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MSC THESIS TOPIC

HYDROGEOLOGY AND MAJOR ION HYDROGEOCHEMISTRY OF BORKENA RIVER CATCHMENT, AWASH BASIN, AMHARA REGIONAL STATE, SOUTH WOLLO, ETHIOPIA

BY
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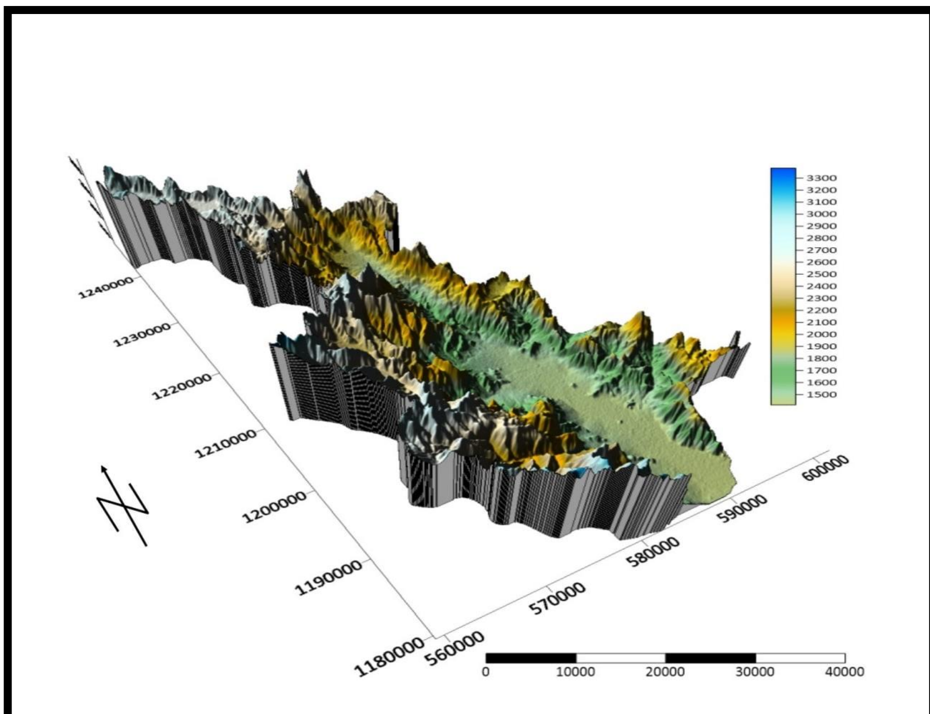

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Thesis Approval Form

The research entitled as:" Hydrogeology and *Major Ion Hydro-Geo-Chemistry of Borkena River Catchment, Awash Basin, Ethiopia"* has been approved by the school graduate committee of School of Earth sciences for the partial fulfillment of the degree of Master of Science in Hydrogeology.

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Abstract

The study was conducted at Borkena River Catchment 1192km^2, in Amhara regional state, south wolo zone, encompasses Dessie, Kombolcha, Harbu and Kemisse towns to characterize the hydrogeology of the catchment by giving particular emphasis to major ion hydrogeochemistry. Data has been analyzed using GIS and remote sensing, Aquachem and Strater softwares. The results indicate that, the highland receives more precipitation than the lowland, the highest rainfall which is 1573.6 mm recorded at 2428m elevation in western part in Albuko station and the lowest rainfall which is 1013.3 recorded in Cheffa station at 1400m elevation. Areal depth of precipitation of the area was estimated by using Arthemetic, Thiesson and Isoheytal methods. All the three methods provide nearly closer value. The analysis result of three methods is used as the annual average rain fall of the study area. Potential evapotranspiration (PET) of the area was estimated using Thornthwaite method. The estimated value of PET is 1462.6mm. *Wetspass modeling and baseflow separation was used to estimate recharge. The average annual long term groundwater recharge is estimated using wetspass as 145.95mm of which 110.63mm occurs during wet and 35.329 mm occurs during dry seasons. About75.7% of the annual groundwater recharge of the watershed occurs during the wet season (summer), and the remaining 24.3 % in dry season (winter). The annual average precipitation (1190.1 mm) is distributed as* 49% *Evaporation, 43.3 %runoff, and 12.26 % recharge. The alluvial deposits in the central part are the major aquifers of the area. The general ground water flow direction is from the northwestern part to southeaster part. The geology, recharge estimation, hydrogeological system and hydrogeochemistry of the study area assessed using respective approaches. Based on test wells and previously drilled wells studied by* ADSWE *aquifer parameters and qualitative hydrogeological interpretation, the study area is characterized in to* ***high, medium to high, medium, low and very low*** *aquifer productivity. To characterize the aquifer system of the area pumping test data, well completion reports, well logs and geology of the area were analyzed. The pumping test analysis results indicate that the hydraulic conductivity of the area ranges from 0.2 – 20.2m/d and the mean and the transmissivity of the area ris greater than 500. Aquachem software has been employed to identify the different water types. Piper plots and Durov plot were used to classify the water chemistry and evolution of water type respectively. The dominant water type of the area is Ca-Mg-Hco3 .Waters of the area generally has Ca-Hco3 and Ca-Mg-Hco3 in the recharge area with Low TDS to Na-Ca-HCO3 discharge area with high TDS evolutionary trend this is due to the process of hydrolysis silicate minerals.*

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List of Acronyms

ADSWE- Amhara Design and Supervision Works Eniterprises
AET- Actual Evapotranspiration
DEM - Digital Elevation Model
Ec- Electrical conductivity
El - Elevation in meter
EMPDA- Educational materials production and distribution agency
EMA - Ethiopian Mapping Agency
FAO- Food and Agriculture Organization
GIS - Geographic Information System
ITCZ - Inter Tropical Convergence Zone
Km2 - Square km
M - Meter
m/s - meter per second
mm - millimeter
MoWIE - Ministry of Water Resource Irrigation and Energy
MWR - Ministry of Water Resources
NMA - National Meteorological Agency
P - Precipitation
PET - Potential Evapotranspiration
TDS- Total dissolved solvent
WMO - World Meteorological Organization
WWDSE - Water Works Design and Supervision Enterprise

CHAPTER-ONE

1. Introduction

Water is an essential chemical compound for all living things (Human beings, plants and animals). As we all are dependent on water, study of chemical physical and biological characteristic of water is necessary to understand Hence, the need for the management of water resources is crucial. This task becomes even more pressing as industrialization and development advances. It is easily fragile resource threatened by pollution. A case study conducted in USA report revealed that cancer mortality due to exposure of groundwater to hazardous chemicals is increasing (Yesehak Worku et al., 1998). There may be several layers of aquifer systems lying on the top of another that have different water quality. Moreover, the quality of ground and surface waters are closely associated.

Monitoring, mapping, testing and preserving and protection of the ground water at specific area is a key for success of water resource management, for communities' health and for sustainable development of our society. Analyzing and understanding the governing factors such as geology and geomorphology for contaminant transport takes a major parts in finding solutions for most pollution problems; The ability to reliably predict the rate and direction of groundwater flow and contaminant transport in the aquifer systems would be of great importance in planning and implementing the remediation of contaminated aquifers.

The study area is rich in surface water and groundwater resources. The area is also fertile. Groundwater utilization for community water supply is using hand dug wells, shallow and deep boreholes and springs. Shallow and Deep boreholes have been drilled in different areas. Thermal deep artesian wells also found in the study area. There is also an increasing demand for water supply and irrigation in the area. Taking this into consideration, assessing the groundwater potential involves aquifer characterization, quantification of the current rate of groundwater recharge and evaluation of hydrochemistry is a necessity for the efficient and sustainable groundwater resource management in the study area. Groundwater recharge is considered as the amount of water, which contributes to the sub surface which leads to temporary or permanent increase of groundwater resources.

The geology of the area is related with the formation of the East African rift system which results in formation of complex geomorphology, where by the topography of the study area gradually decreases towards to the rift zone. Different topographic and geological features such as tertiary volcanic rocks which consist of flood basalt, shield volcanic rocks, and quaternary alluvial and alluvial deposits are formed in the area due to volcano-tectonic process.

The study of water quality (water chemistry) gives important indications on the direction of water movement, the geologic history of the aquifer material through which the water is moving, the presence of waste disposal and the residence time. The groundwater quality of Ethiopia is both anthropogenically and naturally affected and in some cases in urban centers, the chemistry of groundwater is controlled by the quality of surface water due to hydraulic connection (Tamiru Alemayehu et al 2006).

1.2. General Background

Borkena River emanates from Kutaber and it passes through Dessie, Kombolcha, Harbu Kemise and Chefa robi towns and finally it feeds Awash River.

Access to the fresh water resources development is beyond the reach of the interest of majority of the population in the study area, Borkena river catchment. Although the distribution is uneven, the area has enormous surface water and ground water resources. Very little researches have been carried out in the field of development of the water resources, particularly in areas of groundwater.

An intensive sustainable water resources development can have a great role in the socio-economic growth of a country and in preventing the recurrent drought problems in the study area. A pre-requisite for an appropriate utilization and management of the water resources is conducting detail investigation and planning of the resources on small and large scale. The Borkena catchment in the central high lands of Ethiopia is one of the richest water resources found within the Awash basin. Groundwater utilization has been limited to community water supply using shallow hand dug wells and unprotected springs. Limited deep boreholes were drilled in few rural areas. There is also an increasing demand for water supply and irrigation.

1.3. Problem Statement

Many researchers have been done regarding to the ground water potential, the ground water resource has been evaluated, conceptualized and developed. However there is lack of significant research conducted on the chemistry of the ground water in the Borkena river catchment. As the chemistry of the water is the main concern; the ground water resource of the area should be studied well using major ion geo chemistry approaches. This study will work on the chemistry of the area of the ground water resource and check out their usage for different purposes.

In addition to this the research area is characterized by a fast rate of population growth, urbanization and industrialization, as a result the demand to groundwater also increase. Groundwater should be well managed and studied. This research is also characterizing geochemical evolution of the groundwater for understanding the ground water flow system and recharge mechanism. The output of this research will be a good input for managing the groundwater resources for the study area.

1.4. Scope of the study

The study uses hydro geochemical tool to investigate the aquifer systems and different methods to characterize the ground water of study area. This study tries to evaluate the ground water potential of the Borkena in terms of quantity and quality. To determine the ground water in terms of quantity; different recharge estimation methods namely Wetspass and base flow separation method has been used. And to determine in terms of quality hydro- geochemical approaches has been used to assess the ground water resource.

1.5. Research questions

The most important research questions for the work are:

- How major element geochemistry can be of fundamental use to decipher groundwater flow, recharge and water quality evolution?
- What are the hydrogeological characteristics of the study area?
- What are the recharge and discharge zones within the study area?
- Is the hydro-geochemistry of the area variable spatially?

1.6. Literature Review

Several Researches have been carried in Borkena river catchment. The most notable study have been carried out by Ketema Tadesse, 1980. According to his research, the hydrogeology of the catchment varies from place to place whereby there exists a high groundwater potential in flat low laying alluvial deposit while less significant amount of groundwater is observed in high terrain volcanic aquifers. He also point out that majority of spring suited in volcanic terrains have a discharge of 5l/sec.) the recharge of the study area is estimated as 185.11 x 10 6 m3 which is 10.02% of the precipitation. The actual evapotranspiration in the area amounts to 872, 834.8 and 836.1 mm for Cheffa, Dese and Kombolcha respectively. The hydrology of the area varies in different parts of the basin. Consequently, the hydrogeology of the basin also differs, such that there is a great potential of groundwater in the flat low lying alluvial sediments while a less significant amount exists within the volcanic rocks forming the uplifted borders of the graben.

According to a study made on hydrogeological investigation of upper and middle Borkena River (Mesfin Sahele, 2001), Four hydrostat graphic units were identified namely colluvium and river channel deposits,scoracious and basaltic lava flow, fractured massive basalt, welded tuff and rhyolites where by the volcanic rocks suited in the recharge zone while quaternary deposits lies in discharge zone. A numerical groundwater flow modeling has been carried out in Borkena river catchment (Getachew Wale, 2016).in his study he shows that two groundwater senarios namely increase in groundwater withdrawal and recharge alteration has been made but, they doesn't show adverse effect on groundwater table.in addition to this geological structures NW-SE and E-W faults control the surface and groundwater flow form volcanic out crop (West and East margins of high terrains of Borkena catchment) tothe graben alluvial aquifer. A study has been made by (walle Jinie ,2020) on modeling on surface water and groundwater interaction of Borkena catchment, in his research SWAT modeling has been used to estimate the hydrological system of the basin in his research , the calibrated result shows that, the annual rainfall of the whole catchment is found to be 1017.5mm where annual recharge ,runoff and evaporation accounts for 12%,62% and 58% of the total annual rainfall.

According to the study of the hydrogeological investigation of upper and middle Borkena river by (Mesfin Sahle, 2001) Beside on a technical report prepared by Amhara design and supervision works enterprise (ADSWE, 2013) the potential for groundwater is very high especially on the intermountain valleys around kombolcha from drilled wells with different depth on Borkana graben in Kombolcha plain, it was possible to obtain 30- 50l/s. Kombolcha plain area is a continuation of Borkena marginal graben; clearly observed a fault crossing Gerado valley running E - W direction along Borkena river and intersect with N-S major fault area and continues to Mitikolo – Cheleka stream and then to Degan area (ADSWE,2013). Those E-W direction faults allow a trough flow between Gerado and Borkena. (Mola Demile, 2000) On the study of hydrology hydrogeology and hydrochemistry of lake systems of Hayk and Ardibo classified hydrostratigraphic units of the area into two which are the quaternary unconsolidated sediments and fractured volcanic units. According to him, the unconsolidated sediments are very good aquifers while fractured volcanic is classified as a poor aquifer due to morphological setup. He also suggests that the Groundwater flow direction from field observations is towards the respective lakes locally and towards Lake Hayk at the scale of the study catchment.

(GSE, 2017) On Hydrogeological and hydrochemical study of the Dessie map sheet suggested the groundwater flow in the study area is significantly influenced by geomorphology, geological structures (faults, fractures, joints, and lineament), the existence of impermeable layers and the hydraulic properties and continuity of the aquifers. According to GSE (2017), the groundwater flow in the western highlands and associated deep gorges are from north to west and south to west. Another possible groundwater flow, which can be deep and regional, is from the western Afar rift escarpment towards the deep aquifer of the Afar rift floor and they form geothermal systems. They also recommend hydrogeological investigation supported by isotope hydrology and drilling of deep wells both on the escarpment and the rift floor would help determine the hydraulic condition at the rift boundary fault and define the regional flow from the highlands to the lowlands more precisely.

According to (Sadam Ebrahim, 2020) Boreholes and spring in the Borkena catchment show a complex groundwater type and variation in TDS (500- 938 mg/l) Based on its flow pattern. The water types in Borkena catchment generally dominated by Na and Ca cations. Based on inverse Geochemical Modeling and ionic ratio calculations dominant reaction happened on the flow paths of Groundwater is likely to be cation exchange which Na is Exchanging Ca and dissolution of silicate minerals.

1.7. General Objective

The general objective of this research is to evaluate the hydrogeology and hydro geochemistry of the Borkena river catchment in terms of quantity and quality.

1.7.1. Specific Objectives

The specific objectives of this research are to:

- Evaluate the recharge of the catchment by using Wetspass modeling confirm the result using baseflow separation method.
- Characterize the major aquifer systems from existing pumping test data.
- Determine ground water flow systems within the catchments
- Determine the spatial variation of hydrochemistry and the water quality of the catchment.

1.8. Methodology and materials

Different methodologies were employed in this study area in order to achieve the above mentioned objectives.

- **Pre-field works**

To meet the desired objectives all relevant existing papers i.e. published journals, MSc. and PhD thesis, geological, hydrological and hydrogeological reports have been reviewed. Hydro metrological data, well completion reports, pumping test data and hydrogeological logs have been collected from different responsible organizations and bureaus. Such as National Meteorological Service Agency (NMSA), Geological survey of Ethiopia, Ethiopia water works design construction and Amhara water works design.

- Field work

Samples have been taken from Boreholes, springs hot springs and rivers. In situ measurement of EC, temperature, pH and TDS has been made during the field activity using Ph meter and Ec meter. Most samples reported here were taken from drinking water wells in small villages and settlements scattered throughout the study area. The wells were subdivided into 'deep wells' and 'shallow wells. The majority of deep wells are thermal artesian wells thus draws water from bedrocks, while the majority of shallow wells from the alluvial sediments.

- **Post field work**

Secondary sources of water quality data have been used in assessing the hydro chemical parameters of the study area. Software packages were employed during data processing, among these Wetspass-M Microsoft Excel 2010, Arc GIS, Global Mapper, Strater, Aquachem and the results are presented in maps and tables. Representative water Samples were sent to Ethiopian water works and construction design analytical laboratory and analyzed for major ion and cation analysis.

The research methodology includes EC, PH, TDS and T Insitu measurement and laboratory analysis for major ions, determination of recharge using WetSpass model and Base flow separation method and determines ground water flow condition from water level measurements.

Based on the detailed field observation, yield measurements of water points, chemical analysis of the water samples and secondary data, aquifer classification and identification of productivity based on lithologic, structural, field hydraulic properties, transmissivity data, topographic setting and recharge condition of the study area has been characterized.

1.8.1. Materials and software's

In order to achieve the objectives stated above, the appropriate materials and methods are listed as following:-The materials used to conduct this research are;

Materials

- 1:50,000 topographic map
- GPS
- Field camera to take photo of different features
- PH and EC meter (for measurement of pH, electrical conductivity, TDS and temperature)

Software's

- ARCGIS to create interpolation, location and different kinds of maps.
- Global mapper to download Aster images with 30*30 resolutions.
- Aquachem software`s to analyze chemical data's.
- Surfer to make 3D view of the study area.
- Starter to make lithological logs
- Wet-Spass and river flow analysis to estimate the recharge.

CHAPTER-TWO

2. Description of the study area

2.1. Location and accessibility

The study area is located in central Ethiopia, in Amhara regional state, South Wolo administrative zone, it encompasses Dessie, Kombolcha and Kemise towns. The area is approximately bounded between 117000N to 1260000N latitude and 560000E to 680000E longitude. The total area of the catchment is 1192 square kilometers and the elevation of the area is between 3370.7 meters and 1408.2m above sea level.

The study area is accessed by the major asphalted road on the way from Addis Ababa to Mekele via Dessie (Figure 1). In addition, the recently paved dry weather roads connect major towns with various parts of the study area.

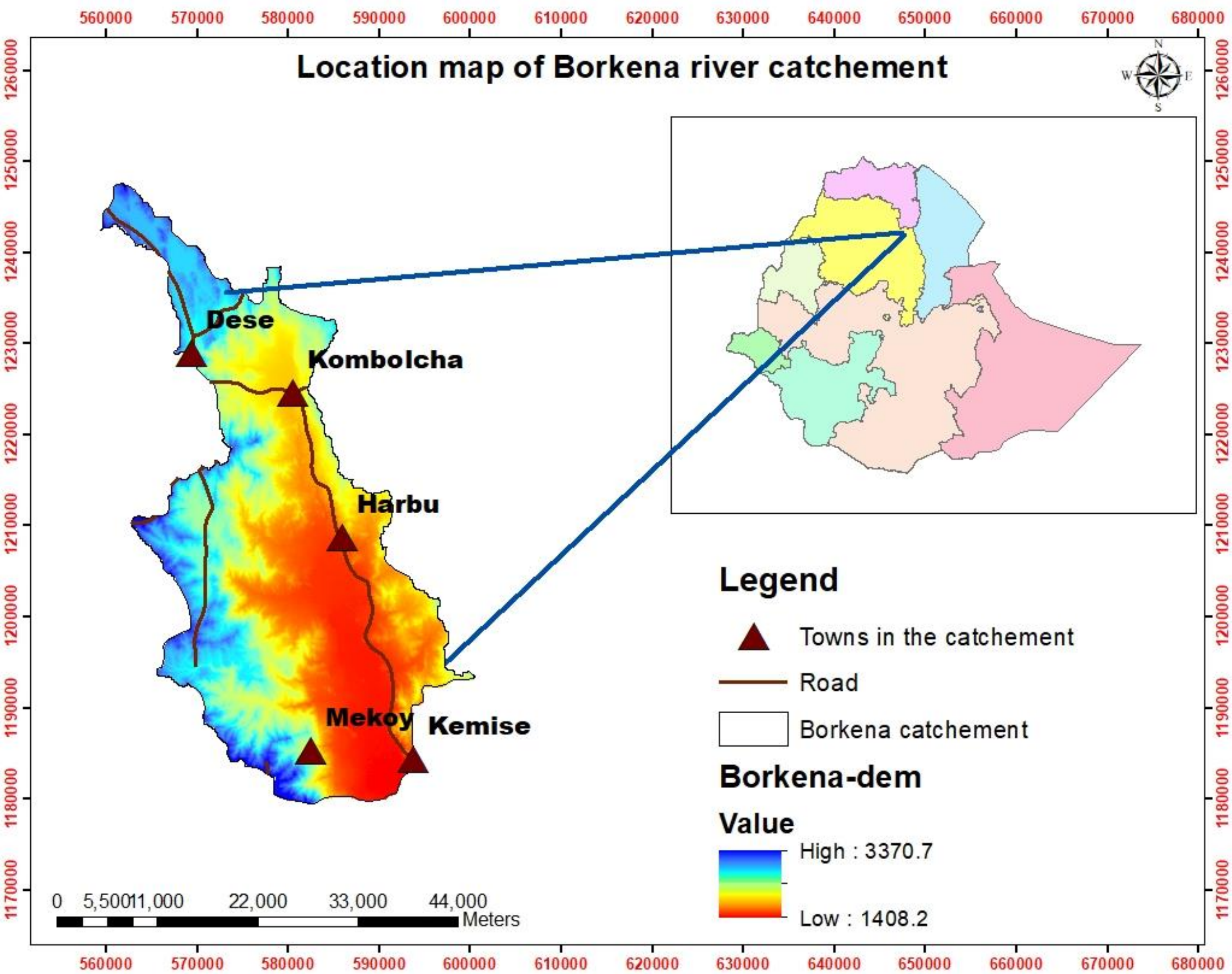

Figure 1 Location map of the study area

2.2. Drainage and Physiography

2.2.1. Drainage

The streams are sourced from the surrounding mountains. Most of the streams are perennial and some of tributary streams are interminnent. The drainage system is mainly controlled by topography and geological structures. There are perennial rivers and streams that flow towards east- south and west-south directions. The drainage network of the area can be categorized as dendritic drainage pattern.

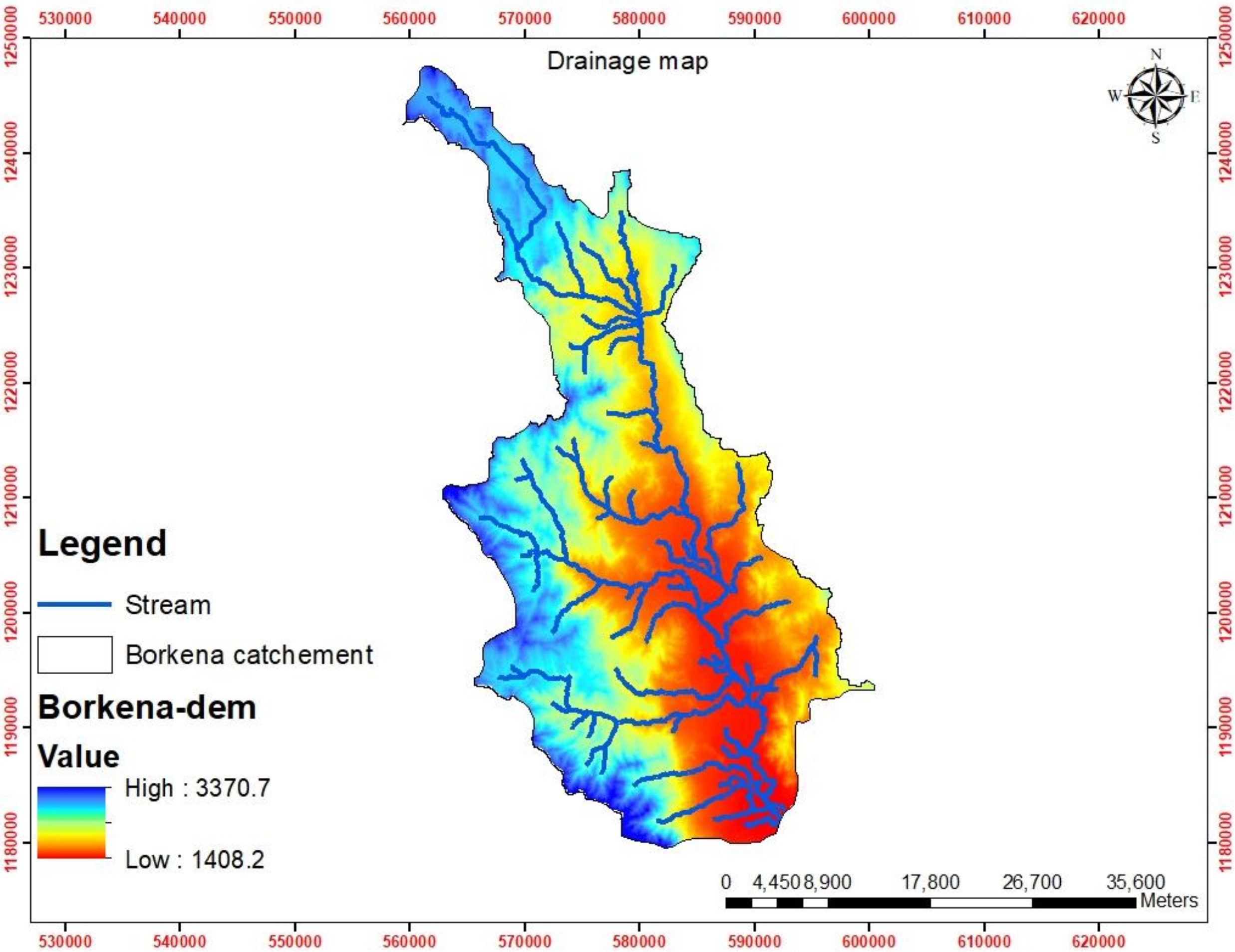

***Figure 2** Drainage map of the study area*

2.2.2. Physiography

The study area is characterized by low land plain, deeply dissected gorges, plateau and high altitude continuous chain of mountains and ridges. It occupies parts of the highlands of the North-central Ethiopian plateau and the Afar depression. A north-northwest-south-southeast striking escarpment, which forms the Western Afar margin, separates the plateau from the Afar depression. The contrasting topography prevalent to the study area is the result of prolonged tectonics and geomorphologic processes related to rift forming tectonic processes.

The study area is characterized by highly rugged topography, high land plateau and intermountain valley plain areas. The lithology of the rugged topography is volcanic rocks (dominantly basalt, rhyolite, ignimbrite and trachytes whereas the intermountain valley plain areas are covered with unconsolidated alluvial sediment. Volcanic high land plateau prevail North western part of the catchment whereas the plain part of the study area is located in the south eastern part of study area.

The study area is surrounded by large mountains in the west direction which have elevation of about 3370.7 m a.s.l and the rest of the area is flat land which has 1408.2 m a.s.l. The study area is being situated in the plain area. It is characterized by plain land features with gentle slopes and stream channels. The elevation of the rift gradually decreases from the western margin (highlands such as Kutaber,Dessie) towards the rift floor (Kemise town) . The digital elevation model of the area shows that there is a sharp topographic variation close to the ridge in the north-west parts, while east part of the area is flat.

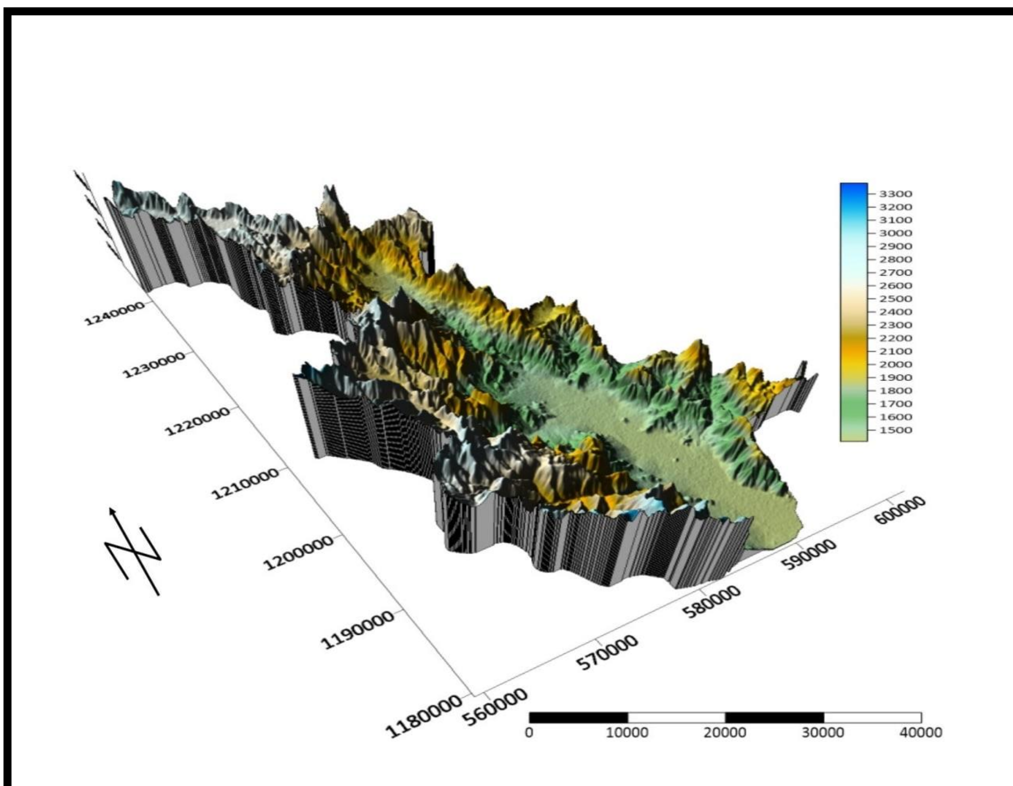

Figure 3 Physiography map

2.3. Soil of the study area

Soil characteristics of an area depend on land escape, geology (parent material), the type of land use practice and agricultural activities. Soil types determine the capability of the catchment water holding and transmission capacity. The soil units of the study area were extracted from Arc GIS using Analysis tool in Arc Map environment and classified as FAO. The dominant soil type of the study area is classified in to five: Chromic Vertisols, Eutric Cambisols, Eutric Regosols pelic vertisoils and Leptosols with their textures with different areal coverage (Figure 4).

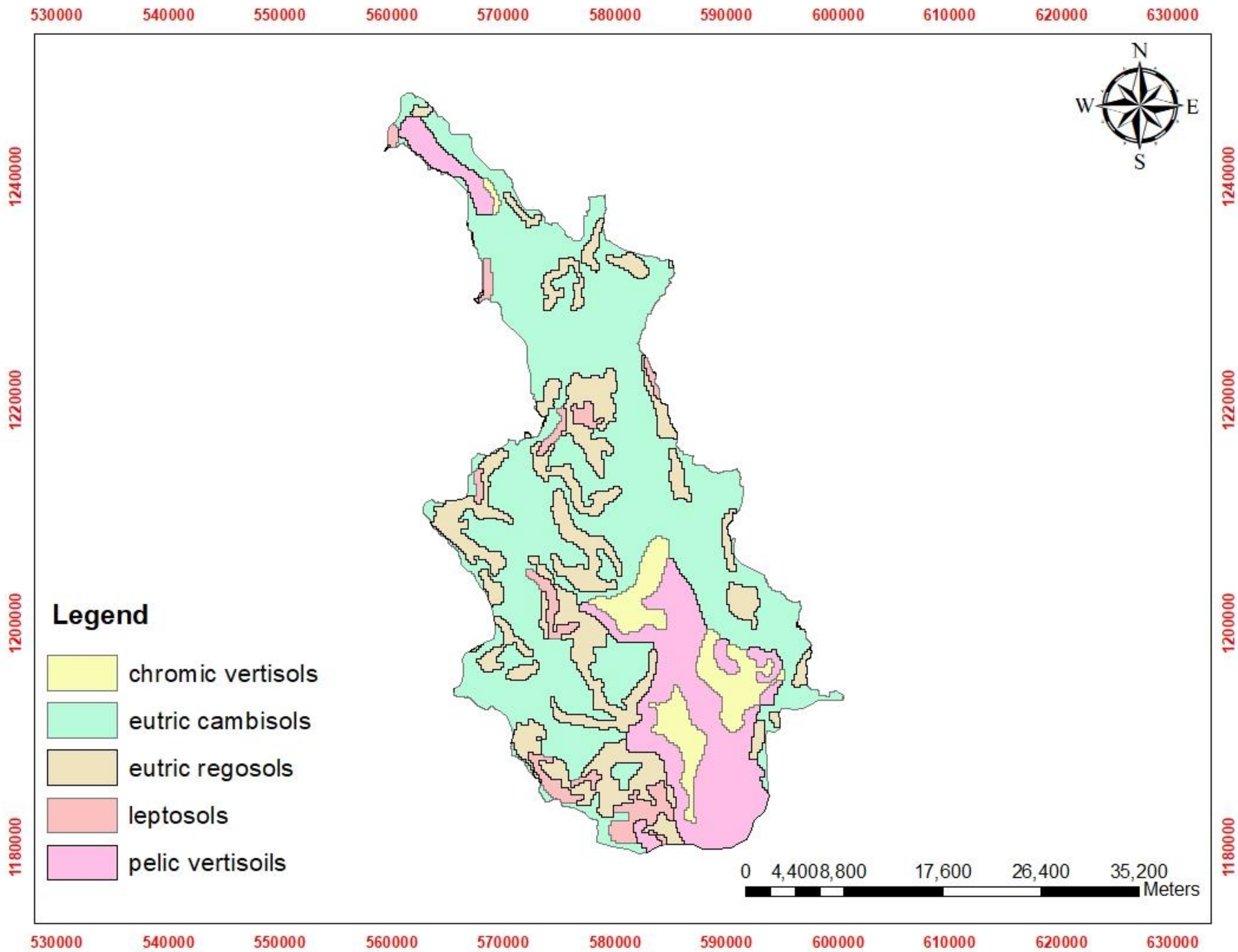

Figure 4 Soil type map of the study area

Chromic vertisoils: This kind of soil found in t southern part of the catchment that covers **79 km^2** and comprises about **6.6%** of the total area. It has silty clay to clay soil texture.

Eutric Cambisols: This soil type dominantly covers the area where farming activity is moderately intensive. It distributed in most parts of the area and it has **640km**^{2} of areal coverage, occupying about **53.7%** of the total area. It has loam soil texture.

Eutric Regosols: This kind of soil sparsely distributed in the middle of the study area with **244 km^2**. It occupies **20.46%** coverage of the total study area. It has sandy soil texture

Lephtosoils: This kind of soil has small areal coverage than the other soil types with **49km^2** and around **4.1 %** of the total study area with loam soil texture.

Pelic vertisoils: This soil type observed only in north and south part of the catchment with **180 km^2** which is **15.1%** of the total catchment area.it has clay soil texture.

2.4. Climate

Climate is one of the most crucial parameters considered in any groundwater exploitation and usage. According to (EMPDA, 1984) Temperature-altitude relationship of the Ethiopian climate are classified in to five zones the Desert (local name Berha) Tropical (local name, Kola), Sub tropical (local name woina dega), Temperate (Dega) and Alpine (Wurch (Kur). The study area has an average minimum temperature 10.5 and maximum temperature 22.1. Therefore the study area lays on Temperate and Tropical temperature zones.

Table 1 *Classification of climate zones according to* (EMPDA, 1984)

Temperature Zone	Local Name	Altitude (masl)	Mean Annual Temperature (^{0}C)
Desert	Bereha	Below 500	30-40
Tropical	Kola	500-1500	20-30
Sub-Tropical	Woina Dega	1500-2300	15-20
Temperate	Dega	2300-3300	10-15
Alpine	Wurch (Kur)	3300 and above	10 or less

2.5. Land use land cover and Vegetation

Land use land cover has It is obvious that the presence of vegetation protects the soil surface from the impact of rainfall. Root systems of vegetation tend to enhance soil porosity and permeability (Kresic, 2007).Urban areas and development generally decrease infiltration rates and increase surface runoff because of the increasing presence of various impervious surfaces (rooftops, asphalt, concrete). Urban areas are facilitating the water runoff other than percolation. Most of the basin has covered by annual crops. The area is also considerably covered with sparse forests. The study area has the following land covers (FAO, 1997).The map (Figure 5) Show land use/covers of the study area.

Vegetation is one of the parameter to be taken during hydrological assessment as it is related with infiltration process. Vegetation cover of an area used to minimize water loss or degradation through surface run off or flooding by intercepting rainfall and increasing infiltration of water to soil and to ground water table. Vegetation distribution in the study area varies from place to place depending on variation in altitude, climatic conditions and population density. The northern part of the study area, which receives the highest rainfall, is partly covered with green forests, while the eastern part of the study area with little rainfall has scattered trees and large farm lands.

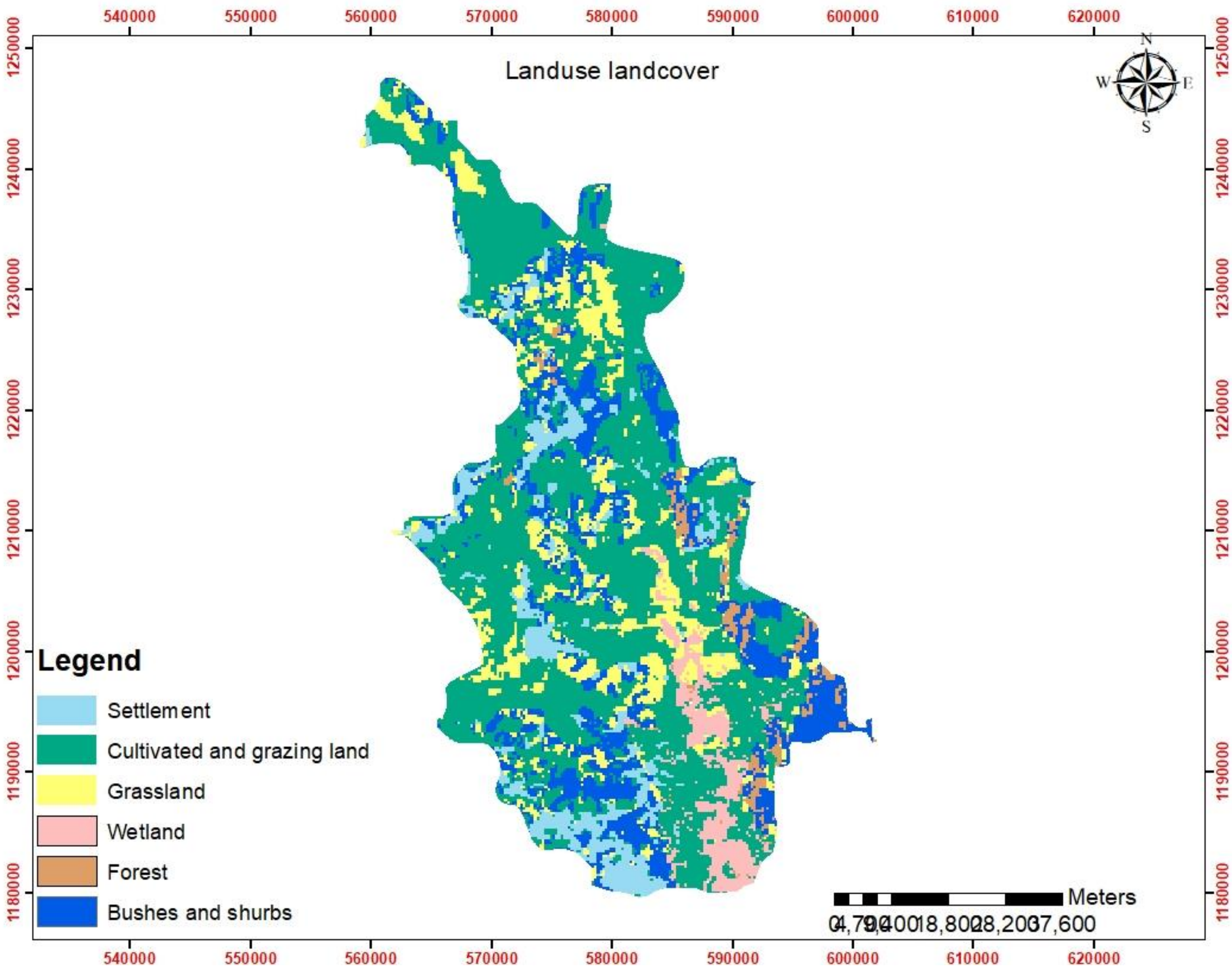

Figure 5 Land use land cover map **(FAO, 1998)**

CHAPTER- THREE

3. Geology

3.1.Regional geology

The Ethiopian geology is studied by many searchers and organizations, as summery the geology of Ethiopia divided in to four major physiographic regions, widely known as the **western plateau**, **southeastern plateau**, **the main rift** and **the afar depression**. The study area is located at eastern margin of western plateau.

The Ethiopian plateau is underlain at depth by Precambrian rocks of the Afro-Arabian Shield. The Precambrian basement is covered for the most part by glacial and marine sediments of Permian to Paleogene period and Tertiary volcanic rocks with related sediments.

The southwestern Afar Depression merges southward with the northeast striking Northern MER and eastward with the east-northeast striking Gulf of Aden. Northern MER, the Southern Red Sea and western Gulf of Aden lie within the Afar Depression forming a rift-rift-rift triple junction between the Nubian, Somalian and Arabian plates (Wolfenden et al., 2004).The southwestern block of the Afar depression separates in the west from the Northwestern plateau by the Western Afar margin. The Western Afar margin is bounded by a seismically active right stepping N-S trending discontinuous grabens that extend for 500 km.This grabens in the study area found in Kemise and Kombolcha areas. Tesfaye et al., 2003 indicated that the termination these marginal grabens near Kara Kore is abrupt, which Wolfenden et al. (2004) interpreted as the termination of the Oligocene Red Sea rift.

In northwest Ethiopia the early Cenozoic extensive fracturing and/or faulting is accompanied by widespread volcanism. Attempts have been made to relate the rifting and volcanism to the uplift in East Africa, which is related to Afar plume (Tefera et al., 1996, Pik et al., 1998 & 1999). However, there are discrepancies in the estimation of the extent, magnitude and timing of the uplift and an overall evolutionary model of the volcanic province. Cenozoic volcanism in the northwestern Ethiopian plateau was started by eruption of Ashangi basalt during the Eocene- Oligocene, and then followed by extrusion of Aiba basalts and Alajae formation during the Oligocene-Miocene. These volcanic episodes were characterized by the extrusion of flood basalts, with interbeds of pyroclastic rocks of rhyolitic or less commonly trachytic compositions, particularly at upper stratigraphic levels. These fissural volcanics were followed by central-type eruptions of alkaline Tarmaber-Gussa basalts during the Middle to late Miocene (Kazmin, 1979). The Ashangi and Aiba pulses consist of dominantly basalts whereas the Alajae Formation is represented by a bimodal rhyolite (ignimbrite) and basaltic volcanism. Silicic rocks of the Alajae cycle are mainly restricted to the plateau-rift border.

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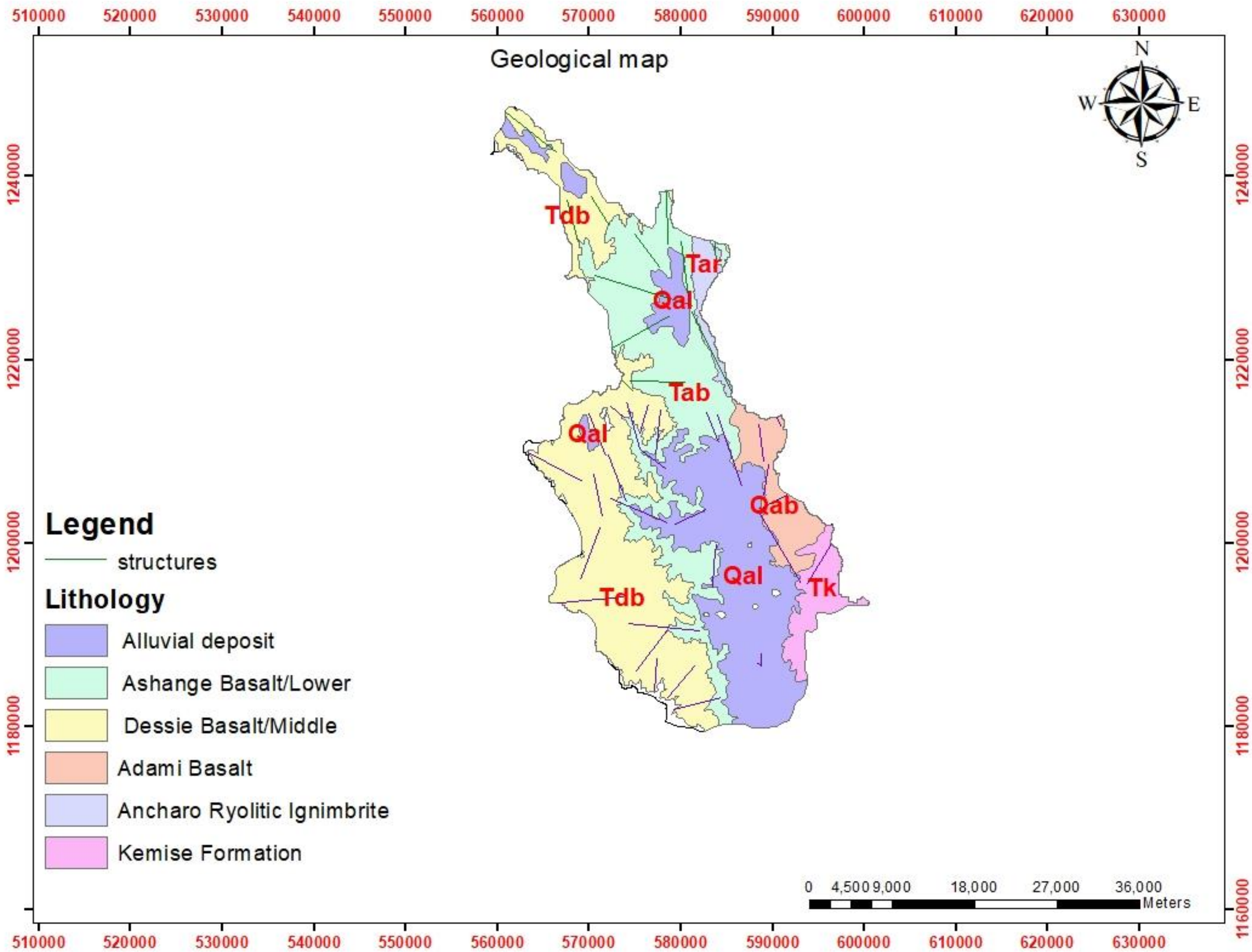


Figure 6 Geological map of the study area extracted from Dessie and Wereillu map sheet produced by Geological survey of ethiopia.

3.2.Local geology

The local geology is reviewed and summarized from Geology of Dessie map sheet and Wereillu map sheet studied in large map scale (GSE 2009).

Generally the study area comprises four major groups of the

- Cenozoic volcanic rocks:
- Eocene-Oligocene,
- Oligocene-Miocene,
- Late Miocene and Quaternary volcanic rocks and associated lacustrine and superficial sediments.

Previous formational names Ashangie basalt, Dessie basalt, Formation, Kemise Formation, Ancharo rhyolite and Adami basalt are adopted from Zanettin et al. 1974; Tefera et al.,1996; Hoffman et al., 1997; Ayalew et al., 2002 and Wolfenden, 2003. The lithologies which are found in the study area are presented in (Figure 6) above

Eocene-Oligocene volcanic rocks

Ashangie basalts

The Ashangie basalts represent the earliest (pre-oligiocene) of Tertiary fissural volcanism in the Dessie area (e.g. Tefera et al., 1996). They are exposed in the western plateau and the western Afar marginal area. Its north western part of the study area thickness decreases towards south (< 200 m) along Dessie Kombolcha road. The volcanic products of this cycle are highly weathered crushed by tectonics activity with large-scale erosion having probably removed the upper portions (Zanettin and Justin–Visentin, 1974). The Ashange basalts ranges in total thickness from 600 to 800m These basalt flows represent the lower most parts of volcanic successions.. Characteristically the exposures of the Ashangi basalt are strongly weathered, intensely fractured and jointed, friable and rarely vesicular.

3.2.1. Oligo-Miocene sequences

Dessie basalt formation

The name Dessie basalt formation is adopted from Wolfenden (2003). It is exposed in the western plateau area forming chain of ridges like Tossa Mountain. The formation is about 1500 m thick (Tossa). This unit is represented by association of different types of aphanatic and porphyritic, massive and vesicular basalts, with subordinates of pyroclasts and ash layers. The basalts of this formation were produced by fissural eruptions and unconformably overlie Ashange formation and attain a thickness of 200 to 600m. They are generally aphyritic compact rock, in places showing stratification and columnar jointing and pinch out southward and westward.

3.2.2. Late-Miocene

Kemise Formation

Kemise formation has been previously mapped as Kemise rhyolite formation (Wolfenden, 2003). It is exposed in the central eastern part along the western margin of the Afar rift. It consists of rhyolite, ignimbrite, tuff and ash. The outcrop is found usually as discontinuous

tectonic blocks bounded by normal slip faults. The Kemise formation comprises pink and greenish gray rhyolitic ignimbrite, which is weathered to yellowish brown, light gray and reddish brown Figure 5. It is medium to coarse grained. The rhyolitic ignimbrite forms NW-SE oriented isolated or chains of ridges.

Figure 7 A) pinkish rhyolite unit top view B) Fractured, gray ignimbrite unit quarry exposure in the study area

Ancharo rhyolite ignimbrite

This unit forms a north-south trending hill east of Kombolcha, which is named after the locality called Ancharo. It is well exposed in quarry site along Kombolcha-Bati road, where the exposed thickness is about 50m. The rock is white, pink, gray and medium to coarse grained. A Miocene succession of rhyolite flows, domes and minor pyroclastic rocks exposed in the eastern, south-eastern parts of the study area between the western margin of the Afar rift and along the eastern border of the marginal grabens has been shown as Kemisse and Ancharo Rhyolite Flows, Domes and Ignimbrites.

3.2.3. Quaternary volcanics

Adami basalt

The Adami basalt is exposed in the southeastern part of the study area. The unit forms plain and hilly topography. Adami basalt is named after Adami village, located northeast of Harbu town. The unit forms small to big hills and flat-lying topography and well exposed. The basalt is greenish gray, friable, strongly weathered to reddish brown and green color.

Alluvial deposits

These are exposed in the eastern low land plain and in the central part along the western Afar marginal basin. They are covered by black cotton and reddish brown silty to sandy soil with few outcrops of diatomite which are found between the blocks evidently lacustrine deposition is related to the intermountain plains which used to hold significant depths of fresh water. Those are the main aquifer system in the study area.

The black cotton soil is commonly seen along the western marginal basins. The thickness of the soil is more than 3 m as observed along the main road. Reddish brown sandy soil is mainly seen on the plain on the top of the western plateau and on the eastern low land plain of the Afar rift floor. The lacustrine sediment is 1 m thick weathered gray, horizontally thinly laminated to thickly laminated and bedded diatomite exposed along the Afar rift floor in the southeastern part. The fluvio-lacustrine sediments are mostly covered by thick reddish brown silty to sandy soil with rare layers of diatomite. It is evident that there was interplay between lacustrine and fluvial facies at many exposures. In the Afar rift floor in the south-eastern part of the project area Tadesse et al (2011) reported that the lacustrine sediments are 1m thick weathered to grey and yellowish from light color, horizontally thinly to thickly laminated and bedded diatomite.

3.3.Structure

The structures in the area are characterized by normal faults; lineaments represented by fractures and/or joints of variable strike and length, and minor strike slip.

3.3.1. Normal faults

Normal faults in the study area exist into two major forms: low-angle normal slip (Detachment) and high angle normal faults.

Low-angle normal-slip (detachment) faults

The low angle normal-slip (detachment) faults are SW- to NW and WNW- trending and dipping to the north and northeast. The two prominent big detachment faults are the Bati-Kombolcha-Dessie fault and Mile-Mersa. Both faults are characterized by top to NW and SW sense movement. The former separates Ashangie basalt, Ancharo rhyolitic ignimbrite and Wederage basalt at the foot wall with Kemise rhyolitic ignmbrite at hanging wall, whereas the latter separates the Ashangie basalt at the foot wall with Kemise rhyolitic ignimbrite at the hanging wall.

High-angle normal-slip faults

High-angle normal faults in the area exist in two forms:

(i) Marginal fault/ escarpment and

(ii) The faults associated with low-angle normal slip (detachment) faults.

The marginal fault/ escarpment separate the plateau from the Afar rift depression. The trend and the amount of displacement along the escarpment vary along the strike. They have an overall NNW general orientation, long, widely spaced and have large vertical offset (> 1000 m). They also form the western Afar rift boundary. The high angle normal faults associated with low-angle slip faults (detachment) are closely spaced with the general NNW trend dipping towards west and east. These faults include the Bati fault. The earlier high angle and low-angle extensional deformations are followed by younger ENE-trending sinistral strike-slip faults. In southern part in the Were-Ilu map sheet these strike slip faults have dextral slip movements and clearly seen bounding the marginal basins

CHAPTER FOUR

4. Hydrometeorological data analysis and recharge estimation

4.1.Hydrometeorology and Hydrology

Hydrometeorology is the branch of study which links both hydrology and meteorology (Shaw,1988). Hydrometeorological data are required to determine the water balance of a basin for developing and managing its water resources. The most useful hydrometeorological elements are precipitation, evaporation, evapotranspiration, solar radiation (sunshine hours), air temperature, humidity, soil moisture, water levels (surface and underground), stream discharge, water quality (Raghunath, 1987). The main objective of analyzing hydrometeorological data is to compute evaporation, potential evapotranspiration, Actual evaporation and runoff thereof can be used the analysis further used in calculation of the water balance of the study area.

Hydrology is a science which deals about predicting and understanding the management of water resources. Hydrology is comparatively a new science. The science perhaps found in the year 1930. Since that time, it has progressed considerably giving us more and more confidence in predicting hydrological events such as rainfall run off, ground water accretion etc (Garag, 2010). Monthly meteorological data including rainfall, maximum and minimum temperatures, relative humidity, wind speed and sunshine hours are collected from the National Meteorological Agency (NMA).

4.3. Rainfall data

The spatio- temporal variation of rainfall in Ethiopia is mainly controlled by the movement of position of inter tropical convergence zone (ITCZ) (Tenalem and Tamiru, 2001).During the principal rainy season from June to September, the ITCZ which is located north of Ethiopia. During this time South west winds bring rain from the Atlantic Ocean and the study area receives majority of rainfall in these months (JJAS). The dry period from October to February occur when the ITCZ lies south of the country. In these months the north easterly trade winds moving to Arabia dominates whereby the area produces little or no rainfall. During March, the ITCZ is located south of the country moving northwards. At that time low pressure is developed in Sudan and Arabia while high pressure is developed in Gulf of Aden and Indian Ocean. The high pressure generates south east winds which bring the small rain from the Indian Ocean. Rainfall data have been collected from relevant meteorological stations. Rainfall has direct relationship with altitude as shown in (figure 9) the highest rainfall which is 1573.6 mm recorded at 2428m elevation in western part in Albuko station and the lowest rainfall which is 1013.3 recorded in Cheffa station at 1400m elevation.

The annual mean average precipitation is 1190 mm, mean summer precipitation is 810.6 and mean winter Precipitation is 380.1.

Table 2: *Meteorological stations Rainfall data availability within Borkena river catchment*

Year	X	Y	Z	Station	Annual Rainfall
2007-2017	577980	1195287	2428	Albuko	1573.6
2002-2016	583672	1214036	1400	Cheffa	1013.3
2001-2018	585906	1207412	1507	Harbu	1014.1
1986-2003	591029	1184568	1450	Kemise	1071.0
1986-2018	578284	1225144	1857	Kombolcha	1027.6
1986-2006	569065	1229115	2553	Dessie Zuriya	1264.4
2002-2018	573179	1234191	2465	Tita	1138.2

Table 3 : *Long term mean monthly precipitation of the stations in the catchment*

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Albuko	16.5	45.6	56.4	110.5	123.8	59.3	404.0	475.7	143.0	60.4	52.5	25.8	1573.6
Cheffa	21.3	22.2	71.8	94.1	58.3	24.3	261.2	298.6	90.3	29.4	20.5	21.3	1013.3
Harbu	15.2	22.4	87.8	96.4	40.9	32.0	259.8	293.9	98.8	19.3	19.4	28.2	1014.1
Kemise	26.2	36.1	62.5	101.3	61.1	28.0	257.5	288.3	120.5	51.3	22.8	15.4	1071.0
Kombolcha	22.7	24.2	62.8	94.9	56.9	33.2	281.1	264.8	106.3	44.9	19.4	16.5	1027.6
Dessie Zuriya	25.7	35.7	77.9	91.9	70.1	39.3	322.9	339.6	160.8	54.5	24.2	21.7	1264.4
Tita	20.7	28.6	75.3	91.6	78.6	36.6	287.4	334.8	96.2	50.3	25.1	12.9	1138.2

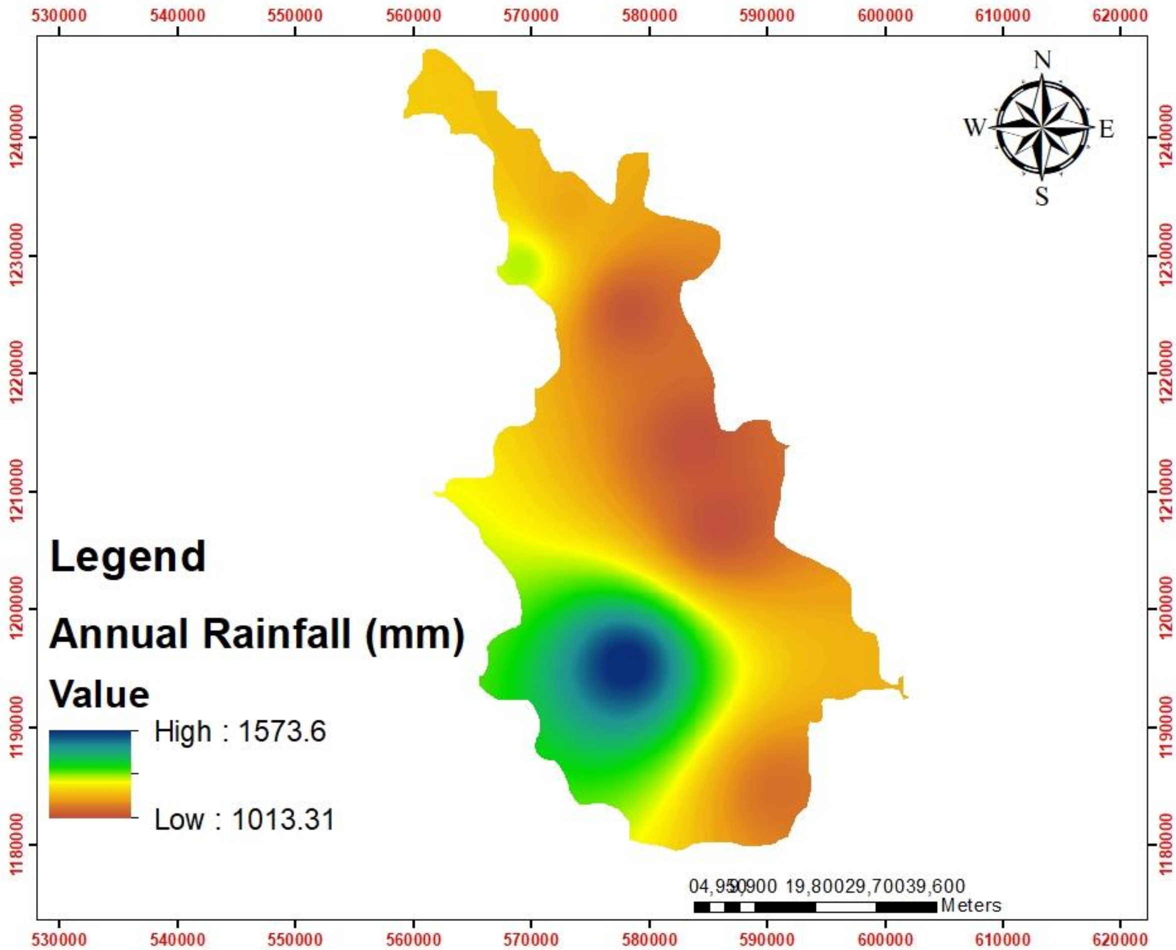


Figure 8 *Annual Rainfall of the study area*

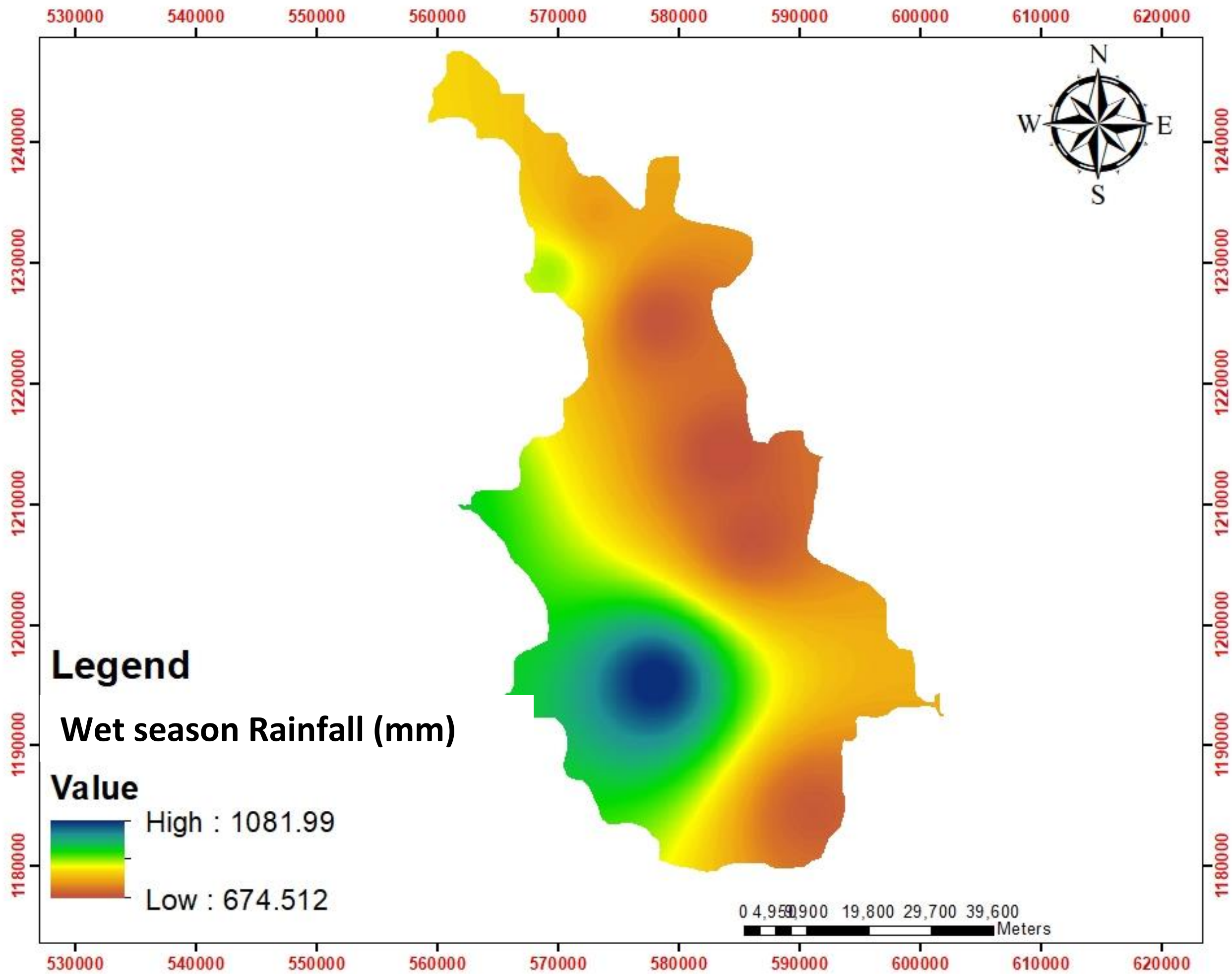


Figure 9 summer (wet season) rainfall

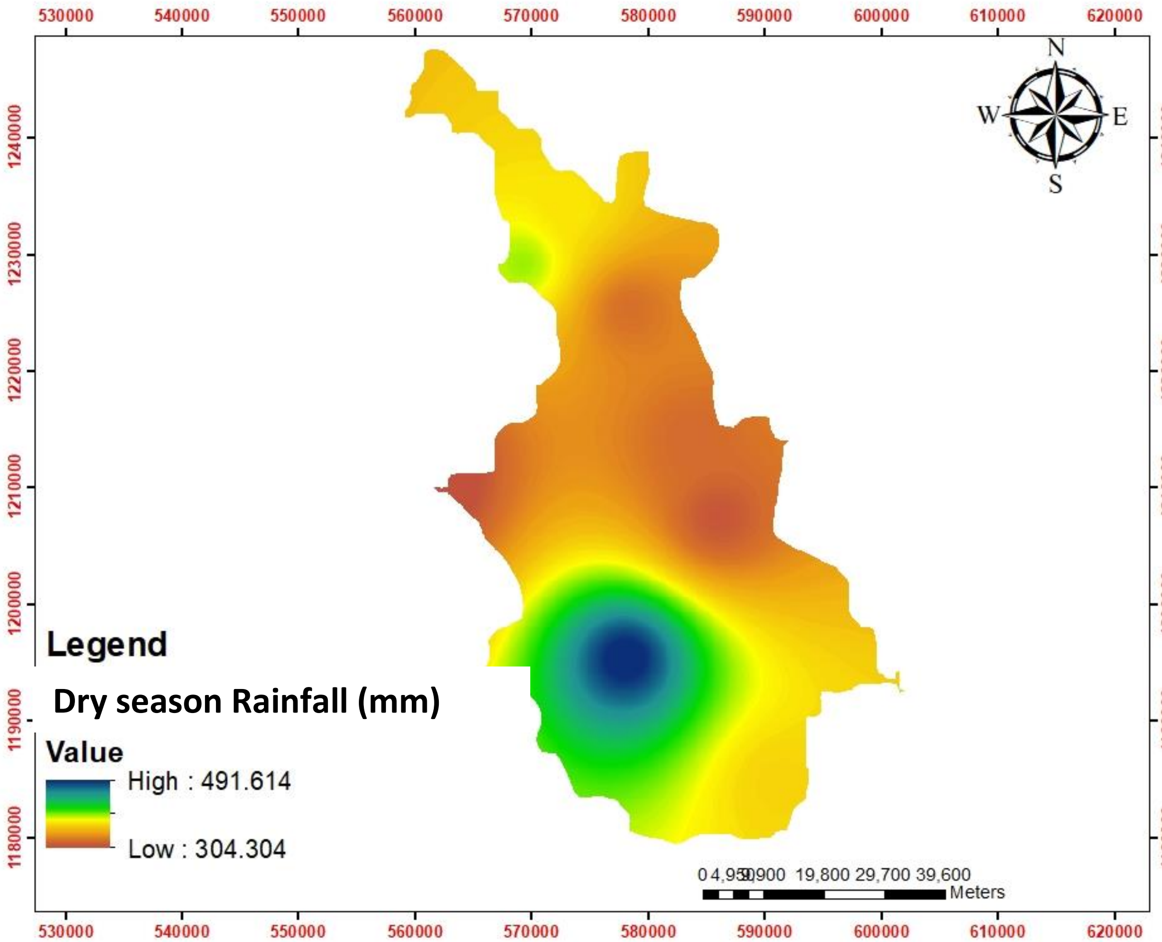


Figure 10 Winter (dry season) rainfall

The following long term monthly rainfall values of representative stations located in the study area shows the Wet and dry seasons. From the figure 11 it can be observed that July and August are wettest months, while December to January are dry months with the lowest amount of rainfall recorded.

The rainfall distribution in the study area ranges from 1013.3mm to 1573.6mm. The highest rainfall is recorded in Albuko highland area and the lowest rainfall is from Chefa low land plain. The bar graph shows, the maximum rainfall is recorded in the month of July and the minimum in the month of January. The majority of rainfall in the catchment is concentrated during Ethiopian wet season (Kiremt). The main rainfall season of the study area is during the wet season from June to September. The rainfall distribution patterns of the area for the stations are of bimodal type that is relatively higher rainfall records in the month of March and April apart from the wet season is observed

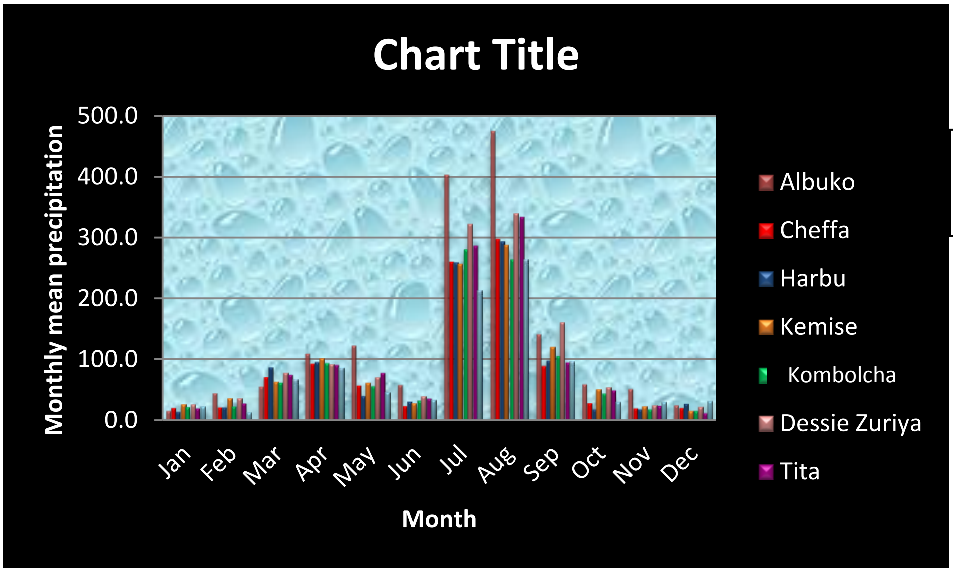


Figure 11 long term monthly rainfall which has bimodal rainfall system

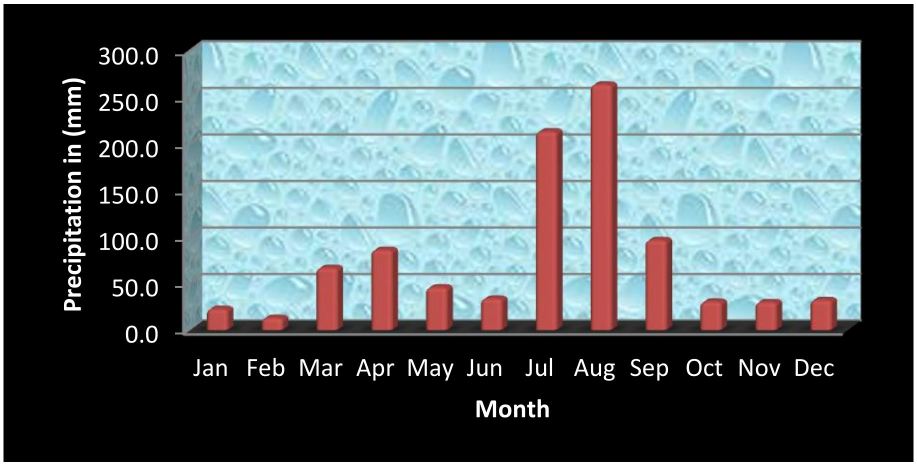


Figure 12 Monthly annual rain fall

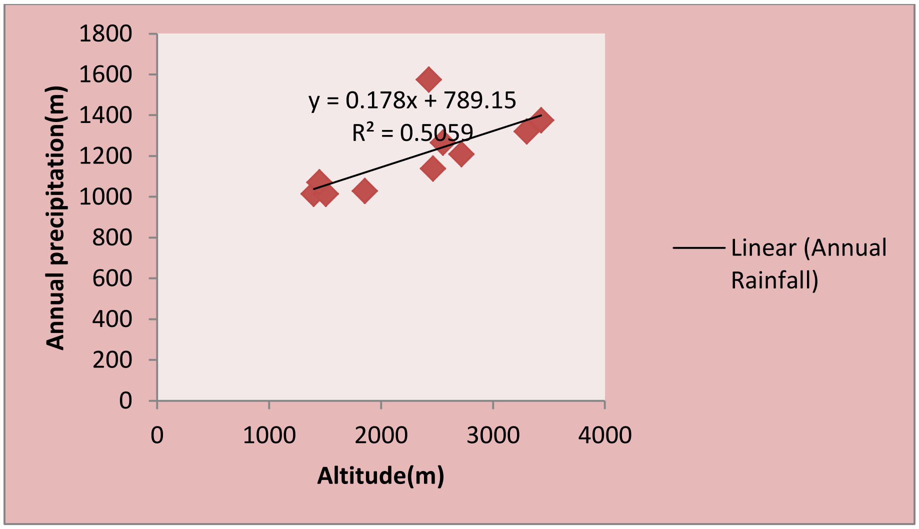


Figure 13 r elationship of Anuual rainfall and altitude

4.2.Determination of aerial depth of precipitation

A rainfall measurement is a point observation and may not be used as a representative value for the whole area under consideration. To obtain more reliable and representative result, the effective uniform depth of precipitation for the catchment has to be worked out. Therefore, the point measurement has to be averaged over the area (Tenalem Ayenew and Tamiru Alemayehu, 2001). There are three different methods to determine the average depth of rainfall over the study area, these are

- Arthmetic mean
- Theisson polygon method
- Isoheytal method

These methods are used to weigh the station rainfall to estimate the areal rainfall of the catchments.7 stations in the study area and 3 additional nearby stations were used to calculate the aerial depth of precipitation of the catchment. The long term mean monthly precipitation is listed on Table.

4.2.1. Arithmetic Mean Method

Arithmetic mean method 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 station.

$$P_{A=}\frac{P1 + P2 + \ldots Pn}{n}$$

Where PA is the average depth of precipitation of the area and P1, P2, and Pn are the rainfall records at the stations. Accordingly, the areal depth of precipitation of the area as calculated by using 7 stations included in the study area is 1200.5 mm.

4.2.2. Thiessen Polygon Method

The method of Thiessen polygons consists of giving more weight in which it is considered that the rainfall is equivalent to that of the station. The influence zones are represented by convex polygons. These polygons are obtained using the perpendicular bisector of the segments which link each station to the closest neighboring stations (Figure 15). This method is more accurate than that of the simple arithmetic mean method.

The method $P = \frac{P1A1 + P2A2 + \cdots .PnAn}{At}$

Where P1, P2... Pn are mean annual rainfall recorded at each rainfall stations where as A1, A_2, A_3 is polygonal areas around each gauging stations enclosed in the catchment and A_T is total area of the catchement . The result obtained from using this method is displayed in table below. Accordingly the average annual precipitation of the study area using this method is 1204.87 mm. Boru meda, Tebasit and Guguftu stations are not included in the study area but as they are nearby stations can be used as additional station as the average monthly mean precipitation is similar to the result of the three methods.

Table 4 Areal depth of precipitation using Thiesson polygon

Station	Annual RF	Area(km^2)	Weighted area (%)	Weighted RF
Albuko	1573.6	342	28.69	451.49
Cheffa	1013.3	176	14.77	149.61
Harbu	1014.1	188	15.77	159.94
Kemise	1070.9	189	15.86	169.80
Kombolcha	1027.6	143	12.00	123.28
Tita	1138.2	119	9.98	113.63
Dessie zuria	1264.4	35	2.94	37.12
TOTAL	1157.44	1192.00	100.00	**1204.87**

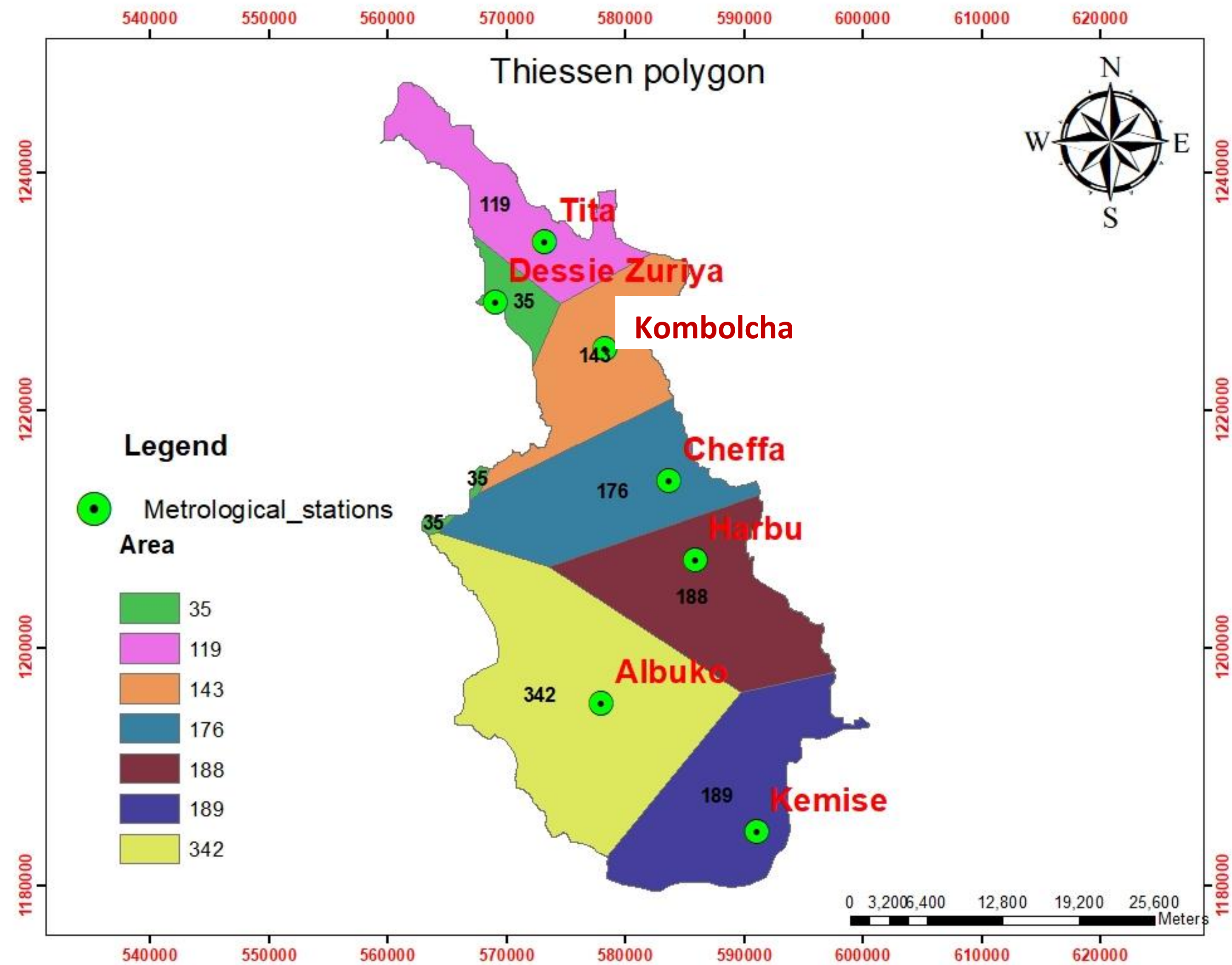


Figure 14 Thiessen polygon

4.2.3. Isohyetal method

This method is applied by preparing an isohyetal map that join points of equal rain fall value and then measure their inter-isohyetal area. It consists of drawing lines of equal rainfall depth (Isohytes) by interpolation between observed rainfall depths at observed points. The average depth of precipitaion is given by:

$$P_{A=} \frac{P1{,}2*A1{,}2 + P2{,}3*A2{,}3 \ldots Pn-1{,}n* An-1{,}n}{At}$$

P1,2, P2,3... Pn -1,n are mean annual rainfall recorded between two countour lines rainfall stations where as A12, $A_{2,3}$, $A_{n-1,n}$ is area between two isoheytal lines enclosed in the catchment and A_T is total area of the catchement (Figure 16)

One advantage of the method for determining catchment average is that it allows the influence of physiographic parameters to be taken in to account. These factors include elevation, slope, and distance from the coast and exposure to rain- bearing winds (Shaw, 1988). The method yields an annual mean precipitation of 1219.6.

All the above methods are used to calculate areal depth of precipitation from point measurement. However, depending on distribution of gauging stations and the effect of topography validity of Arthemetic mean and Thiessen Polygon methods is less. Thiessen polygon method for determine areal rainfall is sound and objective, but it is dependent on a good network of representative gauges (Shaw 1988). In the study area the network of gauges is poor. Arthemetic mean is also unreable in the study area.

Table 5 : Areal depth of precipitation using isohyet method

OBJECTID *	Enclosed area	Rainfall	Weighted area	weighted Rainfall
1	58.0	1071.0	0.05	52.1
2	35.7	1573.6	0.03	47.1
3	55.4	1537.0	0.05	71.4
4	92.5	1462.5	0.08	113.5
5	106.7	1387.5	0.09	124.2
6	142.2	1237.5	0.12	147.6
7	91.2	1013.7	0.08	77.6
8	18.4	1027.6	0.02	15.8
9	228.0	1087.5	0.19	208.0
10	18.6	1264.4	0.02	19.7
11	345.3	1182.0	0.29	342.4
	1192.1		**1.0**	**1219.6**

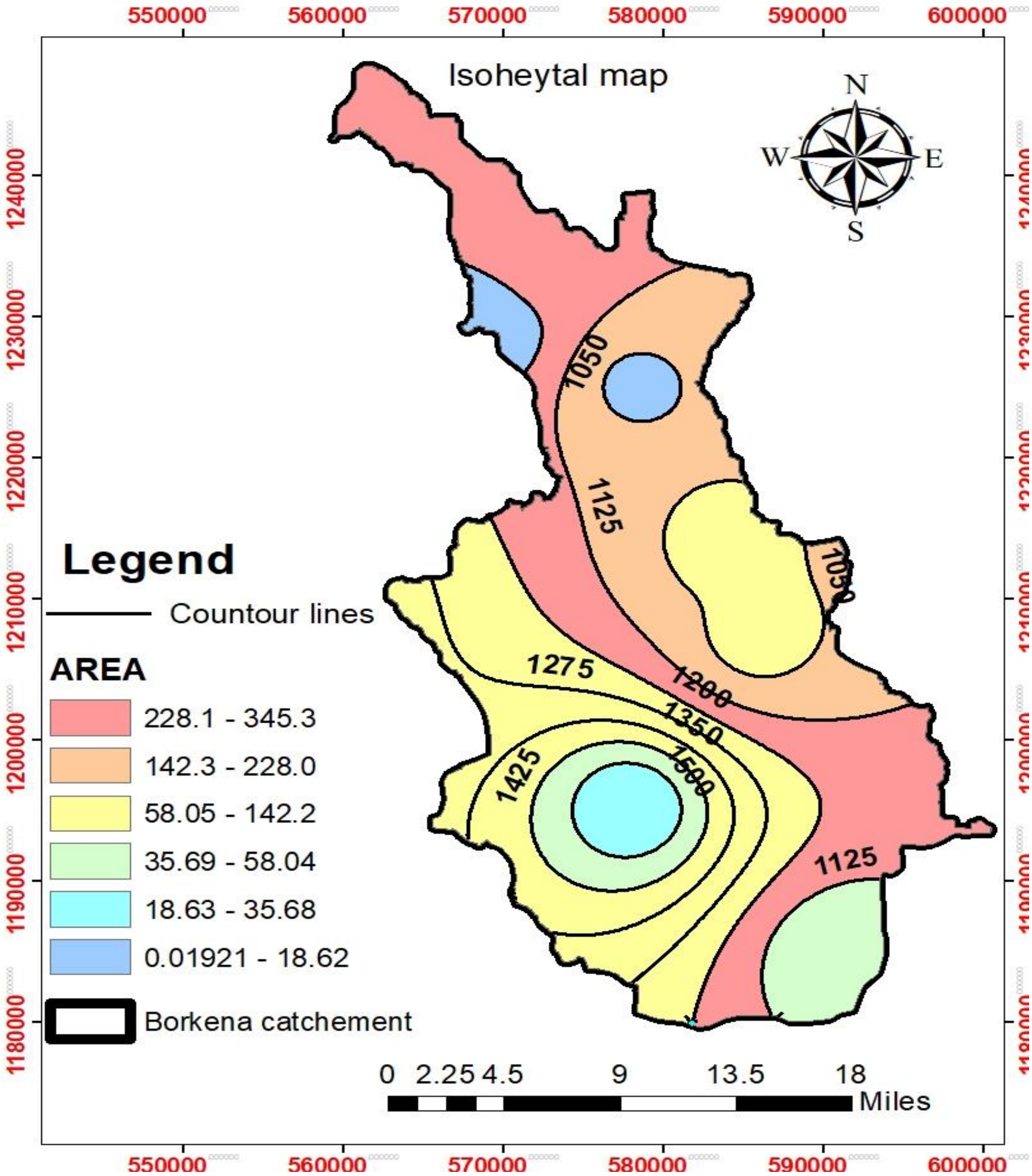
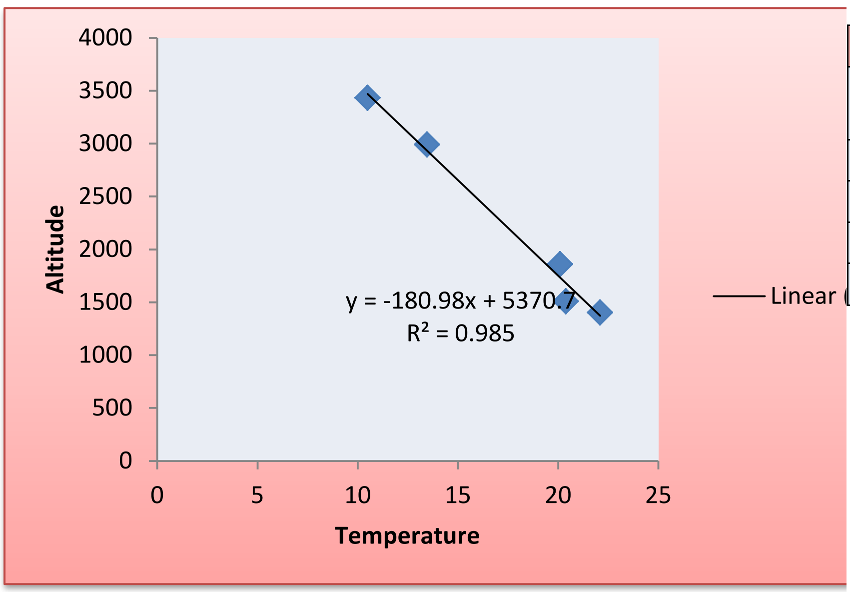


Figure 15 Isoheytal map

4.3.Temperature

There is high correlation between the temperature and the altitude. From the spatial distribution of the temperature in the catchment, 22.03 is the highest which is being observed in the lowland portion of the study area i.e., is in Chefa with an elevation of 1400. The lowest temperature is 13.3 in Guguftu which is being observed in the highlands of Ethiopia in the northern part of the basin. The study area encompasses different climate zones from **sub-tropical (dega-weyna dega** to **Warm Temperate (Kola)** climatic zone. Six stations are selected to analyze the temperature. Mean Minimum temperature of the stations was 10.01and mean maximum temperature was 24.21.



Station	altitude	Temperature
Amba Mariyam	2990	13.475
Kombolcha	1857	20.1
Harbu	1507	20.4
Guguftu	3431	10.5
Cheffa	1400	22.1

Figure 16 relationship of Temperature with altitude

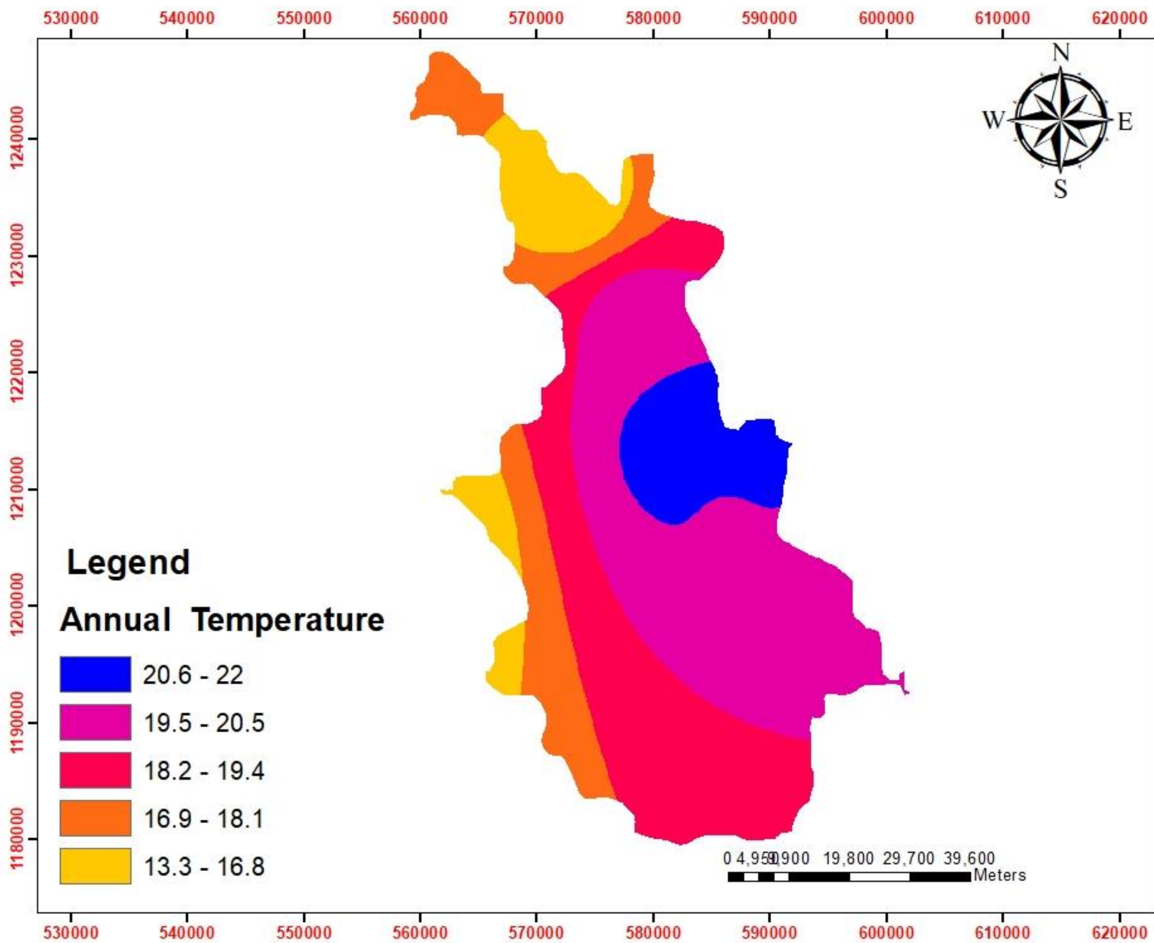


Figure 17 Annual Temperature

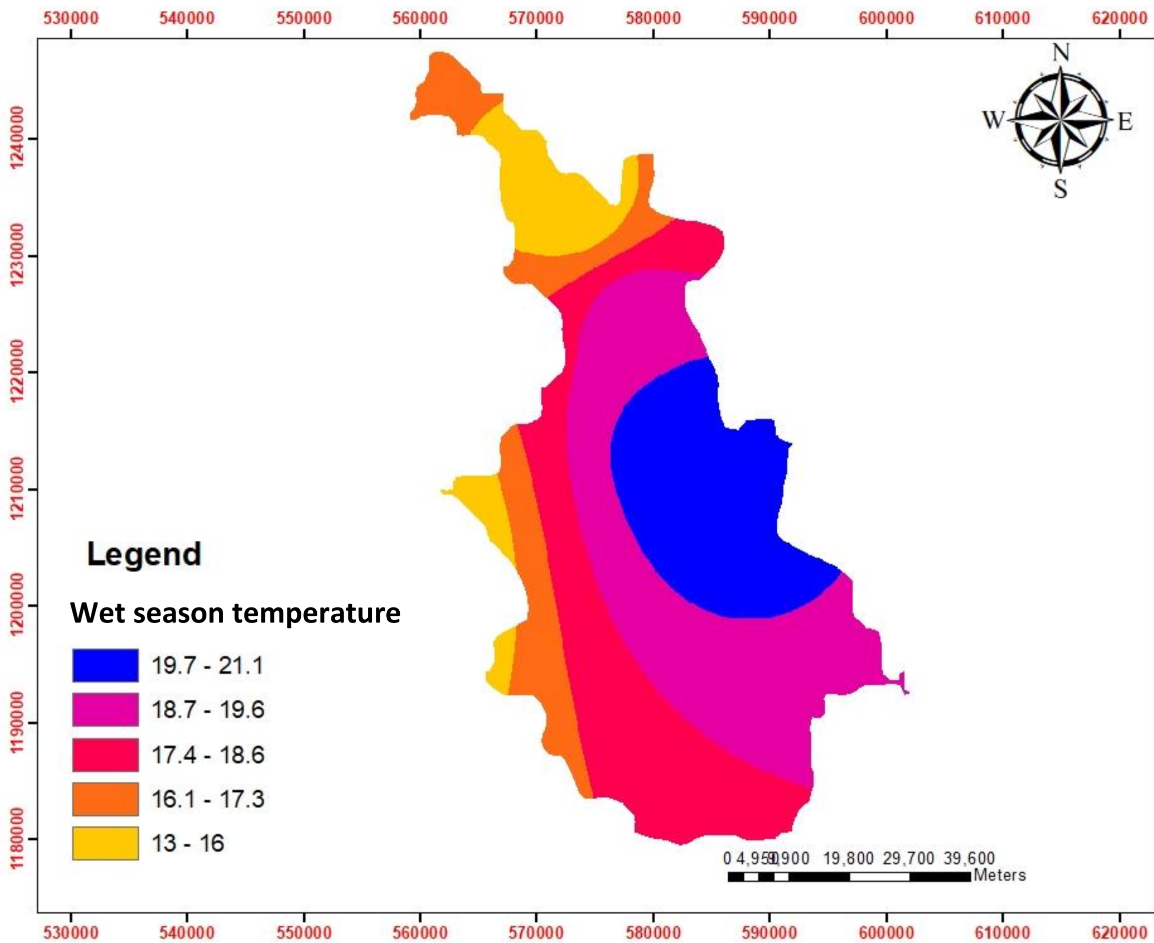


Figure 18 Summer (wet season) Temperature

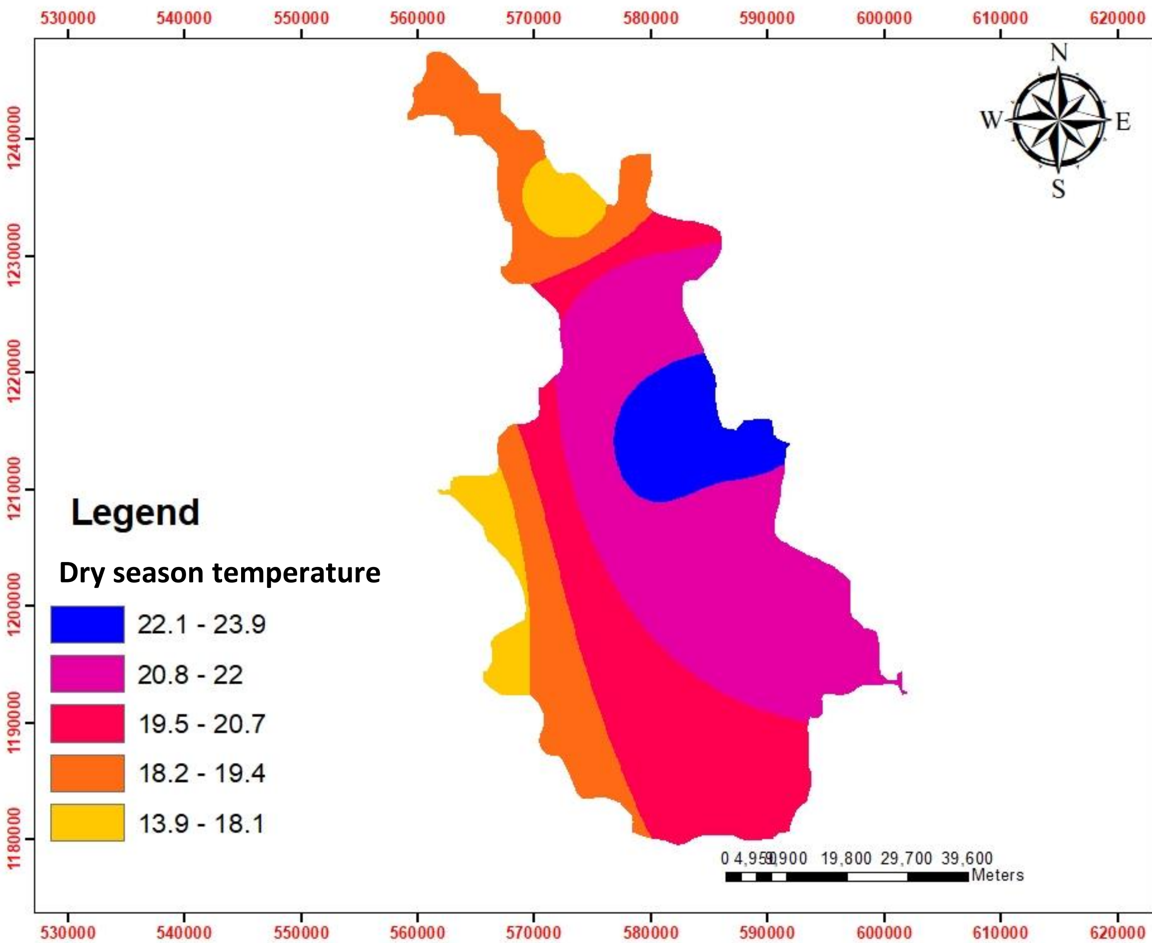


Figure 19 Winter (dry season)Temperature

4.4.Wind Speed

Wind direction refers to the direction from which the wind is blowing. It is expressed by its direction and velocity. The maximum average wind speed is recorded at Kombolcha station that is 1.36m/s and the minimum wind speed is recorded at Cheffa station that is 0.61m/s.

Table 6 Monthly and annual wind speed of the study area

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Kombolcha	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.6	0.4	0.4	0.4	0.5	0.61
Cheffa	1.4	1.5	1.6	1.5	1.5	1.6	1.6	1.2	1.0	1.0	1.1	1.2	1.36

4.5.Sunshine Hours

Evaporation take place almost without interruption during both day and night, however the process is almost active under direct radiation from the sun.

The sunshine hour was analyzed from few stations. The maximum mean annual average sunshine hour has been observed in Amba Mariam station that is 8.2, which is the highland of the study area and the minimum sunshine hour is 7.82 in Cheffa station which is the low land of the study area.

Table 7 Monthly and annual sunshine hour of the study area

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Kombolcha	8.1	9	8.3	8.3	8.6	7.5	6.3	6.4	6.9	8.2	8.8	8.4	7.9
Cheffa	7.5	8.5	8.1	8.1	8.9	7.2	6.1	6.6	7.2	8.5	8.8	8.3	7.82
Amba Mariyam	9	9.2	8.5	8.3	8.9	7.1	5.4	6.2	7.7	9.5	9.3	9.3	8.2
Average	8.20	8.90	8.30	8.23	8.80	7.27	5.93	6.40	7.27	8.73	8.97	8.67	7.97

4.6.Relative humidity

It refers the amount of water vapour present in air expressed as a percentage. It measures the amount of water in the air in relation to the maximum amount of moisture at a given temperature. The annual average RH is 59.9. The maximum and minimum mean annual RH is observed in Amba Mariam station which is 60.9 and Cheffa station which is 58.6 respectively.

Table 8Monthly and annual relative humidity of the study area

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Cheffa	62.3	55.7	55.6	57.2	56.1	42.6	58.2	71.2	68.8	61.3	59.3	57.9	58.9
Kombolcha	62.8	55.6	55.4	59.6	54.8	44.3	57.4	67.8	64.5	60.1	61.3	60.0	58.6
Amba Mariyam	53.9	49.1	54.7	57.7	59.4	53.0	75.1	81.2	70.1	61.8	59.7	55.4	60.9
Average	59.7	53.5	55.2	58.2	56.8	46.6	63.6	73.	67.8	61.1	60.1	57.8	59.5

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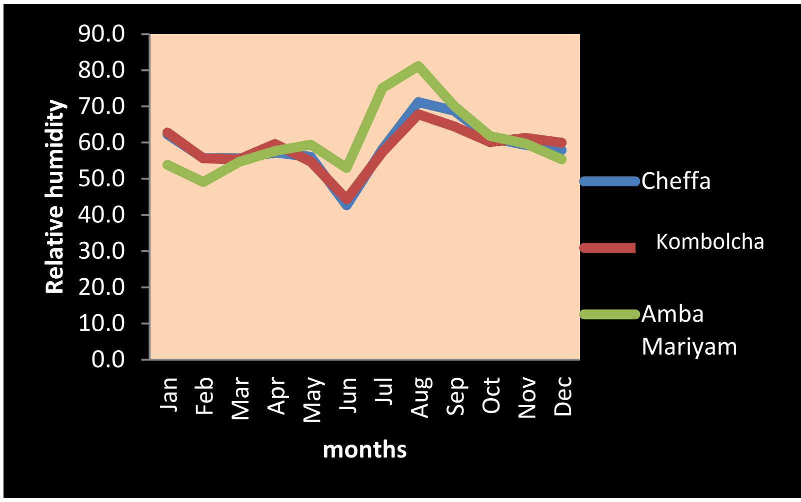
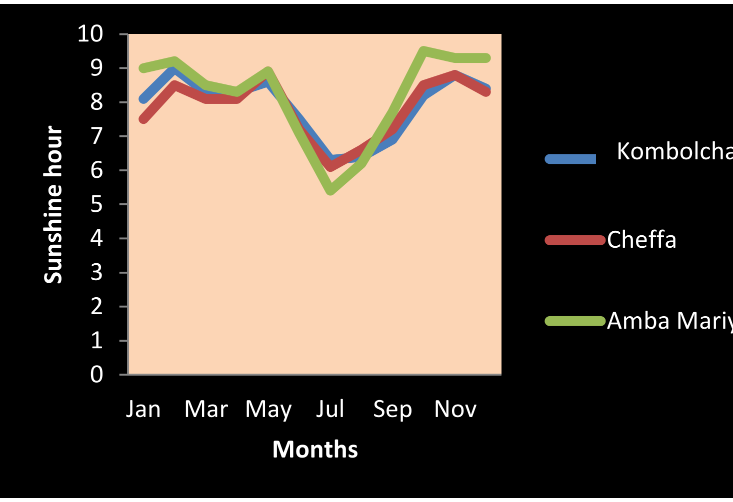
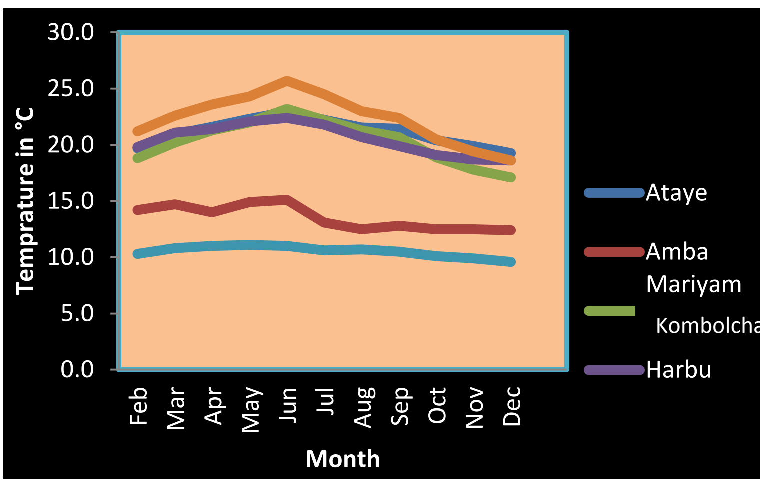


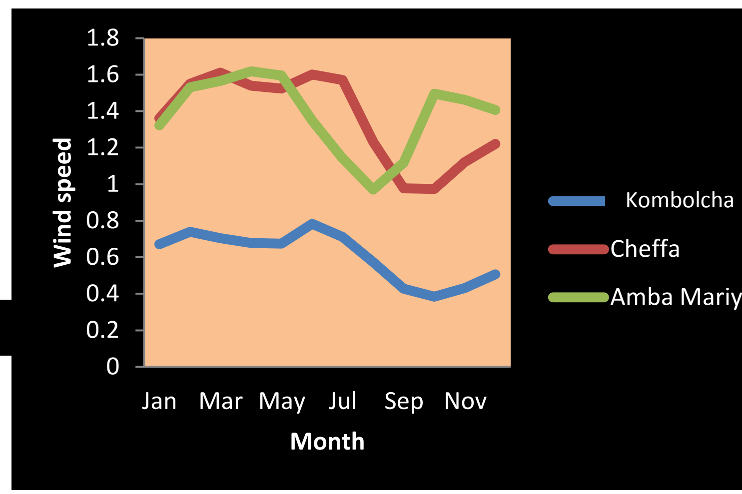
A. Relative humidity



B. Sunshine hour



C. Temperature



D. Wind speed

Figure 20 Monthly metrological data graph

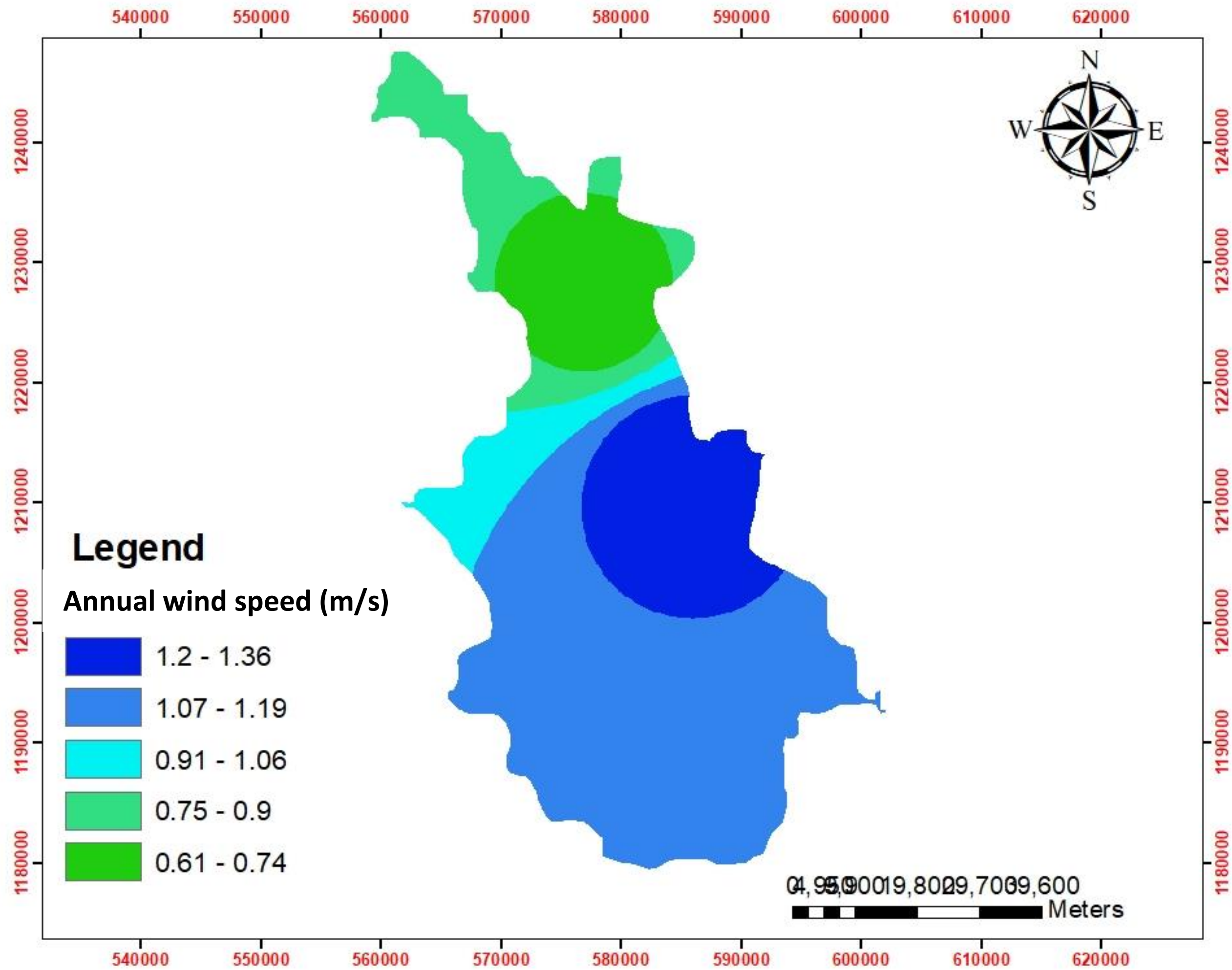


Figure 21 Annual wind speed of the study area

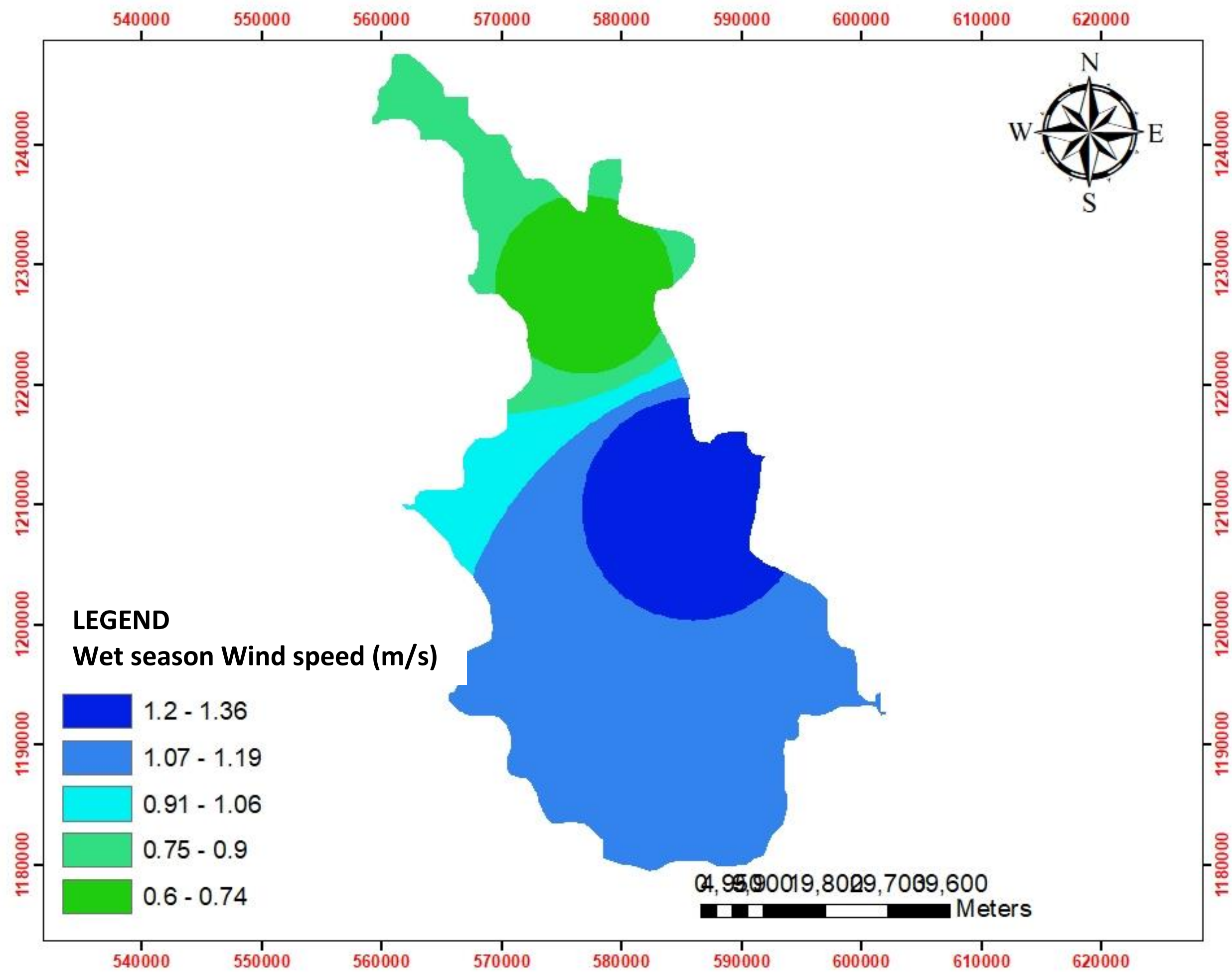


Figure 22 Summer (Wet season) wind speed of the study area

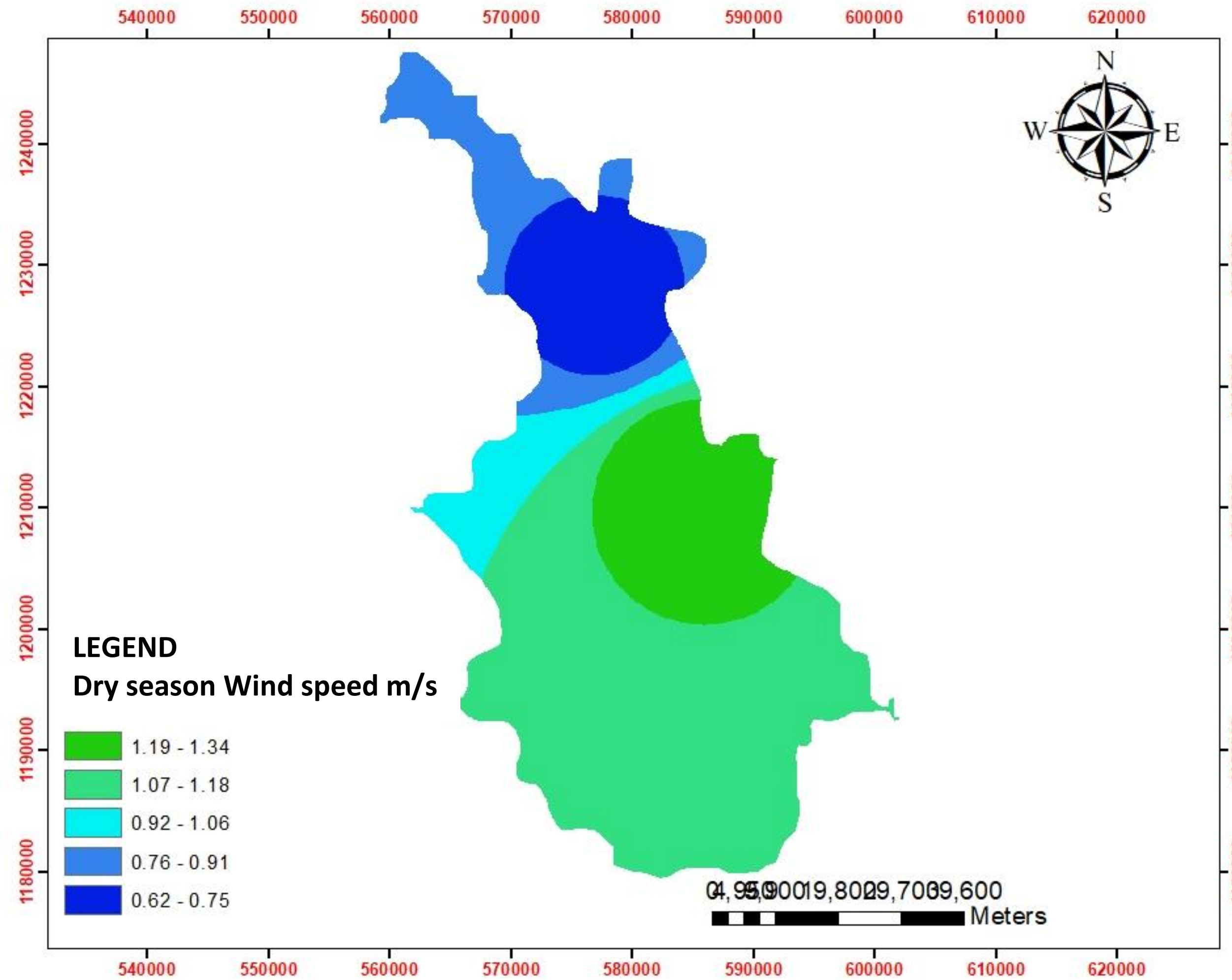


Figure 23 Winter (dry season) wind speed of the study area

4.7.Potential Evapotranspiration

Potential evapotranspiration or PET is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply.

It is the evaporation from vegetation cover if sufficient water is supplied to obtain optimum growth or it is the maximum amount of water which might be transferred under the existing metrological condition (Tenalem Ayenew and Tamiru Alemayhu, 2001). There are few stations having only sunshine hours, relative humidity and wind speed records, The Thornthwaite method used in this study based on the available input data as it requires temperature data as to calculations of potential evapotranspiration. By making some adjustment of latitude correction, this approach has been used to calculate the potential evapotranspiration of the catchment.

4.7.1. Thornthwaite method

Thornthwaite method is based upon the assumption that potential evapotranspiration is dependent only up on meteorological conditions and ignores the effect of vegetative density and maturity. Thornthwaite produced a formula for calculating PET based on temperature as index of energy available for evapotranspiration with an adjustment being made for the latitude, location and number of daylight hours (Dunne and Leopold, 1978) First, Thornthwaite defined the heat index i_m for any month *m* as

$$i_m = (t_m/5)^{1.514}$$

m = 1, 2, 3…12 Where t_m is mean monthly temperature in °C. The twelve monthly heat indexes are then added to obtain the annual heat index. $I = \Sigma(t_m/5)^{1.514}$

The monthly potential evapotranspiration is then calculated from the equation:

$PET = 16N_m (10t_m/I)^a$ (4.4) $a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 0.49239$…

The monthly potential evapotranspiration is then calculated from the equation:

$PET = 16N_m (10t_m/I)^a$ (4.4) $a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 0.49239$

N_m is the day light factors used to correct unequal day length between months obtained from a table by dividing the possible sunshine hours for the appropriate latitude by 12 (in our case 9 N) and expressed by:

$$N_m = \frac{\text{possible sunshine hours for the particular month}}{12}$$

Table 9 PET calculated using Thonthwaite method

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Tm	16.5	17.3	18.4	18.8	19.5	20.1	19.1	18.3	18.0	16.9	16.4	15.9	
tm/5	3.30	3.47	3.68	3.76	3.89	4.01	3.81	3.66	3.59	3.38	3.27	3.19	
Im	6.09	6.57	7.18	7.44	7.82	8.19	7.59	7.12	6.93	6.33	6.02	5.78	

Nm	0.68	0.74	0.69	0.69	0.73	0.61	0.49	0.53	0.61	0.73	0.75	0.72	0.66
PET	103.74	118.68	130.38	132.12	138.72	143.28	130.92	123	119.1	115.74	105.66	101.28	1462.6

The mean average potential evapotranspiration is 1468.99, mean summer evapotranspiration is516.79 and mean winter potential evapotranspiration is 952.1 9. Therefore PET is high during winter season.

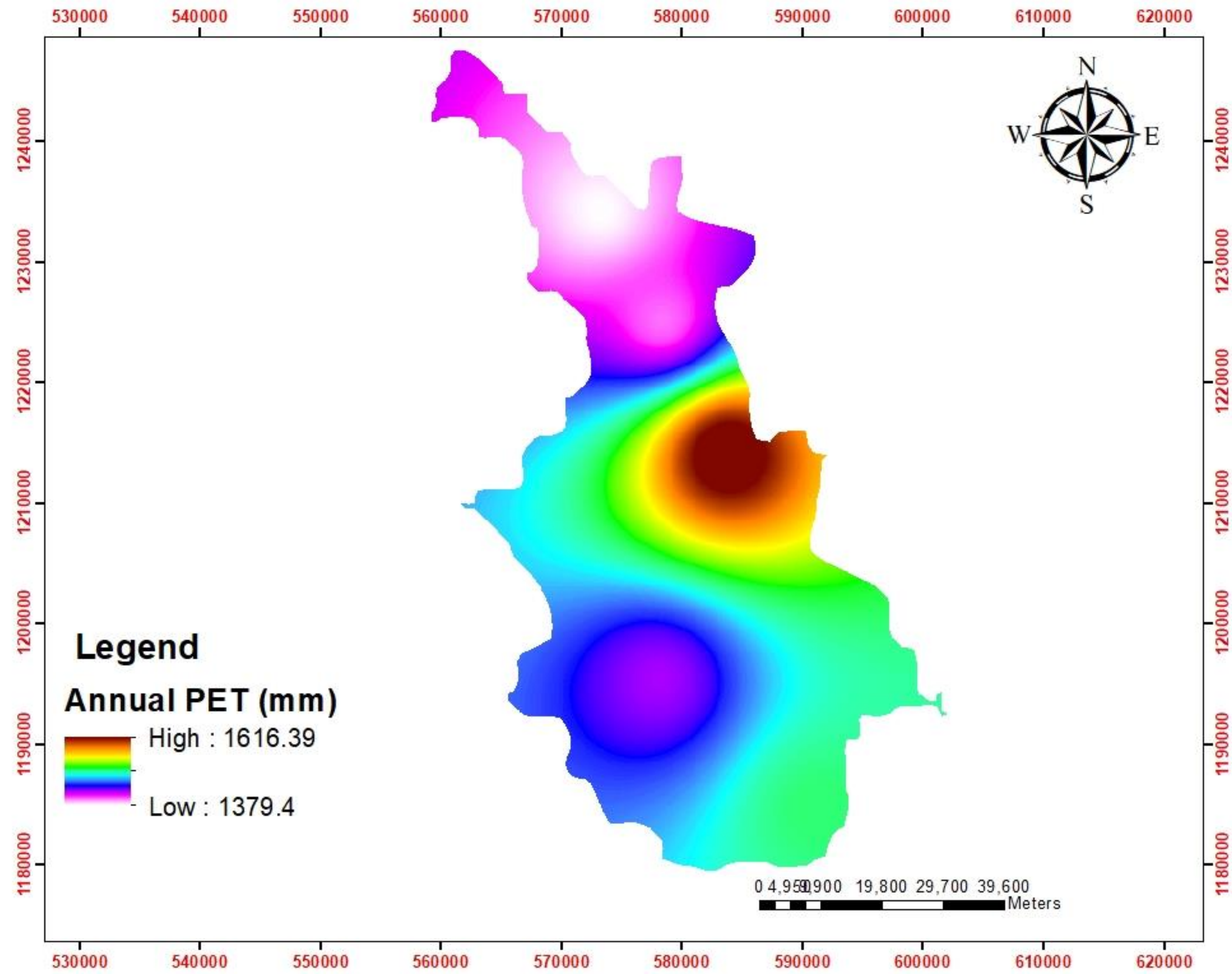


Figure 24 Annual potential evapotranspiration

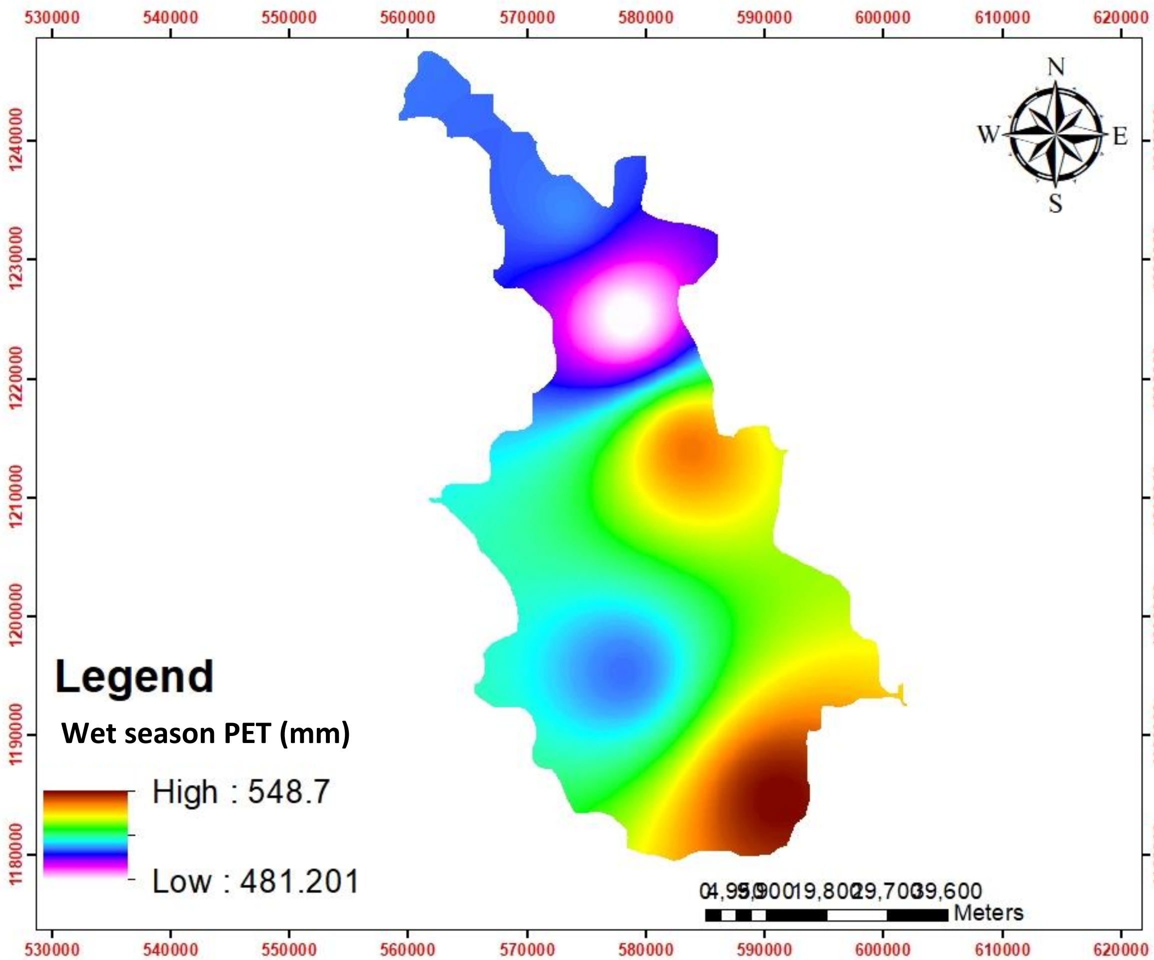


Figure 25 summer potential evapotranspiration

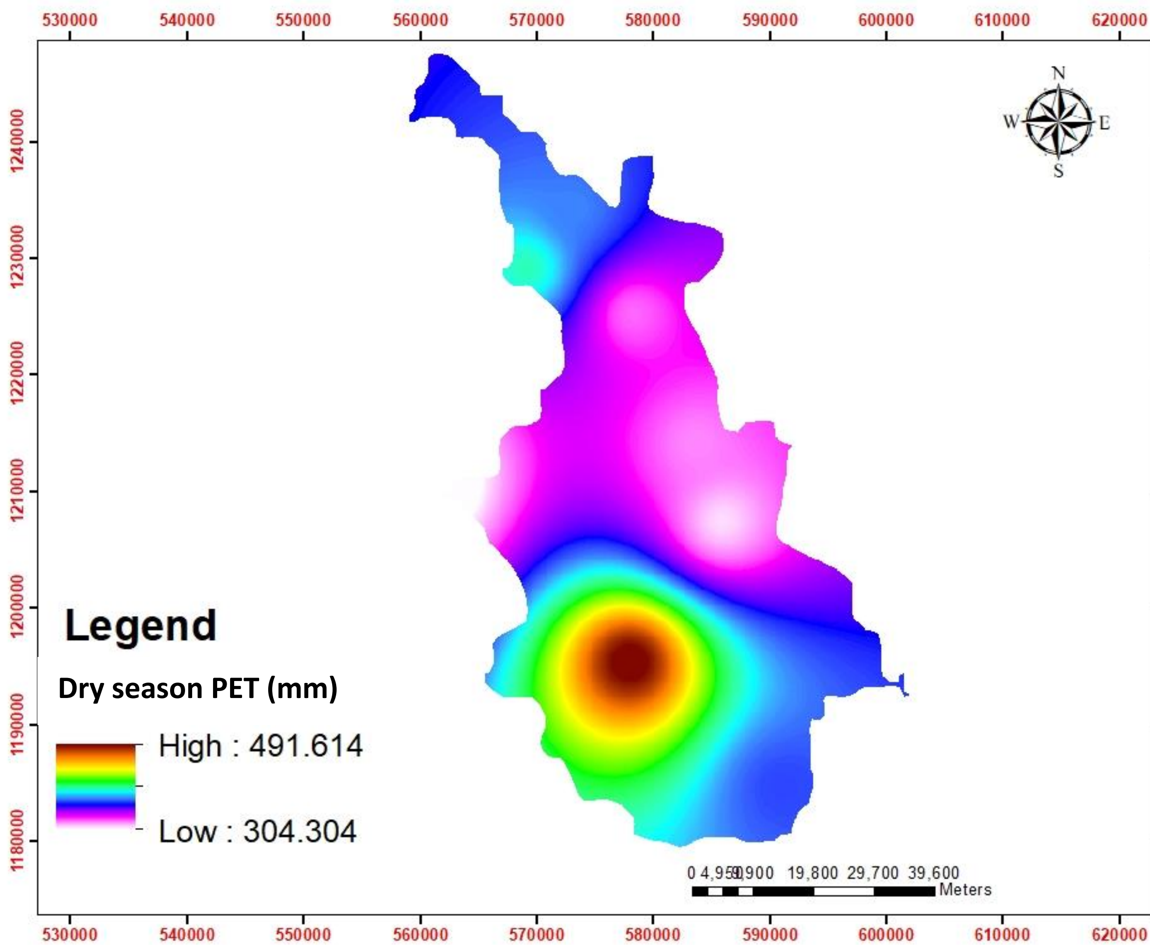


Figure 26 Winter (dry season) potential evapotranspiration

4.8. Recharge estimation using Wetspass model

4.8.1. Meaning of WetSpass Modeling

WetSpass modeling is GIS integrated model for water balance evaluation which has the ability to simulate spatially distributed recharge, surface runoff, and evapotranspiration for seasonally averaged conditions. The models provide the output in the form of spatially distributed recharge, runoff and actual evapotranspiration raster maps. It requires the basic input data prepared in grid-maps using the ARCGIS tool. It comprises monthly climatological data (rainfall, potential evapotranspiration, temperature, windspeed), distributed land use, soil texture map, groundwater depth, topography, elevation and slope. (Khodayar Abdollahi et.al, 2017).

4.8.2. Input data for WetSpass model

WetSpass model uses physical and empirical relationships for its efficiently running processes. WetSpass used for analyzing groundwater systems are often steady state and, therefore, need long-term average groundwater depth inputs. The model needs long term average hydro meteorological data and spatial patterns of watershed physical maps as the main inputs.

In order to work with the model efficiently, all data has to be prepared in a seasonal manner. The land use and soil grid maps are supported by attribute lookup table data available in the Study area. Borkena river catchement is characterized with definite summer and winter seasons. Hence, four months of June, July, August and September are considered as summer (wettest season) and the remaining eight months are considered as winter (dry season) in Ethiopian condition.

All the input map data's for the WetSpass model are prepared with Arc GIS software tools. These maps are land-use, soil, slope, spatial topography and slope map of the watershed is prepared and used in the WetSpass model. Inaddition , FAO based land use and soil map has been prepared and used in the WetSpass and 30m resolution ASTER map used to prepare the elevation map.

WetSpass model uses grid maps prepared based on seasonal, summer and winter some datas such as
topography, slope and soil type maps are not seasonal that they don't show variation during summer and winter season.However datas such as, land use, precipitation, temperature, potential evapotranspiration, wind speed and ground water depth are variable in nature when time goes up. As a result, these data were prepared separately in winter and summer. The mean annual and

seasonal average values of precipitation, PET and temperature. Precipitation, potential evapotranspiration and average temperature are listed in Table 13.

4.8.3. WetSpass model simulation

After running the WetSpass model effectively, spatial grid maps of the watershed has been produced in winter, summer and yearly basis annual, winter and summer average values of surface runoff, actual evapotranspiration, interception and recharge were produced for the study area. This watershed based physiographical maps are raster-shaped, in which every pixel represents the magnitude of the respective water balance component at that cell in the watershed. The watershed simulated values are unique average values produced from each cell in the watershed.

Table 10 Mean annual summer and winter data

parameters	**Summer(Wet season)**	**Winter (Dry season)**	**Annual**
Precipitation	810.6	380.15	1190.1
Runoff	485.85	4.69	527.54
recharge	35.32	110.63	145.95
PET	516.79	952.79	1468.99
Interception	70.38	73.15	143.54
Evaporation	353.81	310	582.99

4.9.Recharge

The average long term seasonal and annual groundwater recharge in the Borkena catchment has been Simulated by WetSpass hydrological model. As a result, the long term average annual simulated groundwater recharge is 145.95 mm. winter and summer groundwater recharge as simulated by the model is given as 35.32 and 110.63 mm respectively. Out of the annual precipitation (i.e., 1190mm) that is precipitated in to the catchment, about 12.26 % of long term annual rainfall is contributed to recharge.. Based on that, the groundwater recharge in Borkena watershed was estimated 173.97 M m3/ year. This amount of recharge is estimated for the whole 1192 km2 area of the watershed. About75.7% of the annual groundwater recharge of the watershed occurs during the wet season (summer), and the remaining 24.3 % in dry season (winter).

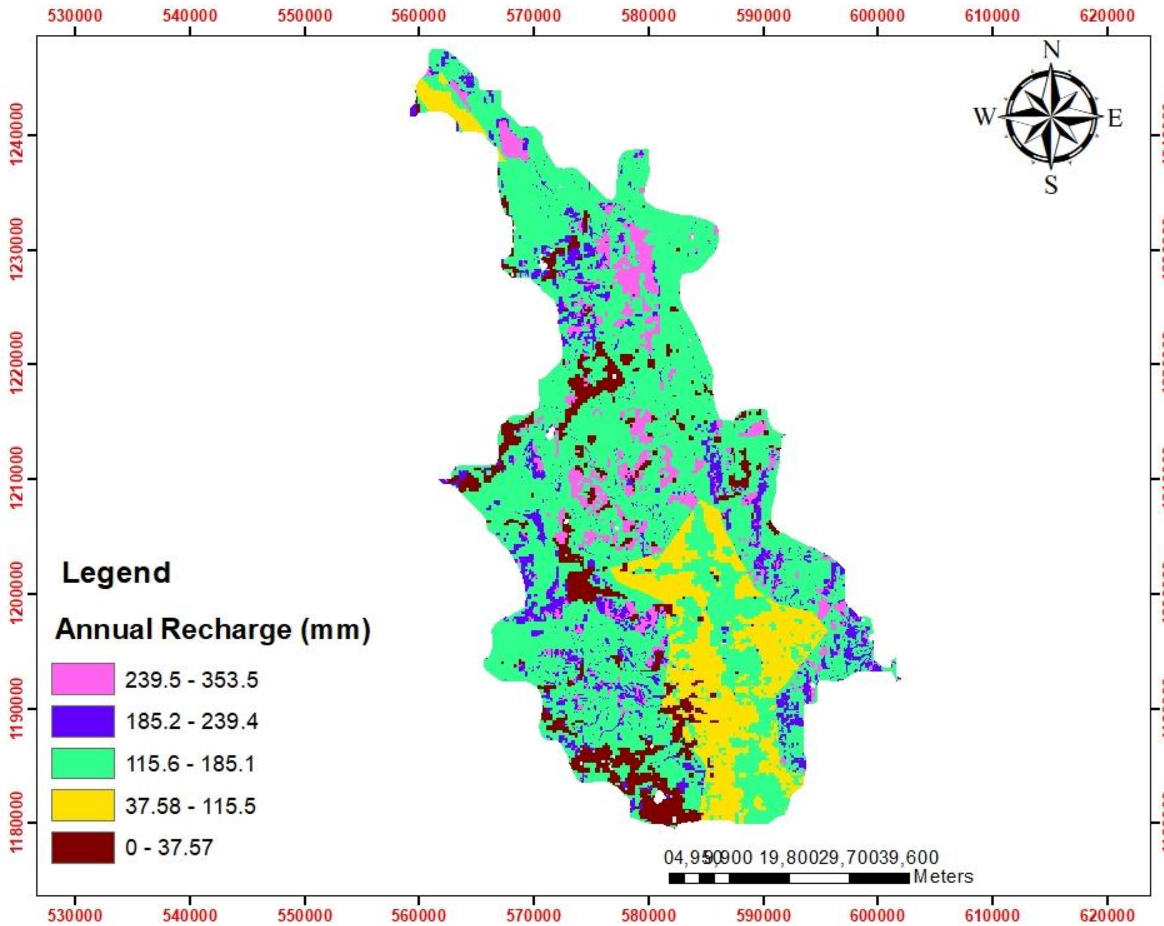


Figure 27 *Annual recharge*

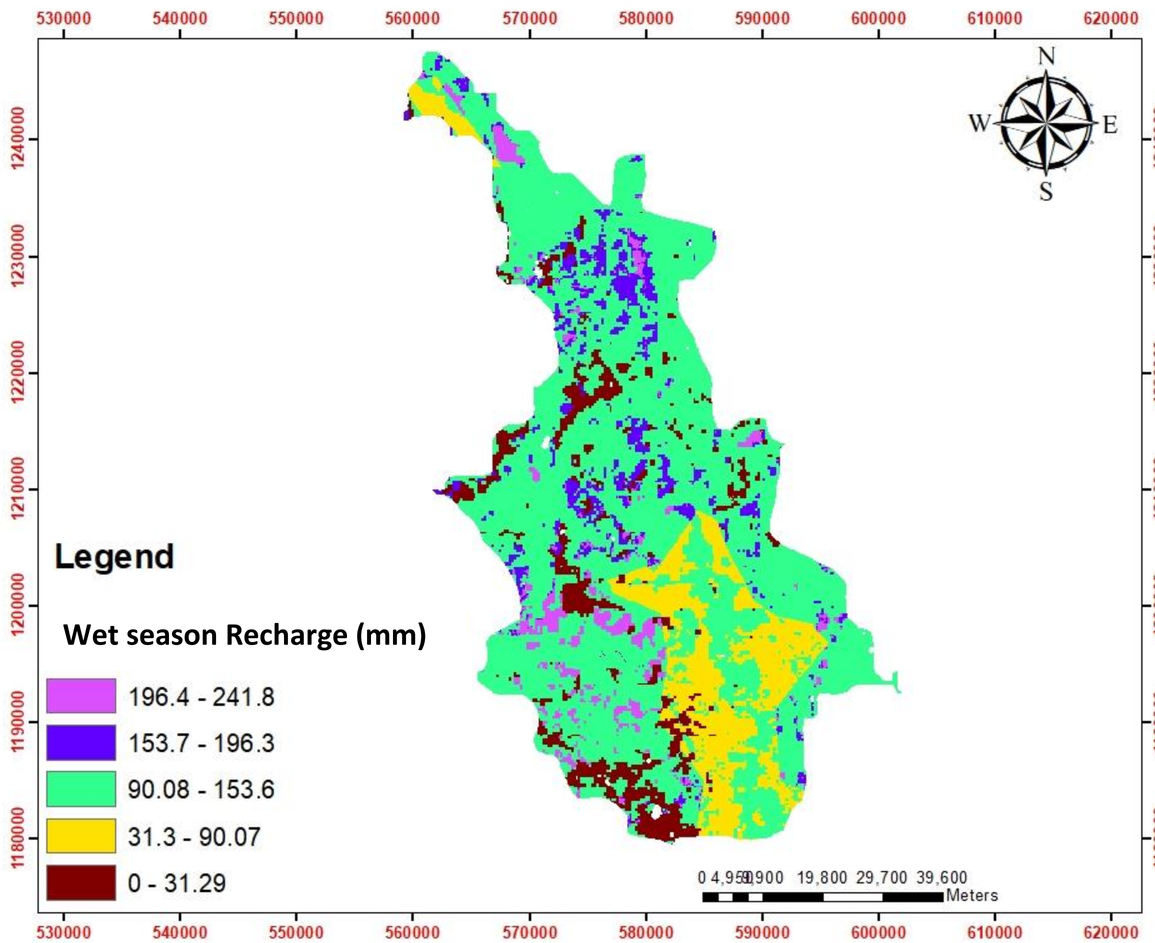


Figure 28 Summer (Wet season) recharge

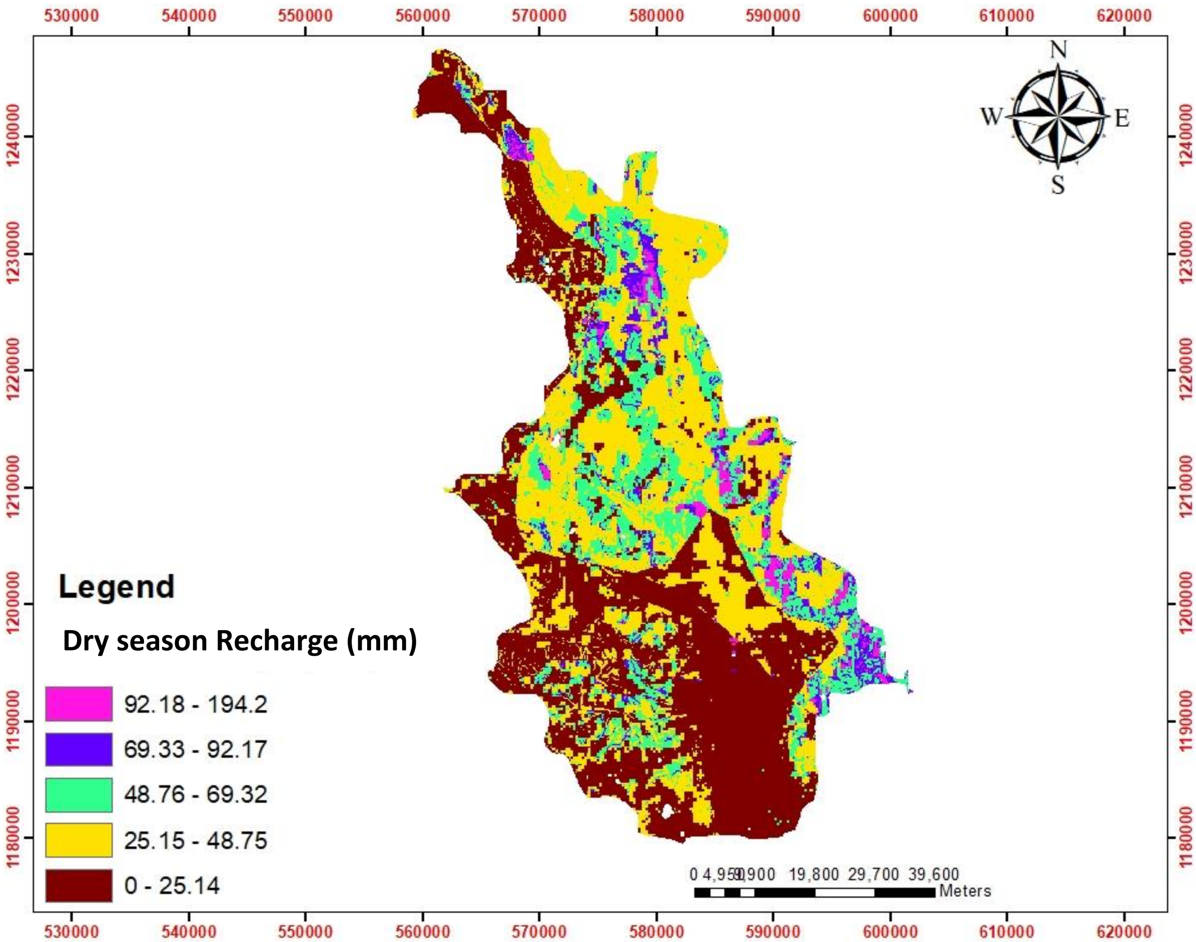


Figure 29 Winter (Dry season) recharge

4.10. Base flow Analysis

Estimation of base flow and direct runoff is important to understand the hydrology of a given watershed. Baseflow varies spatially and temporally influenced by several factors including geology, topography, climatic season, and anthropogenic activities (Smakhtin, 2001). Baseflow can nurture river flows during periods of dry weather. Although dry season flows are significantly reduced and in some rivers approach zero flow, this water can be a vital life source for those who depend on it (Smakhtin, 2001).

River is directly proportional to the intensity of rainfall within a given basin. There is a high discharge fluctuation between the wet and dry seasons of the year. The first high flow period is in April, the highest flow period is from July to September, and the peak flow for all rivers is usually recorded in August. The period from December to March is characterized by low flow, and most of the small streams become completely without water on this period.

The river flow hydrograph is obtained from the total storm hydrograph by separating the **quick-response** flow (the direct response to a rainfall event including overland flow (runoff), lateral movement in the soil profile (interflow) and direct rainfall onto the stream surface (direct precipitation)from the **slow response** flow (Base flow longer-term discharge derived from natural storage).

Factors affect the base flow

- Infiltration to recharge subsurface storage increases base flow
- Evapotranspiration reduces base flow because trees absorb water from the ground.
- River incision can decrease the base flow by lowering the water table and aquifer.
- Macrospores, microspores, and other fractured conditions in the soil and shallow geomorphic features also affect the baseflow.

Base flow analysis of the given catchment has been calculated from a kemise river guage suited at the outlet of Borkena river catchment. From analyisis of river gauge data, the mean annual base flow (MABF) is 4.8 m3 /s for Borkena River at the swamp and the recharge as calculated using Baseflow separation is 127.5 mm/year which represents 11% of Average precipitation on the catchment.

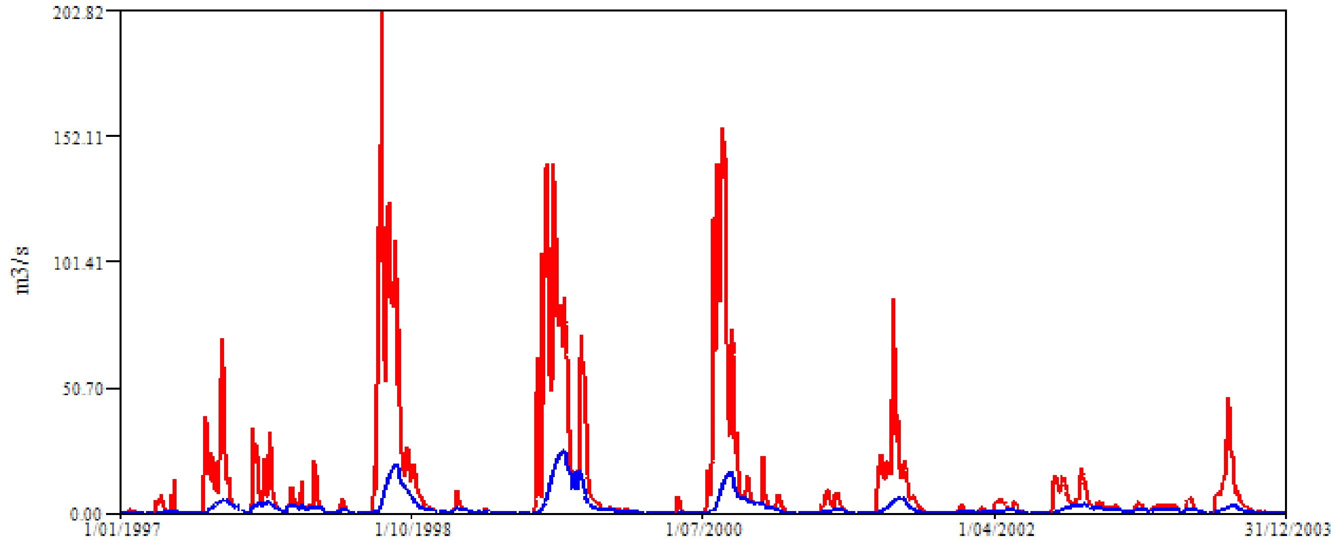


Figure30 Base flow separation

4.11. Evapotranspiration

Evapotranspiration is the water lost to the atmosphere by two processes-evaporation and transpiration. Evaporation is the loss from open water body, such as lakes and reservoirs, wetlands, bare soil, and snow cover; transpiration is the loss from living-plant surfaces. The most important factors include solar radiation, surface area of open bodies of water, Relative humidity, wind speed, density and type of vegetative cover, availability of soil moisture, root depth, reflective land-surface characteristics, and season of year.

Evaporation from soil was also simulated during WetSpass model running process for the watershed (Figure 32). Accordingly, annual average soil evaporation was estimated to be 582.99 mm with winter and summer averages of 353.81 mm and 310 mm respectively indicating that evaporation is higher at winter than summer season whereby 48.9% of precipitation is contributed to evaporation.

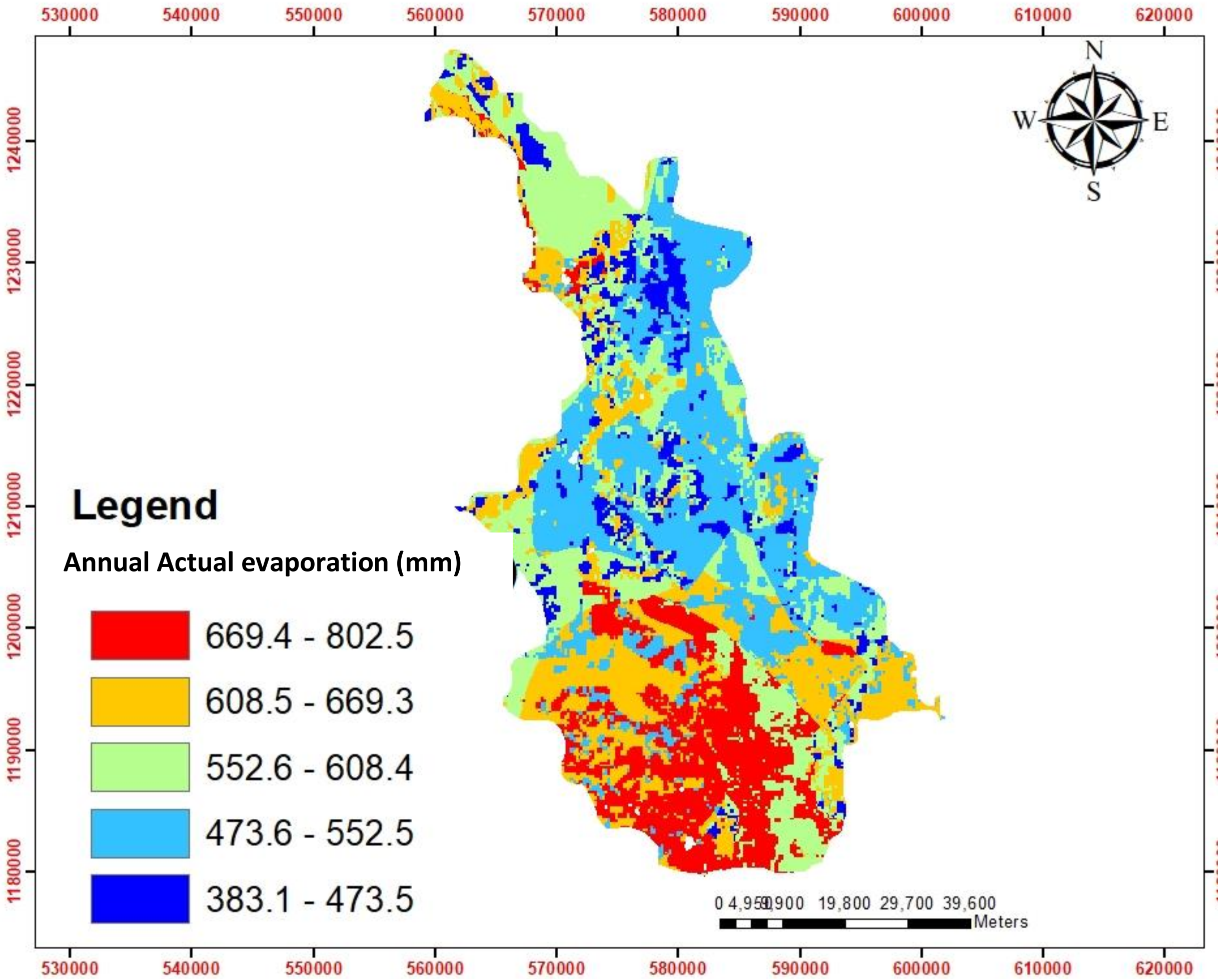


Figure 31 Annual evaporation

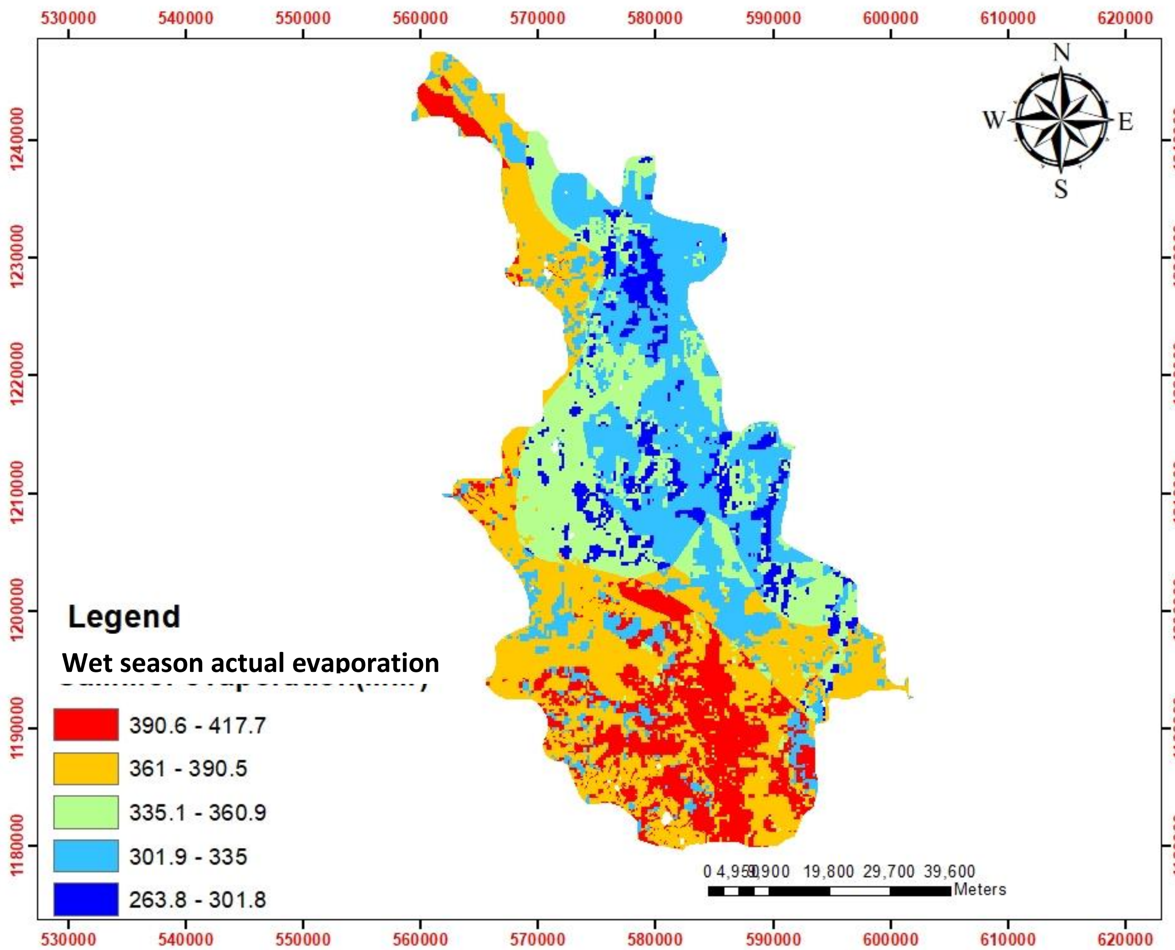


Figure 32 summer (wet season) actual evaporation

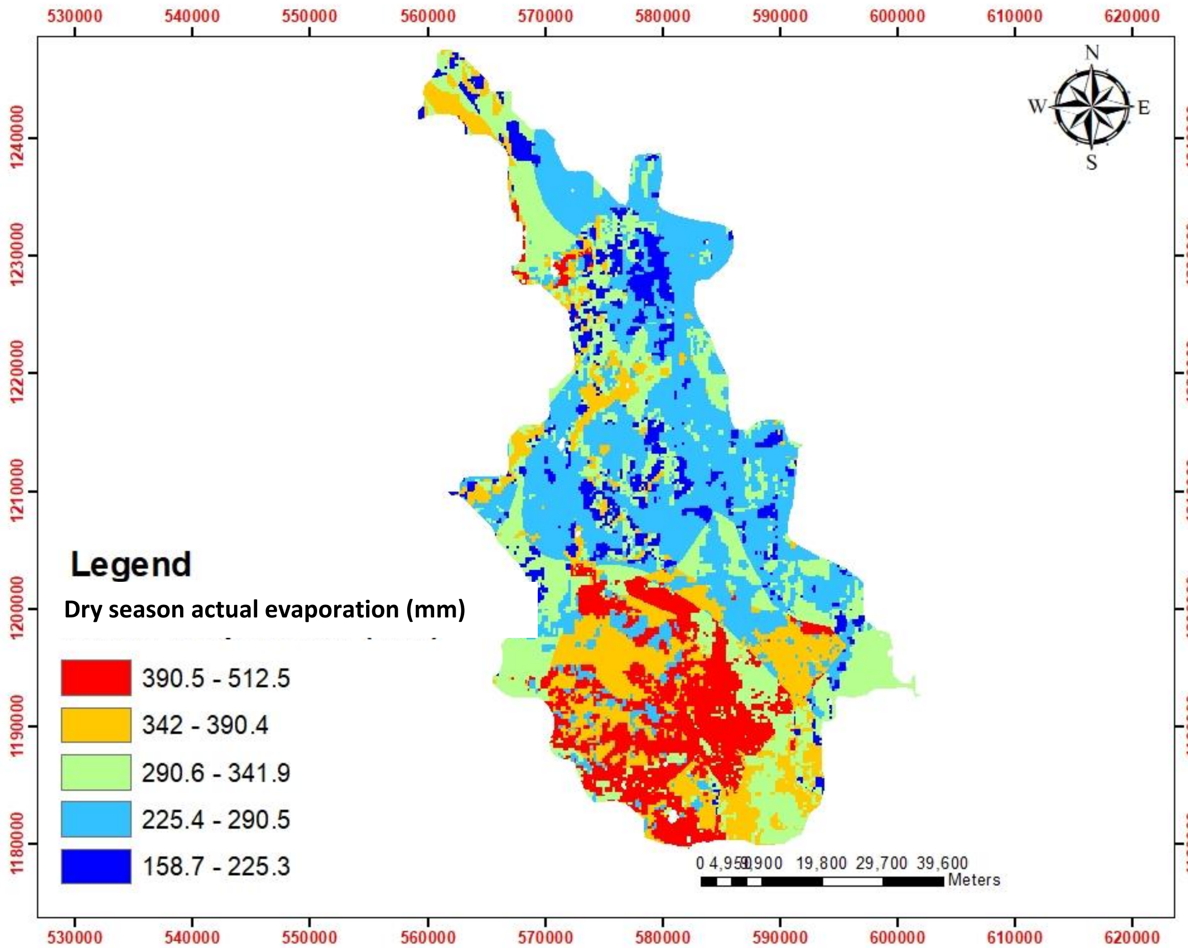


Figure 33 winter (dry season) actual evaporation

4.12. Surface runoff

Surface runoff is dependent on the availability of vegetation, soil type and slope of the watershed. The spatial annual average surface runoff is simulated by Wet Spass model is presented in Figure 35. The

The long term annual average mean value of surface runoff is 527.54mm.The maximum runoff observed in the watershed is found sparsely at very steep areas in the catchment. The mean average summer and winter runoff occurred in the study area is 485.5 mm and 41.69 mm respectively. 92% of the surface runoff is occurred in summer and 8% is in winter where by about 44.3% of precipitation is contributed to runoff.

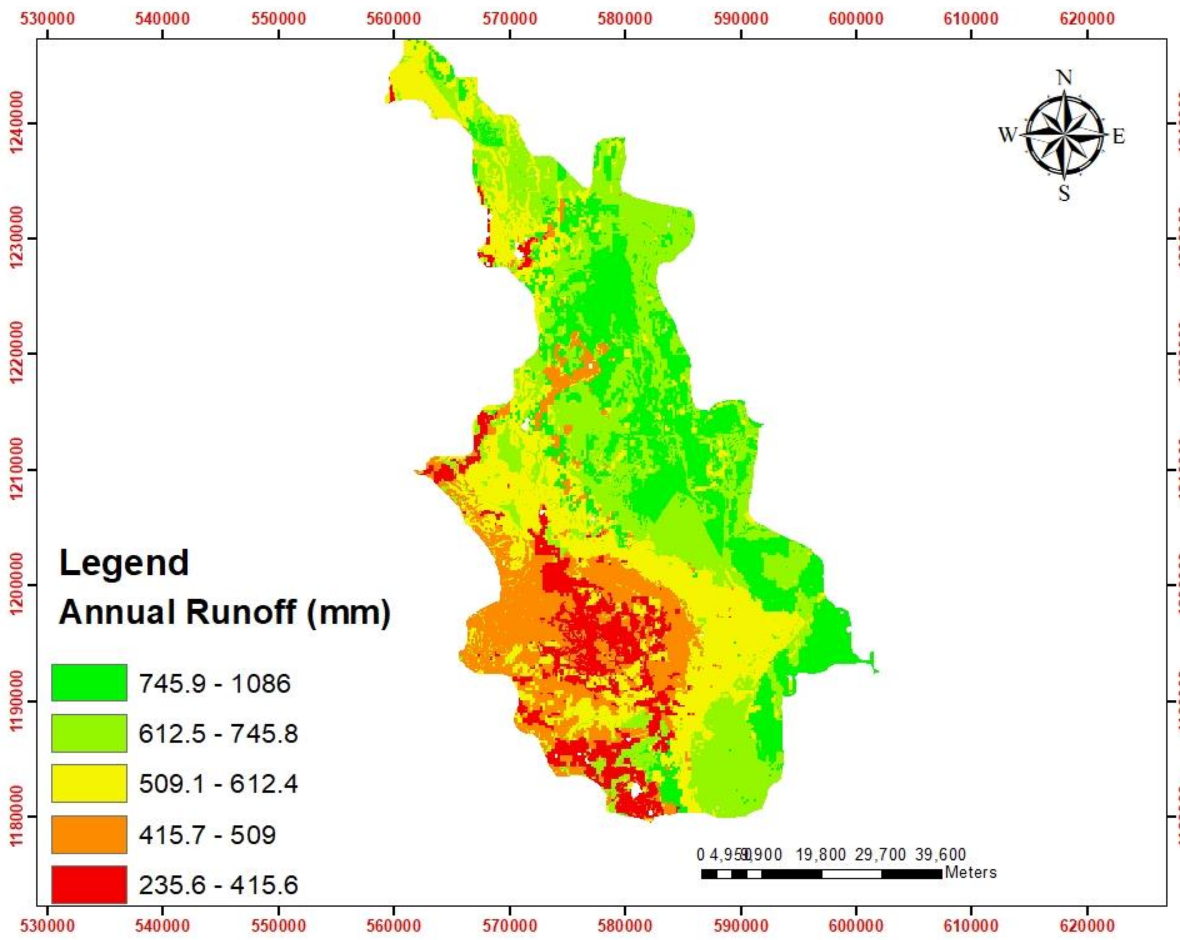


Figure 34 Annual runoff

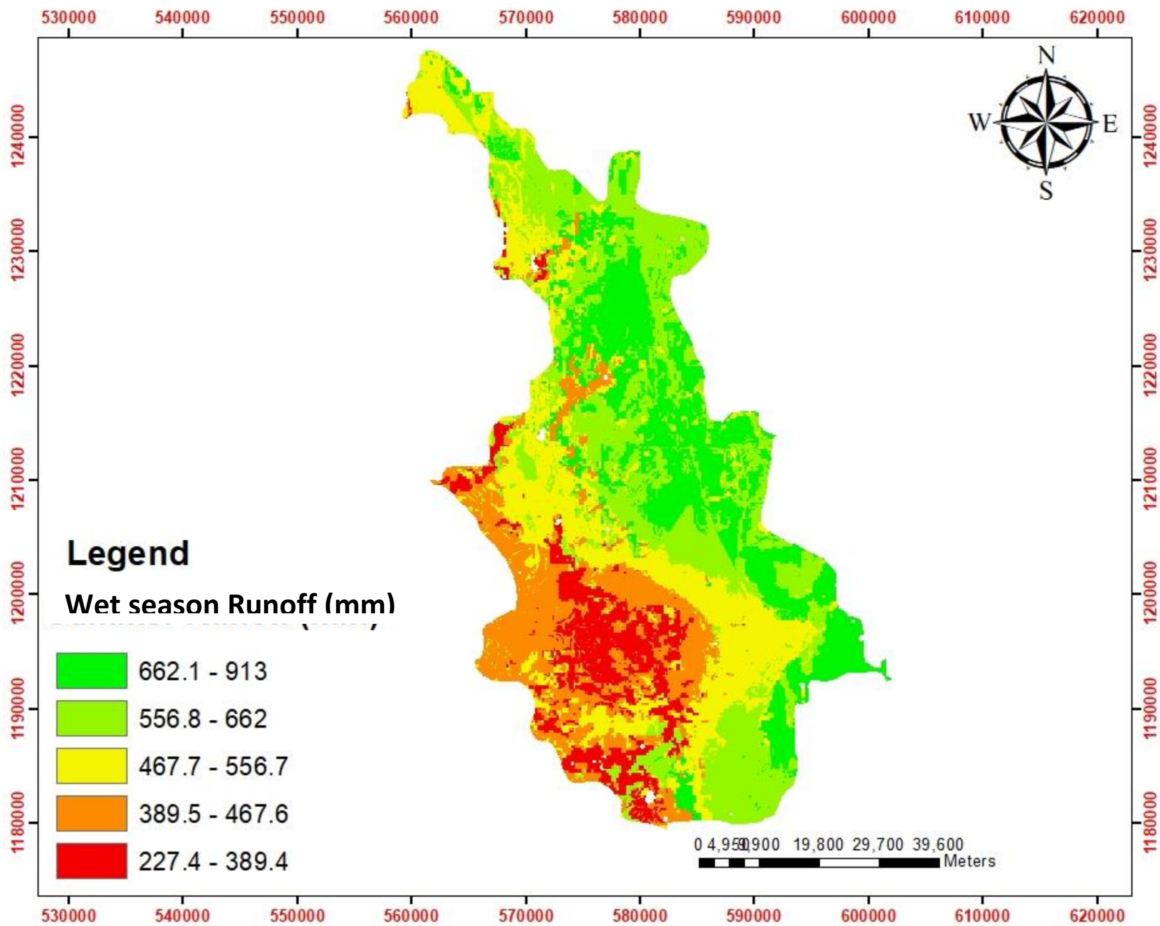


Figure 35 Summer (wet season) runoff

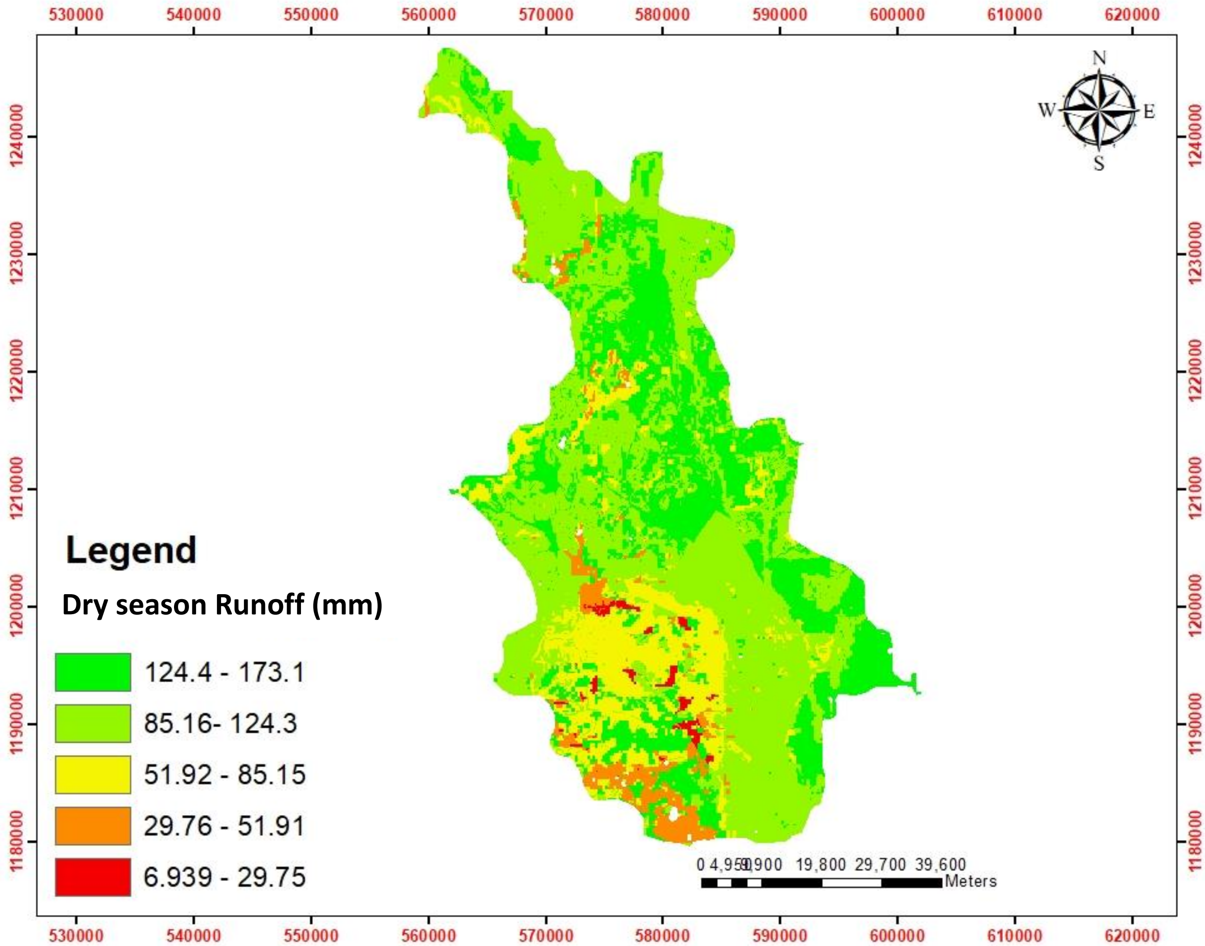


Figure 36 Winter (Dry season) runoff

4.13. Interception

Interception is the rainfall which didn`t arrive or reach the soil and mostly affected by vegetation cover.

Interception is occurred due to presence of vegetation when rainfall rains in the watershed.

The mean average annual interception in Borkena catchment is 143.54 respectively. The mean summer and winter interception is 70.38 and 73.15. Therefore 49% of annual interception is occurred in summer whereas 51% in winter.

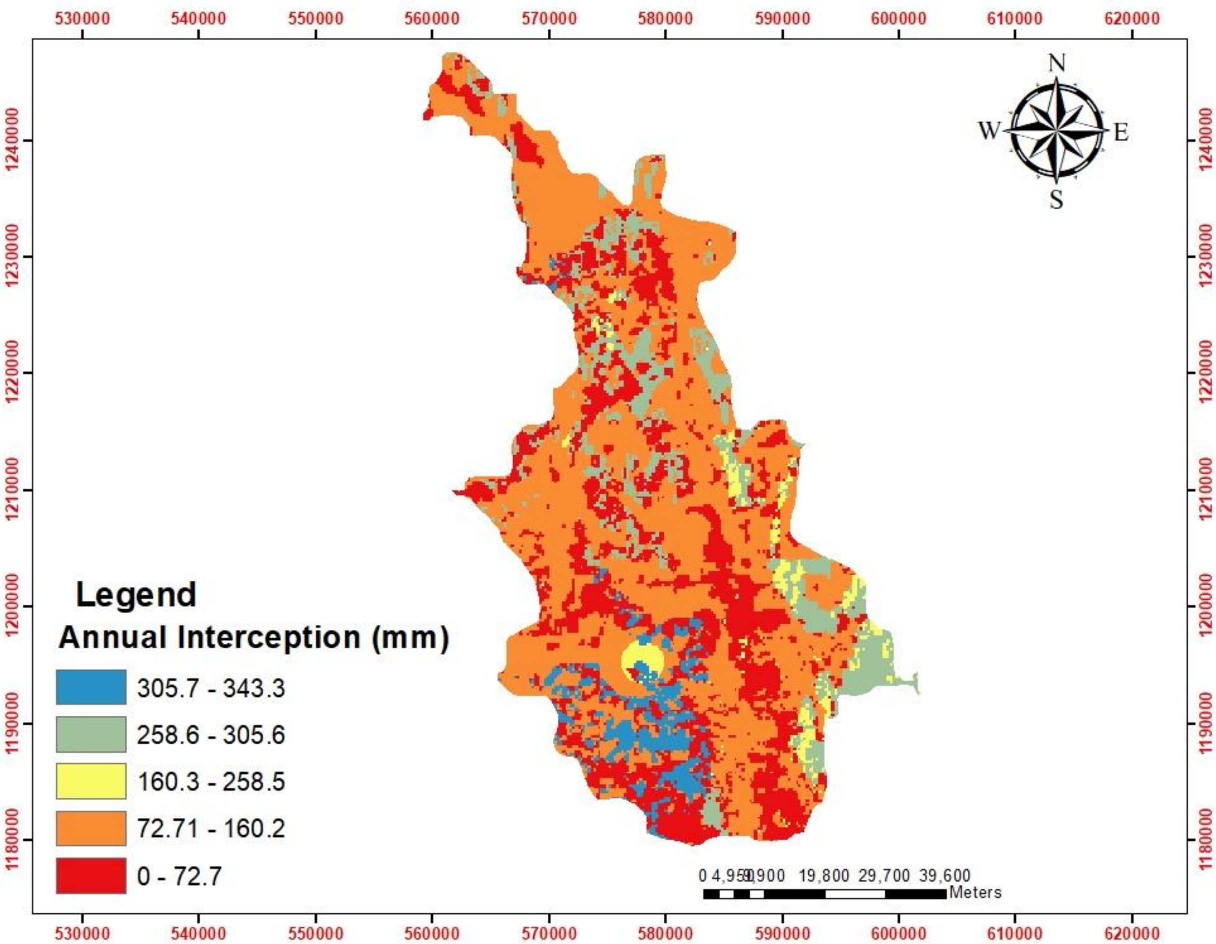


Figure 37 Annual interception

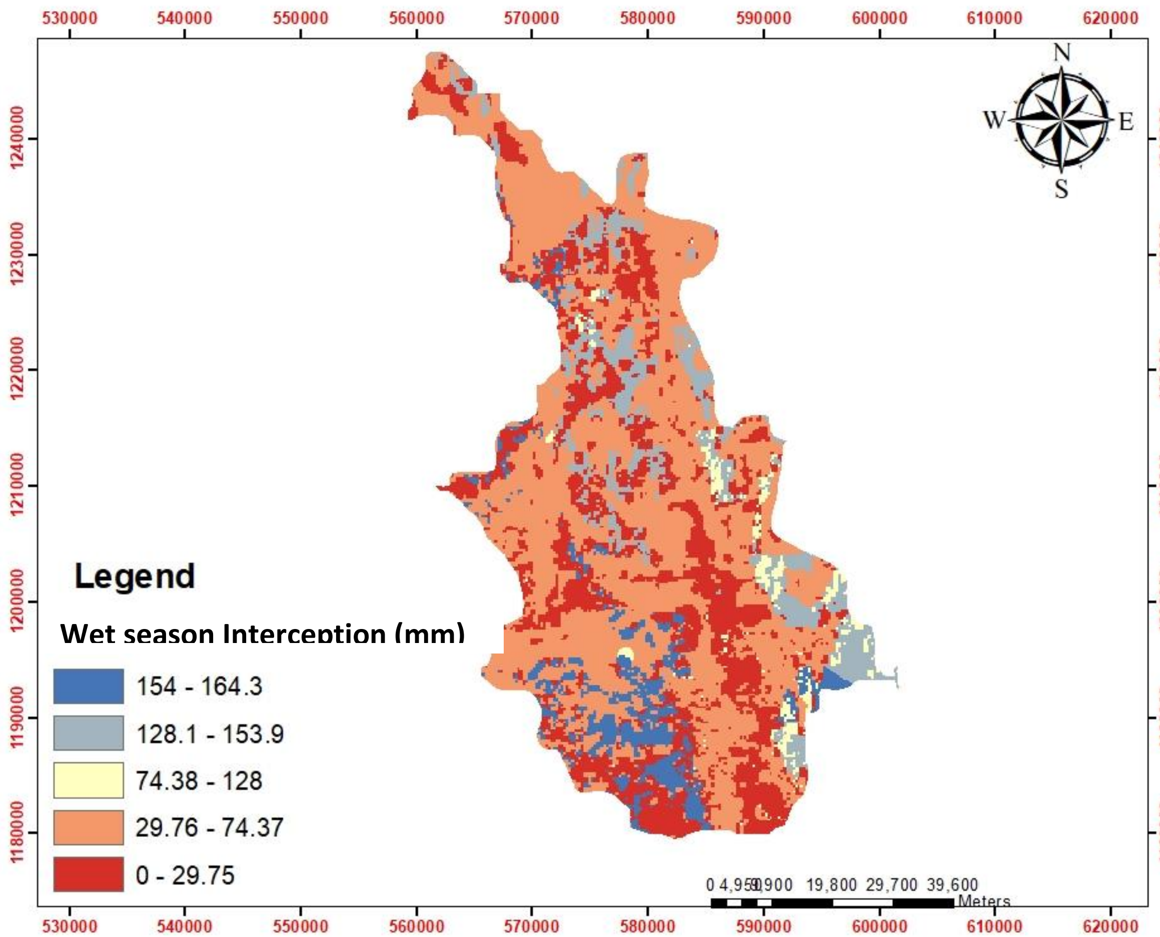


Figure 38 summer (wet season)interception

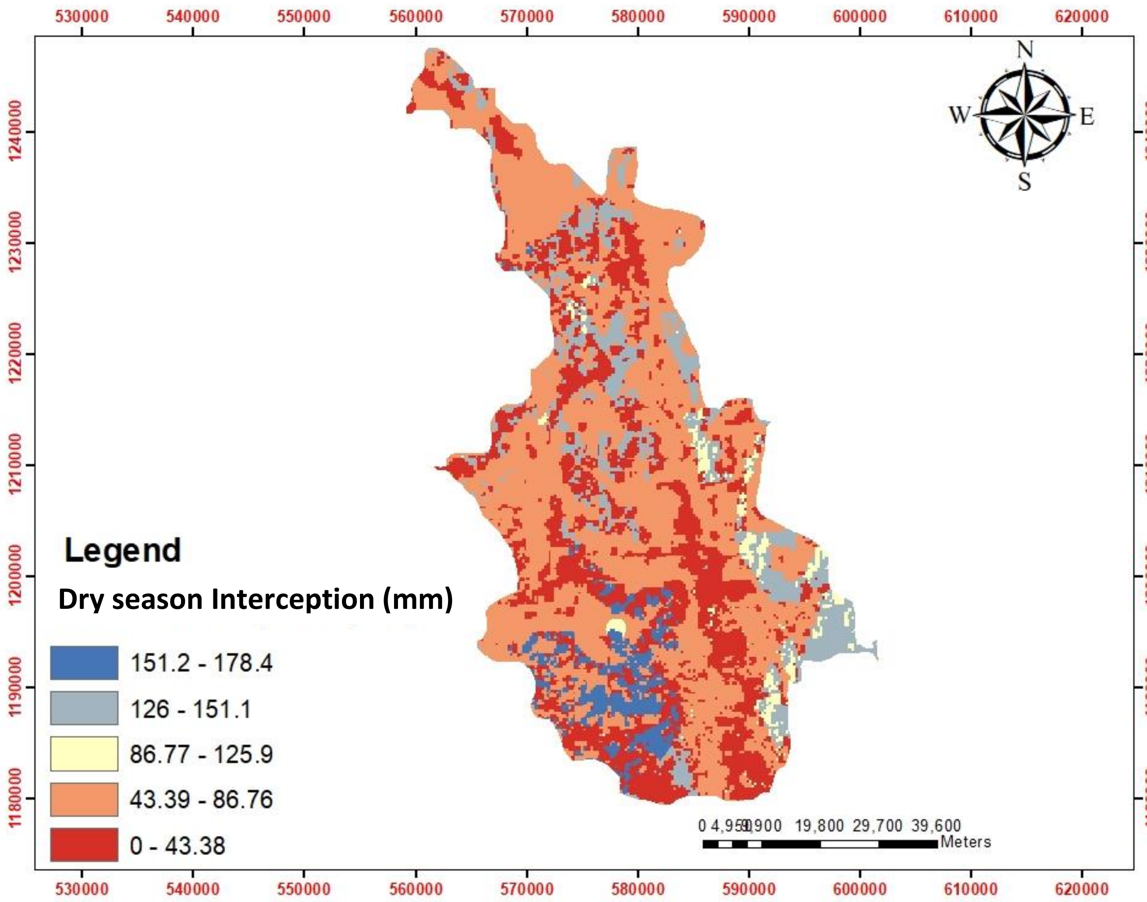


Figure 39 winter (dry season) interception

Table 11 Recharge estimation by different researchers

Researchers	Estimation Method	Recharge
ADSWE (2013)	water Balance	134
Mesfin sahle (2001)	Water Balance	155.6
sadam Ebrahim (2020)	base flow separation and chloride method	132.7and 80 respectively
ketema tadesse	Water Balance	185.11

CHAPTER FIVE

5. Hydrogeology

Hydrogeology deals with water occurring or on the surface of the earth and concerns with entering of water in to the sub surface as recharge and flow of the water through aquifers and interaction with the sub surface or surrounding geologic materials.
The interaction of geologic and geomorphic factors governs the movement of water from the time up to which reaches the land surface till the time of leaving it. Geomorphic features control the distribution and amount of precipitation that contributes to run off and ground water recharge.

The controlling factors of ground water

- The nature of the geology
- Distribution of vertical and lateral geologic formations.
- Geological structures.

These factors are controlling the occurrence, movement and availability of ground water. The nature of the geology governs the occurrence of ground water in confined, unconfined and as leaky aquifer. The distribution of the geologic formation in terms of lateral and vertical extents and also its continuity governs the movement of the ground water throughout the porous media and its interaction with the surroundings geologic material.

The geologic structure has a marked influence on the lateral and vertical extent of aquifers and associated less permeable rocks and they act as barriers to ground water movement.
The surface and subsurface run off are governed, in part, by geology on which depends up on the development of land forms, infiltration characteristic of zone of aeration and characteristics of aquifers. The porosity and permeability of consolidated rocks are attributed to process of rock fracturing and weathering which are mainly controlled by topography, lithology, structure and climate. The depth of fracturing and weathering as well as the nature of weathered product, together determine availability of ground water and its supply to wells.

The study area is elongated in the north - south direction with having different geophorphological set up, including mountains, escarpments, rivers, and plains. Physical observation and description of the nature of geologic materials, degree of weathering/fracturing, porosities, discharge conditions, sustainability of water points, lithological log etc. are some of the sources of important qualitative parameters to describe the hydrogeology of the study area.

The western volcanic escarpment and the eastern ridge bound alluvial sediment-filled graben which constituted the physiography of Borkena catchment. The escarpments are highly dissected by stream networks often with rugged topography. The graben (valley floor) is often gently extends to the south with isolated hills as observed in southern extreme part of the area. Elevation reaches 3300m on the escarpment, whereas the wide Borkena graben lies at an average elevation of 1400-1500 m a.s.l. From hydrogeological point of view, three distinct physiographic areas have been delineated within Borkena sub basin namely:

i) Kutaber (Alasha Meda) - Boru Meda – Dessie;
ii) Kombolcha, and
iii) Harbu-Chefa-Kemissie.

i) Kutaber (Alasha Meda) - Boru Meda – Dessie

Borkena River (Kutaber high land area) up to Dessie town with elevation ranges of 3300 to 2400 m.a,s.l. There are some small valley plains between the NW elongated chains of ridges. The deposit within Alasha Meda (near Kutaber), Boru Meda and Hotie Meda (Dessie town) is clayey sand underlain by fine to medium sand.

There is also colluvial deposit close to the foot of ridges. Borehole drilled at Boru Meda for Wollo University, Boru Kurkur and Hotie Meda have thick clayey sand at the top and underlain by water bearing formation of sand & gravel, colluvial deposits, and weathered and fractured basalt.

ii) Kombolcha area

This area comprises part of the study area located between downstream of Dessie town (Azewagedel)
and Borkena basin. Even though the area is faulted; volcanic rocks at the foot of the ruined Borkena Dam and the surrounding ridges could be the possible groundwater barriers or these features may tend to slow groundwater flow from Kombolcha area to Habru area. Kombolcha town Water Supply and different factories and institutions (Textile, BGI Brewery, Meat, Leather and other factories etc) water demand is mainly obtained from bore-holes.

Kombolcha plain area is a continuation of Borkena marginal graben; clearly observed a fault crossing Gerado valley running E - W direction along Borkena river (downstream of Dessie up to Kombolcha town) and intersect with N-S major faularea and continues to Mitikolo – Cheleka stream and then to Degan area. The intersection of these two major faults create deep valley and deep alluvial fills of the Kombolcha plain area. Most of drilled wells within Kombolcha area are flowing (artesian) wells.

iii) Harbu - Chefa – Kemissie area

Harbu - Chefa – Kemissie is the widest of all the alluvial plains in the southern part of the study area .The most part of *Harbu -Chefa – Kemissie plain* is located in Oromo special administrative zone and North Showa administrative zone except the northern part, which is in *Kallu* woreda of South Wollo administrative zone). It is elongated to NNW-SSE direction that starts around Harbu town and ends around Chireti village where the outlet of Borkena River is located. Most of the rivers emerge from the western highlands & flow towards east. Whenever these streams reach at the beginning of the plain, they form alluvial fans and leave coarse alluvial deposit first and finer deposit at the middle of the valley. Groundwater level of Harbu - Chefa – Kemissie plain area is very shallow at middle of the valley commonly forming wide marsh or swamp. The volcanic area at the eastern and southern part of the sub-basin is mainly fractured Ataye rhyolitic ignimbrite while the western part is Alaje rhyolite.
The following well detail information and the pumping test datas was taken from amhara design and supervision works enterprise to describe the hydrogeology and lithological setting of the area.

These rocks form unconfined aquifers within the mentioned sub-basins. Intergranular aquifers have been classified to moderate and high productivity aquifers. Volcanic aquifers have also been grouped into very low and low productive aquifers.
The drilling also shows that from 0-210m in harbu Test well (HCKTW1) is unconsolidated sediment (alluvial) and the Mekoy test well (HCKTW2) is 217m deposit. The pumping test result also show that the fractured basalt and the unconsolidated deposits make high productive aquifer in the area. The following lithologic log and describition (Figure 40) is prepared by Strater software based on the secondary well detail datas.
The well MGTW-1 with 251m depth Boulder (medium and uniform sand sized cuttings) was the dominant lithologic units of the well and next is coarse sand , gravel without and with different amount of clay and sil. It has estimated yield of 35l/s and static water level of 21meter. MGTW-2 with 282m depth has deposit of sand, coarse sand ,gravel , and with various amount of clay and boulders are the dominant lithologic units where the test well passes through.

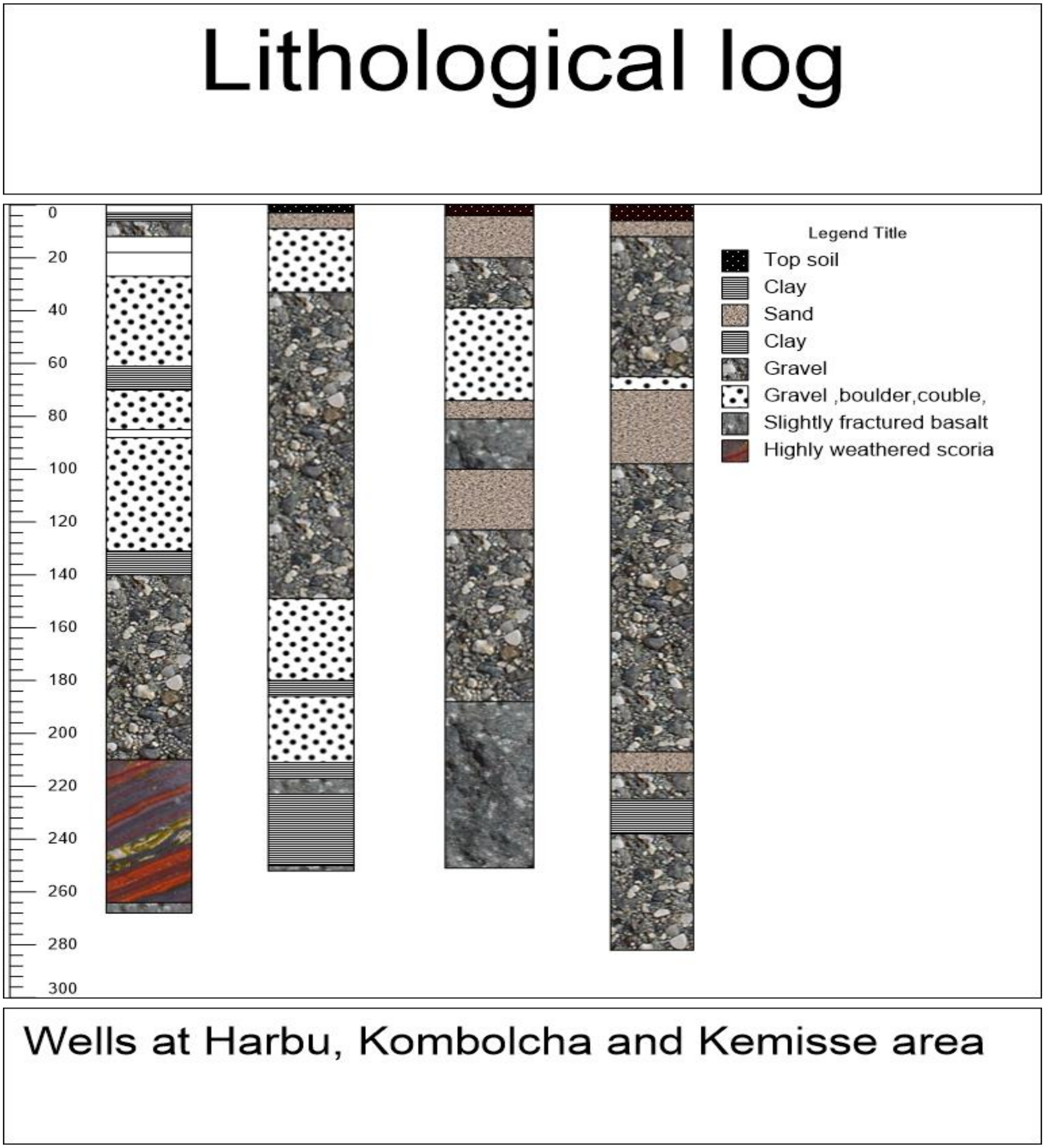


Figure 40 Lithologic log

5.1.Aquifer characterization

Qualitative aquifer classification is based on topographic and geomorphic position, lithology, weathering and fracturing effects (depth and extents) of the rocks; grain size, sorting, roundness and degree of cementation of interglanular formations, distribution and discharge of springs are hydrogeological information's. Quantitative aquifer classification is based on yields, transmissibility and permeability values from previous drilled data's.The study area is characterized by highly rugged topography, high land plateau and intermountain valley plain areas. The lithology of the rugged topography is volcanic rocks (dominantly basalt, rhyolite, ignimbrite and trachytes) whereas the intermountain valley plain areas are covered with unconsolidated sediment. Volcanic high land plateau prevail study areas are characterized by both volcanic and intergranular formations (Alluvial and Fluvio – Lacustrine Sediments).

There are drilled wells mainly within intermountain valley plain covered with unconsolidated sediment & volcanic rocks and high land volcanic plateau of the study area.

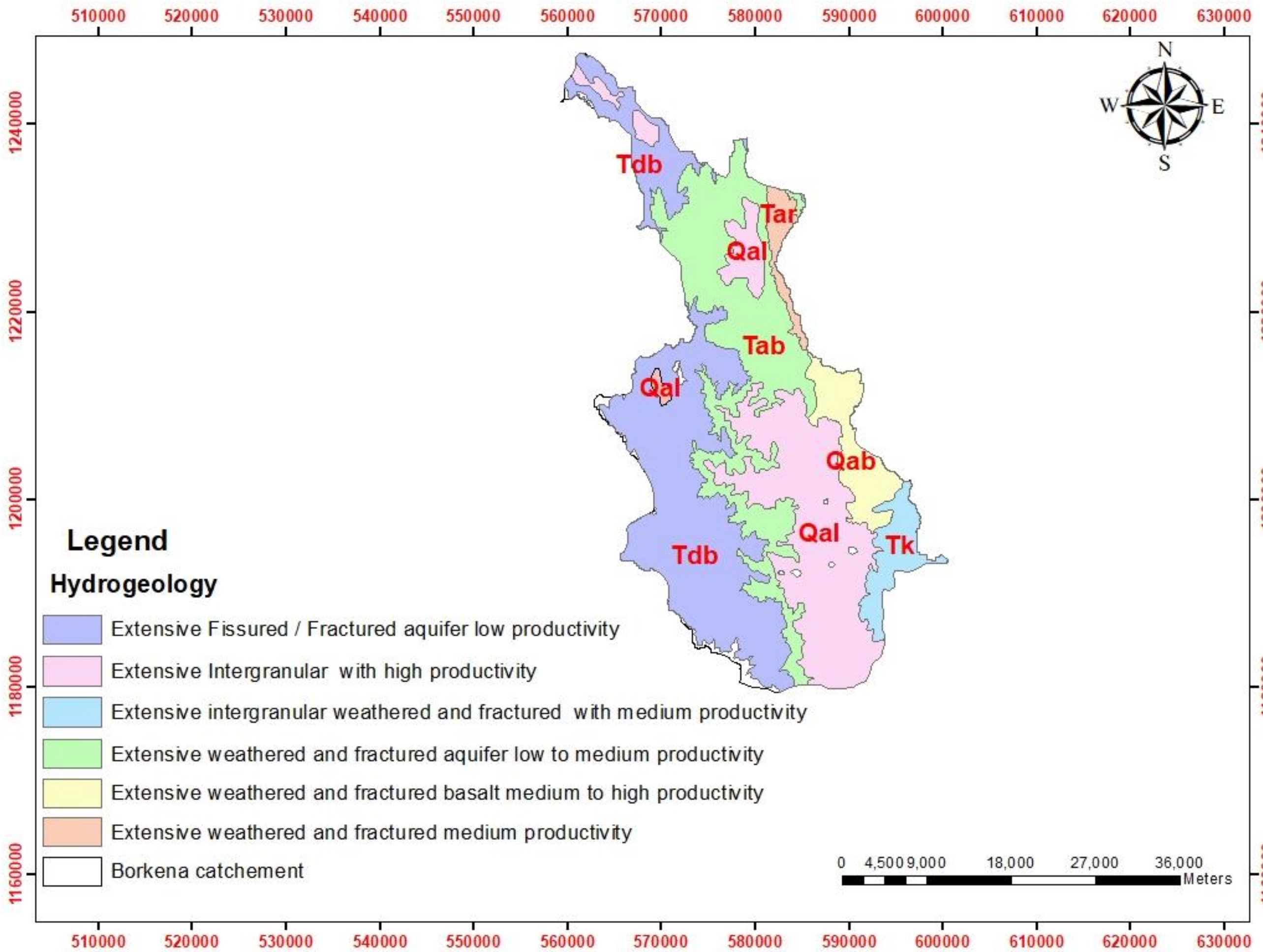


Figure 41 Hydrogeological map

Extensive Fissured/Fractured aquifer with low productivity

Aquifer systems of this Units are exposed mainly in the western part of the study area where majority of being exposed in the southern region (i.e., SW) and some amount in the northern region (i.e., NW).it comprises of Dessie basalt (Tdb), forms mountainous regions with low fracture medium in the catchment (Hydrogeological and Hydrochemical map sub sheet of Dessie.2013).

Extensive intergranular aquifer (high productivity)

Extensive intergranular aquifer with high productivity is quaternary alluvial deposits located dominantly at the southern part of the study area with minor exposed in the northern region. Alluvial aquifer systems are suited geographically, within north – south extended graben and intermountain valley plain. Alluvial deposits consists of coarse grain size (boulders, gravels and coarse sand) mainly localized at western and at the bottom of middle graben having a yield of 50 to 80 lit/sec with 20 to 30 m draw down, greater than 400 m2/d transmissivity is classified as high productive aquifer.

Extensive intergranular, weathered and fractured aquifer (medium to High productivity)

In the study area, alluvial deposits with alternative layers of gavels and sand that intercalate with clays and silt and weathered and highly fracture volcanic rocks (basalts and rhyolite).

Intergranular, weathered and fractured aquifer with medium Productivity

Aquifer systems of this formation are located in the south eastern part of the study area, consisting of ignimbrite and rhyolite known to be kemisse formation. These formations are watered and fractured due to the presence of overlaying geological formation which gives them a good capacity to transmit groundwater. There are so many isolated intermountain valley plain areas located within marginal graben which has 20 to 80 m depth alluvial deposits and underlain by weathered and fractured volcanic rocks. These intermountain valley plain areas yield economical amount of groundwater from both alluvial deposits and underlain weathered and fractured volcanic rocks.

Extensive weathered and fractured aquifer with very low productivity

Aquifers with Very Low Productivity mainly exposed on steep slopes and rugged topographic terrains of the study area. Faulted blocks and escarpments, dissected plateau, domes and shield volcanic centers are classified within Very Low to medium Productivity aquifers. The aquifer systems of such formations within the study area are known as Ashange basalt exposed in mainly the northern part of the study area. The weathering and fracturing effect makes highly permeable and favor for groundwater recharge but due to steep slopes and rugged topographic terrains the recharged groundwater could not stored, instead it flows to low land marginal graben plain areas. Within narrow intermountain valleys, sometimes it is possible to obtain wells having 5 to 20 lit/sec yields from local groundwater storage but due to low storage coefficient and transmissivity, mostly the wells drilled within this area could not have more 2 lit/sec yields and 5m2/d transmissivity.

5.2. Recharge and Discharge Areas

Generally, the major sources of groundwater recharge of the study area are mainly the western part of the catchment i.e. the dissected high land plateau, fault block high lands and escarpments, shield volcanoes, high land plateau, isolated domes within the valleys, whereas marginal graben basins, low land and faulted plains are the discharge areas where groundwater is released in various ways.

The recharge sources of prospective groundwater potential area i.e. marginal graben basins, low land and faulted plains are runoff that emerges from the mountainous areas surrounding the alluvial plains (particularly the western highlands), groundwater inflow and infiltration from direct precipitation on the alluvial plains.

The discharge zone of the study area is base flow through effluent springs/ streams that flows mainly from west to east from the highland escarpment to the lowland alluvial plains and leaves the study area further towards Afar region in the east. In Cheffa area water table is exposed to the surface as swamps it is easily accessed through hand dug wells, shallow and deep wells for miscellaneous uses including irrigation.

5.3. Groundwater Flow

Groundwater in the saturated zone is always in motion (Kresic, 2007). It moves through the porous media under the influence of fluid potential (Fetter, 2001).The most driving factor for the movement of groundwater is hydraulic gradiant. Groundwater flow takes place from the higher hydraulic head towards the lower hydraulic head. For the reason that groundwater is hidden it is not possible to directly measure the groundwater rates within an aquifer. However, observation piezometers can be constructed to determine the elevation of the water level in the piezometer. This water level offers information about the groundwater head at the open section of the piezometer. Groundwater head gradients can be used to estimate the extent and direction of groundwater velocities (Rushton, 2003). Toth (1963) classifies groundwater flow regimes in to three flow systems which are local, intermediate, and regional and understanding of groundwater movement in adjacent small basins makes possible an accurate representation of the motion of groundwater.

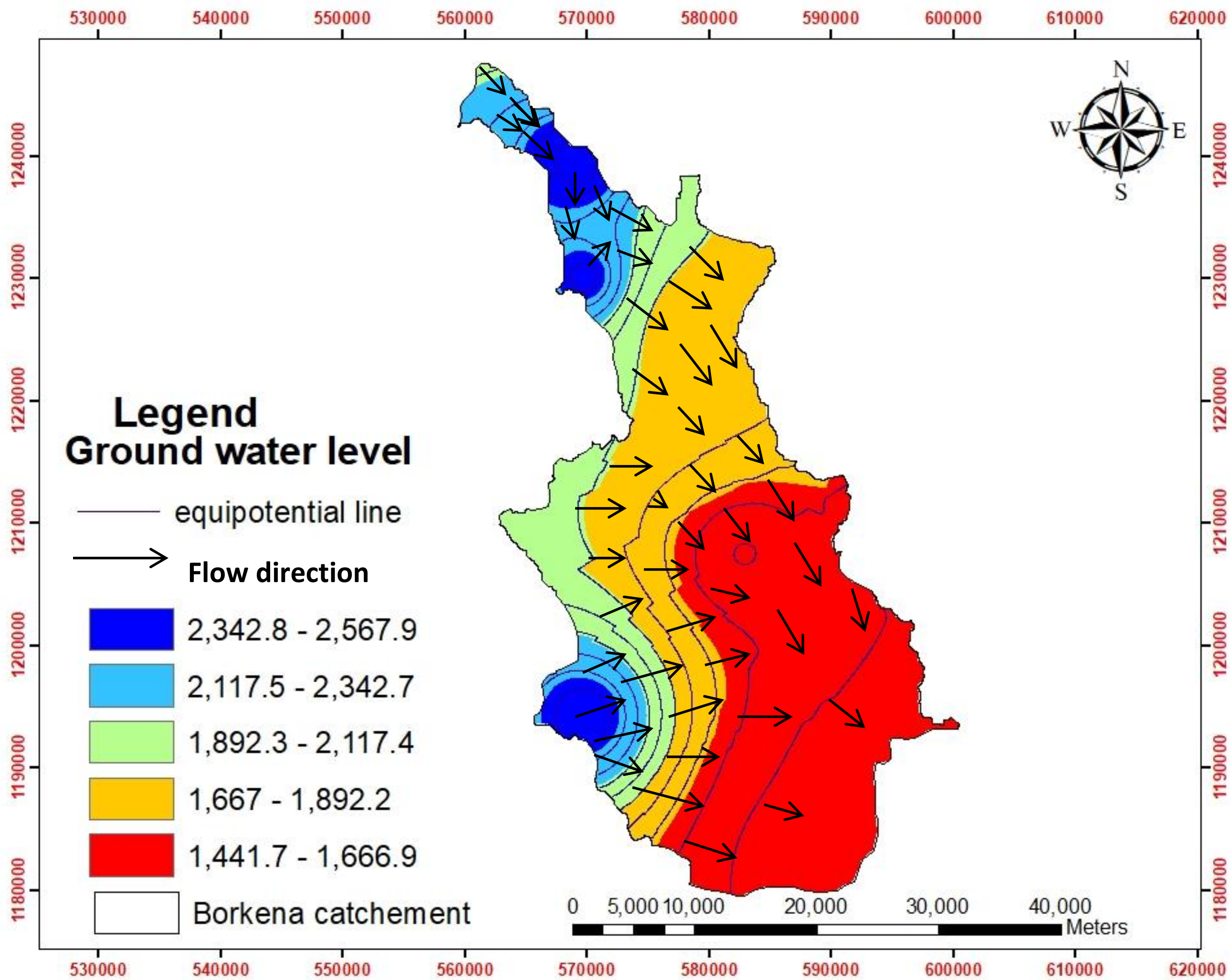


Figure 42 Ground water flow map

5.4.Hydraulic conductivity

Hydraulic conductivity is the ease with which water can move through pore spaces or fractures (Fetter, 2001). It is dependent on the intrinsic permeability of the aquifer material and the degree of saturation. The hydraulic conductivity of fractured rocks depends largely on the density of the fractures and the width of their apertures. Fractures can increase the hydraulic conductivity of solid rocks by several orders or magnitude (Kruseman and de Ridder, 1994). Many empirical and experimental methods have been developed to determine the hydraulic conductivity. Among them, a pumping test is the most reliable method to calculate the coefficient of permeability. From calculated values using pumping test data on different boreholes, the alluvial aquifers in the central parts of the Kombolcha sub-basin have the very high values of hydraulic conductivity (10.01-30.00 m/d). Relatively high hydraulic conductivity values (7.51-10m/d) have also been encountered from alluvial aquifers in the northern and southern limits of the Kombolcha sub-basin. Moderate values of hydraulic conductivity (5.1-7.5m/d) have been depicted by alluvial aquifers in the southern tip of the Kombolcha area. Low hydraulic conductivity values (2.51-5.0 m/d) have been indicted by the alluvial aquifers in the area surrounding Kemissie. Very low hydraulic conductivity values also (0.06-2.5 m/d) have been revealed by the alluvial aquifers in the central parts of the study area around Harbu.

5.5. Transmissivity

The transmissivity of an aquifer is a measure of how much amount of water can be transmitted horizontally thourh a unit thicknes of aquifer. Mathematically it can be expressed as, the Product of the hydraulic conductivity times the thickness of the aquifer (Dricoll, 1986)Transmissivity (T) is a hydraulic parameter of an aquifer that is known used in most Groundwater flow equations to understand the flow dynamics and is generally estimated from Pumping tests (Freeze and Cherry, 1979). The transmissivity values in the Area calculated from pumping test ranges from 10 m2/d to about 1750m2/d. Data which has been obtained from ADSWE (2013) and MoWIE (2018) show that transmissivity value for alluvial aquifer of Borkena river catchments has relatively high transmissivity values (i.e; >500 m2/d). Most of the area of an alluvial aquifer upper of Borkena river catchment having a range of transmissivity values (100-500 m2/d). Low transmissivity values (10-50 m2/d) have been observed in the volcanic rock aquifers surrounding the alluvial aquifer in the western and eastern side of the alluvial aquifers.

Table 12 Aquifer characterization parameters

	Specific capacity	Transmissivity	Conductivity
Average	176.1	256.3	4.5
maximum	158.3	1690.0	20.2
minimum	21.3	20.5	0.2

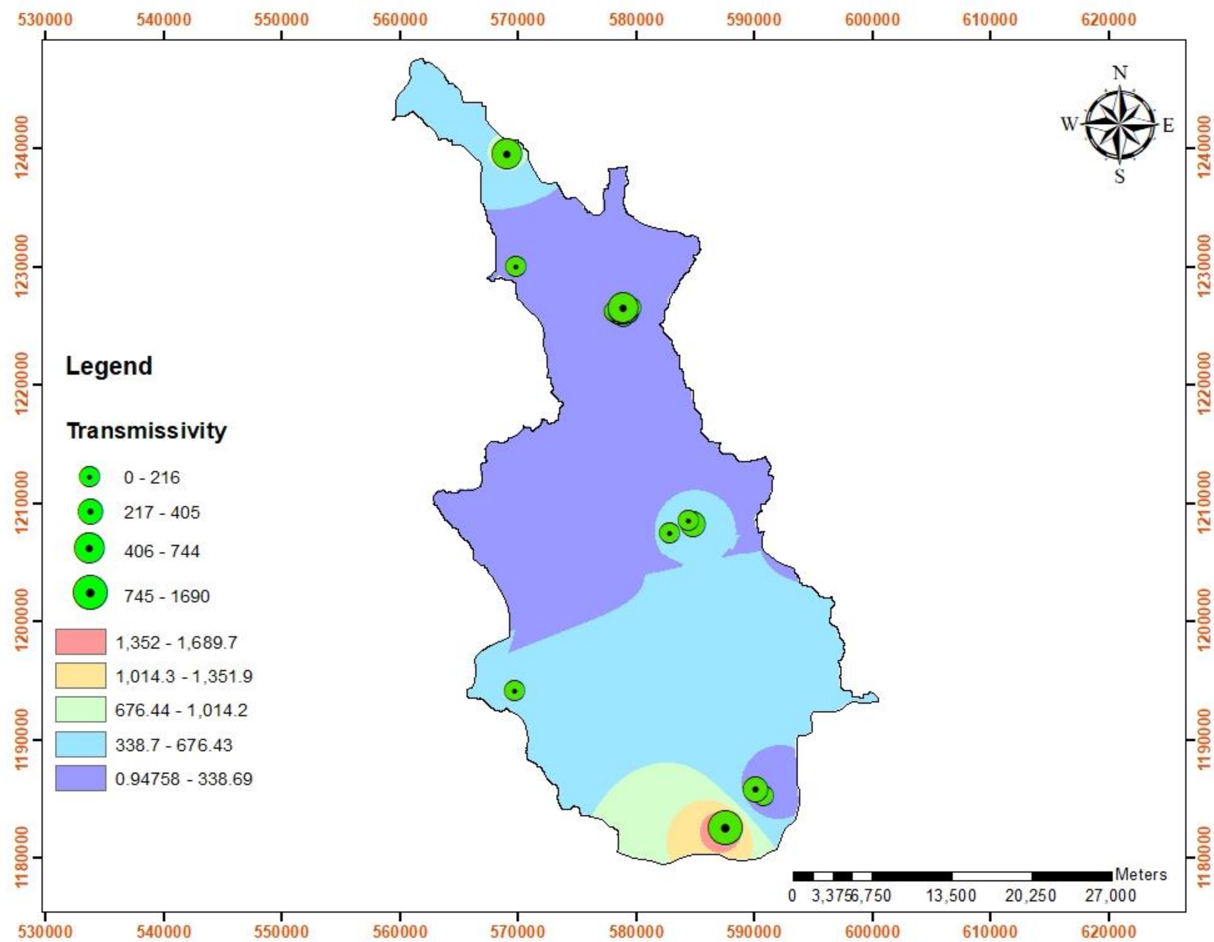


Figure 43 Transmissivity map

5.6. Specific Capacity

Specific capacity is material physical properties that characterize the capacity of an aquifer to release groundwater from storage in response to a decline in hydraulic head. The Specific Capacity of a well is simply the pumping rate (yield) divided by the drawdown. It is a very valuable number that can be used to provide the design pumping rate or maximum yield for the well. The average specific capacity is 176.1, the maximum 1585.3 and the minimum is 21.3.

CHAPTER SIX

6. Hydrogeochemistry

6.1.Water point inventory

Water point's inventory has been conducted in order to collecting available information, verify the previous records of water points and identify additional new data for analysis of groundwater potential assessment of the project area in terms of quantity and quality.

Existing water points within the study area are manual dug wells with hand pumps, machine drilled shallow wells, developed and undeveloped springs and boreholes. Water samples were collected from those representative water points for physical and chemical analysis.

Most samples were taken from drinking water wells in the villages and settlements. The wells were shallow wells and mostly hand dug well drilled or dug in alluvial sediments. Some additional samples were taken from one eye, two eye and three eye springs and from Perennial Rivers which are available for irrigation purposes and few additional samples were taken from hot springs.

The field work takes 15 days (from February 8, 2021 to February 22, 2021) during these days systematic sampling and locating of water points were done. Therefore 24 samples are taken such as 7 from spring, and hot spring5 from boreholes 7 from hand dug wells and 5 from rivers. Beside of taking samples discharge, PH, Temperature, Electrical conductivity and Total Dissolved Solvents (TDS) measurement were taken.

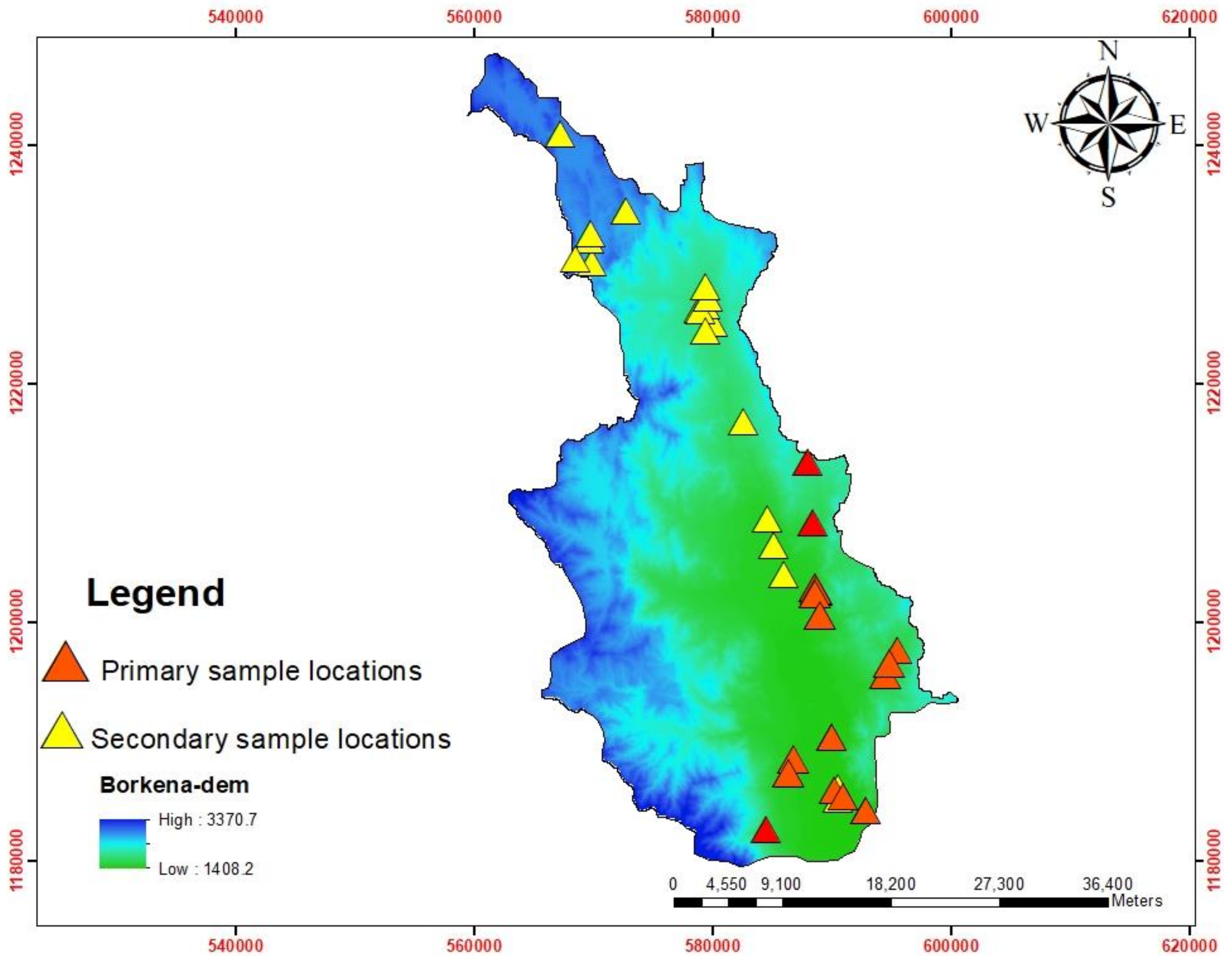


Figure 44 *Distribution of representative sample*

Characteristics of the samples

a) Springs

Many springs has been observed within the study area. During field work activity 7 spring were sampled having one, two and three eye exhibiting characteristics show a low yield capacity ranging from 0.2 l/s to 1.21 l/s .Out of the sampled spring two of them were found to be hot spring of artesian condition emanating from plains of Mekoye. Most of the springs are used for domestic and irrigation purposes by the local peoples. Most of the springs emanate from highly the surrounding escarpments the fall to the plain due to gravity. The springs are used for irrigation and domestic uses.

b) Boreholes

A number of wells were drilled within the study, but most wells are out of services. 7 borehole samples were under taken within the catchment. Out of these two were of thermal bore holes and artesian they just flow on the farm and because of the high temperature it burns the crops around the well. A number of boreholes have been drilled within the Borkena catchment, but most of the wells were out of function.

c) Hand dug wells and Shallow wells

Hand dug wells are manually hand dug with a depth of ranging mostly from 4 to 10 m depth with hand pump installed to it whereas shallow wells are drilled with Rigs with a depth ranging mostly from 30 to 60 m depth with hand pump installed to it.. There are many hand dug and shallow wells distributed within the study area which are used for domestic purpose by the community. 7 hand dug wells has been collected exhibiting low yield (1l/s).

d) Rivers

Many perennial and intermittent tributary rivers are found in the study area and 5 samples are collected including the main river Borkena. They have high discharge values (from 100- 250 l/s). They are used for irrigation purposes.

6.2.Water Sampling and Analysis

Water sampling has been carried out by first selecting representative site in which the water point exists. 24 samples have been collected from representative sites and a secondary source of hydro geochemical data from previous work has been supplemented for interpretation and analysis. Each insitu samples has been collected using 1 liter plastic bottle. Therefore representative sample from for different water sources i.e. Boreholes, Shallow wells, Hand dug wells and springs were undertaken from representative sites. Representative samples have been taken from each water sources at different locations (Figure 45). The secondary geochemical data taken from WWDSE have been used for interpretation and evaluation of the geochemical spatial variation of the study area.

A total of about 51 water samples (Both primary and secondary) data have been used for interpretation and evaluation of the Spatio-temporal variation of hydro-geochemical signatures. Three primary samples are analyzed in the laboratory and the analysis result supplemented with secondary inorder to make reliable information for hydrochemical interpretation. Physical parameters such as PH, EC and Temperature are measured with pH meter and EC meter immediately during sampling.

6.3. Physical Parameters

Temperature, pH, electric conductivity and total dissolved solids are some of the parameters that are measured both in the field during sampling and in the laboratory. These parameters have their own effect on the chemistry of water.

6.3.1. Temperature

Temperature of water is one of the parameter that determines the capability of water to dissolve substances as it pass through the subsurface lithologic units. Different geological materials are made of different minerals, having different physical and chemical properties, some mineral that makes up the rock units are easily dissolved at room temperature while some minerals are temperature dependent to wear out and their chemical constituents. Temperature is one of the major controlling factor that leads to activation of chemical reaction for the formation of new compounds. Within the study area generally temperature of water samples taken from highland area generally shows low temperature values compared to water samples taken in lo elevated area.

6.3.2. pH

The PH (Hydrogen ion activity) of a substance is the measure of acidity and alkalinity of a substance. PH has a value of 1 to 14.in a pure substance the concertation of hydrogen ion and hydroxyl is equal making water to be neutral in this case the PH of water is exactly equal to 7.the unbalance concentrations of hydrogen and hydroxyl ion make water to be acidic or alkaline. When the concentration of hydrogen ion more dominant than hydroxyl ions the water is said to be acidic making water to have PH value less than 7.Whereas when the concentration of hydroxyl ions are dominant as opposed to hydrogen ions the water is said to be Alkaline making the water to have a PH value greater than 7.

According to WHO standard set on water resources used for domestic purpose ,most natural waters shows a PH value range from 6 to 8.5. PH is one of the parameter that has been measured insitu ranging with a value 9.7being the maximum and 6.6 being the minimum PH record within the study area.
According to WHO standard, majority of the samples lies within the acceptable limites except the maximum value

- < 6.5 is acidic so, There is no acidic water in the study area.
- 6.5-8.5 is normal, so, most of the water samples in the study area are with in this range considered as satisfactory

- 8.5 is basic water, so that one water sample is considered as unsatisfactory.

Within the study area about for 28 water points, institu measurement of PH have been carried out as shown in figure 43.a PH value below 6.5 have not been observed. The number of PH values ranging from 6.5-8.5 is found to be 28 whereas a PH value ranging from 8.6-9.1 was counted to be 1.Acoording to WHO almost all water points les within the acceptable limit as standardized by WHO for drinking purpose.

PH	*Frequency*
7	1
7.5	9
8	14
8.5	3
9.7	1

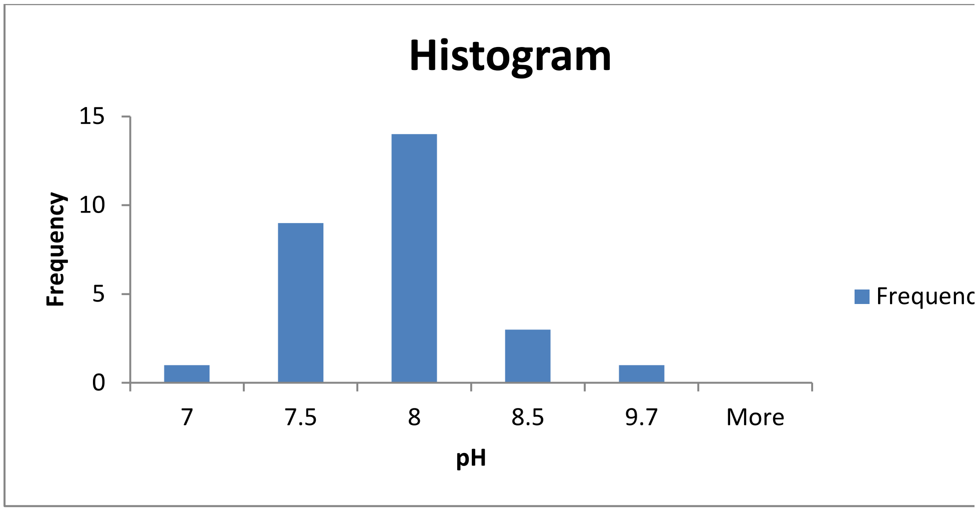


Figure 45 Histogram plot that shows frequency

6.3.3. Total Dissolved Solvent (TDS)

TDS (Total Dissolved Solids) refers organic and inorganic constituents dissolved in liquid water. There are many processes that control the concentration of amount of dissolved substance in groundwater. Among them, processes such as movement through rocks containing soluble mineral matter, concentration by evaporation, contamination due to influx of sea water, industrial and municipal waste water disposal may cause an increase in TDS content of ground water (Karkaranth, 1987). The major cations are (calcium, magnesium, sodium and potassium), major anions (chloride, sulphate, carbonate, and bicarbonate) and silica though not in ionic form constitute the bulk of the mineral matter contributing to total dissolved solids. In addition there may be minor constituents present, including iron, manganese, fluoride, nitrate, strontium and boron. According to WHO water standard a water that has a TDS value greater than 1000 µS/cm is not acceptable for consumption. Insitue measurement of TDS has been undertaken within the study area for analysis of spatial distribution of TDS map form the figure below it is observed that majority of TDS values lies between 210.12 and 630.15 where certain anomalies of higher than this value has been seen in some areas.

From ins-situ measurements the highest TDS value is recorded at Kemissie that is 880 µS/cm on thermal hand dug well associated with fault along to rift zone and the lowest TDS which is 150 µS/cm. Hot springs which are found around Harbu and Kemisse are characterized by high temperature, Ec and TDS. The study area has mostly low TDS range from (210350 µS/cm) to medium TDS range from (630-700). High TDS value which has a range 1050 – 1189.8 is rare in the study area. The maximum and minimum TDS values are 192 and 1194mg/l respectively.

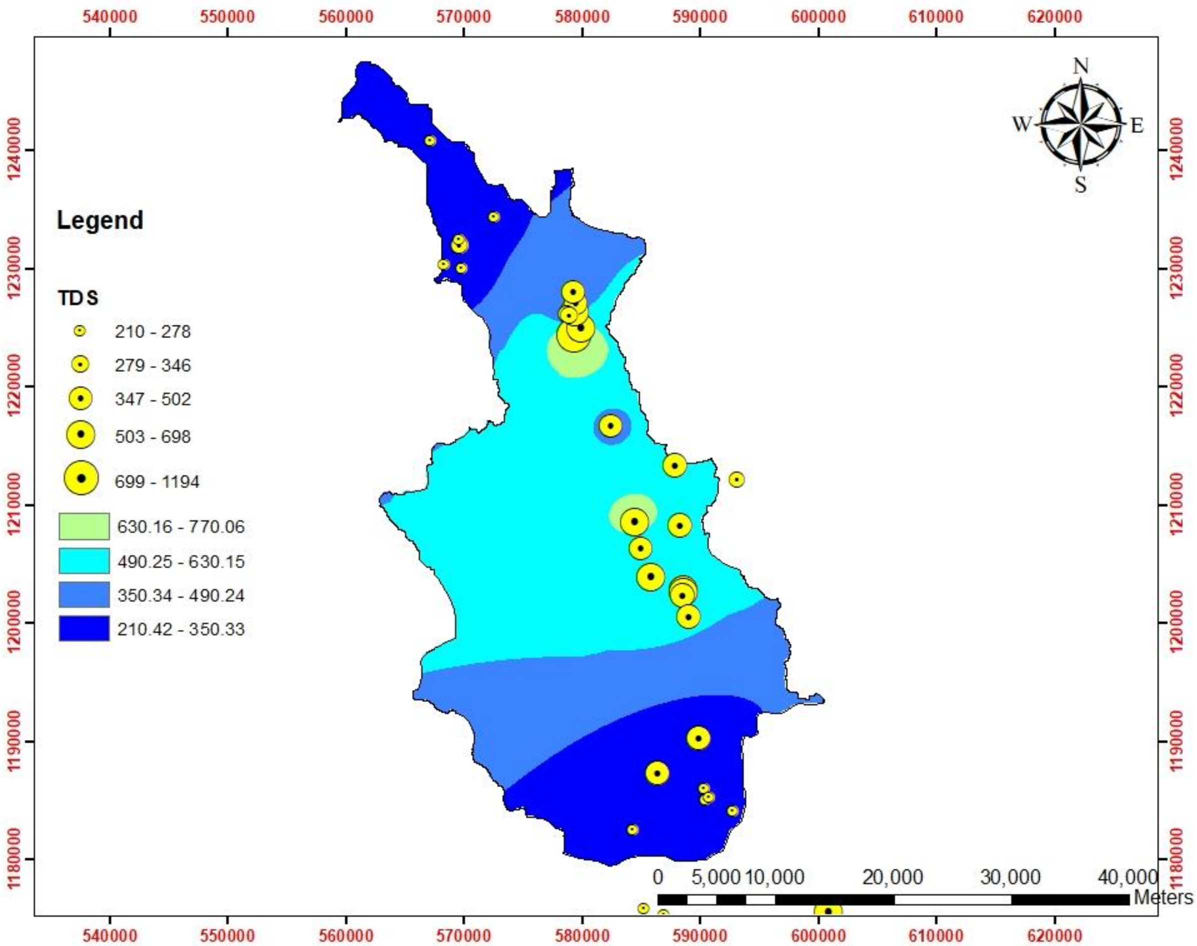


Figure 46 TDS distribution in the study area

6.3.4. Electrical conductivity (Ec)

The electrolytic property of water (i.e., the ability of water two dissociate substance in to ionic form) makes water to conduct electric current. Therefore measuring of electrical conductivity of a substance is the indirect measurement of its chemical constituents. As observed in the figure

(Figure 48) below there is strong relationship between EC and TDS which give correlation coefficient of 0.89. Thermal wells and hot spring also shows high TDS and EC values, therefore Temperature is also the governing factor to increase these parameters. The relationship between EC and TDS is more exact in most ground waters (Karkaranth, 1987).

The presences of chemical constituents give water the ability to conduct electricity. Thus, the electrical conductivity (EC) of water is an indirect measure of its dissolved constituents. The TDS and the EC are in a close connection and they show positive relationship approximately to ~1. EC does not measure the chemical constituents present in water, but it enables for determination of TDS, which is an acceptable indicator of water quality. In general the larger the value of specific conductance makes the concentration of dissolved solids greater in the water sample this leads the water quality to be poor.
In the highlands the EC of groundwater is usually less than that of the rift zone.

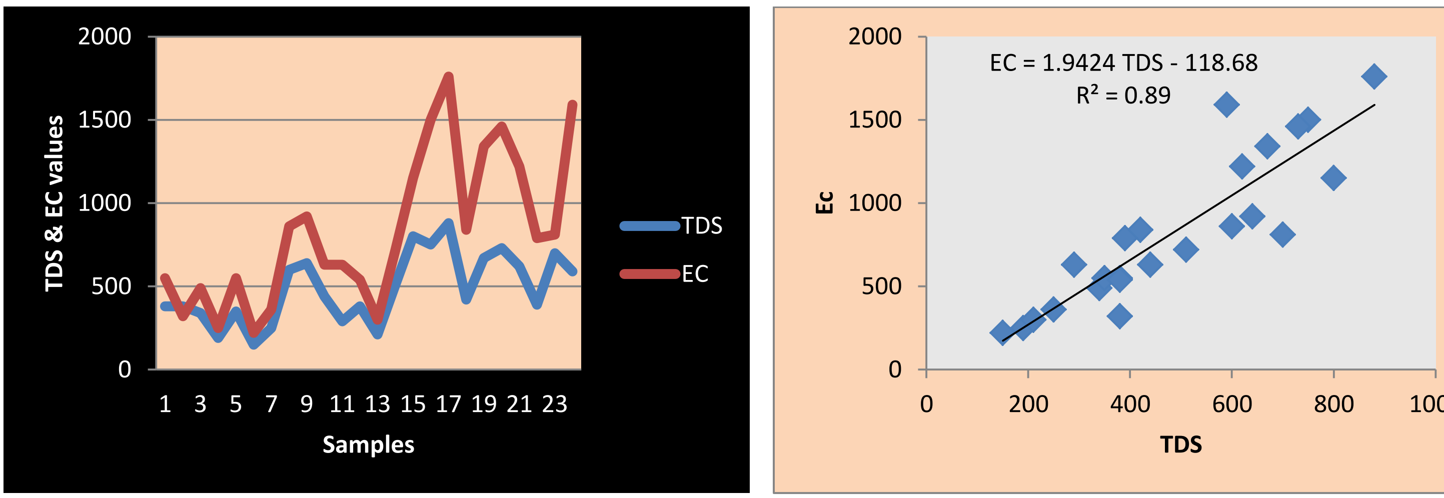


Figure 47 The relationship between EC and TDS from field Measurement

6.4.Chemical parameters

The chemical composition of surface and groundwater is controlled by many factors that include composition of precipitation, mineralogy of the watershed and aquifers, climate, and topography. These factors combine to create diverse water types that change spatially and temporally.

6.4.1. Cations and Anions

Sodium Ion (Na)

Sodium is one of among major ions that helps us to characterize the groundwater system.one of the among reactions that are involved in groundwater systems are cation exchange reactions whereby Ca and Mg minerals found in water are exchanged for Na minerals that are wear out from clay minerals during evolutionary processes(Hem,1985). Other major importance of Na measurement in water is used to decide whether the water is applicable for the sole purpose of domestic and irrigation. A guideline set by WHO the maximum allowed concentration for drinking water is about 200mg/l. within the study area the average concentration of sodium is found to be 72.1mg/l which is within the acceptable limit. As observed, in almost all sample the concentration of sodium concentration is found below the desirable and permissible level of standard except one river exhibiting higher than the standard value i.e., 470mg/l.

Calcium Ions (Ca)

Calcium is an essential constitute of many igneous rock minerals, especially of the chain silicates pyroxene and amphibole and feldspars. In the study area the calcium concentration varies Surface waters have Concentration ranging from

Magnesium Ion (Mg)

In igneous rocks, the magnesium is typically a major constitute of the dark colored ferromagnesian minerals. Specially, these include olivine, the pyroxenes, the amphiboles and the dark-colored micas, along with various less common species. The magnesium ion Mg^{2+} will normally be the predominant form of magnesium in solution in natural water. The ion pair $MgSO_4$ (aq) has about the same stability as the species $CaSO_4$ (aq), and magnesium complex with carbonate or bicarbonate have approximately the same stability as the similar species of calcium.

Potassium Ion (K)

The principal potassium minerals of silicate rocks are the feldspars orthoclase and microcline ($KAlSiO_8$), the micas and the feldspathoid leucite ($KAlSi_2O_6$). The potassium feldspar is resistant to attack by water. In dilute natural water in which the sum of sodium and potassium is less than 10 mg/l, it is not unusual for the potassium concentration to equal or even exceed the sodium concentration. In the study area sodium and potassium samples from water supply wells, springs and surface water shows that the concentration of Na^+ (mg/l) is greater than concentration of K^+ (mg/l) in all sampled data.

Bicarbonate ions (HCO_3)

The presence of carbonates and bicarbonate influences the hardness and alkalinity of water. The weathering of rocks contributes carbonate and bicarbonate salts. Bicarbonate is the dominant anion in most surface waters in the study area, the maximum bicarbonate ion concentration HCO_3^- ion is relatively higher in the norther and middle of the study area; specifically, around Dessie and combolcha. It generally decreases from north towards south of the sub basin.

The Bicarbonates are one of the major anions that are important in groundwater studies. The presence of carbonate and bicarbonates are strongly related to the hardness and the alkalinity of water. Within the study area bicarbonates are much more dominant in in the surface waters. In terms of the sub-suraface the concentration of sodium is higher in the northern and middle part of the study area; specifically around Dessie and Kombolcha. In general the concentration is decreases from north to south.

Chloride (Cl)

Chloride is another major anion element that is found within groundwater. It is known for its conservative nature during chemical evolutionary processes and good indicators of ages of groundwater compared to cations. High concentration of chloride ions is strongly related with the type of with the type of geologic materials, and pollution from surface environment. Within the study area the chloride concentration for almost all samples taken from groundwater is under range of the limit of the standard.

Fluoride Ion (F-)

The fluoride concentration of natural water in the study area shows almost uniform with small variations. In some parts especially in the rift zone and samples from some boreholes which are associated with fault Zones show higher fluoride concentration than the normal drinking water standard. The higher concentration of fluoride in the study area is associated with recent acidic volcanic Concentration of fluoride within the study area shows almost uniform distribution with except some certain anomalies of high signatures of floride.in some parts, specifically in the rift zones associated with faults some sample of borehole exhibits high concentration of fluoride making concentration of floride to be higher that the acceptable drinking water standard.in most cases, higher concentration of fluoride is related to acidic volcanic(Berhanu Gizaw 1996). High Fluoride concentration, up to in central and rift zones associated with thermal waters. Very low fluoride concentration is observed in plateau zone waters. In the study area, the maximum concentration of fluoride ion is about 5.

Nitrate (NO3)

Concentration of Nitrate is groundwater studies are linked to potential contamination sources. Like chloride, concentration of chloride is much higher in municipals where industrialization is expanded which leads to release of waste product to subsurface bodies containing this ions which eventually percolates to the sub surface.

Table 13 Stastical distribution Major cations and anions

	Na	**K**	**Ca**	**Mg**	**F**	**Cl**	SO4	**HCO3**	**NO3**
Average	72.1	1.8	62.1	13.8	0.7	22.9	24.9	309.3	4.4
Maximum	470	7	153.6	42.2	5	95.4	155.9	555.2	17.29
Minimum	15	0.2	14.4	1	0.4	5	3.9	151.2	0.05
Median	50	0.9	60	12.5	0.6	15.9	13.5	286.6	2.47

STDV	108.7	2	34.4	11.1	1.1	25.4	33.4	113.4	5.18

6.5.Graphical Presentation of Laboratory Measured Geochemical data

The objective of interpreting of physical and chemical analysis of water samples is used to classify waters of different geochemical characteristics and visualize any similarity or differences among water types from different sources and describe possible geochemical evolutionary trend by comparing with standards. The conventional hydrochemical tool was applied to study groundwater quality and classify the water samples. AquaChem V.4.0 software by Waterloo Hydrogeologic Inc. was applied for data processing, archiving and the production of hydrochemical plots. The water quality parameters considered for the hydrochemical analysis are physical and chemical characteristics are used:-

- To define origin of the water
- To understand geochemical process in the aquifer
- To define the hydrogeology
- To define suitability

Geochemical studies often involve synthesis and interpretation of mass of analytical data. Variation in groups of water from existing data for example can provide insight to chemical difference between types of flow system and the accompanied chemical changes as well as the aquifer heterogeneity and connectivity.

The examination of tabular geochemical data of a large number of samples is monotonous and tiresome process. For such a reason analytical data are better represented by diagrams. Multi variant diagrams bring together the result of analyses of different water samples and permit direct comparison of various ground water types and genetic and classification Statements.

6.5.1. Water Type , Piper and Durov Diagram

Groundwater in the study area has a mean pH value of 7.7 and median 7.32 showing normal distribution of pH throughout the catchment; indicating that with respect to pH the groundwater of the study area is within acceptable limits of WHO standards for drinking water. The overall examination of the chemistry of groundwater of the study area suggests that alkaline earths (Ca+Mg) in deeper wells significantly exceed the alkalis (Na+K) while in shallower wells the alkalis (Na+K) relatively exceed the alkaline earths (Ca+Mg) and the weak acids (HCO3+CO3) exceed the strong acids (Cl+SO4). The dominant Water type in the catchment is Ca-Mg-Hco3. It is widely distributed in the study area especially in the middle and upper parts of the study area. Almost all river samples are dominated with this water type except two river samples which mainly consists of Ca-Mg-So4-HCo3 and Ca-Mg-Hco3-So4. Calcium bicarbonate water Ca-

Hco3 is Prominent in the highland area of Dessie and surrounding areas. Samples from different springs and hand dug wells shows that Ca2+ and HCo-3 are the governing cation and anions respectively. Magnesium on the other hand appears in one sample from recharge Zone.
A clear evidence from the hydro chemical analysis in the area shows that the hand dug well adjacent to the borehole and thermal spring water has different water chemistry. Both Ca2+ and Mg 2+ which disappear in the thermal spring and borehole prevails in the hand dug well. This tells us that at least there is a different aquifer system with different Hydrochemistry and possibly connected with the surrounding geology. In the lowland areas especially of alluvial deposit the water is dominated with sodium ion.

Table 14 Water quality analysis using Aquachem software that shows water types

Sample_ID	Water_Type	pH	EC	TDS	Na	K	Ca	Mg	F	Cl	HCO3
BBR	Ca-Mg-HCO3	7.41	378	228	17	0.4	53.6	12.96	0.44	10.93	225.7
BR	Ca-Mg-Na-HCO3	7.53	574	346	31	1.5	62.4	29.28	0.537	25.84	304.7
CHBH-2	Ca-Mg-Na-HCO3	7.09	395	254	19.5	4.6	35.2	12.48	0.58	5.96	185.07
CHBH-3	Na-HCO3	8.14	338	192	73	0.6	16	4.8	0.63	7.95	194.1
CHW-2	Ca-Na-HCO3	6.61	499	284	28	4.6	60.8	7.68	0.49	16.9	230.21
DHBH-2	Ca-Na-HCO3	7.59	418	262	41	0.7	64	5.28	0.48	25.84	185.07
ER-2	Ca-Na-HCO3-Cl	7.55	1113	634	110	7	100.8	10.56	0.694	87.47	455.91
GBH	Ca-Mg-HCO3	7.41	494	328	23	0.9	63.22	14.88	0.52	18.89	277.61
HrBH-2	Ca-Na-HCO3	7.49	826	502	100	0.8	92	4.8	0.46	30.81	417.55
HrBH-4	Ca-Na-HCO3-Cl	7.32	1189	698	146	1.3	132	4.8	0.705	95.42	417.55
HrBH-5	Na-Ca-HCO3	7.81	1044	618	188	1.2	42.4	3.36	0.553	60.63	338.55
HrSP-1	Ca-Mg-Na-HCO3	8	685	460	50	0.2	67.2	31.68	0.53	18.89	415.29
JR-1	Ca-Na-Mg-HCO3	7.9	537	362	36	2.3	52.8	18.72	0.72	7.95	286.64
JRW-1	Ca-Na-HCO3	7.63	414	248	39.5	2.4	60	11.52	0.56	10.93	293.41
KBH-1	Ca-Na-Mg-HCO3	7.61	904	574	62	0.9	92.8	24.96	0.48	15.9	464.94
KBH-2	Na-Ca-Mg-HCO3	7.97	500	332	70	0.6	38.4	14.48	0.49	15.9	286.64
KS	Ca-Mg-Na-HCO3	7.51	388	246	22.5	0.8	49.6	13.44	0.52	13.92	221.19
KTW-1	Na-Ca-HCO3	8.02	349	210	56.5	1.5	30.4	2.4	0.791	7.95	207.64
KTW-2	Ca-Na-HCO3	7.37	709	232	41.5	6	38.4	3.84	0.653	5.96	216.67
KTW-3	Na-Ca-HCO3	7.74	405	262	47.5	0.9	36	9.6	0.51	7.95	248.27
KW-3	Ca-Na-Mg-HCO3	7.1	752	502	57	3.8	88	26.4	0.6	25.84	435.6
KW-6	Ca-Na-HCO3	8.48	365	234	74	0.3	153.6	0.96	0.73	4.97	151.22
Sire-1	Ca-HCO3	7.49	337	214	17	0.2	53.6	6.24	1.063	10.93	196.36
TS	Ca-Mg-HCO3	7.64	602	278	15	0.4	60.8	23.52	0.528	10.93	270.84
W-2	Ca-Na-HCO3	7.59	600	418	68	0.6	64	16.8	0.47	14.91	379.18
W-3	Mg-Ca-HCO3	7.53	886	394	36	0.7	57.6	42.24	0.44	12.92	446.89

WR-1	Na-Ca-Mg-HCO3	7.26	363	360	80	1.7	60	21.6	0.58	17.89	353.41
WR-2	Na-HCO3-CO3	9.69	2040	1194	470	4.8	14.4	5.76	5.01	50.69	555.22

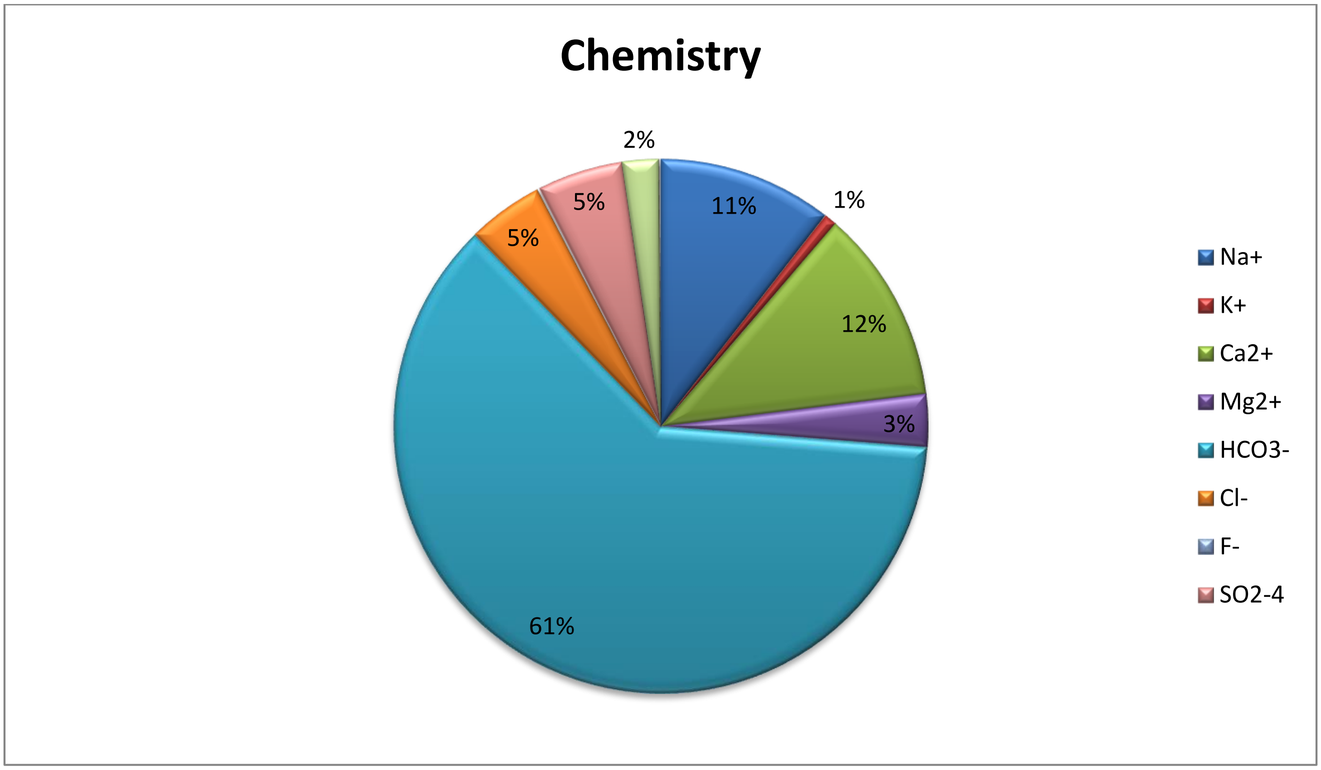


Figure 48 Proportions of cations and anions

The dominant Water type in the catchment is Ca-Mg-HCO3. It is widely distributed in the study area especially in the middle and upper parts of the study area. Almost all river samples are dominated with this water type except two river samples which provide Ca-Mg-SO4-HCO3 and Ca-Mg-HCO3-So4. Calcium bicarbonate water Ca-Hco3 is Prominent in the highland area of Dessie and surrounding areas.

Samples from different springs and hand dug wells reveal that Ca2+ and HCO-3 are the governing cation and anions respectively. Magnesium on the other hand appears in one sample from recharge Zone.

A clear evidence from the hydrochemical analysis the area shows that the hand dug well adjacent to the borehole and thermal spring water has different Chemistry. Both Ca2+ and Mg 2+ which disappear in the thermal spring and borehole prevails in the hand dug well. This tells us that at least there is a different aquifer with different Hydrochemistry and possibly connected with the surrounding geology. In the lowland areas especially of alluvial deposit the water is dominated with sodium ion.

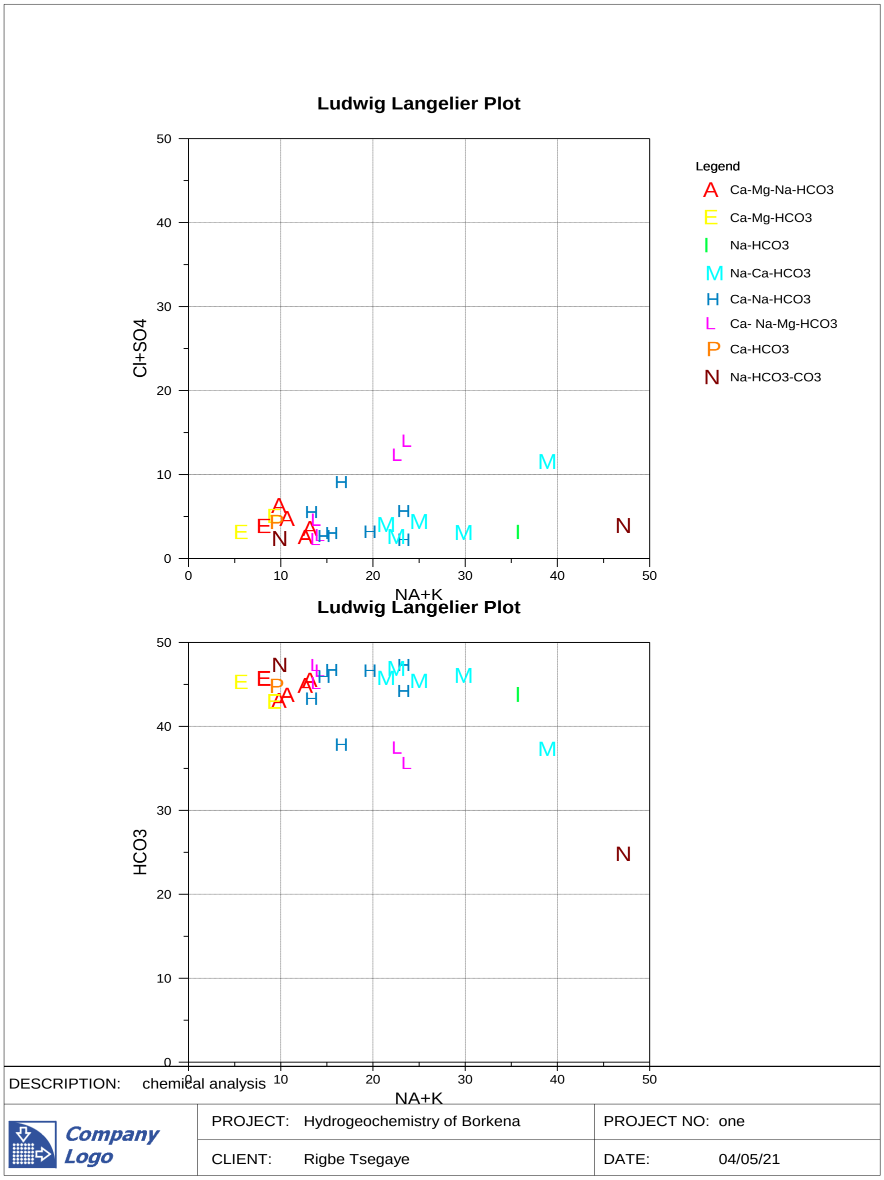


Figure 49 *Ludwig Langelier plot showing the correlation of (Na++K+) ions with the anions of (Cl -& SO4-2) and HCO3-*

The correlation shows that the cations of (Ca+2+ Mg+2) are not correlated with the anions of (SO4-2 + Cl-). The correlation of the cations of (Na++ K+) with the anions of (HCO3-) is generally negatively and positively correlated respectively; nevertheless, the cations of (Na++ K+) & (Ca+2+ Mg+2) shows positive correlation with the anions of the (SO4-2 + Cl-). This reveals the dominant water type in the area to consist of the ions of (Na++ K+), (Ca+2+ Mg+2), HCO3-1 and Cl-.

Besides the Ludwig Langelier plot further correlation has been observed between the cations of (Ca+2+ Mg+2) and HCO3-1, electrical conductivity and total dissolved solids. The scatter plot of HCO3-1 Vs Ca+2 in borehole groundwater samples shows that the two parameters are correlated with correlation coefficient of 0.617.

6.5.2. Evolution of Major Cations (Ca2+, Mg2+, Na+, K+)

As ground water flows from an aquifer from point of recharge to appoint of discharge, it undergoes change in water quality. The evolution of water chemistry in ground water proceeds from near surface oxidizing condition typically producing calcium bicarbonate water chemistry to deep ,reducing condition producing sodium chloride water chemistry (Pyne,1995). The evolution includes cation exchange reactions such as between dissolved calcium and dissolved sodium, oxidation of inorganic materials to carbon dioxide and water, chemical weathering (digenesis), dissolution and leaching of inorganic substances from soil and sediment particles creating a relatively stable mineralogy compatible to water chemistry.

In the study area progressive change in the chemical character of the ground water has been observed from point of recharge to point of discharge. In the study area the ground water observed from the analyzed chemical data and the change in the water type is the replacement of calcium by sodium ion towards east. The chemical evolution map has shown that the Ca-Hco3 water type from the recharge area is progressively changed along the flow path till calcium is dominated by Na- rich water type that is Na-Ca-Hco3. Therefore, with the exception of geothermal water the evolution in relation to cation generally becomes: Ca-HCo3 - Ca-Mg-HCo3- Na-Ca-Hco3.

6.5.3. Evolution controlling factors

During the prolonged contact of ground water with the reservoir rock psycho-chemical process leads towards the attainment of equilibrium between the mobile constituents of the rock mineral and the solute in ground water.

The geochemical processes which possibly take place include

- Dissolution and precipitation
- Ion exchange
- Hydrolysis of the silicate minerals

Hydrolysis of silicate minerals: The breakdown of mineral under the influence of H+ and OH- in the water is known as Hydrolysis (Matthess, 1982). Hydrolysis attack the surface of minerals which are relatively insoluble and cause the formation of new mineral as the same time as the removal of Ca^{2+},Mg^{2+},Na^{+} and K^{+} ions in solution. The hydrolysis process is responsible for the removal of cations from their parent rock (alkali feldspars, plagioclase). Since the study area is dominated by volcanic rocks, the above silicate minerals are expected to undergo hydrolysis reaction which is responsible for the evolution of cations. Thus, hydrolysis is one of the factors which control the evolution.

Dissolution and Precipitation: Dissolution and precipitation of soluble minerals play a fundamental role for the evolution of cations along ground water flow direction. The evolution is dependent on the availability and solubility of the minerals. During the course of its flow ground water picks up dissolved solids, dissolution continues to proceed until saturation takes place between the ground water and the mineral phase. Under saturation of the ground water with respect to the mineral result in the net dissolution provided the mineral is present. Super saturation on the other hand results in precipitation of the minerals.

Therefore the spatial variation and evolution of the ions in ground water is a function of nature of the mineral and reaction with the ground water.

Cation exchange: The extent and velocity of an ion exchange process depend on the kind of dissolved substances, their properties, their ionic composition and the type and concentration of dissolved ions and their accompanying complementary ions (Matthess, 1982). Cation exchange process is a chemical reaction in which the calcium and Magnesium ions in water are exchanged for sodium that is adsorbed to aquifers solids such as Clay minerals, resulting in higher sodium and lower Calcium and Magnesium concentration in water.

For this purpose a bilinear diagram of Ca, Ma, Na and potassium or their sum or ratios against TDS is used to assess the evolutionary trends. Some bilinear plot of cations, sum of cations and ratio of

cations which indicate evolutionary trend is plotted in the diagrams below.

The main possible source of bicarbonate ion in the study area is the dissolved carbon dioxide. The source of CO_2 that produce HCO_3^- ion in water is the CO_2 gas fraction of atmosphere or atmospheric gases between the land surface and the water table.

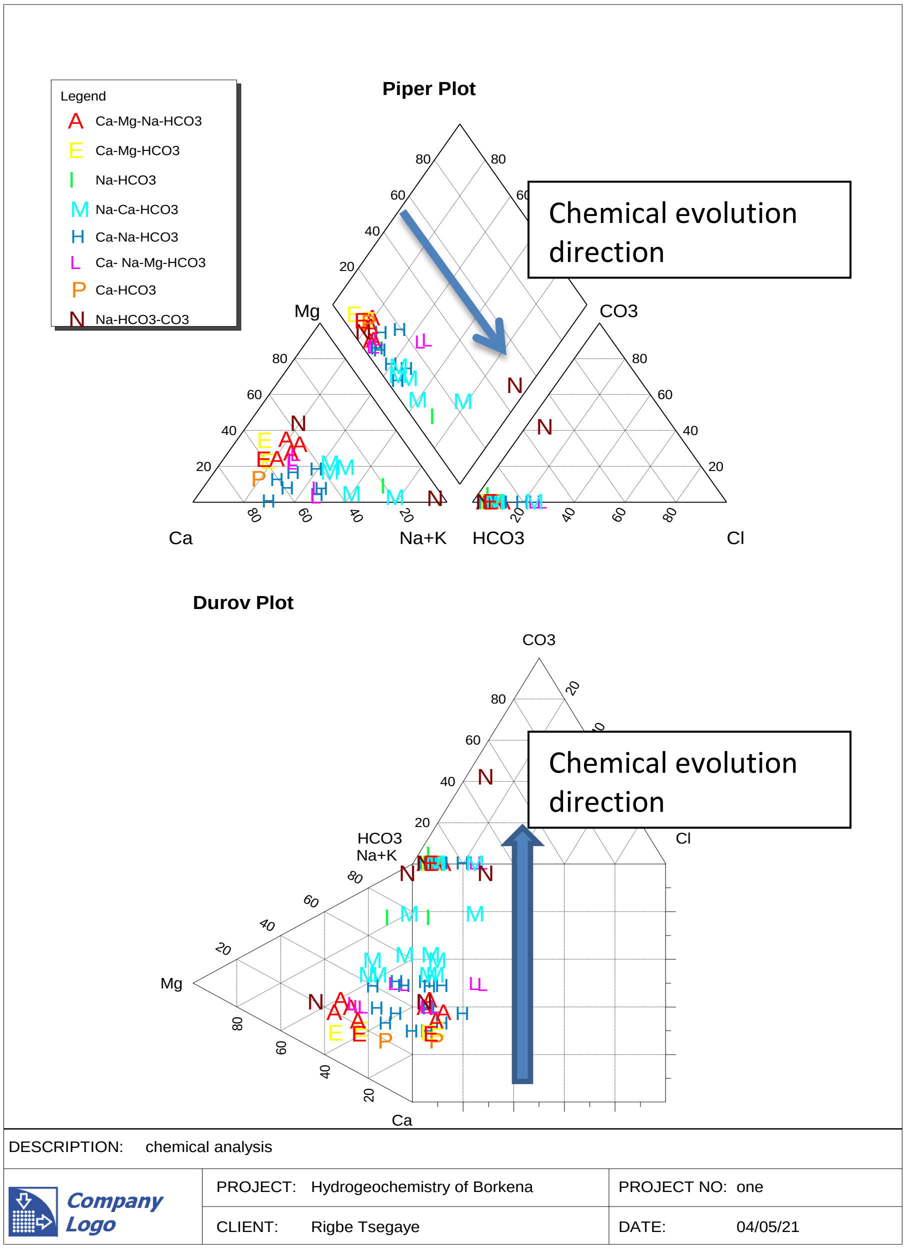


Figure 50 Piper and Durov plot

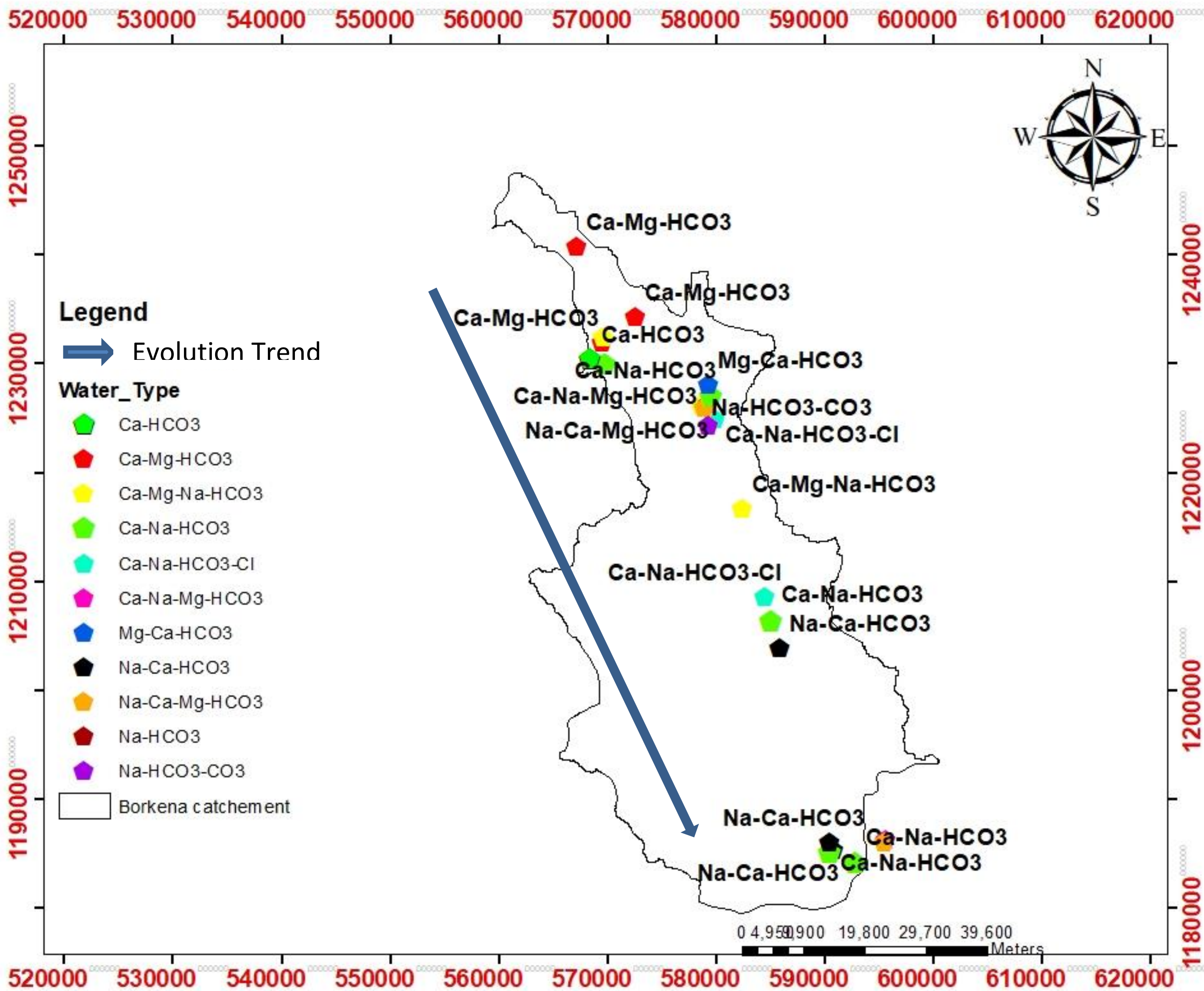
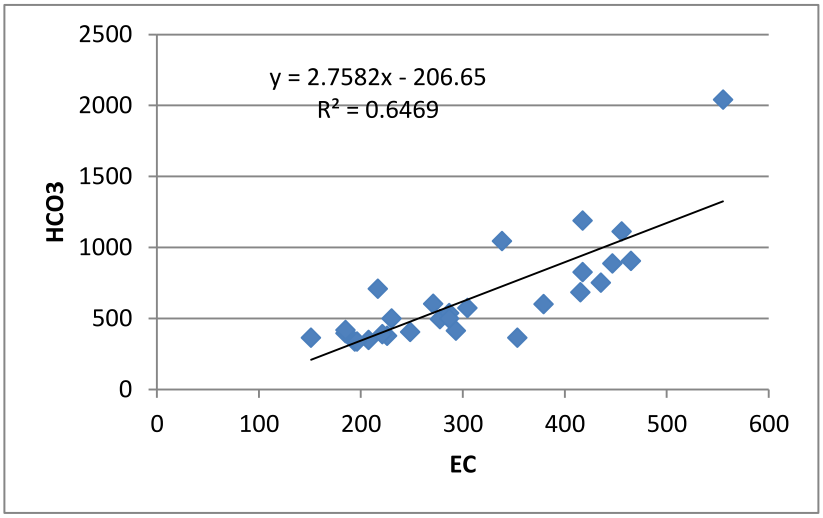
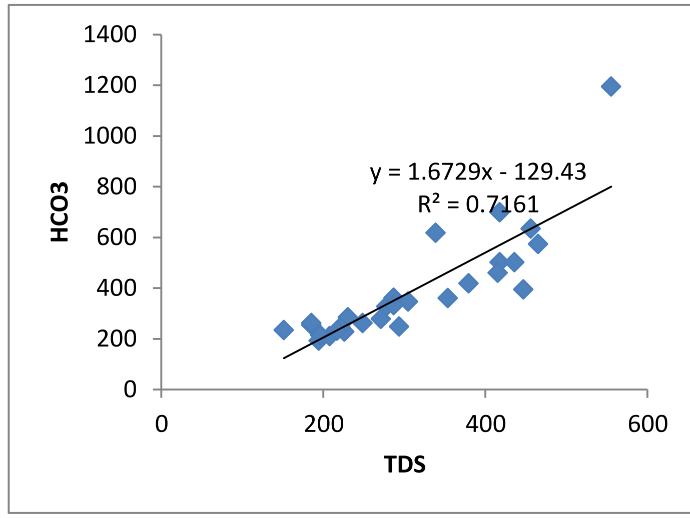


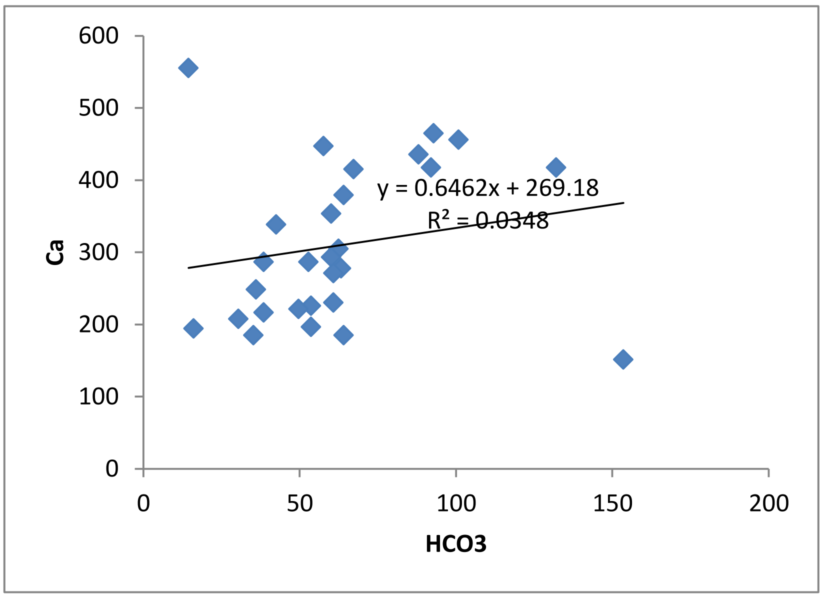
Figure 51 Water type evolution of the study area



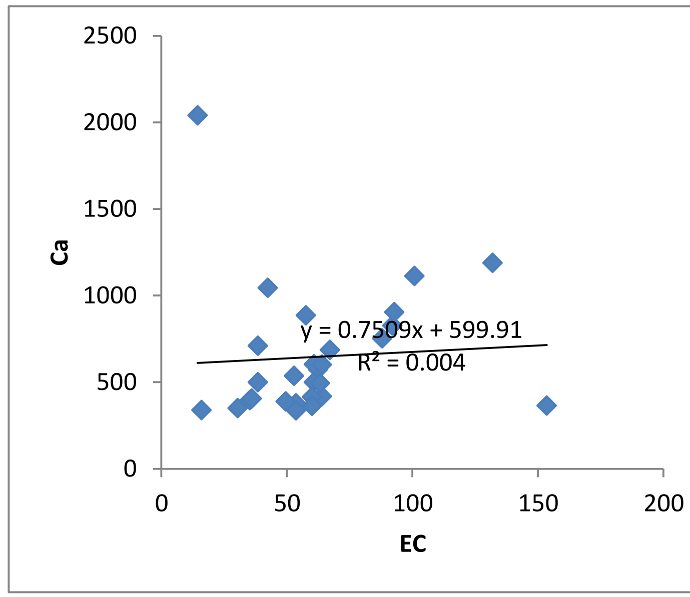
a. Ec Vs HCO3



b. TDS Vs HCO3



c. HCO3 Vs Ca



d. Ec Vs Ca

Figure 52Relationship of Ca with EC and HCO3 and HCO3 with TDS and EC

6.6.Rock-Water Interaction

During weathering and water passage in rocks and soils, ions trickled out and dissolved in groundwater. The geological formations, water-rock interaction and relative mobility of ions are prime factors influencing the geochemistry of groundwater. The use of scattered plots for TDS vs Na/ (Na + Ca) and TDS vs. Cl/ (Cl + HCO3) can be used to identify rock-water interaction processes. Among the cations, Ca, Na and Mg are the dominant ions in groundwater which are influenced by the dissolution of carbonate minerals. This can be explained through the scattered plots of (Ca + Na) vs (HCO3+SO4). In the scattered plots, the ionic concentrations falling above the equi-line result from carbonate weathering. Carbonate weathering results from the action of rainwater impregnated with CO2 and becomes rich in carbonic acid. The carbonic acid influences the dissolution of carbonate minerals (Calcite and dolomite) in the aquifer system.

The mean percentage concentration of Ca+2, Na+ and HCO3- are much more significant. This may imply that dissolution of carbonate minerals characterized by high loadings of Ca played an important role in the hydrochemistry characteristics of the groundwater.
The mean concentration value of Na and chloride ions in the water samples is in the maximum admissible limits of WHO standards. Besides that, the two parameters, Na and Cl, are insignificantly (R= 0.53) correlated. It indicates that the most likely sources of sodium are the dissolution of Nafeldspars, halite, evaporation and cation exchange within some clay.

The dissolution of salts or halite (NaCl) is sometimes cited as a source of both sodium and chloride in ground water. A qualitative technique to determine if halite dissolution is an influence on ground-water chemistry is to plot sodium concentrations relative to chloride concentrations. Because sodium and chloride ions enter solution in equal quantity during the dissolution of halite, an approximately linear relationship may be observed between these ions (Hem, 1985). If the concentrations are plotted in millequivalents per liter, this linear relationship should be described by a line with a slope equal to one. No clearly-defined linear relationship between concentrations of chloride and sodium is apparent in the ground-water samples under consideration. This suggests that the concentrations of sodium and chloride in ground water of the catchement heavily influenced by factors other than to the dissolution of halite. Na/Cl ratios in excess of 1 at lows alinities imply that meteoric NaCl is not the only source of sodium and indicates feldspar dissolution (Petrides and Cartwright, 2006). Thus, the higher Na/Cl ratios are probably associated with weathering of Na-feldspars, for example, albite.

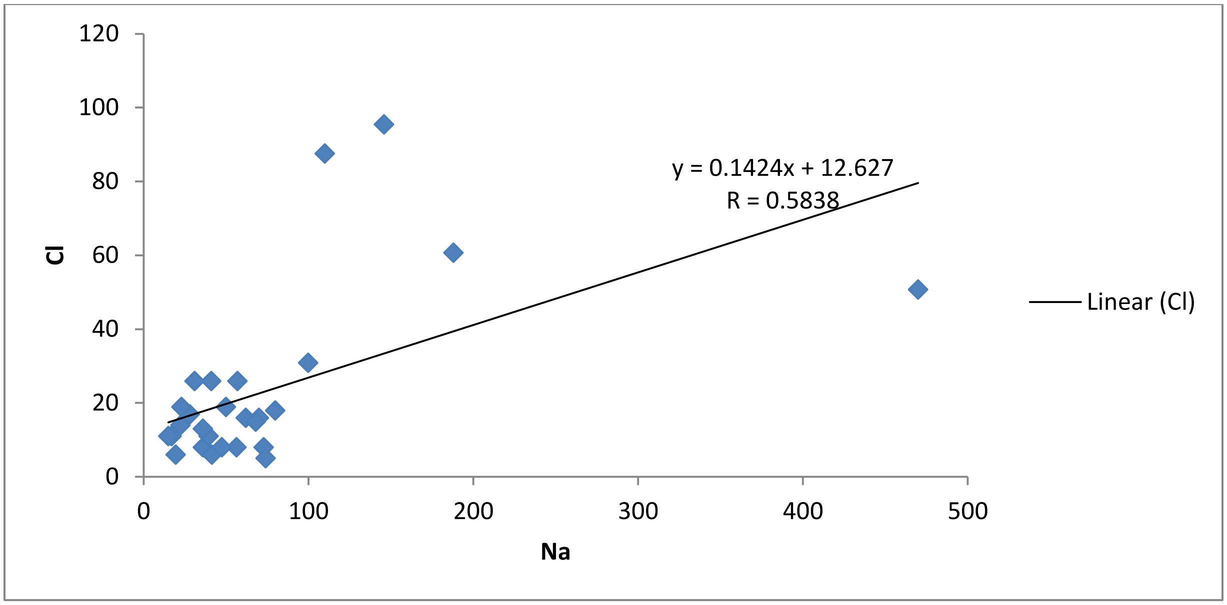


Figure 53 Scatter plot of the Na Vs Cl

6.7.Water Quality Assessment

Ground water can be classified with regard to their suitability on human use for domestic, agricultural and industrial purposes. Statements about water quality offer an important base in this context. Water quality guidelines is established to safe guard the health of users and thus eliminate adverse effect or reduce to a minimum of water constituents. A guideline value represents the level or concentration of constituents that ensure visually agreeable water that does not result in any significant risk to the consumers. In this viewpoint, quality refers to fitness for a purpose. Hence, for practical application, it is very useful to assess and evaluate the quality of water resources of the area for intended purposes. Despite all the constituents of ground water are not identified in the analytical laboratory, the analysis results of major and important parameters have been used to assess the suitability of waters of the study area for intended purposes especially of domestic and irrigation.

Domestic Use

Water guide line for drinking purpose is established taking into consideration the socioeconomic status, availabilities of alternative water resources, geographical location (climate condition) and dietary condition of the people (Fetter, 1994).

Water that is to be used for drinking must meet high standard of physical, chemical and biological purity. According to Punimia (1995), the water quality should fulfil the following criteria.

It should be colourless and sparkling clear.

It must be free from solid in suspension and must not deposit sediments on standing.

It should be of good taste and free from odour

It should be free from disease causing bacteria and organism

It should be free from objectionable dissolved gases

It should be free from harmful salts
It should be free from objectionable minerals such as iron, manganese lead, arsenic and other poisonous metals
It should be free from radioactive substances such as radium and strontium,etc
It should be reasonably free from phenolic compounds, fluorides and iodine
It should not lead scale formation and should not be corrosive

Irrigation water quality

Irrigation water whether derived from springs, streams or pumped from wells, the waters contain appreciable quantities of chemical substances in solution, dissolved from the geological strata through and over which the waters have flowed. The composition of salts in water varies according to the source and properties of the constituent chemical compounds. To understand the water quality and functional aspects of groundwater, chemical parameters like, Sodium Adsorption Ratio (SAR), and salinity are used from analytical results.

The Wilcox diagram has been used to determine the variability of water for irrigation purposes. Therefore the plot shows that most samples are lies on C2 and S2.based on Wilcox classification the most water samples have medium salinity hazard and sodium hazard zone. Salinity hazard zone based on electrical conductivity used to characterize the water. It is observed that the quality of groundwater is suitable for drinking and domestic purpose in most water samples

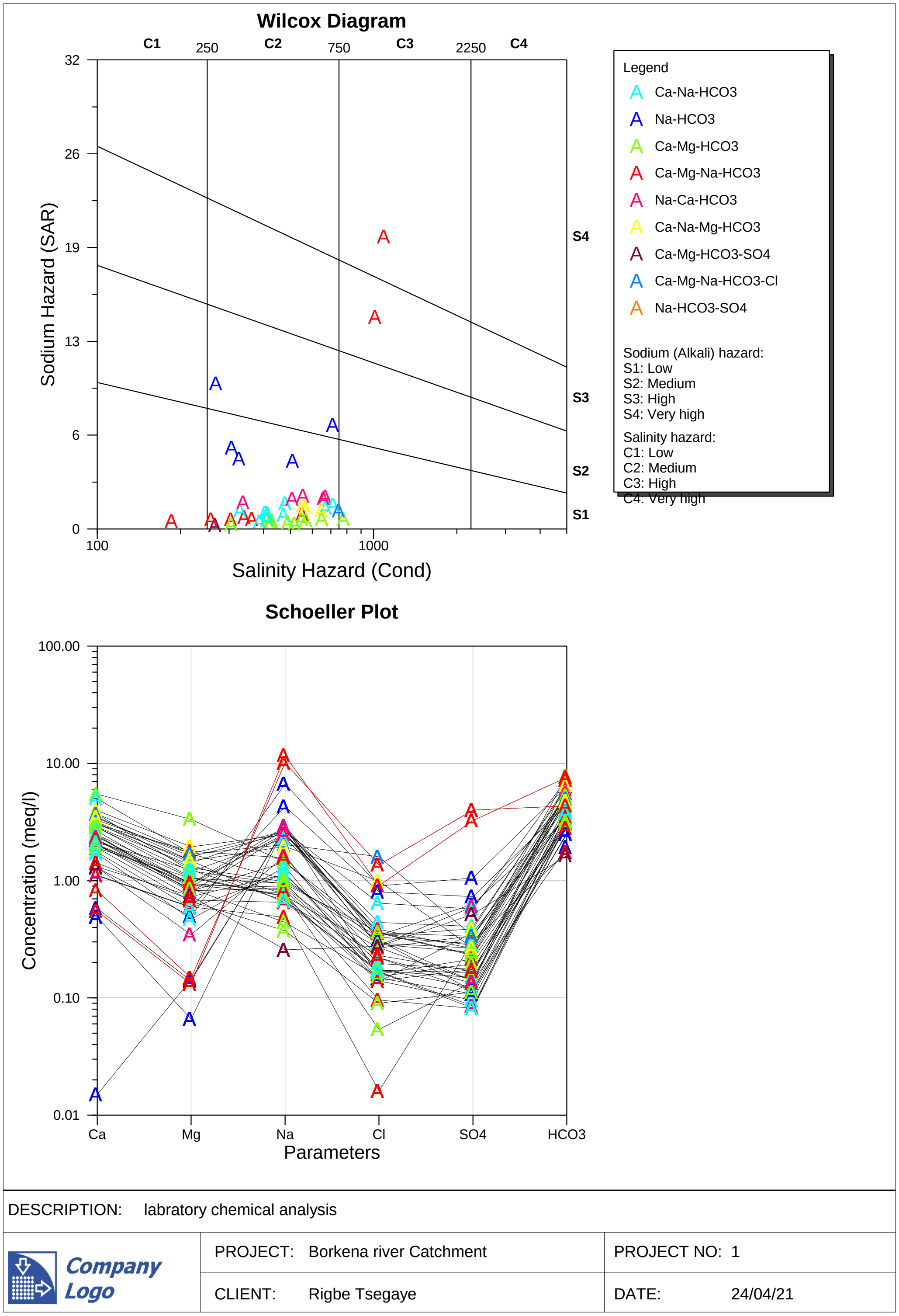


Figure 54 **Wilcox and schoeller plot**

Table 15 Suitability of waters for irrigation based on their EC and SAR (After USDA)

water class	Ec	Na	SAR
Excellent	<250	<20	UP to 10
Good	250-750	20-40	18-26
Medium	750-2250	40-60	18-26
Bad	2210-4000	60-80	>26
very bad	>4000	>80	_

Na	SAR	EC
72.11	2.70	646.57

6.8. Water quality criteria

The quality the quality of water is mainly determined through comparison of the analyzed result with the standard limit set by WHO, hence, this determines their usefulness for industry, agriculture and domestic purposes (Todd, 1980)

More often TDS and EC values measured at the laboratory/ field is used as one of the basic tool limiting their utilization. Accordingly the average TDS and EC measured for the water in the catchment was **646.6** and **388.1** respectively as a result all waters can used for all purposes.

Another parameter which can be used as water quality parameter is hardness which is generated due to the presence of divalent metallic cations such as Mg and Ca present in water. The higher concentration of this divalent cations in water limit their utilization for house hold cleaning purposes. The main problem utilizing this water is the development of scale on water surface and needs extra consumption of soap (Todd, 1980). The degree of hardness in water is commonly based on the classification listed in the table Hardness classification based on (Todd, 1980).

Hardness	Water class
0-75	Soft
75-150	Moderately hard
150-300	Hard
Over 300	Very hard

	Sample type	Hardness, mg/l	Water class
Primary data’s	Hot Spring	35.36	Soft
	Thermal Bore hole	185.12	Hard
	Borkena River	312	Very hard
Secondary data’s	Springs,Borehole,River	4.2	Soft

CHAPTER SEVEN

7. Conclusion and recommendation

7.1. Conclusion

Borkena river catchment is located in the Awash basin. It has a total area of 1192 km^2 and is characterized by flat, gentle slope to steep slope or hills of undulating topographic feature.

The catchment possesses temperate climatic zone with long-term mean annual precipitation of. The precipitation is bimodal in nature with the rainy (wet) season between June to September and the other remaining months correspond to the dry season and from March to May which is Belg rain is occurred in the study area.

The potential evapotranspiration is estimated by Thornthwaite method which is 1462 mm. The annual groundwater recharge of the catchment is estimated using wetspass modeling and base flow separation 145.3mm and 127.3mm respectively. The main recharge of study area is from the highlands of Dessie and Guguftu and surrounding areas which slopes towards Borkena river catchment. The ground water recharge and discharge condition of the area is controlled by the topography, the prevailing geologic set up especially the existence of weathered and fractured geologic materials, the associated geological structures and rainfall amount.

The major aquifer in the study area is the weathered and fractured tertiary and quaternary volcanic rocks. The existence of alluvial and lacustrine deposits in the area provides additional potential aquifer. The alluvial and lacustrine deposits are dominantly covered by clay layers on the top surface; minimum direct recharge to the aquifer prevails and the recharge is from associated volcanic rocks exposed out of the deposits in the surrounding areas.

Based on the observation of the characteristics of the nature of geologic material, degree of weathering and fracturing of volcanic rocks and associated pyroclastic materials and alluvial deposits, the aquifer of the study area is classified into four categories. These are aquifer very high productivity, high productivity, medium productivity and low productivity zones. The justification for such classification is the few pre-existing boreholes and their hydraulic characteristics, the discharge of different ground water points, consistency and nature of springs emanated from aquifer, reliability of hand dug wells in delivering water during the whole dry season and so on.

The hydrochemistry of the study area is characterizing using Aquachem software. The prominent water of the study area obtained from different water sources is Ca-Mg-Hco3. Graphical representations using piper has been used to identify the prevailing water type and visualize the distribution and evolution in the diagram.

7.2. Recommendations

- This study recommends geophysical investigation to identify the source of the hot springs and thermal wells which are found in the study area and development of this natural resource for various purposes (i.e. recreational and tourism) is recommended.
- To better understand and increase the knowledge on the hydrogeological framework of the study area,appropriate use of current data and generating new data is vital. Therefore further hydrogeological studies throughout time are mandatory to generate updated data.
- There exist few and unevenly distributed boreholes even in a ground water potential zone. The rural people will benefit more if additional boreholes are drilled in rural areas which in turn help for further quantitative characterization of the aquifer system.
- Local irrigation activity has already been practiced using dewatering pump from springs and from the tributary rivers therefore utilization of ground water for irrigation purpose should be practiced and used by drilling deep wells in agriculturally feasible local areas..
- To better understand the geochemical evolutionary trend, much more geochemical data with even distribution and minimum spacing is recommended.
- Different governmental and nongovernmental organizations that entail in the preliminary and detail study of the water resources as well as construction of water wells should develop the habit of data base management system.

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ANNEX`S

primary sample laboratory analysis data

Parameter	WHO (mg/l)	**Sample type** **SPRING**	**BOREHOLE**	**RIVER**
Mg^{2+}	30	2.00	16.97	34.94
Na^{+}	200	247.5	166.0	90.0
K^{+}	10	4.5	9.9	7.1
Ca^{+}	100	10.82	45.76	66.56
SO_4^{2-}	250	258.27	217.4	63.04
F^{-}	1.5	15	0.54	1.6
Cl^{-}	250	59.64	37.77	45.72
HCO_3^{-}	-	301.58	354.36	452.38
Total hardness	-	35.36	185.12	312.00
Alkalinity	-	247.2	290.46	370.8

Primary data`s

Sample ID	latitude	longitude	SOURCE OF SAMPLES	PH	T	TDS	EC
Ksp-1	589549	1169847	Spring	6.8	19.5	380	550
ksp-2	588433	1169794	Spring	6.6	20.3	380	320
ksp-3	589037	1170695	Spring	7	21	340	490
krv-1	587044	1175324	River	6.45	18.8	190	250
KDw-1	591035	1174741	dug well	6.8	22.3	350	550
krv-2	585305	1175900	River	6.32	18.4	150	220
krv-3	584381	1182602	River	6.56	20.7	250	360
kBH-1	589871	1190333	Well	6.44	41.3	600	860
kDw-2	603105	1163617	dug well	6.47	25.8	640	920
kSw-3	601705	1163247	dug well	6.44	25.6	440	630
krv-5	603423	1162985	River	7.76	25.9	290	630
KBH-2	601624	1167176	Well	6.13	28.1	380	540
KBH-3	595254	1173715	Well	7.92	35.4	210	300

krv-6	601340	1175207	River	7.49	30.1	510	720
kshp-1	600843	1175567	hot spring	7.1	55.1	800	1150
KDw-3	588577	1202891	Well	7.38	44.5	750	1500
KDW-4	588600	1202665	dug well	7.6	32.6	880	1760
KSP-4	588716	1202436	Spring	7.2	27.3	420	840
KDW-4	588491	1202324	dug well	7.28	36.9	670	1340
KDW-5	588983	1200616	dug well	6.84	25.5	730	1460
KDW-6	586335	1187304	dug well	7.54	23.5	620	1220
KBH-4	593139	1212231	Well	7.4	25.4	390	790
ksp-5	587879	1213432	Spring	7.42	23.6	700	810
kshp-2	588299	1208314	hot spring	7.64	56	590	1590

	PH	sample type	EC	sample type	Temperature	sample type	TDS	sample type
Average	7.6		802.9		51.4		485.8	
Maximum	19.9	spring	1760	hand dug well	550	spring	880	hot hand dug well
Minimum	6.13	well	350	spring	18.4	well	150	river

Metrological station in and around the study area

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Annual
Albuko	16.5	45.6	56.4	110.5	123.8	59.3	404.0	475.7	143.0	60.4	52.5	1573.6
Borumeda	17.5	24.8	66.6	94.4	55.9	34.9	337.5	351.9	127.2	51.8	18.8	1208.6
Cheffa	21.3	22.2	71.8	94.1	58.3	24.3	261.2	298.6	90.3	29.4	20.5	1013.3
Guguftu	20.1	26.2	65.0	78.6	70.6	75.2	427.6	432.0	113.0	34.9	18.3	1375.0
Harbu	15.2	22.4	87.8	96.4	40.9	32.0	259.8	293.9	98.8	19.3	19.4	1014.1
Kemise	26.2	36.1	62.5	101.3	61.1	28.0	257.5	288.3	120.5	51.3	22.8	1071.0
Combolcha	22.7	24.2	62.8	94.9	56.9	33.2	281.1	264.8	106.3	44.9	19.4	1027.6
Dessie Zuriya	25.7	35.7	77.9	91.9	70.1	39.3	322.9	339.6	160.8	54.5	24.2	1264.4
Tebasit	18.0	18.6	49.5	66.8	77.5	65.6	394.7	436.7	129.5	32.7	20.7	1319.1
Tita	20.7	28.6	75.3	91.6	78.6	36.6	287.4	334.8	96.2	50.3	25.1	1138.2
average	20.4	28.5	67.6	92.1	69.4	42.9	323.4	351.6	118.6	42.9	24.2	1200.5

Lithological log of HCKTW-1

ID	FROM	TO	
BH1	0	3	top soil
BH1	3	6	Clay
BH1	6	12	Gravel
BH1	12	18	Clay
BH1	18	27	Sand
BH1	27	61	Gravel ,boulder,couble,
BH1	61	70	Clay
BH1	70	85	Gravel ,boulder,couble,
BH1	85	88	Clay
BH1	88	131	Gravel ,boulder,couble,
BH1	131	140	Clay
BH1	140	210	Gravel
BH1	210	264	Highly weathered scoria
BH1	264	268	Slightly fractured basalt

Lithological log of HCKTW-2

ID	FROM	TO	
BH1	0	3	top soil
BH1	3	9	Sand
BH1	9	33	gravel , cobble ,boulder
BH1	33	149	Gravel
BH1	149	180	gravel , cobble ,boulder
BH1	168	180	Fine to Medium gravel
BH1	180	186	Clay
BH1	186	211	gravel , cobble ,boulder
BH1	211	217	Clay

BH1	217	223	Weathered basalt
BH1	223	250	Clay
BH1	250	252	Weathered basalt

Lithological log of MGTW1

ID	From	To	
BH1	0	4	top soil
BH1	4	20	Sand
BH1	20	39	Gravel
BH1	39	74	gravel cobble Boulder
BH1	74	81	Sand
BH1	81	100	weathered basalt
BH1	100	123	Sand
BH1	123	188	Gravel
BH1	188	251	weathered basalt

Lithological log of MGTW-2

ID	From	To	
BH1	0	6	top soil
BH1	6	12	Sand
BH1	12	65	Gravel
BH1	65	70	gravel cobble Boulder
BH1	70	98	Sand
BH1	98	207	Gravel
BH1	207	215	Sand
BH1	215	225	Gravel
BH1	225	238	Clay with some gravel
BH1	238	282	Gravel

Secondary chemical datas

Sample	pH	EC	TDS	SAR	Total Hardness	Sum of Anions	Sum of Cations	Na	K	Ca	Mg	F	Cl	HCO3
RIVER	7.41	378	228	0.54	3.74	4.05	2.62	17	0.4	53.6	13	0.44	10.93	225.7
RIVER	7.53	574	346	0.81	5.52	5.8	4.15	31	1.5	62.4	29.3	0.54	25.84	304.7
BH	7.09	395	254	0.72	2.78	3.38	2.36	19.5	4.6	35.2	12.5	0.58	5.96	185.07
BH	8.14	338	192	4.11	1.19	3.56	3.79	73	0.6	16	4.8	0.63	7.95	194.1
BH	6.61	499	284	0.9	3.67	4.36	3.17	28	4.6	60.8	7.68	0.49	16.9	230.21
BH	7.59	418	262	1.32	3.63	4.01	3.62	41	0.7	64	5.28	0.48	25.84	185.07
RIVER	7.55	1113	634	2.79	5.9	9.98	7.91	110	7	101	10.6	0.69	87.47	455.91
BH	7.41	494	328	0.68	4.38	5.3	3.21	23	0.9	63.2	14.9	0.52	18.89	277.61
BH	7.49	826	502	2.75	4.99	7.74	6.87	100	0.8	92	4.8	0.46	30.81	417.55
BH	7.32	1189	698	3.4	6.98	9.6	9.87	146	1.3	132	4.8	0.71	95.42	417.55
BH	7.81	1044	618	7.48	2.39	7.44	9.4	188	1.2	42.4	3.36	0.55	60.63	338.55
SPRING	8	685	460	1.26	5.96	7.48	5.16	50	0.2	67.2	31.7	0.53	18.89	415.29
RIVER	7.9	537	362	1.08	4.18	4.97	3.71	36	2.3	52.8	18.7	0.72	7.95	286.64
BH	7.63	414	248	1.22	3.94	5.15	3.75	39.5	2.4	60	11.5	0.56	10.93	293.41
BH	7.61	904	574	1.48	6.68	8.17	6.06	62	0.9	92.8	25	0.4	15.9	464.9

												8		4
BH	7.97	500	332	2.44	3.11	5.18	4.61	70	0.6	38.4	14.5	0.49	15.9	286.64
SPRING	7.51	388	246	0.73	3.58	4.15	2.79	22.5	0.8	49.6	13.4	0.52	13.92	221.19
BH	8.02	349	210	2.65	1.71	3.7	3.35	56.5	1.5	30.4	2.4	0.79	7.95	207.64
BH	7.37	709	232	1.71	2.23	3.75	3.07	41.5	6	38.4	3.84	0.65	5.96	216.67
BH	7.74	405	262	1.82	2.59	4.34	3.38	47.5	0.9	36	9.6	0.51	7.95	248.27
BH	7.1	752	502	1.37	6.56	7.91	5.87	57	3.8	88	26.4	0.6	25.84	435.6
BH	8.48	365	234	1.64	7.74	2.7	7.1	74	0.3	154	0.96	0.73	4.97	151.22
SPRING	7.49	337	214	0.59	3.19	3.6	2.34	17	0.2	53.6	6.24	1.06	10.93	196.36
SPRING	7.64	602	278	0.41	4.97	4.9	3.15	15	0.4	60.8	23.5	0.53	10.93	270.84
BH	7.59	600	418	1.96	4.58	6.67	5.26	68	0.6	64	16.8	0.47	14.91	379.18
BH	7.53	886	394	0.88	6.35	7.75	4.76	36	0.7	57.6	42.2	0.44	12.92	446.89
RIVER	7.26	363	360	2.25	4.77	6.33	5.91	80	1.7	60	21.6	0.58	17.89	353.41
RIVER	9.69	2040	1194	26.47	1.19	14.58	21.16	470	4.8	14.4	5.76	5.01	50.69	555.22
Average	**7.7**	**646.6**	**388.1**	**2.7**	**4.2**	**5.9**	**5.3**	**72.1**	**1.8**	**62.1**	**13.8**	**0.7**	**22.9**	**309.3**
Maximum	**9.7**	**2040.0**	**1194.0**	**26.5**	**7.7**	**14.6**	**21.2**	**470.0**	**7.0**	**153.6**	**42.2**	**5.0**	**95.4**	**555.2**
Minimum	**6.6**	**337.0**	**192.0**	**0.4**	**1.2**	**2.7**	**2.3**	**15.0**	**0.2**	**14.4**	**1.0**	**0.4**	**5.0**	**151.2**

Previous well datas

ID	SWL	Well_field	Depth	DWL	DD	Q	Specific capacity	T	K	Aquifer_type

HCKTW2	8.32	Mekoye	252	11.59	3.27	60	1585.32	1690	20.2	alluvial deposits (sand and gravel)
HCKPW-15	0	Kemisse	260	0	0	0	0	0	0	alluvial deposits and Moderately fractured and weathered trachyte
HCKTW3	0	Kemissie	260	28.25	28.25	66	201.85	316	4.07	alluvial deposits (sand and gravel)
DGBH1	4.76	Degaga	121	21.66	16.9	13.4	68.51	142	3.93	Basalt
HCKTW1	5.04	Harbu	268	86.21	81.17	20	21.29	20.5	0.22	alluvial deposits (sand and gravel)
HrBH3	0	Harbu	146	56.67	56.67	26	39.64	405	1.12	alluvial deposits
HrW4	0		121	53.63	53.63	27	43.5	81.4	2.01	alluvial deposits
AWWCE	0	Sheshaber	60	0	0	0	0	0	0	alluvial deposits
Well-Two	2.3		144	14.68	16.98	0	152.65	126	2.67	alluvial deposits
KBH2	2.3		144	19.28	16.98	30	152.65	149	3.14	alluvial deposits
PW1	0	Kombolcha	112	15.86	15.86	14.3	77.9	81.4	1.69	alluvial deposits
BH-5	0	Sheshaber	112	40	0	20.5	0	0	0	alluvial deposits
KBH1	0		140	25.69	25.69	51	171.52	216	5.18	alluvial deposits
Well-one	1.66		140	24.03	25.69	0	168.16	125	2.98	alluvial deposits and Highly fractured & weathered basalt
PW1	0	Sheshaber	112.5	15.86	15.86	14.3	0	81.4	2.01	alluvial deposits
PW2	0		97.5	12.23	12.23	14.3	101.02	135	2.64	alluvial deposits
BH-6	0	Sheshaber	97	41	0	18.7	0	0	0	alluvial deposits
KCPW-2	6.96	Dewey	152.5	80.4	73.44	43	50.54	64.9	6.29	Alluvial
PW2	0	Sheshaber	105	12.3	12.3	14.3	0	135	2.61	alluvial deposits
PW3	0		110.7	7.16	7.16	14.4	173.77	201	3.9	alluvial deposits
BH-4	0	Dewey	110	0	0	25	0	0	0	alluvial deposits
PW3	0	Dewey	110.7	7.16	7.16	14.4	0	201	3.89	alluvial deposits
KCPW-2R	0	Dewey	258	78.8	78.8	63	69.03	552	7.27	Alluvial
DHBH2	14.2	Dessie Hotie	75	27.65	13.45	41	263.38	171	4.76	Basalt
Boru-Selassie	41	Hoteh	133	42.16	1.1	6.8	534.12	744	18.1	Fractured Basalt