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Groundwater Resource Potential Assessment in Temcha River Catchment, Upper Blue Nile Basin, Ethiopia

By

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Groundwater Resource potential Assessment in Temcha River Catchment, Upper Blue Nile Basin, Ethiopia

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Abstract

Temcha river catchment is located in central part of upper Blue Nile river basin in North West Ethiopia. The area covers 1979km^2 and elevation varies from 4000 to 1400 meter above sea level.

The groundwater potential assessment of the catchment has been done by integrated aquifer characterization, hydrogeochemical evaluation and recharge estimation.

Lithologic units in the catchment include, Quaternary sediment, Miocene shield volcanic rocks (Choke basalt, trachyte plug, Choke rhyolite, Kutye basalt and Arat Mekeraker basalt rob-Gebeya basalt), tertiary flood basalt; such as Lumame basalt, upper basalt, middle basalt and lower basalt, and Mesozoic sandstone. Lineaments have NE-SW and S-N orientation.

Different Volcanic rocks and quaternary unconsolidated sediments countered in the catchment were categorized into high, moderate and low productive aquifer system.

Weathered and fractured tertiary flood basalts and thick alluvial deposits are the main water bearing aquifers in the study area. Accordingly, the intermountain areas i.e. sentera and Yewula plains are groundwater potential zones for groundwater exploitation and development.

The occurrence of groundwater in the catchment is controlled by the structural and geomorphological setting of volcanic rocks and their associated sediment. Fractured and moderately weathered volcanic rocks interlayered with clay sediments are suitable for groundwater storage.

The main recharge source of the area is precipitation and areal depth of precipitation is 1606.6mm/year. The Recharge rate estimated from soil water balance and base flow separation methods are 126.4 mm/year and 147.6 mm/year respectively.

From physicochemical analyses of water sample, the dominant water type is Ca-Mg-HCO3 with low TDS value in highland areas (recharge zone) and the water type at a discharge area are Ca-Na-Mg-HCO3 with relative high TDS value compared with the recharge area. Piper Schoeller and pie diagrams have been used to understand the hadrochemical facies. Most of the water samples quality result shows the area is suitable for domestic and irrigation purpose.

Keywords: groundwater potential, Groundwater recharge, Temcha River Catchment, water quality

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CHAPTER ONE

1. INTRODUCTION

1.1. Background

Due to the frequent drought, groundwater plays a vital role in the rapidly expanding Urban, industrial, and agricultural water requirements in Ethiopia.

The area has enormous surface water and groundwater resources. Groundwater utilization to community water supply is using hand dug wells, shallow boreholes and unprotected springs. Shallow and Deep boreholes have been drilled in different areas. There is also an increasing demand for water supply and irrigation in the area.

Taking this into consideration, Assess the groundwater potential involves the 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 temporary or permanent increase of groundwater resources.

Different topographic and geological features such as shield volcanic rocks, flood basalt and quaternary alluvial and eluvial deposits are formed in the area due to volcanic and tectonic processes.

This study has been aimed to assess groundwater potential in detail and evaluate groundwater recharge based on the available data. From the study recharge and discharge zones, a good groundwater potential zone indicated in the study area.

The Suitability of groundwater quality has been evaluated. Temcha catchment is one of the catchments having a good aquifer system which provide water supply to rural and urban areas; For instance, Debre markos town get their water supply from Sentera well field

1.2. Statement of the Problems

Rapid urbanization coupled with increasing population growth increases the demand of the groundwater in the study area. However, there is no significant research conducted to know the resources of the groundwater, aquifer characteristic and water quality so far. To overcome this problem the study aim to conduct a detail groundwater resource potential assessment at a scale of 1:50,000 and the suitability of groundwater for intended purpose, estimation of recharge, characterization of the aquifer system and hydrogeochemical properties has been assessed.

1.3. Objective

1.3.1. General Objective

The main objective of the thesis is to assess the groundwater resource potential of Temcha river catchment.

1.3.2. Specific Objective

The specific objective of the study is to:

- Evaluate the aquifer character of each lithologic unit and categorize the aquifers based on their productivity.
- Review the hydrochemistry and assess the suitability of the ground water for different purposes by comparing with international and local standards.
- Quantify the groundwater recharge of the area by using Base flow separation and soil water balance methods.

1.4.Previous Work:

Several studies have been conducted on geological, hydrological and hydrogeological settings at different scale. The major studies are reviewed as follows.

Hydrogeology of Ethiopia and Water resources development (Tesfaye Chernet, 1993) classified the aquifer into two groups, this are intergranular and fractured aquifer. General recharge to groundwater from rainfall is estimated at 50 to 150mm/year (moderate) and general recharge to groundwater from runoff localized along streams is estimated as moderate to high, the map indicates that in the upper Blue Nile Basin, dominantly low salinity groundwater occurring in moderately productive basaltic and alluvial aquifers.

According to Tenalem Ayenew (2008) the main groundwater resources in the highlands are confined in fracture and weathered trap series volcanics.

Groundwater recharge, circulation and geochemical evolution in upper Blue Nile river basin of Ethiopia (Seifu Kebede et al., 2005) has been conducted. From the study two major structurally deformed regions with distinct groundwater circulation and evolution history were identified. In the basaltic pleatu outside Lake Tana Graben and Yerer Tullu wellel Volcanic Lineament region, rapid groundwater recharge takes place through basaltic fractures and the hydrochemistry of the area is characterized by the dominant Ca-Mg-HCO3 water type with total dissolved solid less than 500mg/l.

Geology of Debre Markos and bure map sheet 1:250, 000 scale compiled by (Ferede Chimburo et al., 2010) and (lulu tsige, 2007) respectively. Structural pattern and rock classifications were identified. Based on the study, the general structural features of sentera river catchment has NE-SW and S-N orientation.

Regional Hydrogeological Investigation of Debre markos and bure map sheet at a scale of 1: 250 000 (GSE, 2012) has been done and characterized aquifers qualitative and quantitatively. The main source of groundwater recharge is precipitation and estimated the groundwater recharge of the area ranges from 8 to 10 % of the annual precipitation.

Assessing the Impacts of Land use/cover Change on the Hydrological Response of Temcha watershed, upper Blue Nile basin, Ethiopia, compiled by walelign dilnsa; a result from after model calibration and validation a unique trend of continuous groundwater decline was noticed from 1992 to 2000, the annual groundwater recharge decreased.

1.5.Methodology

A systematic approach has been made throughout the progress of the project in order to achieve the objectives with available resource and time. Different application software's including Arcmap10.7, Surfer12, AquaChem4 and Microsoft Office Word and Excel2007extensively used for analytical and presentation stages. The following key tasks have been undertaken:

Geomorphology and drainage pattern evaluation: Topography of the area has been studied with the help of digital elevation model, shaded relief and three-dimensional surface models generate from SRTM data. The drainage pattern is assessed by interactively overlying the topographic map.

Meteorological data analysis: Mean monthly precipitation, temperature, has been calculated Based on the available meteorological data obtained from stations within and out of the study area. Actual and potential evapotranspiration of the area also generated using Soil water balance and Thornthwaite formula respectively.

Groundwater recharge estimation: Quantification of the groundwater recharge has been done using base flow separation and soil water balance methods.

Geological and structural information compilation: Based on stratigraphic relationship, Lithological characteristics and orientation of major geologic structures, geological map of the study area has been produced. Field observation of Lithology has been significantly assisted by information obtained from previous works conducted around the study area.

Aquifer characterization of Different geological formations: In order to assess the groundwater potential of the area, all lithologic units have been categorized into different Hydrogeological units based on the type of Lithology and hydrodynamic properties.

Hadrochemical data analysis and interpretation: After a complete laboratory chemical analysis of collected water samples, the physco-chemical behavior of the groundwater and its usage for drinking, agriculture and industrial purpose were determined by comparing with local and international standards.

Final recommendations have been forwarded after considering analytical results of the entire project work.

CHAPTER TWO

2. Description of the area

2.1. Location and Accessibility of the area

The study area is located in East Gojjam and partly covers west Gojjam, Amhara regional State. Geographically, the area is bounded between 10^0 20' to 10^0 50' latitude and 37^0 10' to $37^0$50' longitude and covers parts of Amanueal, Yewula, Robgebeya, Dembecha, Inewend, Shelel, Senyin, Anjeni and Tame weredas. The study area covers about 1979.7 km^2.

The area is accessed through asphalt road from Addis Ababa to Debre markos. Localities and towns in the study area are also connected by weathered roads.

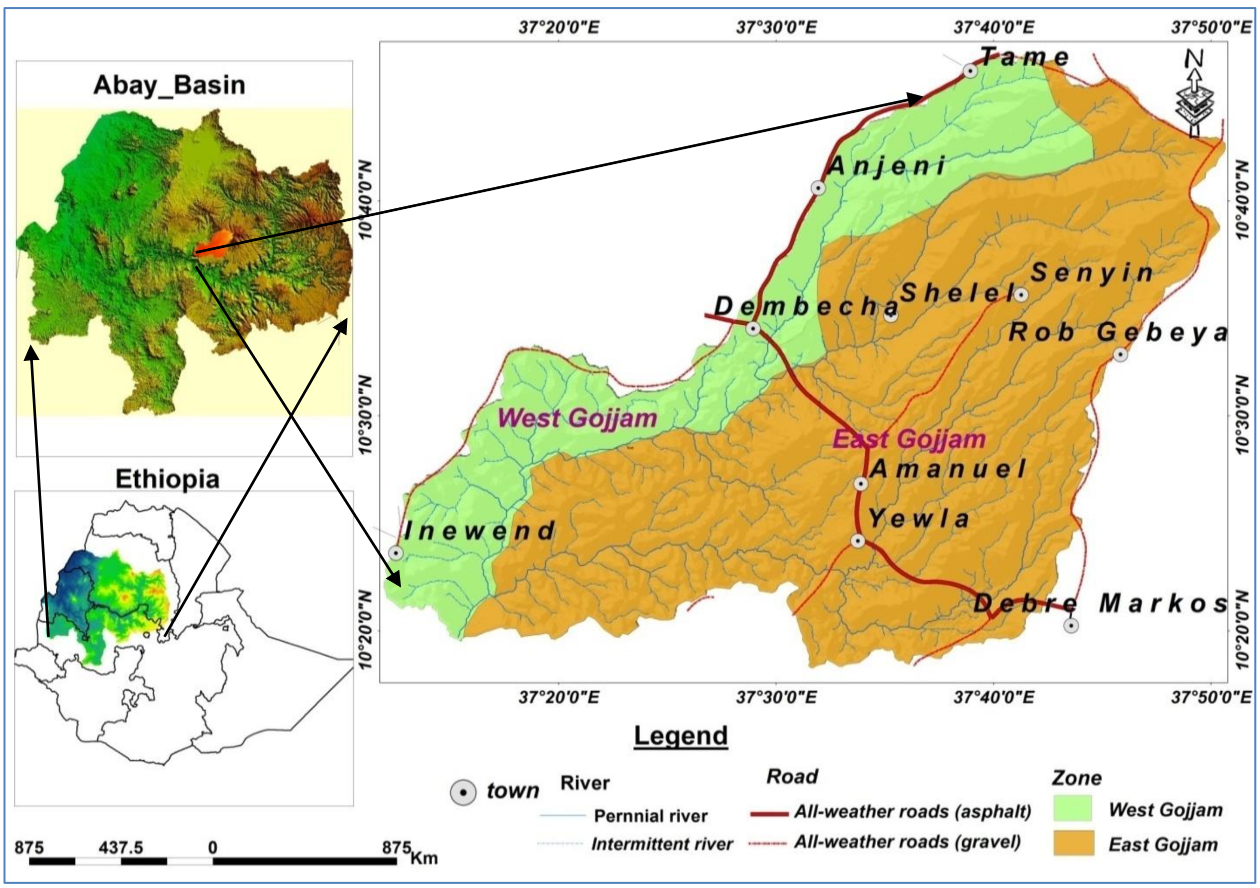


Figure2. 1.Location and Accessible Map of Temcha River Catchment

2.2. Physiographiy

Temcha river catchment is found associated with Choke Mountain in the Upper Blue Nile highland regions of Ethiopia. The elevation varies from 4000 to 1400 meter over a distance less than 75 km. In the area, three main features can be distinguished: mountain, highly dissected cliff and flat lands (figure 2.2).

The flat low land within the study area has a considerable depth with depositional characteristics. It reaches an average elevation of 2200 meter and this flat land includes alluvial deposit consisting of clay and swampy areas.

The upper reach of the catchment consists of hill and mountains undulating topography. The catchment is characterized by east west slope descending from Mt. Choke. The seasonal rivers along with their tributaries; originate from high mountain ranges and joins Temcha Main River.

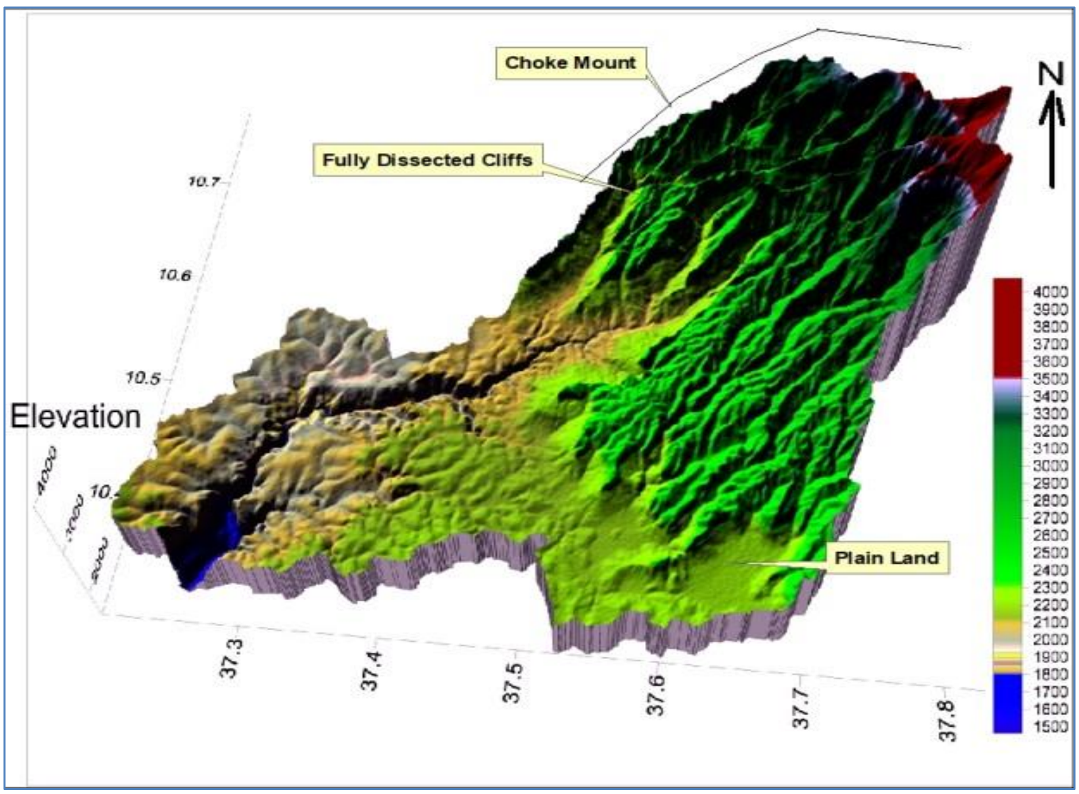


Figure2. 2.3D Physiographic Map of the study area

2.3. Land use/Land cover

Both surface and groundwater are influenced by the land use and land cover of the area. Due to the variation in the topography, rainfall distribution and landscape, the catchment has a mosaic of land cover (Melesse Assefa et.al, 2011). Intense cultivation is practiced in the area. The major cereals cultivated seasonally includes, Wheat, Maize barley Sorghum and teff. According to Ethiopian Geospatial Information Agency Land use/land cover raster map (EGII 2013), the study area of land use land cover classified in to 6 groups. These are seasonal and annual croplands which are the dominant land use type and covers 57.1% of the total catchment. Dense and sparse forest covers 25.7% of the catchment and the coverage is associated with highland areas and follows the main river channels in south western part. Grassland and shrubs cover 9.6 and 7.6% of the total catchment respectively. Bare soil and settlement also cover the total area of 0.05% (Table 2.1). The cropland is covered by shallow and moderately deep-rooted crops like potatoes, Barely, maize or corn, wheat and Teff. These crop practices are largely undertaken within the study area see (figure2.3). Different vegetation covers have significant impact on the surface water budget.

Table2. 1. Land use/cover of the area

Land use/cover	***Area(km^2)***	***weight***
Dense and Sparse Forest	507.4	25.7
Annual and Seasonal Cropland	1130.4	57.1
Closed Grassland	190.8	9.6
Open and closed Shrub land	150.3	7.6
Wetland	0.1	0.004
Settlement and bare soil	0.8	0.05

The highland and plateau, which receive relatively high rainfall are partly covered with green forests (junipers, eucalyptus and Hagenia Abyssinia trees) and are highly cultivated.

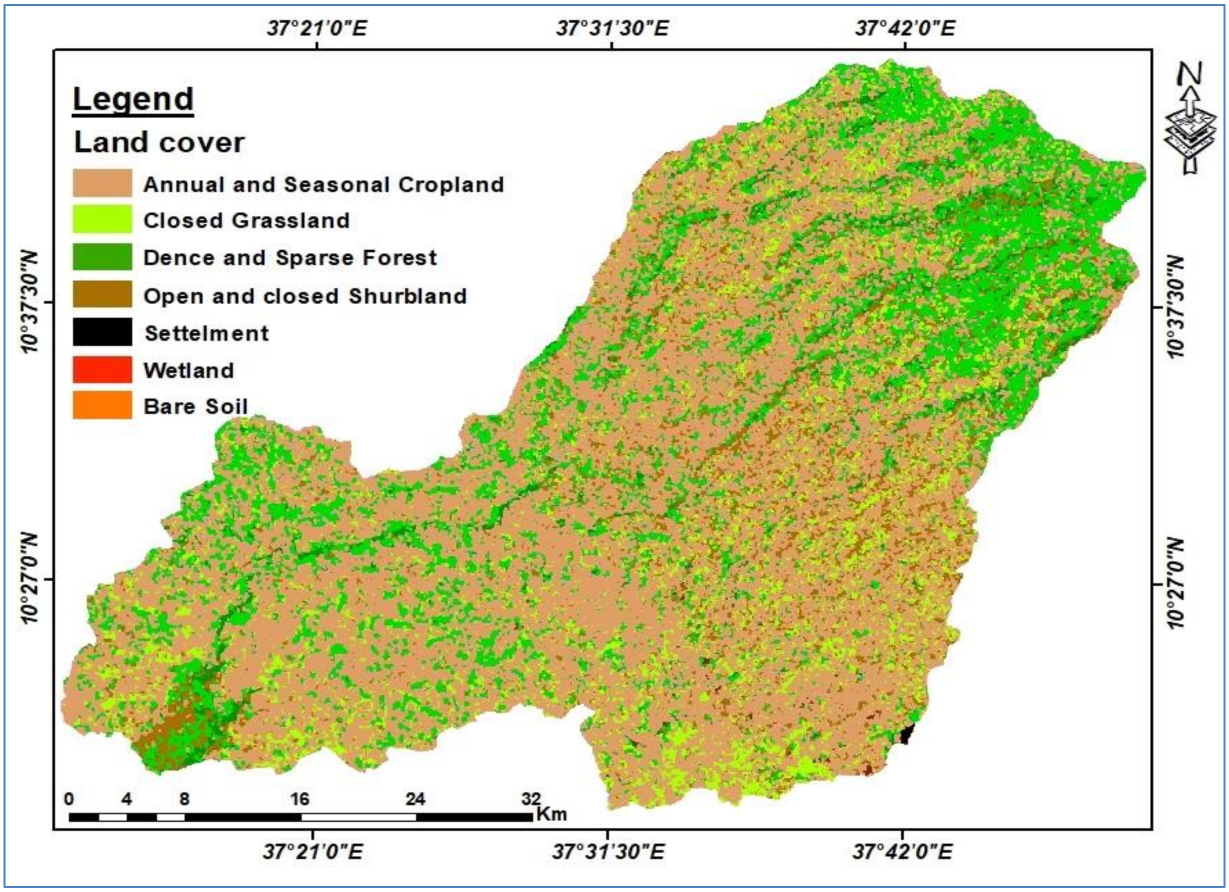


Figure2. 3Land use /Land Cover Map of Temcha River Catchment modified from (EGII, 2013)

2.4. Soil cover

According to FAO Soil classification (FAO, 1997), Chromic, humic ntosole, lithic liptosole and fluvic vertisole covers the area. These soil units are texturally grouped into clay, clay loam and sandy loam class.

Clay soil covers 35.7 $km^2$and found in sentera and Yewula plain. Clay loam soil is the dominant soil type in the catchment and covers 1862.3 km^2.Sandy loam soil found south western part of the area and covers 81.4 km^2.

Due to active morphological processes (erosion & landslides) the soil depth can vary between zero and several meters.

the size of soil particles and their spacing determine how much water can flow through the soil. The larger the spacing, or pore size, the greater the infiltration rate. Thus, sandy soils will have high infiltration rates because pore sizes are large and there are no finer materials to block the pores.

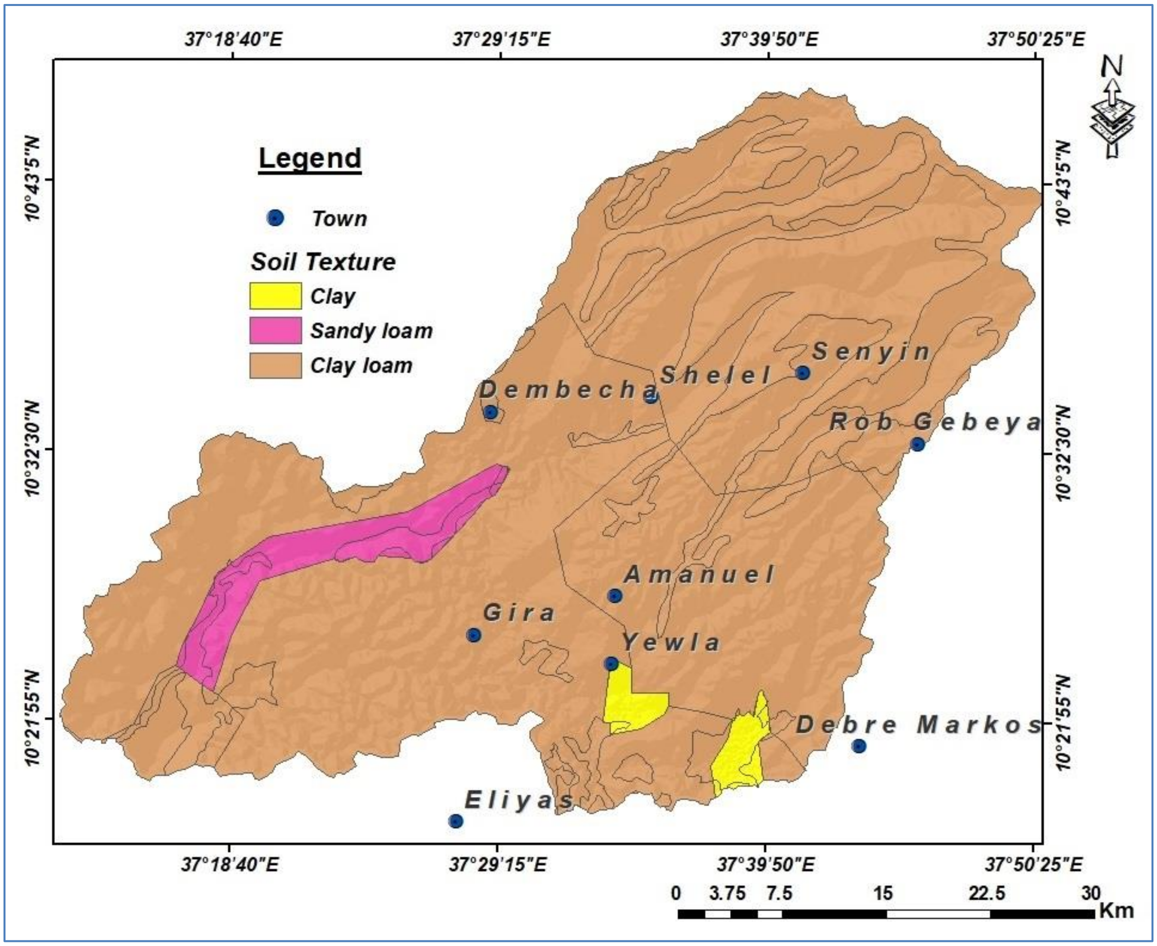


Figure2. 4.Soil texture map of the area modified from (FAO, 1997)

2.5. Hydrometeorology

2.5.1. Climate

The climate of Ethiopia is mainly controlled by the seasonal migration of the ITCZ and associated atmospheric circulations as well as by the complex topography of the country.

The climatic conditions of the study area are mainly influenced by elevation, which is in the range of 1400 to 4,300 m a.s.l. Based on the climatic divisions of Ethiopia; almost all of the climatic zones are available in the study area except for the desert region. The temperate climatic region represents the majority of the area, followed by sub-tropical Region. The highly elevated mountain of Choke is represented by the alpine (Kur) climatic zone. The climatic zoning of the area is done based on the Ethiopian climatic classification after Tesfaye Chernet (1993), Javier GozáIbez and Dulce Cebrián (2006) is shown below in table.

Table2. 2. Climate classification of Ethiopia

Name / Elevation / Mean annual temperature	***Precipitation below 900 mm***	***Precipitation between 900 and 1,400 mm***	***Precipitation above 1,400 mm***
High Wurch (Kur) above 3,700 m below 5 °C			**Afro-alpine** meadows of grazing land and steppes, no farming Helichrysum, Lobelia
Wurch (Kur) 3,700–3,200 m 5–10 °C		**Sub-afro alpine** barley Erica, Hypericum	**Sub-afro alpine** barley Erica, Hypericum
Dega 3,200–2,300 m 10–15 °C		**Afro-mountain** (temperate) forest – woodland barley, wheat, pulses Juniperus, Hagenia,	**Afro-mountain (temperate)** bamboo forest barley, wheat, nug, pulses Juniperus, Hagenia, Podocarpus, bamboo
Weina Dega 2,300–1,500 m 15–20 °C	**sub-tropical** Savannah wheat, teff, some corn acacia savannah	**Sub-tropical** Shrub-savannah, corn, sorghum, teff, enset, nug, wheat,barley,Acacia, Cordia, Ficus	Wooded savannah **(sub-tropical)** corn, teff, nug, enset, barley Acacia, Cordia, Ficus, bamboo
Kolla 1,500–500 m above 30 °C	**Tropical** sorghum and teff acacia bushes	**Tropical** Sorghum, teff, nug, peanuts, acacia, Cordia, ficus	**Wet tropical** mango, sugar cane, corn, coffee, oranges Cyathea, Albania
Bereha below 500 m above 40 °C	**Semi-desert and desert** crops only with irrigation thorny acacias		

The transition between lowland and highland within the study area is very sharp. This leads to induce a variety of climate from kola to high Wurch (very humid) type (See figure 2.5).

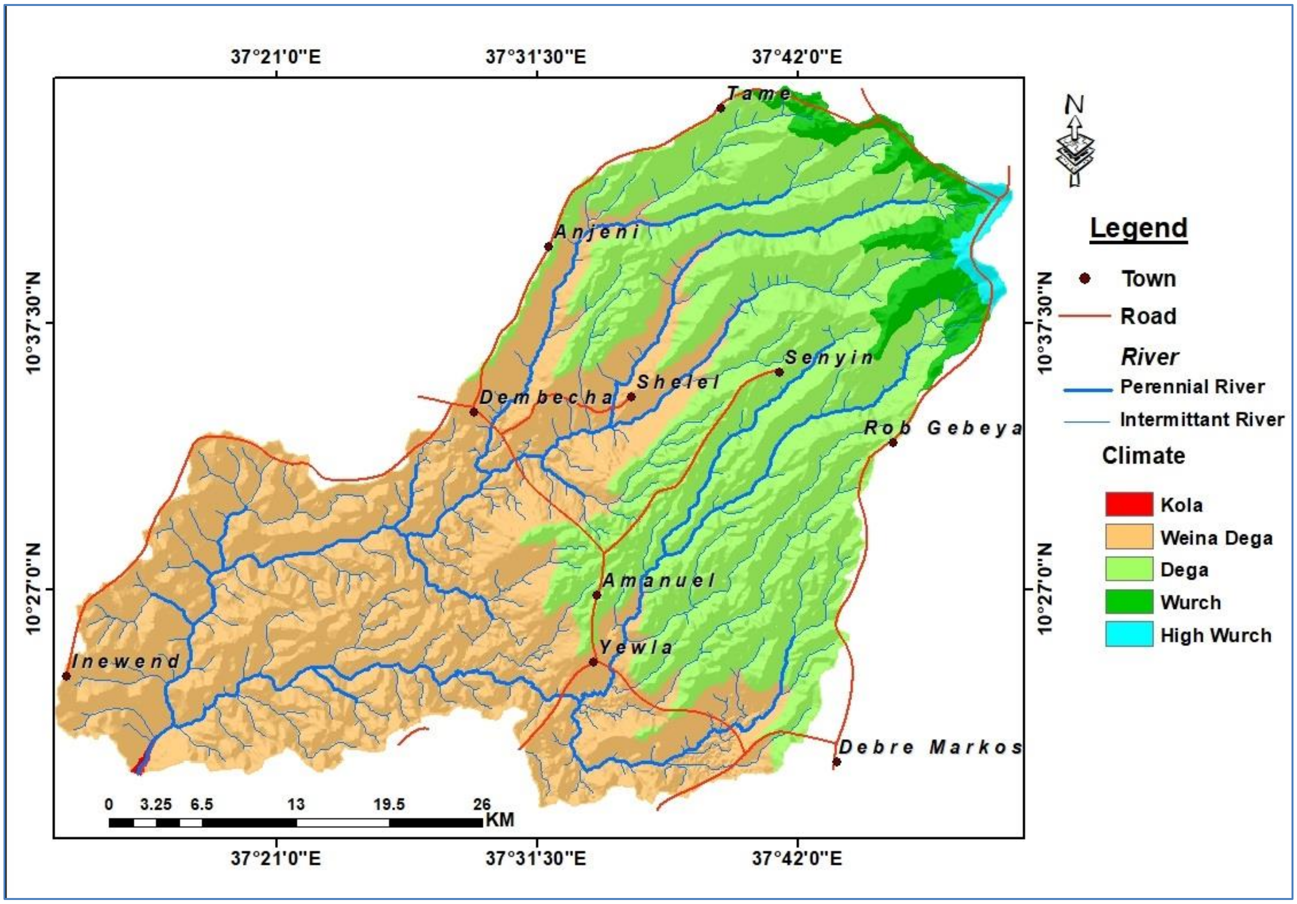


Figure2. 5.Climate map of the study area (modified from Daniel Gemechu, 1977)

2.5.2. Precipitation

The spatial and temporal variation of rainfall in Ethiopia is controlled by the movement of the position of the Inter Tropical Convergence Zone; ITCZ (Tenalem and Tamiru, 2001). The climate in the study area is largely influenced by westerly's air from Atlantic Ocean. Daily meteorological data were provided by Ethiopian meteorological agency and the rainfall data for 9 long-term records of rainfall stations lying within or around the Temcha river catchment were used for the computation of rainfall. Most stations were found to have fewer missing records and the data that have a gap of more than three month are rejected. The annual rainfall in the study area is range from1142.97mm to 2237.03mm/ year. Rainy season months are June, July August and September, and dry season include November December January February, April and March. May is the transition month from the dry season to the wet season and October is the transition month from the wet season to the dry seasons (see figure2.6). In east Africa there is a meridional arm of the ITCZ due to the difference in heat capacity of the land surface and the

Indian Ocean. This produces rainfall over the south west of Ethiopia in February/march even though the main ITCZ is still in the southern hemisphere (gulilat et al., 2011).

Table2. 3. Mean monthly precipitation of the area

Station	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***	***Annual***
Amanueal	4.9	15.8	40.1	39.2	161.4	204.4	310.1	307.1	278.8	78.5	44.5	9.2	1493.9
Debre Markos	10.8	14.4	45.7	66.9	118.6	165.1	267.6	296.4	221.8	76.8	29.0	15.2	1328.3
Dembecha	7.7	6.7	38.1	49.1	121.9	211.4	308.0	266.4	206.8	91.7	47.0	15.1	1369.8
Dengay Ber	16.9	9.2	46.8	61.8	151.9	347.7	517.7	527.9	352.7	124.1	56.3	24.1	2237.0
Elias	5.5	9.2	40.8	65.5	168.6	294.5	416.8	403.3	370.2	140.0	36.4	7.5	1958.2
Feres Bet	16.7	16.2	48.6	58.6	166.4	247.5	441.7	415.4	209.9	123.9	57.8	19.8	1822.6
Robgebeya	21.4	27.0	72.3	76.1	113.6	174.0	300.4	277.5	170.2	75.1	44.7	30.6	1382.9
Yechereka	8.1	8.4	29.7	46.1	117.8	248.5	472.8	493.6	326.7	125.1	31.5	10.8	1919.1
Wadeyesus	10.7	5.0	28.3	54.6	140.1	210.9	271.0	268.1	250.4	118.2	26.8	14.3	1398.4
Kuy	3.2	23.8	59.5	43.8	112.7	168.0	399.3	302.4	166.4	37.9	30.4	5.8	1353.2
Average	10.6	13.6	45.0	56.2	137.3	227.2	370.5	355.8	255.4	99.1	40.4	15.2	1626.4
Coefficient	0.7	0.8	2.8	3.5	8.4	14.0	22.8	21.9	15.7	6.1	2.5	0.9	100.0
weighted average	10.5	13.4	44.4	55.5	135.6	224.4	366.0	351.5	252.3	97.9	40.0	15.1	1606.6

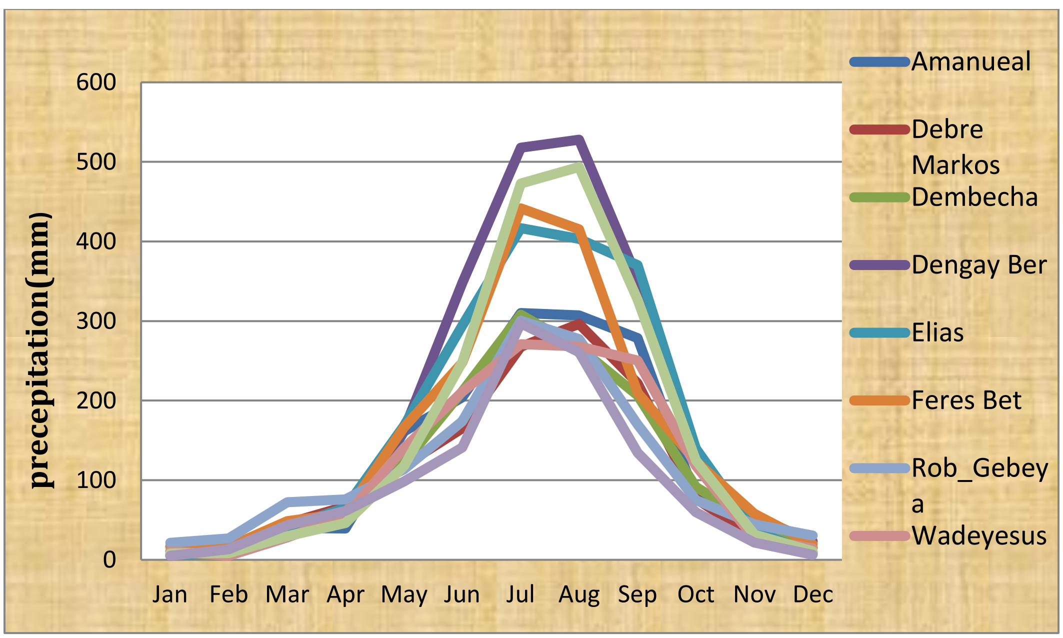


Figure2. 6.Temporal variation of Mean monthly rainfall in the study area

The annual migration of ITCZ has prominent effect over the study area. As it has seen from the above figure the rainfall distribution of the area is monomodal. The highest peak of rainfall occurs during the months of July and August for all stations.

Rainfall versus altitude has poor correlation coefficient (R2 = 0.18), this could be associated with moisture advection from a variety of different direction (Charles, 1995). When air is cooled as a result of the converging of two contrasting air masses, it can produce more widespread rainfall independent of surface land features (Shaw, 1994).

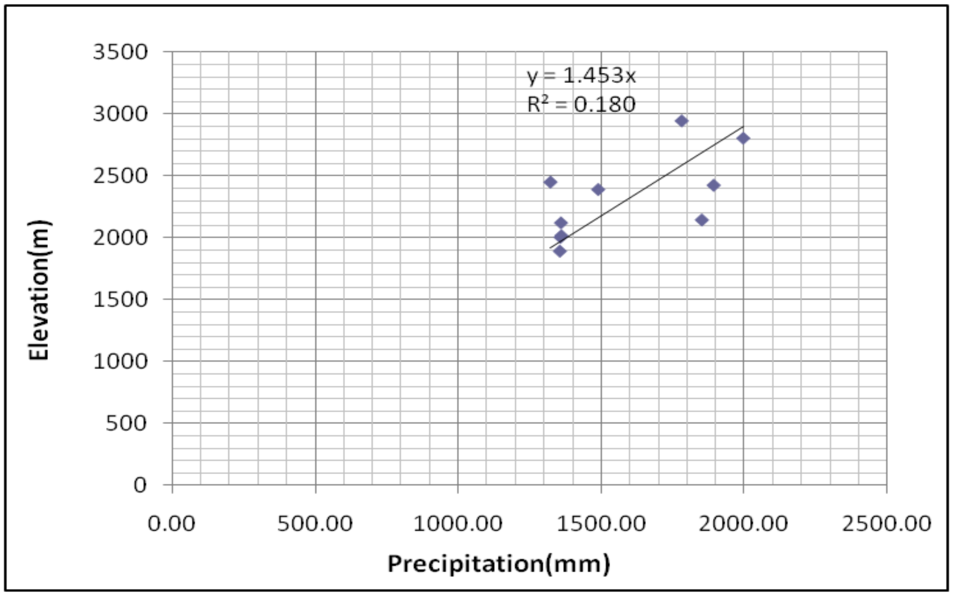


Figure2. 7. Relationship Between Rainfall and Elevation

2.5.3.Determination of Areal Depth of Precipitation

Different approaches are exist for the estimation of areal precipitation over a given basin.in ths cause Arithmetic mean, Thiessen polygon and Isohyetal methods are used to get approximate result of average depth of rainfall of the catchment.

2.5.3.1. Thiessen Polygon Method

The Thiessen polygon provides a weighting factor for each gage and influence zone in which it is considered that the rainfall is equivalent to that of the stationsee (figure2.8). The influence zones represented by polygon, these polygons are formed by connected the perpendicular bisector of the segment which link each stations to the closest neighboring stations. As per Thiessen polygon method, the areal precipitation would be calculated using equation.

$$P = \frac{A1PA+A2P2+\ldots AnPn}{A1+A2+\ldots An},$$

Where P1, P2….Pn are the rainfall recorded at rain gauge stations with A1, A2….An as the polygon areas.

The average depth of rainfall computed using Thiessen method is about 1590.6 mm/year and the arithmetic mean value is 1626.4mm/year (see table.2.6).

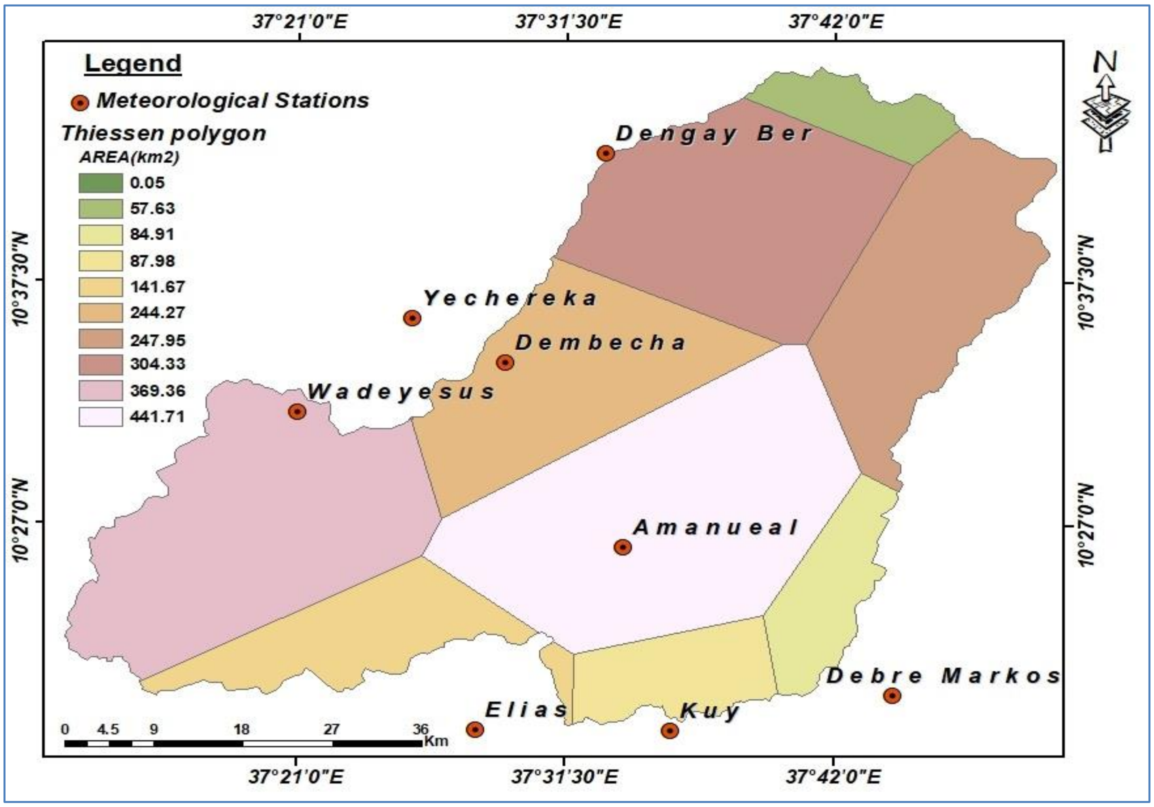


Figure2. 8.Thiessen polygon map of the study area

Table2. 4. Mean annual rainfall computed using Thiessen polygon and arthimatic mmean

Stations	***Easting***	***Northing***	***Precipitation (mm)***	***Thiessen polygon area(km^2)***	***Total area (km^2)***	***Weight (Ratio of area)***	***Aerial Precipitation(mm)***
Amanueal	342708.4	1153589	1493.94	441.71	1979.87	0.22	333.30
D/Markos	361951.3	1141696	1328.30	84.91	1979.87	0.04	56.97
Dembecha	334321.9	1168350	1369.80	244.27	1979.87	0.12	169.00
Dengay Ber	341431.2	1185024	2237.04	304.33	1979.87	0.15	343.86
Elias	332091.1	1138984	1958.21	141.68	1979.87	0.07	140.13
Feres Bet	347896.8	1199731	1822.56	57.63	1979.87	0.03	53.05
Rob Gebeya	376363.4	1166447	1382.89	247.95	1979.87	0.13	173.18
Wadeyesus	319455.2	1164410	1398.38	369.36	1979.87	0.19	260.88
Kuy	346037.6	1138920	1353.22	87.99	1979.87	0.04	60.14
Yechereka	327685.9	1171911	1919.15	0.05	1979.87	0.00	0.05
Total	**Average**		**1626.35**				**1590.55**

2.5.3.2.Isohyet

The method is done by preparing isohyetal map.This methodallows the influence of physiograph on precipitation to be take in to acount (Fetter,2001).

The equivalent uniform depth of precipitation between isohyet is ussualy assumed to be equal to median value of the two isohyet.Based on this isohyte of the mean annual rainfall in the catchment is 1602.95 mm/year(see table2.5).

Table2. 5. Mean annual rainfall computed using Isohyet

Isohyet(mm)	*Estimated EUD*	*Net area(km²)*	*Percent*	*Weighted Precipitation(mm)*
<1400	1383.93	27	1.36	18.88
1400-1450	1425	121	6.11	87.13
1450-1500	1475	233	11.77	173.66
1500-1550	1525	510	27.77	393.00
1550-1600	1575	424	21.42	337.44
1600-1650	1625	224	11.32	183.93
1650-1700	1675	130	6.57	110.03
1700-1750	1725	85	4.30	74.09
1750-1800	1775	61	3.08	54.71
1800-1850	1825	46	2.32	42.42
1850-1900	1875	32	1.62	30.32
1900-1950	1925	23	1.16	22.37
1950-2000	1975	17	0.86	16.97
2000-2050	2025	13	0.66	13.30
2050-2100	2075	11	0.56	11.53
2100-2150	2125	9	0.45	18.76
2150-2200	2175	8	0.40	8.79
>2200	221.82	5	0.25	5.61
Total		**1979km^2**		**1602.95**

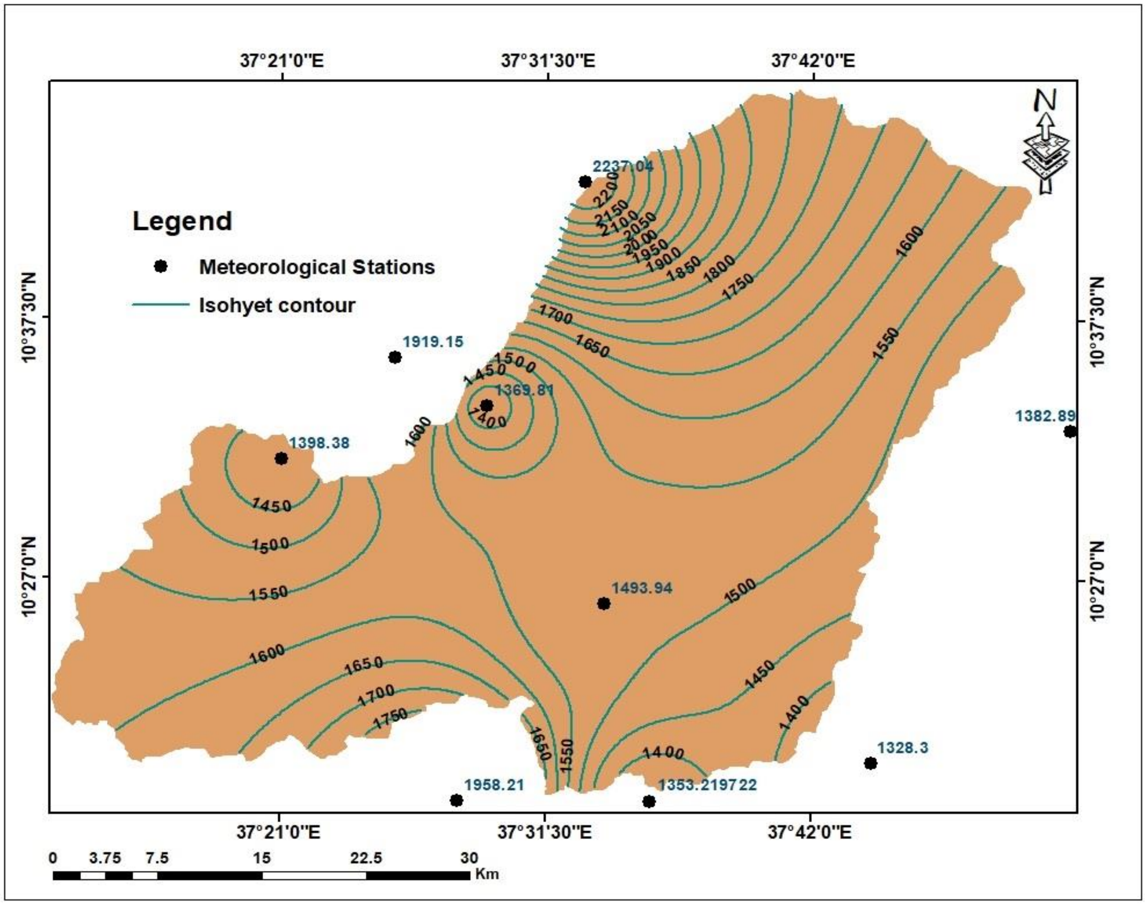


Figure2. 9. Isohyet map of thr catchment

2.5.4.Temprature

Temperature data were collected from 6 meteorological stations of within and outside the study areas over different time periods.

The monthly maximum and minimum temperature data collected from the stations at Amanueal, Debre Markos, Dembecha, Dengay Ber and Elias computed mean temperature are shown in the corresponding diagram (see figure3.5 and 3.6).

The average temperature ranges from 7.2 ºC to 29.3ºC. The highest mean temperature is recorded in Dembecha station and minimum temperature is recorded in Yetnora station. The hot months occur in December, January and February and March. Temperature in August and July is relatively low.

Table2. 6.Monthly minimum, maximum and average temperature of the stations

Stations	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Amanueal Max T	27.15	28.91	28.97	28.01	25.58	22.98	21.40	21.28	22.33	24.37	24.94	25.63
MIN T	11.00	11.92	12.62	12.81	12.41	11.88	11.48	11.26	11.01	10.56	10.45	10.45
Average	19.08	20.41	20.79	20.41	19.00	17.43	16.44	16.27	16.67	17.46	17.70	18.04
D/ Markos MAXT	24.18	25.60	25.96	25.65	24.09	21.12	19.16	19.25	20.70	22.11	23.00	23.48
MIN T	9.13	10.52	11.66	12.29	12.09	11.10	11.16	11.04	10.38	10.06	9.08	8.69
Average	16.65	18.06	18.81	18.97	18.09	16.11	15.16	15.14	15.54	16.09	16.04	16.09
Dembecha MAX T	27.60	28.86	29.31	29.03	27.09	24.49	22.49	22.77	23.77	25.32	25.89	26.75
MIN T	8.81	9.68	11.34	12.05	11.96	11.57	11.26	11.17	10.77	10.23	9.53	8.66
Average	18.21	19.27	20.33	20.54	19.52	18.03	16.87	16.97	17.27	17.77	17.71	17.71
Dengay Ber MAX T	22.19	23.53	24.05	24.37	23.51	20.23	17.98	17.81	18.65	19.51	20.28	21.24
MIN T	10.47	11.17	11.21	11.57	11.19	9.96	9.14	9.02	9.20	9.47	9.66	9.57
Average	16.33	17.35	17.63	17.97	17.35	15.09	13.56	13.42	13.93	14.49	14.97	15.40
Elias MAX T	27.57	28.94	29.43	29.18	28.03	23.77	21.67	21.07	21.79	23.73	25.78	27.52
MIN T	12.32	13.58	14.19	14.71	13.78	12.17	11.62	11.44	11.52	11.94	12.22	13.30
Average	19.94	21.26	21.81	21.94	20.91	17.97	16.65	16.26	16.65	17.84	19.00	20.41
Kuy Max t	23.05	24.50	24.34	24.70	23.41	22.45	20.68	21.39	22.37	22.80	22.74	22.20
MIN T	11.66	13.16	11.64	12.01	12.07	11.40	10.11	10.68	11.47	11.50	10.14	9.36
Average	17.35	18.83	17.99	18.36	17.74	16.92	15.40	16.04	16.92	17.15	16.44	15.78

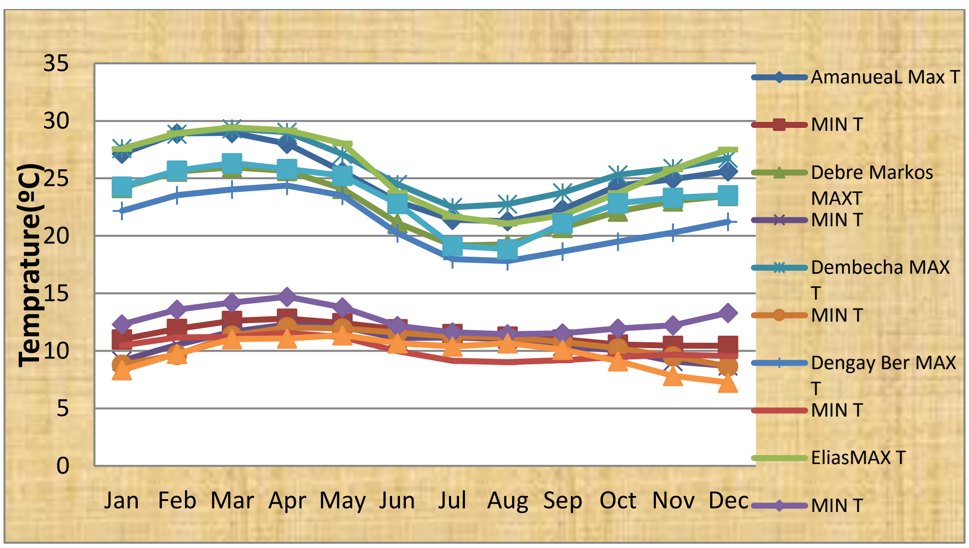


Figure2. 10. Mean monthly Maximum and Minimum temperature of the area

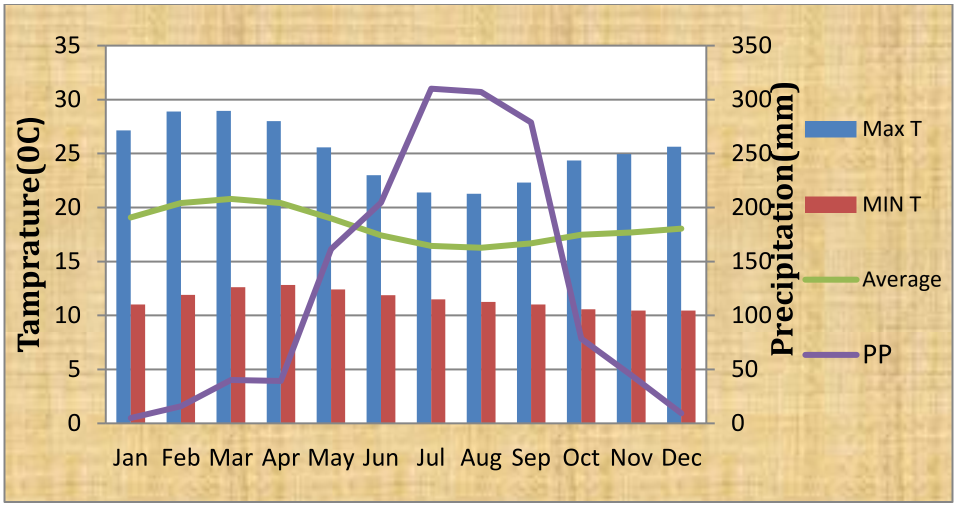


Figure2. 11. Mean monthly rainfall, min, max and average temperature of Amanueal station

2.5.5. Evapotranspiration

Evapotranspiration is the major use of water in all but extremely humid, cool climates. If evapotranspiration were reduced, then runoff or ground-water infiltration or both could increase, as would the available water supply. It is limited by soil moisture supply, surface and atmospheric temperature and the dew point threshold (Law et al. 2002). The coupling of evapotranspiration, temperature, and precipitation is particularly pronounced in moisture-limited subtropical regions at the interface between wet (monsoonal) and dry climate regimes.

There are potential and actual evapotranspiration. Potential evapotranspiration is the water loss that will occur under given climate condition with no deficiency of water for the vegetation, while actual evapotranspiration is the amount of water that actually returns to atmosphere depending on the availability of water.

2.5.5.1. Estimation of Potential evapotranspiration

There are two widely used calculation approaches for potential evapotranspiration. These are Thornthwaite and penman-Monteith methods. In this study, Potential evapotranspiration (PET) is obtained by using Thornthwaite method (Thornthwaite C.W, 1948), which is based on temperature with an adjustment being made for the number of daylight hours. The equation for calculation of PET on monthly basis is given as follows:

$$PET=16Nm\,(10Tm/I)^{a}$$

Where, PET= Potential Evapotranspiration

Nm=monthly adjustment factor related to hours of daylight

Tm=mean monthly air temperature

I=heat index

$a=0.67+0.0179*I-0.0000771*I^2+0.000000675*I^3$

Heat index calculated as follows:

$I = \sum_{i=1}^{12}(Tmi/5)\ a$, Using the data from 6 meteorological stations for the 1990–2018-time range.

Table2. 7. Potential Evapotranspiration of gauge station

Stations	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
D/Markos	57.2	68.8	75.9	80.0	76.1	63.7	57.0	55.9	56.4	57.7	55.3	54.7
Amanueal	68.8	80.1	85.4	85.8	77.3	66.8	59.4	57.2	57.8	60.9	60.2	61.4
Dembecha	61.6	70.1	79.7	84.5	79.2	69.5	60.9	60.5	60.3	61.4	58.8	57.9
Elias	70.4	81.9	88.7	93.4	87.4	65.9	56.3	52.7	53.4	59.0	64.4	72.9
Dengay-Ber	58.6	65.9	69.6	74.5	72.7	59.7	50.3	48.6	49.7	51.0	51.6	53.1
Kuy	62.2	72.7	69.7	74.8	72.9	68.6	58.5	61.2	64.4	63.6	57.3	52.9
Average PET	63.1	73.2	78.2	82.2	77.6	65.7	57.1	56.0	57.0	58.9	58.0	58.8
Day light hour	0.95	0.97	1.00	1.04	1.07	1.09	1.08	1.06	1.02	0.99	0.95	0.94

High potential evapotranspiration is estimated from Elias station and minimum is from Dengay Ber Station. The average monthly evapotranspiration values are shown in Figure indicate that the lowest values occur in July and August. The highest mean monthly values occur in March and April.

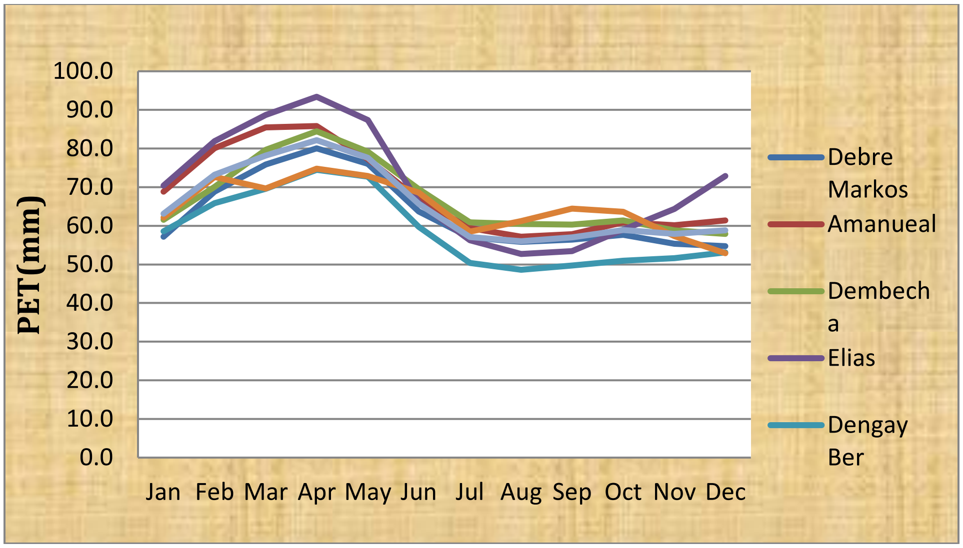


Figure2. 12. Potential Evapotranspiration of the stations

2.5.5.2. Actual Evapotranspiration

Actual evapotranspiration is the evaporation from vegetation cover under the natural or given condition of supply of moisture. It is used to describe the amount of evaporation that occurs under field condition and depends on the availability of water to meet the atmospheric demand. Actual evapotranspiration is obtained by calculating the potential evapotranspiration. There are different approaches to obtain actual evapotranspiration; among these, Thornthwaite and Mather (1957) soil moisture balance method has been used to compute. The value obtained from this method is **704.4** mm/year (table.2.10).

- **Thornthwaite and Mather (1957) water balance method**

Based on soil classification (FAO, 1997) and land use land covers classification, precipitation and potential evapotranspiration; the actual evapotranspiration of the catchment area is calculated using Thornthwaite and Mather soil water balance method.

A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constants. For this purpose a classification of the vegetation covering the catchment is important for water budgeting. The vegetation covering the area is Forests, annual and seasonal crops, dense and open wood lands, shrub and grass lands and cultivated lands (figure.2.4). Therefore, it grouped into deep, moderately deep-rooted vegetation and forest type.

In 35.7km^2 clay soil coverage, 63.35% moderately deep, 26.8% deep root and 9.9% forest vegetations are grown with the root depth of 0.5, 0.67 and 1.17 m respectively. The total available water capacity of the root zone (AWC) for both types of land covers on clay soil is calculated as follow:

63.3% (150mm) + 26.8% (200mm) +9.9 %(350mm) = 183mm.

Table2. 8. Weighted AET and RO of the study area

Class	*Soil Texture*	*Vegetation cover*	*AWC (mm)*	*Root Depth (m)*	*Area(km2)*	*AET (mm/year)*	*RO (mm/year)*
1	Clay	Forest	350	1.17			
		Moderately deep root	150	0.5	35.7	683.3	796.0
		Deep rooted	200	0.67			
2	Sandy loam	Forest	300	2			
		Moderately deep rooted	150	1	81.6	689.2	790.4
		Deep rooted	150	1			
3	clay loam	Forest	400	1.6			
		Moderately deep rooted	200	0.8	1862.4	705.7	774.4
		Deep rooted	250	1			
Weighted AET &RO					**1979.7**	**704.4**	**775.6**

Similarly, for 81.6 km^2 sandy loam and 1862.4km^2 clay loam soil cover the available water capacity is 200mm and 260 mm respectively. In the model all units are described in mm and the explanation to the symbols is listed below. The soil water balance of each soil cover is tabulated in (Appendix 1.1, 1.2&1.3).

Soil moistures (SM): - Accumulated potential water loss is used to obtain the soil moisture during the dry months using the following formula:

$$SM = AWC \exp\left[-\frac{(|APWL|)}{AWC}\right]$$

Where AWC, Maximum available water capacity

APWL, accumulated potential water loss

Change in soil moisture (ΔSm): - represent the amount of water held in soil storage.

P: - Mean monthly precipitation (mm), calculated using Thiessen polygon isohyets and arithmetic methods.

P – PET:-Difference between rainfall and potential evapotranspiration; negative value of P–PET represents a potential deficiency of water or monthly demand of moisture by the vegetation which is not satisfied by the monthly rainfall, whereas the positive value represents a potential surplus of water or additions of moisture to the soil while the negative values.

Accumulated potential water loss (APWL):- is calculated as a running sum of the P-PET values during periods when P-PET is negative. The running sum represents the total amount of unsatisfied potential evapotranspiration to which the soil has been subjected. Soils typically yield water more easily during the first month in which P-PET is negative. On subsequent month as the APWL grows, soil moisture is less readly gives up.

AET: - Actual evapotranspiration, monthly actual evapotranspiration is found as:

AET=PET if Pm >PET

Otherwise, AETm = Pm (monthly precipitation) plus change in soil moisture, m stands for month.

SMD: - Soil moisture deficit. Monthly SMD is the difference between PETm and AETm.

When there is rainfall and abundant moisture in the soil, the soil is saturated. After rainfall ceases, saturated soil gives up water and becomes unsaturated until it can just hold certain amount of moisture against the force of gravity and is said to be at field capacity. Under this condition, evaporation occurs at the maximum possible rate determined by the meteorological conditions (i.e. the actual evapotranspiration rate is equal to potential evapotranspiration). When there is no rain to replenish the water supply, the soil moisture gradually becomes depleted by the demand of vegetation and produces soil moisture deficit by the amount of water required to restore the soil to the field capacity. As the soil moisture deficit increase AET Becomes increasingly less than PET (see figure 2.13).

S: - Soil moisture surplus, is the excess of soil moisture values (Sm). It is the difference between rainfall and change in soil moisture and actual evapotranspiration.

TARO: - total available for runoff. The value is determined starting from the first month of the water surplus period. The first month's surplus is the TARO for that month, and from the surplus, 50% value is detained (D) and carried over to the next month TARO, and 50% is river discharged (RO). Therefore, the TARO of preceding month is given by the surplus of that month (SM) plus the detention of last month.

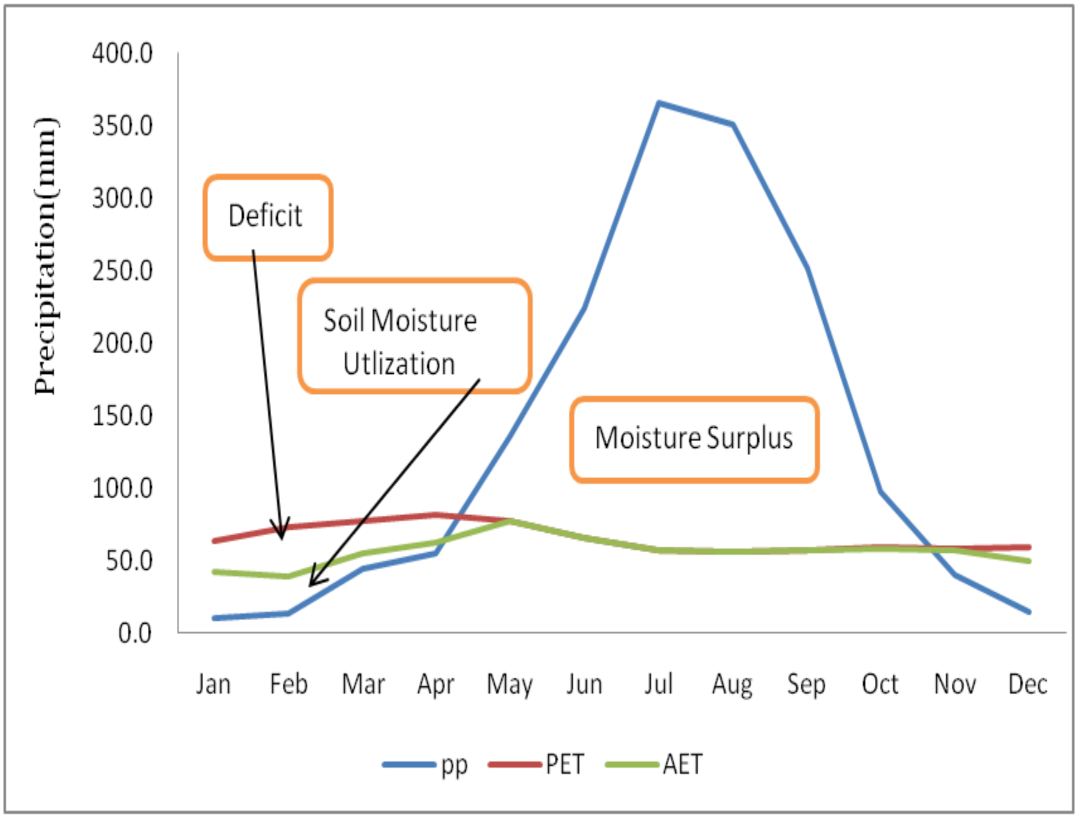


Figure2. 13. Potential and actual evapotranspiration diagram of the area

2.6. Hydrology

Choke Mountain is the water tower of the region serving as headwater of the upper Blue Nile basin. Many of the tributaries of the Upper Blue Nile originate from this mountain range. Many number of rivers and springs are originates in the catchments of choke mountain. Temcha river catchment is one part of this mountain and springs and different perennial rivers are originated in the catchment.

2.6.1. Drainage of Temcha river catchment

Temcha River is one of the Abay river tributaries in Abay river basin. A perennial river in the catchment include the Temcha, Jedub and Gudla are originates from Choke Mountain. The drainage density is higher in the relatively elevated areas, especially when the weathered section is thick and the drainage patterns of both the perennial and seasonal streams in the area mostly have a dendritic and angular pattern. In general, narrow deep to shallow gorges are found in the highlands and relatively wide river channels are found in the lowlands.

2.6.2. Hydrograph Analysis of Rivers

Hydrograph analysis is the method of separating river discharge in to surface flow (runoff) and base flow. In the study area there are three river gauging stations which are Temcha, Jedub and Gudla rivers gauges. These entire rivers are analyzed based on base flow separation methods.

2.6.3. Base flow Analysis

The river analysis package is a computer code developed by marsh 2003. The separation of the river flow data into their respective components of base flow and over land flow has been made by using this code. It uses daily river flow data and the separation of base flow component from the river discharge was done by taking the Lyne and Hollick filter parameter of 0.975 values for α (marsh et al., 2003). The purpose of the filter is to create a relatively smooth transition from period of base flow before a storm event to the usually elevated base flow following the storm event (Marsh et al., 2003). The parameter value applied in the filter will influence the nature of the attenuation of the stream flow hydrograph.

The base flow component separated from a hydrograph of a gauged river in a single hydrologic year represents the total recharge over the catchment upstream of the gauging site, assuming that there is no groundwater inflow and outflow into and out of the basin.

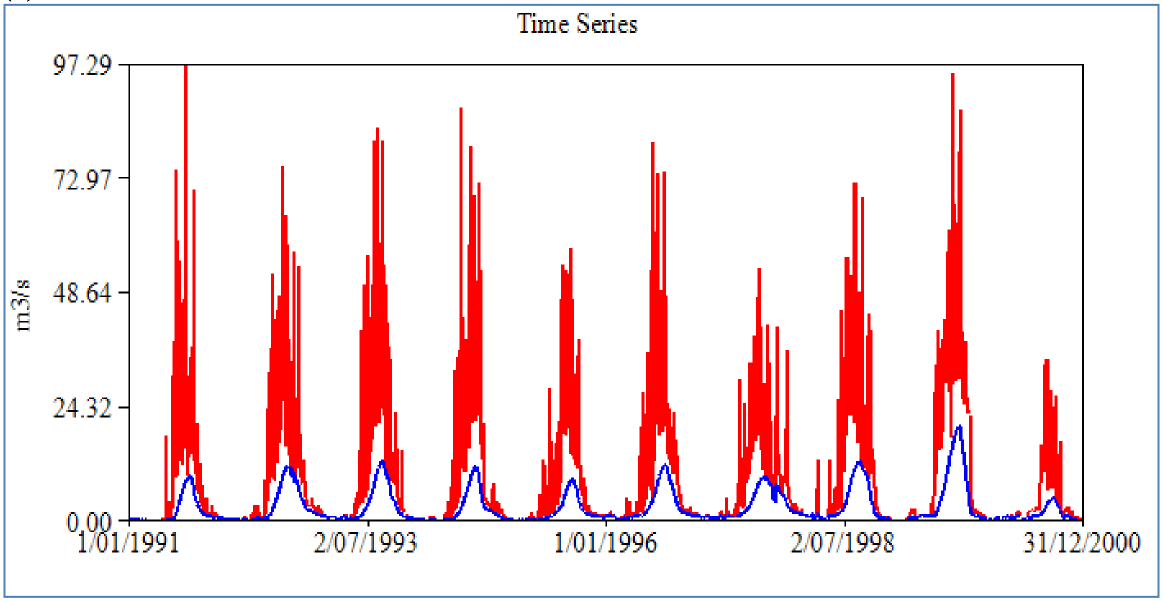
Base flow indices (BFI), is the sum of base flow divided by the total flow over the period of available raw data segments. Weighted mean BFI by the number of years used is then calculated for the station using all the data sets (Table2.11).

There are 3 river gauge Stations within the catchment; Gudla gauge station near to Dembecha town, Jedub gauge station near to Amanueal, Temcha gauge near to Dembecha town. All gauge stations are functional but not have full data recorded. Based on this, base flow separation has been done using a 10 to 13-year daily river flow data (see figure 2.14).

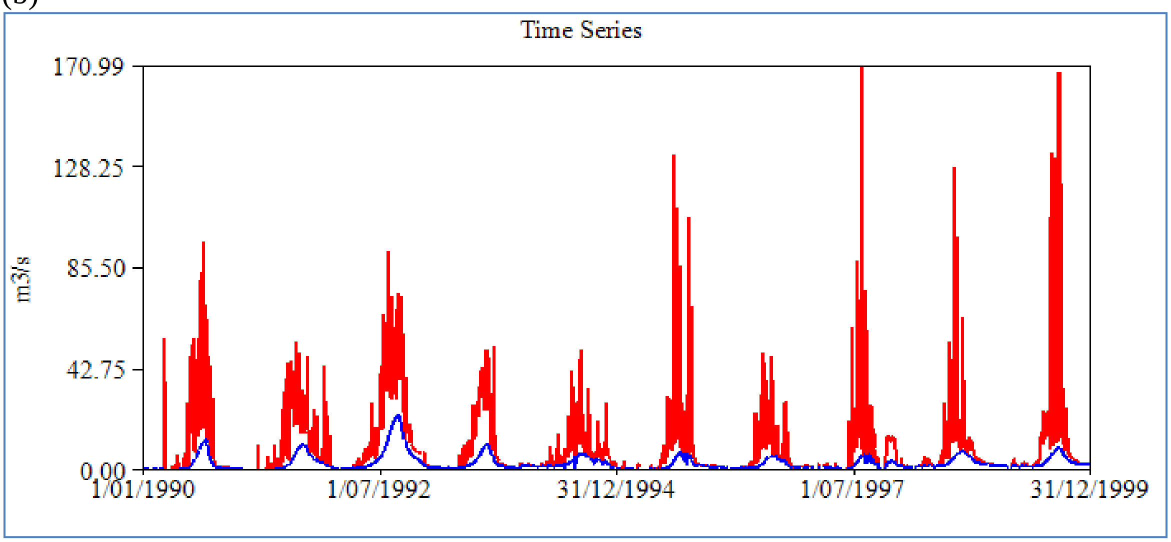
Table2. 9.Mean (1988 – 2000) BFI value in the gauge stations

Station	***BFI***	***Base flow (mm/year)***	***Area(km2)***
Temcha	0.33	113.76	888.78
Jedub	0.34	131.80	830.49
Gudla	0.26	314.95	260.44

(a)



(b)



(C)

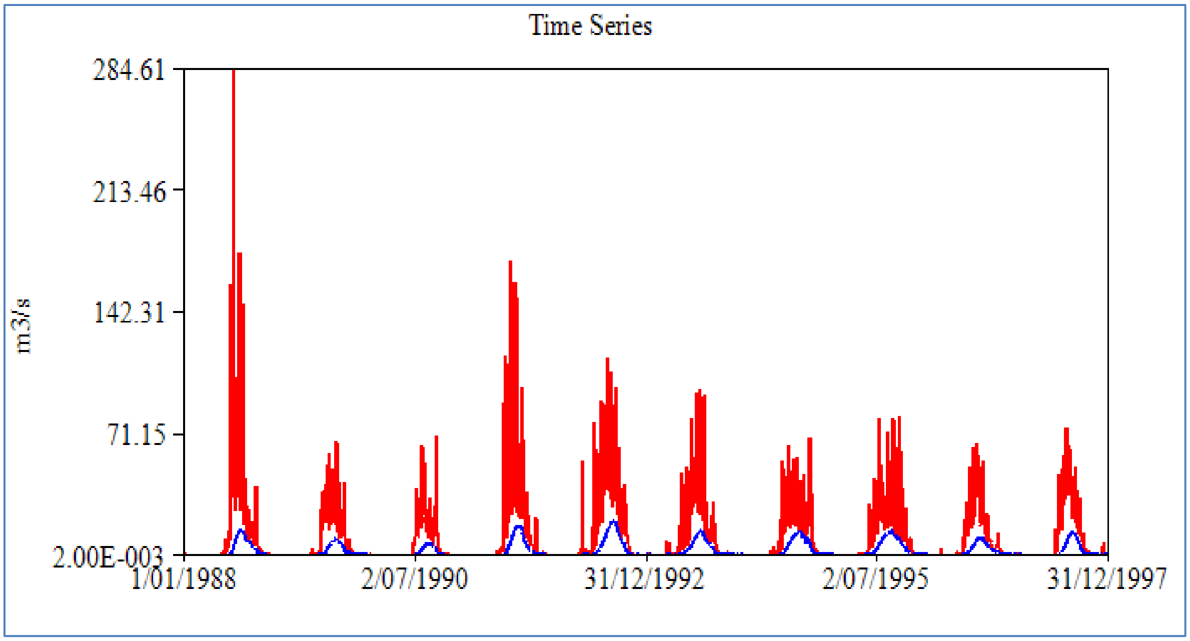


Figure2. 14. Hydrograph of base flow and flood flow for Temcha (a), Jedub (b) and Gudla (c) Gauge stations; the blue and red line represents base flow and flood flow, respectively.

2.6.4. Surface Runoff

Precipitation is transformed into runoff after water has been evaporated and transpired to the atmosphere. According to (Kersic, N., 2009) Available rainfall will infiltrate the subsurface until the rate of precipitation exceeds the infiltration capacity of the soil, at which point ponding and subsequent runoff will occur. Runoff either collects in discrete drainage channels or moves as overland sheet flow.

Runoff occurs, when rainfall exceeded potential evapotranspiration and satisfy a soil moisture deficit (SMD) (Conway, 1997). The soil water balance model shows that, from May to October the soil moisture deficit becomes zero and surplus is high. At this stage surface runoff is occurred. The added direct runoff that is generated from the surplus has to be 775.6 mm/year.

The volume of surface runoff represented by the area under the hydrograph minus base flow can be determined as the movement of water over the surface and in the ground. The boundary between surface runoff and base flow is difficult to define and depends on the geological structure and compositional properties of the area (Shaw, 1984).

Mean annual precipitation of the catchment is calculated based on arithmetic, Thiessen polygon and isohyets method. Therefore, the mean annual precipitation is 1606.6mm/year.

2.7. Geology

2.7.1. Regional geology

According to Canon et al., (1981, as sighted in GSE, 2015) the break-up of Gondwanaland in the Permo-Triassic under a NE-SW oriented stress was responsible for the initiation and development of the Karroo rifting initiated in South Africa and passes north into Ethiopia. The early Karroo sedimentation in the Blue Nile Basin commenced with deposition of thick continental Karroo sediments (Wolela, 2000).

The highly fractured and jointed Trap volcanics of the Tertiary overly the Debre Libanose Sandstone Formation; which are the youngest Mesozoic sedimentary rocks of the Blue Nile Basin (Getaneh, 1991). The Mesozoic rocks are exposed mostly in deeply eroded surfaces (gorges).Mesozoic sediments interns of the aerial extent in the Abay Basin are buried under thick Cenozoic volcanics as the deeply eroded surfaces indicate in the studied area.

2.7.2. Lithology of the study area

The lithologic units of the study area are Mesozoic sedimentary rocks, Tertiary flood and shield volcanic basalt and Quaternary Alluvial and eluvial deposits.

The Mesozoic sedimentary rocks are: Abay Sandstone unit, the sandstone at its top part alternates with siltstone and/or shale and mudstone; the siltstone and/or shale and mudstone sediments occupy the top most part while the sandstone occupies the lower part in terms of the stratigraphic position.

The Tertiary rocks are dominated with basalt lava flows, which are unconformably underlain by the Mesozoic sedimentary rocks. The Tertiary uplifting due to the out pouring of lava flows has been variably eroded the Mesozoic sedimentary rocks. The separation of the lava flows into different units based on the unconformities and radiometric age. According to (GSE,2015) The Tertiary lava flow identified as the four major basalt lava flow dated at 25.3 – 29.4 Ma, the Choke shield volcano dated at 22.4 – 23 Ma, the Anferfira shield volcano dated at 22.3 Ma, Alem Ketema flood basalt lava flow dated at 21.6 Ma and the Demasko ridge – Tulu Lemi basalt dated at 18.58 – 19.1 Ma.

Mesozoic Sandstone unit (Mss)

The Mesozoic sandstone (Msst) occurs in the southern part of the map area. It is outcropped in the Temcha River. It usually forms gentle to steep slopes and rarely plain topography. It is unconformable overlain by Tertiary volcanic rocks (mainly basalt- unit Tlb). At the contact the sandstone is reddish in color with indurate pebbles probably indicating the baking effect of the basalt on the sandstone rocks. It consists of medium to coarse grained sandstone, minor layers of conglomerate.

At the base of Temcha river dissection, is exposed a 41 m thick medium grained quartz arenite. It is composed of rounded and equal sized quartz grains (that is, well sorted and free of clay and therefore matured sandstone both texturally and mineralogical).

- **Flood Basalt (25.3 – 29.4Ma)**

The flood basalt represents four major basalt lava flows and, the sedimentary rocks and pyroclastic rocks deposited between each successive basalt lava flow. Each unit will be described in the following sections.

Lower basalt (Tlb)

The Lower basalt (Tlb) occurs at the base of the Tertiary volcanic rocks pile or succession of the southern area, covering about 188.36 sq.km and constitutes 9.51% of the map area. This unit commonly forms gently to moderately steep topographic features and rarely short cliffs. Occasionally the pyroclastic tuff interlayer with the Tv1 basalt. The top most part of this unit is occupied by volcanic breccia (basaltic composition).

The rock appears dark, porphyritic with dominant olivine phenocrysts. The Tv1 basalt is occasionally partly amygdaloidal and partly vesiculated.

Yejube basalt (Tv2)

This unit is found unconformably overlying the Lower basalt at the root of the coke mountain in south east of the area. It covers 362.79 km^2 that accounts 18.32% the study area (see fig.2.15). It forms escarpment or cliffs, moderate slope topography and flat-lying topography, and columnar jointed. Occasionally the Tv2 basalt has interlayer with pyroclastic tuff. The pyroclastic tuff is very fine-grained and unidentified through the microscope. The basaltic course to lapilli lithic tuff is with maximum of 30 cm basalt bomb and exhibit weathering layers.

Sandstone and pyroclastic tuff (Tsp)

It forms flat lying area, gentle slope and moderate slope topography. This unit separates the overlying Tv3 basalt and the underlying Tv2 basalt.

The rocks constitute this unit are sandstone, ignimbrite and pyroclastic tuff. Stratigraphically sandstone occupies lower position and, the ignimbrite and pyroclastic tuff occupy upper position. The sandstone is bedded with maximum bedding thickness 30 cm with occasional lamination, semi-friable to friable and cross-bedded. It has light-gray, gray, dark and white colors.

The ignimbrite has boulder exposure and massive. The ignimbrite is composed of unidentified minerals (ash) with considerable plagioclase and olivine crystals, and vesiculated. The pyroclastic tuff is white, light weight and very fine grained (volcanic ash as petrographic study depicts) and thinly bedded or laminated and occasionally massive.

Debremarkose basalt (Tv3)

It forms escarpment/cliffs, ridges, hills, moderate slope, gentle slope and flat-lying topography, and columnar jointed. The Tv3 basalt occasionally interlayer’s with pyroclastic tuff. The top most part of this unit overlain by hill forming pyroclastic tuff, lithic tuff and the associated siltstone.

The Tv3 basalt is dark with porphyritic and aphyric texture and, has blocky appearance and spheroidal weathered. Occasionally it is vesiculated and amygdaloidal with calcite amygdules. The boulders of the Tv3 basalt mantled the down slope surface, where the topography is steep slope and moderate slope. The petrography of Tv3 basalt represents olivine-plagioclase phyric basalt, plagioclase-olivine phyric basalt and olivine phyric basalt, one grade into another.

The pyroclastic tuff is white, light weight, laminated/massive and very fine grained (volcanic ash from petrographic study). The siltstone is white, very fine grained, has light weight and very thinly bedded.

Lumame basalt (Tv4)

It forms hills, ridges, escarpment/cliffs, moderate slope and flat-lying topography and columnar jointed. These units locally interlayer with pyroclastic tuff. The top most part of this unit overlain by the Choke shield volcano. The Tv4 basalt is dark, porphyritic with maximum of 1.1 cm size plagioclase phenocrysts and occasionally aphyric; sometimes vesiculated and amygdaloidal with silica amygdules.

- **Choke Shield Volcano (22.4 – 23Ma)**

The Choke shield is one of the three major shield volcanoes enclosed within a large meander of the Blue Nile. It is a broad flat symmetrical shield made up dominantly of lava flows and extends radially out from the central conduit with dips less than 5^0. Unconformity was recognized at the base of the choke shield volcano rising above the trap and Volcano consists of trap and shield volcano presumably separated by a break (Kzmin, 1973).

The Choke shield volcano represents four major basalt lava flows, one rhyolite lava flow and trachyte plugs. Each unit will be described in the following sections.

Rob Gebeya basalt (Tvc1)

The pyroclastic tuff and trachyte sills interlayer with Tvc1 basalt. The Tvc1 basalt is dark, porphyritic with occasional aphyric texture and, sometimes vesiculated and amygdaloidal with silica amygdules.

The pyroclastic tuff is white, laminated, light weight and very fine-grained (volcanic ash) occasionally grades to lithic tuff.

Arat Mekeraker basalt (Tvc2)

This unit is overlying the Tvc1 unit. At places the top most position of the Tvc2 basalt overlaid by pyroclastic lithic tuff, basaltic agglomerate and pyroclastic tuff with thin layer of coal seam, which are cross-cut by the basalt dyke. The Tvc2 unit and the Tvc3 unit are separated by these layers.

The Tvc2 basalt is dark, porphyritic and aphyric, occasionally vesiculated and amygdaloidal with silica amygdules.

Kutye basalt (Tvc3)

The trachytic sills and pyroclastic tuff interlayer with Tvc3. The top most part of this unit overlaid by the Tvc4 unit (Choke rhyolite).

The Tvc3 basalt is dark, porphyritic and aphyric. The Tvc3 basalt represents plagioclase phyric basalt, olivine-plagioclase phyric basalt and aphyric basalt (GSE, 2015).

Choke rhyolite (Tvc4)

This unit is overlying the Tvc3 unit and exposed towards top of the Choke Mountain; near the Choke mountain peak.

Choke trachyte plugs (Tvc5)

It exposed at different elevations/altitude in Choke Mountain. It forms prominent hills and gives scenic beauty to the surroundings. The trachyte is white and greenish-gray and porphyritic.

Choke peak basalt (Tvc6)

Choke peak basalt is the thin layer exposed at top most part of the Choke Mountain, in the north part of the study area. It forms flat-lying area at the top most part of the Choke Mountain.

Quaternary eluvial sediments (Qel)

The eluvial sediments in the study area developed from all rock types from the incipient alteration of the bed rocks. The eluvial sediments appear in reddish, reddish-brown, brown, dark-brown and dark colors depending on the composition of the rock where they have derived, addition of the organic matter, land topography and other factors. The soil size varies from sand-silt-clay, silt-clay and clay size particles.

Quaternary alluvial sediments (Qal)

The foot of the mountain slopes is fringed by alluvial and colluvial deposits composed largely of silty sand soils. In some place’s sediment deposit occur along stream or river channels and vary in size from clay, silt, sand, pebble, cobble and boulder at different parts of the area.

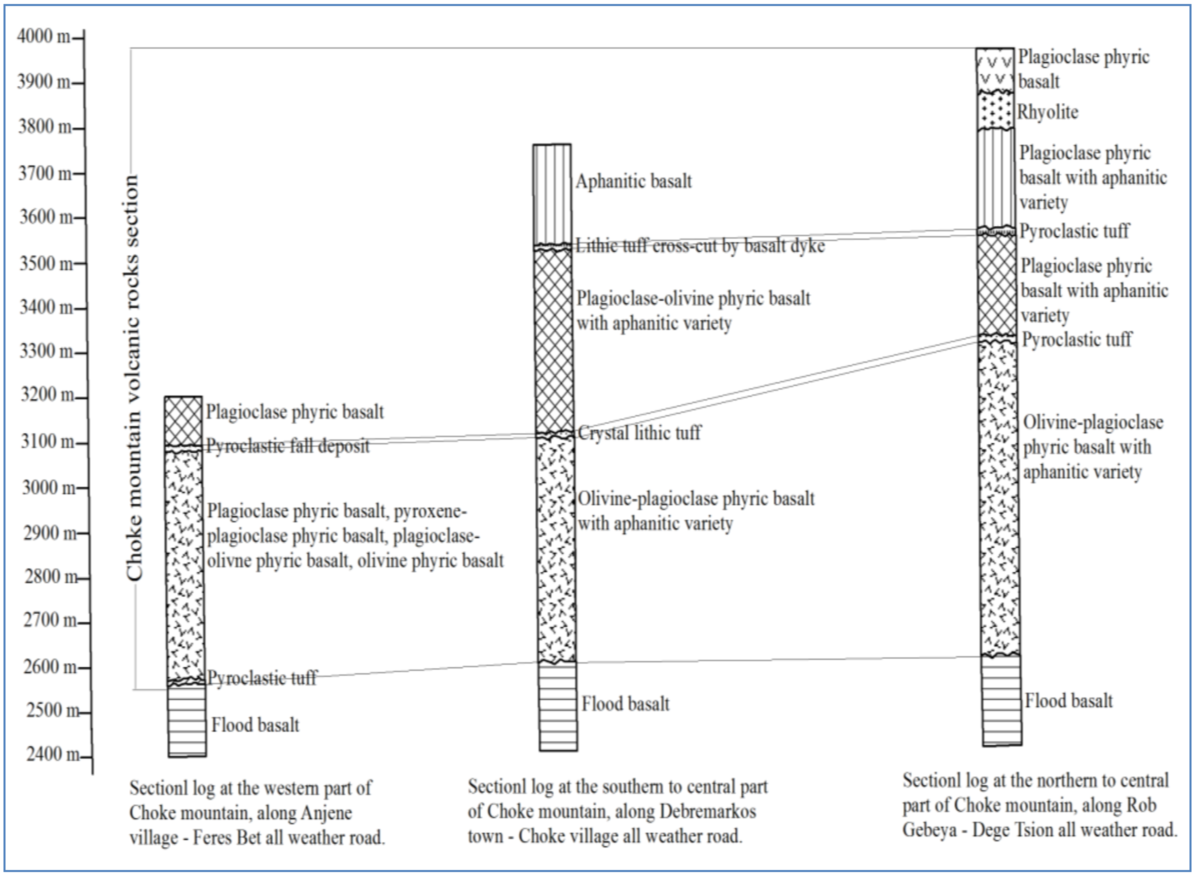


Figure.15. Stratigraphic section taken from GSE, 2015

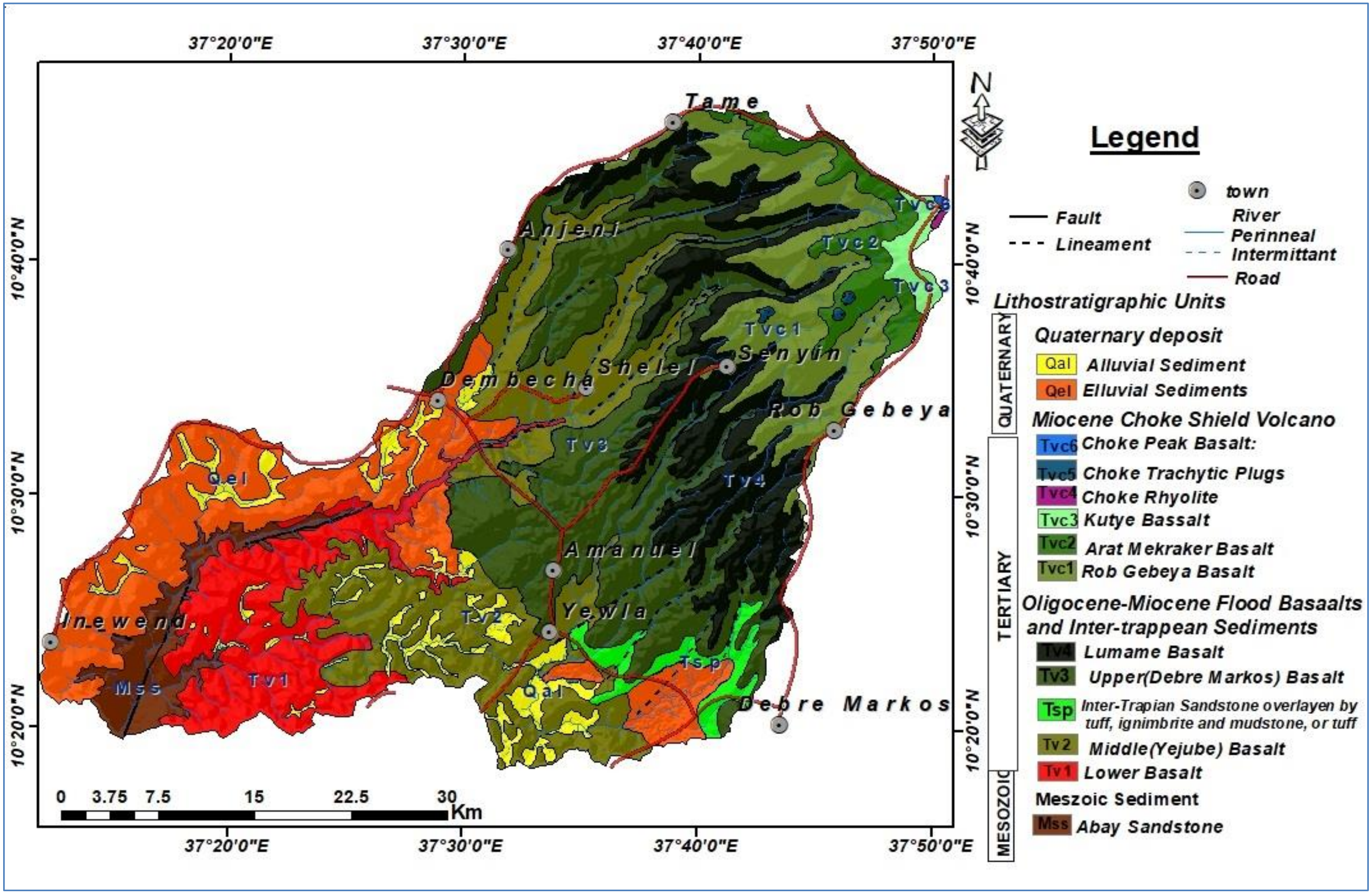


Figure2. 15. Geological Map of Temcha River Catchment modified from GSE, 2010

2.7.3. Structure

Structural features, such as fractures folds and faults are the geometrical properties of the geologic systems produced by deformation after deposition or crystallization. Fractures may be oriented parallel, perpendicular, or oblique to bedding. A fault is a fracture, or a fracture zone, along which there has been displacement of the sides relative to one another and parallel to the fracture (maliva, 2016).

Lineaments (or fracture traces) are natural linear features that can be mapped from aerial photography or remote sensing images. These features might include light or dark lines in the soil, alignment of vegetation, aligned gaps in ridges or straight reaches of streams. Such features often reflect subsurface geology, and may denote the presence of faults or major fractures.

Lineaments that are occurred in the study area are associated with the volcanic eruptions. They have NE - SW and N-S orientation (see figure 2.16).The trachyte plug might be formed along pre-existing weak zones or fractures.

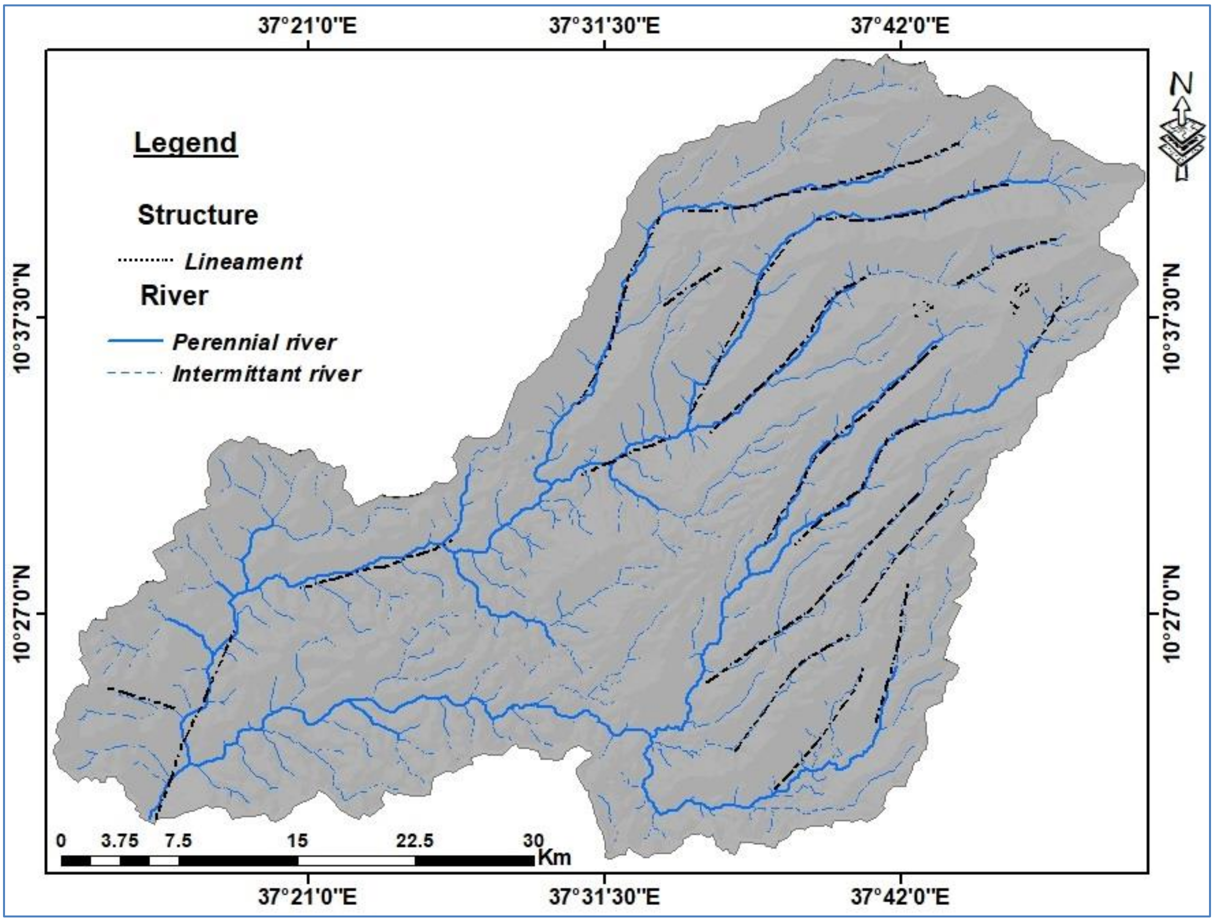


Figure2. 16.Structural map of the catchment

2.8. Hydrogeology

2.8.1. Introduction

Temcha river catchment has a variable hydrogeological property from upstream to downstream of the area. The groundwater availability in the catchment is controlled by the presence of weathered and slightly fractured Tertiary rock, and the redeposited alluvial and some eluvia sediments along the flat land.

Rock units that do not allow water through them become barriers to flow and in turn change the direction of groundwater movement. Other features such as fault zones may serve as conduits to groundwater flow or act as barriers.

The hydrogeology and groundwater occurrence is complex due to existence of different volcanic rocks covered with thick alluvial sediments of the catchment.

Volcanic rocks and unconsolidated sediments encountered in the area have been classified into different aquifer units based on their field hydraulic properties, borehole and spring yields and pumping test data (transmissivity). Furthermore, topographic setting and recharge conditions have been considered to evaluate the productivity of hydrostratigraphic units.

Fractured lava flows in the shield volcano act as excellent conduits but they have only limited storage. The ability of fractures to act as conduits for groundwater flow is affected by the degree to which the fractures are interconnected. Fracture connectivity increases with increasing fracture length and fracture density, as the chance of fracture intersection increases (Cook, P.G., 2003).

The presence of paleosols between basaltic lava flows produces perched water systems, which are frequently represented by mountain slope springs and wetlands (Tamiru Alemayehu and Seifu Kebede, 2011).

The flood basalt and quaternary alluvial and eluvial deposits are the main water bearing formations in the study areas. The position of groundwater varies considerably in depth extending essentially from the surface to considerable depths below the surface.

CHAPTER THREE
3. RESULT AND DISCUSSION

3.1. Aquifer Characterization

The nature and distribution of aquifers and Aquitard in a geologic system are controlled by the Lithology, stratigraphy and structure of the geologic deposits and formations (Freeze and Cherry, 1979).

The aquifer is characterized based on the water bearing and permeability of different geologic units of the river catchment and quantitative water point data evaluation. Quantitatively can be characterized based on the data collected from various boreholes pumping tests obtained from different organizations. Since quantitative data such as permeability, aquifer thickness and yield are inadequate and are not evenly distributed enough to perform detailed quantitative potential classification, qualitative assessment such as distribution and magnitude of discharge of springs, degree and depth of fracturing, weathering of rock masses, physiographic and absence or presence of adequate recharge help to prioritize the groundwater potential of an aquifer for development.

Hydrogeological field observations such as the distribution and magnitude of spring discharges, the degree of fracturing of the rock units, the thickness of the formations, the grain size rounding and sorting, the clay proportions, the type and degree of cementation, and the extent of weathering are some of the significant field observations which provided indirect evidence as to weather a rock unit is likely to be an aquifer of low, moderate or high productivity.

The Borehole pumping test data, through available only in limited amounts, provided a basis for estimation of yield, specific capacity and permeability values which after a simple statistical treatment were used to rank the aquifer in to low moderate and high productivities.

The Study Area is classified in to 5 aquifer groups and some geologic unit based on the character of groundwater flow (fissure and porous), transmissivity and spring discharge.

1. Extensive (larger than 100km^2), locally developed and highly productive intergranular (unconsolidated) aquifers (T=10-100 m^2 /day and well Q= 5-25 l/s).aquifers are Quaternary alluvial and eluvial deposit (Qel & Qal).

2. Extensive (>100km^2), locally developed high productive fractured aquifers (T=10.1- 100 m^2/day and 5- 25 l/s for wells and springs), the aquifers are shown on the map in green colour and include upper basalt (debre markos) and middle basalt (Yejube).

3. Extensive (above 100km^2) and moderately productive fractured aquifers (T=1.1-10 m^2/day and Q=0.51-5 l/s for borehole and spring) local or discontinuous but highly productive aquifers, Aquifers are represented light green color on the map. The aquifer includes Lower basalt. Lumame, rob Gebeya basalt and Mesozoic sediment are categorized under this aquifer.

4. Extensive (above 100km^2) and low productive fractured aquifers (T=0.11 – 1m2/day and Q = 0.051-0.5 l/s for well and/or springs) Kutye, Arat Mekeraker basalt and inter trapped sandstone with ignimbrite and tuff are part of low productive aquifer.

5. Aquitard and/or minor fissured aquifers with local and limited groundwater storage (T=0.01 -0.1m^2/day and Q= 0.001- 0.055 l/s for wells and/or springs).this are Choke trachyte plug and choke rhyolite.

The hydrogeological and aquifer characteristics of each lithological unit are described based on field data inventoried in Temcha and adjacent areas as well as (GSE, 2012).

3.1.1. Extensive and high productive intergranular aquifer

Alluvial sediment: Contain interbedded stream-flow and debris-flow deposits, which is a source of higher degree of heterogeneity. Stream-channel deposits consisting of sand and gravel occur where the flow is channelized. Springs from soil have better yield when there is relatively thick soil (lateritic and reddish-brown clay soil) especially when the slope angle is low to moderate, and at the foot of the second or third minor to moderate sized cliff steps. Fresh water can be exploited from this aquifer by shallower drilled holes or dug wells. The thickness of the aquifer in many places varies 1.5 to over 3 meters mostly and in some places reaches up to 10 meters.

Eluvial deposit

This aquifer unit is important for domestic uses of shallow wells and dug wells. a number of shallow wells are drilled in this aquifer and sentera well field is part of this. As the lithologic log shows the thickness of this aquifer reach 4 up to 32 m around sentera and wad localities. it also comprises clay and bedded tuff. The gain size sorting as well as the thickness of the eluvial determines the aquifer potential which generally has high productivity.

3.1.2. Extensive and High productive fractured aquifer

Upper Basalt

The upper basalt is rarely vesicular basalt, but vesicles are smaller in size usually less than 5 mm (GSE, 2017). This aquifer is characterized by highly productive in the place where it has weathered and fracture areas. For instance, in localities around anjen and Shelel the depth of weathering has significant role. Springs are emerged in contact between the underlying flood basalt aquifer and through fractures with discharges of 0.1 to 3 l/s within and around the study area of this aquifer unit. Borehole yield around shele and debre markos town ranges from 4.55 to 20 l/s.Transmisivity and hydraulic conductivity of the aquifer is varying from 4.49 to 550 m^2/day and 0.38 to 6.34 m/s respectively. The transmissivity and hydraulic conductivity data of the upper basalt obtained from the adjacent areas.

Table.3. 1.Aquifer Parameter values of Upper basalt

Parameters	***Minimum***	***Mean***	***Maximum***	***No. Of sample***
Borehole yield(l/s)	4.5	12.19	20	4
Spring Yield(l/s)	0.1	0.8	3	4
Transmissivity(m2/day)	4.49	152.2	550	4
Conductivity(m/day)	0.05	1.45	4.97	4
Static water level(m)	3.36	25.91	100	5
Depth(m)	144	212	267	5

Middle basalt

This aquifer is outcrops around south east and central part of the study areas and also found in boreholes below the upper basalt aquifer and eluvial aquifer around Shelel and sentera plain respectively. The aquifer is separated from the overlaying upper basalt aquifer by thin clay Paleosol and it is fractured aquifer. Weathered and fractured parts of the formation are highly productive and borehole yields vary from 2 to 39 l/s. Borehole depth in this aquifer varies from 70 to 300m.Transmissivity vary from 3.03 to 5750 $m^{2/}$day. Spring discharge inventoried from this aquifer yields ranges from 0.1 to 0.6 l/s. Aquifer conductivity ranges from 0.04 to 160 m/day.

(a)  (b) 

Figure3. 1. (a) Spring from fractured basalt (b) Columnar basalt near to Temcha River

Table.3. 2.Aquifer Parameter values of Middle basalt

Parameters	*Minimum*	*Mean*	*Maximum*	*No. Of sample*
Borehole yield(l/s)	3	18.79	39.5	28
Spring yield(l/s)	0.1	0.3	0.6	4
Transmissivity(m2/day)	3.05	559.14	5750	16
Conductivity(m/day)	0.04	16.34	160	16
Static water level(m)	4.9	19.71	62.8	26
depth(m)	70	146	300	28

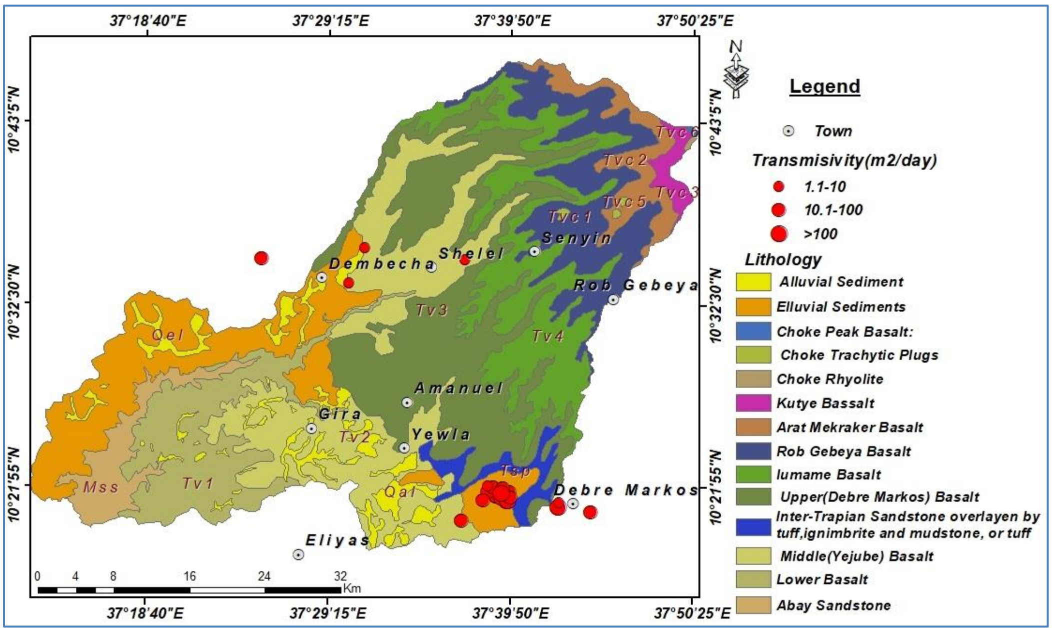


Figure3. 2. Transmissivity of aquifers labeled on map

3.1.3. Extensive and moderately productive fractured aquifers in volcanic and sandstone units

This aquifer covers the total areas of 262.44sq.km. Topographic position, degree of weathering and structure and the rate of recharge makes the water bearing properties of the flood basalt vary significantly from place to place.

Rob Gebeya basalt

This aquifer is outcropped on the northern parts of the study area especially around yeted and rob Gebeya town. It is interlayered with pyroclastic tuff and trachyte sills. In some place of weathered and fractured basalt has moderate potential for shallow well. Inter layered pyroclastic tuff serve as storage and has the contribution for emerging spring between the contacts. Spring discharge in this aquifer varies from 0.2 to 6.5 l/s. borehole yields around rob Gebeya and yeted ranges from 0.5 to 3 l/s.

Table.3. 3.Aquifer parameter values of Rob Gebeya

Parameters	*minimum*	*Mean*	*maximum*	*No. Of sample*
Spring yield((l/s)	0.02	0.9	6.5	12
Borehole yield(m)	0.5	1.3	2.5	3
Static water level(m)	3	17.67	31	3
depth(m)	61	63	67	3

Lower Basalt:

It is highly weathered and fractured. The occurrence of weathering and fractures increases the porosity and permeability of the aquifer. This allows the groundwater circulation and occurrence increase within the aquifer. Springs emerge through fracture and lithologic contact has been inventoried from different places with discharge ranges from 0.4 to 2 l/s at fetegem – Amanueal. According to GSE (2017) very high discharge springs are found within and around the catchment of lower basalt aquifer ranges from 75 to 100 l/s at workma - laye bir shelala. Borehole from adjacent area at debre alias town has a yield 5.7 l/s.

Mesozoic Sandstone: It is unconformable overlain by Tertiary lower basalt and their contact is usually marked by a sharp topographic break (GSE, 2017). It usually forms gentle to steep slopes and rarely plain topography. The permeability of Sandstone increases due to weathering in addition to closely spaced vertical joints and horizontal bedding. The overlain weathered and fractured basalt has the contribution for recharge through the storage of this aquifer. Spring discharge from this aquifer varies from 0.6 to 1.3 l/s.

3.1.4. Extensive and low productive limited fractured aquifer

Kutye, Arat Mekeraker and inter-trap sandstone overlain by tuff ignimbrite and mudstone

Shield volcanic rocks are categorized under low productive aquifer. The distribution of low productive aquifers is developed in Elevated Mountain and ridges as well as steep escarpments of choke shield volcanos. The weathering of rock in this volcano region is not extending deeper than the infiltrated precipitation moves as subsurface flow.

Apart from the significance of these prominent geomorphic characteristics of the shield volcanoes in the groundwater recharge and circulation, the structure of the lava flow units make the shield volcanoes a distinct hydrogeologic units as compared to the underlying horizontally lain flood basalt plateau. The lava flows the shield volcanoes are thinner and less continuous than the underlying flood basalts. This leads to the close association of spring emergence at frequencies with the shield volcanoes (Seifu, 2013).

Kutye Basalt

This unit is in the form of secondary permeability due to fracturing and weathering, but usually this unit is massive and fresh, and the degree and intensity of fracturing is low.

3.1.5. Local and Aquitard

Trachyte pug and choke rhyolite

Trachytic plug have stepper slopes, massive and slightly weathered surfaces. Due to less fracture this unit has low permeability. Water points are not emerging directly from these units. Since this unit acts as an impervious unit, it would be the cause for springs emerge at the contact zones.

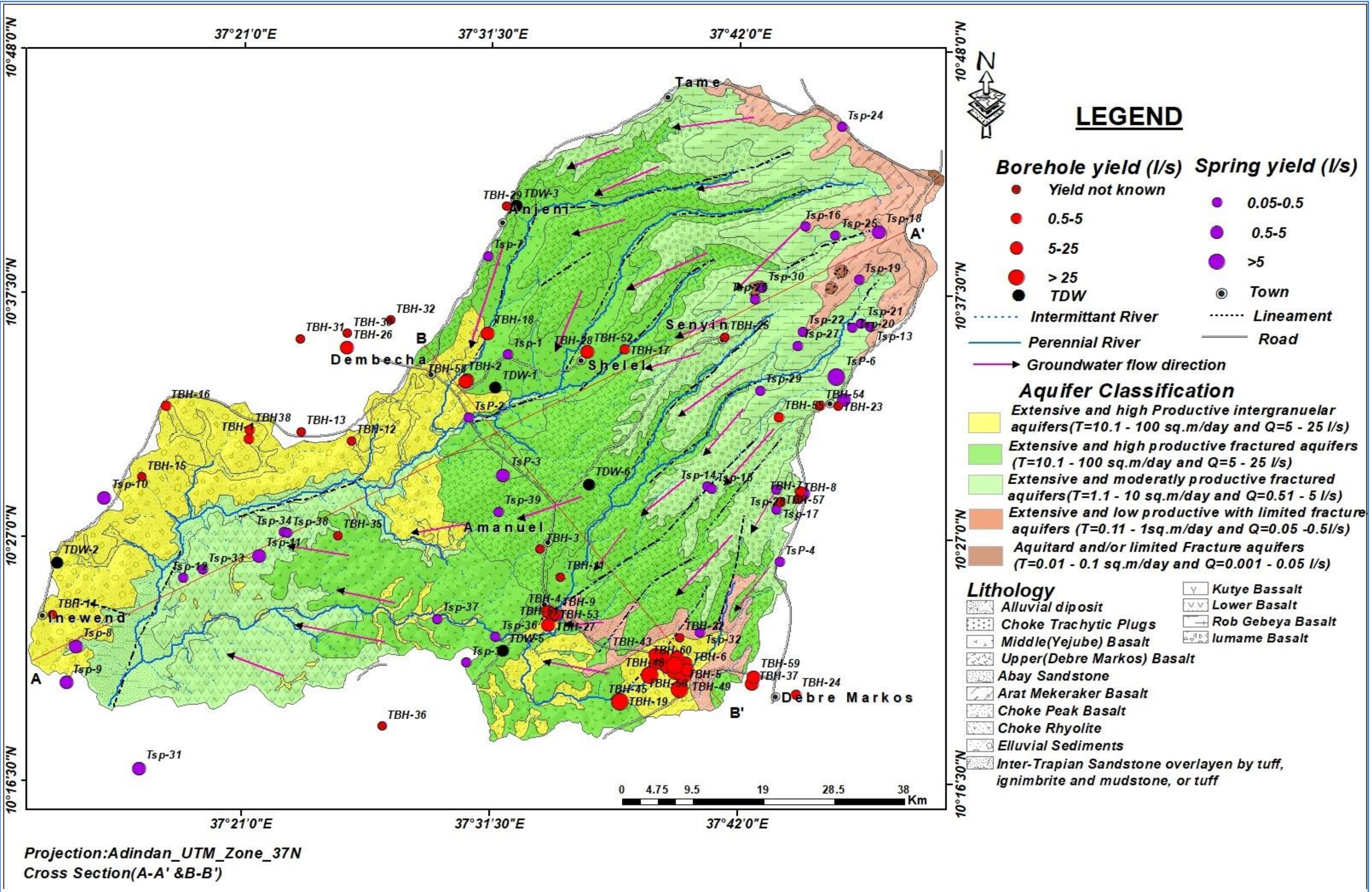


Figure3. 3.Hydrogeological map of Temcha river catchment

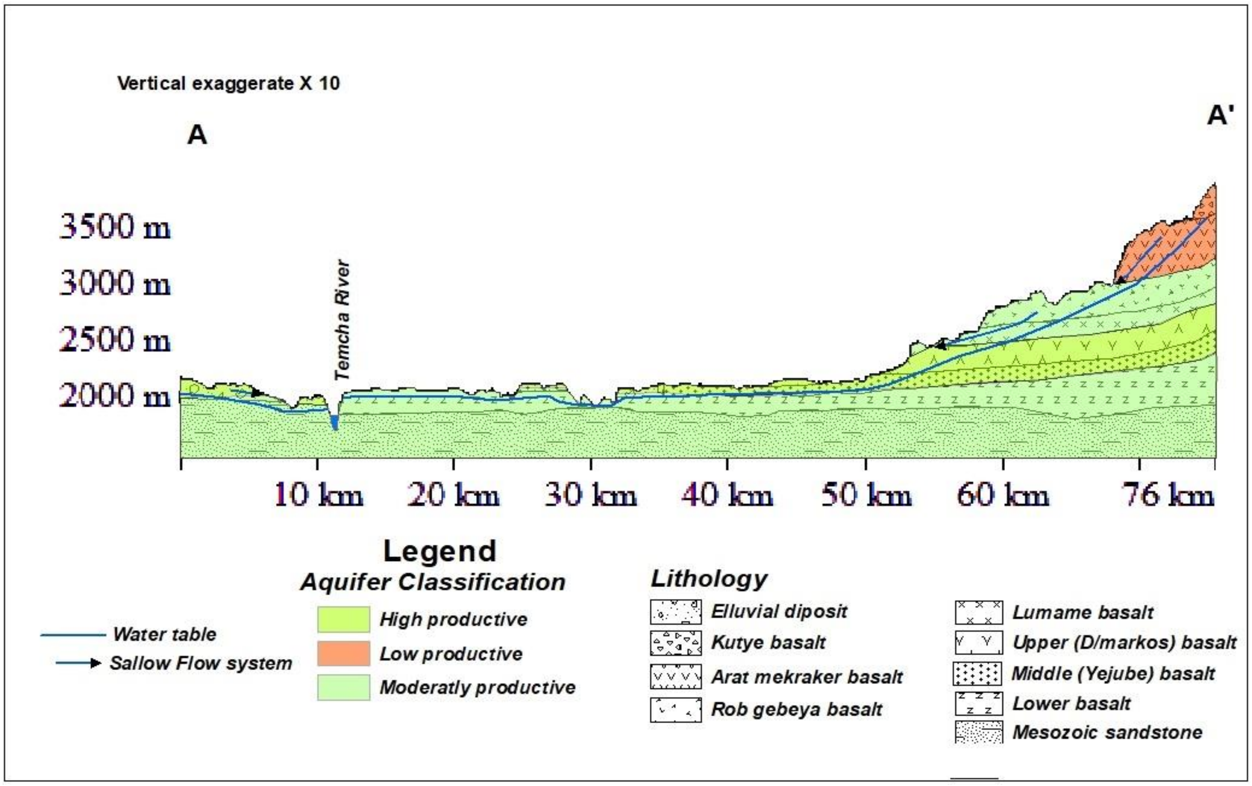


Figure3. 4. Hydrogeological cross-section of the area from A –A'

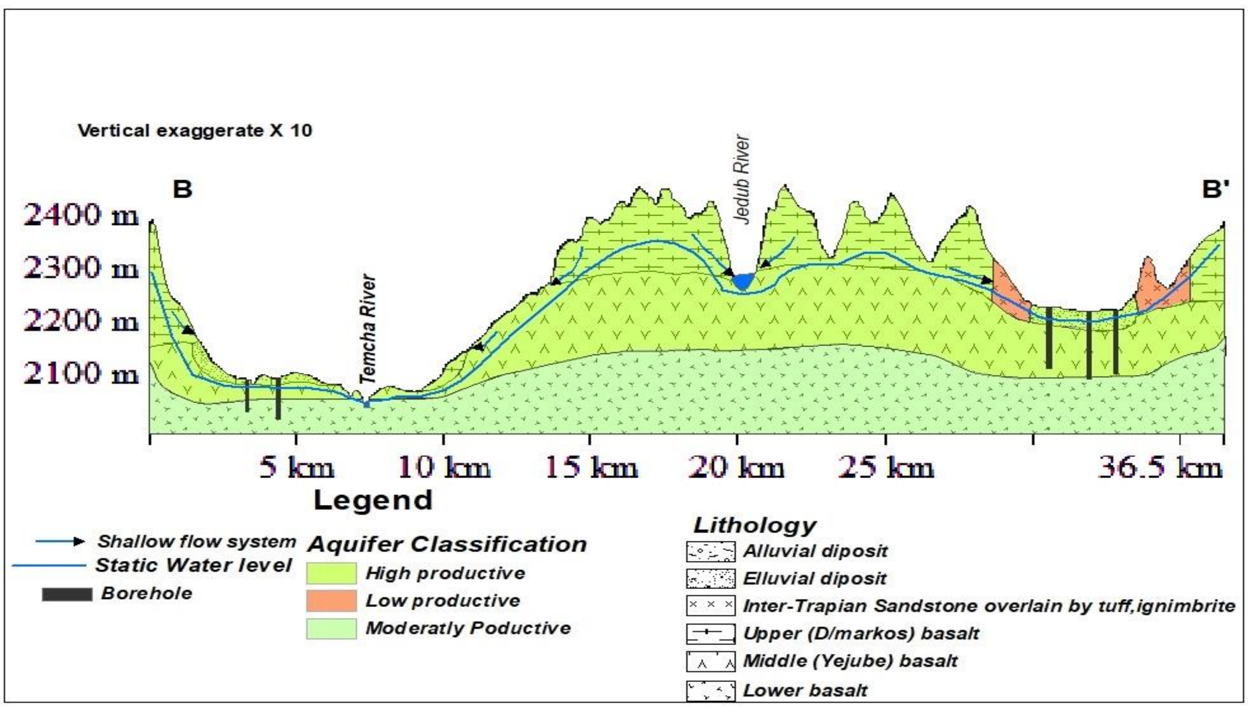


Figure3. 5. Hydrogeological cross section of the area from B – B'

3.2. Groundwater Recharge, Discharge, Flow and Wetland

3.2.1. Groundwater Recharge

Groundwater recharge is defined as the downward flow of water that is added to the groundwater reservoir and that joins the regional groundwater system (Tenalem Ayenew and Tamiru Alemayehu, 2001)

The highland and some of the gently falling terrain of the catchment area (i.e. anjen and rob Gebeya in choke mountain) is considered as recharge area, while the foot hills and depressions, some of the flat lands and few of the gently falling areas (i.e. yewla and sentera plain) also considered as discharge areas.

Recharge takes place in to the groundwater in the form of diffuse, indirect from flood, mountain front and mountain block, fast selective recharge from heavy rains, from loosing stream and flash floods (Seifu Kebede, 2013). Based on geoenviromental setting of the recharge mechanism for aquifer in Temcha river catchment is direct or diffuse recharge, which means water, added to the groundwater reservoir in excess of soil moisture deficits and evapotranspiration, and by direct vertical percolation of precipitation through unsaturated zone.

3.2.1.1. Recharge estimation

The rate of recharge is strongly influenced by the distribution and amount of rainfall, the permeability of the rocks, the geomorphologic setup and the availability of surface water bodies close to major unconfined and semi-confined aquifers (Tenalem Ayenew, 2008).

Quantification of the rate of natural groundwater recharge is basic for efficient groundwater resource development and management. The amount of water that is extracted from an aquifer without causing depletion is primarily dependent upon the groundwater recharge.

There are different methods to estimate the recharge rate. In this cause, based on the available data and resources as well as possibilities of obtaining supplementary data; the groundwater recharge has been estimated by using river discharge analysis and soil water balance methods.

3.2.1.1.1. Base flow separation methods

The major assumptions in using base flow for estimating recharge are that base flow equals groundwater discharge, and that groundwater discharge is approximately equal to recharge.

Implicit is the assumption that groundwater losses from the gauged watershed caused by underflow, ground-water evapotranspiration, and exports of ground water are minimal. If these conditions are met, base flow may provide a reasonable estimate of recharge for long time periods (Dennis et al., 2005).

Values of Annual base flow were estimated by stream flow hydrograph separation method by using river analysis package (see table 3.4). The annual mean base flow weighted by areas of each river gauge for Temcha catchment during 1988 to2000 has to be 147.8 mm/year.

Table.3. 4.Estimated recharges using Base flow separation

Station	***BFI***	***Base flow (mm/year)***	***Direct runoff(mm/year)***	***Total flow mm/year***	***watershed Area(km^2)***	***Base flow*Area***	***Runoff*Area***
Temcha	0.33	113.8	240.9	354.7	888.8	101107.6	214133.8
Jedub	0.34	131.8	248.0	379.8	830.5	109458.6	205930.1
Gudla	0.26	315.0	895.9	1210.9	260.4	82025.58	233336
Total					**1979.7**	292591.8	653399.9
Weighted base flow and runoff						**147.8**	**330.**

3.2.1.1. 2. Soil water balance method

Water balance model were developed in the 1940s by Thornthwaite (1948) and revised by Thornthwaite and Mather (1955).This method is essentially a book keeping procedure which estimates the balance between the inflow and outflow of water. In standard soil water balance calculation, the volume of water required to saturate the soil is expressed as an equivalent depth of water and is called the soil water deficit. The soil water balance for a long term can be represented as:

$$Gr = P - AET + \Delta \mathrm{S} - \mathrm{Ro}$$

Where, Gr: Groundwater recharge

P: Precipitation

AET: Actual evapotranspiration

ΔS: Change in soil moisture

Ro: Runoff

Since the computation is made annually, net change in soil moisture and groundwater storage is assumed to be zero.

Mean annual precipitation calculated by using weighted Thiessen polygon, isohyets and arithmetic method has to be 1606.6 mm/year or3180.9MCM.

Actual evapotranspiration calculated from soil water balance method is to be 704.6 mm/year (1394.9MCM).

Surface Runoff obtained from soil water balance by added direct runoff that is generated from the surplus is also 775.6 mm/year or (1535.5MCM).

Accordingly, the annual groundwater recharge in the aquifer is estimated as follows:

$$Gr = 1606.6\,mm - 704.6\,mm - 775.6\,mm$$

Gr=126.4 mm/year

The result shows that, from a give annual rainfall of the catchment 8% is available for groundwater recharge, 43.8% for evapotranspiration and 48.2% is Surface runoff.

The groundwater abstraction from a total of 33 boreholes is estimated to be3.25mm/year(6.4 MCM/year) with the assumption of 8 hour pumping rate per day from 17 boreholes and 12 hour pumping rate per day from 16 boreholes.

Generally the recharge estimated from Soil water balance and Base flow separation is 250MCM/year and 292.6MCM/year respectively with271.4MCM/year average value.

Comparison of the results of the study with the Chemoga river adjacent catchment is done. The recharge of the catchment is estimated using WetsPass method. The estimated average recharge was 116.3 mm/year and this estimated recharge result is comparable with my study area.

3.2.2. Groundwater flow

Groundwater flows from areas where the water table is recharged to a location where groundwater discharge occurs (fetter, 2001).It is subjected to gravity and is almost always in motion, flowing from areas of higher elevation to areas of lower Elevation. The rise in elevation is from the high pick of Choke Mountain to lowest flat plain of sentera and yewla.

The groundwater flow direction is depicted from groundwater contour maps. Hence, groundwater contour maps for the shallow and deep aquifer systems are constructed from water level elevations of boreholes in the study area. However, the water level data used is collected at different times and this will be affected by the seasonal fluctuation of water level.

Narrow contour spacing corresponding to high hydraulic gradients indicates rapid change in elevations of water level compared with those of wider spacing indicating presence of localized aquifers within the regional aquifer domain (Tilahun, 2015).

Regional (at catchment scale) and shallow groundwater flow systems are hosted in the catchment. The shallow groundwater flow seems subjected to a shorter travel distance. It appears to the surface as spring or contributes to river valleys. Such kind of flow system is common in the mountainous part of the catchment (figure 7.1).The deeper groundwater flow indicates the regional groundwater flow and occurs in deeper parts of the reservoir. Generally, groundwater flow in the area can be indicated from the highest northern part to lowest southern area.

As the map indicates, the general trend of groundwater flow system is from north to south direction (figure 7.1).

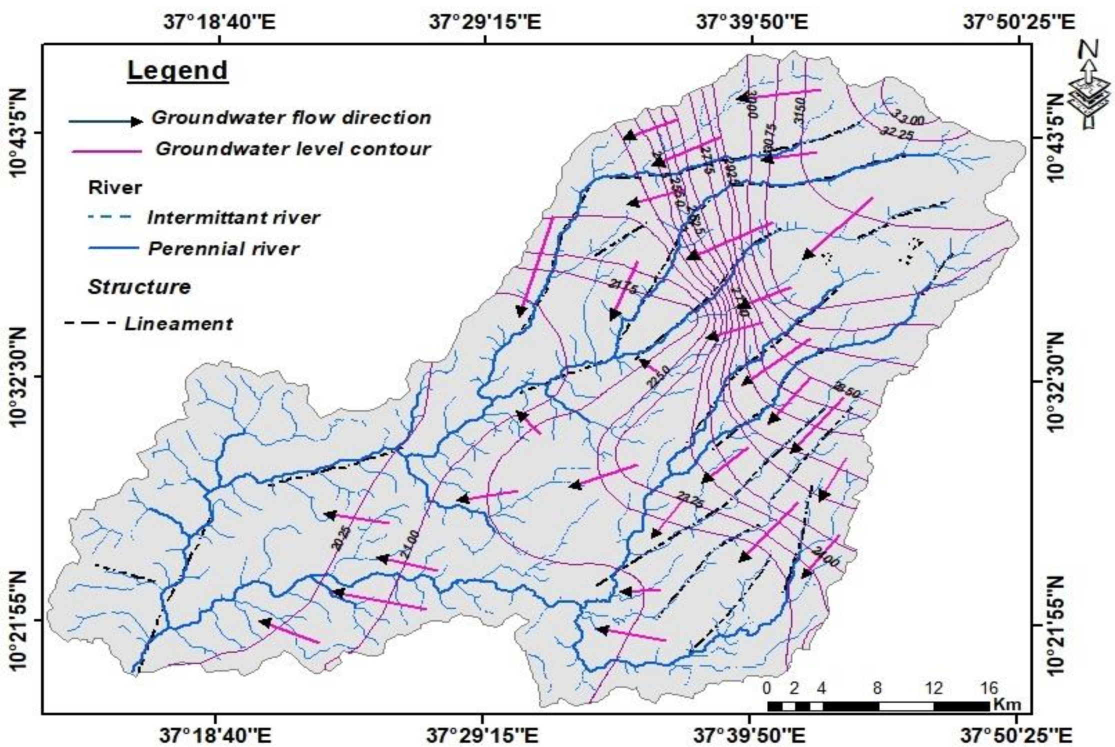


Figure3. 6. Groundwater flow map of the areas

3.2.3. Groundwater Discharge

Groundwater discharge can be defined as the release of water from the saturated zone across the water table together with associated flow towards the water table with in the saturated zone (Freeze and cherry, 1979). Groundwater discharge areas can be manifested by surface water features such as springs, swamps and seepages.

In the field, vegetation and surface water can sometimes be used to locate discharge areas. There may be some physical manifestation of the discharging ground water, which can take the form of a spring, seep, lake, or stream.

In addition to physiographic setting the groundwater recharge and discharge zone can identified from the groundwater contour orientation. The flow direction lines tend to diverge from recharge areas and converge toward discharge areas. Convergence of groundwater flow direction lines are clearly seen around sentera and yewla plain, and neat to Dembecha town. Divergence flow direction lines are also observed in the choke mountainous area.

Generally, as the groundwater contour orientation and physiographic feature shows, the discharge area of the catchment starts from the foot of mountain.

3.2.4. Wetlands

Wetlands are water saturated environments and are commonly characterized as swamps, bogs, marshes, mires and lagoons. In many cases groundwater and wetland interaction is driven by the dynamics of a large groundwater flow system, in which the position of wetlands is closely related to surface topography and the spatial pattern of groundwater discharge.

According to (Seifu Kebede, 2013) there are four types of major wetlands: flood plains wetland, groundwater fed wetlands, wetlands associated with lake water and wetlands associated with headwater of river valley.

Wetlands associated with headwaters of Rivers are generally smaller in size and form at the foothills of higher elevation areas where surface and groundwater emerging from the higher ground is unable to be removed rapidly from the lowland terrain. Origins of these wetlands are riverine and form in local depressions or small flat plains. Accordingly, wetlands are common in the flat plain of sentera, yewla and Amanueal, which is discharge zone of the study areas.

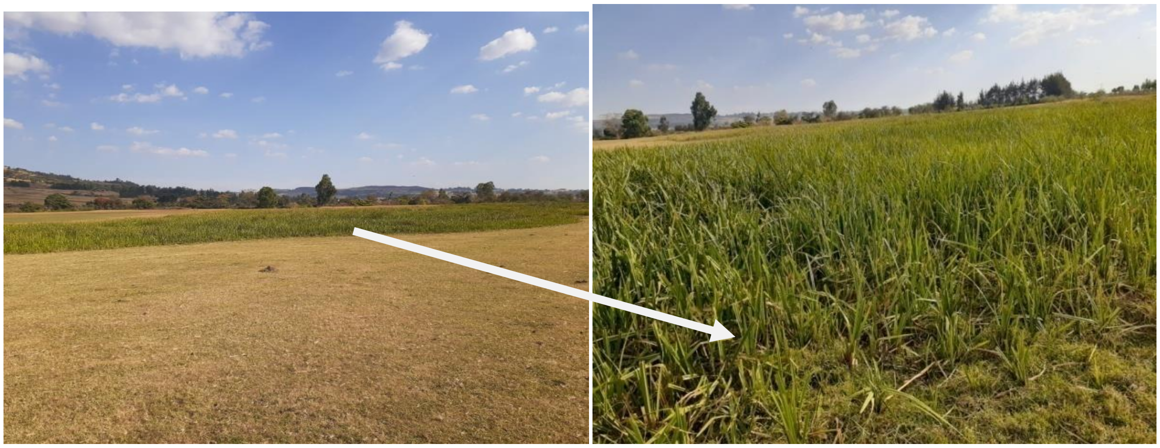


Figure3. 7. Wetland at yewla plain near to Jedub River

3.3. Hydrochemistry

3.3.1. General

Understanding and identifies the hydrochemical evolution of water types and water quality using dominant ions in groundwater system is one part of the study. The result of hydrochemical study helps to understand ground water circulation within aquifers in addition to comparing the water quality with various standards. Before using the water points, it is crucial to evaluate the reliability of the water chemistry.

Study of water quality is an essential component of groundwater resources investigations. A total of 19 samples from boreholes, springs and hand dug wells were collected from field investigation and 7 representative samples were delivered to Saba engineering company for hydrochemical analysis of major cation and anion (Ca+2, Mg+2, Na+, K+ HCO3-, SO4-2, Cl-) and minor ions with Electrical Conductivity (EC) and PH. Besides, 38 additional samples with complete hydrochemical data have been used from secondary sources. Generally a total of 45 samples were used for analysis. Among these 32samples from borehole, 2 from dug well and the remaining 11 samples were from spring.

All laboratory results and field measurements were checked and analyzed. According to reliability check for ionic balance of the laboratory results, all laboratory results with ionic balance error ranging between -10 % to 10 % are taken for the analysis. AquaChem 4.0 and Microsoft Excel are the main tools for the analysis. Out of 45 sample 37 samples has the ionic balance error less than five, which is reliable and 8 samples has ionic balance error greater than ten that are rejected. One sample that has ionic balance error above ten is including for analysis.

$$Balance = \frac{\sum cation - \sum anion}{\sum cation + \sum anion} x100$$

Table.3. 5.Ionic balance error

Error %	Number of Sample	Simple in %	Remark
<5	37	82	Excellent
5-10	--	--	Good
>10	8	18	Not reliable

3.3.2. Spatial Variation of physicochemical Parameters and Ions

3.3.2.1. Physicochemical Parameters

Total dissolved solid (TDS)

The total dissolved solids vary from 67 to 637 mg/L in the catchment. Since the area is mountainous and found in the basalt pleatu, recharge is rapid, groundwater circulation is shallow and the waters are characterized by low total dissolved solid. Deep ground water in discharge area of sentera plain has relatively higher TDS value.

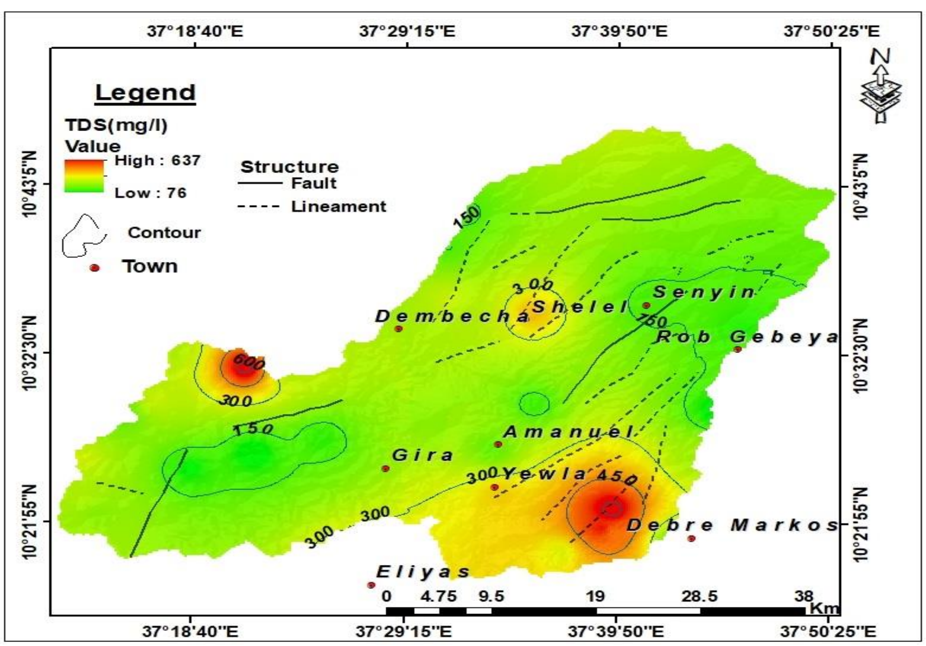


Figure3. 8TDS Map of the catchment

Electric conductivity (EC)

Electric Conductivity is the measure of the capacity of water to conduct the electric current. A high EC value is an indication of the presence of abundant dissolved ionic species. It is measured using a 1 cm cell and expressed in unit of micro Siemens (μs/cm). The electrical conductivity of water sample that are measured from the field and secondary data has a mean a value 252.6 μs/cm with the minimum 55 and maximum 873 μs/cm values.

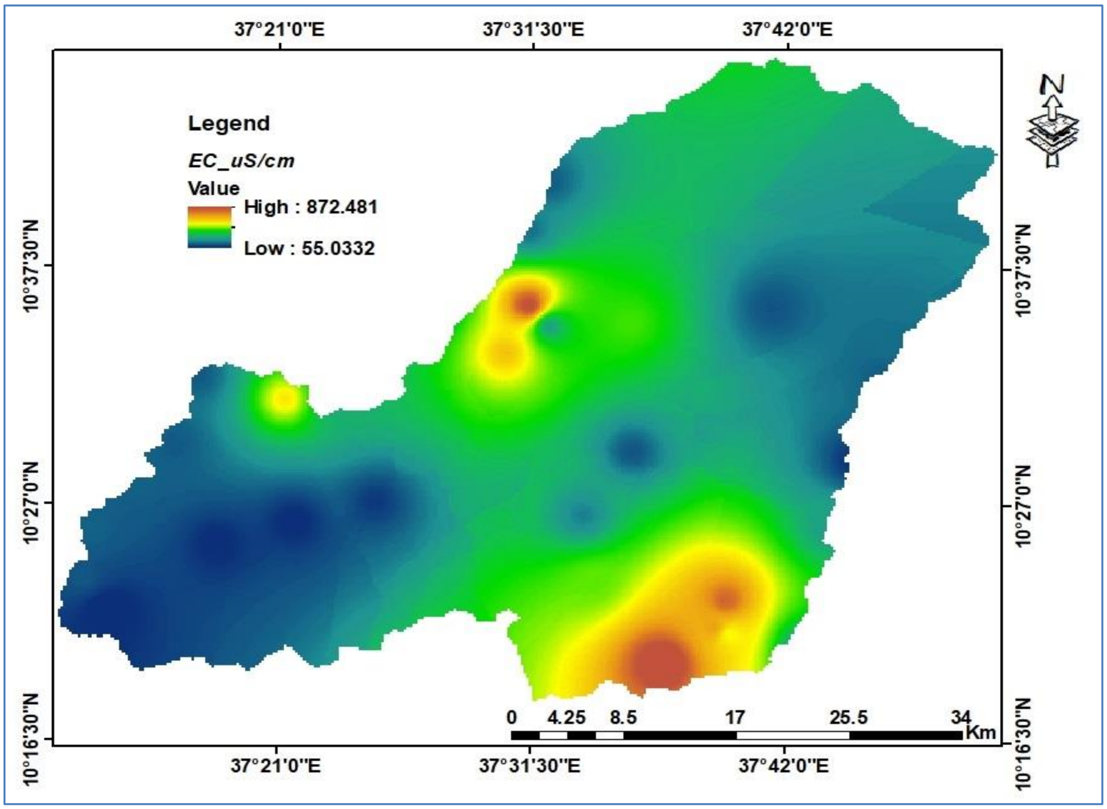


Figure3. 9Electric Conductivity Map

Total Hardness

The hardness represents the equivalent concentration of dissolved $CaCO_3$ an effect similar to the actual calcium and magnesium concentrations. It is a measure of the relative abundance of bivalent cations that will react with soaps to form a soft precipitate or react in boilers to form a solid scale precipitate. Hardness of the water sample ranges from 20 to 300 mg/l in the catchment (see figure3.10).

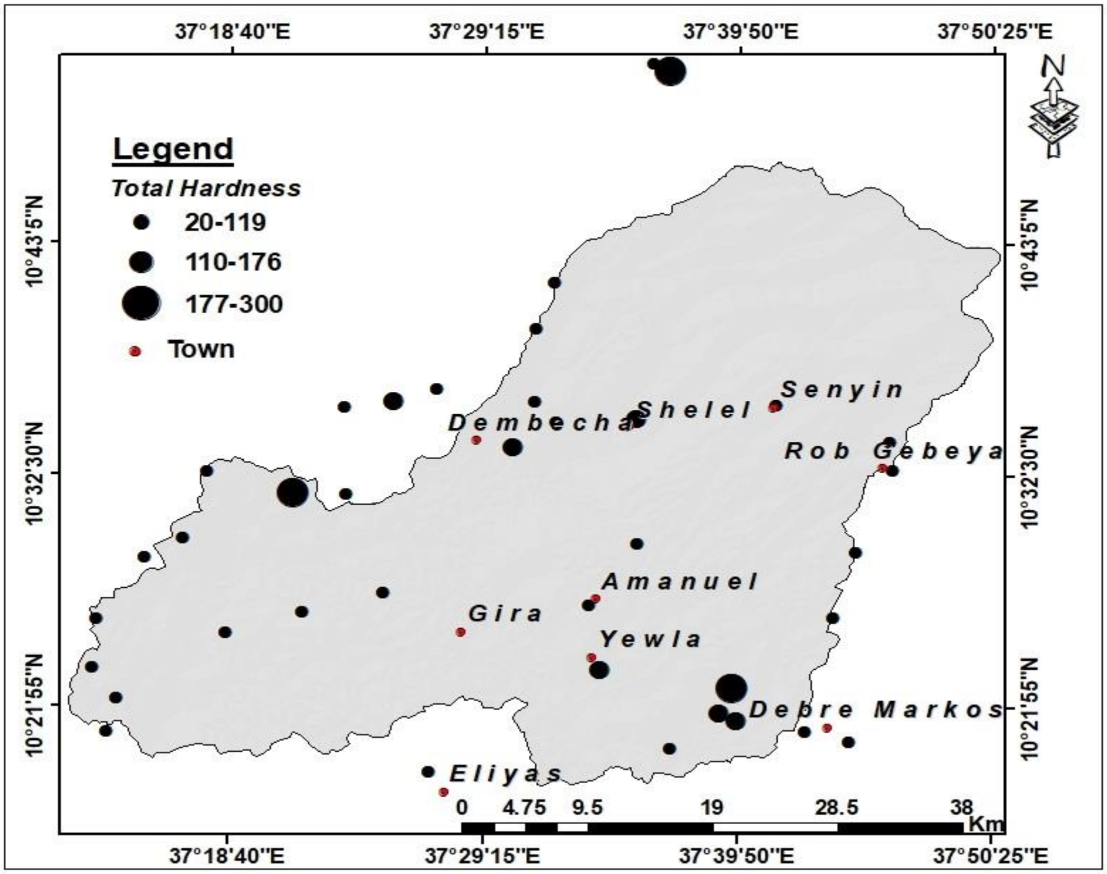


Figure3. 10. Total Hardness map

PH

PH measures the concentration of hydrogen ions. It is controlled by the dissolved chemical compounds and biochemical processes in the water. PH of laboratory analysis of water samples range from 6.04 to 8.25.

The contribution of carbon dioxide in the atmosphere is important. It readily dissolves in water to form carbonic acid which in turn dissociates to form free hydrogen and bicarbonate ions.

The pH of natural water is largely controlled by chemical reactions and equilibrium among the ions in solution (Hem, J.D, 1959).

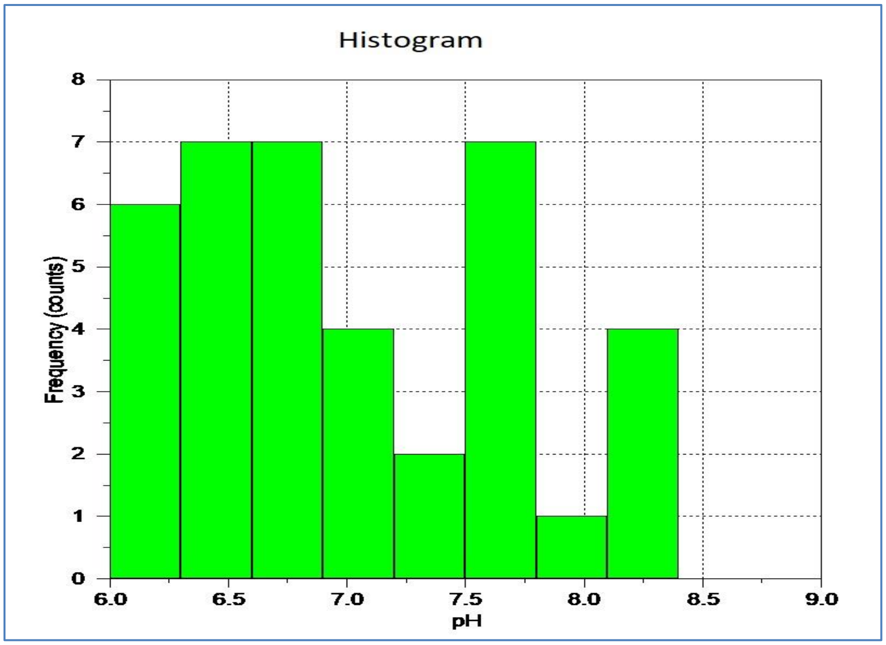


Figure3. 11. PH Frequency diagram

3.3.2.2. Major Ion constituent

Ca is the dominant cation available in the water samples with the range of 5.15 to 69 mg/l and mean concentration of 20.68 mg/l out of 38 samples. Sodium, magnesium and potassium also have 14.12, 7.83 and 3.15 mg/l respectively. From major anion, bicarbonate is the dominant concentration of anion occurred in the solution with the range of 30 to 450 mg/l and average of 132.85 mg/l. Sulfate and chloride also found in the solution with the mean values of 6.89 and 4.79mg/l respectively. The variability of cation is more pronounced than anions. Beyond to this; bicarbonate is exclusively the dominant water type in the catchment. Sulfate and chloride also followed with the mean concentration values of 6.89and 4.79mg/l respectively.

3.3.3. Sources of dissolved ions

3.3.3.1. Ionic Ratio

The relationships between the measured hydrochemical parameters may help to identify the main processes contributing to groundwater salinization. Groundwater residence time along flow path, length of water-rock interaction, Lithology and ionic exchange may have a great role in the increment of groundwater composition.

Ca^{2+}/Mg^{2+}

According to Maya and loucks (1995, as mentioned by Srinivasamoorthy, K., 2013) the sources of calcium and magnesium ions can determine by the ratio of Ca^{2+} /Mg^{2+}. If the Ca^{2+}/Mg2+ ratio <1, indicates dissolution of Dolomite, and >1 reflects an effect of silicate minerals that contributes calcium and magnesium to the groundwater (Katz et al., 1998).all water samples are above 1 and the Ca and Mg concentration in the water originate from silicate minerals.

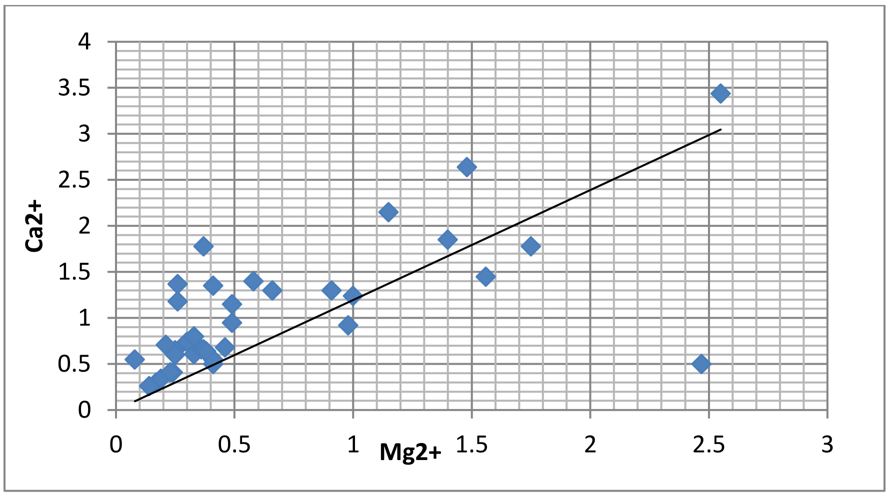


Figure3. 12. Ca^{2+} and Mg^{2+} ratio

$HCO^{-}3$ / (HCO3 + $SO^{2-}4$)

The $HCO^{-}3$ / (HCO3 + $SO^{2-}4$) ratio can identify carbonic acid mediated reactions. The ratio is more than 0.5 if the carbonic acid mediated reaction is more important than evaporate dissolution (anhydrite/gypsum, sodium sulfate) or sulfide oxidation (Fuqiang Wang et.al, 2019). Accordingly, all samples fall in 1 and above except one sample, hence the area water type is formed by carbonic acid mediated reactions.

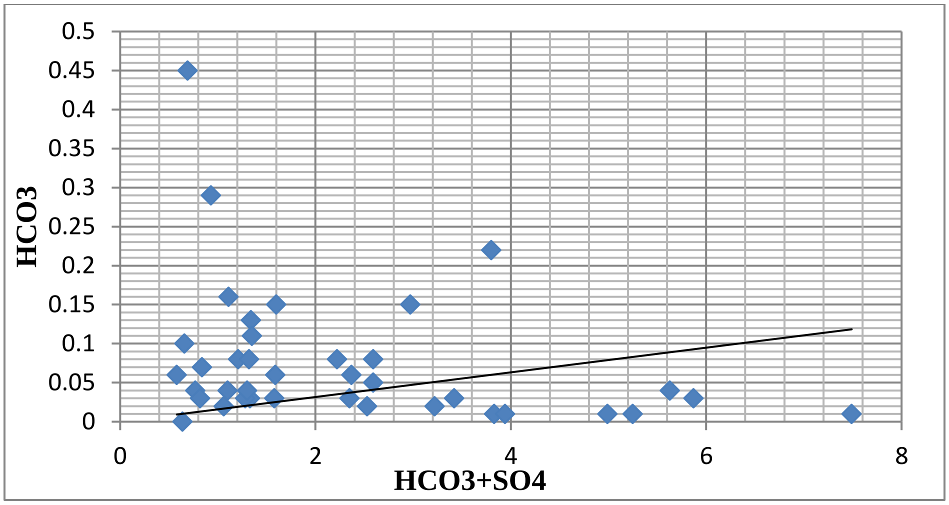


Figure3. 13. HCO3 and (HCO3+SO4) ratio

Na/Cl

The increasing Na concentrations, relative to the Cl concentrations, may be due to dissolution of aluminosilicate (i.e. albite) weathering and cation exchange processes. If Na/Cl ratio is greater than 1 Na^+ released from silicate weathering. Based on this, all water samples are originated from silicate weathering. The Na and Cl Scatter diagram (figure 3.14) shows that the water point below and above the 1:1 equiline. This also indicates the source silicate weathering.

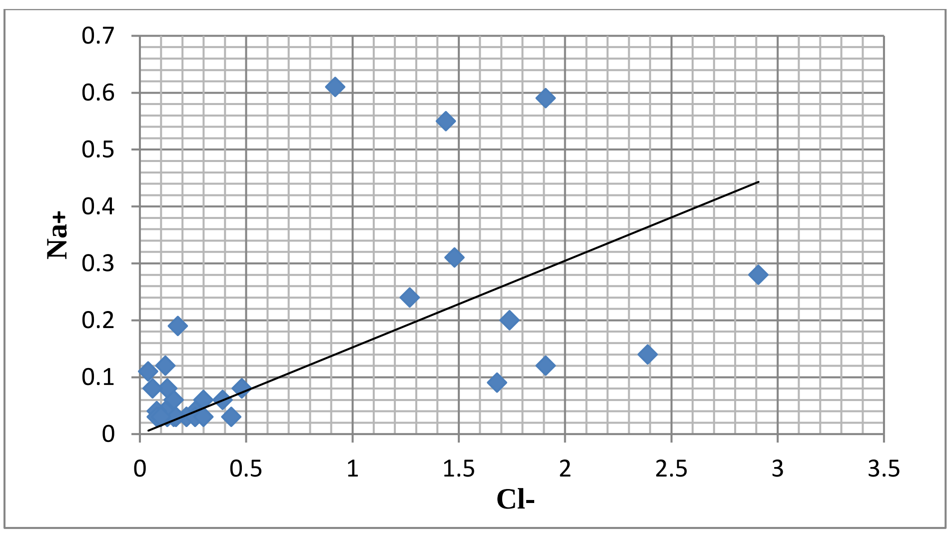


Figure3. 14. Na^+ and Cl^- ratio

The concentration ofNO3 in spring and dug wells has been identified. This is due to anthropogenic activity (agricultural or domestic waste). Agricultural activities including fertilizers and manure application in farmland are probably the most significant anthropogenic sources.

The fluoride concentration in Borehole 18 is relatively high. The source is probably from acid volcanic rocks and tuff layer, which is found in the study area.

Table.3. 6.Statistical summaries of geochemical parameters

Parameter	*Unit*	*Min*	*Max*	*Average*	*Standard Deviation*
Ca	mg/l	5.15	69	20.68	13.65
Mg	mg/l	1	31	7.83	7.51
Na	mg/l	1	67	14.12	17.46
Cl	mg/l	1	21.5	4.79	5.77
HCO3	mg/l	30	456	132.85	100.68
SO4	mg/l	1	35	6.89	7.73
Si	mg/l	16.7	175	66.11	51.60
NO3	mg/l	0	35.4	5.92	6.97
K	mg/l	0.15	17.1	3.15	4.63
F	mg/l	0.08	2.4	0.34	0.46
pH		6.04	8.25	6.64	6.59
EC	uS/cm	55	873	272.53	217.13
TDS	mg/l	62	625	250.44	157.00

3.3.4. Classification of Natural Waters

The classification scheme of each water sample is evaluated by the hydrochemical type and Meq% of cations and anions. The hydrochemical type indicates the dominating cations and anions in the solution, whereas the Meq% classification categorize the sample into basic transition and mixed based on the criteria mentioned bellow.

- Basic Hydrochemical type, the content of main cation and anion is greater than 50 Meq %.
- Transitional hydrochemical type, the content of main cation and anion ranges between 35 and 50 Meq% or exceed 50 % for one ion only.
- Mixed hydrochemical type, the content of cation and anion are not over 50 Meq % and only one ion has concentration over 35 Meq%.

The hydrochemical water type classification made by the dominant cations and anions, as well as based on the concentration number of transitional ions. Piper and schoeller diagram has been used to classify (see figure 3.15 and 3.16). In this case, AquaChem 0.4 software was used to prepare the diagram. Different water types are identified and given under the following table. The concentration of Cations and anions arranged decreasing and increasing order respectively. Based on this, the groundwater is classified into 12 water type.

The levels of six ion groups, i.e. calcium, magnesium and sodium plus potassium cations, and sulfate, chloride and hydrogen carbonate anions were considered in the plot.

Ca and Mg cations concentration is high in the area. The dominance of this calcium and magnesium is mainly associated with basaltic rock.

Table.3. 7 hydrochemical water type

Water type	***Classification in Meq%***	***Number of sample***
Ca-HCO3	Basic	2
Ca-Mg-HCO3	Basic	19
Mg-HCO3	Basic	1
Ca-Mg-Na-HCO3	Transitional	2
Ca-Na-Mg-HCO3	Transitional	2
Ca-SO4-HCO3	Basic	2
Ca-K-Mg-HCO3	Mixed	1
Ca-Na-HCO3	Transitional	2
Na-Mg-Ca-HCO3	Transitional	2
Na-Ca-HCO3	Transitional	3
Na-Ca-Mg-HCO3	Transitional	1
Na-Ca-Cl-HCO3	Transitional	1

Calcium and Magnesium cations as well as bicarbonate anion are the major hydrochemical water type with transitional and basic nature in the catchment. Sodium calcium bicarbonate and sodium magnesium bicarbonate is dominate in south east part of the catchment, which is the discharge attributed by choke shield volcano.

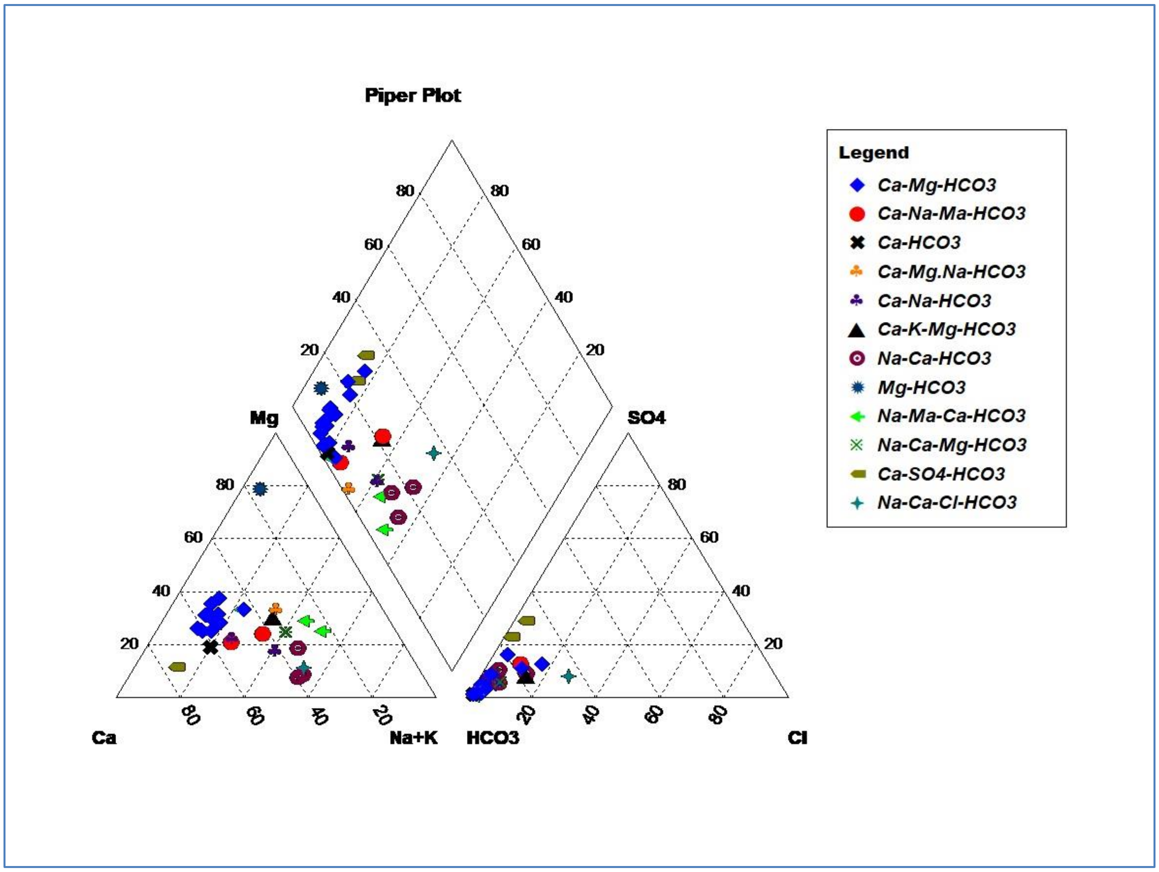


Figure3. 15. Piper Diagram

The piper diagram (Figure 3.15) indicate that the dominant hydrochemical water type is Ca–Mg-HCO3 (19 samples, 50 %), Na-Ca-HCO3 (three samples, 7 %), Ca-HCO3 (two samples, 5 %) and other water type (14 samples).

The origin and geochemical composition of water sample can be represented by piper diagram. This diagram is used as an effective graphical representation of chemistry of water samples in hydrogeochemical studies. Combination with TDS concentrations, analyzing the levels of cations and anions tells the origin and geochemical composition of the water sample.

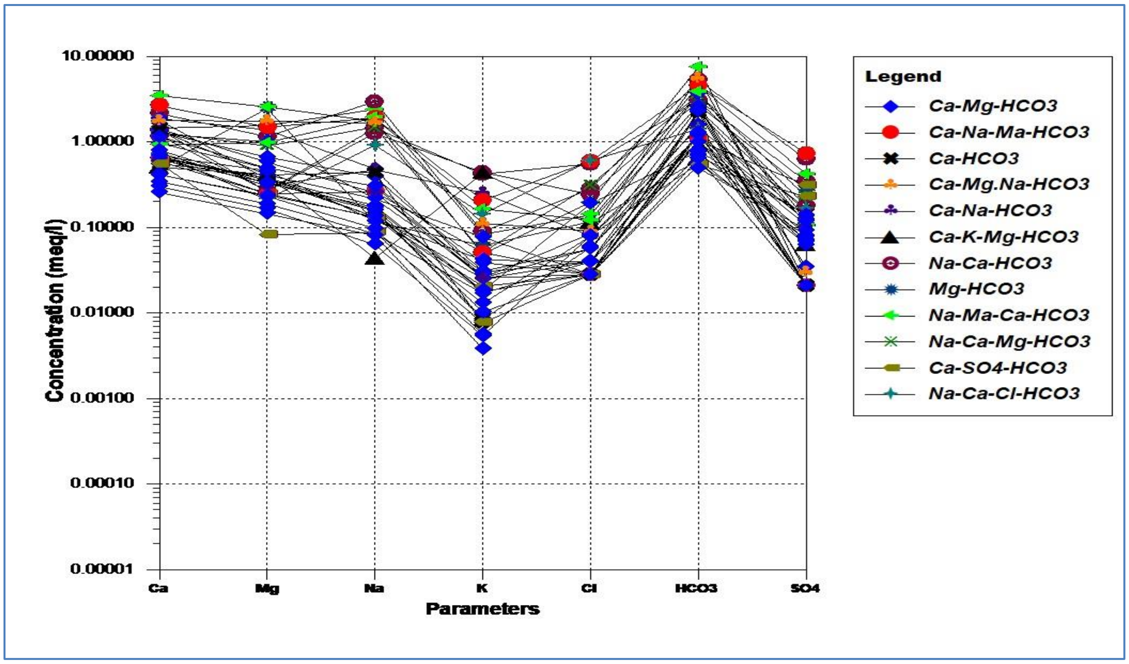


Figure3. 16. Schoeller diagram

3.3.5. Geochemical Evolution of Groundwater

Knowing hydrogeological and geological sitting of the area is an essential part in order to understand hydrochemical evolution of the groundwater. The geological stratification and variation in degree of weathering and leaching have their own role on slight local quality variation of water.

Choke shield volcano which is the northern part of the catchment is represented by the dominant calcium and magnesium cations, and bicarbonate anion, hence it is characterized by Ca-HCO3 and Ca–Mg-HCO3 water type with the TDS values of less than 500 mg/l. These indicate the recharge area is at the early stage of geochemical evolution and rapid groundwater circulation is takes place without water-rock interaction. Shallow wells and springs are distributed with these types of water in all the upper and lower part of the catchment.

Topographically high to low land area the groundwater changes from Ca-Mg-HCO3 to Na-Mg-Ca-HCO3. Hydrochemistry of Water samples from deep wells at the foot of Choke Mountain also varies from west to east. Groundwater around Dembecha area, which is the western part of the catchment, shows Ca-Mg-Na-CHO3 water type.

Around sentera plain the geochemistry of water is characterized by Na-Mg-Ca –HCO3 type (see figure 3.17). These are indications of a considerable geochemical evolution with a considerable residence time at the deeper aquifer from the recharge area. This is because of further hydrolysis of silicate minerals by the Ca-Mg-HCO3 water type, the concentration of sodium, potassium, magnesium and bicarbonate increase while Calcium enrichment is limited by an earlier saturation and precipitation of carbonates (Seifu, 2013). Therefore, water type is evolved. Around sentera well filed the groundwater TDS value varies from 300 to 637mg/l.

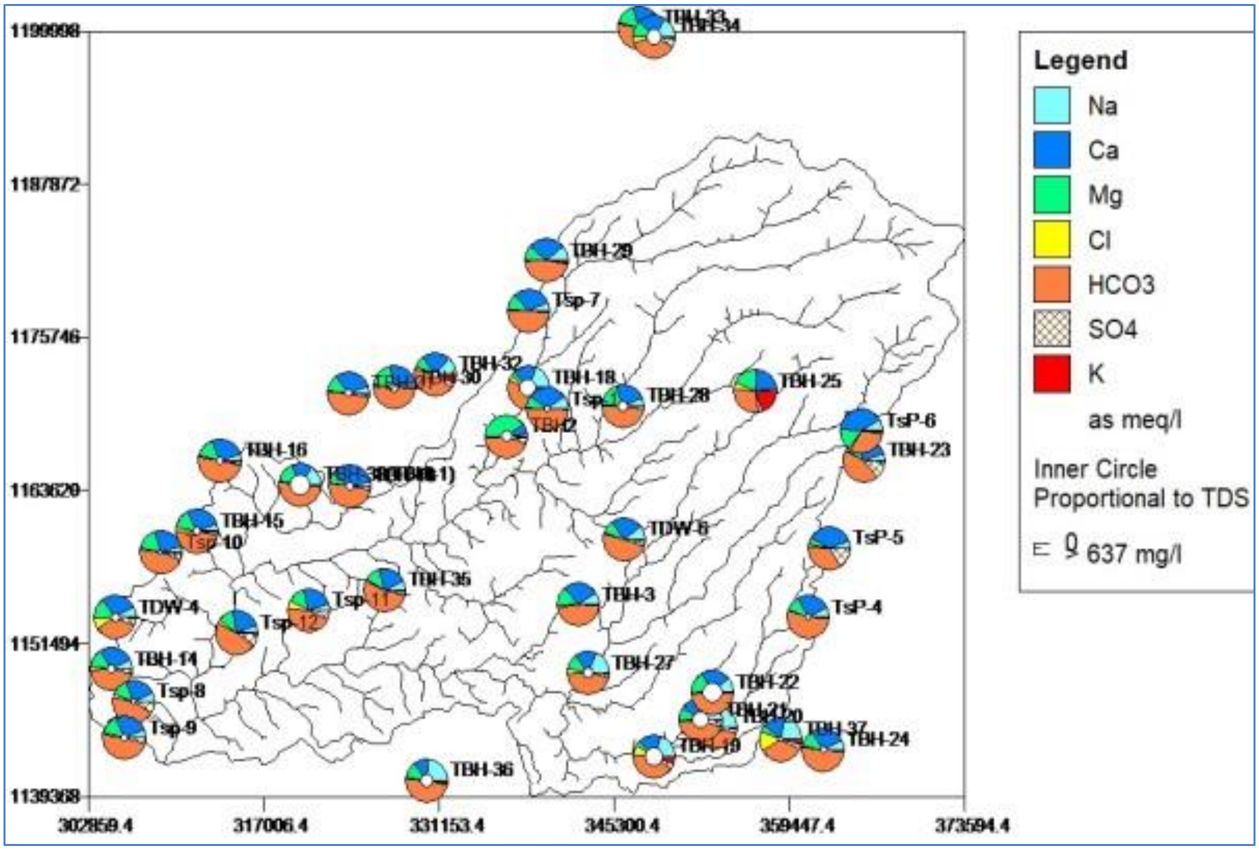


Figure3. 17 Representation of groundwater with different dissolved ion constituent.

3.3.6. Water Quality

Water quality is determined by the solutes and gases dissolved in the water, as well as the matter suspended in and floating on the water. It is a consequence of the natural physical and chemical state of the water as well as any alterations that may have occurred as a consequence of human activity. The usefulness of water for a particular purpose is determined by the water quality (Fetter, 2011).

Groundwater is mainly used for drinking, irrigation and industrial purposes. Therefore, quality criteria depend on the use of water for a particular purpose, and quality standards have to be maintained in water supply for different uses to avoid the risk.

Different water quality guidelines have been established by different organization and countries to eliminate the adverse impacts of water to the wellbeing of users. Guidelines provide the recommendations of the world health organization (WHO) for managing the risk from hazards that may compromise the safety.

3.3.6.1. Domestic use

In order to assess the suitability of groundwater for drinking purpose, the samples were evaluated based on World Health Organization (WHO, 2006) and Ethiopian standard guidelines for drinking water (ES261, 2001) (table 3.18).

The physicochemical parameters such as total hardness, electric conductivity total hardness and major ions were used to assess the suitability of groundwater for domestic purpose. The groundwater quality for drinking is above the permissible limits of Ethiopian standard by F^- in 2.6%, K^+ in 42.1% and PH in 2.6% of analyzed water samples.

Table3. 18.Water quality guide line for domestic use

Parameters	***Maximum-Permissible level(ES261,2001***	***Maximum Permissible level(WHO,2006)***	***Range of concentration***	***Number of Sample In permissible level (ES261,2001)***	***Number of Sample In permissible level (WHO,2006)***
Na^+(mg/l)	200	200	1-67	38	38
Ca^{2+}(mg/l)	75	75	5-69	38	38
Mg^{2+}(mg/l)	50	30	1-31	38	38
K^+(mg/l)	1.5	--	0.15-17.1	16	--
Cl^-(mg/l)	250	250	1-21.5	38	38
$SO4^{2-}$(mg/l)	250	200	1-35	38	38
NO3(mg/l)	50	50	0.00-35.40	38	38
F^-(mg/l)	1.5		0.08-2.48	37	
PH	6.5-8.5	7.0-8.5	6.04-8.25	29	16
EC(uS/cm)	1000	750	55-873	38	16
TDS(mg)	1000	500	75.6-637.4	38	34
TH,as CaCO3(mg/l)	300	500	20.11-299.98	38	38

The parameters Total Hardness (TH), total dissolved solid (TDS) and Electric Conductivity (EC) fits the permissible limit of Ethiopian standard. Based on the guide line, most of the water sample in the study area found to be permissible for domestic purpose.

Table3. 19. Groundwater classification based on CaCO3

Hardness as CaCO3	*Water class*	*No. of sample in cases*
<75	Soft	22
75-150	Moderate	10
150-300	Hard	6
>300	Very hard	None

3.3.6.2. Irrigation purpose

Agricultural standards of ground water quality used in irrigation are mostly determined based on Sodium Adsorption Ratio (SAR), total dissolved solids and American Salinity criteria (USSC).

3.3.6.2.1. Salinity Hazard

High salt concentration increases the osmotic pressure of the soil water and affects the plant roots from absorbing water, even if the field appears to have sufficient moisture (Hiscock, 2005).

Table.3. 8.US Salinity classification

EC (μS/cm)	*Class*	*Number of sample in range*	*Remarks*
< 250	Low salinity	24	Good
250-750	Moderate	11	Good for soils of medium permeability for most plants
750-2250	Medium high	2	Satisfactory for plants having moderate salt tolerance, on soils of moderate permeability with leaching

2250-4000	High	None	Satisfactory for salt tolerant crops on soils of good permeability with special leaching
>4000	Excessive	None	Not fit for irrigation

The total soluble salt content of irrigation water generally is measured either by determining its electrical conductivity (EC), reported as micro Siemens per centimeter, or by determining the actual salt content in parts per million (ppm). The large variation in EC is mainly attributed to lithologic composition and anthropogenic activities prevailing in this region.

3.3.6.2.2. Sodium Hazard

It relates to the accumulation of excessive sodium which causes the physical structure of soil to breakdown. Sodium adsorption ration and sodium percentage has been used to evaluate the sodium hazard of irrigation water.

- **Sodium absorption ratio (SAR)**

The United State Salinity Laboratory (US, 1954) proposed that the sodium effect calculated by the sodium adsorption ratio (SAR method).

Water used for irrigation with high sodium and low calcium concentration can destroy the soil structure owing to dispersion of the clay particles.

SAR = $\frac{(Na+)}{\left(\frac{Ca+\quad(Mg+)}{2}\right)0.5}$, Where all concentrations are expressed in Meq/l. Based on the

Suitability SAR value can classify as Excellent, Good, fair and poor based on their SAR value. A low SAR (2 to10) considered as Excellent; medium or 10 to 18 meq/l is good, high hazards between 18 and 26 meq/l indicate fair, and above 2. Therefore, the calculated SAR value of all water samples of the area is tabulated on table 3.11 and found to be Excellent for irrigation.

Table3.9. Classification based on SAR value

SAR Value	***Water Class***	***Number of Samples in range***
SAR< 10	Excellent	38
10-18	Good	None
18-26	Fair	None
>26	Poor	None

- **Sodium Percentage**

By using Wilcox formula, the sodium percentage is calculated based on the relative ratio of cations existing in water.

$$Na\% = (Na + K)/(Ca + Mg + Na + K)$$

Using the above equation sodium percentage values are calculated and illustrated in the table below (table8.9).water samples of the study area fall under the range of 5.67 to 54.17%.

Table.3. 10.Sodium percentages

Na%	***Class***	***Number of Samples in range***
<20	Excellent	22
20-40	Good	10
40-60	Permissible	8
60-80	doubtful	None
>80	unsuitable	None

3.3.6.2.3. Sodium and Salinity hazard analysis using Wilcox diagram

Based on the salinity classification standard of the US Department of Agriculture diagram or Wilcox plots the hydrochemical samples ranged from low to very high salinity hazard (Wilcox, 1955).36 water samples are falls in medium and low salinity hazard class and 2 water are samples falls in high salinity hazard class. Groundwater that falls in the medium salinity hazard class (C2) can be used in most cases without any special practices for salinity control. Concerning on sodium hazard, all water samples are falls in low sodium hazard class.

Generally all water samples collected from the study area is used for irrigation practice without any sodium and salinity hazard problems.

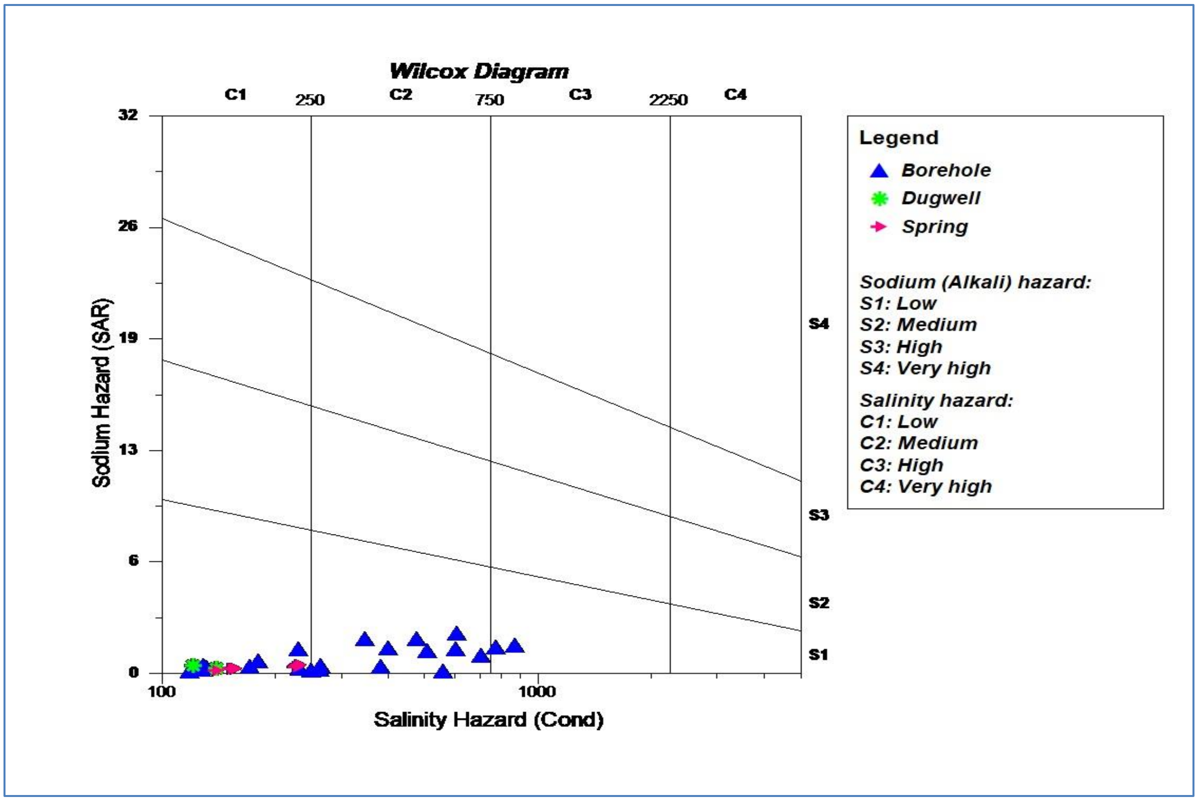


Figure3. 18. Wilcox Diagram

In general, hydrogeochemical analysis is very crucial for a sustainable development of groundwater resources. i.e., the origin, and hydrochemical and geochemical compositions of groundwater resources should be known for a healthy and sustainable use of groundwater resources.

The natural geochemical composition of groundwater is one of the factors that affect the potential of aquifers for water resources development (Seifu, 2013). The groundwater of the vast volcanic plateau is geochemically the most suitable for domestic water supply, irrigated agriculture and industrial uses.

3.4. Groundwater Resource

The spatial and temporal variability of climate, soil, topography and geology of the country hosted high variability in the amount and distribution of water resources in Ethiopia. It hinders the water sector development (Belete Berhanu et.al, 2014). According to MoWR and GM-MATE (2011, as sited in Belete Berhanu et al., 2014) Groundwater resources are estimated to be 30 BCM.

The groundwater potential of Temcha river catchment is controlled by different lithological and structural conditions as well as rainfall distribution. The ultimate source of natural potable water in the area is precipitation. The highland area is characterized by high rainfall and rugged topography. Due to this rugged topography the groundwater moves into the alluvial and fractured aquifers of discharge areas.

The presence of high rainfall on the shield volcano and the large lateral extent of the aquifers on the pleatu the groundwater storage potential are high.

Yewla and sentera plains are High groundwater potential zones in the catchment. Water availability of the plain is controlled by the presence of reworked alluvial deposit along the river side, thick eluvial deposit and high fractured tertiary basalt. According to Water well drilling enterprise (WWDE, 2011), the well completion report show that aquifer in sentera has the transmissivity of 5750m^2/day and 30 l/s discharge.

The natural water quality for drinking and irrigation purposes in the catchment is assessed based on the recommended standard of the national and international health organization (WHO).based on the assessment the water quality of the area is suitable and can be used for drinking and irrigation by diversion the river and developing the spring and wells.

Although the livelihood of the local people depends on groundwater, the available groundwater is not efficiently used so far in the catchment. The widespread groundwater use in the area is through springs and shallow wells. The presence of paleosols between basaltic lava flows produces perched water systems, which are frequently represented by mountain slope springs and wetlands (Tamiru Alemayehu and Seifu Kebede, 2011).

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Shallow wells and dug wells are developed in all places of low land and high lands. In the low land around wadi, shallow wells and dug wells are developed with the depth 20 to 25m.

The long term mean annual rainfall of the Catchment is 1606.6mm/year. Among this, 8% of the precipitation is available for groundwater recharge. The total estimated recharge for the Catchment is 250MCM.

CHAPTER FOUR

4. Conclusion and Recommendation

4.1. Conclusion

The Groundwater resource potential assessment of Temcha River Catchment has been accompanied based on aquifer characterization, groundwater recharge estimation and evaluation of hydrochemistry.

The rainfall distribution of the area is characterized by monomodal pattern, and the rainy season is May, June, July and August. The annual rainfall depth of the area is computed using arithmetic mean, Thiessen polygon and isohyets methods and the mean annual value is 1606.6 mm/year.

Quaternary alluvial and eluvial aquifer and tertiary fractured and weathered volcanics interbedded with paleosoils aquifers are the most productive aquifer in the catchment.

Groundwater in the study area generally flows from north to south direction. A minor local irregularity of flow pattern is attributed to existence of geologic structures

Groundwater recharge of the catchment has been estimated using soil water balance and base flow separation methods. The recharge obtained from soil water balance method 126.4mm/year, which means 8% of the precipitation is available for groundwater recharge,

The dominant water type of the area is Ca-Mg-HCO3.The hydrochemistry of groundwater changes from recharge area with Ca-Mg-HCO3 type to discharge area with Na-Mg-Ca-HCO3 water type. There is a significant variation of water chemistry between shallow and deep wells. Around sentera well field Total dissolved solid ranges from 300 to 637mg/l.

Most of the sample fits the ES261, 2001 and WHO, 2006 drinking water quality guidelines. The groundwater quality for domestic use is above the permissible limits of Ethiopian standard guidelines by F^- in 2.6%, K^+ in 42.1% and PH in 2.6% of analyzed water samples.

Wilcox diagram classification, Sodium absorption ratio and sodium percentage were used to identify suitability of natural water for irrigation, and based on the classification all water samples have medium to low salinity and sodium hazards.

4.2. Recommendation

There are number of boreholes for groundwater abstraction from sentera well field for Debremarkose town water supply. Due to this, proper groundwater management should be implemented.

From chemical analysis result, nitrate concentration is identified form shallow and dug wells and their source is anthropogenic. Therefore, emphases should be given to achieve sustainable water conservation through the participation of local people and concerned stake holders should take action.

Reference

Belete Berhanu, Yilma Seleshi and AssefaMelesse (2014). Surfacewater and groundwater resources of Ethiopia, Springer International Publishing, Switzerland, 97–117 pp.

Conway. (1997).Water balance model of the upper Blue Nile in Ethiopia. Hydrological Sciences Journal, United Kingdom, 42:2,265-286.

Cook, P.G.,(2003).A Guide lineto Regional Groundwater Flow in Fractured Rock Aquifers, CSIRO Land and water, Glen Osmond, Australia, 115 pp.

Daniel Gemechu (1977).Aspect of climate and water budget in Ethiopia. Addis Ababa University,Ethiopia, 71 pp.

Didier, G., Ian, H., Amauri, A.M. and Hung, K.C. (2016). Geochemical evolution of groundwater in a basaltic aquifer based on chemical and stable isotopic data.Journal of Hydrology, 535: 598–611.

Ethiopian Geospatial information institute (EGII) (2013).The spatial Land use/Land cover map of Ethiopia (EGII), Addis Ababa, Ethiopia.

Ethiopian Standard (ES 261) (2001). Ethiopian Drinking Water Quality Standard, 2nd edition, Addis Ababa, Ethiopia.

Fetter, C.W. (2001).Applied Hydrogeology, 4th Edition, Prentice Hall, Upper Saddle River, New Jersey,567pp.

Food and Agriculture Organization (FAO) (1997). The Digital Soil and Terrain Database of East Africa (SEA),via delle Terme di Caracalla, Rome, Italy.

Freeze, R.A. and Cherry, J.A. (1979). Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersy,604pp.

Geological Survey of Ethiopia (GSE) (2012). Hydrogeological and hydrochemistry map of Debre Markos map sheet,Unpublished technical report, GSE, Addis- Ababa, Ethiopia.

Geological Survey of Ethiopia (GSE) (2015). Geological map of Debre markos Map sheet, unpublished technical report, GSE, Addis- Ababa, Ethiopia.

Hem, J.D. (1959). Study and Interpretation of the Chemical Characteristics of Natural Water, Washington, US.

Hiscock, K.M. (2005). Hydrogeology: principles and practice, Blackwell Science Ltd, School of Environmental Sciences, University of East Angelica, United Kingdom,403pp.

Jung, H. C., Getirana, A., Policelli, F., McNally, A., Arsenault, K. R., Kumar, S., Tsegaye Tadesse & Peters-Lidard, C. D. (2017). Upper Blue Nile basin water budget from a multi-model perspective. Journal of Hydrology, 555: 535–546.

Kazmin, V. (1972). The Geology of Ethiopia. Unpublished report, Ethiopian Institute of Geological Survey, Addis Ababa, Ethiopia.

Marsh, N. A. Stewardson M. J. Kennard, M. J. (2003) River Analysis Package, Cooperative Research Centre for Catchment Hydrology, Monash University Melbourne.

Fazzini, M., Bisci, C. and Billi, P.(2015). The Climate of Ethiopia, Springer Science + Business Media Dordrecht, Camerino, Italy, 65–87 pp.

Menagesha Teferra, Tadiwos Chernet and Workineh Haro (1996). Geology of Ethiopia, 2nd ed., Institute of Ethiopian Geological Survey, Addis Ababa, Ethiopia,85 pp.

Neven Kersic (2009).Groundwater resource, Sustainability, Management and restoration. McGraw-Hill.

Seifu Kebede (2004). Environmental isotopes and geochemistry in investigating groundwater and lake hydrology: case from the Blue Nile Basin and the Ethiopian Rift (Ethiopia).Unpublished PhD Thesis, University of Avignon, France, 162 pp.

Seifu Kebede, Travi, Y., Tamiru Alemayehu & Tenalem Ayenew (2005). Groundwater recharge, circulation and geochemical evolution in the source region of the Blue Nile River, Ethiopia. Applied Geochemistry, 20(9):1658–1676.

Seifu Kebede (2013). Groundwater in Ethiopia, Springer Verlag, New York, 294 pp.

Seleshi Mamo(2015).Integrated Hydrological and Hydrogeological System Analysis of Lake Tana Basin, Northwester Ethiopia. Unpublished PhD Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 280 pp.

Shaw, E. (1994). Hydrology in Practice, 3rd edition, Chapman and Hall, London, UK,628 pp.

Srinivasamoorthy, K., Gopinath.M, Chidambaram, Vasanthavigar, M. Sarma, V.S. (2013). Hydrochemical characterization and quality appraisal of groundwater from Pungar sub basin, India. Journal of King Saud University Science.

Tamiru Alemayehu (2006). Groundwater occurrence in Ethiopia. Addis Ababa University, Addis Ababa, Ethiopia.

Tamiru Alemayehu Abiy & Seifu Kebede (2011). The role of geodiversity on the groundwater resource potential in the upper Blue Nile River Basin, Ethiopia. Environmental Earth Sciences, 64(5):1283–1291.

Tenalem Ayenew, Molla Demlie & Wohnlich, S. (2008). Hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers. Journal of African Earth Sciences, 52(3): 97–113.

Tenalem Ayenew and Tamiru Alemayehu (2001). Principles of hydrogeology. Department of Geology and Geophysics, Addis Ababa University, Ethiopia.

Tesfaye Chernet (1993). Hydrogeology of Ethiopia and water resources development, Ethiopian Institute of Geological Surveys, Unpublished report, Addis Ababa,Ethiopia,222 pp.

Thornthwaite, C.W. and Mather, J.R. (1957). Instructions and tables for computing potential evapotranspiration and the water balance, Laboratory of Climatology, Drexel Institute of Technology, New Jersey, and USA. Publication in Climatology,**10**(3):185-311.

Tilahun Azagegn, Assfawosen Asrat, Tenalem Ayenew andSeifu Kebede (2015).Litho-structural control on interbrain groundwater transfer in central Ethiopia.Journal of Africa Earth Sciences, 101:383-395.

Walelgn Cherie (2018). Assessing the Impacts of Land use/cover Change on the Hydrological Response of Temcha watershed, upper Blue Nile basin, Ethiopia.International Journal of Scientific Research in Civil Engineering, 2(5), ISSN: 2456–6667.

Wilcox, L. V. (1955). Classification and use of Irrigation Water, U.S Department of Agriculture, Circular, 969, Washington, D.C., 19 pp.

World Health Organization(WHO) (2006). Guidelines for drinking-water quality. World Health Organization.

APPENDICES:

Appendix1. 1.Soil water balance model for clay soil covered with moderate, deep root and forest vegetation with available water Capacity of 180mm

mm	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*
pp	10.5	13.4	44.4	55.5	135.6	224.4	366.0	351.5	252.3	97.9	40.0	15.1	1606.62
PET	63.1	73.2	78.2	82.2	77.6	65.7	57.1	56.0	57.0	58.9	58.0	58.8	785.74
P-PET	-52.7	-59.8	-33.7	-26.7	58.0	158.7	309.0	295.5	195.3	39.0	-18.0	-43.8	
ACPWL	-114.4	-174.2	-208.0	-234.6							-18.0	-61.8	
Sm	97.9	70.6	58.7	50.8	108.8	183.0	183.0	183.0	183.0	183.0	165.9	130.6	
ΔSm	-32.7	-27.3	-11.9	-8.0	58.0	74.2	0.0	0.0	0.0	0.0	-17.1	-35.3	
AET	43.1	40.7	56.3	63.5	77.6	65.7	57.1	56.0	57.0	58.9	57.1	50.3	683.3
SMD	20.0	32.5	21.8	18.7	0.0	0.0	0.0	0.0	0.0	0.0	0.9	8.5	
S	0.0	0.0	0.0	0.0	0.0	84.5	309.0	295.5	195.3	39.0	0.0	0.0	
TARO	31.8	15.9	8.0	4.0	2.0	84.5	351.2	471.1	430.8	254.4	127.2	63.6	
RO	15.9	8.0	4.0	2.0	1.0	42.3	175.6	235.6	215.4	127.2	63.6	31.8	796.02628
Detention	15.9	8.0	4.0	2.0	1.0	42.3	175.6	235.6	215.4	127.2	63.6	31.8	

Appendix1. 2.Soil water balance model for Sandy loam soil covered with moderate, deep root and forest Vegetation with available water Capacity of 200mm

Mm	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Pp	10.5	13.4	44.4	55.5	135.6	224.4	366.0	351.5	252.3	97.9	40.0	15.1	1606.62
PET	63.1	73.2	78.2	82.2	77.6	65.7	57.1	56.0	57.0	58.9	58.0	58.8	785.74
P-PET	-52.7	-59.8	-33.7	-26.7	58.0	158.7	309.0	295.5	195.3	39.0	-18.0	-43.8	
ACPWL	-114.4	-174.2	-208.0	-234.6							-18.0	-61.8	
Sm	112.9	83.7	70.7	61.9	119.9	200.0	200.0	200.0	200.0	200.0	182.8	146.9	
ΔSm	-34.0	-29.2	-13.0	-8.8	58.0	80.1	0.0	0.0	0.0	0.0	-17.2	-35.9	
AET	44.5	42.6	57.4	64.3	77.6	65.7	57.1	56.0	57.0	58.9	57.2	51.0	
SMD	18.7	30.6	20.7	17.8	0.0	0.0	0.0	0.0	0.0	0.0	0.8	7.8	
S	0.0	0.0	0.0	0.0	0.0	78.6	309.0	295.5	195.3	39.0	0.0	0.0	
TARO	31.8	15.9	7.9	4.0	2.0	78.6	348.3	469.6	430.1	254.1	127.0	63.5	
RO	15.9	7.9	4.0	2.0	1.0	39.3	174.1	234.8	215.0	127.0	63.5	31.8	790.4
Detention	15.9	7.9	4.0	2.0	1.0	39.3	174.1	234.8	215.0	127.0	63.5	31.8	

Appendix1. 3.Soil water balance model for clay loam soil covered with moderate, deep root vegetation and forest with available water Capacity of 260mm.

Mm	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*
Pp	10.5	13.4	44.4	55.5	135.6	224.4	366.0	351.5	252.3	97.9	40.0	15.1	1606.62
PET	63.1	73.2	78.2	82.2	77.6	65.7	57.1	56.0	57.0	58.9	58.0	58.8	785.74
P-PET	-52.7	-59.8	-33.7	-26.7	58.0	158.7	309.0	295.5	195.3	39.0	-18.0	-43.8	
ACPWL	-114.4	-174.2	-208.0	-234.6							-18.0	-61.8	
Sm	167.4	133.0	116.8	105.5	163.5	260.0	260.0	260.0	260.0	260.0	242.6	205.0	
∆Sm	-37.6	-34.4	-16.2	-11.4	58.0	96.5	0.0	0.0	0.0	0.0	-17.4	-37.6	
AET	48.0	47.8	60.6	66.9	77.6	65.7	57.1	56.0	57.0	58.9	57.3	52.6	705.7
SMD	15.1	25.4	17.5	15.3	0.0	0.0	0.0	0.0	0.0	0.0	0.6	6.2	
S	0.0	0.0	0.0	0.0	0.0	62.2	309.0	295.5	195.3	39.0	0.0	0.0	
TARO	31.6	15.8	7.9	4.0	2.0	62.2	340.1	465.5	428.0	253.0	126.5	63.3	
RO	15.8	7.9	4.0	2.0	1.0	31.1	170.0	232.8	214.0	126.5	63.3	31.6	774.4
Detention	15.8	7.9	4.0	2.0	1.0	31.1	170.0	232.8	214.0	126.5	63.3	31.6	
	260	260	260	260	260	260	260	260	260	260	260	260	

Appendix1. 4.Water points x y coordination

ID	**Location**	**X**	**Y**	**Z**	**Yield(l/s)**
Tsp-1	gten/seregla/Dembecha	339936	1170025	2223	0.25
TsP-2	Temcha bridge/Dembecha	336899	1165032	2011	0.2
TsP-3	Embule/Amanuel	339576	1160452	2243	3
TsP-4	Mehilit	360960	1153558	2528	0.4
TsP-5	Yeted	362727	1159004	2673	0.9
TsP-6	Robgebeya, Yesenan	365319	1168294	2959	6.5
Tsp-7	keri gidib, chereka tion,dembecha	338421	1177839	2451	0.045
Tsp-8	abelen, inwend Dembecha	306576	1146859	2015	0.6
Tsp-9	mekare legabedesa Dembecha	305801	1144010	1994	1.3
Tsp-10	asteboje,dembecha	308721	1158654	2010	1.75
Tsp-11	fetegem, amanuel	320687	1154066	2040	1.5
Tsp-12	gudam werkma, amanuel	314862	1152310	2015	0.38
Tsp-13	senane	367965	1172190	3157	0.05
Tsp-14	senane	355369	1159551	2534	0.069
Tsp-15	senane	355665	1159342	2575	0.038
Tsp-16	senane	362900	1180164	3239	0.033
Tsp-17	senane	360708	1157743	2565	0.05
Tsp-18	senane	368588	1179742	3452	0.5
Tsp-19	senane	367060	1175953	2868	0.1
Tsp-20	senane	366565	1172162	2924	0.0385
Tsp-21	senane	367237	1172488	3061	0.025

Tsp-22	senane	362708	1171820	3138	0.023
Tsp-23	senane	365916	1166399	2928	3.04
Tsp-24	senane	365745	1188056	3380	0.05
Tsp-25	senane	365251	1179478	2896	0.05
Tsp-26	senane	359027	1174410	3527	0.06
Tsp-27	senane	362329	1170709	2973	0.083
Tsp-28	senane	360669	1159282	2609	0.04
Tsp-29	senane	359419	1167155	2636	0.03
Tsp-30	senane	359580	1175309	2916	0.028
Tsp-31	d/elliase,guaye	311403	1137188	2208	0.5
Tsp-32	korache	354730	1147990	2316	0.19
Tsp-33	Janabete	316347	1152965	2016	0.08
Tsp-34	Ybuya, aroga, aneba	322644	1155935	2046	0.08
Tsp-35	Kerer	336712	1145575	2171	0.08
Tsp-36	Yewula	338958	1147617	2146	0.08
Tsp-37	Yewula	334446	1149038	2131	0.07
Tsp-38	G/akena	322873	1155853	2020	0.09
Tsp-39	Abebe	339236	1157550	2229	0.08

ID	Location	X	Y	Z	Depth(m)	Swl	Yield(l/s)
TBH-1	Atefen/Wadi/Dembecha	319945	1163346	1952	105	18	4.4
TBH-2	Dembecha Town	336753	1168017	2087	200	21	6
TBH-3	Amanuel/Machakel	342456	1154603	2342			
TBH-4	Yewla/Machakel	343065	1149592	2171	70	12	5
TBH-5	Sentera/Dembecha	353173	1143477	2200			30
TBH-6	sentera/Dembecha	353546	1144864	2214			35
TBH-7	Yeted/Senan	362579	1158726	2674	37		
TBH-8	Yeted/Senan	362382	1158586	2661	61		
TBH-9	Yewla,Machakal	343549	1149336	2192	75	24.6	20
TBH-10	yebokla	345737	1126724	2106	43	4	0.8
TBH-11	sasi kebele,amanuel	344040	1152400	2238	120	7.2	
TBH-12	Yeted, Dembecha	327878	1163199	2059	66.8	5	
TBH-13	Yeted	323978	1163930	2014	60.8	14	
TBH-14	inwenede,dembecha	304776	1149411	2059	61		
TBH-15	Asteboje,dembecha	311666	1160357	1976	66.7		
TBH-16	jagerab,dembecha	313517	1165945	1988	34.2		0.5
TBH-17	Shelel	348978	1170426	2143	196.1	4.9	4
TBH-18	Dembecha-well2	338390	1171713	2095	179	22	7
TBH-19	Sentera D/ Markos	348588	1142531	2191	181	7	30
TBH-20	Sentera	353518	1144830	2213	106	19.13	39.5
TBH-21	Sentera	352318	1145413	2205			
TBH-22	Sentera	353257	1147580	2224			
TBH-23	Rob Gebeya	365493	1165964	2939			
TBH-24	D/Markos	362213	1143042	2411	144	5	4.5
TBH-25	Dega Signit, Machakel	356713	1171441	2745			
TBH-26	Dembecha	327460	1170539	1958	200	6.39	20
TBH-27	Yewla,Machakal	343267	1149124	2186			
TBH-28	Shelel, Machakel	346053	1170261	2205			
TBH-29	Anjene,dembecha	339873	1181800	2461			
TBH-30	Yechereka01,dembecha	327585	1171732	1970			
TBH-31	sersem, angota dengera,dembecha	323927	1171296	1965			
TBH-32	laymender,dembecha	330919	1172781	2038			
TBH-33	Feres bet,degadamot	347377	1200217	2978	77		
TBH-34	Feres bet,degadamot	348572	1199511	2983	115	7.75	3.5
TBH-35	Elala, Gobata akena, Amanye	326823	1155692	2132	36	33	
TBH-36	Teshete, Debre Elyase	330227	1140595	2164	97	5.7	
TBH-37	debremarkos,gozamen	358787	1143874	2384	251	3.36	19.24
TBH38	Wadi/Dembecha	319963	1164063	1965	86	20	2
TBH-39	Sentera	353413	1144609	2213	84	12.35	22.24
TBH-40	Sentera	352229	1145203	2208	102	10.4	23
TBH-41	Sentera	351349	1145548	2210	150	10.76	20

TBH-42	Sentera	351929	1146087	2214	162	18	21
TBH-43	Sentera	351344	1146171	2216	152	32.9	7
TBH-44	Sentera	353104	1145300	2210	106	15.45	37
TBH-45	Sentera	350905	1144642	2200	184	9.8	30
TBH-46	Sentera	353630	1145536	2215	150	34.77	15
TBH-47	Sentera	352950	1145988	2213	120	26.48	7
TBH-48	Sentera	352820	1144920	2206	102	12.57	30
TBH-49	Sentera	353420	1144623	2213	106	19.67	39.5
TBH-50	Sentera	353739	1144996	2215	110	12.2	15
TBH-51	Yewla/Machakel	343065	1148592	2171	152	27.3	11
TBH-52	Shelel/Machakel	346053	1170261	2205	200	30	5
TBH-53	Yewla/Machakel	343544	1149327	2179			
TBH-54	/Esatbegel Robgebeya	364069	1165935	2940	61	3	1
TBH-55	Tach chabi/Robgebeya	360891	1165064	2771	61	19	2.5
TBH-56	Tena tabiya/Yeted	362522	1159166	2705	67	31	0.5
TBH-57	Yeted/Senyin	360996	1158329	2578	148	5	4
TBH-58	Dembecha Town	336648	1167853	2076	300	62.8	5
TBH-59	debremarkos_BH2	358921	1144424	2382	267.04	14.84	5
TBH-60	D/Markos BH-1	352796	1145405	2207	106	43	30

Appendix1. 5. X and Y coordinate of Pumping test data

ID	*Location*	*X*	*Y*	*Z*	*Depth (m)*	*SWL (m)*	*Yield (l/s)*	*Transmissivity (m2/day)*	*Conductivity (m/day)*
TBH-17	Shelel	348978	1170426	2143	196.1	4.9	4	10.2	0.15
TBH-18	Dembecha	338390	1171713	2095	179	22	7	3.05	0.04
TBH-19	D/ Markos	348588	1142531	2191	181	7	30	11.6	0.17
TBH-24	D/Markos	362213	1143042	2411	144	5	4.5	25.3	0.39
TBH-26	Dembecha	327460	1170539	1958	200	6.39	20	29	0.38
TBH-37	D/markos	358787	1143874	2384	251	3.36	19.24	550	4.97
TBH-39	Sentera	353413	1144609	2213	84	12.35	22.24	768.1	25.57
TBH-40	Sentera	352229	1145203	2208	102	10.4	23	772.42	21.43
TBH-41	Sentera	351349	1145548	2210	150	10.76	20	48.47	1.24
TBH-42	Sentera	351929	1146087	2214	162	18	21	24.88	0.57
TBH-43	Sentera	351344	1146171	2216	152	32.9	7	4.64	0.23
TBH-44	Sentera	353104	1145300	2210	106	15.45	37	709.34	20.3
TBH-45	Sentera	350905	1144642	2200	184	9.8	30	34.56	2.47
TBH-46	Sentera	353630	1145536	2215	150	34.77	15	31.02	1.19
TBH-47	Sentera	352950	1145988	2213	120	26.48	7	22.81	1.14
TBH-48	Sentera	352820	1144920	2206	102	12.57	30	85.54	2.38
TBH-49	Sentera	353420	1144623	2213	106	19.67	39.5	1183.68	39.48
TBH-50	Sentera	353739	1144996	2215	110	12.2	15	41.56	1.43
TBH-58	Dembecha	336648	1167853	2076	300	62.8	5	3.46	0.036
TBH-59	D/markos	358921	1144424	2382	267.04	14.84	5	4.49	0.05
TBH-60	D/Markos	352796	1145405	2207	106	43	30	5750	160

Appendix1. 6.Calculated Potential evapotranspiration of the stations

Amanueal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TM	19.1	20.4	20.8	20.4	19.0	17.4	16.4	16.3	16.7	17.5	17.7	18.0
Tm/5	3.8	4.1	4.2	4.1	3.8	3.5	3.3	3.3	3.3	3.5	3.5	3.6
(Tm/5)1.5	7.5	8.2	8.5	8.2	7.4	6.5	6.0	5.9	6.1	6.5	6.7	6.9
I	84.3	84.3	84.3	84.3	84.3	84.3	84.3	84.3	84.3	84.3	84.3	84.3
I2	7107.0	7107.0	7107.0	7107.0	7107.0	7107.0	7107.0	7107.0	7107.0	7107.0	7107.0	7107.0
I3	599140.5	599140.5	599140.5	599140.5	599140.5	599140.5	599140.5	599140.5	599140.5	599140.5	599140.5	599140.5
A	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
TM/I)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
10TM/I	2.3	2.4	2.5	2.4	2.3	2.1	2.0	1.9	2.0	2.1	2.1	2.1
(10TM/I)a	4.5	5.2	5.3	5.2	4.5	3.8	3.5	3.4	3.5	3.9	4.0	4.1
Nm	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.0	0.9
16*Nm	15.1	15.5	16.0	16.6	17.1	17.4	17.2	16.9	16.3	15.8	15.2	15.0
PET	68.8	80.1	85.4	85.8	77.3	66.8	59.4	57.2	57.8	60.9	60.2	61.4
	68.80	80.07	85.43	85.82	77.31	66.83	59.40	57.18	57.83	60.88	60.17	61.39

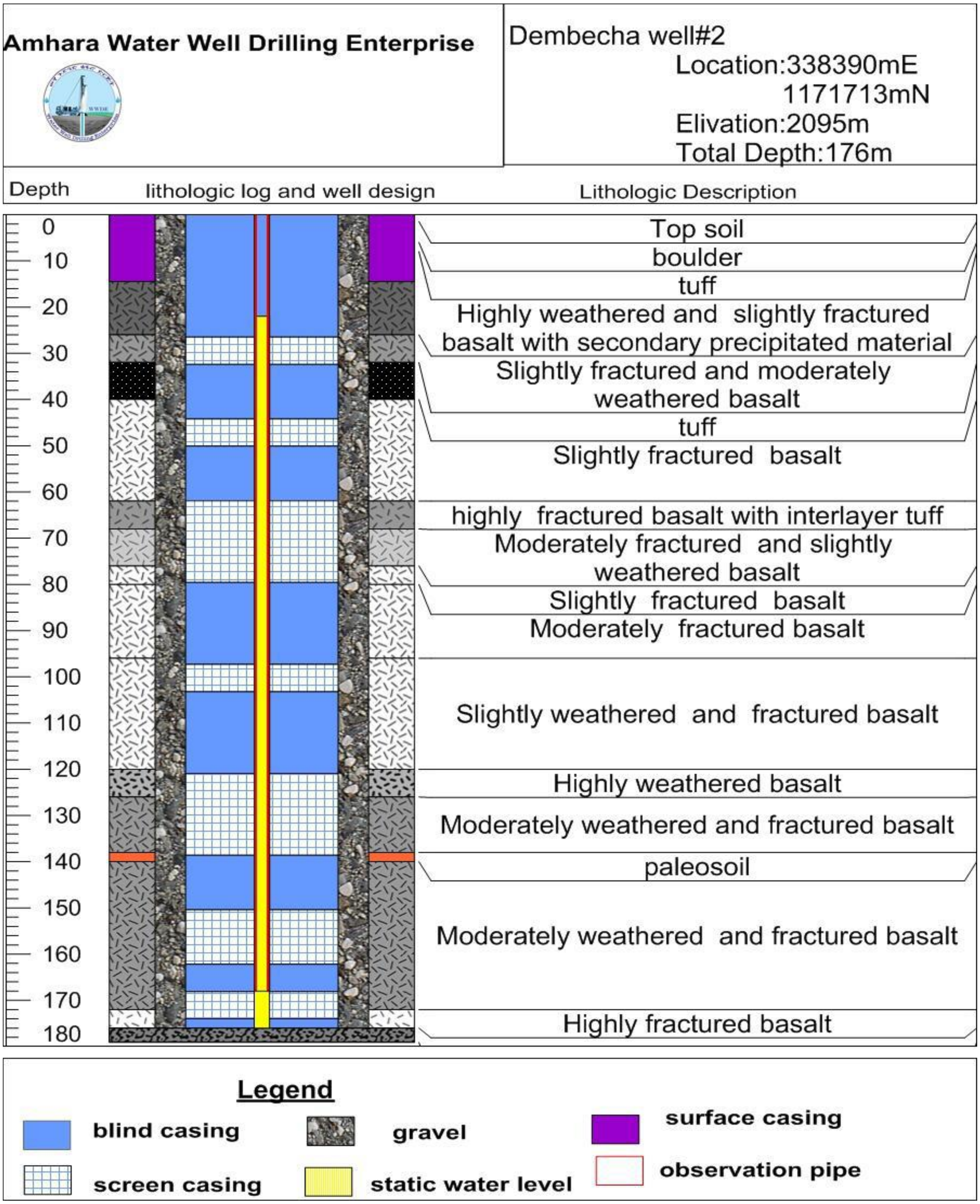
D/Markos	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TM	16.7	18.1	18.8	19.0	18.1	16.1	15.2	15.1	15.5	16.1	16.0	16.1
Tm/5	3.3	3.6	3.8	3.8	3.6	3.2	3.0	3.0	3.1	3.2	3.2	3.2
(Tm/5)1.5	6.1	6.9	7.3	7.4	6.9	5.8	5.3	5.3	5.5	5.8	5.7	5.8
I	73.6	73.6	73.6	73.6	73.6	73.6	73.6	73.6	73.6	73.6	73.6	73.6
I2	5419.1	5419.1	5419.1	5419.1	5419.1	5419.1	5419.1	5419.1	5419.1	5419.1	5419.1	5419.1
I3	398921.4	398921.4	398921.4	398921.4	398921.4	398921.4	398921.4	398921.4	398921.4	398921.4	398921.4	398921.4
A	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
TM/I)	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
10TM/I	2.3	2.5	2.6	2.6	2.5	2.2	2.1	2.1	2.1	2.2	2.2	2.2
(10TM/I)a	3.8	4.4	4.7	4.8	4.4	3.7	3.3	3.3	3.5	3.7	3.6	3.7
Nm	0.95	0.97	1.00	1.04	1.07	1.09	1.08	1.06	1.02	0.99	0.95	0.94
16*Nm	15.1	15.5	16.0	16.6	17.1	17.4	17.2	16.9	16.3	15.8	15.2	15.0
PET	57.2	68.8	75.9	80.0	76.1	63.7	57.0	55.9	56.4	57.7	55.3	54.7

Dembecha	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TM	18.2	19.3	20.3	20.5	19.5	18.0	16.9	17.0	17.3	17.8	17.7	17.7
Tm/5	3.6	3.9	4.1	4.1	3.9	3.6	3.4	3.4	3.5	3.6	3.5	3.5
(Tm/5)1.5	6.9	7.6	8.2	8.3	7.7	6.8	6.2	6.3	6.4	6.7	6.7	6.7
I	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5
I2	7139.8	7139.8	7139.8	7139.8	7139.8	7139.8	7139.8	7139.8	7139.8	7139.8	7139.8	7139.8
I3	603299.2	603299.2	603299.2	603299.2	603299.2	603299.2	603299.2	603299.2	603299.2	603299.2	603299.2	603299.2
A	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
TM/I)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
10TM/I	2.2	2.3	2.4	2.4	2.3	2.1	2.0	2.0	2.0	2.1	2.1	2.1
(10TM/I)a	4.1	4.5	5.0	5.1	4.6	4.0	3.5	3.6	3.7	3.9	3.9	3.9
Nm	0.95	0.97	1.00	1.04	1.07	1.09	1.08	1.06	1.02	0.99	0.95	0.94
16*Nm	15.1	15.5	16.0	16.6	17.1	17.4	17.2	16.9	16.3	15.8	15.2	15.0
PET	61.6	70.1	79.7	84.5	79.2	69.5	60.9	60.5	60.3	61.4	58.8	57.9

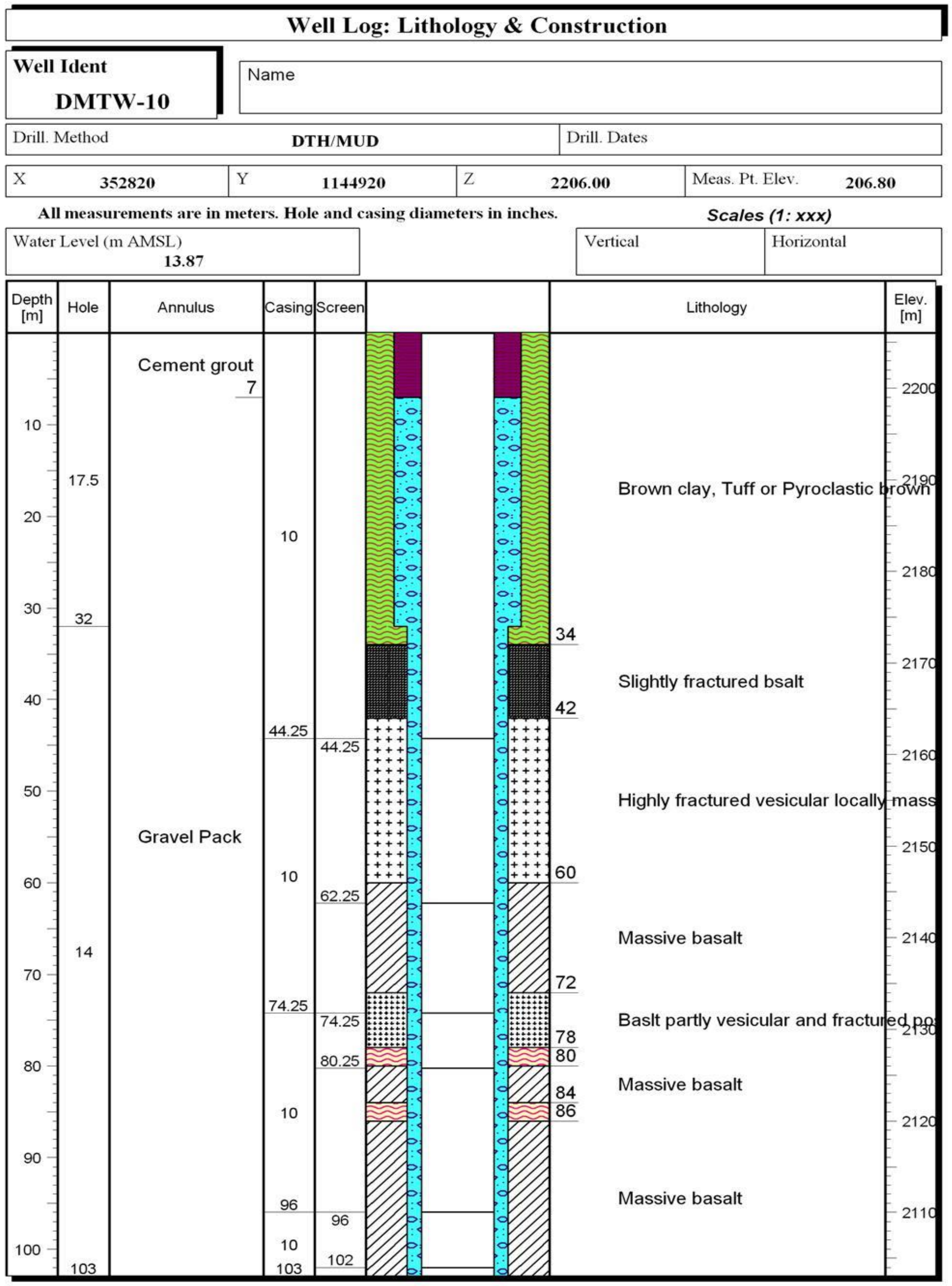
Dengay Ber	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TM	16.3	17.3	17.6	18.0	17.4	15.1	13.6	13.4	13.9	14.5	15.0	15.4
Tm/5	3.3	3.5	3.5	3.6	3.5	3.0	2.7	2.7	2.8	2.9	3.0	3.1
(Tm/5)1.5	5.9	6.5	6.6	6.8	6.5	5.2	4.5	4.4	4.6	4.9	5.2	5.4
I	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5
I2	4427.3	4427.3	4427.3	4427.3	4427.3	4427.3	4427.3	4427.3	4427.3	4427.3	4427.3	4427.3
I3	294578.8	294578.8	294578.8	294578.8	294578.8	294578.8	294578.8	294578.8	294578.8	294578.8	294578.8	294578.8
A	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
TM/I)	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
10TM/I	2.5	2.6	2.6	2.7	2.6	2.3	2.0	2.0	2.1	2.2	2.2	2.3
(10TM/I)a	3.9	4.2	4.3	4.5	4.2	3.4	2.9	2.9	3.0	3.2	3.4	3.5
Nm	0.95	0.97	1.00	1.04	1.07	1.09	1.08	1.06	1.02	0.99	0.95	0.94
16*Nm	15.1	15.5	16.0	16.6	17.1	17.4	17.2	16.9	16.3	15.8	15.2	15.0
PET	58.6	65.9	69.6	74.5	72.7	59.7	50.3	48.6	49.7	51.0	51.6	53.1

Appendix1. 7.Borehole Loges

Borehole 18 on map



Borehole 48 on map



Borehole 49 on map