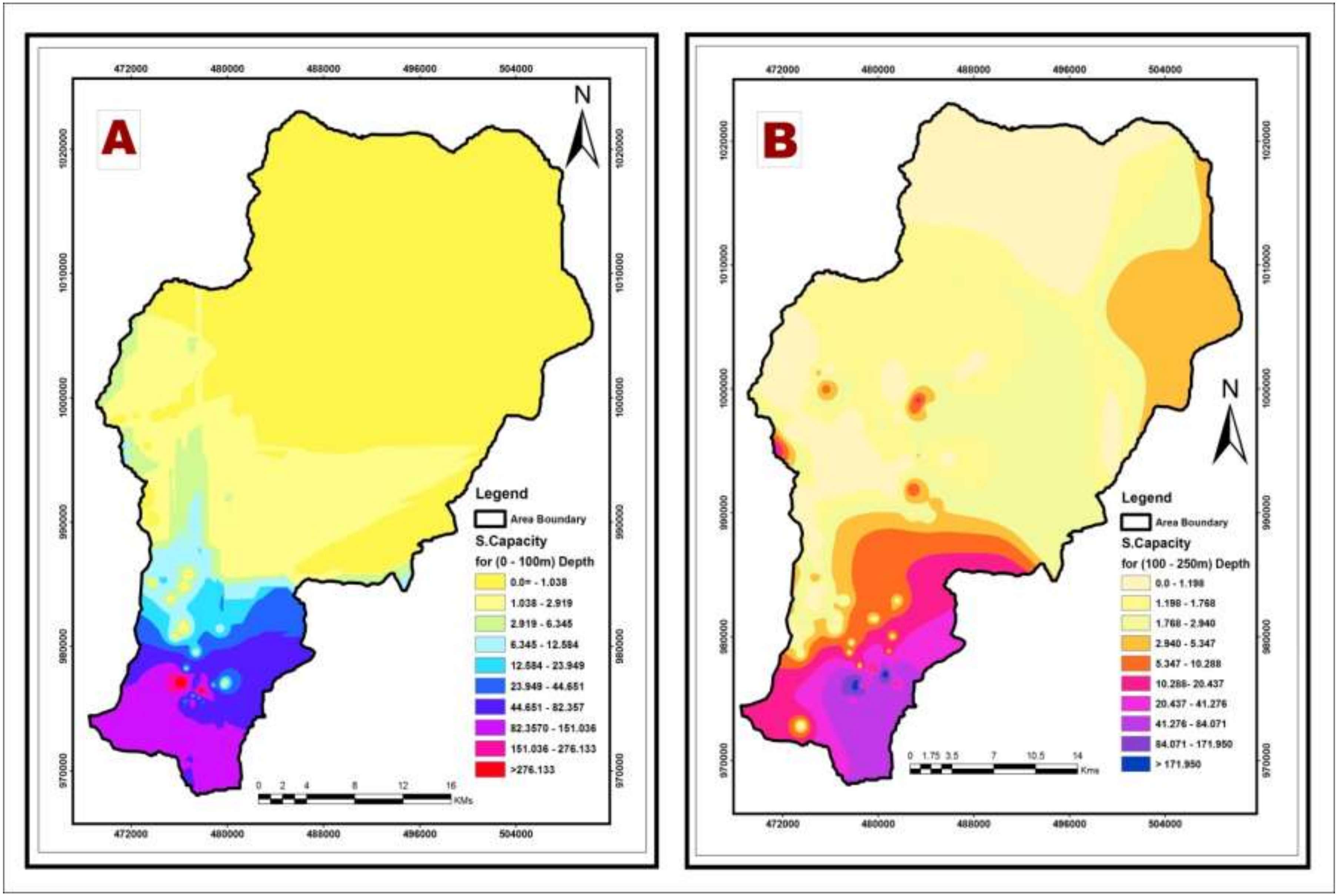


Figure 42; specific capacity spatial variation distribution map measured from point data for (0 - 100m)A & (100 - 250M)B

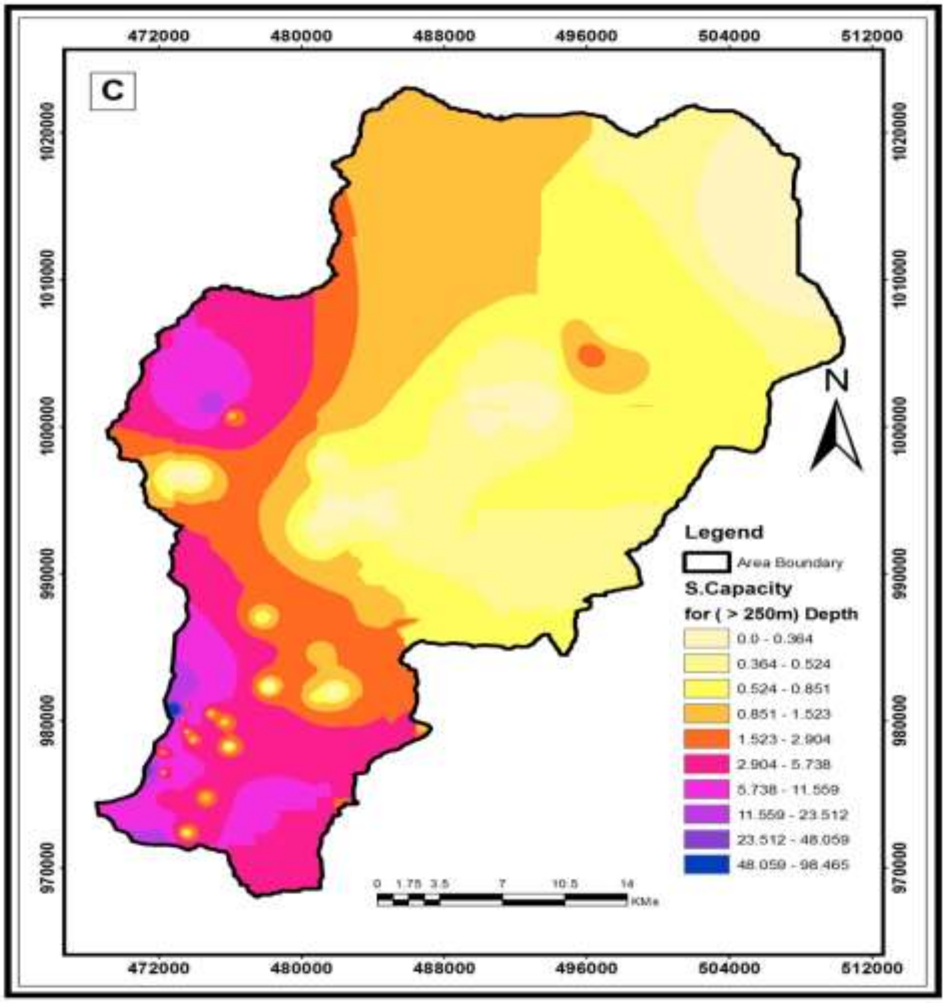


Figure 43; Specific capacity spatial variation distribution map of the catchment measured from point data for (>250m depth) C.

5.8.4 Safe Yield

Safe yield is the amount of naturally occurring groundwater that withdrawn from an aquifer on a sustained basis, economically and legally, without weakening the native groundwater quantity or creating an undesirable effect such as environmental damage (*Nata Taddese.2014*).

The term safe yield is using in practice as early as (1915). During that time, safe yield was regarded as the amount of water that could be pumped "regularly and permanently without dangerous depletion of the storage reserve."

Later other necessary factors added, such as economics of groundwater development, protection of the quality of the existing store of groundwater, and protection of existing legal rights and potential environment degradation.

The safe yield spatial variations of aquifer is developed by obtaining the calculated result by using safe yield formula which is Safe Yield (Sy) = SC*Ha*Safety factor (0.6 to 0.7); Where; SC = Specific capacity

Ha = Available head between SWL and Dynamic water level. Therefore the safe yield distribution variations are calculated using such above formula and classified on map (figure; 29) in to seven parts which is (zero – 14, 14 -20, 20- 30, 30 – 40, 40 – 60, 60 -80 and > 80 L/s). This implies that the well abstraction system should be in these ranges to obtain sustainable and economical use of water for long range. It also helps the well to stay longer with a minimum depletion and for the managing of aquifer.

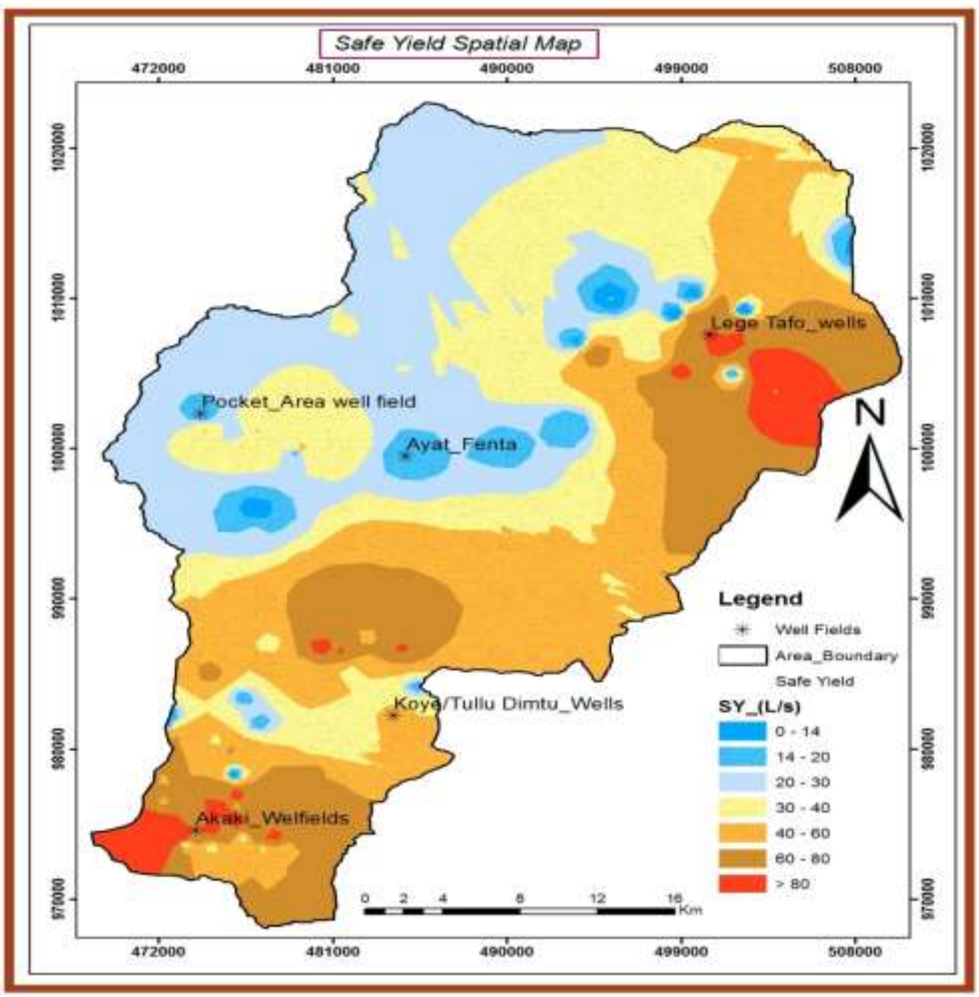


Figure 44; Safe yield spatial variation distribution map of the catchment measured from point data

According to analysis, high discharge area has high safe yield while moderate and low discharge area has moderate and low safe yield respectively. Hence high safe yield is recorded at akaki and legetafo well field. Whereas tullu dimtu well fields and ayat fenta wells has relatively moderate and pocket area has low safe yield.

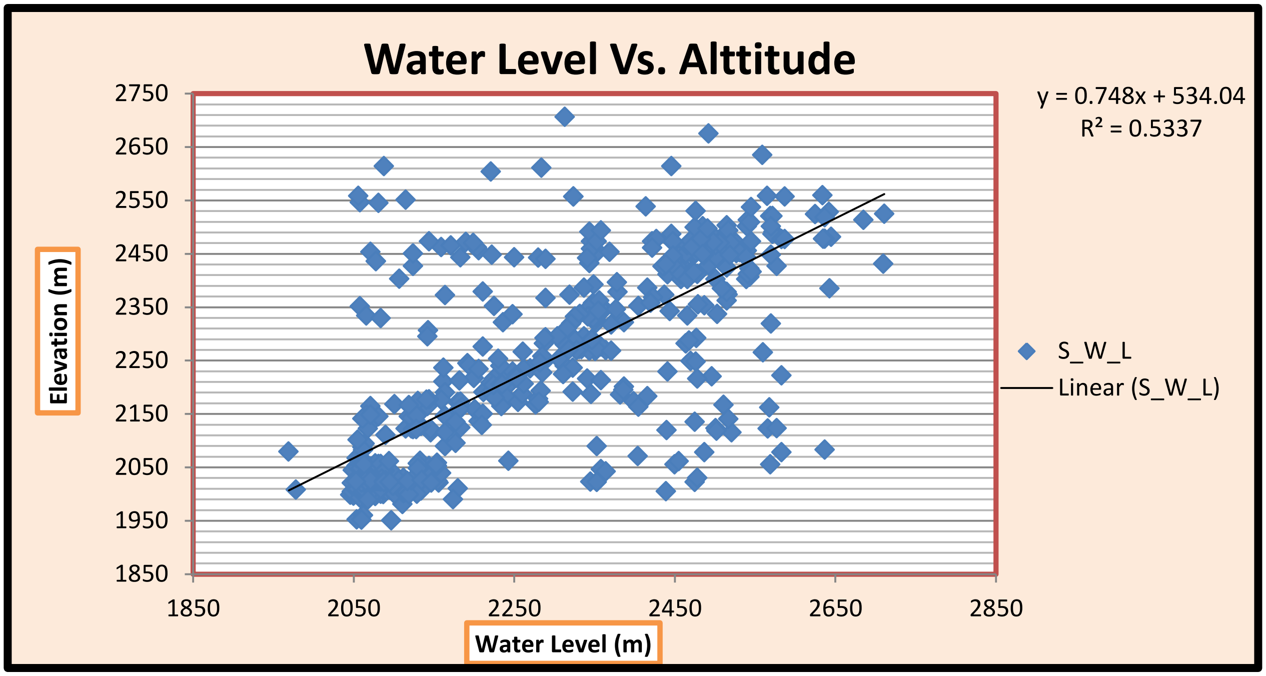
5.8.5 Water level and Drawdown

Static water level (SWL) is at which water stands in a well or unconfined aquifer when no water is being removed from the aquifer either by pumping or free flow.

The most important index of well behavior is the difference between the water level at rest and the pumping level called the drawdown. Larger draw-downs are associated with higher pumping rates or lower producing wells or aquifers The higher yielding an aquifer or well, the smaller the drawdown for a given flow rate and the faster water levels will recover once pumping stops.

The groundwater level and drawdown has direct relationships meaning that as the water not abstracted from the well or under equilibrium, the drawdown may become zero, if water is abstracting with certain discharge the drawdown drops and the water level also changed to dynamic water level. In this case, the amount of discharge defines the change of the drawdown.

Generally drawdown increases the longer pumping continues and is greatest in the pumped well and it reduces with distance from the well, forming a shape called cone of depression. The water level distribution map developed by using the potentiometric surface of the aquifer (figure; 32)



Figure; 30 Correlation Groundwater level (m) and altitude difference (m).

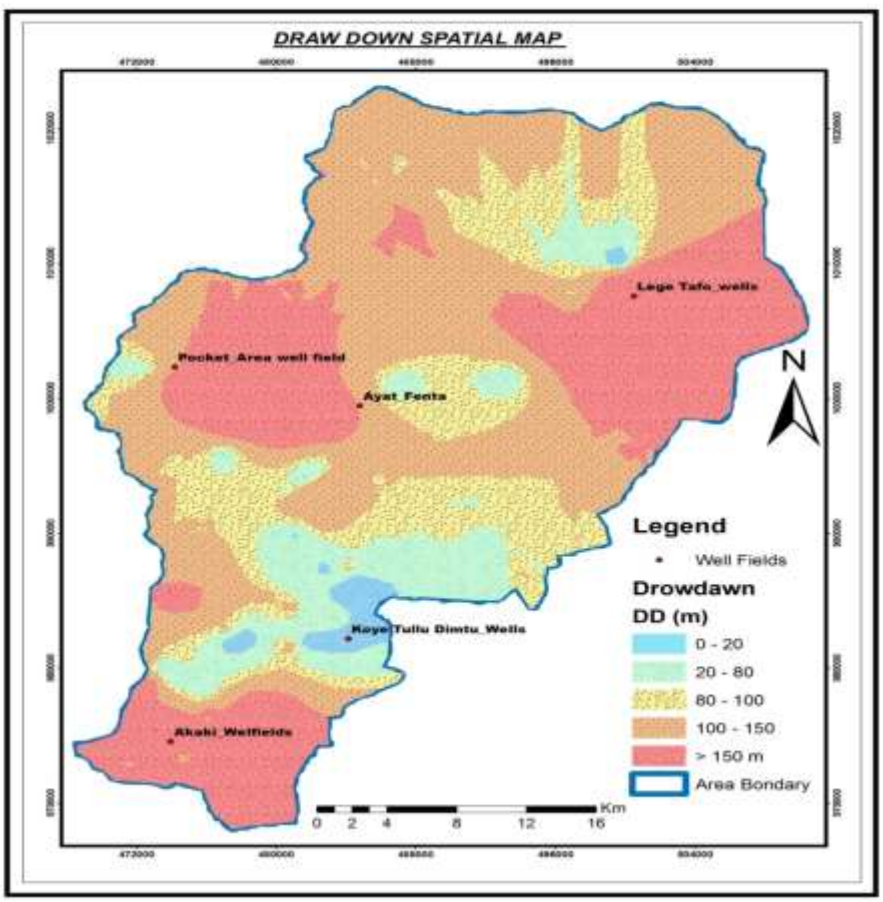
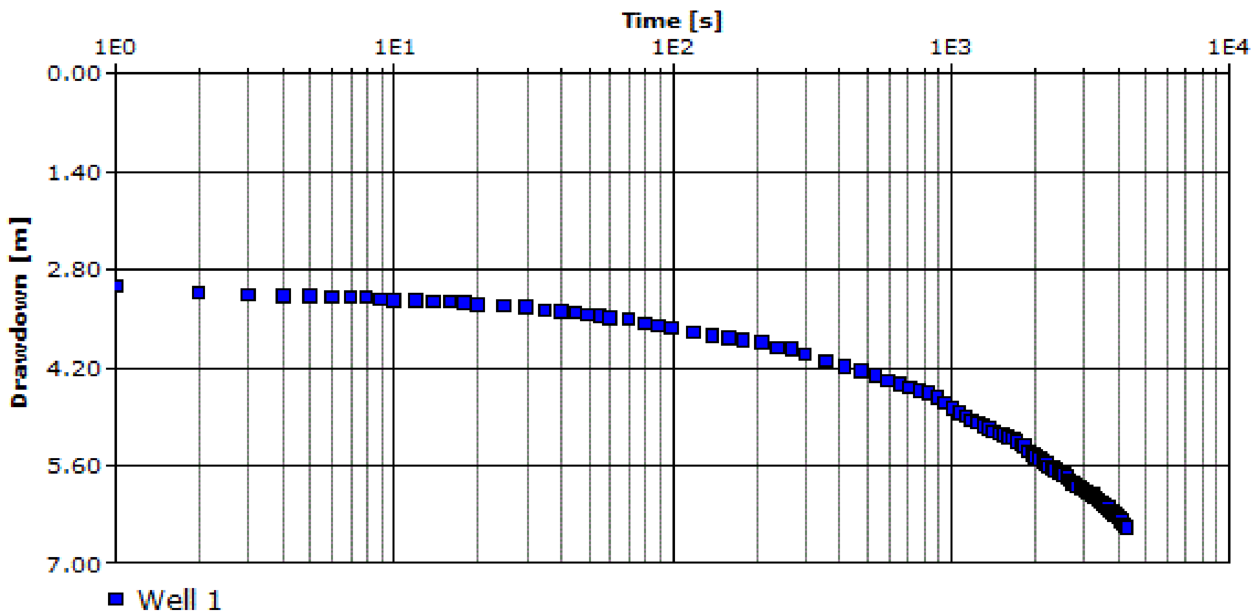


Figure 45; Water level Drawdown variation map measured from point data

The higher water level drawdown is recorded at southern (akaki well field), western (pocket area well fields) and northeastern part of the study area catchment. Even if the aquifer is highly productive its draw down may higher or not.

Location: akaki	Pumping Test: constant testing	Pumping Well: Well 1
Test Conducted by: wasihun		Test Date: 10/2/2021
Analysis Performed by: wasihun kibret	constant testing	Analysis Date: 2/1/2022
Aquifer Thickness: 30.00 m	Discharge Rate: 113 [U.S. gal/min]	
	excel	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Well 1	8.64×10^1	2.88×10^0	1.00×10^{-4}		

Figure 46; constant testing graph using cooper Jacob analysis (well id; SL-PW12)

well ID	X(m)	Y(m)	Z(m)	W.D(m)	Q(L/S)	T (m2/d	K(m/d)	SWL(m)	M.SWL(m)	max.DD/old	SCl/s/m	SY l/s
(24KPW-01-17)	477052	995894	2351	468	8.5	48.9	25.3	83.5	98.5	130.3	0.0652	3.8
(SL-PW-07)	476098	976183	2055	535	46.7	654	38.78	53.52	63.52	77.51	0.602	40.2
(SL-PW-12)	470835	974233	2046	320	113.48	8456.9	56.89	49.45	67.25	6.5	17.458	100
SL-PW-30	478528	973384	2113	533	46.29	756	908	132.4	143.4	1.31	18.7	35
(SWAWF3)	471027	973709	2054	378	90	7989.9	28.2	44	52	14.2	6.34	82
(WF02-PW10)	474558	972286	2112	480	42.9	620	7.45	107.62	116.62	48.66	0.88	34.58
WF01-PW3	474918	980486	2081	481	28	78.9	2.86	21.83	34.83	68.65	0.408	24.5
SWAWF1R	475945	978251	2060	417	12.09	48	5.96	45.2	59.2	111.7	0.108	8.8
SANF-PW3	482119	982234	2277	523	40	410	0.18	32.2	56.2	103.95	3.843	34
(SANF – PW4)	477224	981760	2289	542	30	90	5.64	40.5	60.5	126.22	20.54	27
(SANF – PW21)	484142	982196	2289	550	45	350.6	4.89	13.23	34.23	125.15	0.36	44
(SWAWF2)	475697	979915	2062	448	54.45	820	27.1	9.45	31.03	89.39	0.61	42
BHT-603	481507	976220	2120	132	5	72.5	12.8	120	Dry	4.5	15.6	2.7
BHT-851	479526	977468	2019	129	35	586.2	17.89	71.7	91.7	1.28	18.2	30.2
BHT-1143	479061	976370	2089	103	10	110.63	20.2	67.2	87.2	3.4	17.8	8
(SWAWF4A)	472826	980785	2180	121.5	30	6.06	14.2	8.45	39965	52.23	0.57	22.5
BHT-1010F1	479000	981400	2075	120	40	681.8	25.6	10	30	5.5	20.42	38.5
BHT-1147	478347	976752	2190	92	10	145.32	23.45	39.45	59.45	9.2	28.8	7.5
BHT-1144	476246	977104	2189	90	69.02	789.98	34.2	58.7	78.7	12.68	30.2	59.5
BHT-1154	477162	976038	2130	90	10	107.2	21.2	41.95	61.95	5.2	34	8
BHT-1152	477477	977216	2100	92.5	10	102	45	33.96	53.96	3.58	23.52	7.5
BHT-1138	477330	976793	2113	90	10	98.98	47.89	42.93	62.93	2.35	8.5	9
BHT-1142	479696	976897	2156	97	15	189.6	12.4	67.3	87.3	5.6	6.3	10.2
BHT-607	476600	978200	2145	79.2	2.12	91.58	28.3	46.4	66.4	5	14.8	1.2
BHT-768	478462	977721	2210	150	4	72.3	56.8	50	70	12.2	22.3	1.8
BHT-832	478780	977307	2100	138	81.1	2180.5	78.9	61.1	81.1	2.2	156.8	74.5
BHT-769	477608	978689	2130	116	2.96	38.9	189	57.7	77.7	8.5	48.2	2
BHT-737	477446	978851	2180	82.3	3.33	32.5	57.9	52.4	72.4	3.5	150.5	1.5
BHT-605	477400	979500	2198	96	2.5	18.96	48	27.4	47.4	6.3	169.2	1
(KDPW-1)	479316	999941	2643	271	50	446	27.3	118.36	10000	23.48	2.14	40.5
(KDPW-2)	479175	999755	2711	250	15	4.82	52.3	107.3	8116	45.7	0.34	10

Table 17; measured and well inventory raw data

CHAPTER SIX

6. Hydrochemistry

6.1 General

Hydrochemistry is using to assess the overall occurrence and distributions of the various chemical constituents in natural waters, controlling factors and the relation of these constituents to water use. The physical, chemical and biological characteristics of water determine its usefulness for various purposes. Hydrochemistry plays a significant role to provide information both in space and in time related to origin, quality and history of natural water.

The composition of the geological materials that may consist of various rock types affects water chemistry. Composition of water represents the results of rock water –interaction based on the lithological-type, temperature, type of minerals, solubility, PH and rates of geochemical reactions.

The variation of water composition through reactions may provide information about the environment through which the water has circulated. This in turn can used to investigate the correlation water quality (type) and the geological environment (*Leathern et.ai., 1990*).

Groundwater circulation in a basin usually takes place within one or more flow systems. Within each flow system, recharge zones and discharge zones identified. The atmospheric chemical composition of rainwater, the composition and chemical conditions of the soil and geological formations determine the chemical composition of the groundwater in the basin, further down a flow line. In addition, the effect of changes in groundwater circulation on the hydro chemistry of an aquifer is visible in places where human activities have taken place. This implies that different hydro chemical conditions in the past can strongly influence the development of groundwater chemistry.

Hydrochemistry can help to consider at some ways in which the protection and management of groundwater resources achieved. In general, the water chemistry at any point in a groundwater basin relates to the hydro chemical history of the basin, the composition of the geological formations, the groundwater circulation of the basin etc.

Under this chapter, the aquifer properties of the study area (big-Akaki watershed) analyzed with concerning to the water chemistry variation, problem identifications and evaluations of the well over the catchment. Due this the physical and chemical quality analyzed was used to describe and understand in detail, water quality spatial maps , graphs or charts, water type values, hydro geochemical facies diagrams, hydro geochemical evolution.

6.1.1. Geo-statistical analysis

The geo statistical analysis tool of ArcGIS 10.3 software used to analyze and interpret the spatial variation and distributions of the spatial GW quality parameters. The ordinary and simple kriging and inverse distance weighted (IDW) used to interpolate and generate the point at no data localities and generate the surface map.

Kriging is a statistical method that quantifies the correlation of the measured points through variography. When making a prediction for an unknown location, kriging weights the nearby measured points by their configuration around the prediction location and uses the fitted model from variography to determine a value. There are two kriging methods: Ordinary and Simple kriging.

In Ordinary Kriging, the randomized spatial function is non-stationary and the mean varies over the area of interest. Ordinary Kriging amounts to re-estimating the mean at each new location. In Ordinary Kriging, you can influence the number of points that should take into account in the calculation of an output pixel value by specifying a limiting distance and a minimum and maximum number of points. Only the points that fall within the limiting distance to an output pixel will used in the calculation for that output pixel value. Ordinary Kriging is highly reliable and is recommended for most data sets..

Inverse Distance Weighted (IDW) based on a basic principle of geography, that things close to one another are more alike. Thus, if you are at a location with no measured value, in IDW, you will look within a specified neighborhood-or distance-around you and identify the measured values.. Hence, the name IDW-as the distance increases; you will inversely weight the values. This process continues for each location in the study site.

The IDW method was modeled using best-fitted power; while Kriging selected the lowest error by comparing the sampled and the predicted values through employing the empirical semi variogram models. The spatially analyzed water quality parameters are (TDS, EC, PH, Fe, FL, sodium+ potassium, calcium + magnesium and total hardness) variation in compositions distribution of the watershed (figure).

6.2. Water quality analysis

The Major cations and anions spatial distribution analysis map prepared and detail narration relative of water quality analysis described by comparing the WHO and Ethiopian standards. Hence, the physical parameters (TDS, PH and Ec) measured and collected over 20 well data at the field to recognize physical parameters of the groundwater system of the catchment. Around 286 well sample data used to identifying water, types and generate spatial maps for both for physical and chemical parameters.

Additionally Shlumberger AquaChem version 14.2 from Waterloo hydro geologic software widely used to analyze plot, and report aqueous geochemistry and water quality of the GW. General water quality diagrams generated such as Piper and Wilcox Plot for irrigation, the changes in saturation state used to identify the geochemical reactions governing the GW chemistry.

6.2.1 Physical Parameters

6.2.1.1 Hydrogen Ion Activity (pH)

The balance of positive hydrogen ions (H+) and negative hydroxide ions (OH-) in the water determines how acidic or basic the water is. The pH scale ranges from zero (high concentration of positive hydrogen ions, strongly acidic) to 14 (high concentration of negative hydroxide ions, strongly basic). In pure water, the concentration of positive hydrogen ions is in equilibrium with the concentration of negative hydroxide ions, and the pH measures exactly 7. In this specific water wells the pH value is ranges from 6.65 to 9.32, which found all most acceptable range for drinking purpose.

According to (*Hem , 1992*) Hydrogen ion of natural waters, mainly fall in between 6.5 to 8.5 generally considered as satisfactory for drinking and it controlled by interrelated chemical reactions that produce or consume hydrogen ions. The dissociation equilibrium for water is always applicable to any aqueous solution, but many other equilibrium and many non-equilibrium reactions that occur in natural water among solute, solid and gaseous, or other liquid species also involve hydrogen ion. Field pH values generally are higher or lower than laboratory pH values by as much as ± 1pH unit or more (*Pyne et al. 1995*).

Field values are commonly lower than laboratory values because collection, transport, or storage causes a release of dissolved carbon dioxide from the water into the headspace of the sample and a release to the atmosphere when the sample opened.

In the field, pH measurements were made of each sampling point since this parameter may immediately change with time. The water quality analysis regardless of their source displayed and chemical property is compared within the WHO and Ethiopian Water standard guideline (6.5-8.5). The PH ranges varies through the study area well fields due the higher PH is observed at legetafo lege dadi wellfields (8.45 to 9.32) ,relatively moderate at ayat fenta well fields (7.48 to 7.93) and lower at akaki well fields (6.65 to 7.46)

Type	Minimum pH	Maximum pH	Average
BH (LLA and pocket and koye)	6.65	9.32	7.985

Table 18; showing minimum and maximum PH source of the catchment

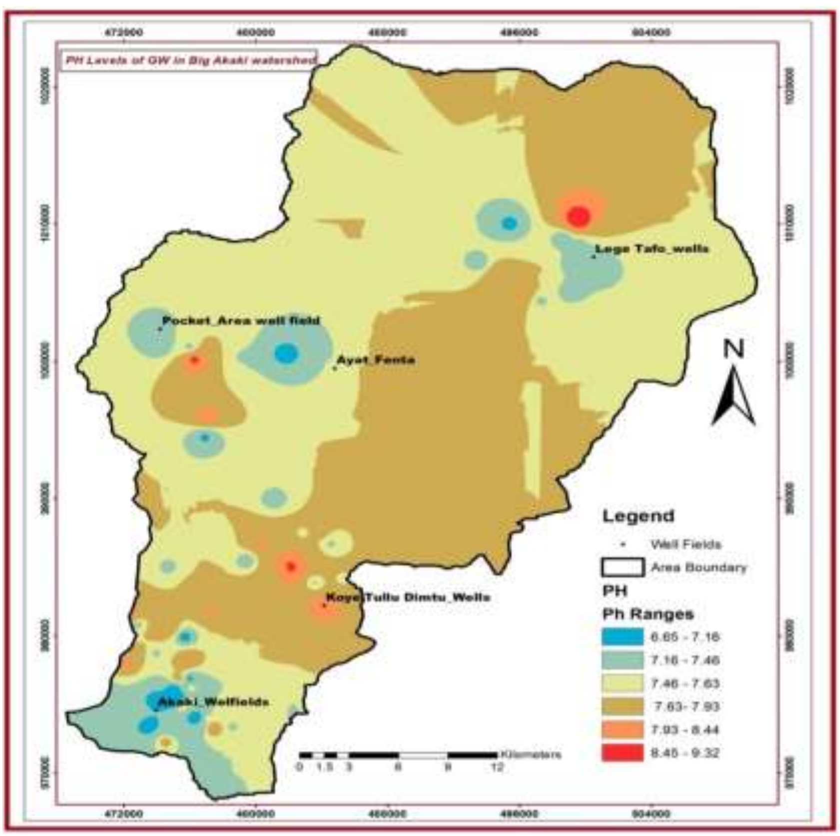


Figure 47; PH- spatial variation distribution map of the catchment measured from point data

6.2.1.2 Electrical Conductivity (EC) and (TDS)

Conductivity or conductance is a measure of the ability of water to conduct an electric current or the presences of all the chemical constituents give water the ability to conduct electricity. Thus the electrical conductivity (EC) of water is an indirect measure of its dissolved constituent's variations in dissolved solids mostly mineral salts. In addition, it also the degrees to which these dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on conductivity. In practice, EC often expressed in terms of mill Siemens (ms) and micro Siemens.

The TDS and the EC are in a close connection. The more salts are dissolved in the water; the higher is the value of the electric conductivity. The conductivity of most freshwaters ranges from 10 to 1,000 µS/cm but may exceed 1000 µS/cm, especially in polluted waters, or those receiving large quantities of land run-off. Usually measured in situ with a conductivity meter, and may be continuously measure and recorded.

In the study area, generally the concentrations in the study area well fields from boreholes EC values range from 16.17 µs/cm to 3630 µs/cm and the overall average EC values of bore holes in the study area is about 585.4617 µs/cm.

The minimum or lower EC observed at akaki ,Tullu dimtu or koye feche well fields and legetafo lege dadi well fields wich ranges in between (16.19 to 511.17 µS/cm) while relatively moderate at koye feche or tullu dimtu and ayat fenta ranges from (511.17 to 921.34 µS/cm).

The highest observed at pochet area well field general ranges from (921.11 to 3630 µS/cm). (Figure…..)

Conductivity is expressed in (µS/cm) at a specified temperature, usually 25 0C and for given water body is related to the concentrations of total dissolved solids (TDS) and major ions. In general, the larger the value of specific conductance the greater also the concentration of dissolved solids in the water sample.

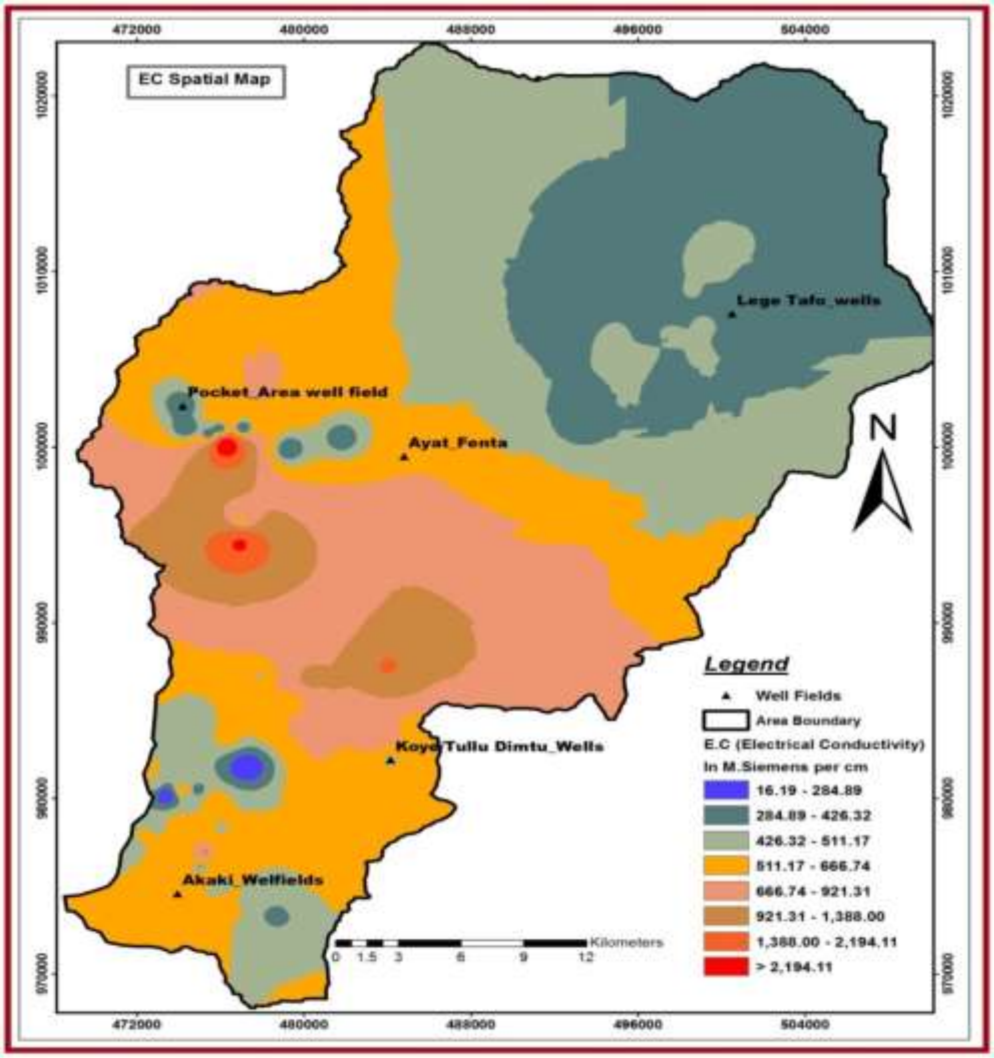


Figure 48; EC- spatial variation distribution of the catchment measured from point data

The Total Dissolved Solids (TDS) concentrations in groundwater vary over many orders of magnitude. As it is cited in ***(Fetter, 1994),*** more than 90% of the total dissolved solids ingroundwater can be attributed to eight ions, Na+, K+, Ca2+, Mg2+, Cl-, CO32-, HCO3-, and SO4-. These ions are usually present at concentration greater than 1 mg/l.

Total dissolved solids, TDS (in mg/l) may obtain by multiplying the conductance by a factor (A) which is commonly between 0.55 and 0.75. This can be expressed as TDS = EA (where E is conductivity in µs/cm and TDS is total dissolved solids in mg/l.

This specific water sample has a Total Dissolved Solid (TDS) value of 406 (mg/l) which is bellow maximum allowable WHO standards (1000mg/l) and Electrical conductivity (EC) value of

610(μS/cm). As a result, the water grouped under fresh water. The portability of water in terms of TDS is suggested optimum only when TDS value is up to 500mg/l (WHO, 1984).

The TDS conditions of the study areas demonstrated as spatial variation of well fields in which the lower, moderate and highest TDS concentrations evaluated. Thus, the minimum values ranging in between 27 and 300mg/l at lege tafo, well fields and moderate values (300 to 500mg/l) observed at upper and lower part of the catchment. While the central part relatively higher pocket area specifically at legehar and fellwuha area and ayat fenta well fields or Tullu dimtu well fields which ranges from (500 to 1000 mg/l).

The mean TDS of boreholes of the study area is 342.49 mg/l that lower than the WHO standard of 1000 mg/l. or very good permit able concentration. Hence, the EC and TDS analysis results compared with the WHO standards. The general increasing of both EC and TDS in the catchment may due to the high concentrations of cations (Na, K, Mg, CA) in groundwater system of the area.

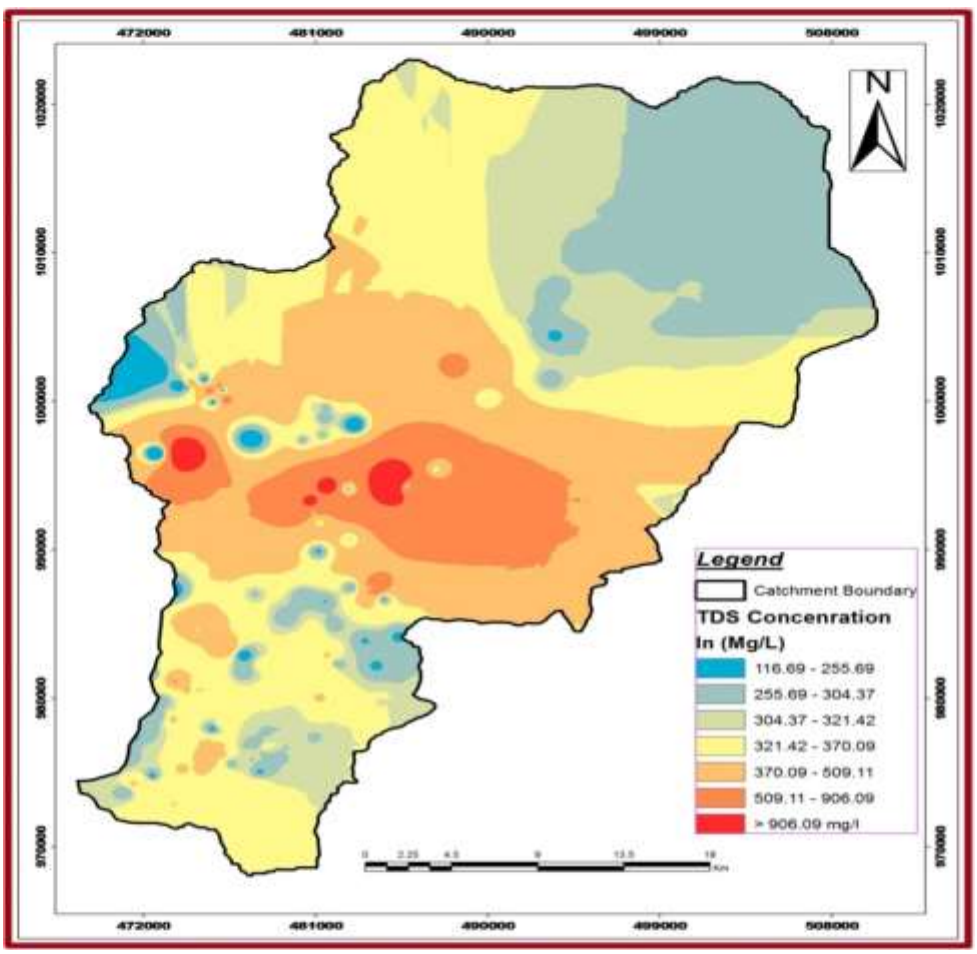


Figure 49; TDS (Total dissolved solid) spatial variation distribution map of the catchment measured from point data

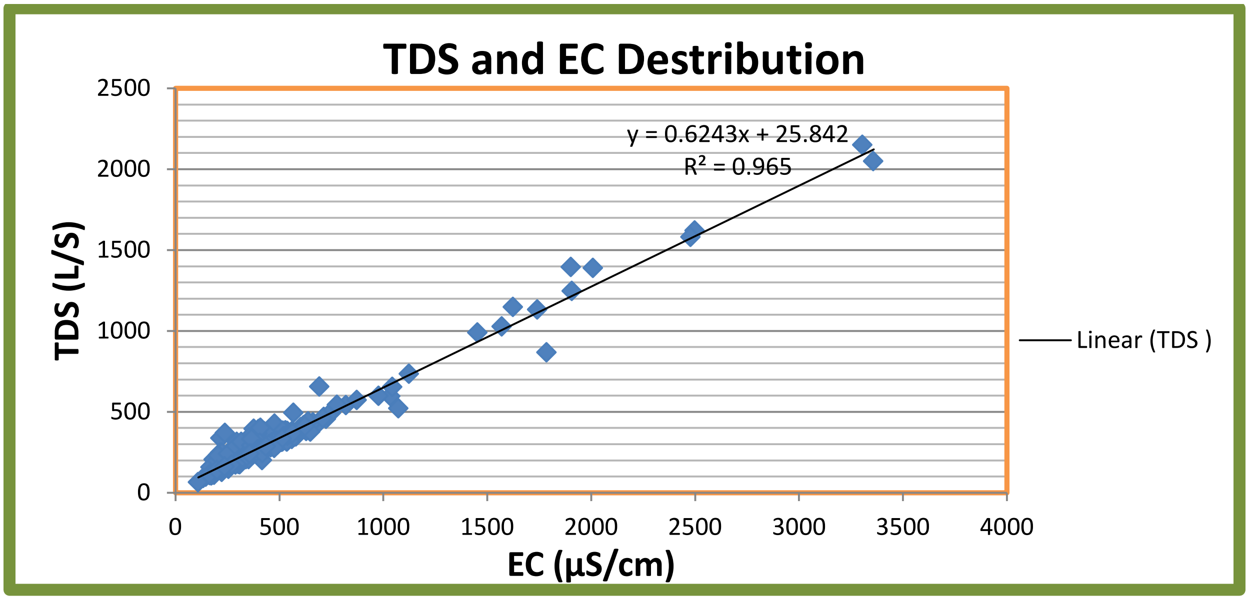


Figure 50; Relationship between EC (µS/cm) and TDS (mg/l)

Based on the above (figure; 37), the Electrical Conductivity (EC) increases with the increase of Total Dissolved Solids (TDS). Hence, the electrical Conductivity of Groundwater both the deep and the shallow wells tend to have very high values and this is due to the high concentration of dissolved salts. According to the TDS analyzed in map, it concluded that the general trend in increase of TDS is from the middle of the area to southern parts of the catchment (figure; 37) .

Table 6.3 Classification of water based on TDS (Freeze & Jerry 1979)

Class	TDS (mg/l)
Fresh Water	0-1000
Brackish water	1000-10,000
Saline water	10,000-100,000
Brine water	More than 100,000

Table 19; classification of water based on TDS (Freeze & jerry 1979)

Fresh water is water that contains less than 1,000 mg/l of dissolved solids; generally, more than 500 mg/l of dissolved solids undesirable for drinking and many industrial uses. Hence the boreholes in the study area has categorized as fresh water that shows below the maximum TDS (1000mg/l).

6.2.1.3 Total hardness

The total hardness defined as the sum of calcium and magnesium concentrations, both expressed as $CaCO_3$ in mg/l. The total hardness is relatively high in water due to the presence of calcium, magnesium, and chloride and sulfate ion. It can be determined by substituting the concentration of Ca^{2+} and Mg^{2+}, expressed in milligrams per liter, in the expression The degree of hardness of the water is classified in terms of its calcium carbonate concentration (after Sawyer and McCarty, 1967).

No.	Hardness, (mg/l as $CaCO_3$)	water class
1	0-75	Soft
2	75-150	Moderately hard
3	150-300	Hard
4	Over 300	Very hard

Table 20; standard for Total hardness and general water classifications

The pocket area and some part of koye feche or tullu dimtu, well fields has minimum of Total Hardness that categorized under the soft water (10-70mg/l) respectively.

Additionally the moderate total hardness (70 -100mg/l) covers ayat fenta and Koye/tullu dimtu well fields which has moderately hard water. Finally the legetafo ranges (100 -159mg/l) and akaki well fields (159 – 265mg/l) has contains relatively hard water.

These values indicate that the sample from the borehole is moderately hard water.), in comparison, the total hardness of the aquifer in the study area is below the maximum WHO standard. The WHO maximum allowable concentration is 500 mg/l ($CaCO_3$ Generally the total hardness of the study area is increasing and relatively maximum at the discharge area rather than the recharge localities. Hence the general total hardness increment may due to the increasing of cations particularly CA^{2+} and Mg^{2+} ion in water with corresponding $CaCo_3$ concentration.

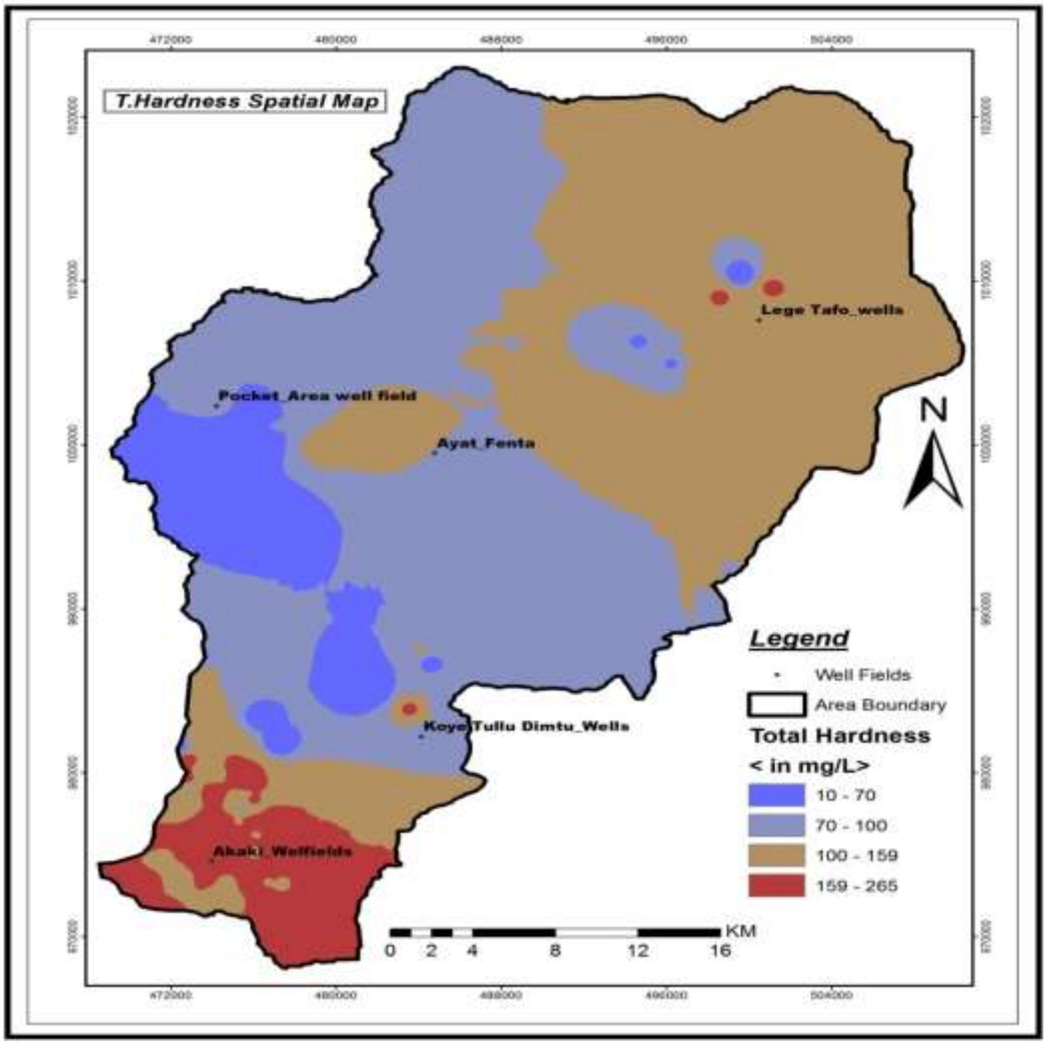


Figure 51; Total hardness spatial variation distribution map of the catchment measured from point data

6.2.2 Major Cations and anions

6.2.2.1 Major Ions and Their Evolutions

The Major ions classified as Cations (sodium, Potassium, Magnesium, Calcium) and Anions (Chloride, Bicarbonates nitrate and Sulfate) are naturally very variable in surface and groundwater due to local geological conditions, nature of climate and geomorphological variations. In the study area aquifer Sodium, Calcium and Bicarbonates are the dominant ions in both surface and groundwater. Hence, magnesium and potassium are relatively low.

6.2.2.1.1 Sodium ions (Na+)

The sodium ion is the most abundant element in natural water; it is the reactive and highly soluble especially with water quickly to produce hydroxide and hydrogen. Sodium is also a component of sodium chloride (NaCl) a very important compound found everywhere in the living environment. The WHO guideline value for sodium in drinking water is 200mg/l. However, the Ethiopian guideline value is a little bit higher which 358 mg/l is. Most of the well fields existed in the area has sodium values below the guideline levels and this also true for Awash River.

Sodium commonly measured where the water used for drinking or agricultural purposes particularly for irrigation. In the study area, most groundwater samples shows similar increasing trend from recharge (highland topography) to discharge zones such as akaki catchment area. The concentration of Sodium in groundwater samples analyzed is within the range from11.5 mg/l leghare well (LPW-01-17) to 355mg/l at (SANFTW-2). Hence the maximum sodium concentration is recorded as (610mg/l) at bole high school well (BHSPW-01-17), this is due to the hot spring found in leghare area (fel wuha) in which the hot water has high temperature water and high rate of material solubility including the chemical constituents existed in geological materials.

Generally, the recharge area (Entoto and surrounding ridges) of the catchment has low sodium levels relatively from the discharge areas (akaki well fields) Concentration. This implies that sodium evolution does not show regular pattern in the area.

The much higher concentration of sodium than potassium in the study area may be due to cation exchange process. Cation exchange is the chemical reaction frequently cited to explain the high percentage of sodium compared to calcium and magnesium in water (*Lee, 1981) and (Woessner et.al., 1986*). Cation exchange is a reaction in which the calcium and magnesium in the water are exchanged for sodium that is adsorbed to aquifer solids such as clay minerals, resulting higher sodium concentrations (Hem, 1985).The general reactions are given by (*Hem, 1985*)

$Na_2X + Ca^{2+} \Leftrightarrow CaX + 2Na^+$

$Na_2X + Mg^{2+} \Leftrightarrow MgX + 2Na^+$

Where, X = aquifer solid

6.2.2.1.2 Potassium ions (K+)

Potassium found in low concentrations in natural waters since rocks that contain potassium are relatively resistant to weathering. Usually found in the ionic form and the salts are highly soluble. In the study area relatively the much higher concentration of Sodium and calcium than Potassium observed. This may be due to cation exchange process the concentration of potassium in the analyzed well field data ranges from 0.9 mg/l for LLA PW 16 to 66 mg/l for BHSPW-01-17. The potassium levels trends in the well fields are consistent.

Generally the higher sodium and potassium implies that the basicity of the ground water is high due to this the basicity increases in central part of the catchment and medium and lower at upper and lower part of the catchment. The maximum or higher concentrations in groundwater may exists due to the geological materials or minerals composed of potassium and sodium in rocks.

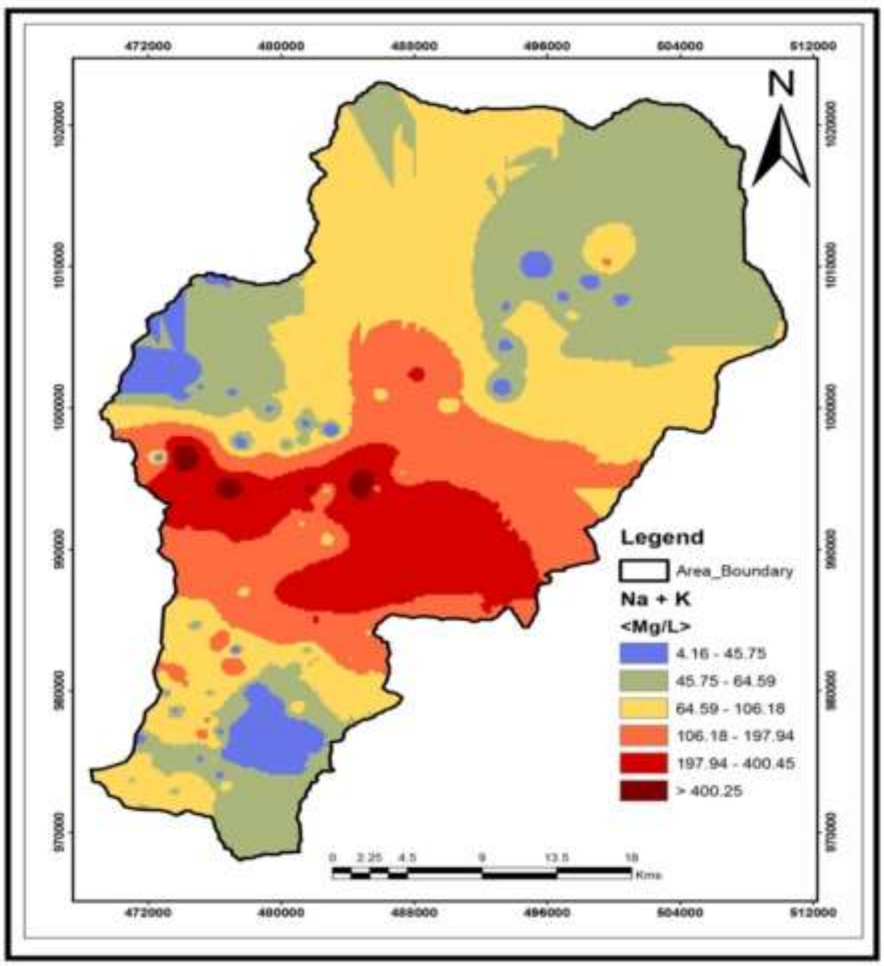


Figure 52; Sodium plus potassium (Na + K) concentration spatial variation distribution map of the catchment measured from point data

6.2.2.1.3 Calcium ions (Ca+2)

Calcium is present in all waters as Ca+2 and is readily dissolved from rocks rich in Calcium minerals. This cation is abundant in groundwater of the area. Acidic rainwater can increase the leaching of calcium from soils. water quality analysis result the concentration of Calcium in Groundwater sources shows variability and is generally from 3.56 mg/l at akaki near Abba Samuel lake SWAWF3 to 87.4 mg/l at akaki salogora kebele WF01-PW17, Awash River has calcium concentration ranges from 49.97 mg/l legetafo reservoir (LL4) to 93 mg/l at downstream of akaki well fields.

Hard water is water containing high concentrations of dissolved minerals, usually calcium or magnesium carbonates ($CaCO3$ or $MgCO3$), chlorides ($CaCl2$or $MgCl2$) or sulfate ($CaSO4$or $MgSO4$). The hardness of water depends on its source of ; generally the maximum and minimum calcium cation concentration is existed in the discharge are of the catchment (akaki well fields).

6.2.2.1.4 Magnesium ions (Mg+2)

Magnesium is common in natural water as Magnesium ion (mg^{*}), and it originates from substantial contribution from the weathering of rocks as the rock water interaction. Along with calcium, is a main contributor to water hardness in the study area, Magnesium arises mainly from the weathering of rocks containing Ferro magnesium minerals.

From sample analysis result of different water source bodies, the concentration of Magnesium is generally less than that of Calcium.

The concentration of Magnesium in the analyzed borehole waters range from 0.96 mg/l for Serti wells (SPW-01-16) to 30.2 mg/l for (SL-PW-05). The minimum below 1mg/l of calcium concentrations 0.96, 0.98, and 0.98 mg/l existed at serti well (SPW-01-16), leghare well (LPW-01-17) and Ayat fenta (SANF – PW4) well respectively.

The WHO standard for magnesium metal in water is 150mg/. Hence, in the maximum concentration of magnesium in the area groundwater is 30.2 mg/l for (SL-PW-05) which is below the permissible level or standard.

According to the addition of magnesium and calcium spatial analysis result the acidity is higher at legetafo , akaki and pocket area well field well fields and lowers at central and upper parts of the catchment. The increasing of the acidity may come from the acidic rocks, while the akaki well fields gaining through groundwater transportations from the recharge area.

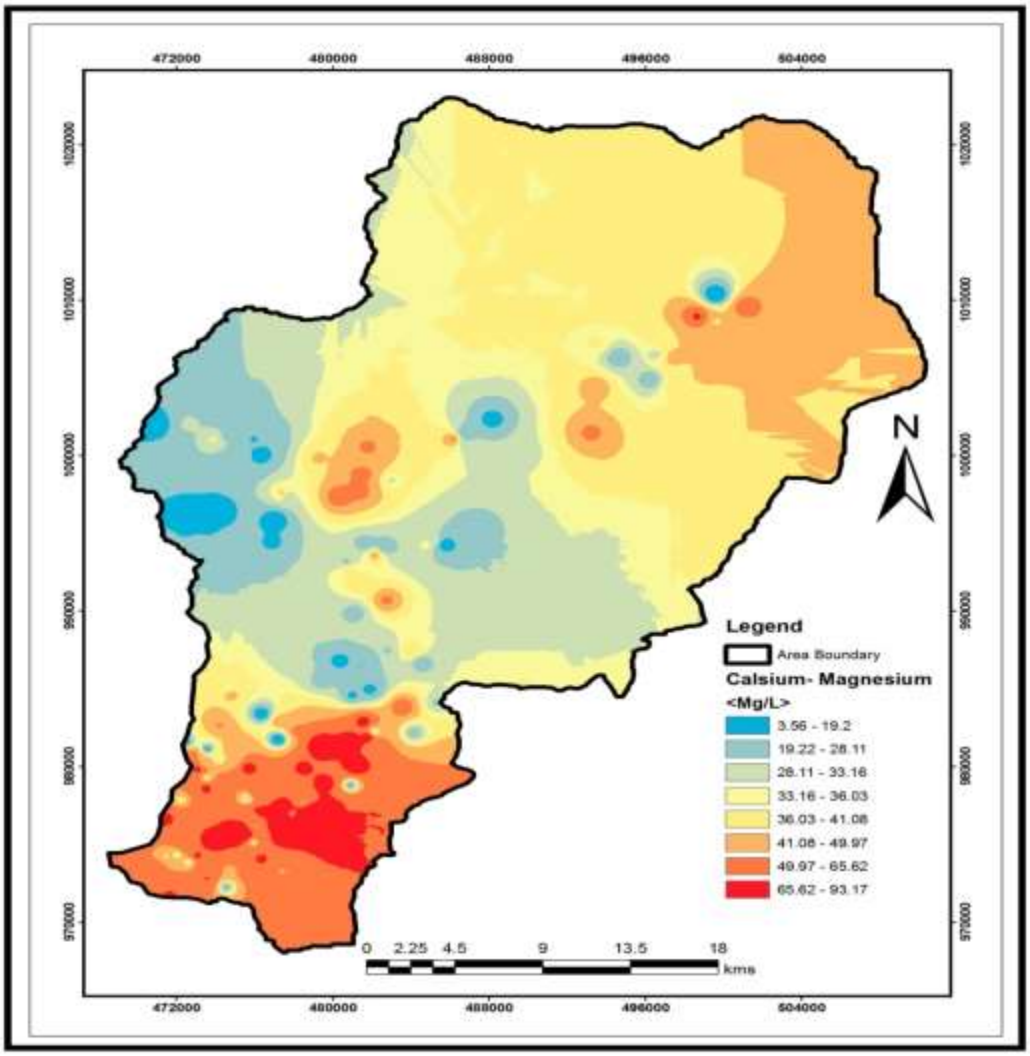


Figure 53; Calcium plus magnesium (CA +Mg) concentration spatial variation distribution map of the catchment measured from point data

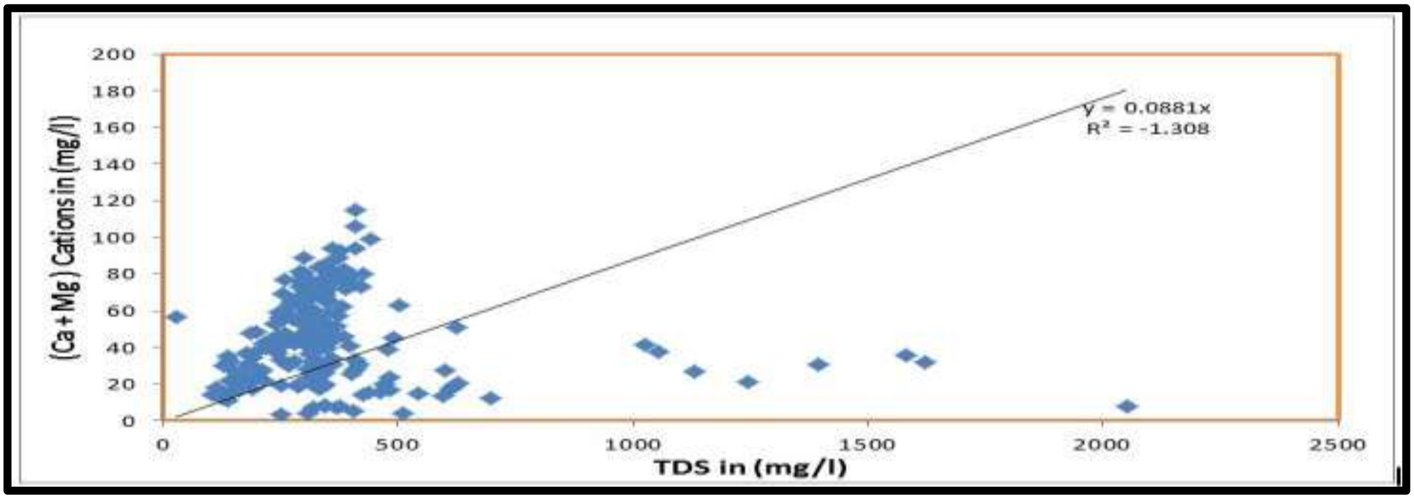


Figure 54; Graphical (scatter plot) distribution relation between TDS and Mg + Ca

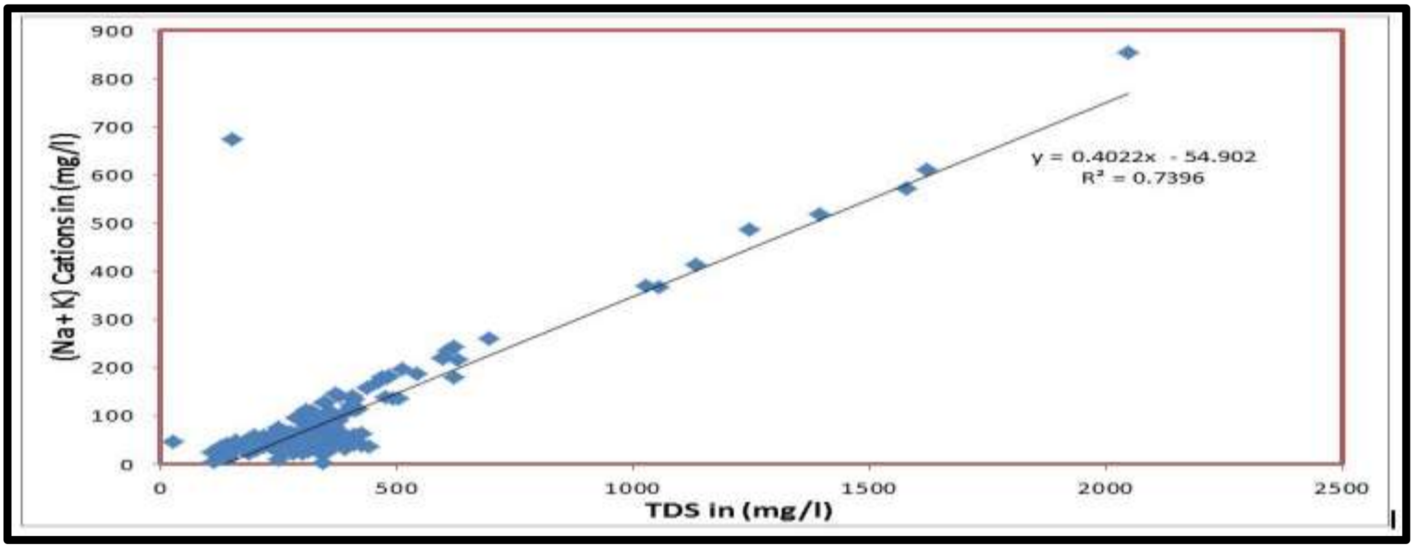


Figure 55; Graphical (scatter plot) distribution relation between TDS and Na + K

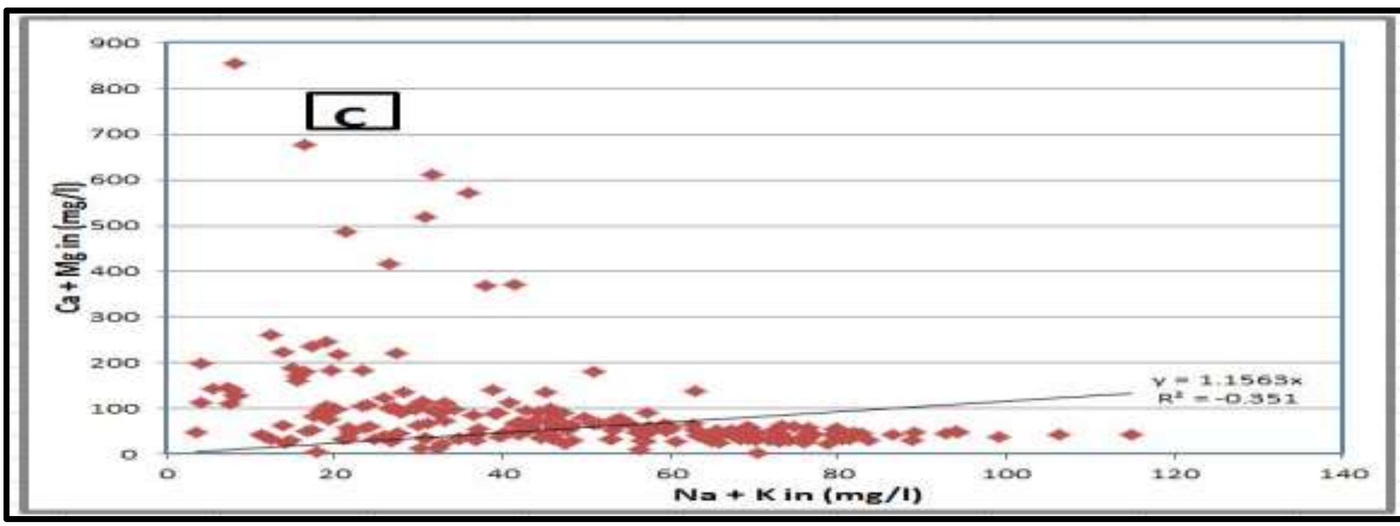


Figure 56; Graphical (scatter plot) distribution of (Na + K) and (Mg + CA)

6.2.3 Major Anions

6.2.3.1 Chloride ions (Cl-)

Most chlorine occurs as chloride (Cl-) ions in solution. It enters surface waters with the atmospheric deposition, with the weathering of some rocks, mostly rock salt deposits, and from industrial and sewage effluents, and agricultural and road run-off. As chloride is frequently associated with sewage, i often incorporated in to assessments as an indication of possible contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies.

In the investigated area the chloride concentration ranges from 4.69mg/l at akaki well (SWAWF4A) to 157.2mg/l Kotebe Hanamariam well (KHPW-1). High chloride concentration found in the upstream side of the area (kotebe) which is 157.2 mg/l. And the minimum values existed at downstream of the area (akaki well fields).For WHO, maximum acceptable level of chloride is 250 mg/l and that of Ethiopian drinking water standard is 533 mg/l. In the investigated area, the chloride concentration of the area for groundwater is under range of the limit of the standard. The water in all wells was suitable for drinking purposes.

6.2.3.2 Nitrate (NO3)

Nitrate commonly used as a quality indicator of potential contamination of groundwater. The content of nitrates not related to the rock composition (type) but it reflects pollution of groundwater by human and/or animal waste. Also nitrate pollution in groundwater may originate from several different sources, including point source pollution (such as industrial pollution and intensive animal husbandry) and non-point source pollution (such as fertilizers, fungicides, atmospheric deposition. minimum nitrate concentration recorded is 0.005mg/l at Gurara kidane mihret well (GKPW-01-16) and higher which is 50.26 mg/l at Sansuzi Asko site (SAPW-1).

High nitrate concentration levels indicate contamination from municipal wastes. As the WHO recommended maximum limit for drinking water is 10 mg/l of NO3- Water with higher concentration of represents a significant health risk.

6.2.3.3 Fluoride (FL^-)

Fluoride exists abundantly in the earth's crust originates from the weathering of fluoride containing minerals and enters surface waters through run-off and groundwater through natural processes. Liquid and gas emissions from certain industrial processes can also contribute fluoride ions (F-) to water bodies.

Fluoride mobility in water depends, to large extent, on the Ca2+ ion content, since fluoride forms low solubility compounds with divalent cations. This infers that fluoride levels can related to changes in calcium concentration. Other ions that determine water hardness can increase F- solubility. According to *Hem (1992)*, rocks rich in alkali metals and obsidians are higher in fluoride content than most other igneous rocks. Besides, he noted that fluoride often is associated with volcanic or fumarole gases. In the study area, these are true because, acidic volcanic rocks such as ignimbrites, rhyolites, pumice, pyroclastic deposits are the dominant lithological units. WHO standard for fluoride 1.5 mg/l and that of Ethiopian drinking water standard is 3.0 mg/l (JICA, 2013).

In The study area the overall spatial variations of fluoride levels ranges from 0.05mg/l for akaki well (SL-PW-21) to 7.8mg/l at Gurara kidane mihret (GKPW-01-16) and leghare well (LPW-01-17) Very high levels of fluoride concentrations is indicated or recorded at south western of the catchment specially pocket area and small parts of akaki well fields

The ground water wells which has fluoride concentration values exceeding the Ethiopian guideline (3.0mg/l) are listed as South Ayat North Fenta prospective area (SANF-PW14), Akaki Kality Sub City SL-PW-30, Akaki Kality Sub City (SL-PW-17), legetafo legedadi around sendafa well LLA-PW7, ayat fenta (SANF-PW18), ayat fenta (SANF-PW18), Gurara Kidane mehret well (GKPW-01-16), Leghare (LPW-01-17) arranged as increasing trends 3.24, 3.25, 4.07, 4.24, 4.66, 7.78,7.8 mg/l respectively (Table;21)

In the area the fluoride data analysis result shows that it is generally The occurrences of high fluoride level in groundwater associated with pyroclastic deposits specially ignimbrite. In addition, downstream of the catchment including akaki well fields the scoriaceous basalt has also high fluoride level this may occurs due to transported from the upper pyroclastic deposit area.

Measurement of fluoride content is especially important when a water body used for drinking water supply. At high levels, fluoride is toxic to humans and animals and can cause bone diseases. However, a slight increase in natural concentration can help prevent dental caries although, at high concentrations (above 1.5-2mg/l), mottling of teeth can occur (WHO, 1984b). High fluoride levels provide a constraint on the use of groundwater for potable supply. Once encountered, fluoride levels are unlikely to change with time.

Well Index	Long.	Latt.	Altti.(m)	WD(m)	Fl. (mg/l)	Aquifer Material
SANF-PW14	481129	989896	2236	460	3.24	Ignimbrite
SL-PW-30	478528	973384	2113	533	3.25	Ignimbrite & s. basalt
SL-PW-17	474733	973382	2078	501	4.07	scoriaceous basalt
LLA-PW7	499253	1006931	2510	378	4.24	Ignimbrite & basalt
SANF-PW18	485313	984138	2270	550	4.66	Ignimbrite
GKPW-01-16	477067	1001053	2573	500	7.78	Ignimbrite
LPW-01-17	476287	1000116		409	7.8	Ignimbrite & s. basalt

Table 21; maximum fluoride concentration exceeding both WHO and Ethiopian guideline

Location	South Ayat N F	South AN F	South Ayat N F	WHO Standard (mg/l)
Lab ID No.	911/2008	912/2008	913/2008	
Turbidity(NTU)	Trace	Trace	Trace	5
Total Solids 1050c(mg/l)	676	472	492	-
T. Dissolved Solid 1050c	672	468	488	1000
Electrical Conductivity(µS/cm)	984	810	798	__
PH	7.45	7.44	7.47	6.5-8.5
Ammonia(mg/l NH3)	0.35	0.033	0.031	__
Sodium(mg/l Na)	140	126	124	200
Potassium(mg/l k)	4.8	4.9	4.8	__
Total Hardness(mg/l CaCo3)	196.8	187.2	184.8	500
Calcium(mg/l Ca)	49.92	48	44.16	200
Magnesium(mg/l Mg)	17.28	16.13	17.86	150
Total Iron(mg/l Fe)	0.06	0.07	0.09	0.3
Manganese(mg/l Mn)	Trace	Trace	Trace	0.1
Fluoride(mg/l F)	0.82	0.071	0.75	1.5
Chloride(mg/l Cl)	28.92	32.54	34.35	250
Nitrate(mg/l No3)	4.09	7.68	8	45
Alkalinity(mg/l CaCo3)	344	360	352	__
Carbonate(mg/l CO3)	Nil	Nil	Nil	__
Bicarbonate(mg/l HCO3)	419.68	439.2	429.44	__
Sulphate (mg/l SO4)	159.341	9.26	9.36	400
Phosphate(mg/l PO4)	1.6	1.49	1.14	_
Aluminu(mg/l Al)	Trace	Trace	Trace	
Copper(mg/l)	Trace	Trace	Trace	1.5
Chromium(mg/l Cr)	Trace	Trace	Trace	0.05
Molibidium(mg/lMo)	Trace	Trace	Trace	0.07

Table 22; chemical analysis results of (SANF-PW12) well and WHO standard of water samples.

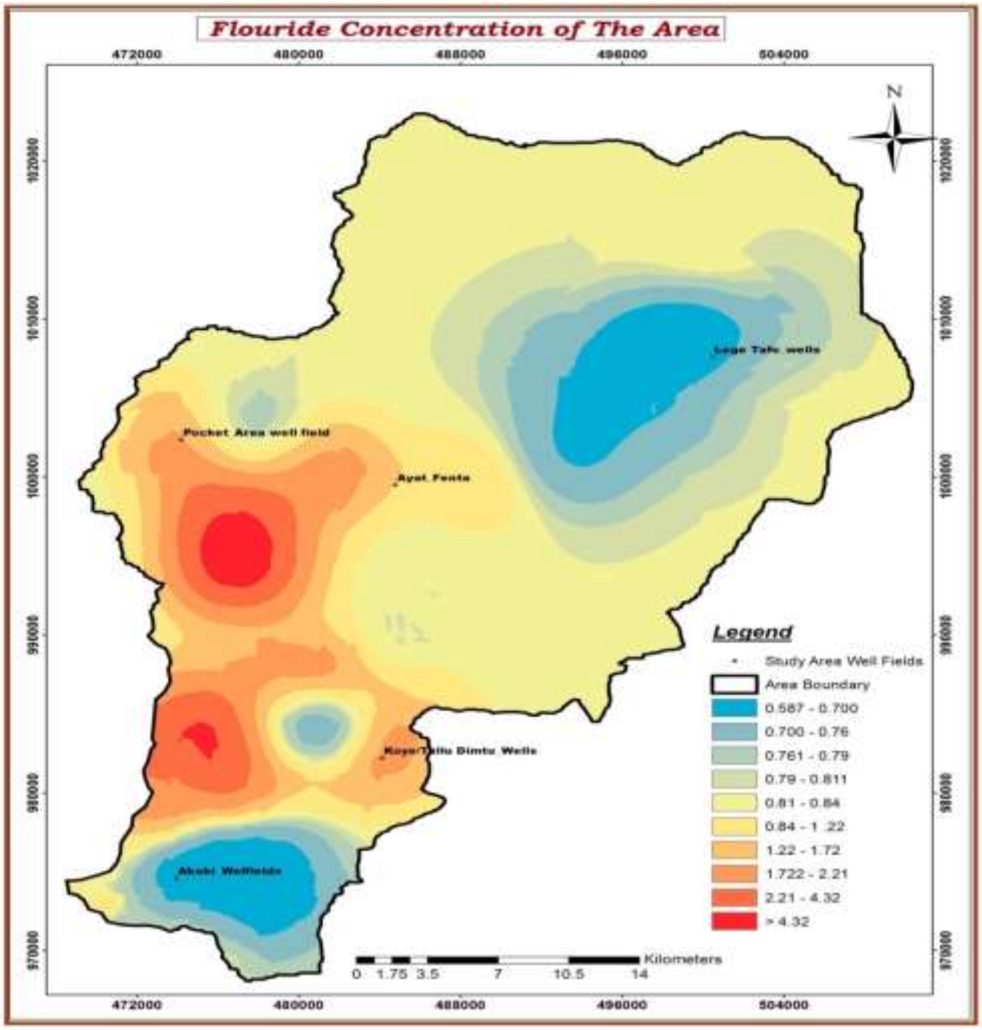


Figure 57; Spatial variation distribution map of fluoride (f-) concentration in (mg/l) measured from point data

6.2.3.4 Iron (I)

Like other chemical concentrations Iron is a concerning chemical in water supplies. Making up at least five percent of the earth's crust, iron is one of the earth's most plentiful resources. Rainwater as it infiltrates the soil and underlying geologic formations dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for wells, (*W. Jefferson St. 2010*), the iron concentration for WHO guideline is to 0.3mg/l. Although it presents in drinking water, iron is occasionally found at concentrations greater than 0.3 milligrams per liter (mg/L) to 10 parts per million. However, as this study area case iron levels exceeds (0.6mg/l) at Kotebe Dehininet site (DCPW-2). Other than this well all wells which found at this catchment iron ranges from 0 to 0.3 mg/l.

Iron is mainly present in water in two forms: either the soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colorless because the iron completely dissolved. When exposed to air in the pressure tank or atmosphere, the water turns cloudy and a reddish brown substance begins to form.

The sediment composed of iron is oxidized or ferric form of iron that will not dissolve in water**.** Iron considered a secondary or visual contaminant. Essential for good health, iron helps transport oxygen in the blood. Most tap water in the United States supplies approximately 5 percent of the dietary requirement for iron.

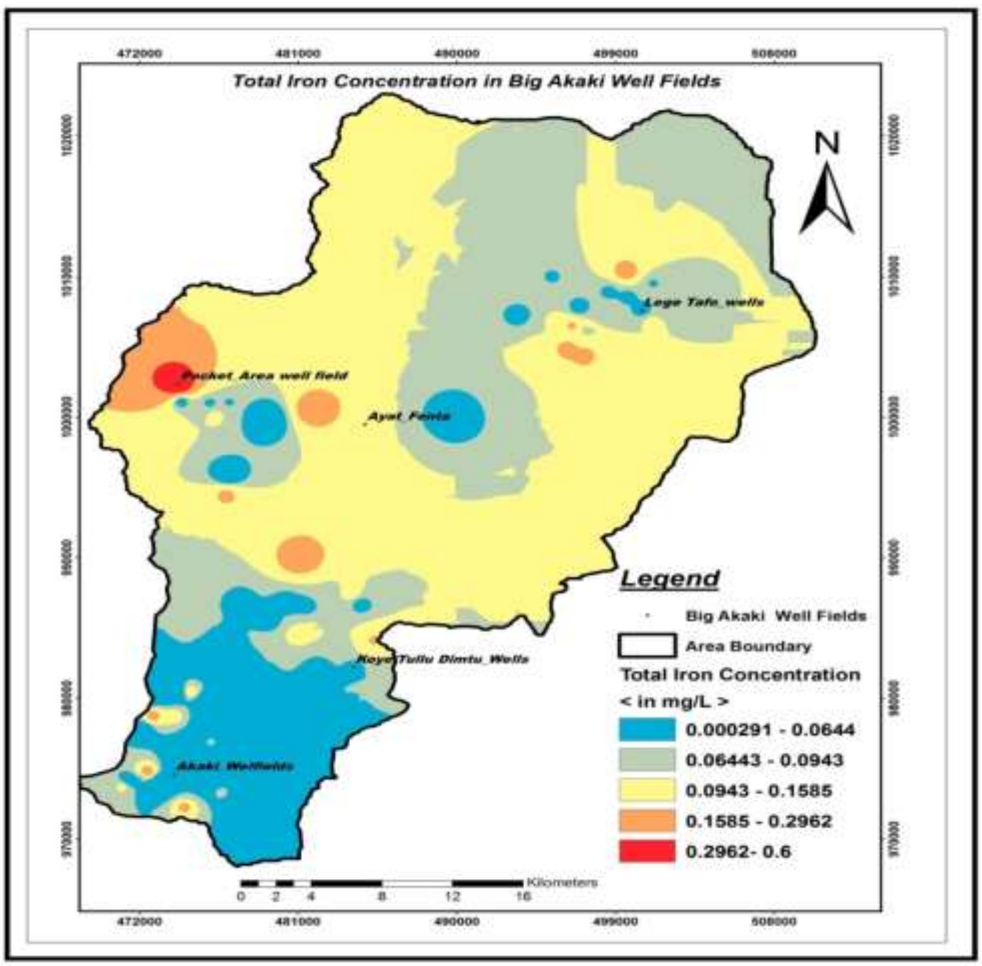


Figure 58; Total Iron concentration spatial distribution map of the catchment measured from point data

6.3.1 Hydro geochemical facies and general water quality diagrams

Hydro geochemical properties of the GW attributed to the Groundwater resident time, lithology, geology, and water regional flow pattern (*Alsuhaimi et al., 2019*). Hydrochemical facies utilized to analyze the chemical composition of Grounwater and illustrate the origin and chemical water types (*Othman, 2005*). General water quality diagrams are an appropriate method to describe the water types according to the ionic composition (*Adimalla & Venkatayogi, 2018*). According to the ratio of anion and cation concentrations in the GW, usually classified into three main groups, namely bicarbonate, sulfate, and chloride types (*Alsuhaimi et al., 2019*). Aquachem (4.0) software is widely used to analyze, plot, and report aqueous geochemistry and water quality of the GW supply wells. General distribution anions and cations in the GW is illustrated by a Piper diagram. The hydro geochemical plots Piper, Schoeller, Durov, Ternary, and Ludwig Langelier plots respectively. These diagrams provide a “fingerprint” by plotting the common cations and anions. These diagrams allow visualize the position of cations , anions and characterization of general water quality

6.3.1.1 Piper plot

Piper plots (also known as tri-linear diagrams) are very powerful tools for visualizing the relative abundance of common ions in water samples. permits the cations and anions composition of many samples to be represented on a single graph in which the data can be separated visually and also showing the effects of mixing two or more waters from different sources.

It displays the relative concentrations of the major cations and anions on two separate tri-Linear plots, together with a central diamond plot where the points from the two tri-Linear plots are projected. Diamond-shaped field (quadrilateral field) is used to show overall chemical character of the water. Calculate the percentage milli equivalent and milligram per litter of anions and cations respectively, combining Ca^+ , Cl^- , HCO_3^-.Piper diagram using Aquachem computer software was employed to identify the groundwater type.in this case the graph shows.

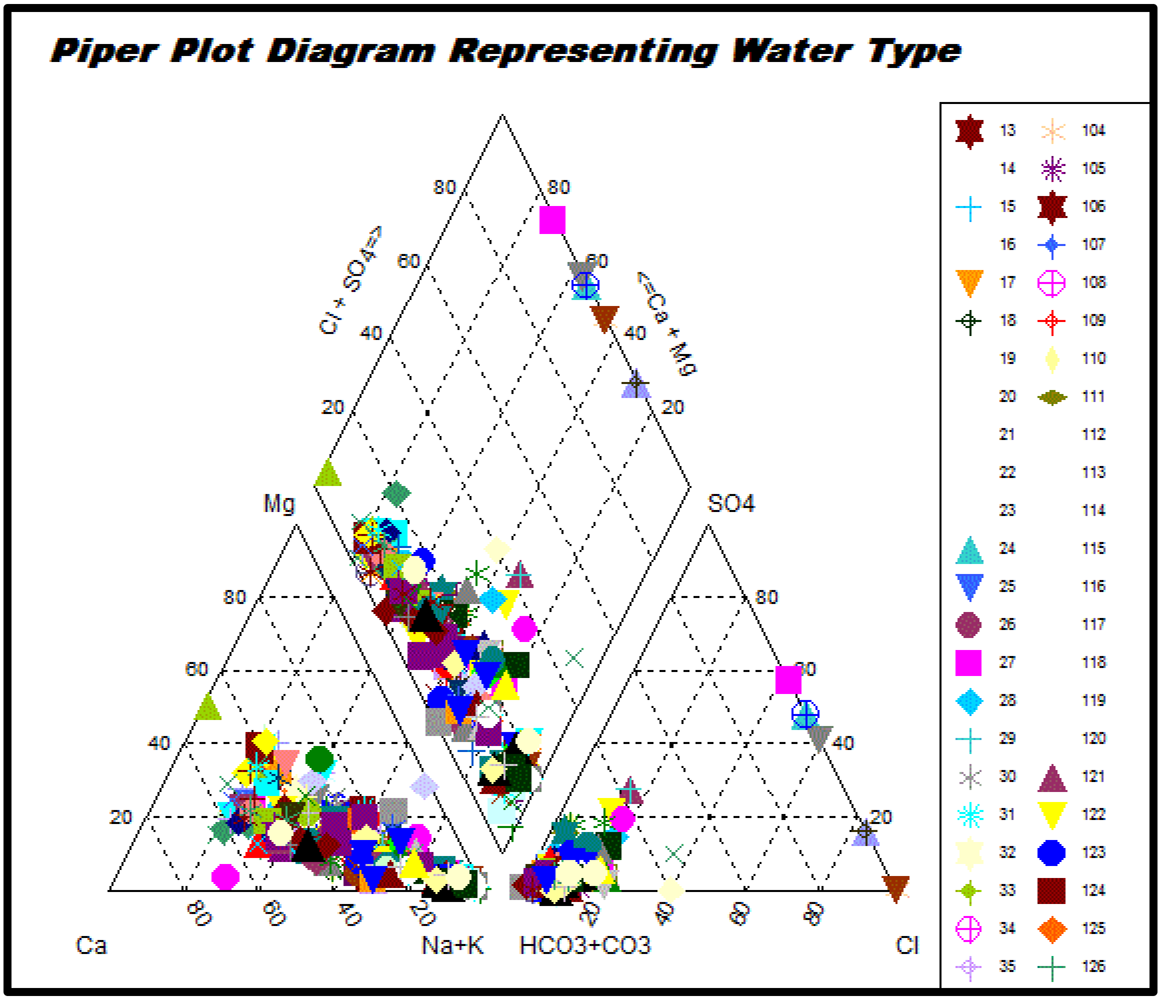


Figure 59; the piper plot diagram of the groundwater quality in big akaki river catchment

6.3.1.2 Water Types

Water Types classification of the samples collected from all sources made to observe the major water groups, their relationship and evolution along the flow path by using a graphical method. The piper diagram is the most widely used graphical form. The diagram displays the relative concentration of the major cations and anions on two separate tri- linear plots, together with a central diamond plot where the points from the two-tri-linear plots are projected.

The ion concentration in most of the water samples is dependent on elevation, lithology, structures and climatic conditions. Lithology of the area has a significant effect on the concentration of chloride, sulfate and sodium. The presence of high Concentration of chloride, sulfate and sodium shows a complex process of rock-water interaction and ion exchange. The predominant water types in Ethiopia based on the dominant anions that are bicarbonate, sulfate, and chloride types (*Tesfaye 1993*).

In general, the classification of water types of the area by using Aqua-chem software analysis is produced are then their distribution map generated as follows based on (arc map. 10.3 Software)

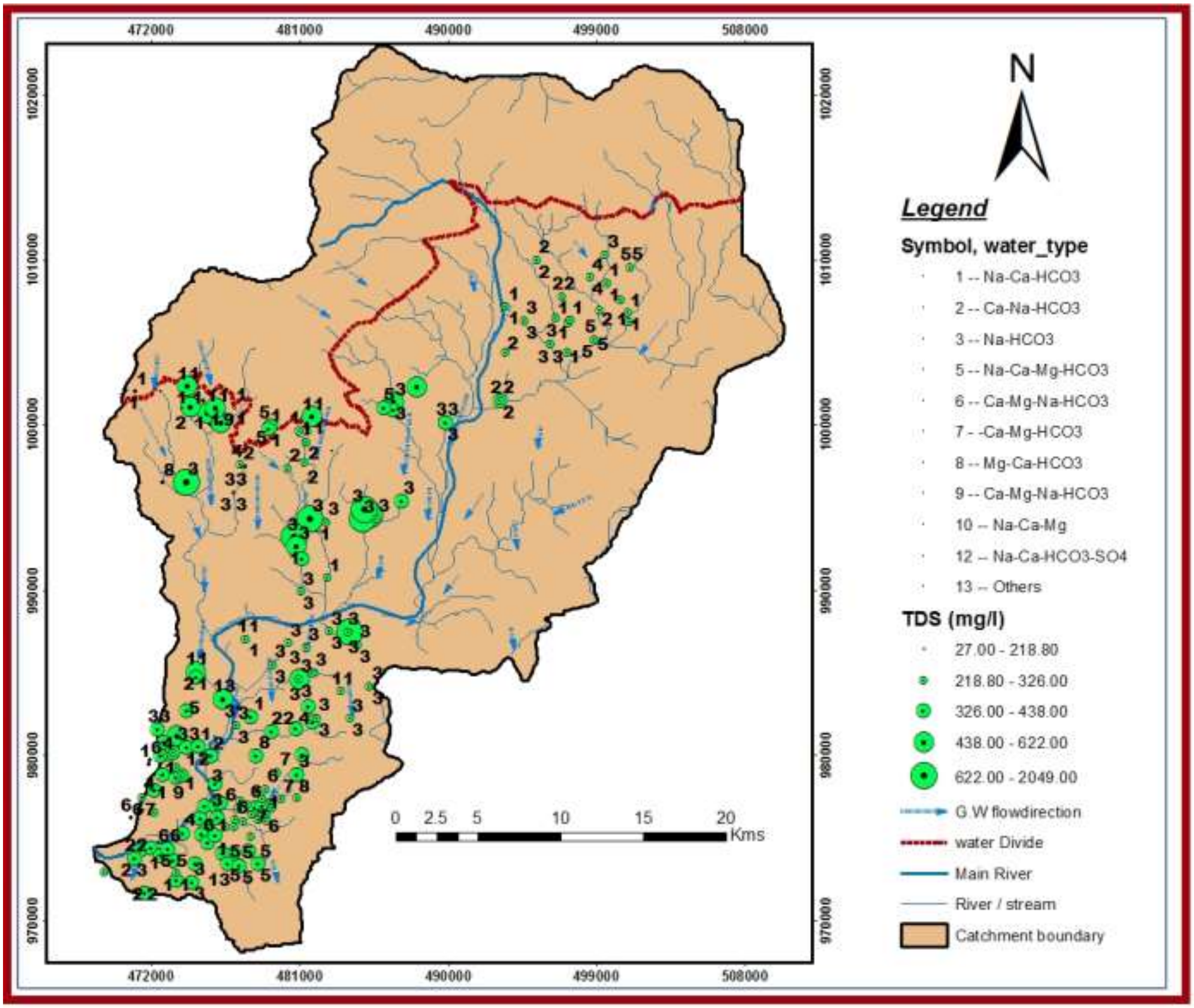


Figure 60; Groundwater quality water type and TDS distribution map of the catchment

Well Index	LONGITUDE	LATTITUDE	ALTITUDE(m)	Water Type	GEOLOGY
24KPW-01-17	477052	995894	2351	Na-HCO3-CO3	Basalt & rhyolite
BHSPW-01-17	476933	994457	2334	Na-HCO3	Basalt &ignimbrite
GKPW-01-16	477067	1001053	2573	Na-Ca-HCO3	T. baslt and ignimbrite
LPW-01-17	476287	1000116		HCO3	Basalt &ignimbrite
F1PW-01-16)	475466	1000729	2516	Na-Ca-HCO3	Basalt &ignimbrite
F2PW-01-16	475976	1001005	2515	Na-Ca-HCO3	Basalt &ignimbrite
H19PW-01-16	474402	1001122	2515	Na-Ca-HCO3	Basalt &ignimbrite
KGPW-01-16	474716	985017	2515	Na-Ca-HCO3	Basalt &ignimbrite
SPW-01-16	476370	983392	2054	Na-HCO3	Basalt &ignimbrite
KPW-1	474203	1002351		Na-Ca-HCO3	ignimbrite
KHPW-1	481763	1000506		Na-Ca-HCO3	ignimbrite
KDPW-1	479316	999941	2465	Na-Ca-Mg-HCO3	Basalt &ignimbrite
KDPW-2	479175	999755	2543	Na-Ca-HCO3	Basalt
SL-PW-03	475288	976908		Na-HCO3-Cl	Basalt
SL-PW-04	476037	976861	2643	Na-Ca-Mg-HCO3	Basalt &ignimbrite
SL-PW-05	475058	976100	2711	Ca-Mg-Na-HCO3	Basalt &ignimbrite
SL-PW-07	476098	976183		Na-Ca-HCO3	Basalt &ignimbrite
SL-PW-08	475528	975585	2058	Ca-Na-Mg-HCO3	Basalt &ignimbrite
SL-PW-09	475128	975184	2068	Ca-Mg-Na-HCO3	Basalt
SL-PW-10	473954	975244	2062	Ca-Na-Mg-HCO3	Basalt &ignimbrite
SL-PW-11	471453	974241	2055	Na-Ca-HCO3	Basalt
SL-PW-13	472078	974359	2056	Na-Ca-HCO3-SO4	Basalt
SL-PW-14	472640	973882	2068	Na-Ca-HCO3-SO4	Basalt &ignimbrite
SL-PW-15	473428	973584	2053	Na-Ca-Mg-HCO3	Basalt &ignimbrite
SL-PW-17	474733	973382	2048	Na-Mg-Ca-HCO3	Basalt
SL-PW-18	477023	973986	2046	Ca-Na-Mg-HCO3	Basalt
SL-PW-19	476375	974046	2050	Ca-Mg-Na-HCO3	Basalt &ignimbrite
SL-PW-21	477959	974168	2072	Na-Ca-Mg-HCO3	Basalt
SL-PW-22	475507	974679	2078	Na-Mg-Ca-HCO3	Basalt
SL-PW-24	475941	975137	2069	Na-Ca-HCO3	Basalt &ignimbrite
SL-PW-25	473071	974284	2078	Ca-Mg-Na-HCO3	Basalt &ignimbrite
SL-PW-30	478528	973384	2087	Na-Ca-Mg-HCO3	Basalt &ignimbrite
SL-PW-32	476717	973370	2112	Na-Ca-Mg-HCO3	Basalt
SL-PW-33	477434	973280	2103	Na-Ca-Mg-HCO3	Basalt
WF01-PW2	474204	980459	2070	Na-HCO3	Basalt
WF01-PW3	474918	980486	2064	Na-Ca-HCO3	Basalt
WF02-PW10	474558	972286	2060	Na-HCO3	Basalt &ignimbrite
WF01-PW15	473944	978720	2113	Ca-Na-HCO3	Basalt
WF01-PW16	473386	980122	2111	NH4-HCO3	Basalt
SWAWF1R	475945	978251	**2112**	Mg-Na-Ca-HCO3	Basalt
SWAWF2	475697	979915	2077	Ca-Na-HCO3	Basalt
SWAWF3	471027	973709	2081	Na-HCO3	Basalt
SWAWF4B	472836	980785	2061	Ca-Na-HCO3	Basalt
LLA-1	493247	1001478	2112	Ca-Na-HCO3	Basalt
LLA-2	489927	1000153		Na-HCO3	Basalt
LLA-3	496269	1004908	2065	Na-HCO3	Basalt &ignimbrite

LLA-4	498961	1005177	2060	Na-Ca-Mg-HCO3	Basalt &ignimbrite
LLA- 5	497374	1006185	2062	Na-Ca-HCO3	Basalt &ignimbrite
LLA-6	497470	1006388	2054	Na-Ca-HCO3	Basalt &ignimbrite
LLA-PW1	497270	1004423	2180	Na-Ca-HCO3	Basalt
LLA-PW3	500497	1007598	2180	Ca-Na-HCO3	Basalt
LLA-PW4	494679	1006306	2399	Na-HCO3	Basalt
LLA-PW5	496568	1006495	2349	Na-Ca-HCO3	Basalt &ignimbrite
LLA-PW7	499253	1006931	2444	Ca-Na-HCO3	Basalt
LLA- PW 11	500982	1006789	2250	Na-Ca-HCO3	Basalt
LLA - PW 8	496944	1007787	2470	Ca-Na-HCO3	Basalt &ignimbrite
LLA - PW 10	501115	1009538	2280	Na-Ca-Mg-HCO3	Basalt
LLA PW 16	499607	1010323	2476	Na-HCO3	Basalt
LLA - PW 19	498657	1008943	2515	Ca-Na-Mg-HCO3	Basalt
LLA - PW 20	493561	1007179	2492	Na-Ca-HCO3	Basalt
LLA – PW12	495420	1009986	2487	Ca-Na-HCO3	Basalt
SANF – PW1	481952	984973	2510	Na-HCO3	Basalt &ignimbrite
SANFTW-1	477819	987018	2497	Na-Ca-HCO3	Basalt &ignimbrite
SANFTW-2	484001	987465	2527	Na-HCO3	Basalt &ignimbrite
SANFPW2	481883	984954	2527	Na-HCO3	Basalt &ignimbrite
SANF-PW3	482119	982234	2540	Na-HCO3	Basalt
SANFTW-3	481012	984597	2540	Na-HCO3	Basalt &ignimbrite
SANF – PW4	477224	981760		Na-HCO3	Basalt
SANF – PW5	479454	985457	2531	Na-HCO3	Basalt
LLA-PW6	499681	1008600	2531	Na-Ca-HCO3	Rhyolite and basalt
SANF-PW7	480385	986784	2515	Na-HCO3	Rhyolite and ignimbrite
SANF – PW09	481467	986506		Na-HCO3	Basalt &ignimbrite
SANF-PW11	482852	987470		Na-HCO3	Basalt &ignimbrite
SANF-PW12	483560	983856		Na-Ca-HCO3	Basalt &ignimbrite
SANF-PW14	481129	989896	2206	Na-HCO3	Basalt &ignimbrite
SANF – PW16	484553	986685	2277	Na-HCO3	Basalt &ignimbrite
SANF-PW18	485313	984138	2192	Na-HCO3	Basalt &ignimbrite
SANF – PW21	484142	982196		Na-HCO3	Basalt &ignimbrite
BH1R	478074	975053	2185	Ca-Na-Mg-HCO3	Basalt
BH26R WELL	472446	974756	2511	Ca-Na-HCO3	Basalt &ignimbrite
WF01-PW4	475585	977958	2204	Na-HCO3	Basalt
WF01-PW7	471898	979463		Na-Ca-HCO3	Basalt
WF01-PW11	472245	977865	2220	Na-Ca-HCO3	Basalt
WF01-PW14	470778	976165	2240	Ca-Mg-Na-HCO3	Basalt
WF01-PW12	471476	977396	2236	Ca-Na-Mg-HCO3	Basalt
WF01-PW8	472779	978788		Na-Ca-HCO3	Basalt
WF01-PW18	471918	979657	2270	Ca-Mg-Na-HCO3	Basalt
WF01-PW17	472460	981553		Na-HCO3	Basalt
WF01-PW6	472630	979912	2543	Ca-Na-Mg-HCO3	Basalt
WFO1-PW20	471027	973709		Ca-Na-HCO3	Basalt

Table 23; ground water types of the wells with respective lithology

6.3.1.3 Sources of Salinity

Groundwater contains salts in solution. The types of salts depend on the geological environment, the source of the groundwater, and its movement. The weathering of primary minerals and rocks is the direct source of salts in groundwater. Bicarbonate (HCO3) is usually the primary anion in groundwater and forming because of the solution of carbon dioxide in water

Sodium in water originates from the weathering of feldspars (Albite), clay minerals, and the solution of evaporates (halite). Evaporates are also the major natural source of chloride in groundwater, while sulfate originates from the oxidation of supplied ores or the solution of gypsum and anhydrite. Such primary minerals as amphiboles (hornblende), apatite, fluorite, and mica are the sources of fluoride in groundwater. Hence, most of the wells in the catchment have positioned at the salinity ranges (200 – 800) that mentioned as medium salinity recorded.

Groundwater quality also related to the relief of the area. Fresh groundwater usually occurs in topographic highs which, if composed of permeable materials, are areas of recharge On its way ,SAR values is out of range at one locality with the value of 15.04 meq/l. For TDS (Total Dissolved Solid) the concentration of all the eight samples are within the range of standard.

High concentration of sodium are undesirable in water because sodium adsorbs in the soil cations exchange sites causing soil aggregate to break down de-flocculation ,sealing the pore of the soil and making it impossible water flow the tendency of sodium.

To increase its proportion on the cations exchange site at the expense of other types of cations is estimate by the ratio of sodium content to the content calcium, magnesium in the irrigation water. This called sodium adsorption ratio (SAR) according to (*Thakur, 2001*).

Designation (meq/l)	Water Quality
< 10	Ideal/ Excellent
10 - 18	Good
18 - 26	Doubtful
>26	unstable

Table 24; Standard of SAR in water quality

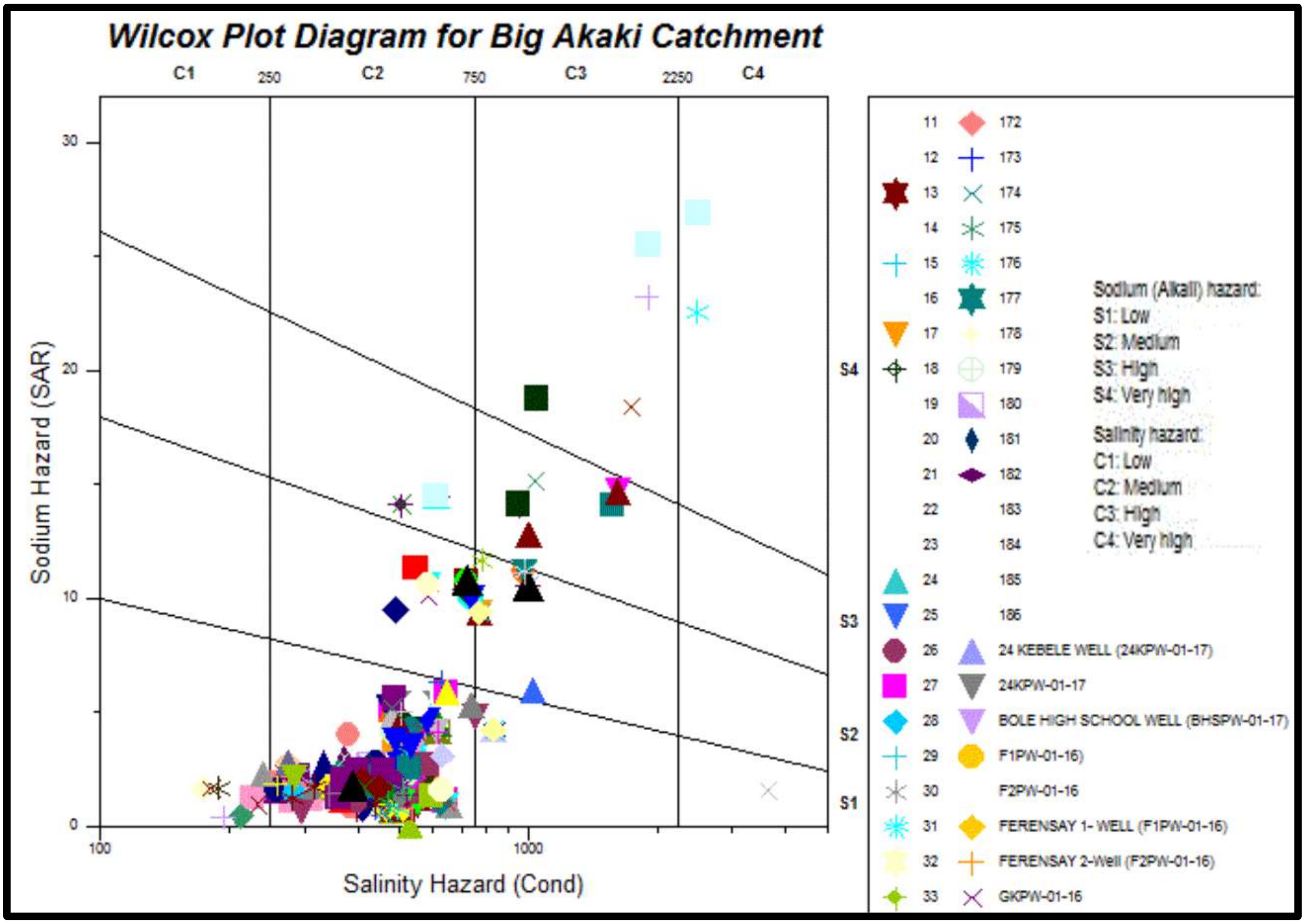


Figure 61; Wilcox diagram for SAR (sodium absorption ratio) and salinity hazard ranges in the catchment

The maximum distribution results in the graph for the sodium hazard situated *s1* that indicates that the sodium hazard is lower and excellent for irrigation purpose. In addition, some of the wells are located at medium and high specially (well id: SL-PW19, BH 26R, 24PW-01-07, KPW-1 and SLPW-25) SAR ranges that are good for irrigation.

6.3.1.4 Hydro-Geochemical Evolution

The geochemical data of dissolved major and minor constituents in the groundwater samples indicates the main processes responsible for the geochemical evolution are; Minerals weathering process and dissolution of bicarbonate minerals characterized by high loadings of Na, CA, and Mg ions. Using the Shlumberger Aquachem14.1 software, water quality analyzed as a results of piper diagrams for water source pattern identifications of the general water type for the groundwater also indicated as follows Ca-Mg-Na-HCO3,Ca-Na-HCO3,Ca-Na-Mg-HCO3,Na-Ca-HCO3,Na-Ca-Mg-HCO3,Na-HCO3,Na-HCO3-CO3,Na-Mg-CaHCO3,Na-Mg-Ca-HCO3.

The dominant water type that takes vast coverage of an aquifer at the investigation area is sodium bicarbonates (Na-HCO3) and sodium, calcium bicarbonates (Na-Ca-HCO3) water. The water type shows some extent of anion evolution but the cations are in early stage of evolution. The path of evolution is as follows. CA Mg Na HCO3 + SO4 SO4+HCO3 SO4 +CL Cl+SO4 CL

General groundwater within the catchment principally evolves from Na-Ca-HCO3 type water into Ca-Na-HCO3 type water into Na-HCO3 type water into Na-Ca-Mg-HCO3 type water into Ca - Mg-Na-HCO3 type water into Ca-Mg-Na-HCO3 type water into Na-Ca-HCO3-SO4 Type water along its flow path due to ion-exchange reactions and therefore, largely characterized by recharge processes through mixing with waters of geochemically different.

Main cause of geochemical evolution in the study area is dissolution of bicarbonate and sulfate minerals in the akaki catchment and leaching of the industrial wastages agricultural fertilizers and by other artificial and natural conditions making the groundwater may susceptible for contamination.

In unconfined groundwater aquifers water analysis from downstream show both CL- type and HCO3 type which implies the presence of mixing of fresh water most likely due to recharge from the river and flooding. Direct recharge from precipitation has no significance, as it is almost equal to the AET. Accordingly, the groundwater chemistry shows significant variation throughout those aquifers. Additionally, groundwater of an area is affect by climatic conditions.

The hydrochemistry of shallow aquifers on the unconsolidated sediments dominated by climatic effect while the deep fractured aquifers dominated by lithological effect. In the study area the chemical evolution, show a major ion change process along flow path. From piper plot diagram the evolution, sequence shows change is as follows.

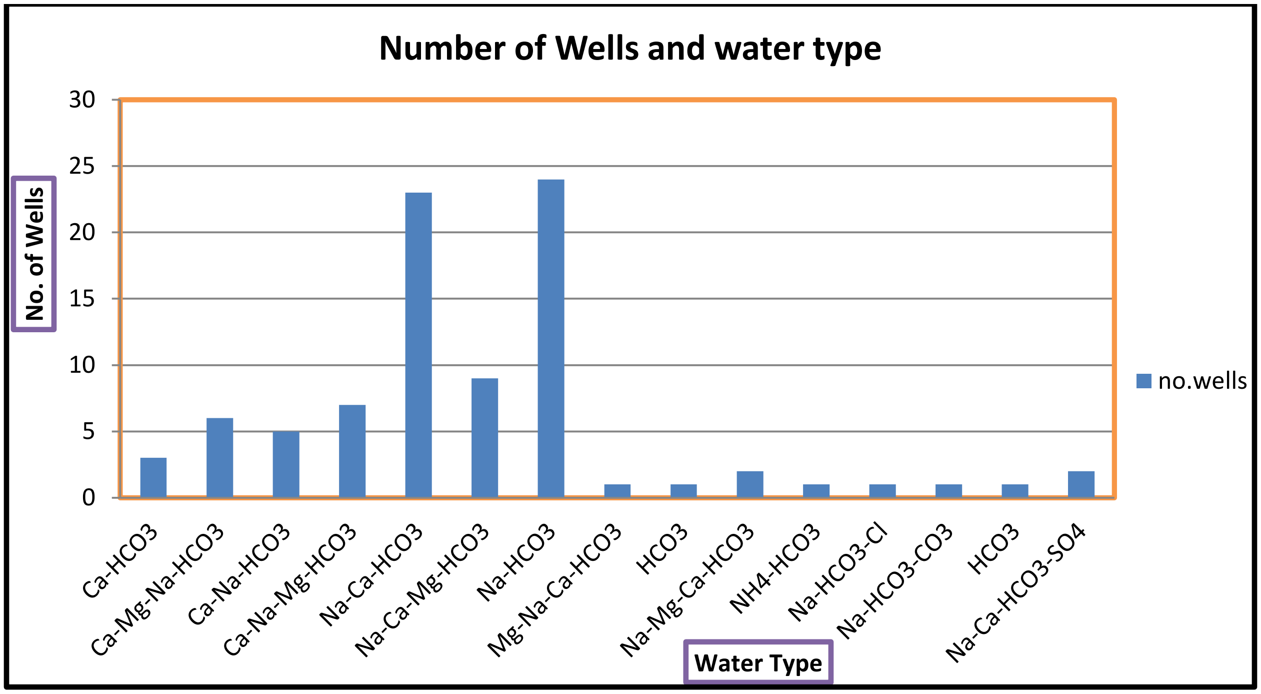


Figure 62; number of wells and water types

Location	***WHO Standard (mg/l)***	***Ethiopian st.(mg/l)***
Turbidity(NTU)	5	
Total Solids 1050c(mg/l)	-	
T. Dissolved Solid 1050c	1000	1000
Electrical Conductivity(µS/cm)	__	_
PH	6.5-8.5	6.5 - 8.5
Ammonia(mg/l NH3)	__	1.5
Sodium(mg/l Na)	200	200
Potassium(mg/l k)	__	
Total Hardness(mg/l CaCo3)	500	300
Calcium(mg/l Ca)	200	75
Magnesium(mg/l Mg)	150	50
Total Iron(mg/l Fe)	0.3	0.3
Manganese(mg/l Mn)	0.1	0.5
Fluoride(mg/l F)	1.5	1.5
Chloride(mg/l Cl)	250	500
Nitrate(mg/l No3)	45	50
Alkalinity(mg/l CaCo3)	__	200
Carbonate(mg/l CO3)	__	_
Bicarbonate(mg/l HCO3)	__	_
Sulphate (mg/l SO4)	400	250
Phosphate(mg/l PO4)	_	_
Aluminu(mg/l Al)		0.2
Copper(mg/l)	1.5	
Chromium(mg/l Cr)	0.05	0.05
Molibidium(mg/lMo)	0.07	_

Table 25; comparisons for WHO (current) Vs. Ethiopian water quality standard (2013) for drinking purpose

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusion

The study for aquifer characterizations of the study area manipulated by using hydrology, geology, hydrogeology and hydrochemistry approaches. These results discussed below;

Geomorphology of the study area plays a great role in defining the surface and Groundwater movement and accumulation that regards to the structures availability used to develop or forming the aquifer system. The structures that are distributed and occurred in the catchment area were like lineament, joint, fractures and faults; these are the main conduit for the water to move through the groundwater system.

Hydrology of the area assessed and estimated by the meteorological variables that are characterized the entire catchment. The climate condition of the area is bimodal type (two season) of rainfall and it varies from highland to lowland, as the highly elevated area has high precipitation and lowland has low aerial precipitation this is true for the study area the maximum annual rainfall recorded at (1177.7mm/yr.) at Entoto and (869.9mm/yr.) at akaki. The recharge is estimated by two approaches those are includes soil water balance and hydrograph separation methods. Hence, the result of ground water recharge implies that high recharge recognized with low (minimum runoff) in the study area.

The geology of the area is one of the types of main Ethiopian rifts(pre, sync and post rift) volcano that composed of basalt, rhyolite, ignimbrite, trachyte, scoria, tracky basalt etc. these lithologies has difference in age , area coverage , degree of weathering, fracturing , mineral composition, way of formation ,ground water availability or occurrence , movement and distribution. In this case, the groundwater occurrence classified according to the lithology and hydraulic parameter variations of the aquifer system.

The Regional Geology information obtained from different literatures including Ethiopian geology books. Moreover, they classified as different major rock unit includes; Ashange formation, Aiba basalt, Alaji formation, Tarmaber formation and Nazareth unit. These formations exposed as regionally through basin.

There are Cenozoic continental flood basalt and composed of olivine and pyroxene reach mafic and acidic rocks. These volcanic flows are mostly basalts and rhyolite.

Whereas local geology of the area, akaki basalt, Addis Ababa basalt, Entoto becho rhyolite and chefe donsa unit. The akaki unit is contains two types of volcanic products namely (Phyric basalt lava flows (NakB) and scoria fallout/cones). It exposed in central to southern parts of the study area.

The Addis Ababa basalt formation is outcropped to the central northwest part of the map area it consists of fine grained to olivine -pyric alkaline basalt, olivine basalt and trachybasalt (NadB). In most places it is compact and fine-grained rock but in places, it shows vesicular cavity filled with or without secondary mineral.

The Addis Ababa Ignimbrite (Nadl) is outcropped in most part of the plane area around Addis Ababa and the Becho plane including lege tafo lege dadi area and sendafa town. It covers over 40 percent of an area, it is composed of welded tuff (ignimbrite) and non-welded phyroclastic fall (Ash and tuff. Entoto becho rock unit constitute rhyolite, trachyte, pyroclastic rocks and sediments (NebRy). It also contains obsidian reach formation; all the rocks are highly weathered and jointed with few layers of agglomerate at some places.

The structure found in the study area use as a conduit for the ground water to pass through, this structures are commonly oriented through different direction. The general faults trending are NE-SW, NW-SE and N-S direction observed in the study area. In addition, localized lineament structures occurred and follow the streamline that forms linear trending.

The majority wells penetrate through basalt and ignimbrite and some are through rhyolite, trachyte and pyroclastic materials, pumice, unwelded tuffs (ash) and making up the aquifer system variable in groundwater discharge, hydraulic features and structure of the well field. These aquifer units are existed as variable thickness, different degree of weathering and fracturing. The groundwater movement of these units are both through primarily and secondary porosity.

Intergranular aquifer unit has little bit high GW productivity than fissured aquifer unit these implies that the porous aquifers media also gain water from deep fissured aquifer unit specially basalt. Additionally the increasing of this productivity at this units is because of the fissured unit underlain highly fractured and has high permeability.

High lineament structure density that found at recharge area may imply there is high ground water recharge and lineament density at the discharge area indicates there structures which has economically potable groundwater sources.

The aquifer yield is higher at upper part of the catchment especially at legetafo and sendafa areas this may not only because of phyroclastic but also because of highly fractured basalt that overlain by phyroclastic material particularly ignimbrite unit.

Specific capacity of the catchment is higher through all depth at the akaki well fields these implies that the old akaki wells in the well fields which are find in this area are high specific capacity this may due to high discharge (yield) or low draw down.

By using the water chemistry data obtained from the completion reports the water quality standard for both WHO and Ethiopian standard compared and the result for in-situ parameters are analyzed and the exceeding results are recorded includes;

ph.-concentration varies at legetafo well fields, some part of pocket area and tullu dimtu well fields (8.45 – 9.32) , Tds amount is increased and beyond the standard includes the central part of catchment particularly at pocket area wells (fell wuha area) and part ayat fenta well fields that ranges (from 906 – 2200mg/l), these is also true for electrical conductivity(EC).

Accordingly, for the major cations and anions, described .hence from these cations of sodium added to potassium and result implies that their concentration exceeds both standards (who and Ethiopian at central part of the catchment. This may due to the basic rock (basalt, scoria etc.) groundwater specially interaction at the recharge area and transported through large cavities and fractures Cations involvement (Na +k) and (mg + CA) the spatial variation of general acidity and basicity of the catchment is designated.

Moreover, the central part of an area has higher concentration of Na + k (basicity) (197.9 – 676mg/l) the upper, moderate (106.18 – 197.9mg/l), and low (4.16 – 106.18mg/l). Additionally the acidity of the groundwater concentration higher (41 to 93mg/l) at akaki well fields this May Highly reactive metals are commonly present in this zone because very little groundwater flushing has occurred.

Both at upper part of the catchment (legetafo and sendafa area) and at akaki well field.

The increasing sodium in to groundwater is likely due to leaching of agriculture fertilizers near the study area In addition, the sources of potassium are likely due to silicate minerals, orthoclase, microcline, hornblende, and muscovite and biotitic in igneous deposits release considerable amount of potassium in to groundwater. **(***Sayyed and Arjun, 2011*) .

The fluoride concentrations of the catchment higher that a range from (2.21 to 7.8) (figure; 54), that is above the both WHO and Ethiopian standard detected at pocket area and akaki well fields. This may the contribution of the above acidic formations (especially pumice, ignimbrite and volcanic ash deposit).

7.2 RECOMMENDATIONS

The existing wells drilled in akaki well fields mostly shallow depth ranges from (10 – 200m) that is partial penetration of aquifer. This implies the water tapped from shallow aquifer zones rather than deep aquifer. Additionally the groundwater discharge is good to very good. However, know a days the drawdown is higher (groundwater level is depleted) averagely 20m depth and others becomes dry (according to field measurement and AAWSA monitoring information). The depth of the wells partial, full penetrations of aquifer has significant role in raising the water level head that has in thin and thick aquifer layer. Hence such consequence, the ground water tapped from dip aquifer the well yield may higher with a minimum draw down with a longer abstraction time.

The outputs of this study are significant in filling the gaps of previous works and determining the groundwater abstraction system and enhance the direction of groundwater management system.

The conceptualization of the aquifers has measure role in verifying the hydro stratigraphic unit sequences, lateral and vertical aquifer extensions and structural distributions of the catchment.

The fluoride concentration is more or less higher at some part of the catchment particularly central (are pocket area) to lower catchment (akaki and tullu dimtu) that ranges (2.21 to 7.8) (figure; 54). Hence, during ground water investigations and well field selection this contaminant case should be considering.

Generally, the application of detail aquifer characterization for a given area with the help of different approaches should appropriate particularly includes hydrology, Geology. Hydrogeology and hydrochemistry as a conceptual model in which that enhance the ground water system analysis and has much contribution for groundwater flow modeling and groundwater management system. Additionally aquifer characterization use general tool for understanding the groundwater system of a given basin.

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Annex

Well inventory data

well ID	X(m)	Y(m)	ELEV.(m)	W.DEPTH	Q(L/S)	T (m2/d	K	SWL	D. date	max.DD	SCl/s/m	SY l/s
(24KPW-01-17)	477052	995894	2351	468	8.5	23.2		83.5	42860	130.3	0.06523	6
(BHSPW-01-17)	476933	994457	2334	500	37.5	2.70E+1 n	0.173	62.8	42922	82.4	0.455	25
(LPW-01-17)	472456	995639	2379	500				ARSN				
(GKPW-01-16)	477067	1001053	2573	500	53	164	1.08	81.98	22-03-20	36.11	13.86	40
(IEPW-2)	476287	1000116		409	57	3.39x105	2570	95.3	42350	29.23	1.95	
(F1PW-01-16)	475466	1000729	2516	512	53	566	3.49	142.38	17-02-20	21.44	2.472	30
(F2PW-01-16)	475976	1001005	2515	500	39.5	870000	5800	153.2	42888	16.58		
GPW-01-16)	471925	990400	2212	382	66.2	0.00184(	1.8E-07	21.52	43010	33.63	176.69	
(H19PW-01-16)	474402	1001122	2515	505	53	1450	9200	136.57	14-10-20	14.94	3.547	40
(KGPW-01-16)	474716	985017	2515	480	69	3.46+2	2.66	12.2	28/10/20	15.85	4.353	60
(SGPW-01-16)	472585	982237	2083	537.37	15.5	30300	179	41.4	42624	147	0.1054	10
SPW-01-16)	476370	983392	2054	302				102	43071			
(DCPW-2)	463590	992116		432	50.6	108		80.1	38842	63.85	0.79	
KSPW-1)	484802	999482		500				225	41976			
(KMPW-01	422712	100256	2465	312	8	2.01	98.7	58.85	41993	52.13	0.07	
(KPW-1)	474203	1002351	2543	546.42	14.3	28.7	3.2E-06	158.02	41989	66.39	0.22	14
(KHPW-1)	481763	1000506		237	55	0.263		31.76	30/05/20	31.96	1.72	
(KDPW-1)	479316	999941	2643	271	50	446	5.58	118.36	41764	23.48	2.14	50
(KDPW-2)	479175	999755	2711	250	15	4.82	0.465	107.3	39116	45.7	0.34	15
MKPW-1)	470682	987316	2221	357	50	14	0.682	ASN	41646	141.22	0.354	50
MCPW-1)	466336	1000658		420	53	728		96.8	23/08/20	2.77	19.13	
(MCPW-2)	466841	1000105	2496	392	18	5.2x10-2	470	73.9	23/06/20	52.48	0.34	
(SAPW-2)	465819	100254		332	55.5	52.6	0.522	84.62	28/06/20	94.6	0.5	55
SBH-1)	469302	1001458		540.79	5	0.97	232	147	12/16, 20	67.9	0.074	5
TBH-1 site	470158	1001882	2543	505.8	32	45.3	0.308	61.65	10/3, 201	110.63	0.289	32
TBH-2 site	470503	1002189	2645	410	30	0.66	0.00622	99.15	3/2 2015	110.55	0.27	30
Q11-(SL-PW-3)	475288	976908	2058	582	75.44	448	2.4	54.32	41516	74.67	1.01	74
(SL-PW-04)	476037	976861	2068	595	88	1.5 x 102	0.366	58.18	41620	33.34	2.44	88
SL-PW-05)	475058	976100	2062	501	91	8.22x 102	1.9	48.79	24/02/ 2(	20.2	4.5	90
(SL-PW-07)	476098	976183	2055	535	46.7	309	1.7	53.52	41364	77.51	0.602	46
(SL-PW-08)	475528	975585	2056	569	95	2.79	1.38 x 10	49.19	18/01/20	26.41	3.887	90
(SL-PW-09)	475128	975184	2068	600	70.43	1.00 x 10	1.92	64.54	41457	14.18	4.988	70
SL-PW-10)	473954	975244	2053	591	55	2.55 x 10	1.29	49.28	27/03/20	84.11	0.654	55
(SL-PW-11)	471453	974241	2048	335	112.7	6.35 x 10	2.33	50.04	17/04201	13.31	8.467	100
(SL-PW-12)	470835	974233	2046	320	113.48	1.4 x 102	0.971	49.45	17/11/20	6.5	17.458	100
(SL-PW-13)	472078	974359	2050	319.12	106	1.02 x 10	3.89	51.65	41397	5.92	17.905	106
(SL-PW-14)	472640	973882	2072	518.5	84.9	1010	2.4	70.25	21/11/20	28.08	3.02	84
(SL-PW-15)	473428	973584	2078	623	32.35	8.56 x 10	0.178	70.55	40920	71.2	0.454	30
(SL-PW-16)	474702	974792	2069	602	98	1.17 x 10	3.62	69.98	24/10/20	27	3.63	98
(SL-PW-17)	474733	973382	2078	501	34.55	9.07 x 10	0.341	78.54	15/10/ 2(	46.13	0.75	30
(SL-PW-18)	477023	973986	2087	503	66.17	1.02 x 10	2.62	84.85	25/09/ 2(	29.76	2.22	66.17
SL-PW-19)	476375	974046	2112	568	27	3.25 x 10	0.179	90.5	14/07/20	56.56	0.477	25
(SL-PW-21)	477959	974168	2103	501	90.23	4.04 x 10	23.8	98.47	14/06/20	9.83	9.179	90
SL-PW-22	475507	974679	2070	602	70	1.17 x 10	5..88E+0	76.65	22/11/20	43.48	1.66	70
SL-PW-24	475941	975137	2064	552	102	2.45 x 10	12.7	65	16/06/20	6.67	15.29	102
SL-PW-25	473071	974284	2060	552	109	7.92x 102	1.62+0	56.04	41338	5.53	19.71	108
SL-PW-30	478528	973384	2113	533	46.29	18700	908	132.4	41456	1.31	18.7	46
SL-PW-32	476717	973370	2111	602	46	4.38 x 10	2.2	110	25/07/20	39.74	1.18	47
SL-PW-33	477434	973280	2112	534	37.34	2.24 x 10	1.53	116.38	13/07/20	23.31	1.602	37
WF01-PW2	474204	980459	2077	250	62.5	2.03 x 102		21.23	39993	84.84	0.737	50
WF01-PW3	474918	980486	2081	481	28	5.75 x 102		21.83	40001	68.65	0.408	35
WF01-PW4	475585	9779580	2061	500	122	96.7		37.38	26/12/20	95.42	1.3	
WF01-PW5)	470434	979201	2058	510	140	6.62*101	3.35+E+1	14.53	41341	110.48	0.127*101	
(WF01-PW6)	472630	979912	2096	600	78.78	1.59 x 103		8.43	40199	84.5	0.93	80
(WF01-PW7)	471898	979463	2061	451	7.25	2.65 x 101		8.8	Jan.17, 2(	98.09	0.068	7.5
WF01-PW8	472779	978788	2062	483.7	50	1.06 x 102		17.5	39914	82.36	0.61	50
WF01-PW9	470470	979206	2049	514	70	8.15*101	0.201	19.22	41249	130.52	5.36*10-1	
(WF02-PW10)	474558	972286	2112	480	42.9	1.16 x 10	7.45E+-1	107.62	40259	48.66	0.88	40

WF01-PW11	472245	977865	2048	500	62.15	1.05 x 10	14.7	27.5	40119	54	0.408	50
(WF01-PW12)	471476	977396	2048	480	100	5.81 x 103		34.1	40264	5.63	17.76	80
WF01-PW13	472233	976508	2060	400	22	1.66 x 102		40.4	40577	65.5	0.336	50
WF01-PW14	470778	976165	2061	552	76.32	2.22 x 10	12100	39.79	40282	2.14	36.66	80
WF01-PW15	473944	978720		492.1	40	1.77 * 10	0.935	30.25	24/02/10	87.68		50
WF01-PW16	473386	980122	2065	549.73	31.28	6.54 x 10	5.3E-06	11.38	40464	131.66	0.238	50
WF01-PW17	472460	981553	2080	477.38	48.75			ASN	40349			
(WF01-PW18)	471918	979657	1969	272	140	1.62 x 10	271	9.32	40703	3.68	38.04	120
WF01-PW19	470552	976837	2062	501	67	251	4.16	54.43	41000	54.75	1.22	65
(WF01-PW20)	471289	977837	1978	504	40	2.63 x 10	1.41	26.7	41264	100.32	0.398	35
SWAWF1R	475945	978251	2060	417	12.09	4.76 x 10		45.2	40347	111.7	0.108	10
(SWAWF2)	475697	979915	2062	448	54.45	5.83 x 101		9.45	39794	89.39	0.61	56
(SWAWF3)	471027	973709	2054	378	90	1.97 x 103		44	March 29	14.2	6.34	100
(SWAWF4A)	472826	980785	2180	121.5	30	6.06 x 102		8.45	39965	52.23	0.57	30
SWAWF4B	472836	980785	2180	480	90	1.29 x 104		7.18	39971	9.72	10.06	80
(SWAWF5)	472779	978788	2183	486	90	3.44 x 104		9.69	may,25, 2	4.47	20.13	80
(LLA-1)	493247	1001478	2399	432	15	1.44 x 101		7.3	39926	124.8	0.12	15
(LLA-2)	489927	1000153	2349	500	20	9.53 x 10	2.23*103	6.8	39934	78.68	0.254	20
(LLA-3)	496269	1004908	2444	590	52.03	3.2 x 103	8.53	Artesian	40662	16.12	3.63	52.03
(LLA-4)	498961	1005177	2250	181.33	125			Artesian>	40757			
(LLA- 5)	497374	1006185	2470	180	50	2.84 x 10	6.95x10-3	27.68	40893	10.15	5.22	
LLA-6	497470	1006388	2280	440	38	4.09*102	9.25x10-2	32.2	41059	78.9	0.475	
LLA-PW1	497270	1004423	2476	504	78	3.68	6.97*102	12.86	13/03/20	14.96	5.2*100	
LLA-PW3	500497	1007598	2515	372	97	3*103	2.7X101	29.36	30/06/20	3.43	2.83*10-1	
LLA-PW4	494679	1006306	2492	504	88	6.97*102	15	19.8	20/3/201	6.58	1.337*101	
LLA-PW5	496568	1006495	2487	550	45	7.25*102	4.27	14.24	13/03/20	72.48	6.21*10-1	
LLA-PW7	499253	1006931	2510	378	80	1.20*103	9.36	33.84	13/12/20	36.81	2.17*100	
LLA - PW 9	501977	1007354	2507	270	94	25800	1.19x2	55.15	22/05/20	1.68	55.95	
LLA-07	508854	1001610	2520	254	113	701	9.34	52.2	42591	12.2	9.48	
LLA-08	503937	1003756	2499	501	113.48	4.86*104	15.5	52.69	42748	10.21	11.11	110
LLA-PW15	503284	1005378	2509	323	117.41	9.62*103	31.2	54.8	42750	8.82	13.31	110
LLA- PW 11	500982	1006789	2497	367.8	109.64	21400	25.7	56.6	42911	17.02	6.47	
LLA-9	502084	1008222	2508	514	95	3.96*104	7.46	57.4	42546	28.66	3.33	
LLA - PW 8	496944	1007787	2527	551	50	732	0.997	57.64	Feb.16, 2	91.92	0.54	
LLA - PW 10	501115	1009538	2527	474	82	9.72*103	11.4	71.2	42535	14.22	5.77	
LLA PW 16	499607	1010323	2540	550	7	3.99	7	39	24/07/15	201	0.036	
LLA-11	508321	1013326	2540	550	9	51.1	0.108	85.1	42130	69.2	0.13	
LLA - PW 13	493723	100858		550	80	100.9	0.445	53.45	17/8/15	62.75	1.27	
LLA - PW 19	498657	1008943	2531	558	5	3.7	0.0168	46	42336	57.86	0.086	
LLA - PW 17	501684	1004947	2497	371	95	2860	20.3	73	29/12/15	22.94	4.14	
LLA – PW14	502267	1009162	2515	378	101	5120	1.67+1	62.65	42540	14.27	7.077	
LLA - PW 20	493561	1007179	2531	422	82	1600	3.26+0	68.2	42008	45.25	1.81	
LLA – PW12	495420	1009986	2515	510	32	40.8	0.124	59.1	42696	86.2	0.37	
(SANF – PW1)	481952	984973		528		4.07 * 10	0.205	16.65	41978	113.79	26.57	3024
(SANFTW-1)	477819	987018		411	34.98	1.91*102	1.2E-06	8.2	Aug. 20, 2	72.31	0.48	34.98
(SANFTW-2)	484001	987465		442	52	5.62*102	6.87	0.35	Jan.15, 2	41.17	1.26	60
(SANFPW2)	481883	984954	2206	420	39	4.17 x 10	0.394	38.85	41985	94.88	0.411	39
SANF-PW3	482119	982234	2277	523	40	3.59*101	0.18	32.2	41947	103.95	3.843*10-1	
(SANFTW-3)	481012	984597	2192	440	50	1.60 x 10	1.3	29.8	Mar. 30,	45.7	1.09	
(SANF – PW4)	477224	981760		542	30	2.31 * 10	0.0564	40.5	19/01//2	126.22	20.54	30
(SANF – PW5)	479454	985457	2185	512	60	2.96 * 10	0.736	18.63	30/12/20	58.97	87.9	
LLA-PW6	499681	1008600	2511	504	84	1.91*103	92.8	49.68	42011	2.83	2.968*10-1	
SANF-PW7)	480385	986784	2204	550	100	448	0.938	14.2	42310	101.02	0.99	90
(SANF – PW09)	481467	986506		502	78.58	1.96 * 10	1.04	35.36	26/12/20	80.36	0.97	78.58
(SANF-PW11)	482852	987470	2220	486	52	3.18 x 10	3.81	20.6	42137	125.74	0.4	50
(SANF-PW12)	483560	983856	2240	550	31	106	2.89	68	42323	62.51	0.5	30
(SANF-PW14)	481129	989896	2236	460	72.4	217	1.34	Artesian	Jan04,20	123.32	0.58	70
(SANF – PW16)	484553	986685		550	80	1.36 * 10	0.635	7.1	15/11/20	123.6	55.9	80
(SANF-PW18)	485313	984138	2270	550	23.6	11.9	0.11	59.6	Janury 29	119.65	0.197	20

(SANF – PW21)	484142	982196		550	45	1.07 * 10	0.515	13.23	16/12/20	125.15	0.36	45
SWAWFR	507408	1013586	2587	110	0	0	0	29		21	0	0
SWAWF2	475945	978251	2056	416	12	48	0	45		54	0	0
SWAWF3	475697	979915	2060	448	55	58	0	10		125	0	0
SWAWF4A	471027	973709	2055	379	90	1970	0	44		79	0	0
SWAWF4B	472846	980785	2062	120	30	606	0	8		16	0	0
SWAWF5	472836	980785	2062	481	90	12900	0	8		0	0	0
WF01-PW1	472779	978788	2060	486	90	34400	0	10		10	0	0
WF01-PW2	473597	981135	2073	500	11	87	0	22		79	0	0
WF01-PW3	474204	980459	2072	250	62	203	0	21		15	0	0
WF01-PW8	474918	980486	2077	480	28	575	0	22		7	0	0
WF01-PW11	473583	979260	2066	484	50	106	0	18		3	0	0
WF01-PW13	472245	977865	2059	500	62	105	0	28		72	0	0
WF01-PW14	472233	976508	2060	400	22	166	0	40		3	0	0
WF01-PW15	471521	976630	2059	552	76	2220	0	40		37	0	0
WF01-PW16	473944	978722	2070	492	40	177	0	30		71	0	0
WF01-PW17	473386	980122	2066	549	31	65	0	11		41	0	0
WF02-PW1	472460	981553	2067	500	49	107	0	0		46	0	0
WF02-PW2	472446	974756	2054	468	102	886	0	42		114	0	0
WF02-PW3	473576	972379	2096	453	20	50	0	52		104	0	0
WF02-PW5	470352	972510	2082	511	9		0	92		126	0	0
WF02-PW7R	476795	971654	2174	499	50	1600	0	80		59	0	0
WF02-PW8	471576	972958	2064	550	75	925	0	54		95	0	0
WF02-PW9	469163	973946	2052	502	50	2020	0	46		52	0	0
WF03-PW10	473955	974576	2062	505	0	115	0	51		66	0	0
WF03-PW1	471909	978486	2058	480	43	116	0	108		23	0	0
BH10R	477362	973887	2097	306	65	59300	0	89		46	0	0
BH11R	479055	976033	2095	520	150	1970	0	95		111	0	0
BH13R	478780	977307	2084	550	152	9030	0	82		20	0	0
BH14R	478679	976462	2079	550	55	95	0	77		75	0	0
BH22R	478585	976053	2085	520	140	10500	0	81		36	0	0
LLA1	477628	975889	2072	463	100	3180	0	67		20	0	0
LLA2	493247	1001478	2439	432	15	14	0	7		34	0	0
LLA3	489977	1000102	2344	500	20	11	0	10		78	0	0
LLA4	496269	1004908	2466	598	52	3200	0	0		24	0	0
LLA5	498961	1005177	2466	181	0		0	0		14	0	0
LLA6	497374	1006185	2501	182	50	408	0	28		84	0	0
LLA-PW1	497470	1006388	2506	440	38	195	0	32		13	0	0
LLA-PW4	497270	1004423	2470	504	78	697	0	13		7	0	0
LLA-PW3	494679	1006306	2486	504	88	2940	0	20		6	0	0
LLA-PW5	500497	1007598	2509	372	97	3000	0	29		28	0	0
LLA-PW6	496594	1006485	2484	550	45	725	0	14		64	0	0
LLA-PW7	499750	1008782	2520	504	84		0	50		27	0	0
SANFTW-1	499253	1006931	2506	378	80	1200	0	34		125	0	0
SANFTW-2	477891	987018	2190	411	35	191	0	9		30	0	0
SANFTW-3	484001	987465	2241	442	52	562	0	0		57	0	0
SANFPW-1	481012	984597	2194	440	50	162	0	30		10	0	0
SANFPW-3	483963	985000	2234	528	35	41	0	17		43	0	0
SANFPW-4	482141	982240	2200	523	40	36	0	32		7	0	0
SANFPW-5	477224	981760	2101	519	30	23	0	6		6	0	0
SANFPW-2	479454	985457	2177	512	60	296	0	19		1	0	0
KMPW-01	481887	984954	2201	420	39	42	0	39		40	0	0
KPW-1	472912	1001627	2568	312	8	27800	0	59		23	0	0
KDPW-1	474203	1002351	2544	546	14	29	0	16		0	0	0
KDPW-2	479316	999941	2642	271	50	446	0	118		0	0	0
TBH-2	479175	999755	2625	250	15	5	0	107		0	0	0
TVT-01	470503	1002189	2637	410	30	1	0	99		0	0	0
SL-PW-03	480887	997740	2414	220	21	0	0	63		0	0	0
SL-PW04	475276	976930	2058	582	75	448	0	54		0	0	0

SL-PW-05	476037	976861	2062	595	88	150	0	55		0	0	0
SL-PW-06	475058	976100	2056	502	91	822	0	49		0	0	0
SL-PW-07	475528	975870	2059	600	87	747	0	52		0	0	0
SL-PW-08	476098	976183	2057	550	47	309	0	54		0	0	0
SL-PW-09	474528	975585	2058	569	95	138	0	49		0	0	0
SL-PW-10	473954	975244	2058	600	70	1000	0	65		0	0	0
SL-PW-11	473954	975244	2058	591	55	255	0	49		0	0	0
SL-PW-12	471453	974241	2055	335	113	635	0	50		0	0	0
SL-PW-13	475507	974697	2077	320	113	140	0	49		0	0	0
SL-PW-14	472078	974359	2058	319	106	1020	0	52		0	0	0
SL-PW-15	472640	973882	2075	519	85	1010	0	70		0	0	0
SL-PW-16	473428	973584	2079	623	32	86	0	71		0	0	0
SL-PW-17	474702	974792	2077	60	98	761	0	70		0	0	0
SL-PW-18	474733	973382	2087	501	35	91	0	79		0	0	0
SL-PW-19	477023	973986	2091	503	66	1020	0	85		0	0	0
SL-PW-21	476375	974046	2091	568	27	33	0	91		0	0	0
SL-PW-22	477959	974168	2101	501	90	4040	0	98		0	0	0
SL-PW-24	475507	974679	2077	52	72	1020	0	77		0	0	0
SL-PW-25	475941	975137	2069	551	102	2450	0	65		0	0	0
SL-PW-30	473071	974284	2062	552	109	792	0	56		0	0	0
SL-PW-32	478528	973384	2134	518	46	18700	0	132		0	0	0
SL-PW-33	476725	973381	2113	170	48	438	0	110		0	0	0
GELAN	477415	973284	2116	453	37	242	0	116		0	0	0
GeLAN2	481417	976193	2129	278	0	0	0	19		0	0	0
AdBh0037	478862	974617	2090	222	0	0	0	91		0	0	0
AdBh0045	480641	977009	2119	134	0	0	0	98		0	0	0
AdBh0176A	482463	976154	2156	181	0	0	0	73		0	0	0
AdBh0219A	481337	1001017	2637	135	0	0	0	23		0	0	0
AdBh0290	479021	977596	2088	126	0	0	0	66		0	0	0
AdBh0291A	488161	1002129	2475	102	0	0	0	63		0	0	0
AdBh0292B	494036	1010902	2541	154	0	0	0	21		0	0	0
AdBh0294A	502554	1011850	2572	200	0	0	0	95		0	0	0
AdBH0393A	507408	1013586	2587	110	0	0	0	29		0	0	0
AdBh0403A	474125	1001050	2565	154	0	0	0	28		0	0	0
AdBh0404A	475000	1001300	2545	168	0	0	0	74		0	0	0
AdBh0409A	473400	999600	2498	58	0	0	0	21		0	0	0
AdBh0410A	474200	997400	2427	200	0	0	0	0		0	0	0
AdBh0413	471300	998200	2453	88	0	0	0	17		0	0	0
AdBh0414	491300	1004800	2448	95	0	0	0	5		0	0	0
AdBh0414A	478007	971121	2183	186	0	0	0	137		0	0	0
AdBh0430A	478450	995600	2358	171	0	0	0	87		0	0	0
AdBh0433A	472000	995100	2331	56	0	0	0	44		0	0	0
AdBh0446	471300	995050	2326	114	0	0	0	0		0	0	0
AdBh0453	474395	995211	2352	153	0	0	0	59		0	0	0
AdBh0458	473000	992700	2289	121	0	0	0	111		0	0	0
AdBh0459	474300	992700	2280	129	0	0	0	89		0	0	0
AdBh0461A	475600	994500	2323	139	0	0	0	41		0	0	0
AdBh0462A	473200	992400	2287	72	0	0	0	40		0	0	0
AdBh0463	473200	992400	2287	69	0	0	0	29		0	0	0
Adbh0468A	473100	991900	2285	154	0	0	0	113		0	0	0
AdBh0474	473848	990072	2255	100	0	0	0	39		0	0	0
AdBh0477	473900	989000	2225	201	0	0	0	35		0	0	0
AdBh0485	475000	987800	2164	172	0	0	0	28		0	0	0
Adbh0486	475335	980717	2074	179	0	0	0	17		0	0	0
AdBh0487	476500	981300	2065	53	0	0	0	4		0	0	0
AdBh0489	476600	981500	2061	126	0	0	0	4		0	0	0
AdBh0491	481507	976220	2130	132	0	0	0	120		0	0	0
AdBh0495	476400	980700	2062	126	0	0	0	53		0	0	0
AdBh0497	477400	979500	2084	96	0	0	0	27		0	0	0

Water quality Well Index	x	y	z(m)	NO3	CO3	SO4	Cl	F	Ca	K	B	Na	I	Cr
24KPW-01-17	477052	995894	2351	0.02	0	25.76	26.03	2.91	3.36	6.8	0	136	0	0
BHSPW-01-17	476933	994457	2334	0.18	0	0	65.89	7.78	13.6	66	0	610	0	0
GKPW-01-16	477067	1001053	2573	0.005	0	0	11.33	0.49	21.6	4.7	0	36.5	0	0
LPW-01-17	476287	1000116		0.009	208.08	85.76	47.94	7.8	2.46	36	0	11.5	0	0
F1PW-01-16)	475466	1000729	2516	0.69	0	12.2	15	1.35	21.6	17.5	0	40.5	0	0
F2PW-01-16	475976	1001005	2515	0.006	0	11.04	11.2	0.64	13.74	5.8	0	44	0	0
H19PW-01-16	474402	1001122	2515	0.037	0	8.4	12.2	0.9	20	20	0	40	0	0
KGPW-01-16	474716	985017	2515	0.95	0	7.25	10.31	4.24	23.2	9.2	0	63	0	0
SPW-01-16	476370	983392	2054	0.47	0	18.97	30.89	2.24	6.4	30.5	0	116	0	0
KPW-1	474203	1002351	2543	0.43	0	32	6	2.82	25.3	3.2	0	42	0	0
KHPW-1	481763	1000506		0.37	0	36.32	6.56	2.18	48	2.3	0	63	0	0
KDPW-1	479316	999941	2643	0.16	0	8.09	8.19	1.53	30.4	3.6	0.151	38	0	0
KDPW-2	479175	999755	2711	0.07	0	22.57	18.09	1.15	33.46	3.7	0	42	0	0
SL-PW-03	475288	976908	2058	10.2	0	40.95	157.2	0.89	35	12	0	169	0	0
SL-PW-04	476037	976861	2068	11.2	0	10.34	11	0.56	40	11.8	0	54	0	0
SL-PW-05	475058	976100	2062	21.2	0	11.3	12.2	0.59	59	6.3	0	42	0	0
SL-PW-07	476098	976183	2055	11.2	0	11.2	18.6	0.56	33.6	11.2	0	79	0	0
SL-PW-08	475528	975585	2056	20.15	0	18.2	11.2	0.56	72.2	5	0	39	0	0
SL-PW-09	475128	975184	2068	18	0	12	9.46	0.52	50.4	7.6	0	30	0	0
SL-PW-10	473954	975244	2053	18.5	0	19	10.5	0.7	74	7.2	0	42	0	0
SL-PW-11	471453	974241	2048	3.99	0	38.38	34.58	0.74	32	12.6	0	78	0	0
SL-PW-13	472078	974359	2050	1.8	0	83.25	34	0.7	25	16	0	82	0	0
SL-PW-14	472640	973882	2072	3.2	0	60	28	0.69	25.8	13	0	78	0	0
SL-PW-15	473428	973584	2078	11	0	22	12	0.48	36	9	0	68	0	0
SL-PW-17	474733	973382	2078	14.2	0	18.2	20.8	0.72	27.2	18	0	74	0	0
SL-PW-18	477023	973986	2087	18.2	0	14	12	0.67	41	6.5	0	43	0	0
SL-PW-19	476375	974046	2112	18	0	12	9.46	0.51	50.4	7.6	0	28	0	0
SL-PW-21	477959	974168	2103	5.2	0	10	11.2	0.66	43.2	6.4	0	50	0	0
SL-PW-22	475507	974679	2070	7.58	0	7.2	15	0.6	33.6	7.2	0	54	0	0
SL-PW-24	475941	975137	2064	1.69	0	9.3	11	0.62	20	7.6	0	60	0	0

SL-PW-25	473071	974284	2060	20	0	12.5	8.18	0.59	46.5	7.4	0	36.5	0	0
SL-PW-30	478528	973384	2113	8.2	0	8.53	12.2	0.59	38	6.1	0	52	0	0
SL-PW-32	476717	973370	2111	4.18	0	25.6	28.2	0.95	33.6	7.7	0	72	0	0
SL-PW-33	477434	973280	2112	7.95	0	14.29	13.6	0.39	30.4	6.8	0	58	0	0
WF01-PW2	474204	980459	2077	4.65	0	10	45.2	1.32	23.2	17.5	0	95	0	0
WF01-PW3	474918	980486	2081	9	0	2.9	25.6	1.4	38	10.2	0	77.2	0	0
WF02-PW10	474558	972286	2112	6	0	33	36	1.5	10.2	10.2	0	76	0	0
WF01-PW15	473944	978720		31.8	0	12.9	19	0.72	58.74	6.7	0	50	0	0
WF01-PW16	473386	980122	2065	9.75	0	13.2	18.2	0.79	34.2	10.1	0	58	0	0
SWAWF1R	475945	978251	2060	3.9	0	1.05	13.65	0.72	28.88	8	0	45	0	0
SWAWF2	475697	979915	2062	7.2	0	15.14	14.42	1.4	64.68	8.6	0	46	0	0
SWAWF3	471027	973709	2054	50	0	11.89	20.8	20.8	1.23	10	0	53	0	0
SWAWF4B	472836	980785	2180	24.21	0	6.47	16.48	0.87	55.44	6.8	0	44	0	0
LLA-1	493247	1001478	2399	6.9	0	8.76	9.27	0.53	46.2	1.4	0	32	0	0
LLA-2	489927	1000153	2349	9.14	0	1.7	16.48	1.29	19.32	3.3	0	93	0	0
LLA-3	496269	1004908	2444	6.47	0	5.2	18.2	0.72	13.56	9.6	0	88	0	0
LLA-4	498961	1005177	2250	0.17	0	8.36	17.29	0.65	30.4	7.7	0	54	0	0
LLA- 5	497374	1006185	2470	3.12	0	10.36	15.5	0.69	35.89	7.89	0	44.2	0	0
LLA-6	497470	1006388	2280	6.23	0	7.21	20.1	0.68	34.2	8.8	0	61.5	0	0
LLA-PW1	497270	1004423	2476	9.08	0	3.87	4.69	0.62	27.65	7.3	0	48.5	0	0
LLA-PW3	500497	1007598	2515	1.2	0	7.89	7.23	0.62	37.8	5.7	0	31.5	0	0
LLA-PW4	494679	1006306	2492	14.2	0	0.19	23.66	0.69	14.5	9.95	0	95.5	0	0
LLA-PW5	496568	1006495	2487	14.25	0	6.7	14.56	0.61	19.23	9.6	0	53.5	0	0
LLA-PW7	499253	1006931	2510	0.35	0	1.89	12.56	0.72	39.89	7.2	0	44.5	0	0
LLA- PW 11	500982	1006789	2497	3.56	0	10.5	10.56	0.92	34.52	12.89	0	50.2	0	0
LLA - PW 8	496944	1007787	2527	1.9	0	0	9.89	0.68	34.2	3.5	0	34.5	0	0
LLA - PW 10	501115	1009538	2527	5.59	0	0	16.2	0.51	40.98	3.89	0	51.5	0	0
LLA PW 16	499607	1010323	2540	0.98	0	3.56	6.3	1.89	2.88	0.9	0	112	0	0
LLA - PW 19	498657	1008943	2531	0.72	0	0.099	5.23	0.05	56.7	2.23	0	30.5	0	0
LLA - PW 20	493561	1007179	2531	0.198	0	11.25	11.25	0.59	30.5	3.1	0.157	39	0	0
LLA – PW12	495420	1009986	2515	0	0	0	9.9	0.75	29.3	1.6	0	28.5	0	0
SANF – PW1	481952	984973		0.15	0	3.23	45.89	1.13	12	25.6	0	210.89	0	0

SANFTW-1	477819	987018		12.2	0	6.3	14.56	0.98	25.98	9.8	0	90	0	0
SANFTW-2	484001	987465		0.3	0	16.5	42.89	0.68	28.2	12.8	0	355	0	0
SANFPW2	481883	984954	2206	0.56	0	17.55	34.15	0.95	12.4	7.2	0	152.3	0	0
SANF-PW3	482119	982234	2277	5.23	0	18.62	28.5	1.25	20.3	8.2	0	102	0	0
SANFTW-3	481012	984597	2192	0.61	0	17.2	36.2	0.12	14.6	17	0	164	0	0
SANF – PW4	477224	981760		0.66	0	18.98	36.87	3.24	3.2	6.99	0	192	0	0
SANF – PW5	479454	985457	2185	0.19	0	14.2	20.2	0.88	20.12	6.9	0	100	0	0
LLA-PW6	499681	1008600	2511	8.87	0	5.2	14.58	0.71	34.2	3.87	0	42.98	0	0
SANF-PW7	480385	986784	2204	0.34	0	18.23	49.2	2.71	10.2	6.6	0	255	0	0
SANF – PW09	481467	986506		0.49	0	20.5	44.8	1.55	16.2	10	0	235	0	0
SANF-PW11	482852	987470	2220	0.35	0	1.77	35.89	1.02	24	11.8	0	208	0	0
SANF-PW12	483560	983856	2240	7.6	0	9.23	32.2	0.75	46.2	4.9	0	132	0	0
SANF-PW14	481129	989896	2236	0.36	0	0.21	28.02	0.99	20.2	11.2	0	172	0	0
SANF – PW16	484553	986685		0.45	0	11.8	35	1.32	15.2	20	0	198	0	0
SANF-PW18	485313	984138	2270	0.887	0	2.47	22.49	1.42	22.3	3.4	0	100	0	0
SANF – PW21	484142	982196	0	0.22	0	16.8	20.5	2.05	16.2	6	0	100	0	0
BH1R	478074	975053	2089	3.9	0	9.1	12.6	0.48	54.5	1.9	0	31.2	0	0
BH26R WELL	472446	974756	2089	6.7	0	8.47	21.2	1.4	49.6	3.3	0	48	0	0
WF01-PW4	475585	977958	2061	0.59	0	16.62	40.9	4.66	19.58	4.8	0	117	0	0
WF01-PW7	471898	979463	2061	8.16	0	16.9	28.2	4.07	32	7	0	71	0	0
WF01-PW11	472245	977865	2048	23.6	0	19.5	18.5	1.62	35.2	8.1	0	88	0	0
WF01-PW14	470778	976165	2061	4.5	0	1.2	9.8	0.7	58	6.2	0	25	0	0
WF01-PW12	471476	977396	2048	10.25	0	12.56	13.56	0.78	44.25	9.6	0	38	0	0
WF01-PW8	472779	978788	2062	28.6	0	6.6	9.5	1.5	30.4	11.9	0	79	0	0
WF01-PW18WELL	471918	979657	1969	18.75	0	14.63	15.47	0.68	87.4	7.1	0	35	0	0
WF01-PW17	472460	981553	2080	2.65	0	10.5	29.8	3.25	5.4	8.7	0	120	0	0
WF01-PW6	472630	979912	2096	16.5	0	6.47	12.65	1.58	53.2	5.8	0	50	0	0
WFO1-PW20	471027	973709	2054	50.26	0	11.86	20.5	1.4	60.8	10.2	0	52	0	0