



**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
DEPARTMENT OF EARTH SCIENCE  
HYDROGEOLOGY STREAM**

## **HYDROGEOCHEMICAL EVOLUTION IN THE AMBO- WOLISO AREA**



**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN  
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## Abstracts

The objective of this research is identification of soda spring sources and characterization of hydrogeochemical evolution on the basis of water sample data physicochemical analysis. This is attempted through understanding of geological settings, hydrogeological effects, and tectonic activity including other factors.

Geologically it is composed of sedimentary rock and volcanic products, the later is recognized to be younger resulted from tertiary and quaternary volcanic episodes. Its products spread over the large part as out crop overlying the earlier. Mesozoic sedimentary sequences are limited to the western edge, which is noticed as Adigrate sandstone.

Some hydrometrological parameters are briefly addressed precipitation depth from isohyetal computation is 1143.1-mm/year while arithmetic is 1137.67mm/year, temperature is found to be 18.1°C and annual mean actual evapotranspiration using SEBAL modeling is 320.4mm.

Roughly it can be said scoracious and fractured basalts are the major economical water bearing formations while ignimbrite is the confining layer; moreover geological structures play key role in controlling water resources of the area.

Noticing the eleven variables (pH, Ca<sup>2+</sup> Mg<sup>2+</sup> K<sup>+</sup>, Na<sup>+</sup>, HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, TDS) at least two Ionic evolutions can be notable (Seifu Kebede et al, 2005): fresh low TDS Ca-Mg-HCO<sub>3</sub><sup>-</sup> type envisages most western parts and northern highland (ambo fault belt). Second type high TDS Na-HCO<sub>3</sub><sup>-</sup> is limited to thermal spring emerging zone controlled by regional deep seating geological structures. Perceptible high CO<sub>2</sub> presence from sediment decarbonation and magma degassing is responsible for the evolution, when transferring takes place from shallow circulating to deep groundwater system. In the deep groundwater system both the igneous and Mesozoic sediments most likely contribute for the high ionic species.

*Key words:* Earth processes; Basalt; Ignimbrite; Eleven variables; Ionic evolution; Degassing.

## 1. Introduction

The study area is located in Oromia Regional State West Shewa and South West Shewa part, enclosed between Ambo and Woliso about 125 and 110 kilometer away from the capital city Addis Ababa respectively. Geographically located at 8°37'to 9°07" N and 37°45'to 38°24'E. Two main roads, Addis Ababa Nekemte and Addis Ababa Jima pass through in the north and the south of the area in that order and enclose about 2047km<sup>2</sup>.

Dry and wet seasons are the two major climates that characterize the study area with annual rainfall of 1143.1mm and with mean annual temperature 18.1°C.

Rural people generate their income from agricultural products and livestock breeding, town inhabitants have been engaged into various activities to make their life easy. The ever growing population size is one of the big challenges to meet the living demand to its fullest. Lack of advanced technology introduction and, very limited schooling, etc are the important area seem to be addressed.

Though can not be mentioned quantitatively as a result of no recorded data, ten years back from personal observation the vegetation condition of the area was very dense at least on mountains, hillsides and along the numerous streams emerging from Goro Dendi-Wonchi Mountain chains in the south and Ambo fault belt in the north. Nowadays the area is appearing as if there was no vegetation cover except few locations along the peripheries and in central parts.

Geologically Ethiopia is known possessing all the three rock types such as: Igneous, Sedimentary and Metamorphic.

- The basement rock exposure in Ethiopia is limited along the periphery of the country: southern part, western part and north part
- Sedimentary stratification is formed in Ethiopia during the transgression -regression period where the landmasses under went subsidence and uplifting in the Mesozoic period of which the colorful Ambo sandstone is classical example in association with gypsum and limestone.
- Huge voluminous tertiary and quaternary volcanic eruptions occupy the Ethiopian Great Rift Valley with extension to the western and eastern shoulder of the rift these are evidenced by numerous type volcanic products and tectonic structures such as Ambo fault belt E-W oriented wonji Fault belt with NNW and SSE orientation together with locally growing tectonic structures and various type of volcanic edifices: Volcanic Domes, Shield volcano and dot of cinder cones on toped plains.

The local geology is more or less composed of young volcanic products whose center most probably located at Wonchi and Dandi that formed crater lakes and make the highest point of the study area.

Hydrogeologically the area is rich enough, as it has been seen against water potential as it is witnessed by occurrence of numerous cold springs, few thermal springs and surface waters (streams and lakes), nonetheless improper utilization and mismanagement are casting a shadow on the sustainability of natural resource as a whole. Hand Dug wells drilled boreholes at considerable depth found to have good yields, also indicate economically available groundwater. Occurrence of shallow circulating ground water marks the area as productive fracture controlled aquifer is available.

Unconsolidated recent sedimentary deposits, in association with volcanic products such as highly weathered rhyolitic products, vesiculated fractured basalts with trachaytes are considered as good formation in allowing circulation and storage of groundwater.

Analysis of hydrometeorological data indicate unimodal rain fall type and suitable relative humidity that may support hydrological cycle in safe manner despite the fact that on going unwise act toward natural resource conservation is making the equilibrium imbalance.

From hydrogeochemical point of view the deep groundwater is more mineralized due to long time interaction with the host rock (Tamiru Alemayehu and Seifu Kebede, 2006), according these hydrogeologist the pH of ground water and surface water ranges from 6.2 to 8.2, the thermal water shows low pH due to continuous supply of CO<sub>2</sub> probably from the cooling igneous magma chamber and Atmosphere. Generally, “hydrogeochemical evolution” is the central point, given a weight to be addressed in the thesis.

## **1.2. OBJECTIVE**

- Origin of Soda Spring Identification
- Quality of water Resource Assessment

## **1.3 Specific Objective**

Here, the following specific points may be addressed;

- General hydro geological setting of the study area
- Litho logical influence on water chemistry
- Status of water chemistry (hydrochemistry mapping)
- Yield of springs
- Prevailing hydrometeorology of the area
- Land use land cover against water resource
- Recharge and Discharge condition of the study area

## **1.4 Methodology**

- ✓ Secondary data compilation and interpretation
  - ❖ Geological information (bore hole, data)
  - ❖ Hydrometeorology
  - ❖ Satellite and air photographs
  - ❖ Hydrogeological maps
  - ❖ Surface water and groundwater condition
- ✓ Sample collection for laboratory test and field test

## **1.5 Materials used**

- Global positioning system (GPS)
- Topomap
- Satellite images
- Water sampling pvc bottles
- Electrical conductive meters (EC)
- pH meters

## **1.6 Description of the study area**

The study area is located in Oromia Regional State west Shewa Zone between some part of Ambo and Woliso with geographic coordinate 8°37'to 9°07" N and 37°45'to 38°24'E. It is about 125 kilometer away from the capital, Addis Ababa. The well-known lengthy Ambo liniment borders the north part of the study area whereas wonchi and Dnadi ridges characterize its southern part. From these ridges there are radial flow of streams to the main three drainage basins such as Abay Basin, Awash Basin and Gibe Basin. Huluka, Qerensa, Debis and Jelewan are the major perennial rivers with numerous springs at the base of ridges

Addis Ababa to Jima and Welega Roads are the only asphalt road that pass along the Southern and Northern edge of the area respectively, the gravel roads from Ginchi to Tulubolo and Ambo to woliso are another means to access the area from North to South.

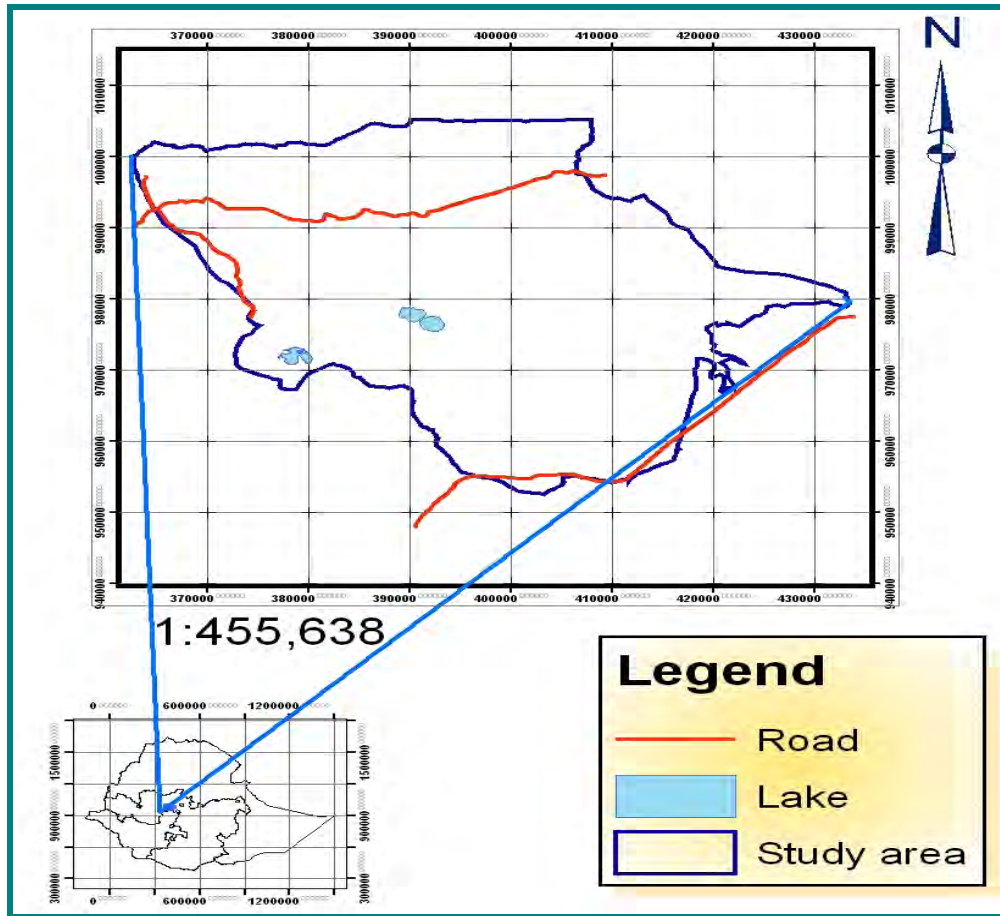


Figure 1:1 Study Area

### 1.7 Physiography

Geographic diversity having high rugged mountains, flat-topped plateaus, deep gorges, incised river valleys, and rolling plains is a specific feature of the study area. Most of it consists of high plateau and mountain ranges with precipitous edges dissected by numerous intermittent streams, tributaries of aforementioned rivers.

The prominent Awash River starts from the ambo liniment, at the base of Herar Kura ridge near Ginchi Huluka tributary of Gudar emerge as out late from Dandi Crater Lake; located in southern part of the study area,

Welga river (goes out of the study area) sub-catchments of Gibe basin and Jelewan, tributary of Awash source is Goro Wonchi and Goro Dandi ridge chain, southern rim of the study area; whereas that of Gudar tributary Dabis source is Workday Gara Ola at the north part of the study area along the Ambo fault belt. More over Lake Wonci and Dandi are one of important drainage element together with numerous fracture controlled cold spring and hot spring of ambo and Woliso fig1.2 Dendritic, parallel and radial drainage patterns are attributed to topographic setting which is characterized by abrupt slope change, dissected gullies and gorges in association with various volcanic landforms that are modified by geological events.

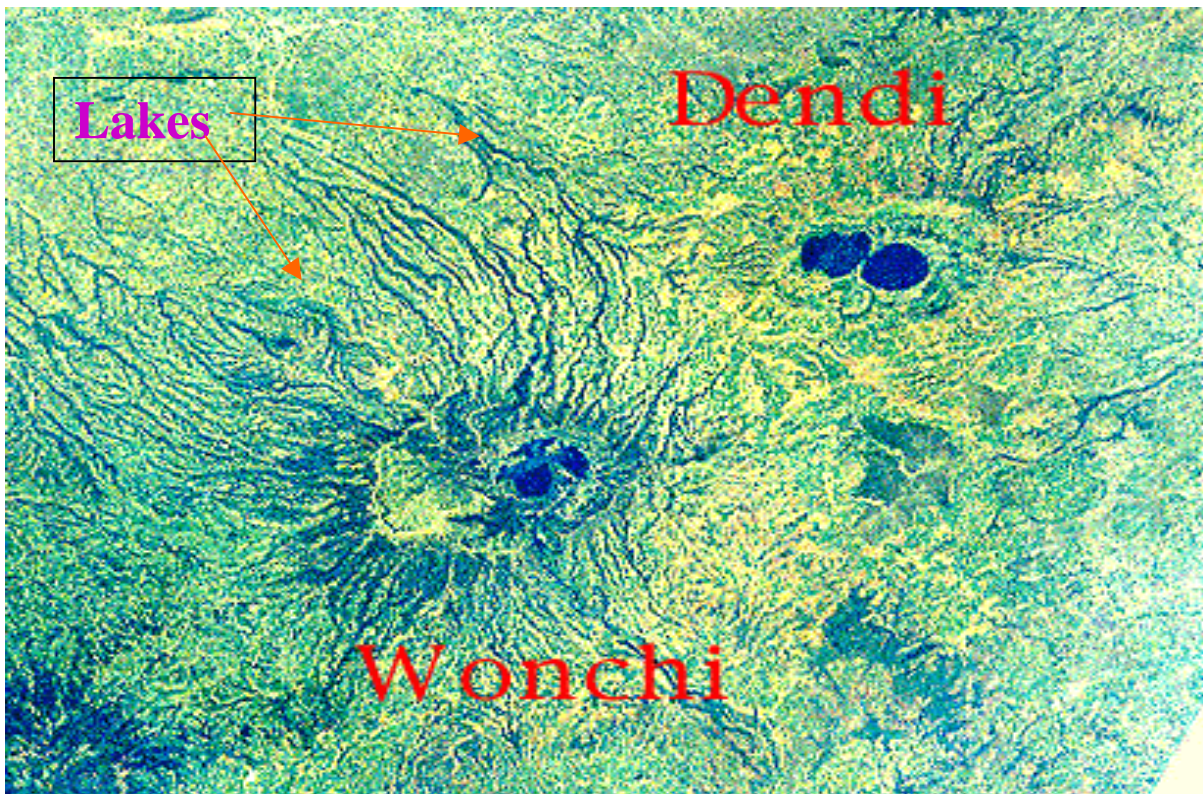


Fig1.2 satellite image of Goro dandi and wonchi showing drainage Pattern dotted with Crater lakes.

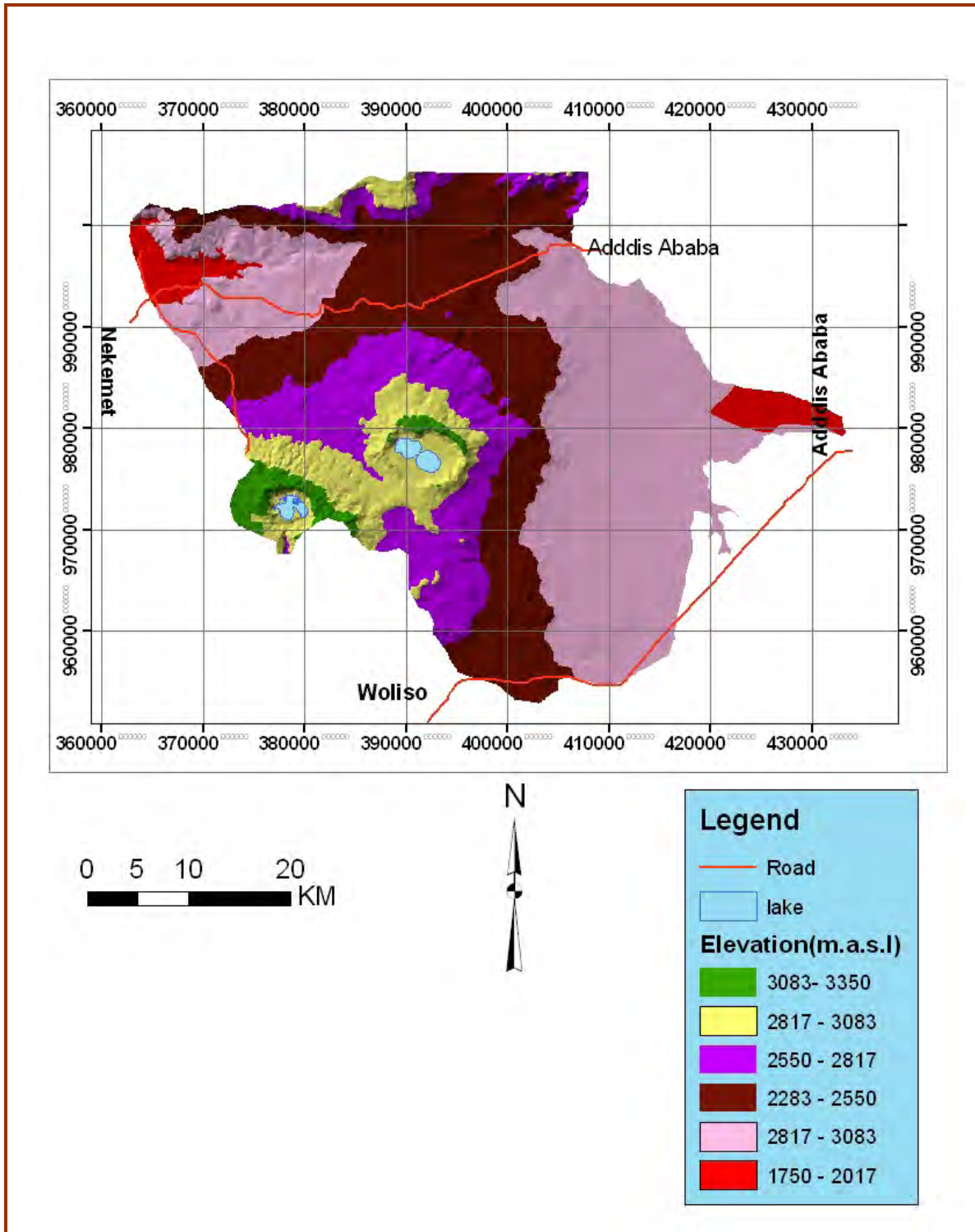


Figure 1.3: Relief setting ( ranges 1750-3350 m.a.s.l)

Normally, as one goes toward either north or south the slope rises gradually and/or abruptly in some places while the eastern and western end are low lying plains to which also the highland streams drain, extensive Becho plain and Gudar valley are the points where the streams converge to leave the area figure 1.3

The physical conditions in altitude have resulted in a slight diversity of climate, soil, vegetation and impressing scene of topography, shaped by volcanic activity together with recent sedimentary processes.

### **1.8 Land Use Land Cover**

Traditional farming is one of the major activities to generate income among the rural inhabitants; The land is intensively cultivated by the indigenous people for production of subsistence crops like Teff, Maize, Cheek beans, peas, wheat, corn, barley, Enstate, Teff, some oil crops, etc. Small scale irrigation is practiced in some areas such as: Buqisa, wodesa from Homi spring Awaro from chanco spring. The crop produced here is significantly contributed to the demand of the country. More livestock breeding is another important activity besides crop production.

Because of ever increasing population size traditional farming is advancing at the expense of deforestation; as a result hillsides, mountains and plain land are stripped of their forest and grasses. Taking advantage of this erosion is also washing away most fertile soils out of the area from all direction every year.

Based on conducive climate Bush, shrubs, big trees and grasses used to cover most part of the study area. Unlike past days the vegetation density is too little if there is any spared remnant forest along the hillside of few streams and Chilomo (protected by Farm Africa), even these are at verge of fading due to all round problems such as, replacement by

eucalyptus tree which is sold for a good amount of money, unlimited farmland expansion, burning for charcoal ect. Generally, unwise natural resource utilization and mismanagement is endangering and complicating the ecosystem.

The towns include Ambo, Ginchi, Meti and Asgori are located in the northern part while Woliso, Tulubolo, Busa and Asgori are the southern periphery. In the town people led diversified livelihood.

From infrastructural point of view there is no as such prominent factory except that of Ambowha bottling factory and Ambo sandstone quarry that is used for construction purpose.

### **1.9 Pervious works**

In western shewa part of the country there are no detailed research activity conducted like main Ethiopian rift valley though the area is interesting from hydrogeological and geological point of view for there are indicative of surface water and groundwater resource potential which may need proper attention.

Some review of existing pervious work include: Tamiru Alemyahu (2006) emphasizes thermal spring occurrence in Ambo as a result of cooling igneous magma chamber that formed Dandi and Wonchi crater lakes.

Major ions composition of the Groundwater and Surface water system and their geological and geochemical controls in the Ethiopian volcanic terrain addressed by Tenalem Ayenew (2005), his paper stresses the chemical composition of natural waters and the amount of species depends on several factors: geology, soil type, solubility of minerals of the rocks, land use land cover condition, residence time of water and

chemical composition of the media in which the water passes or reserved.

Lemessa Mekonta (2001) has described hydrogeological controls in sandstone of Ambo area. He suggests that the major source of travertine is the dissolution of limestone which overlain by the upper sandstone.

Wonchi shield volcano top part is covered by ashy and tuff deposits and the base is marked by tachy-rhyolite he also indicated that there is good groundwater resources at reasonable depth (Kassahune Beyene, 2005), besides thermal spring around Wonchi is characterized by high total dissolved solids.

Tamiru Alemayehu and Seifu Kebede (2006) indicated that continuous supply of CO<sub>2</sub> is linked with degassing of the magma and decarbonation of deep Mesozoic sediments. Moreover the shallow magma chamber of dandi and wonchi is responsible for the high temperature which induces fault controlled thermal springs, located along the structure that runs from Ambo to woliso.

Ferdinand Hercik (1983) suggests that Adigrate sandstone is affected by tertiary tectonic activity and E-W running fractures take control of the mineral water available between Ambo and sankale being trapped in Adigrat sand stone. Travertine outcrop is frequent in ambo swimming pool and Sankale with average thickness of 10-15 and 17m in that respective places. CO<sub>2</sub> comes from deep following structural control and mixes with fresh water in Ambo Sandstone aquifer its concentration is 4976mg/l before degasification. He concluded that CO<sub>2</sub> rich water of Sodium bicarbonate type water in the sandstone is associated with Tertiary or Quaternary volcanic activity.

Seifu Kebede, Tamiru Alemayehu, Tenalem Ayenew, Yves.T, (2005), the paper Addresses groundwater recharge, circulation and geochemical evolution in the source region of blue Nile river, Ethiopia. According to these researchers two major structurally deformed regions with distinct groundwater circulation and evolution history were identified. One of which is the Yere Tullu Wellel Volcanic Lineaments Zone (YTVL).they indicated also CO<sub>2</sub> influx from deeper sources plays major role in controlling groundwater chemical evolution of the high TDS Na-HCO<sub>3</sub> in thermal groundwater.

## **2. GEOLOGICAL SETTINGS**

### **2.1 Summary of Ethiopian Geology**

The basement rocks of Ethiopia consist of Precambrian igneous and metamorphic containing several orogenic episodes. It is in these rocks or from these rocks that the majority of economic mineral deposits exist.

The basement rocks are relatively impermeable and thus water resources are in general only associated with fracturing and faulting resulting from rift development. For much of the early Paleozoic, Ethiopia was in a state of steady uplift, which caused widespread erosion in most part of the country. Subsidence followed in the Mesozoic with a large shallow sea spreading initially over the Ogaden province eventually extending further north and west as the land continued to subside. General uplift and drying out of lakebeds to leave gypsum followed this sequence and anhydrite precipitates.

Regional tectonic activity associated with rifting events in the Red Sea, Gulf of Aden and East African Rift Valley during the late Tertiary caused faulting and fracturing together with widespread volcanism. Vast quantities of basaltic lava were extruded over the western half of Ethiopia. This was accompanied by ash and coarser tephra forming a sequence known as the Trap Series.

Quaternary deposits are mainly confined to those associated with large depressions and lakes. Seismic and volcanic activity continues today along the Ethiopian Rift valley system, manifestation of thermal springs are related to these events.

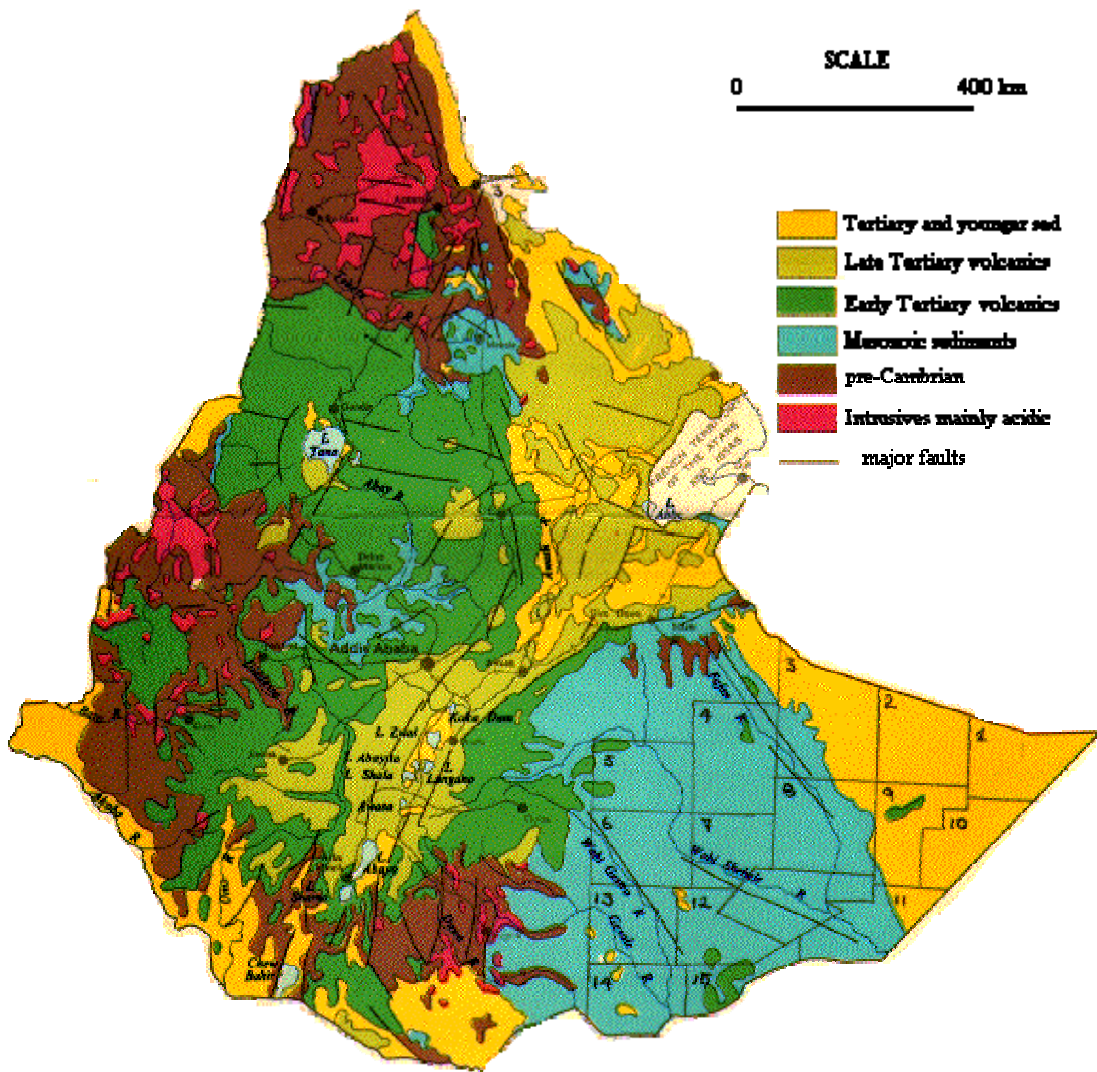


Figure 2.1: Geological map of Ethiopia adapted from Ethiopian geological survey 1983 (includes Eritrea).

Mesozoic limestone, dolomitic and marl deposits in western and northern Ethiopia occur in Tigray, in the Danakil Alps and in the Blue Nile (Abbaya) valley. Equivalent to Adigrat sandstone outcrops of Mesozoic liming materials occur in the central plateau area near Ambo town, in the Didessa valley (Kazmin 1972).

Geologically, Ethiopia lies at the northern end of the continental part of the Eastern Rift. Voluminous piles of mainly Tertiary volcanic rocks occupy large parts of the country along the Rift Valley. Proterozoic rocks occur in western Ethiopia, and Mesozoic and Tertiary rocks underlie most of the eastern part of the country. The floor of the Rift Valley is filled with relatively young lacustrine sediments and volcanics. Several alkaline plugs are known from Ethiopia, for instance volcanic plugs around Wonchi and Dandi are typical example in the study area.

## **2.1 Geology of study area**

The regional geological map of Ethiopia recognizes the area as one unit, early tertiary volcanic. Normally, two major rocks found as outcrops in the study area: sedimentary rocks and igneous rocks. The Mesozoic sedimentary succession boundary is limited to the northwestern part of the study area around Ambo town. The Adigrate equivalent upper ambo sandstone is one of the major Mesozoic formations exposed as outcrop in the area. One can encounter gray colored sand stone on the way from Ambo to Wodesa along the bank of Debis River and extends beyond toward north it is intercalated with variegated shale. The colorful sandstone is exposed west of the town near the agricultural college. These locally exposed sedimentary sequences are due to erosion and faulting effect Tesgaye Abebe, F, Innocenti (1998).

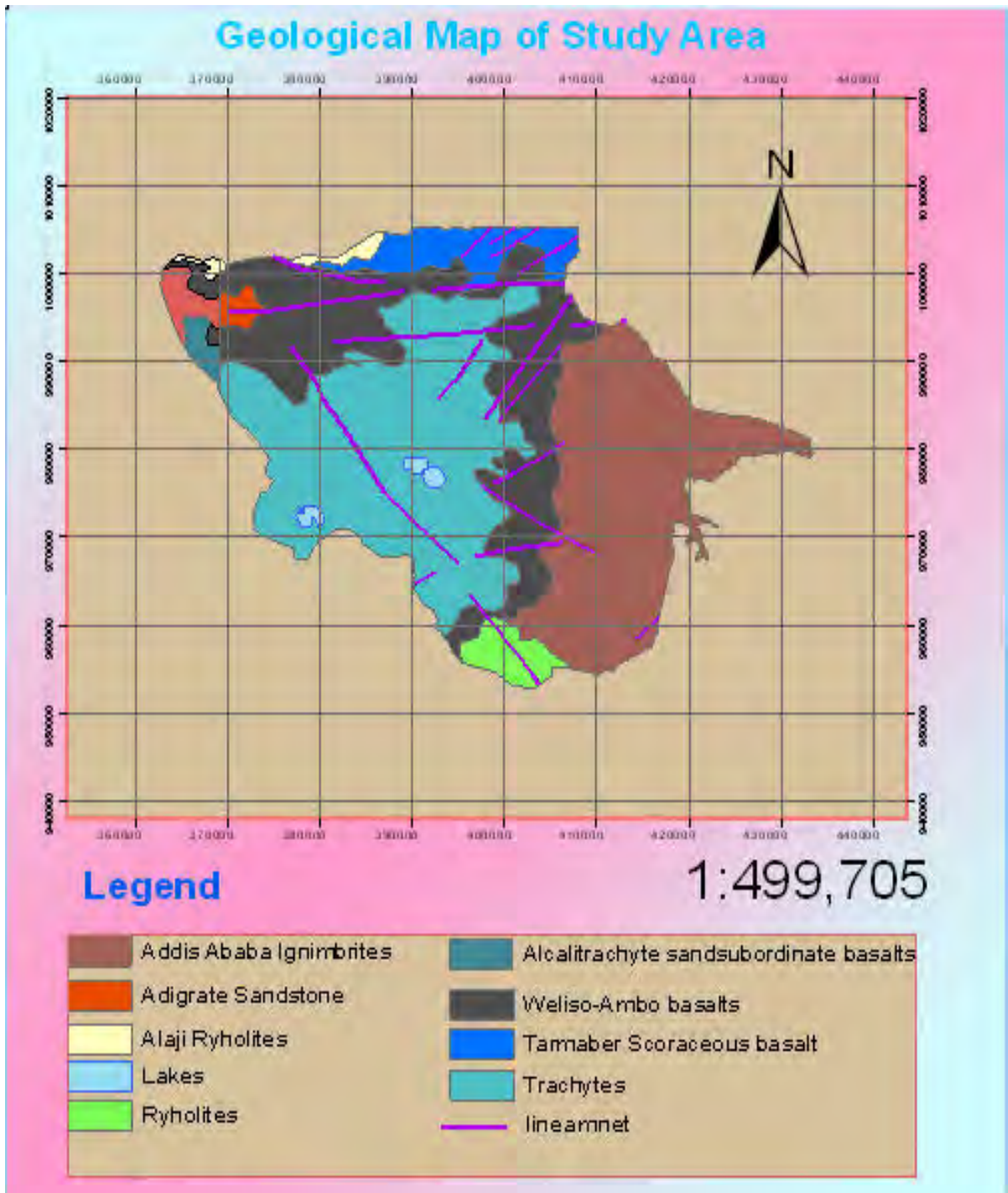
The northwestern tip is marginalized by the Adigrat sandstone formation, which belongs to the lower sandstone unit, formed during Mesozoic as a result of regression and transgression episodes.

Overall, the plateau volcanic exhibit Upper Oligocene-Lower Miocene ages, corresponding to the phase of higher effusion rate that has been regionally recognized (Mohr and Zanettin, 1988); the age distribution of

products of the upper volcanic sequence (Miller and Mohr, 1966; Morton *et al.*, 1979; Berhe *et al.*, 1987; Woldegabriel *et al.*, 1990) Bimodal volcanic products, basaltic and rhyolitic formed the western central plateau of Ethiopia Bekele Abebe, Mario Boccaletti, *et al.* (1998). Dandi and Wonchi Volcanic centers are shoulder of Ethiopian rift western escarpment having general trend east west in parallel with Ambo fault belt. The voluminous volcanic products make up the area with west edge Mesozoic sedimentary unit: -

- Adigrat Sandstone.
- Amba Alaji rhyolite
- Tarmabar scoracious basalt
- Tertiary Trachyte
- Tertiary ignimbrite
- Quaternary basalt.

Detail geological formations, which comprise the area, are given in figure 2.2 from the map trachytes area coverage while the sedimentary sequence pinch out in the area forming a pocket into the Ambo Woiliso basalt.



**Fig 2.2: Geological Map of Study Area**

### **2.1.1 Quaternary basalts**

This unit is found as a ring surrounding Woliso and Ambo characterized by volcanic plugs that extruded through it forming different volcanic edifices. Weathering effect has played role in disintegrating and breaking in to peices the upper part which exposed to the atmosphere at stream cuts, road cuts, and quarries and erosional uncover areas. For instance basaltic boulders in Debis stream, Aleltu stream and Huluka Stream exhibits denser vesicles in the upper than the lower part of the rocks. The exposure of this unit is not limited to those site rather one can see them all around the way ambo to Ginchi and to wliso.

It is affected by lineaments that are oriented in different direction such as NW - SE, W-E and NE-SW these in turn shaped the morphology and controlled the streams patterns by interfering with each other. At macroscopic scale two type of texture is observable: aphanitic (fine grained texture) and porphertic texture (coarse grained) the later is dominated by vesicles and phenocryst minerals such as olivine and plagioclases.

### **2.1.2 Alaji Rhyolite**

It characterize the Northwest border of the area around ambo fault belt being confined in between Ambo-woliso Quaternary basalt in the south and blue Nile basalt in the Northern margin its west ward extension is interrupted by Adigrat sandstone they pinch out within each other.

This unit has formed steep slopes and easily transported being aided by running water and gravity, it is commonly found at the base of ambo fault belt cliffs in association with others. Weathering effect has induced

fragmentation, fillings, cracks and slightly developing joints other growing structures.

### **2.2.3 Tarmabar Scoracious Basalt**

Tarmabar scoracious basalt is found in the northeast part of the area it also extends toward the east outside the area, wider as it advances toward the east. This lithology occupies the slope of ambo fault belts and most of the plugs that created hills adjacent to the lengthy lineament swallowed by scoracious material. It also serves as construction materials

### **2.2.4 Tertiary Trachyte**

The source of this lithology is those prominent volcanic center peaks, Dandi and Wonchi volcanics. The formation is limited to the central part of the study area, it appears that the flow took place to all direction just making those high points as a center in all direction bordered by the quaternary basalt. In the north, east and south part circled by the quaternary basalt

Starting from the peaks of Dandi and Wonchi mountains it spread away forming sloping landscape to all direction, exposed along streams, roads and geological lineaments. Mostly the outcropped one is subjected to weathering, differentiated by dense fractures through which water easily percolate and enhance more weakness, for instance the numerous springs emerging from those mountains chain take advantage of the well developed openings.

The formation is visible along Qernsa stream and its adjacent ridges such as Chefe Qernsa, Boda hills, Golja, Goloe are typical sites where

this unit can be seen to what extent it has suffered weathering by different means like plant roots intensive and heavy Orographic controlled rainfall.

The orientation of this unit is northeast southwest around Dandi Mountain though these dose not mean that it is identical thoroughly because there are various lineament oriented in different direction sometime they interact to stop the progress of the other. The major traceable structure located in between Wonch and Dandi Lake just parallel to Huluqa stream that begins from the Dandi Crater Lake as out let. From the geological map figure2.2 exceeding percentage is covered by this formation starting from the ridge and including the plain of northern part is encompassed by it.

### **2.2.5 Tertiary Ignimbrite**

The tertiary ignimbrite covers the almost the whole Bach plain, just located east of the dandi mountain here the lithology is usually not visible rather covered by soil. But many boreholes logs that are dug for water supply and other purpose bear witness that the immediate underlying unit below the topsoil is ignimbrite. It is also significant to speak about scoracious formation and Palo-soils that are found in association with it as a minor unit.

### **2.2.6 Adigrat Sandstone**

Adigrat sandstone of Mesozoic era is found in Ambo area .it includes various colored sandstones, the naturally decorated; known by the name ambo sandstone is classical example which possesses fine to medium grained intact texture, relatively resistant to weathering. In construction it is preferred for its dual-purpose; beauty and durability.

There is also intercalation of other sedimentary unit in association with the sandstone for instance north of Dabis River variegated cone-shaped shale is typical example.

At the southern adjacent of this formation there is noticeable alcalitrachyte sand subordinate basalt, at this point the quaternary basalt, tertiary treachyte and the sandstone confront and merge to each other; the lithologies are mixed as result of baking, cementing and lithification.

### **3. HYDROLOGY**

#### **3 1 Hydrometeorology**

Ethiopia is located in the tropics and variations in altitude have produced a variety of microclimates. Mean annual rainfall ranges from 2000-mm over some pocket areas in the southwest highlands, and less than 250-mm in the lowlands. In general, annual precipitation ranges from 800 to 2200-mm in the highlands (>1500 meters) and varies from less than 200 to 800-mm in the lowlands (<1500 meters). Rainfall also decreases northwards and eastwards from the high rainfall pocket area in the southwest (Fekadu Bekele. 1992)

In Ethiopia there are three seasons based on climatological mean of rainfall and temperature namely Bega, Belg and Kiremt figure 3.1 Bega (dry season) is from October to January. It is characterized by dry and cool period. Belg (small rainy season) is from February to May. It is characterized by varying dry and wet days. Kiremt (main rainy season) is from June to September violent thunderstorms in the highlands are common in late June.

The study area is known as the central plateau, its relief is very essential in controlling the climatological condition. Considerable rainfall is received in the west central part due to High Point Mountains that poses orographic influence



3.1: Rainfall regime of Ethiopia modified after (Bekele, F., 1992)

To characterize the hydrologic property of the area different hydrometeorological parameters are incorporated these include; precipitation, sunshine duration, relative humidity, evaporation, wind speed and temperature data are obtained from Ethiopian Metrology Service Agency. The largest parts of among the seven stations are within the study except that of Woliso and Asgori, which are located at southeastern and southwestern margin respectively:

- Ambo
- Ginchi
- Woliso
- Asgori
- Tulubolo
- Busa
- Wolokomi

Two prominent climatical conditions prevail in the study area: wet season (June to September) and dry season October to May with slight Belg rainfall from April and May.

Hydrometeorological data obtained from National Meteorological Service Agency (NMSA) are analyzed to understand the hydrometeorological nature of the area and presented in the following manner.

### 3.1.1 Temperature

Temperature is the measure of heat more temperature more heat energy will be. In the study area there is no much temperature variation when considered on yearly basis for the whole catchments. But one can see that significant temperature range if it is considered (by taking maximum and minimum) at individual station on monthly basis see table 3.1 and figure3.2 below. The maximum temperature record is during April it is about 19.6C°while July is the minimum temperature, 17.2C°. Annual mean temperature is 18.1C°.

	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
Mean catchment's temperature	<b>18.1</b>	<b>19.1</b>	<b>19.4</b>	<b>19.6</b>	<b>19.2</b>	<b>18.1</b>	<b>17.2</b>	<b>17.3</b>	<b>17.3</b>	<b>17.2</b>	<b>17.4</b>	<b>17.3</b>	<b>18.1</b>

Table3.1: Monthly temperature able with annual **18.1°C** .

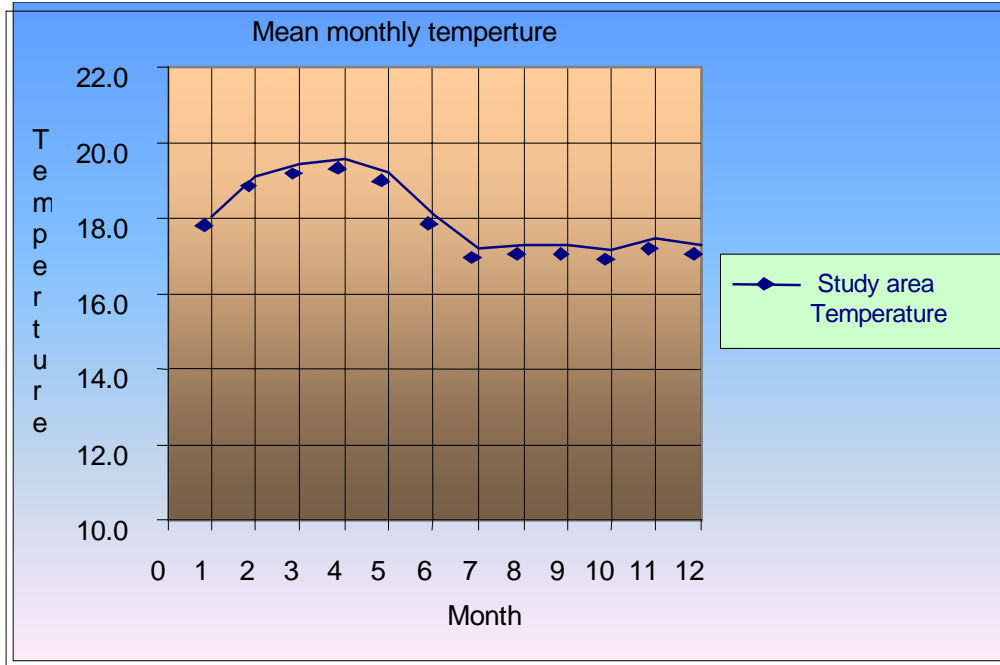


Figure 3.2: Monthly temperature showing narrow range

### 3.1.2 RELATIVE HUMIDITY

Relative humidity is defined as the ratio of the partial pressure of water vapor in a gaseous mixture of air and water to the saturated Vapor pressure of water at a given temperature. Relative humidity is expressed as a percentage and is calculated in the following manner:

$$RH = \frac{P_{(H_2O)}}{P_{(H_2O)}^*} \times 100\%$$

Where:

$RH$  is the relative humidity of the gas mixture being considered.

$P_{(H_2O)}$  is the partial pressure of water vapor in the gas mixture;

and

$P_{(H_2O)}^*$  Is the saturation vapor pressure of water at the temperature of the gas mixture. The relative humidity of a system is dependent not only on the temperature but also on the absolute pressure of the system of interest. Therefore, a change in relative humidity can be explained by a change in system temperature, a change in the absolute pressure of the system, or change in both of these system properties.

The relative humidity data obtained from two stations, Ambo and Woliso. The maximum (79.4%) and minimum relative humidity (44.3%) is during August and February respectively. it is reasonable because august is the month characterized by low temperature and high rainfall that enhances relative humidity. Generally, the relative humidity is above 50% on monthly basis. The annual mean relative humidity is about 59.5% implies the partial pressure of water vapor in the gas mixture is greater.

					MEAN								
					RELATIVE HUMIDITY								
													Annual%
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Mean RH(%)	50.4	44.3	50.5	54	56.7	71.7	78	79.4	76.1	57.6	48	47.8	59.57

Table 3.2: Monthly Relative Humidity usually above 50%

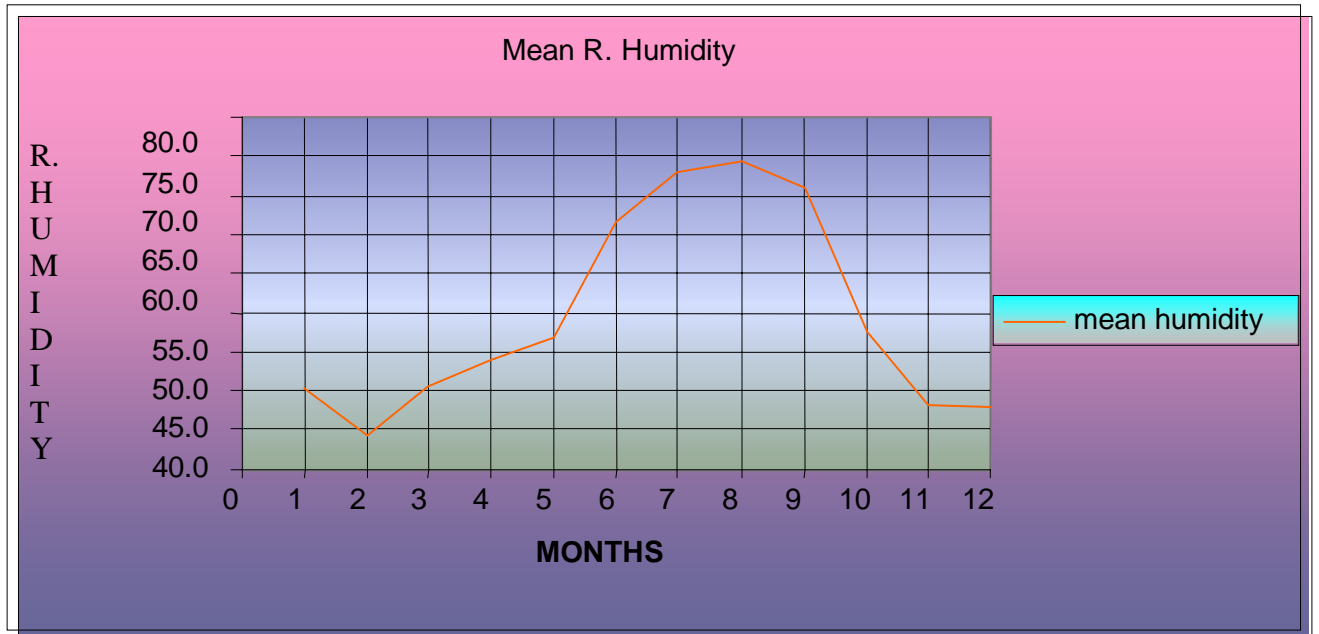


Figure 3.3: Characteristics of relative humidity

### 3.1.3 Wind Speed

**Wind speed** is the speed of movement of air relative to a fixed point on the Earth. Wind is a term applied when talking about the movement of air from one place to the next.

Wind speeds usually mean the movement of air in an outside environment, but the speed of movement of air inside is important in many areas, including weather forecasting, hydrological cycle, aircraft and maritime operations, building, civil engineering. High wind speeds can cause unpleasant side effects. Technically, **wind speed** is given by

$$|\mathbf{v}| = \sqrt{u^2 + v^2 + w^2},$$

Where  $u$ ,  $v$ , and  $w$  are zonal, meridional and vertical components of wind velocity. Except in unusual circumstances (e.g. in cumulus updrafts), the vertical component of the velocity is much smaller than the horizontal

components. Wind speed characteristics of the area is given in the following graph.

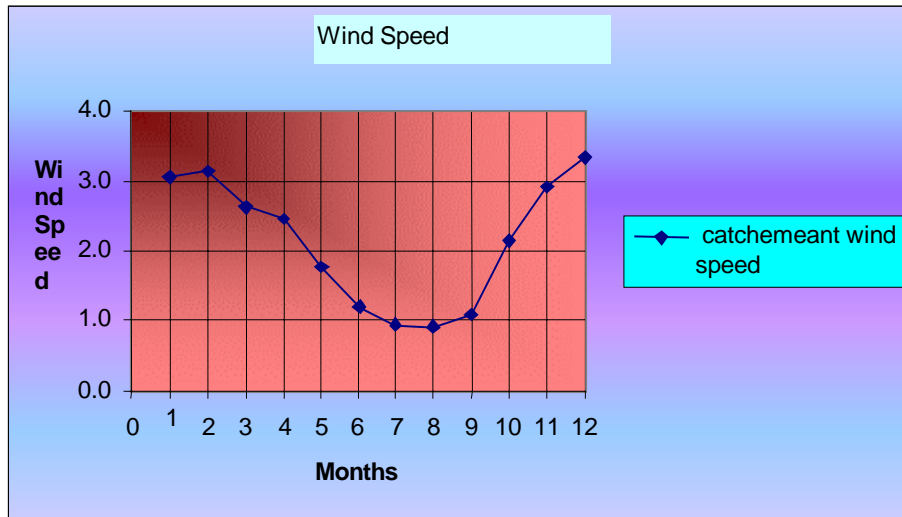


Fig 3.4: Wind speed trend graph

The graph shows that from late May to early September the wind speed is low while the other months relatively experience higher wind speed.

The maximum wind speed of the area is about 3.3m/s, which is recorded during the month December, computed minimum wind speed is 0.9m/s in August.

#### 3.1.4 Sunshine Hours

Maximum sunshine duration is recorded during the month of December it about 10 hours and the minimum sunshine hour is in the month of August it is about 4 hours of sunshine while the average sunshine of the year in the study area is 7 hours.

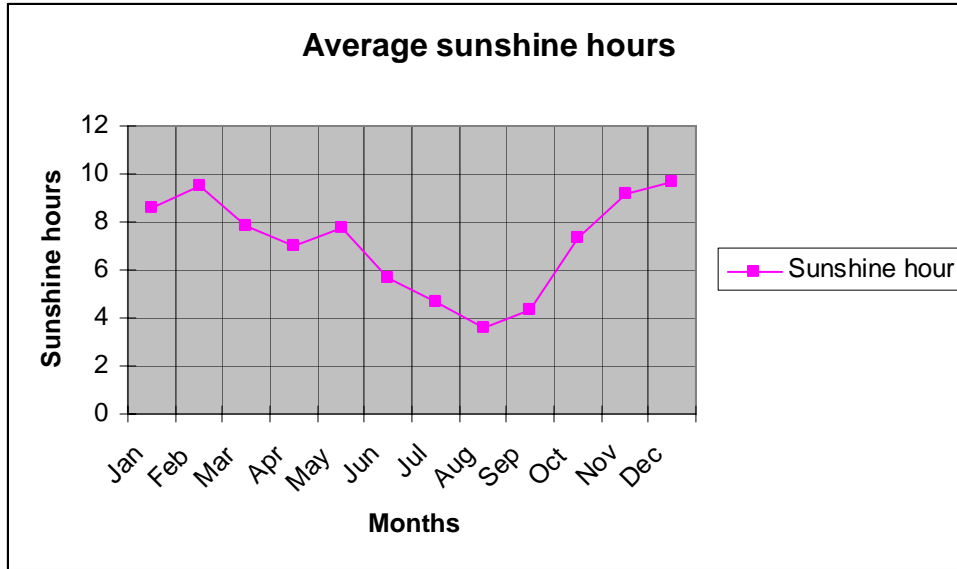


Figure 3.5 . Sun shine duration graph

	Sunshine Duration											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	8.6	9.5	7.8	7.0	7.7	5.7	4.6	3.6	4.4	7.3	9.2	9.7

Table 3.3: Average sunshine hours of the study area.

### 3.1.5 Precipitation

Precipitation is the process of deposition of atmospheric moisture on the earth's surface. It is the general term incorporating the moisture in the form of rain, snow, sleet, dew, etc. However, the major portion of precipitation is obtained from rainfall. Rainfall is the main component of hydrologic cycle it varies with space and time.

The distribution of water on the Earth surface is governed by evaporation and precipitation, which in turn depends on:

- Physical factors refers to geographical condition
- Meteorological factors such as wind speed, temperature, sunshine, etc.

### Averaging of Rainfall

Precipitation amount of a given area is obtained by determining the average of rainfall records over a given period of time. The following methods can be employed to compute the average:

- Arithmetical Average
- Theissen Average
- Isohytal average

Here, Isohytal averaging system and simple arithmetic mean are employed to show the rainfall distribution system of the area. Isohytes are imaginary lines drawn on the earth surface to join the rainfall of equal intensity or precipitation. Isohyets may also be drawn for individual storm over the basin. It has many properties similar to the contours. It assumes that rainfall along isohyets is constant and changes uniformly from one isohyets to the next.

Technically it is given by:

$$R = \frac{\sum_i^n A_i l_i}{\sum_i^n A_i} \quad , \quad \text{Where}$$

R- Average rainfall

A<sub>i</sub> =, A<sub>1</sub>, A<sub>2</sub>...etc. area of influence

l<sub>i</sub> = Precipitation

Number	Rainfall (mm)	Average rainfall (EUD)	Area (km <sup>2</sup> )	Area %	Weighted rainfall (mm)
					EUD*Area%
1	892-1004	948	330	16	151.7
2	1115-1200	1060	342	17	180.2
3	1115-1200	1158	794	39	451.6
4	1200-1297	1249	379	19	237.3
5	1297-1432	1365	194	9	122.9
<b>Total</b>					<b>1143.7</b>

Table3.4: Precipitation depth for each area.

Maximum rainfall= **1432mm/year**

Minimum rainfall= **892mm/year**  
 Mean rainfall= **1143.7mm/year**

From table 3.4 it can be seen that total depth of precipitation is about 1143.7mm on annual basis. Annual regular rainfall starts early June or late May and lasts up to September, July and August receive more rainfall the later get higher amount of rainfall in the year.

The rainfall recording stations are located in the North and South border of the area except Busa station situated near goro Dandi where orographic control is significant. in table 3.5 arithmetic rainfall of the area is given

Arithmetical average is given by the equation

$$\bar{P} \equiv \frac{\sum_i^n P_i}{n}$$

Where,  $\bar{P}$  is mean precipitation,  $P_i$  is rainfall records,  $n$  is number of stations

Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total (mm)
Tulubolo	18.3	18.6	54.2	67.8	78.4	192.9	287.5	277.7	90.6	24.6	7.4	7	1125
Asgori	18.5	32.8	53.6	83.6	67.9	128.1	242.5	239.4	102.2	25.7	6.9	5.3	1006.5
Woliso	23.9	27.4	66.5	84.8	122.8	190.9	271.9	257.3	130.5	40.4	7.6	5.3	1229.3
Busa	21.3	59	55.9	73.7	84.4	179.8	358.2	372.5	164.9	43	10	9.1	1431.8
Wolonkomi	22.8	29.2	66.1	72.4	77.9	154.4	240	234.4	133.7	36	12.2	6.6	1085.7
Ambo	31.87	15.27	52.76	74.65	73.18	149.87	177.2	163.2	87.71	45.83	9.22	11.3	892.09
Ginchi	33.9077	65.93	84.38	105.1	87.46	148.68	238.7	224.3	150.6	32.04	4	16	1191.19
<b>Arithmetic Mean</b>	<b>24.37</b>	<b>35.46</b>	<b>61.92</b>	<b>80.3</b>	<b>84.58</b>	<b>163.52</b>	<b>259.4</b>	<b>252.7</b>	<b>122.9</b>	<b>35.37</b>	<b>8.19</b>	<b>8.66</b>	<b>1137.38</b>

Table 3.5: Arithmetic mean rainfall of the study area annual mean is **1137.38mm**

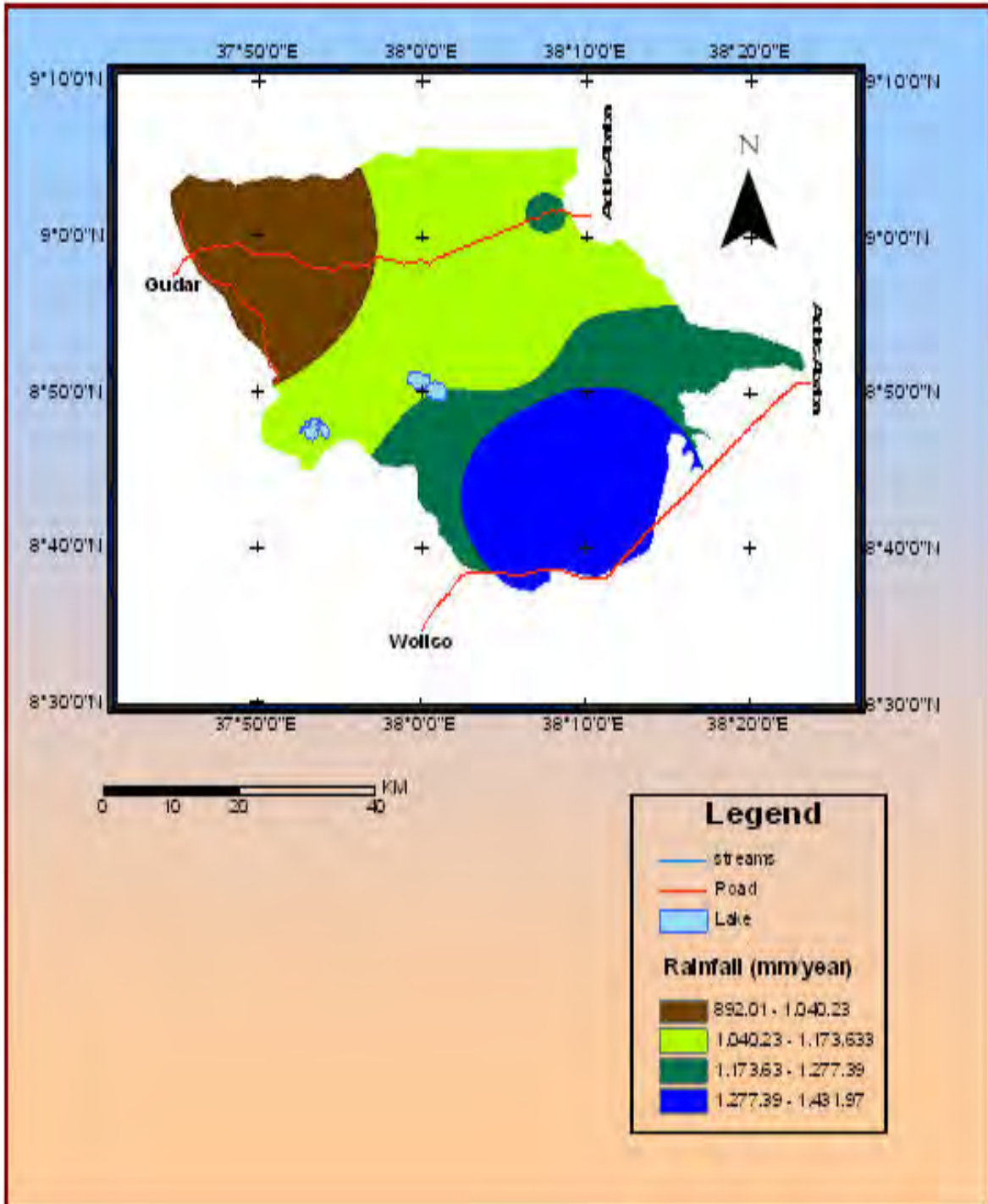


Figure 3.6: Isohytal Map shows Precipitation classification

### 3.1.6 Evapotranspiration

Evapotranspiration is one of the vital hydrometrological components that enable to estimate water lost from the system in the form of evaporation and as well as transpiration that refers to water losses to the atmosphere

Different scholars introduced possible techniques that are applicable based on certain evaporation controlling factors such as wind speed, temperature, vapor pressure, vegetation nature, and etc. These mentioned and other factors weight of influence is not identical at every place.

Here the SEBAL model is employed to compute actual Evapotranspiration (AET) that is analysis of spectral radiances of different land features from remotely sensed satellite image W.G.M. Bastiaanssen, E.J. M Noordman, H , Pelgrum. G. Davids, B.P. Thoreson, and R.G. Allen (2005), technically it is given by

$$R_n = G_o + H + \%E \quad (W.m^{-2})$$

Where  $R_n$  ( $W.m^{-2}$ ) = the net radiation;  $G_o$  ( $W.m^{-2}$ ) = the soil heat flux;  $H$  ( $W.m^{-2}$ ) = the sensible heat flux; and  $\%E$  ( $W.m^{-2}$ ) = the latent heat flux associated with evapotranspiration.

According to this approach the maximum and minimum AET obtained is 641.1mm/year represents those area covered by water and dense vegetation (Wonchi, Dandi and Chilomo area) and 163.9mm/year noticed in bare land area example Becho plain figure 3.7

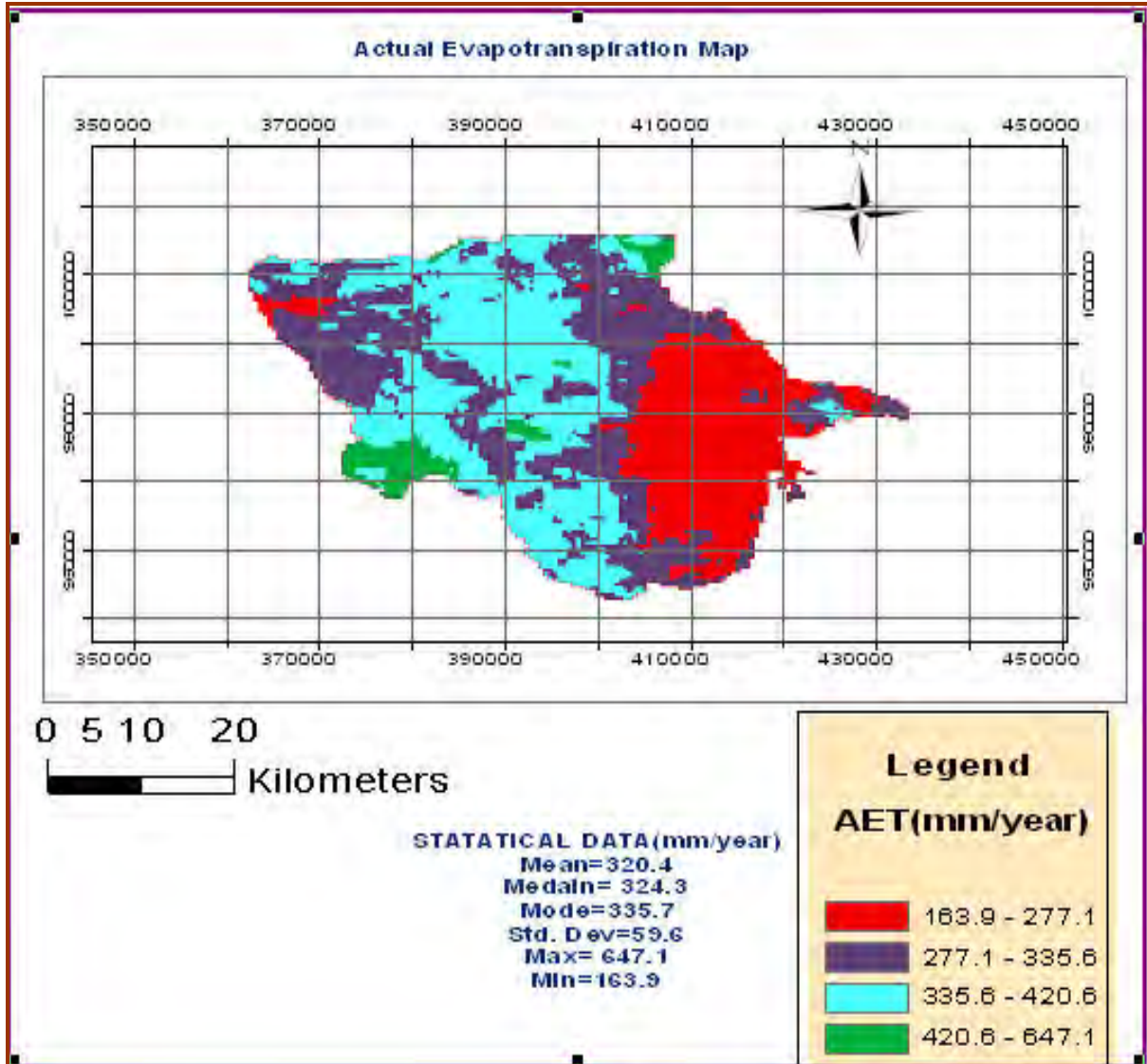


Figure 3.7: Actual Evapotranspiration map produced from satellite images.

### 3.2 Surface Hydrology

Surface hydrology refers to general surface water bodies that may occur in the form of streams, lakes, ocean, sea, ponds, etc. Generally, surface water can be obtained from precipitation, groundwater out flow, irrigation water and other artificially induced source.

Occurrence of both groundwater and surface water depends on several factors such as:

- Geological setting
- Morphological and Physographical condition
- Topographical pattern
- Land use land cover
- Geological structures and Tectonic history.
- Any modification of natural environment.

### **3.2.1 Streams**

Surface water condition in the study area includes streams and lakes. Several perennial and intermittent streams emerge from ridges located in the north and south just parallel to the regional structure, ambo fault belt. Those streams going away from the Dandi and Wonchi Mountains assume radial pattern while streams from the opposing ridge in the north flow parallel to sub parallel figure 3.8

The southern ridge is a kind of triple junction that shades to Gibe, Abay and Awash basin. It is clearly seen that geological structures are the main drainage controlling physical features.

Some of major perennial streams in the study area include: Huluqa, Jaliwean, Qernsa, Dabis, Aleletu, Awash, etc and many more intermittent streams. In the rainy time the intermittent streams themselves carry huge volume of water. The drainage system is highly governed by the regional and local geological structures, perennial streams and seasonal springs occur along the fault lines, fracture and contacts. Presence of intensive faulting contributed for the emergences of numerous cold springs and thermal springs, besides it has enhanced occurrence of groundwater.

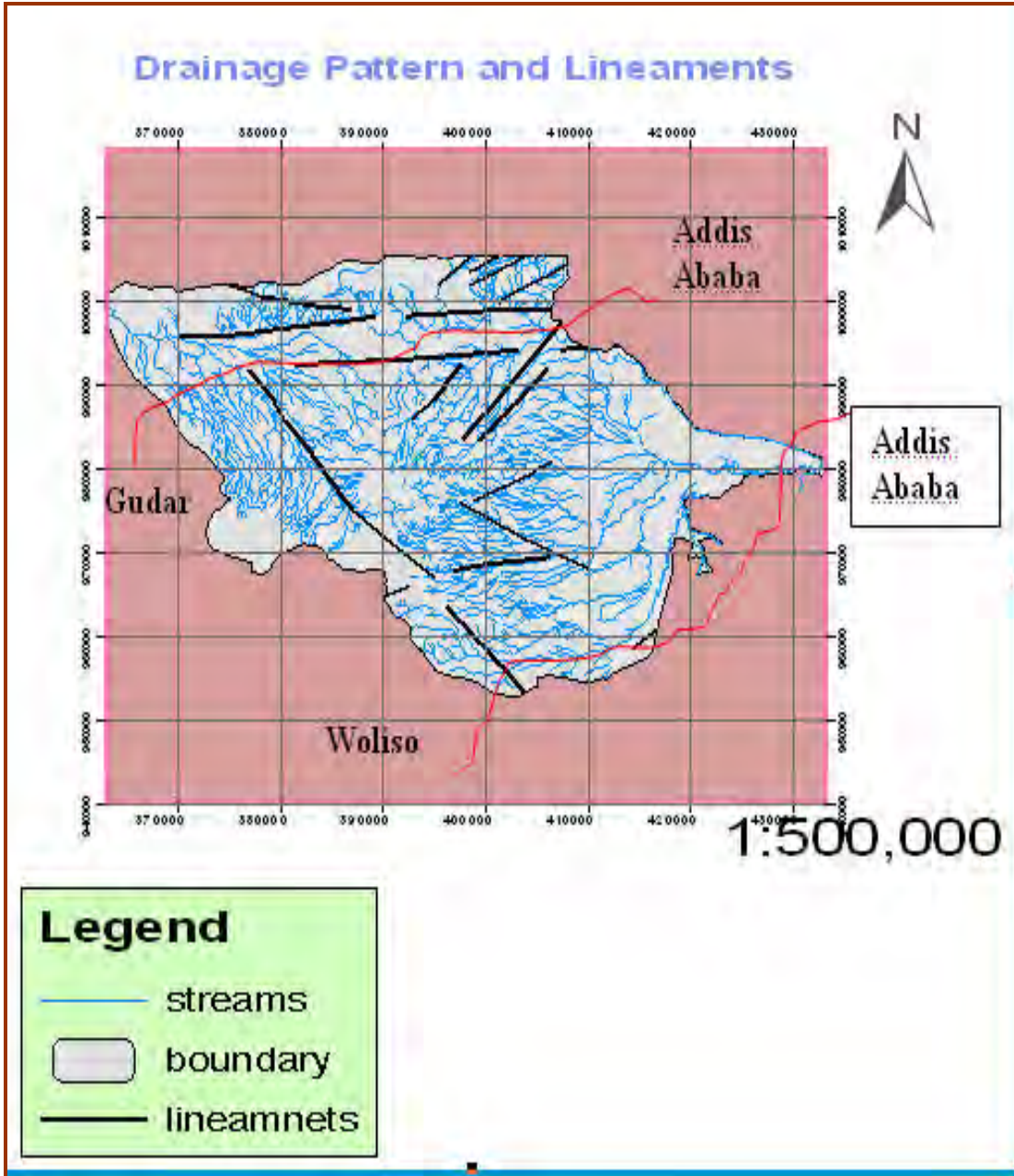


Figure 3.8: Drainage systems of study area

In east of the Dandi volcanic cones, Becho plain receives storms of runoff; Awash and Jeliwan Rivers are the main draining system huge water from the upper slopes through the Becho plain.

There is significant elevation difference in between the eastern plain that dips to main Ethiopian rift and the western plateau of the study area. From the plateau the water storm hurries to the plain where flooding easily spread and displaces people during rainy season. One of Major reasons for flooding is the draining stream widths is too narrow to accommodate enormous gushing floods from the surrounding slopes. Besides, the plane is leveled and the water is incapable of passing with the same velocity it has already acquired at higher elevation.

Moreover, during rainy periods the streams loaded with a great amount of sediments as mentioned earlier the upper catchments of these streams are highly subjected to deforestation, which contribute for fast removal of soil from the area.

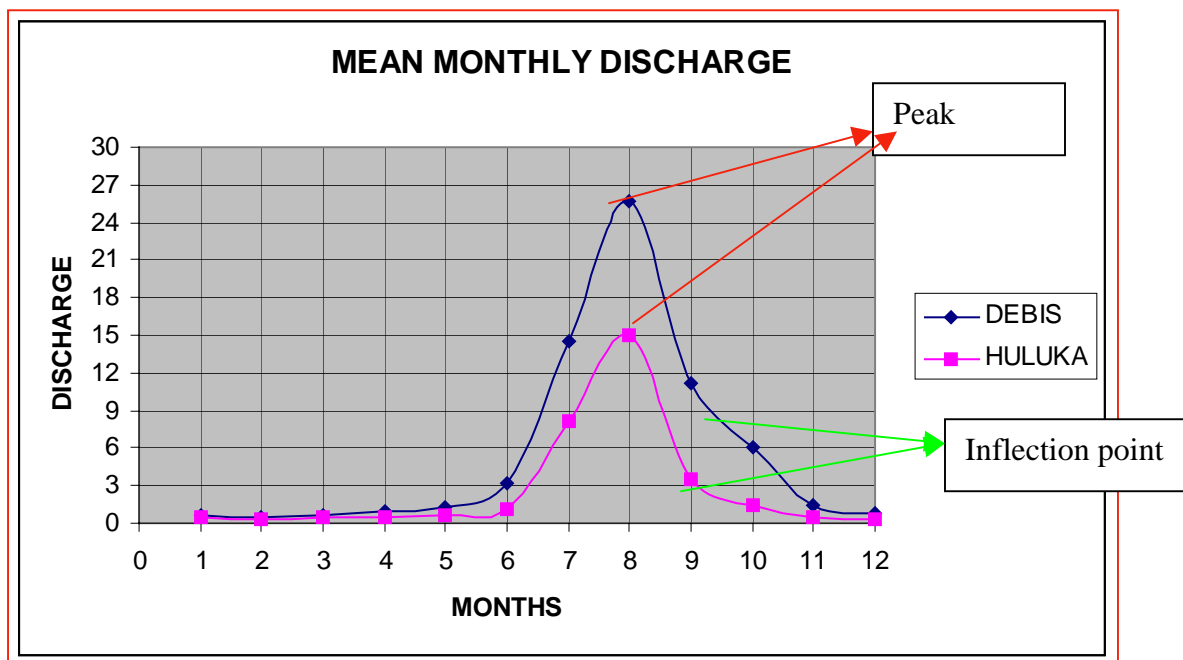


Figure 3.9: Huluka and Dabis hydrograph in million-meter cube (MMC)

Both streams shown in the graph above drain to Abay basin Huluka is from the Dandi Lake as out let while that of Debis is from the ambo fault

belt foot; it share the same surface water divide with that of Awash River, which begins from HerarKura village.

In figure3.9 Debis accommodates more discharge than Huluka this can be linked with geology, length, width and morphology of the streams. Geology may affect stream in a way that facilitating infiltration or overland flow structural control may play key role too.

For both streams, Debis and Huluka the peak month is attained during August, which implies they experience relatively identical rainy Seasons. From the graph it can be seen that there is fluctuation of discharge year to year.

The hydrographs have decomposable parts each part has to do with water flowing characteristics in the streams. Rising limb to attain maximum peak and falling limb from the peak depict period of rainy season and give a clue about the sources of water in the channel.

In the Above hydrograph of Huluka and Dabis the peaks points coincide and stand for maximum runoff time in the month August, normally the area receives more rainfall during this month; it confirms that the stream carries extra water contributed from overland flow and/ or subsurface flow.

Inflection point onward discharge is assumed from groundwater, which is known as base flow that implies groundwater emergence from the ground at a place where water table crosses the surface or else following structural controls.

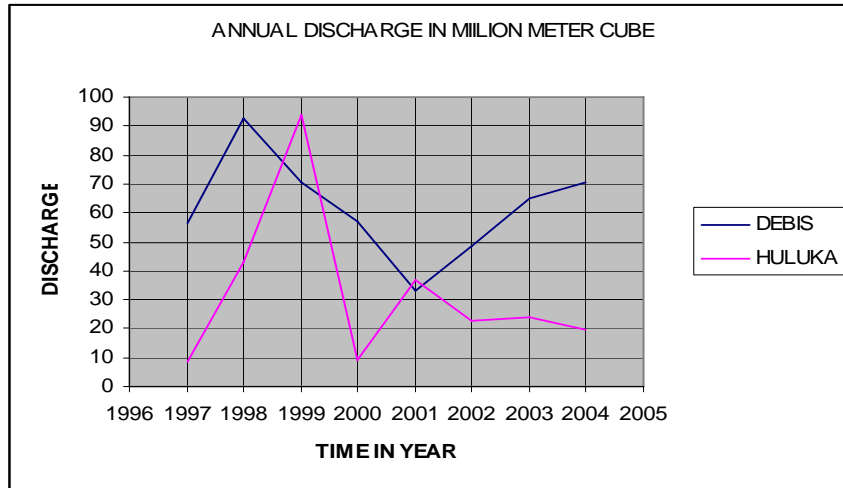


Figure 3.10: hydrograph of Total Annual Discharge

Here Jemjem makes up the upper Awash together with the initial source of the stream located at west of Ginchi on the Chilimo Herarkura range. Jemjem is adjacent of Awash source starts from north of Chilimo near Ginchi town. It may be responsible in recharging Gaji hills from which foots Berodo spring emerges between Holonkomi and Ginchi.

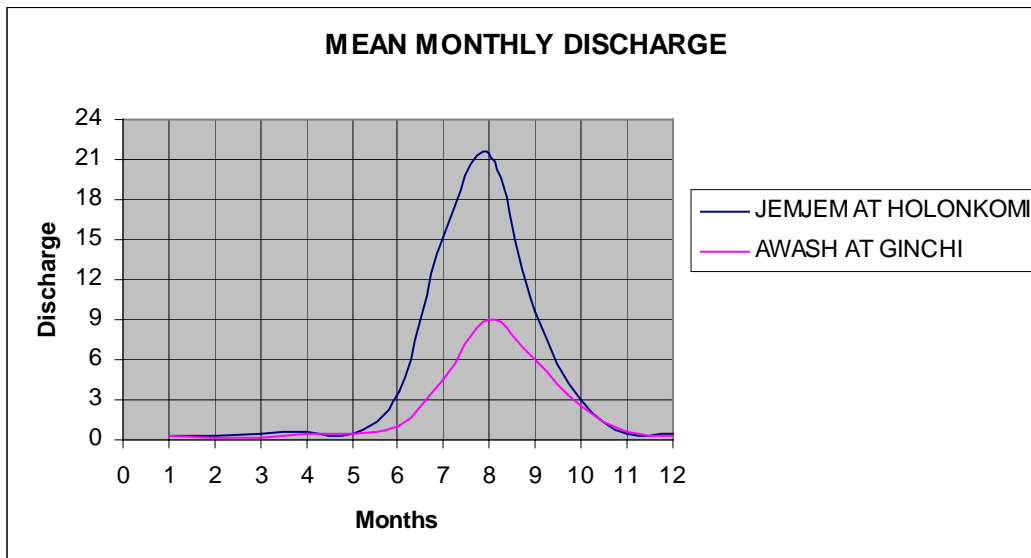


Figure 3.11: Hydrograph showing mean monthly discharge in million-meter cube.

Moreover the streams merge with Awash before it reaches Becho plane, and make up the very upper awash as Perennial River and continues to Somalia drenching Ethiopian rift. The upper Awash is responsible for flooding of Becho plane where many people suffer displacement especially if the season is accompanied by heavy rain.

In rainy time the streams are overloaded with vast sediments that brought by gullies as overland flow washing away from the adjacent slopes, for instance streams joining Awash River leave some of their burden on Becho plane. Huluka and other streams flowing to Abay basin also carry a lot of soil taken from stripped lands, once covered lands by vegetation and grasses become naked and washable at ease.

### **3.2.2 Lake**

Dandi and Wonchi crater Lakes are other important surface water resources in the area. The origin of these Lakes is linked with volcanic centers oriented East-West. They are fresh and the only central highland far west rift escarpment lakes located at high point (>300m.a.s).

Dandi is an 8 km wide caldera in central Ethiopia, quite close to Wonchi caldera. Dandi's rim is made of poorly consolidated ash deposits. The broad flat floor contains two shallow crater lakes. The most remarkable thing in Dendi is a wonderful, brightly painted Coptic Church. The peak of the Dendi volcano is Mt. Boti, and Lake Dendi lies 118 meters below this point (Smeds Helmer, 1964).

Wonchi is a 4.8 by 4.0 km wide caldera in the central Ethiopian highlands close to Dendi caldera. Wonchi contains a single crater lake about 450 meters below the rim of the volcano. Passage into the caldera floor is via a narrow gash worn through the caldera rim by a small stream. It is possible that Wonchi was active as recently as A.D. 550

Smeds, Helmer (1964). Flooding of the lake at that time may have been due to an underwater eruption that raised the lake level, killing many trees on the previous shore. Wonchi's caldera is as much as 900 meters deep, and lake itself could be as deep as 400 meters.

Now a day Wonchi Lake has got more recognition than Dandi, located east of it. Tourists are visiting; development work is on going around the lake. Population density is ever increasing and put a pressure on existing natural resource including the Lake.

However besides any kind of resource utilization proper attention should be given to the ecological balance where by resource sustainability can be ensured.

Professional designed plan is essential to prolong the resource from any kind of spoil such as contamination that potentially alters the chemistry and its aesthetic value even disappearance. Obviously, it is our recent memory that Ethiopia rift Lake are retreating and drying as a result of limitless interference and lack of proper management. Such problem is not limited to a given area and society rather poses impact everywhere as long as interaction is there. Hence it is advisable to take wise measures and feel responsibility during resource utilization.

### **3.2.3 Springs**

Springs in hydrogeology represents out flowing of groundwater from the saturated zones as a result of hydraulic head difference between recharge zone and discharge zone here the driving force will be gravitational energy this holds true for cold springs. Point of groundwater table intersection with the surface is known as eye of spring or the contact point between the atmosphere and the emerging water.

In case of thermal spring the driving force is association of geothermal gradient and/or cooling igneous chamber. The thermal springs are manifested in response to high energy developed from boiling of water in the crust. Cold water circulating beneath may come in contact with hot magma chamber or gain heat from geothermal gradient increment with depth. Heated water forces its way upward following defined routes such as faults and fractures.

Numerous, springs emerging from the ridges are remarkably fresh water resources of the area. There are several springs, occur taking advantage of structures, contacts and topography. A considerable yield springs flows out of Dandi-Wonchi mountain range. Those springs flowing to the east at the foot of Dandi Crater Lake appear as depression springs, OAO spring at Tulubolo, Bashi springs in between Busa and Boda together with springs in Becho plain are examples of topographical controlled springs.

Most springs are flowing toward North from the volcanic center aligned E-W and to the south from the Ambo lineament oriented parallel to the volcanic centers. Springs merge to each other to form perennial streams, for instance structure controlled Qerensa stream is just a spring which source is below Goro Dandi on the way before it joins upper Awash near Ginchi more springs for example Arbu, Shone, Molche, Koromi, ect flow to it.

Shone at central part, Hora Chancha east of Ambo at Awaro, Homi at foot of ambo fault belt in wodesa are cold spring governed by localized and time to time propagating fractures, the mentioned springs clearly seen that their emergence is due to the presence of geological structures that allow the out flowing. Bukisa Spring near Meti town, serves for water supply of Bollo village, comes forward through well defined massive fractured (with considerable spacing and density) basalt.

Most of these springs are perennials and represents shallow circulating groundwater; when it is dry time the rate of discharge decreases in wet season the yield is raised gradually. Moreover seasonal springs also occur starting from the beginning of mid June until mid-September.

The local people claim that now days a lot of springs are drying and diminishing in yield, this can be related with ever increasing population pressure and subsequent impact such as deforestation, over utilization, land use system, rainfall duration and amount etc.

Generally, springs in the study are very crucial from water supply point of view. Most high land inhabitants rely on spring water source for drinking purpose sometimes for local small-scale irrigation where the yield is high and topographic setting is conducive to drive water by gravitational force.

Distribution of springs is well known by the local people as their lives are highly linked with surface water. Those slope inhabitants' in the north and south part of the study are dependant on springs and streams for water supply. Even the down stream part settlements depend on such water body for themselves and their livestock.

The pathway of this springs are governed by structures, topography, geology and availability of shallow circulating groundwater. The fractured trachaytes in the north and highly weathered basalt in the south are key sources for these springs. Local macro fracture and growing faults are responsible in many cases to facilitate pathways.

**Thermal springs** manifestation is noticed around Ambo ,Wonchi,and Woliso town their manifestations are credited to Dandi and Wonchi volcanic center. The residue of cooling magma beneath the volcanic center might have been responsible for the origin of thermal spring,

which emerges through structural conduit in Ambo area. Hot springs in ambo town are located along Huluka River right and left bank just below the main bridge of Huluka near swimming pool, at the swimming pool north side there is hot spring flowing into the pool, Ambo bathing center also caped this hot springs for commercial purpose.

The guiding path for these springs is the structure oriented east west north- south, which defines the path followed by Huluka stream. In woliso the hot spring emerges just following NNE and SSW oriented structures.

## **4. HYDROGEOLOGY**

### **General 4.1**

Hydrogeology is the study of groundwater and geological formation relationship. Geology of certain area may describe what groundwater occurrence suppose to be in that environment in similar manner groundwater commonness give a clue about the terrain type or geological formation.

Groundwater versus geology is an important science in that understanding their coexistence or how they manipulate their nature due to their very tendency of behavioral exchange.

Availability of groundwater in addition shows us what kinds of hydrolithological unit present, of course not only their presence rather give a clue about type of hydrolithological unit which can be known by studying the chemistry of both. Hence, groundwater and geological media exchange signature that bears their coexistence spatially and temporarily.

Practically the aquifer nature of geological formation depends on several parameters such as; Hydraulic conductivity, Transmissivity, Storage capacity, Hydraulic gradient, Percentage of porosity, Macro and microstructures (primary or/and secondary), ect. These properties refer to modification of geological materials during their origin and on going processes.

Subsequently, the modified rock can be rated as impervious or pervious from water bearing viewpoints. Impervious units indicate those hard rock formation mainly act as water bearing formation sealing or confining stamp which include.

- Most fracture lacking crystalline rocks

- Massive basalts and igneous intrusive
- Intact rhyolite such welded ignimbrites and trachaytes
- Hard carbonates rocks example limestone and dolostone
- Shale and intact sandstone

Permeable geological media stands for formation, which let percolation of groundwater at ease. Formation into which water (precipitation) easily infiltrate termed to be unconfined aquifer but if there is overlying lithological unit to prevent direct soaking of water in to water bearing formation it is called confined aquifer. In such case there should be specific location where water can enter the system beneath the confining layer.

Geological structures plays crucial role in creating ways for groundwater infiltration just by interrupting the lateral continuation of confining unit. At the point of discontinuity recharging will take place to enrich the groundwater.

When groundwater totally filled every opening of the soil or the rock the zone is known as saturated zone and the imaginary line drawn in between the fluid filled and partially filled media is water table line; water obtained fro confining aquifer is known as artesian well this is because it is controlled by pressure rather than gravity.

In hydrogeological study recharge and discharge zone identification is so essential in order to utilize, manage and protect the resource. Both cases are influenced by several factors:

Geological formation considered being suitable for groundwater might include.

- ✓ Unconsolidated alluvial deposit or sediments

- ✓ Fractured hard rocks: carbonate rocks, crystalline rocks, etc.
- ✓ Vesiculated scoriaceous basalt.
- ✓ Un welded rhyolite example coarse pumice
- ✓ Any kind of geological unit with good porosity.

#### **4.2 Hydrolithology of Study Area**

Hydrolithology refers to lithological response to groundwater circulation and accumulation. As discussed in the general part lithology of certain water shading could be water passing or preventive. Both types are important in hydrogeology because if all rocks are porous attaining saturation is will be difficult, being impervious alone as well has its own shortcoming for it is with out water.

As explained in the local geology of the study area two terrain types are identified: volcanic and sedimentary the later is minor unit, pinches out near Ambo town west end of the study area.

The Mesozoic unit that does not extend in the east farther than Ambo town absorbs:

- Sandstone
- Mudstone-Shale
- Limestone.

The sedimentary unit constitutes Adigrate sandstone, minor intercalation of shale and limestone under the sandstone on the way to Gudar from Ambo. The sandstone is moderate Aquifer and tap mineral water in Ambo sankale (Ferdinad.H1983) while that of shale is confining bed.

The sandstone is relatively intact and cemented by iron oxide and silicon, especially colorful sandstone formation exhibits bands of colors imparted from cementing minerals, though costly it is preferred for construction on the basis of its dual purpose, durability and beauty.

Unlike the gray colored, outcropped on north of Dabis stream the aforesaid one is characterized by low permeability and shows uniform texture where every grain size grow to each other to fill every voids that can exist as primary porosity. The later posses secondary porosity fractures and less cemented as compared to the earlier.

Generally, the sandstone is considered as confined aquifer fore example Ambo mineral water source formation is designated as this formation Lemessa Mekonta (2001) having the confining layer as Mudstone-shale unit and basalts. The shale unit is not continuous confining layer; somewhat it is localized and found as minor intercalation.

Volcanic products over dominate any type of lithology in the area and believed to be as influential groundwater controlling media. As several borehole log of volcanic area show it is difficult to generalize aquifer nature of the whole based on certain data. In such area hydrolithology heterogeneity with depth and lateral extent is inevitable. The volcanic rock type supposed to govern groundwater system may include:-

- Quaternary basalt,
- Amba Alaji rhyolite,
- Tarmabar scoracious basalt,
- Tertiary Trachaytes, and
- Tertiary ignimbrite.

These listed units are the map able ones; practically there are diversified volcanic products that may determine groundwater occurrence and

movement. Such temporal and special heterogeneity of lithology has to do with unevenness of aquifer parameters:

- ♣ Hydraulic conductivity,
- ♣ Transmissivity,
- ♣ Storativity,
- ♣ Permeability, and
- ♣ Porosity and the likes.

In general, volcanic products spread over the large part of the area from the east west running volcanic centers south border and north counter part ambo lineaments. The groundwater occurrences, discharge, recharge and distribution is largely influenced by the basic and acidic rocks apart from west end Mesozoic sediments (responsible in tapping deep groundwater). Alluvial deposit in the eastern margin (bechoplain head), has large contribution of shallow groundwater provision at depth of 0-5m in the rainy season and 5-12m in dry time. Apart from this, Goda Geber is one of marshy alluvial deposit area in becho plain where local people easily develop hand dug wells that serve for drinking and other purpose, the deposit also has significant function in providing shallow groundwater, allowing recharge to the lower acidic overlain scoracious formation which serves as potential aquifer.

Acidic volcanic products cover Dandi Mountain step slope; rhyolite, ash and tuff. Ash deposit is observed at the rim of Dandi crater and the low lying area in the east also show presence of acidic materials which include trachaytes, ash, tuff and ignimbrite in between the trachaytes and ignimbrite there is basaltic flow all around from woliso to Ambo.

Here, the Ash is characterized by low permeability; typically act as aquitard similar to clay material because of its grain size fineness low permeability to allow passage of water easily to the storage. In some

cases coarse grained pumice is there in association with the ash deposit and it is imperative aquifer provided that secondary fillings do not close the primary porous gaseous cavities, developed in the time of pyroclastic eruption in contemporaneous structure with the rock, the fine grained ash and the coarser pumice manifests phases of eruption.

#### **4.2.1 Trachaytes**

Trachaytes flow from the Dandi -Wonchi volcanic centers mountain range is affected by weathering clearly the rate of weathering is not uniform through out its distribution. The outcropped trachaytes has undergone alteration due to various factor that may include climatological change, biological weathering, ect. Trachaytes exposure on Tuluboda, Golole, and Cheffe qerensa shows fracturing and high weathering effect. There are also places where slightly weathered and intact trachaytes is observable; this is outcropped along some streams just below the Dandi slope.

Exposure of trachaytes in Qerensa stream appears to be very dark in color that is reaction result with iron mineral otherwise lighter when broken. Generally, the fresh part of this unit is impervious as compared to the weathered and fractured parts. Many perennial springs in the central part of study area emerge along the openings of this unit. Normally, in such hard rock terrain fracture and the matrix of the rock is vital in controlling groundwater system.

In figure 4.1 the springs emerge at Qerensa Stream bank from the fractured trachaytes which evidences the lithology can allow both recharge and discharge. Figure 4.1 spring source is could be the eastern Qerensa stream plain of Hubato (Goda Lafen) here the ridge over topped by plain and followed by steep cliff on its rim of west and north part in

the direction of the stream that flows in the direction of N-S running structures. The top flat part together with the slope covered by the trachaytes formation, the earlier is covered by grass and the later is by varieties of vegetation, which may induce farther weathering as roots of the trees advance in to it. Grass covered topped part facilitates recharge slowly in to localized openings, which tend to saturate soon.

In late July (heavy rain time) the area become marshy and covered by water this implies that saturation is attained and also the trachaytes has opening as fracture which tend to be filled soon if that is not so the area can not reach saturation point at ease in letting available water on the surface.



Figure 4.1: Ashane perennial spring flowing through fracture at Qerensa stream bank.

Personal contact with some geophysists who conduct geophysical investigation near becho plane at east slope of Dandi range under instruction of Water Works Design and Supervision Enterprise emphasis that there is deep sitting fracture in the trachaytes formation and labeled

as essential water bearing structure. In the case of trachaytes formation its water bearing nature is restricted to the secondary porosity than the primary.

#### **4.2.2 Tertiary Ignimbrite**

As mentioned earlier in the geological part ignimbrite demarks eastern tip of the study area extending all along the Becho plane. Regionally ignimbrite covered area designated as aquiclude, which may not hold true as whole when viewed at local scale though the unit has no appreciable permeability. Drilling work accomplished in the area testifies the presences of other materials like ash, scoracious basalt. In addition structural influence and weathering effect altered the nature of the unit which in turn tends to improve the permeability, commonly secondary porosity faults, fractures, joints, types of contact; etc are more useful than scarce primary porosity in such hard rock terrain.

The artesian well developed in Becho plain confirms that ignimbrite is confining layer, implying low permeability hydrolithology. In figure 4.2 cross section taken W-E based on the boreholes data it shows the ignimbrite is impervious unit below which weathered basalt, scoria, seldom-massive basalt, clay interblended with scoria unit are the prominent formation considered as good aquifer in the area. Recharge probably takes place along the faults figure 4.2 located near the conduits of volcanic center and at the base of the slope more over the outcropped basalt unit in between the ignimbrite and the trachaytes also most important site which transfer water toward the formation lying below the ignimbrite.



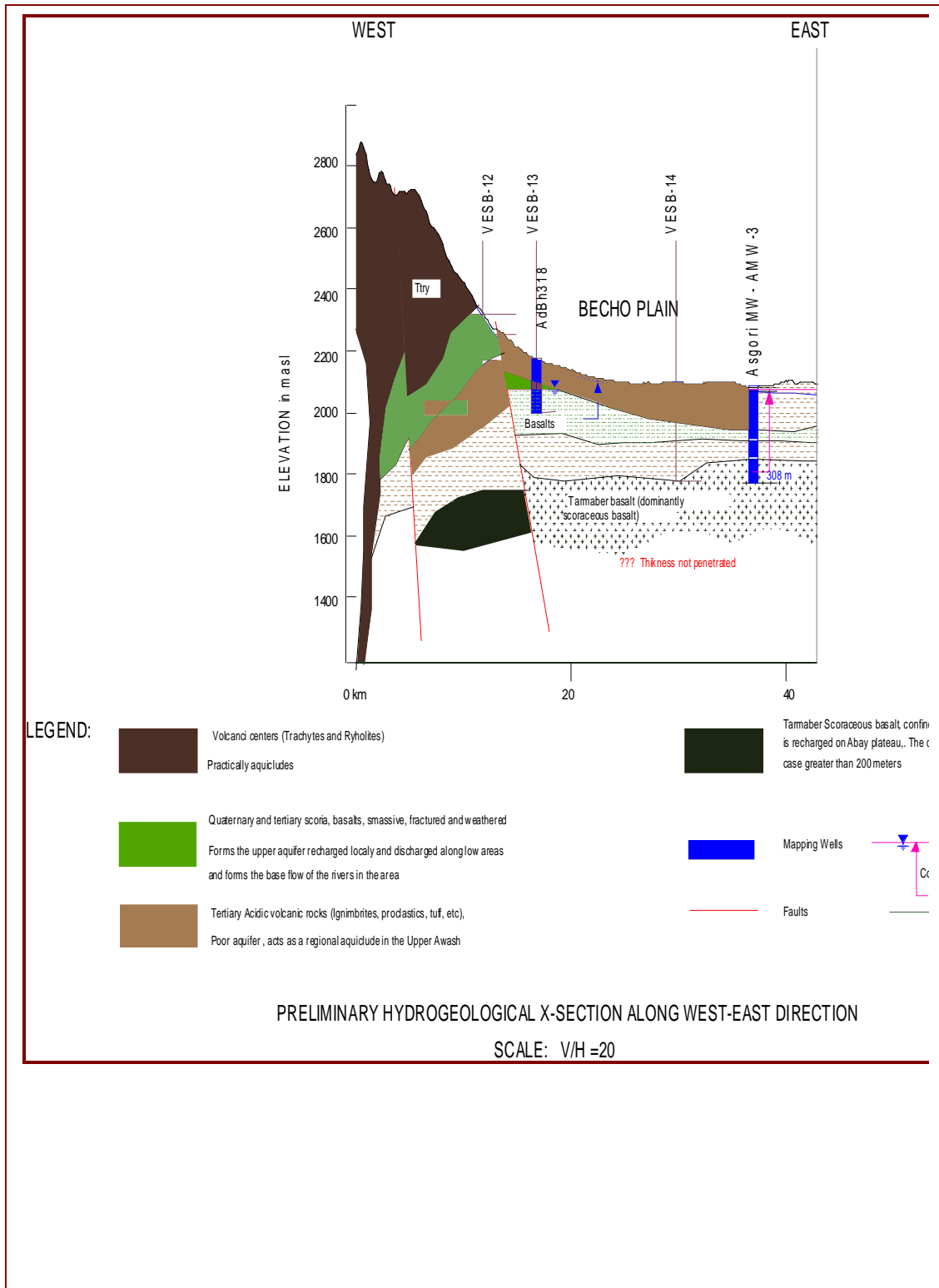


Figure 4.2: Hydrolithological cross section Modified after Water Works Design and Supervision Enterprise prepared by Engda Zemdagnhu, 2007 not published.

### **4.2.3 The Basalt**

The woliso-Ambo basalt is one of important hydrolithology in the area. It is intensely broken and dissected by small scale growing structure and map able lineaments show also other secondary structures and primary porosity such as vesicles. The presence of those principal geological structures uncovered the unit to further weathering and disintegration on the scale of continues geological processes. Due to the effect the lithology come into good aquifer that serve as recharge and discharge controlling.

Occurrence of plenty of springs also strengthens its suitability media to transfer water in to and out of the system. In southern part of the study Area near Woliso borehole construction in Obi (between Woliso and Tulubolo) peasant association indicates that basalt is major aquifer. Borehole, liyhological log description is given in table 4.1

Depth	Description	Table 4.1 showing lithological log in the Ambo Wliso Basalt
0-2	Black cotton clay	
2-10m	Brown silt	
10-16m	Alluvial sand	
16-32m	Fresh basalt	
32-38m	Highly weathered basalt	
38-42m	Weathered basalt	
48-54m	Fresh basalt	
54-60m	Highly weathered basalt	
60-68m	Fresh basalt	
68-80.6m	Scoracious basalt	
80.6-82.6m	Fractured basalt	

From draw down data some aquifer parameters characteristics are given below

- Transmissivity (T) =  $\frac{Discharge(Q)}{Drawdown(\Delta S)} = 214.02m^2/day$
- Hydraulic conductivity (K) =  $\frac{Transmissivity}{aquiferthickness} = 2.59m/day$
- Specific capacity (S.C) =  $\frac{Max.yield(l/s)}{max.drawdown(m)} = 1.153l/s/m$
- Safe yield (S.Y) =  $S.C * Watercolumn * safetyfactor = 27.67l/s$

In the north part of the study area around Ambo, Meti, Asgori, Awaro area the lithology is very crucial aquifer. As log data demonstrate basalt occurs being fractured, weathered and as intercalation with travertine, soil, etc. Geological formation obtained from Awaro and Meti (about 5km and 10 km East of Ambo on the way to Addis Ababa respectively is shown in the table 4.2 below

<b>Awaro area geological log</b>	
Depth (m)	Geology
0-30	Clay and ash dominated
30-68	Weathered and fractured basalt with scoria tuff intercalation
68-96	Fresh basalt (fractured?)
<b>Meti Area geological log</b>	
Depth (m)	Geology
0-6	Soil, gravel and boulders, alluvial Origin.
16-58	Slightly weathered and fractured basalt
58-76	Sand, gravel, pebbles with highly weathered pyroclastic deposits
76-82	Slightly weathered and fractured basalt
82-106	Gravels and pebbles

Table 4.2; Lithological data around Ambo from Awaro and Meti water supply Boreholes

Awaro area potential aquifer weathered basalt and fractured basalt overlain by confining layer of ash and clay, therefore here the basalt is confined aquifer may receive recharge along the major and minor deep setting faults. The subsequent underlying massive fresh basalt probably fractured due to the intensive buried and visible faulting effect.

Unlike Awaro in Meti area the overlying and the immediate basalt together with subsequent units that continue up to the depth of 106m appear to be useful formation in their water holding capacity.

Ambo town three boreholes lithological log also indicate that basalt is preferable aquifer in particular. It occurs now and then as intercalation and thick well-defined unit here also as can be seen from table 4.3 in some borehole it is affected by weathering and make the very upper part of the formation starting from the surface, and behaves as unconfined aquifer, but here does not mean that there is no massive compacted

basalt at all that with stand water movement rather possibly encountered both with depth and lateral extension

Ambo Borehole log Summary Data	
<b>Well 1</b>	
Depth	Geology
0-40	Basalt
40-100	Volcanic ash
100-150	Sandstone
<b>Well 2</b>	
Depth (m)	Geology
0-5m	Weathered basalt and travertine
5-20m	Basalt
20-35	Tuff and pumice
35-93m	Tuff at its upper part then clay
93-131m	Basalt
<b>Well3</b>	
Depth (m)	Geology
0-2m	Soil with basalt fragments
2-55m	Basalt with some gravels, tuff mud with clay as soil horizon
55-103.5m	Dominantly clay with small proportion of peat and gravels

**Table 4.3:** Borehole log summary data, drilled in Ambo Agricultural Institute during 1975. Basalt appear to be unconfined aquifer in all wells

In general, basaltic formation is encountered as multi layer confined and unconfined aquifers in the study area and it is found to be the best water holding media, which attributed to its being affected by geological processes.

In association with basalt, scoriaceous materials are crucial formation in transferring and accumulating water. This unit is found to be good aquifer, its exposure is encountered along the ambo fault belt, in the central part of the study area figure4.3 it is distributed as a cone and some time found in association with other lithologies as observed during borehole drilling. Fore example Tarmabar scoriaceous basalt along Ambo lineament is believed to serve as recharge inducing components. The red colored scoria show dense vesicles of interconnected primary structures, which is very suitable in maintaining groundwater circulation and

storage. The unit is responsible not only for recharge but also vital source of plentiful perennial and intermittent streams and springs that emerges at the base of the slope and along structural controlled routes.



Figure 4.3: Cone of scoria in central part of study area

#### **4.2.4 Alluvial**

The alluvial deposits around Meti has significant importance such formation is not limited there rather it is available here and there. However; it might not be the same age group those lying below the recent volcanic probably belongs to post rift processes while recent alluvial deposit has been originated from slope materials transported to low lying adjacent plane in all direction. The alluvial deposit is found to be indispensable water tapping aquifer, in eastern part of the area (around becho plane) hand dug wells are simply developed in the soft unconsolidated river transported aggregates using local digging tools.

The reason for this material to be obtainable in some area can be linked with geomorphology and topographic settings. As mentioned in the physiographic part, the north and southern portion is distinguished by parallel volcanic landform that rose to highest point in turn denudated and dissected by regional and local structures. Taking the advantage a lot of perennial and intermittent streams explode to all direction from the summits of mountains and hilltops (volcanic plugs) where by slope materials are carried away fast to the surrounding flat low lying bottom where the load is leftover.

### **4.3 Recharge and Discharge Condition**

Recharge stands for the down ward percolation and all direction movement of water in order to fill the vacant space of geological materials. The recharging water may be economically exploitable or not.

Recharging can be point and/or diffusive based on existing situation that affect the transfer. Moreover groundwater recharge system could be classified as regional, intermediate and local; in such case the groundwater could be confined to the local boundary or imported from one basin to the other.

We call discharge when down ward soaking water tend to emerge along weak zone or any other preferential path exist naturally or artificially induced pumping to suck from the store.

Normally, the recharge and discharge condition in the study area can be discussed considering the following leadings:-

- Land use and land cover
- Geology
- Climate
- Topography

- Geomorphology
- Tectonic activities (geological structures)

In the study area rainfall is one of major recharge inducing elements for there is no visible water source coming to it; as precipitation increases a lot of springs begin to emerge along the fracture, routes paved by geological process.

As discussed in the local geology part most of the area is characterized by a kind of volcanic hard rock terrain that potentially with stand infiltration, in some are it is common to encounter impounding formations fore example ignimbrite which comprises tuff, ash and welded gray colored aphanitic rock units, massive basalt and light colored trachaytes.

Naturally these units are not favorable to allow recharge, but thanks to geological activity it is clearly seen that the units have been undergone modification that restructures and reworks out. Weathering activity, Fracturing, a large scale and local faulting let the material to be suitable to facilitate recharge.

The soil cover also vary from place to place the fine red clay cover is more observable around the southern half which comprises the gentle slope north west of Dandi Mountain around Golja, Golole, Boda, and Dule peasant associations with stand infiltration.

There are also places where recharge seems practical through good alluvial surfacial deposits, eastern of Dandi and Boda Mountain, the immediate flat area lying below south of ambo fault belt which ran parallel to it are suitable zone to facilitate recharge and discharge.

On top of this vegetation and grass-covered area exist in the study area normally from personal observation unlike this day in the area there were large grass and forest covered locations even today the remnants are there and it can be considered as potential recharge inducing sites. Recently drilled borehole in Go'da Facha (Boren Plain) the mid way between Ambo and Ginchi is grass covered and from this borehole data it is found to be satisfactory yield to serve more than 4 peasant associations, one of the reason for good reserve of groundwater besides other factors is probably due to the grass water trapping nature and smoothing progress of slow infiltration.

In case of vegetation they are mainly limited along hills, mountain slopes and riverbanks, in association with geological and climatologically condition it is crucial recharge supporting components.

Most vegetated slope are cleared off their vegetation and exposed to erosion in rainy time more soil is carried to the basin along gullies and streams slope farmlands less recharge triggering than vegetated one.

In figure 4.4 and 4.5 below influential physical appearance samples of the area are presented, each has to do with in influencing groundwater recharge and discharge situation.

The basalt fracture in the figure indicates flow path of water in such area is limited to available openings as far as the rest is massive. Resource evaluation and exploitation in such aquifer system requires precautions in locating perfect site to tap the groundwater already held in the fracture and matrix of the rock.

Figure 4.5 shows Geomorphology and Topographical setting of the area, have key role in the process of groundwater and surface water

interaction in most case topographically high points are recharge region with expected local discharges while the flat plateau confined between the Ambo lineament and the southern volcanic centers in the direction of east west together with south eastern side extensive west margin of Becho plane serve as both recharging and discharging zone. High velocity surface water (runoff) and groundwater from the mountains and hill slopes rush down to the next leveled bottoms where the surface water has more chance to enter the ground because of slope gentleness the rest drained out as runoff from the system. Occurrence of swampy, wet, small ponds together with several springs indicates topographical influence in addition to other factors.

The gorges, valleys and dissections refer to action of denudation and tectonic activity. The lineaments oriented NNW-SSE and W-E are important groundwater and surface water controlling factor usually the structures believed to continue to the basement there by serving as path of water to the deeper aquifer system. Moreover the effect of morphological shape clearly has caused surface water divide likewise the deep seating structures might have controlled the groundwater divide.

Climatologically the area is fairly favored as it is located in the central highland, where seasonal rainfall is suitable and normal with annually **1143.7mm**; it is prominent recharge inducing factor. Generally, higher elevation receives more precipitation due to orographic effect, fore example Busa station located near Dandi Mountain show higher rainfall record than any station located there. Implies rainfall amount in the area varies with altitude as a result of which bases of ridges and hills are engulfed by several springs and streams especially in rainy time. They are simply outcome of recharge induced by precipitation at the top.



Figure 4:4 Existing environmental elements determine recharge.

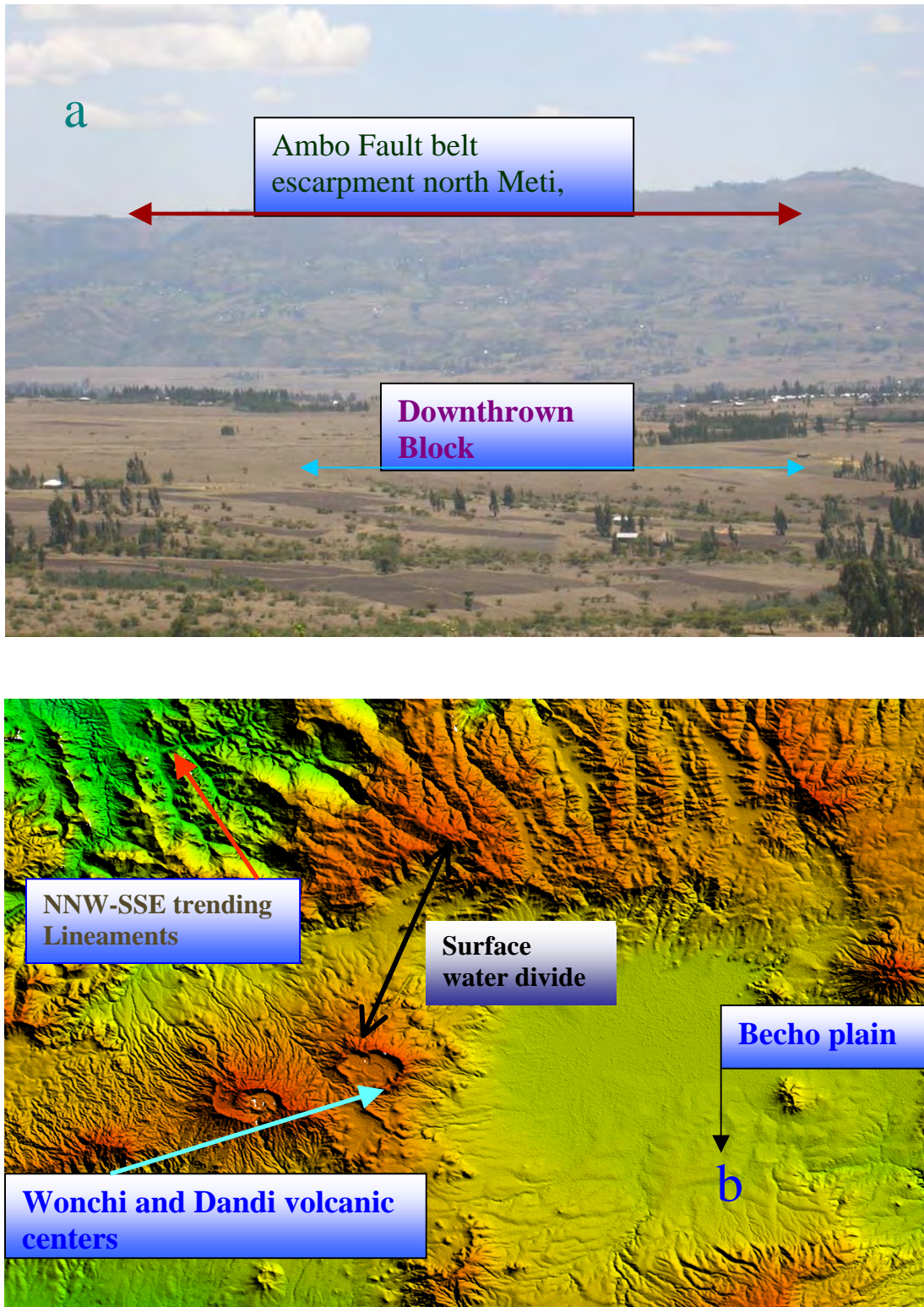


Figure 4.5; (a) photo show elevation variation and image (b ) Clipped from Ethiopia images and indicates morphological evolution.

### **4.3 Groundwater movement.**

Normally, groundwater movement in a certain media depends on the hydraulic gradient, and the hydraulic conductivity, which in turn determined by the extent aquifer heterogeneity. Here the flow direction of groundwater is stated on the basis of static water level. According to the available data and simple visual observation structural control, groundwater occurrence, topographical settings and geomorphologic conditions, generally flow direction appears to follow east and west course, in addition to this O-18 and H-2 isotope enrichment in high altitude and depletion in the down stream part (Seifu Kebede, 2005) point out that movement is in the foresaid direction.

The surface water divides is along the parallel E-W trending ridges located at the North and South peripheries of the study area and it seems that the groundwater also coincides with that of surface water boundary condition. This is because the surface water guiding deep seated structures probably have identical impact on groundwater flow system as well. In figure 4.7 below flow direction is indicates general trend appears as explained above; but this very much susceptible to modification on the basis of reasonable data here it has be produced making use of sparsely distributed data which might not correctly represent the whole study area groundwater flow pattern.

Normally, the map below is prepared by using groundwater elevation as input, which can be obtained by subtracting static water level from surface elevation. One of the major reasons that make this map prone to amendment is that, the boreholes drilled at different site are not fully penetrated and also lack appropriate information to produce flow direction.

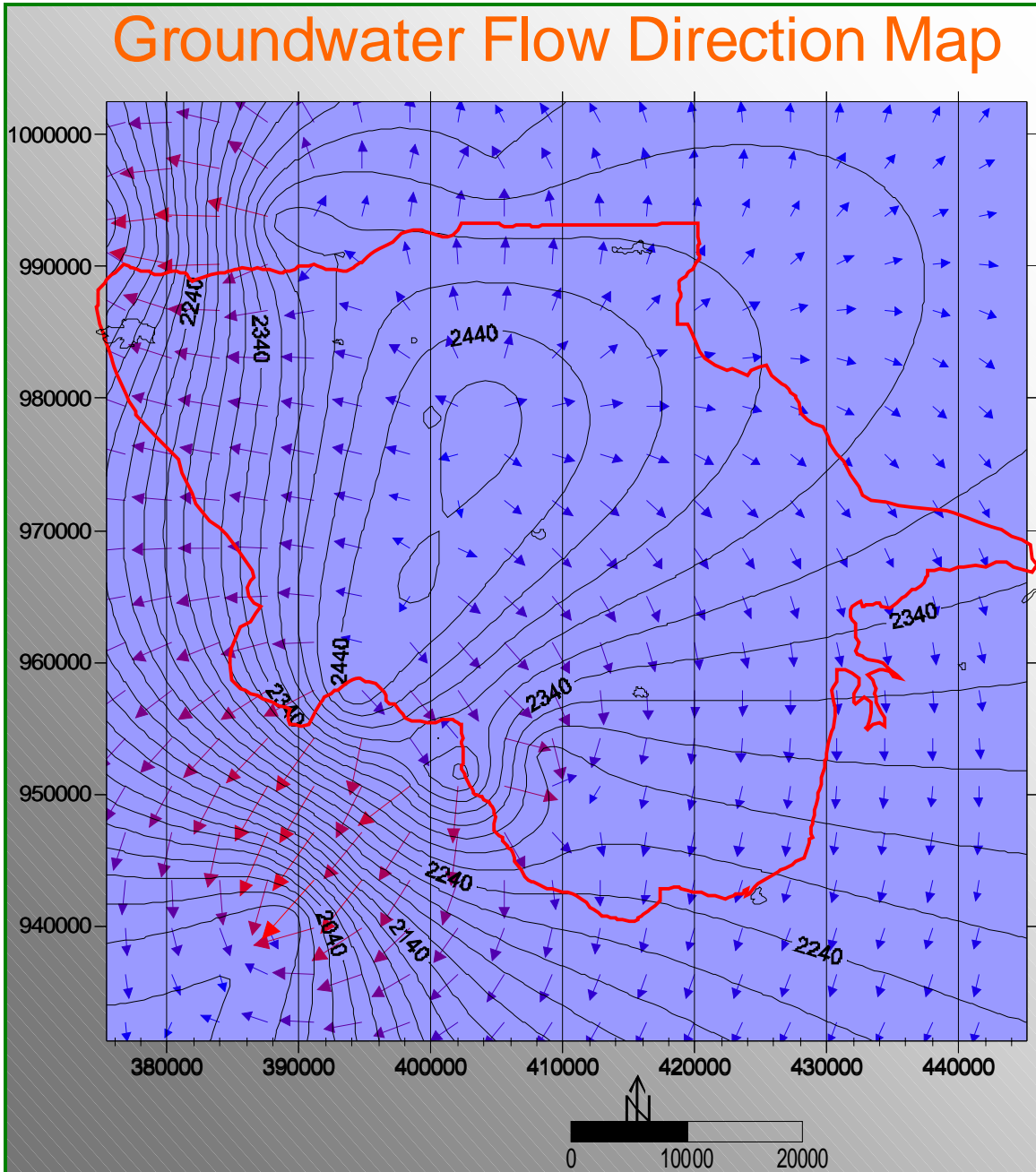


Figure 4.6: General trend of groundwater flow direction produced by surfer8 software.

#### 4.5 Aquifer Characteristics

Some of the geological materials that govern groundwater condition in the study area are briefly addressed under hydrogeology part. The given area aquifer situation is influenced by several factors that potentially alter the parameters of aquifer and its geometry. As the area is central or part of rift western escarpment and recent active volcanic environment, tectonic activity and surficial processes might have modified the aquifer parameters. Some aquifer parameters are obtained from pumping test data are presented below along with lithological log.

Boda1		Boda2	
Depth	Geology	Depth (m)	Geology
		0--1	Light colored clay soil
0-2	Dark clay soil	1--8	Moderately fractured basalt (columnar joint) slightly weathered at the top
2--4	Light clay soil	8--10	Weathered scoria
4--6	Moderate to highly weathered and fractured basalt	10--12	Fresh scoria
10--12	Sand	12--18	Highly weathered tuff
12--14	Slightly weathered and fractured basalt	18--28	Highly weathered tuff (brownish)
14--24	Fresh massive basalt	28-30	Paleosoil
24--26	Fractured basalt	30--39	Highly weathered tuff
26--30	Fractured and slightly weathered basalt	39--40	Paleosoil
30--32	Moderately weathered basalt	40--44	Weathered basalt
32-36	Clay sand	44--48	Moderately weathered basalt
36-38	Scoracious basalt	48--50	Weathered scoria
38-42	Slightly weathered basalt	50-51	Compact scoria
42-48	Scoracious basalt	51--52	Weathered tuff
48-58	Weathered vesicular basalt	52--54	Sand
58--62	Sand and Reddish Scoria	54--57	Paleosoil
62-66	Basaltic sand	57--63	Scoraceous basalt
66-74	Fresh fractured basalt	63-68	Scoria
74-84	Fractured basalt	68-80	Massive basalt
84--94	Scoracious basalt	80--83	scoria(partially penetrated)

Table 4.4: Geological log data of Boda boreholes

### I. Boda locality Borehole data result

The transmissivity (T), specific capacity and safe yield are computed for Boda 1 is:

- Average Transmissivity (T)= 156.39m<sup>2</sup>/day considering both draw down and recover data
- Specific capacity (SC)=154.28m<sup>2</sup>/day
- Safe yield (SY)=9033.86m<sup>3</sup>/day
- Static water level (SWL)=9.95m
- Total Depth= 98.5m

Boda.2 Aquifer parameters include;

- ⇒ Average transmissivity (T)=126.48m<sup>2</sup>/day based on draw down and recovery test
- ⇒ Specific capacity (SC)= 120.67m<sup>2</sup>/day
- ⇒ Safe yield (Sy)=5938.17m<sup>2</sup>/day
- ⇒ Static water level (SWL)=3.8m
- ⇒ Total depth=83m

### II. Asgori water supply Borehole Data

Lithological log data obtained from ambo water resource office documentation center shows penetrated borehole the geology is governed by black cotton soil at the top, fractured, weathered basalt and little massive basalt.

According to aquifer test result in the total depth of 151m with 49.6m static water levels the water level starts to stabilize at 74m after 70minutes of pumping, for Pump position 140m; the other aquifer parameters include

- **Transmissivity (T)= 54.29m<sup>2</sup>/day**
- **Specific capacity (SC)= 4.29m<sup>2</sup>/day**

- **Safe yield = 2l/s**

### III. Ambo Area computed Aquifer Parameters

Aquifer evaluation based on Jacob's best fit graph plotted of recovery and draw down data indicates: -

- **Available draw down= 23.25m**
- **Total draw down (H)= 8.95m**
- **Aquifer thickness (b)=49m**
- **Discharge=216m<sup>3</sup>/day**
- **Total draw down per log cycle ( $\Delta S_1$ )= 4.6m**
- **Total residual corrected draw down per log cycles ( $\Delta S_2$ )= 3.8m**

From this result

- ✓ **Average Transmissivity (T) = 9.5m<sup>2</sup>/day**
- ✓ **Average hydraulic conductivity (K) =0. 2m/day**
- ✓ **Specific capacity (S.C)= 0.3l/s/m**
- ✓ **Safe yield =5.58l/sec**

### IV. Gudar Area Borehole information

0--5	Top soil
5--18	Slightly fractured trachyte basalt
18--22	Scoria
22--24	Slightly fractured trachyte basalt
24-27	Highly weathered ignimbrite
35-38	Gravel
38-42	Degraded Acidic rock
42--48	Fine grained sand stone, white in color
48--50	Fine grained sand stone, pink in color
50-51	Gravel (minor aquifer)
51-80	White and yellow fine to medium <u>graind</u> sandstone
80--82	Coarse grained sandstone gray colored
82--84	Gravel (minor aquifer)
84---86	Dark yellow medium grained sandstone
86--94	Sandy gravel (minor aquifer)
94--95	Yellow colored medium grained sandstone
98--118	Conglomerate
118--120	White fine-grained sandstone
120-128	Conglomerate
128--134	Gravel (minor aquifer)
134-140	White medium grained sandstone
140--160	Cobbles (main aquifer)
160--168	Light brown medium grained sandstone
168--177.9	Light brown fine grained sandstone

Table 4.5: Aquifer characteristics from Gudar borehole

From aquifer test data the following aquifer parameters are computed

**Well data**

- Actual well depth: 177.9m
- Static water level (SWL) = 108.94m
- Discharge = 5.8 l/s
- Draw down = 6.68m
  - ⇒ Average Transmissivity (T) = **191.05m<sup>2</sup>/day**
  - ⇒ Hydraulic conductivity (K) = **2.77m/day**
  - ⇒ Specific capacity (S.C) = **0.87l/s/m**
  - ⇒ Safe yield (S.Y) = **8.71l/s**

Here below in **figure 4.7** also the hydroolithostratigraphic map is produced based on available evidences that are obtained from pervious works and field visits. Normally the hydrogeological units are classified into five categories by considering the quality of permeability these are: -

- Addis Ababa ignimbrite (low permeability)
- Alaji rhyolites (low permeability)
- Trachyte (moderate to low permeability)
- Basalt and scoria (high permeability)
- Adigrate sandstone (Moderate permeability)

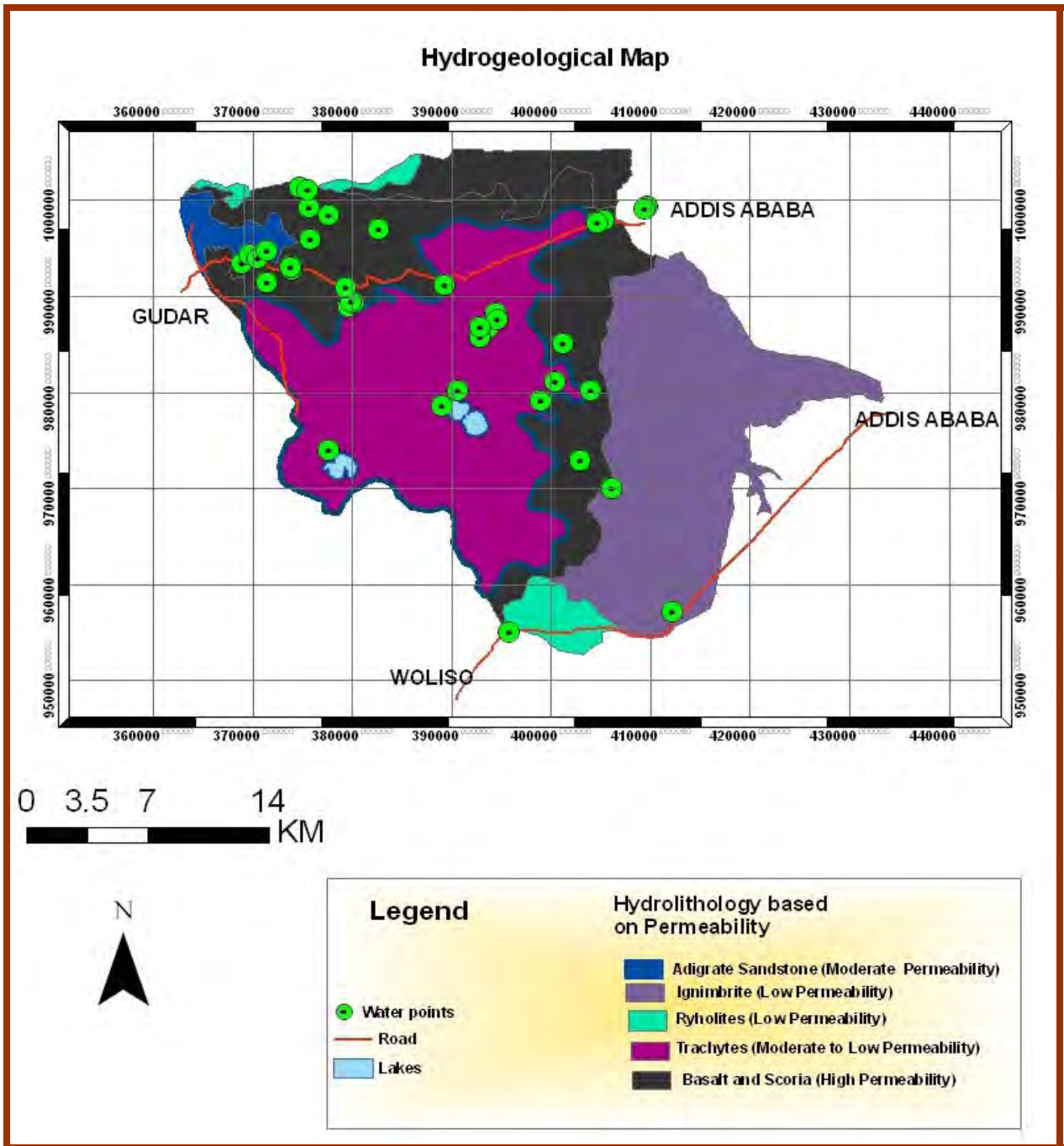


Figure 4.7: Indicates hydrogeology, major streams, and lineaments. as can be seen on the map the basalt and scoria unconfined aquifer is all around, while the confining layer ignimbrite is limited to Eastern part, trachytes occupies the slopy part of the area, rated as moderate to low permeability based on secondary structures.

## 5. HYDROGEOCHEMISTRY

### 5.1 General

Hydrochemistry is an outstanding scientific approach in the field of hydrogeological study. One of the best reasons that make application of hydrochemistry prominent is Water's being universal solvent. Owing to its chemical bonding nature (hydrogen bonding) water is capable of reacting with various substances.

Its being reactive with various elements significantly affects the chemical and physical property, as water comes in contact with a given material it inherits the property of that substance through chemical reaction or physical contact which subsequently alters it accordingly.

Physical property of water refers to behavior of water in response to its environment; any deviation in physical property from the standard set indicates water is altered physically this includes; -

- Density,
- Specific gravity,
- Viscosity,
- Color,
- Turbidity,
- Taste,
- Odor, etc.

The chemical characteristics of pure water is known in terms of composition and structure, changing of chemical manners can be imparted as water takes place in chemical reaction such property can be detected using:

- ✓ Acidity,
- ✓ Basicity,

- ✓ Alkalinity,
- ✓ Total dissolved solids,
- ✓ Extent of salinity,
- ✓ Electrolytic nature, etc.

Any of water property fluctuation from the normal has to do with the environmental condition in which it exists.

Hydrogeochemistry implies the physicochemical nature of groundwater as it passes through different geological media. When water circulates through geological formation it may dissolve the unit based on its solubility which in turn governed by the kind of chemical composition it is made from. All minerals of the rocks are not equally leached out when subject to water. Some minerals are resistant whereas some easily departed from the parent rock. Apart from rocks mineral composition the degree of acidity and basist, residence time, availability of water and structure of mineral also plays crucial role in determining the amount of cations and anions species should involve in the solution.

Generally what makes hydrogeochemistry high-flying tool in hydrogeological investigation is that amass of information more precisely in short period of time at cost effective scale can be obtained from water chemistry data analysis as compared to other exploration activities such as drilling and the likes. Water physicochemical analysis is used to infer or trace what kind of geological setting is there, source and extent of pollution, sources of the water resources, groundwater age, and recharge estimation other vital hydrogeological data can be extracted from it.

For instance isotope hydrogeology study is one of well renowned approach as it is applicable to characterize the general property of both surface water and groundwater resource of a given system. Using isotope

hydrogeology it is possible to determine a given basin water condition some major points may encompass:-

- ✓ Age of water,
- ✓ Sources of water,
- ✓ Recharge and Discharge condition,
- ✓ Aquifer characteristics
- ✓ Terrain type,
- ✓ Exploitation of resources (e.g. hydrothermal minerals)
- ✓ Water balance situation,
- ✓ Chemical composition of the rock,
- ✓ To monitor spatial and temporal change of the water resource, etc.

Hem (1985) listed out some important points, which governs the physicochemical nature of water these include:

- ✱ Climate,
- ✱ Geological effects,
- ✱ Biochemical factors,
- ✱ Hydrologic cycle,
- ✱ Particulates in the atmosphere,
- ✱ Composition of precipitation and
- ✱ Human impact.

The above points are comparatively influential in controlling the chemical signature of water. Above all geological effects are the one that leaves a great scar all over the place where ever the geological media and activity present in association with circulating water through it. The impartation of chemical species in most case is more pronounced in groundwater, which has to do with residence time of water in the rock where by the minerals formed the rock forced to dissolve and they get incorporated to the passing by or/and reserved water.

As we have various geological environments there are diverse water types as viewed from quality point. Igneous rock forming mineral species clearly variable from Sedimentary rock constituents at least by their structures and that of Metamorphic rock , formed by reorganizing those minerals held in the two earlier. Minerals kept in these rocks do not equally respond to the leaching and reactive effective of water that implies the chemistry of water also bear respective signature that tells from which origin (media type) groundwater is coming.

### **5.1 Hydrogeochemistry of study Area**

In this thesis it has been attempted to address the hydrogeochemical behavior of the study area. To characterize chemical nature of groundwater representative water samples are collected mostly from springs and few boreholes in addition secondary data from pervious works accomplished by individual researchers including governmental and private organization are incorporated to see the prevailing hydrogeochemical evolution.

During field sample collection the coordinates and the physical parameters (EC and pH) was measured. pH measurement was not taken for all at field because of instrument failure to do so.

The sample collected analyzed in Addis Ababa university hydrogeology laboratory, Water works supervision and design enterprise laboratory and secondary data were also analyzed in oromia water laboratory and other where, here the samples are examined for major cations and anions mainly.

Though there is no as such detail works in the area generally the hydrochemistry of Ethiopian highland dominantly exhibits Ca-Mg-  $\text{HCO}_3^-$  (calcium magnesium bicarbonate) type water. As explained in the geological part igneous rocks units dominate the area with some sedimentary origin pocket at the eastern margin hence most of the springs chemistry represents the earlier. Characteristics of water quality is presented in the following way

### 5.1.1 pH

There are three especially important acid-base reactions commonly occurring in ground water. First is the *dissociation of water* into hydrogen ions [ $\text{H}^+$ ] and hydroxide ions [ $\text{OH}^-$ ].



Second are the reactions involved in the *solution of  $\text{CO}_2$  gas* into water.



Third are the reactions that involve the *solution of solid silica into water*.



The first reactions are measured by **pH** while the second is measured by **alkalinity**.

Acid-base reactions can result in increases or decreases of protons (i.e., hydrogen ions [ $\text{H}^+$ ]). The concentration of hydrogen ions is measured by pH.

**pH =  $-\log [H^+]$  -----5.8**

Acid-base reactions that provide high concentrations of hydrogen ions result in low pH values (i.e.  $pH < 7.0$ ) in solutions. These solutions are said to be *acidic*. Acid-base reactions that provide low concentrations of hydrogen ions result in high pH values ( $pH > 7.0$ ) in solutions. These solutions are said to be *basic*. The pH of ground water controls which cations; anions, gases and solids dissolve into ground water (i.e., go into solution) and which exit from groundwater (i.e., precipitate or volatilize). Groundwater may be aggressive based on the chemical reaction.

When groundwater attains acidity,  $H_2CO_3$  will be come more dominant, which holds true in the case of the study area. The pH fall in between 6 and 8 figures 5.1 the frequent pH value is 7, specify both spring and groundwater are fresh in the area; which is of course, the characteristic of Ethiopian highland water. Its being fresh attributed to the good amount of precipitation received in time of rainy seasons which potentially pose a sort of adjustment in regulating the concentration through supply of huge waters to the aquifers. As result of dilution owing to the foresaid reason when do not find as such exaggerated concentration of groundwater that may induce wide range of pH value. Low pH water is concentrated at area where the thermal springs are influential this is just effect of  $CO_2$  injection to charge water so that it becomes violent.

On account of low pH around thermal springs the total dissolved solids value is found to be high and Ca and Silica sinters are precipitated which is common features of thermal springs.

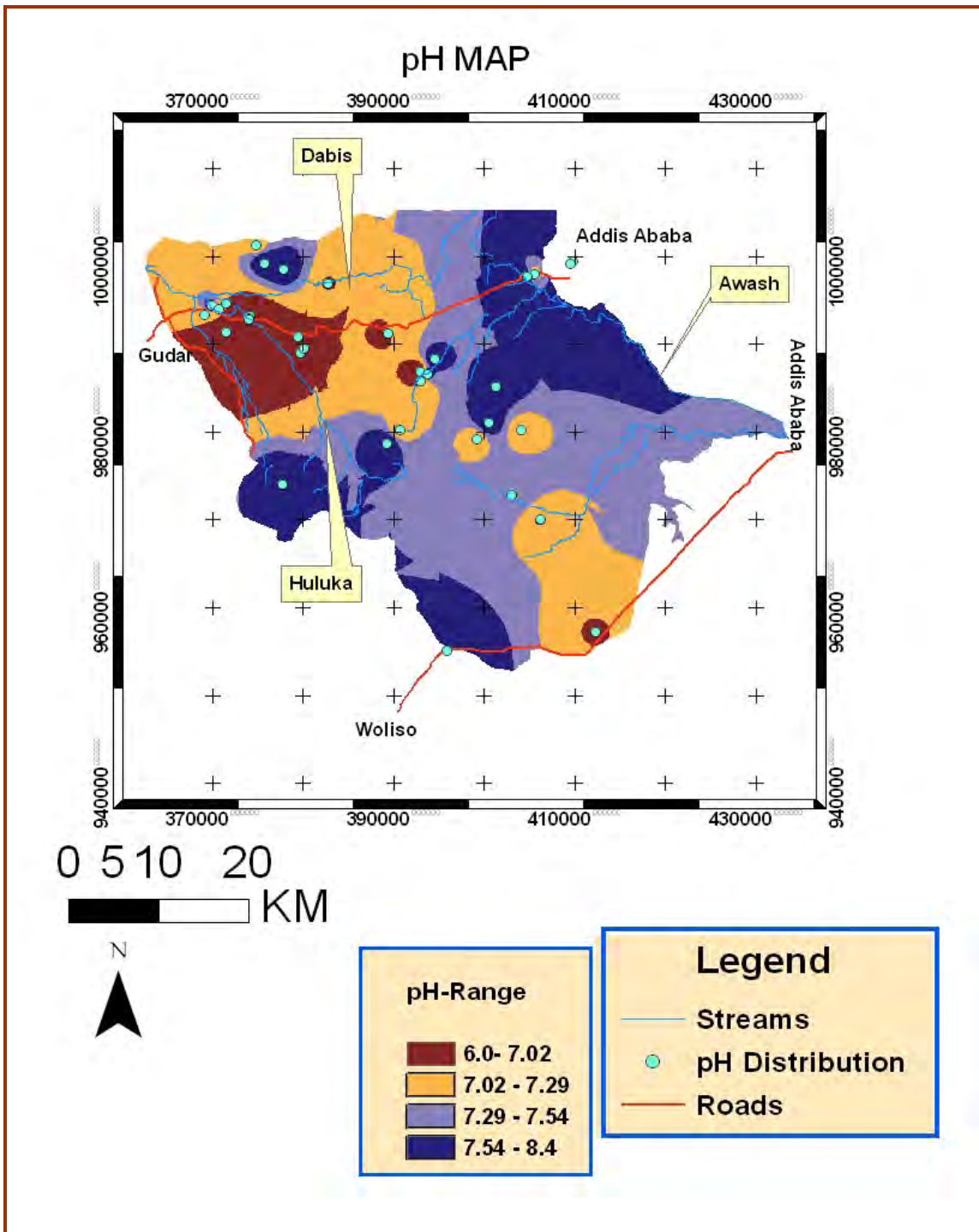


Figure 5.1 pH map of Study Area with narrow range between 6 and 8

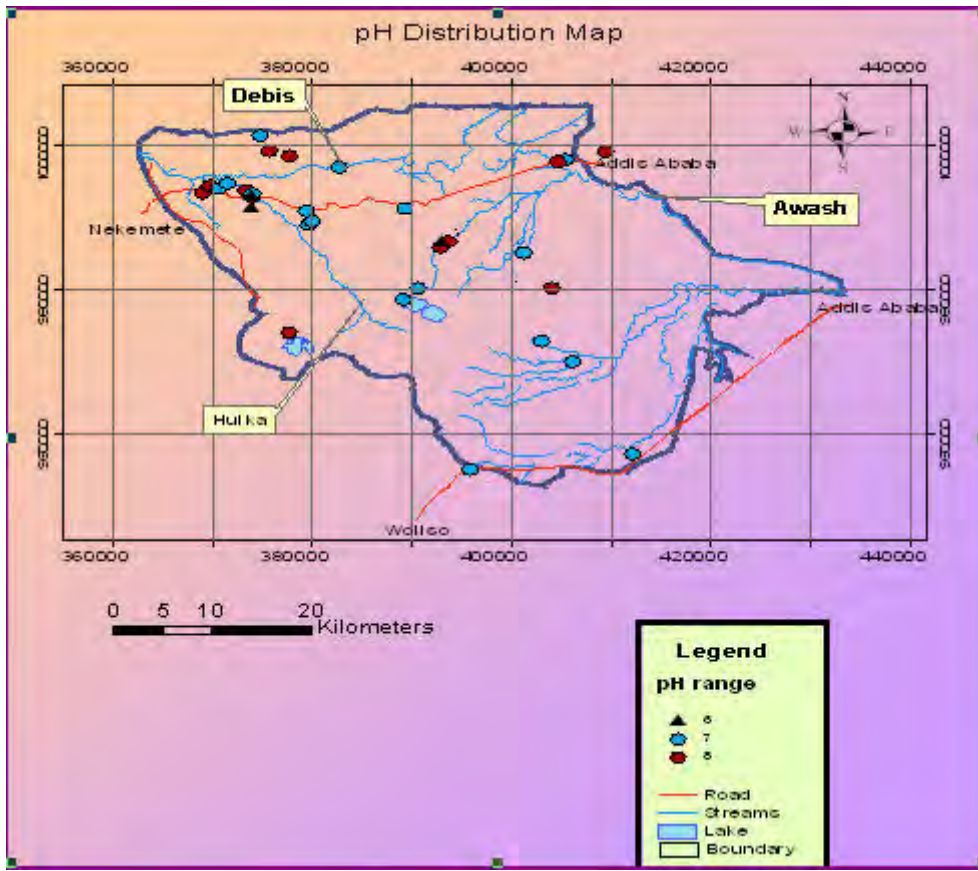


Figure 5.2: pH Distribution map the range is shown in the legend

### 5.1.2 Alkalinity

The pH of groundwater controls which type of carbonate or silicate occurs in solution. In acidic solutions,  $\text{H}_2\text{CO}_3$  is the dominant carbonate anion, followed by  $\text{HCO}_3^-$ , then  $\text{CO}_3^{2-}$  as solutions become more basic. A similar progression would be seen in silicates from  $\text{H}_2\text{SiO}_3$  to  $\text{HSiO}_3^-$  to  $\text{SiO}_4^{2-}$  as solutions pass from acidic to basic. The carbonate and silicate ions serve as strong bases.

Alkalinity is defined as the net concentration of strong base in excess of strong acid with a pure  $\text{CO}_2$  - water system as a point of reference. It is controlled by pH and the concentrations of strong bases such as carbonate and silicate ions.

Strong acids are not common in natural ground water. Their occurrence represents contamination from human activity. The solution of silicate

and carbonate minerals does provide strong bases in solution in natural situations. Consequently, as ground water flows through an aquifer, it dissolves more carbonate and silicate minerals thereby increasing the alkalinity and the pH.

The maximum alkalinity record is shown in Ambo agricultural institute borehole data chemical analysis is about 1050mg/l. generally springs alkalinity is less than that of borehole alkalinity. Some springs (e.g. Buqisa and Molche) located east of ambo at 10 to 15 km on the way to lake Dandi exhibit less alkalinity entails very young fresh water that does not make long time interaction with rock in order that the alkalinity is raised.

Normally not only springs show low alkalinity but also borehole alkalinity is not that much high. Both springs and boreholes holding aquifer usually the same formation in addition the borehole water also can be tapped on average at 150m and less than it indicating their ultimate source is almost the same. According to available data the minimum alkalinity is registered at Ela spring near Dandi Lake with geographic location 390633 east, 980185 north and 2900 m above sea level.

Ambo thermal spring relatively denoted by high alkalinity (970mg/l), which is acceptable as the water, is energetic enough to leach out minerals from the host rock there by boost its chemical concentration. According to data presented in Lamesa Mekonta thesis (2001) Dandi lake alkalinity is slightly greater than Wonchi lake Alkalinity about 204mg/l and 99 mg/l correspondingly.

### 5.1.3 EC electrical conductivity

Electrical conductivity related to the amount of dissolved solid in the water, which raises the electrolytic property of water. If groundwater circulating through geological media aggressive enough as result of acidity or bassist it will tend to cause dissolution of rock minerals by the process of hydrolysis. When EC of groundwater is high it will appreciably conduct electricity but fresh water will have in most cases low EC implying there is short time span of rock water interaction.

The more total dissolved solids (TDS) in water the more it will conduct electricity. EC and TDS are related by:

$$S = AK, \text{-----}5.9$$

Where, S= stands for dissolved solids in mg/l

K = conductance in micromhos

A= Conversion factor and for most groundwater the specific conductance multiplied by a factor of 0.55 to .75 gives reasonable estimate of the dissolved solids (Tenalem Ayenew, and Tamiru Alemayehu, 2001).

The Electrical conductivity behavior of water samples collected can be categorized into two parts. The Southern, northern highlands and Eastern part the second western end Around ambo are which include the thermal springs, boreholes and some mineralized cold springs situated around Ambo area.

As can be seen in the table 5.1 EC of water higher in thermal springs, some bore holes and springs. Thermal springs may incorporates high constituents of the rocks by dissolving along its way as it is forced up

ward from the deep, here the temperature of water plays key role in triggering dissolution of minerals from the rock.

Some borehole also relatively tend to show better EC value for example borehole of Sankale, Ambo Agricultural Research institute (AARI) Awaro borehole, southern Awaro springs such as Horachanco, Hora Daboro. The mentioned water sources are concentrated around ambo.

Reason of highly mineralized water can be linked with volcanic activity in the area, presences of thermal spring demonstrate such effect, apart from thermal spring that emerge around ambo and Woliso there are thermal spring that feed cold springs there by leave a lot of minerals load. Perhaps the cold springs' supply source is more than that of the other due to which we do not feel above normal temperature due to dilution.

In general most of water from spring source can be used for different purposes as their EC is below the guidelines proposed by WHO. According to the standard most samples' EC including the thermal springs are permissible to utilize, however there is high Electrical conductivity around Ambo, here the probable reasons can be; dissolved constituents by the thermal springs and introduction of pollutants from factory and urban residents including fertilizers from surrounding farm lands.

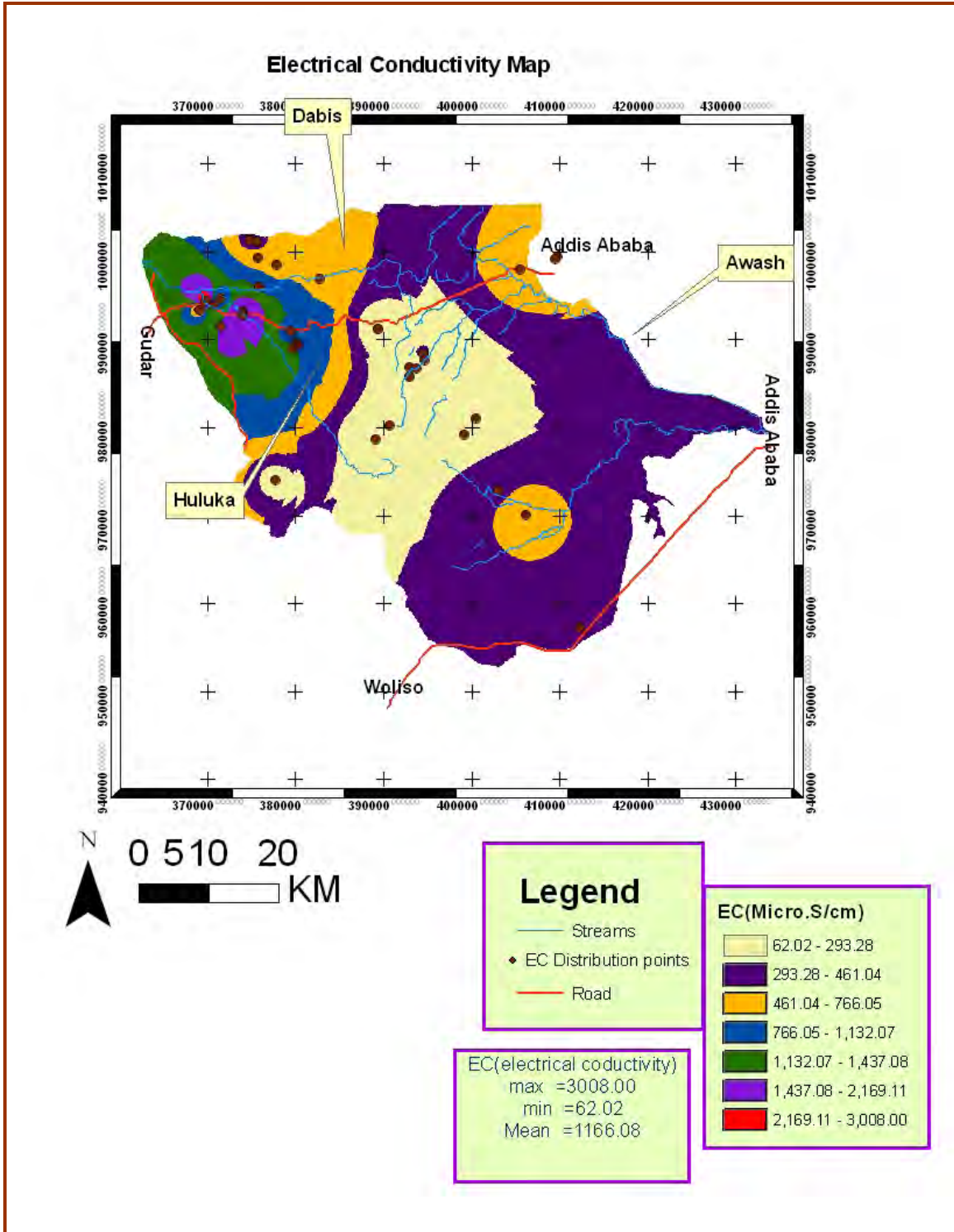


Figure 5.3: Electrical Conductivity Map

Local name	( $\mu\text{S}/\text{cm}$ )	Ec ( $\mu\text{S}/\text{cm}$ )
Koromi	400	
Shone	300	217
Cheefe kernsa	200	
Maja	10	
Meti	200	
Wodesa	557	453
Wodesa		273
Wodesa	293	
Legahola	<b>1120</b>	
Ambotwon	<b>2570</b>	1787
Ambotwon	<b>2440</b>	
Hukoqorke	<b>1500</b>	920
Hukoqorke	<b>900</b>	
Hukoqorke	<b>902</b>	834
Qora	<b>1020</b>	843
Tulubolo	420	319
Busa	627	619.0
Bashi	456	370
Bashi2	454	
Boda	112	
QAO spring	112	
Ginchi town	670	642
Barodo	455	411
Barodo	600	1194
Woliso TS		
Faji galla		104
Wolonkomi		
Boda2		338
Becho dilala		226

Local name	( $\mu\text{S}/\text{cm}$ ) Field	Ec ( $\mu\text{S}/\text{cm}$ ) lab
Qerensa	162	187.9
Molche	64	65
Buqisa	115	120.6
Huluka	141.6	141.6
Chafe	651	32.2
Kilinto	665	665
Huluka	281	281
Wanchi	171	207
Sankale	<b>3700</b>	<b>3940</b>
Ambo	620	641
Hotel	1320	1519
Dule	<b>650</b>	<b>1046</b>
Tiro	379	464
Wachani	387	480
Dandi	120	131.6
Ela	65	87.7
Shamme	395	457
AARI	<b>1447.00</b>	<b>1442.00</b>
Thermal spring	<b>1470</b>	<b>1433</b>

Table 5.1: Electrical conductivity measured in the field and laboratory those indicated by arrow show high value (around ambo).

### 5.1.4 Hardness

Hardness is the chemical property of water suggesting the presence of  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  which principally cause the water to be hard.

Hard water contains cations with a charge of +2, especially  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . These ions do not pose any health threat, but they can engage in reactions that leave insoluble mineral deposits. These deposits can make hard water unsuitable for many uses, and so a variety of means have been developed to "soften" hard water; *i.e.*, remove the calcium and magnesium ions. Mineral deposits are formed by ionic reactions resulting in the formation of an insoluble precipitate. For example, when hard water is heated,  $\text{Ca}^{2+}$  ions react with bicarbonate ( $\text{HCO}_3^-$ ) ions to form insoluble calcium carbonate ( $\text{CaCO}_3$ ), as shown in Equation



Tot. Hardness (CaCO <sub>3</sub> ) mg/l	Local name	
154	Q erensa spring	<p>According to Durfer and Becker (1964) cited in Tamiru and Tenalem (2001) hardness range in milligram per liter (mg/l) is given by: -</p> <p>Hardness range, CaCO<sub>3</sub></p> <p>0-60 -----soft</p> <p>61-120-----Moderately hard</p> <p>121-180-----hard</p> <p>&gt;180-----very hard</p>
130	M olche spring	
120	Buqisa spring	
140	Huluka stream	
460	Chafe spring	
458	Kilinto spring	
76	Huluka stream	
38	W anchi lake	
420	S ankale W ell	
348	A mbo spring	
560	H otel spring	
780	D ule Spring	
380	T iro Spring	
320	W achani spring	
210	D andi lake	
140	E la Spring	
560	S hamme Spring	
420.00	A ARI well	
320	T hermal spring	
253.00	W odesa spring	
385.00	Q ora	
92.40	T ulubolo	
215.60	B usa	
330.00	G inchi well	
15.40	B arodo2 spring	
65.00	F aji galila sprin	
346.30	W olankom	

Table5.2: Total hardness of water sample collected from study area.

As can be seen in table 5.3 most water samples fall in the range of hard to very hard except barodo borehole, faji galilila spring, Huluka stream, wanchi lake, and Tulubolo spring which are soft to moderately hard. Those water samples rich in calcium are categorized as hard water calcium is imparted by leaching of calcium rich rocks (basic rocks), acidic rocks dominated by Na characterized by water low hardness barodo borehole is typical example.

Lake Dandi's hardness is about 210mg/l while Lake Wonchi's hardness is about 38, hardness of Lake Dandi can be attributed to volcanic rock of basic origin that would lie below trachaytes flow along the conduit in the process of episodes of eruption. Lake Wonchi's being low hardness credited to the geological formation that characterize the area which include acidic rocks similar to dandi rim trachaytes and rhyolite deposits

(pumice, tuff and volcanic ash) these are in most case rich in sodium. Apart from Lake Wonchi, spring sampled by (Kasshun Bayene, 2005) result gives clue that high Na concentration is prominent.

### **5.1.5 Temperature and other physical parameters**

Temperature, color, turbidity, odor, taste, etc represent the physical parameters of water and they are the first hand easiest approach in detecting the quality of water. Most water samples temperature is below 25°C except the thermal springs with temperature of 35 to 40°C not irritating when come in contact with the body.

From laboratory analysis and field survey color, turbidity, odor and taste of water points do not show objectionable level except limited shallow bore hole and springs which are affected by anthropogenic effect, runoff carried sediments wastes and tree leaves.

### **5.1.6 Total dissolved Solids (TDS)**

Obviously, we know that starting from lower grades, the chemical composition of pure water is H<sub>2</sub>O practically we do not find both surface water and groundwater in such free state. On account of water very nature to react with a lot of substance (rocks) with in its environment of residence or route of journey we can trace dissolved mineral species contributed from materials with which the water make contact.

TDS of water is an important clue to trace back from which environment or terrain the water is, in addition the extent of solubility of the material with which water making contact. Therefore, TDS is an important parameter to classify water as shown in the table below,

Water type	TDS in ppm
Fresh water	0-1,000
Brackish water	1000-10,000
Salty water	10,000-100,000
Brines	More than 100,000

Table 5. 3 Water classification based on TDS

According to this standard the water sample data analysis show all most all of them are fresh water except the ambo sankale spring, which probably polluted by wastewater released from households and Ambowoha factory.

Thermal spring noted by high TDS as compared to all the other followed by those Hora spring found adjacent to the thermal springs. The general trend of higher TDS significantly noticed around ambo area. Comparatively speaking western north of the area implies the water is aggressive due to CO<sub>2</sub> continuous supply which charges the water to form carbonic acid which is potential fluid to increase dissolved cations and anions species. Atmosphere, organic rich soils, degassing of cooling igneous and dissolution of carbonates perhaps contribute CO<sub>2</sub>; it charges water to form acid shown in the equation.



The acid in the equation is prominent in cause the rock to release their minerals as a result of dissolution; detail of this concept is discussed in section 5.1.7

Local name	Source	TDS	Local name	Source	TDS
Wodesa	Spring	296	Chafe	Spring	490
Qora	Borehole	568	Kilinto	Spring	391
Tulubolo	Spring	229	Huluka	Stream	168
Busa	Borehole	452.0	Wanchi	Lake	107
Ginchi Town	Borehole	432	Sankale	W. Water	2200
Barodo	Spring		Ambo	Spring	394
Barodo	Borehole	778	Hotel	Spring	905
Faji Galila		52	Dule	Spring	1046
Wolonkomi		434	Tiro	Stream	270
Boda2	Borehole	169	Wachani	Spring	290
Becho Dilala	Borehole	108.5	Dandi	Lake	67
Qerensa	Spring	108	Ela	Spring	44
Molche	Spring	42	Shamme	Spring	290
Buqisa	Spring	69	AARI	Well	745
Huluka	Stream	90	Thermal Spring	Spring	950

Table5.4: Summary of water samples TDS data in the study area.

### 5.1.7 Cations and anions

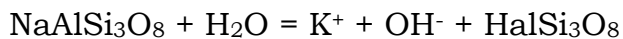
Sample collected during field investigation is analyzed in the laboratory for cations and anions concentration. The laboratory result indicates presence of some charged species; their supremacy is governed by the kind of lithological condition dominating in the area.

As discussed in the geological portion igneous origin materials with small area coverage of sedimentary unity namely Adigrat sandstone below which sedimentary succession is present notably cover the area. Igneous rocks comprised of varieties of extrusive volcanic rocks. These rocks are classified on the basis of their composition, texture, color, etc.

The minerals or color of an igneous rock usually indicates chemical composition. Four main compositional categories result from this approach (based on Travis 1955).

1. Felsic -- Rich in feldspars and silica. Silica content ranges from about 55% to > 70%. **Potassium feldspar** makes up more than one-third of total feldspars; plagioclase (**Na & Ca**) feldspars are less than two-thirds of total feldspars. Typical of continental crust.
2. Intermediate -- Between felsic and mafic. Silica content ranges from about 55% to 65%. Plagioclase feldspars make up more than two-thirds of total feldspars. **Na-rich** plagioclase predominates over **Ca-rich** plagioclase. Found in association with subduction zones.
3. Mafic -- Rich in **magnesium** and **iron** with less silica. Silica content is 45% to 50%. Ca-rich plagioclase is the dominant feldspar with little or no **K- or Na-**feldspars. Typical of oceanic crust.
4. Ultramafic -- Still more **magnesium and iron** and even less silica. Silica content is less than 45%, and little or no feldspar is present. Derived from the mantle.

The feldspars and many of the dark silicate minerals dissolve and undergo **hydrolysis**, the reaction of a mineral with water. These reactions put  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$  and other cations in solution but also leaves produce a new solid phase, clay minerals. These reactions are incongruent in that there is a new solid phase produced by the reaction.



Ions in solution may precipitate due to changes in pressure, pH and/or Eh. These precipitates, such as calcite and siderite deposition may result in massive formations such as stalactites, stalagmites, columns, flowstones, and **travertine mounds**. Quartz deposition in hot springs may form massive siliceous **sinter deposits**. Ambo thermal spring is classical example showing deposition of travertine ( $\text{CaCO}_3$ ) and silica

sinter ( $\text{SiO}_2$ ) formed around the eye of the spring as result of incongruent dissolution.



**Figure 5.4**  
**Silica Sinter at**  
**Hukoqorke mineralized**  
**spring of Hora Chancho**

**Silica sinter** outwash and deposition at the rim of spring around ambo area might have been caused by the thermal springs leaching effect of *Alkaline Systems* located near hukoqorke. Sample taken from this area exhibits dominance of **Na-  $\text{HCO}_3$  -Cl** reflecting hydrolysis of silicates mainly feldspar is effective.

**Travertine Systems:** The travertine areas are the result of carbon dioxide-rich waters dissolving carbonate rocks at depth and then depositing calcium carbonate as pressure and  $\text{CO}_2$  decrease at the surface (Breckenridge et al., 1978). The presence of travertine-type deposits depends on spatial relationships to limestone; however, these deposits may also occur in non-limestone areas as calcium is leached from andesites and basalts. Travertine deposit source in Ambo can be

linked with both the deep seating limestone and basalt unit that continue east and northward.

Major cations and anions data including few others are presented in the following table below.

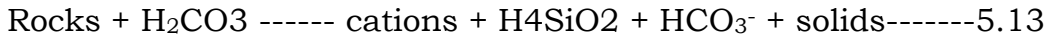
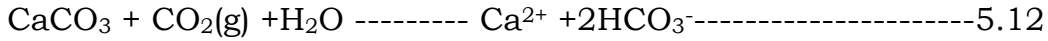
<b>Cations</b>	<b>Max</b>	<b>Source</b>	<b>Anions</b>	<b>Max</b>	<b>Source</b>
Na <sup>+</sup>	336.88mg/l	Well (sankale)	HCO <sub>3</sub> <sup>-</sup>	1183mg/l	Thermal spring
K <sup>+</sup>	30.70mg/l	Spring (hotel)	NO <sub>3</sub> <sup>-</sup>	150mg/l	Stream (huluka)
Ca <sup>+2</sup>	220mg/l	Spring (hotel)	Cl <sup>-</sup>	220mg/l	Spring (hotel)
Mg <sup>+</sup>	78.72mg/l	Well (sankale)	Br <sup>-</sup>	37.95mg/l	Thermal spring
Mn <sup>2+</sup>	22mg/l	Spring (arbu)	SO <sub>4</sub> <sup>2-</sup>	625mg/l	Spring (dule)
Cu <sup>2+</sup>	2.76mg/l	Spring (dule)	CO <sub>3</sub> <sup>2-</sup>	24mg/l	Barodo(borehole)
Cr <sup>2+</sup>	0.1mg/l	Stream (huluka)	NO <sub>2</sub> <sup>-</sup>	7.48mg/l	Spring (Qerensa)
NH <sub>4</sub> <sup>+</sup>	2,57mg/l	Stream (huluka)	PO <sub>4</sub> <sup>3-</sup>	0.96mg/l	Borehole (AARI)
Fe <sup>2+</sup>	2.74mg/l	Stream (huluka)	F <sup>-</sup>	6.4mg/l	Barodo (borehole)

Table5.5 Maximum detected dissolved chemical ionic species

As seen in table 5.5 maximum cations and anions individuals are detected in sample collected near ambo where thermal spring is influential to leach out minerals from the host rocks. Fore example maximum HCO<sub>3</sub><sup>-</sup> identified from the collected sample is observed in thermal springs which implies the water is charged with CO<sub>2</sub> to attain acidity hence, groundwater is aggressive to dissolve minerals from the rock and increases the total dissolved solids. Here CO<sub>2</sub> could be introduced from the degassing of cooling igneous chamber (which formed the dandi and Wonci volcanic centers), atmosphere and organic decomposition in the soil.

In the Ambo thermal area CO<sub>2</sub> contribution is believed to be decarbonation of limestone and degassing of cooling igneous chamber

(Tamiru Alemayehu and Seifu Kebede, 2005). Presence of CO<sub>2</sub> let the water to be low in pH which in turn tends to dissolve the carbonates and silicate minerals as shown in the equations below



Normally, as the water reaches the surface CO<sub>2</sub> is removed due to pressure relief and produce the deposits of travertine and silica sinter as result of rise in pH and drop in temperature.

**5.1.8 Graphical presentation of Hydrochemicals Facies**

Here in order to show ionic distribution according to their occurrence and concentrations is shown using graphical presentation. Different graphical plots shown below are prepared using AquaChem version 3.6. In order to consider ionic distribution Piper, Scholer, Stiff, Durvo and Lingelie-Ludwig are used.

From graphical distribution the cations are slightly scattered as compared to the anions which is more or less concentrated at point namely HCO<sub>3</sub><sup>-</sup>. HCO<sub>3</sub><sup>-</sup> is dominant anion both in the evolved and fresh highland water. Seldom Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> are encountered their source perhaps from wastes and to lesser extent from Mesozoic sedimentary units which present as a pocket in the out crop.

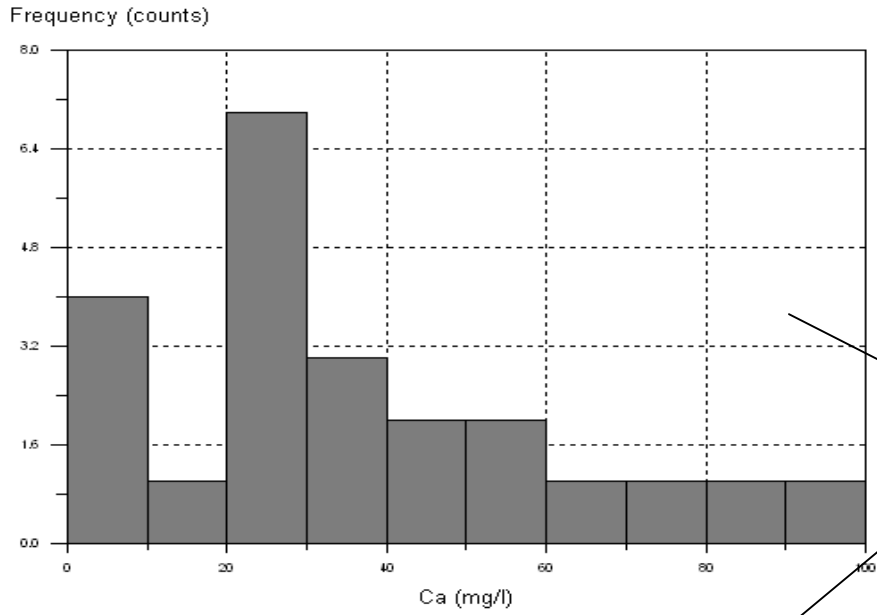
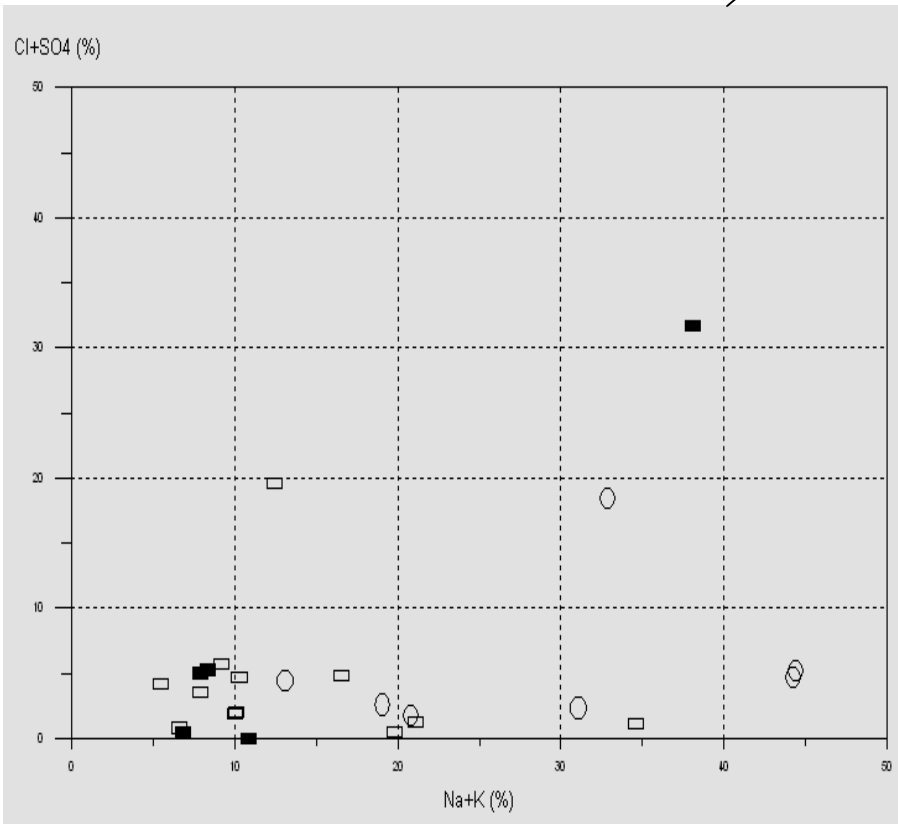


Figure 5.5: Frequency of Ca and Na percentage with respect to Cl + SO<sub>4</sub> indicate the water is fresh.



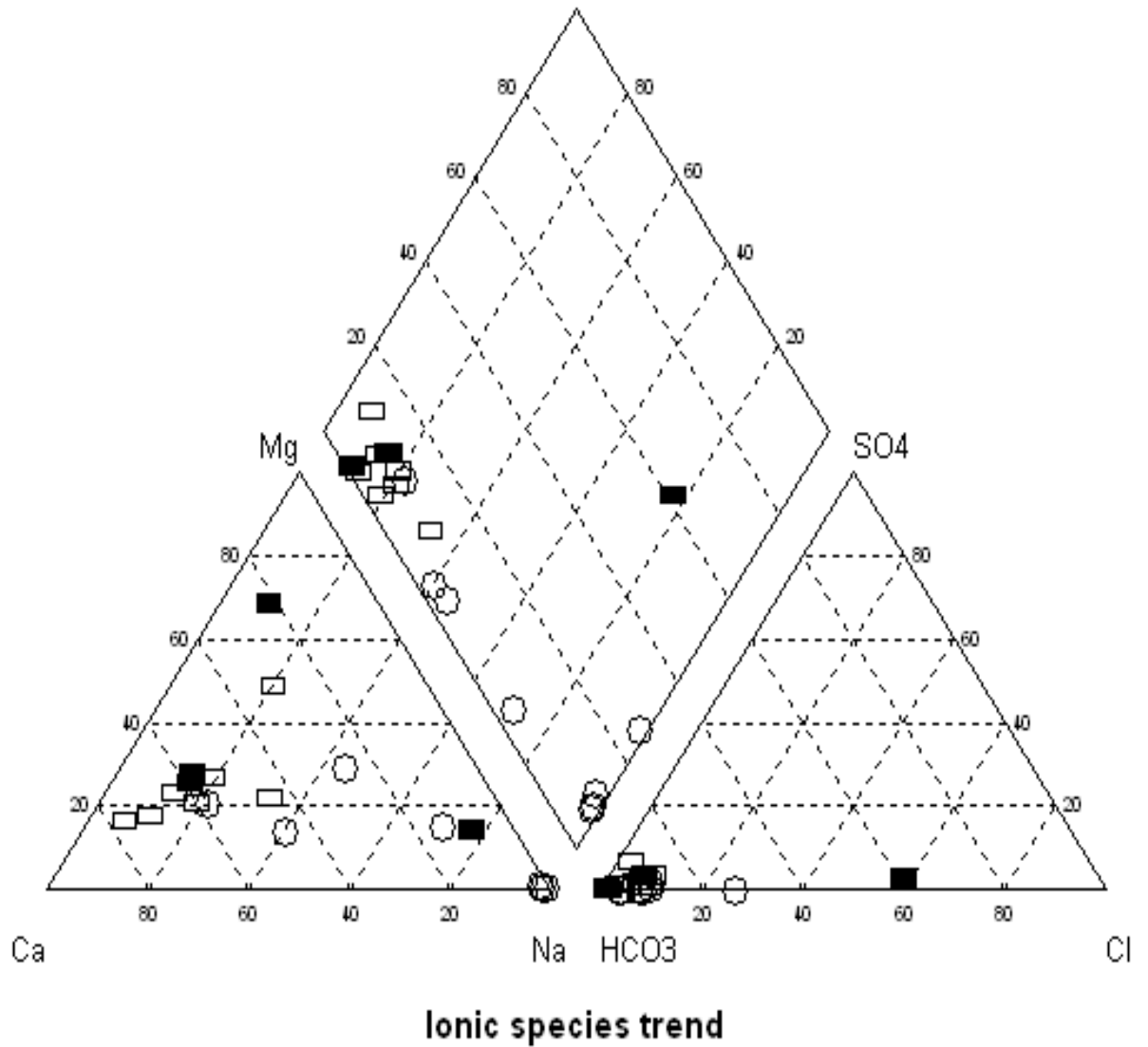


Figure5.6: Piper diagram Showing General trend of the species.

The cations slightly scattered while the anions are concentrated at point namely at HCO<sub>3</sub> end. The calcium bicarbonate type water is more frequent than other type water.

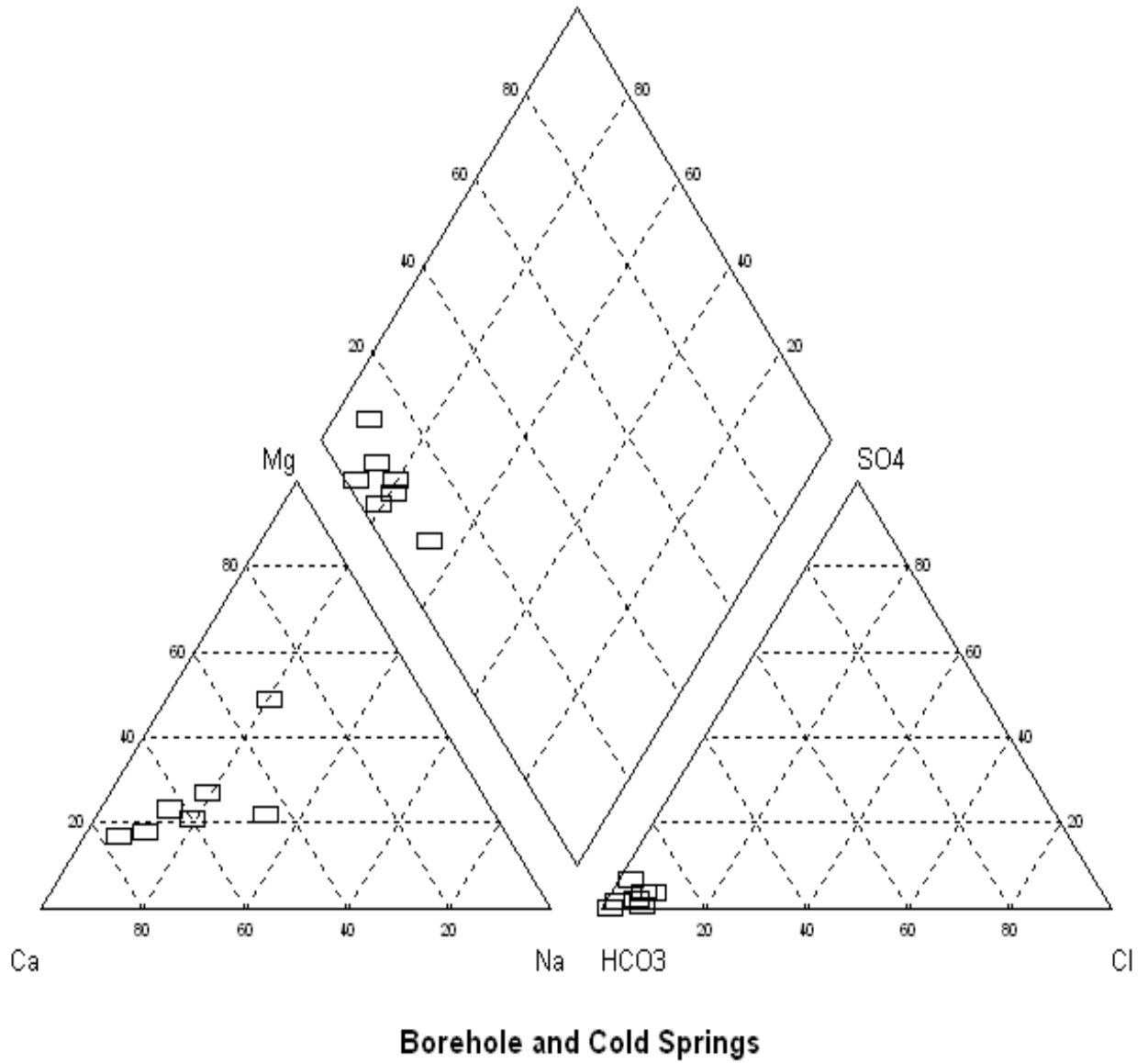
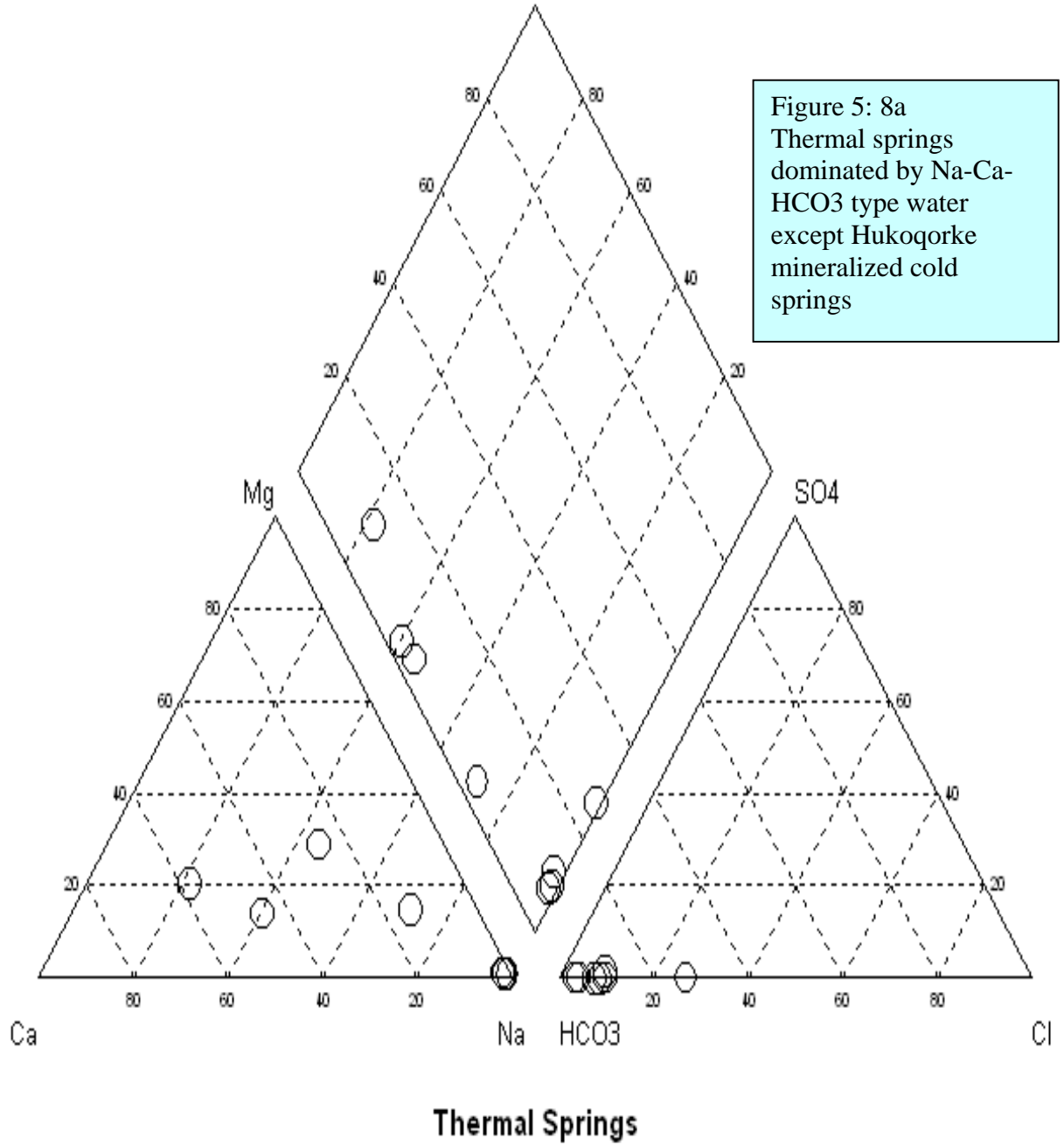


Figure 5.7: Ca-Na HCO<sub>3</sub>- Ca-Mg-HCO<sub>3</sub> dominated Water type with one sample Mg-Ca-HCO<sub>3</sub>



Indicates Na-HCO<sub>3</sub> type water collected from Ambo, woliso and wonchi thermal springs.

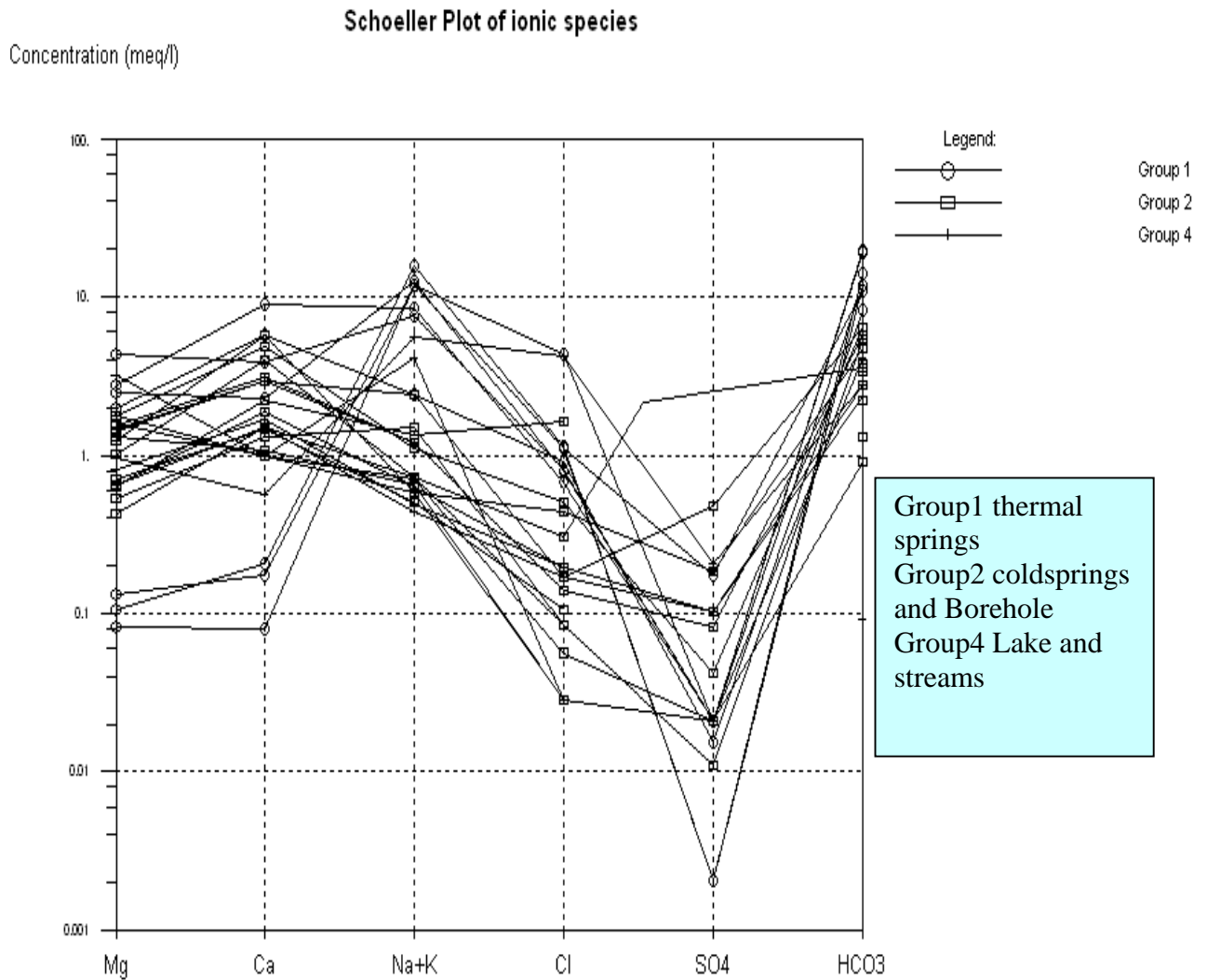


Figure 5.9: Schoeller plot showing the general trend on hydrochemistry of the area

The Schoeller semilogarithmic method indicates the Ca-HCO<sub>3</sub> type more frequent than Na-HCO<sub>3</sub> type water, from the curve we can learn that cations are slightly scattered while the anions are concentrated to a point along HCO<sub>3</sub><sup>-</sup> line. Which confirms the reaction between water and carbon dioxide is responsible in dissolving minerals of parent rocks.

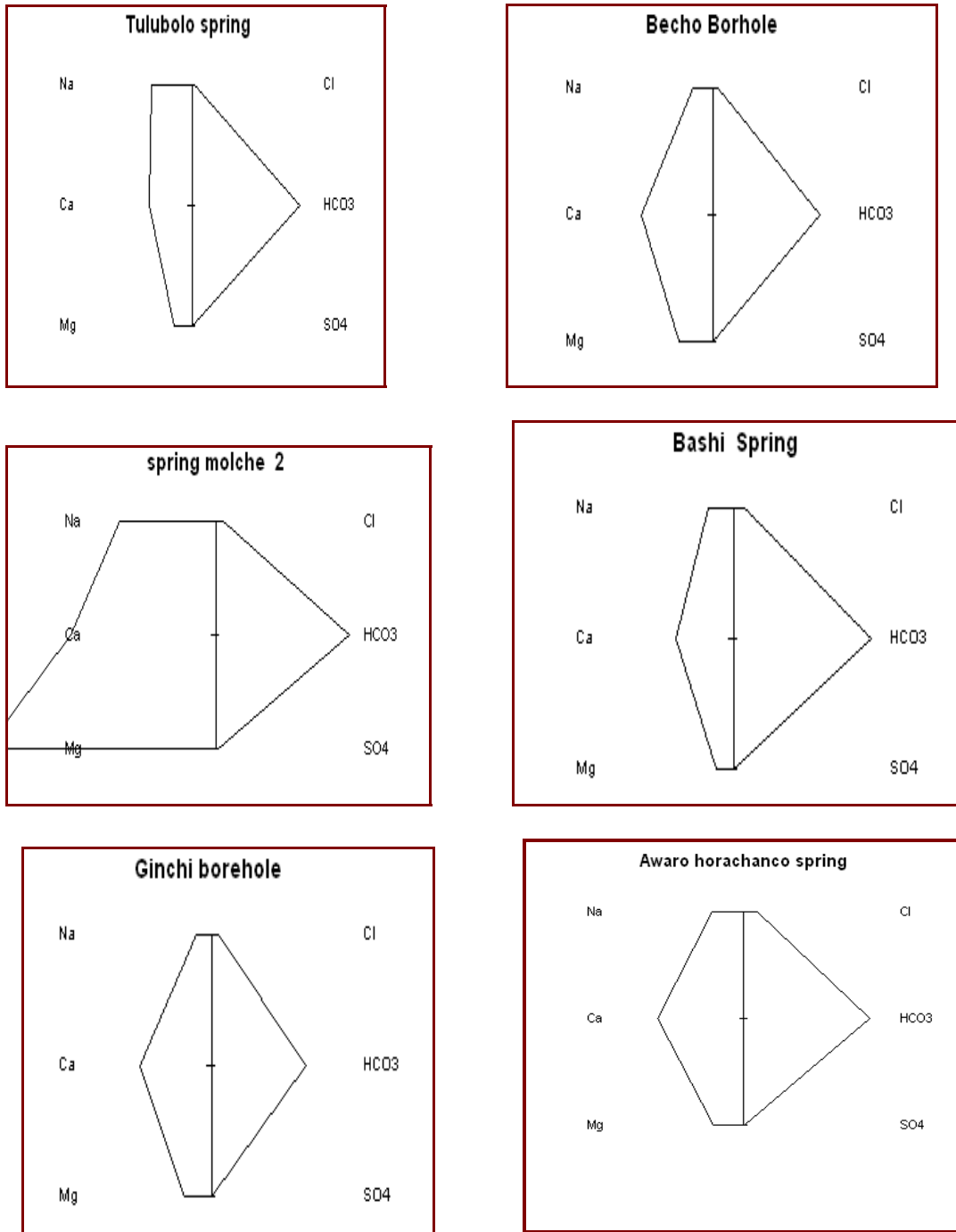


Figure 5.10: Most eastern part cold springs and boreholes depict the dominance of Ca-Na-HCO<sub>3</sub> water type, which is related to the aquifer media.

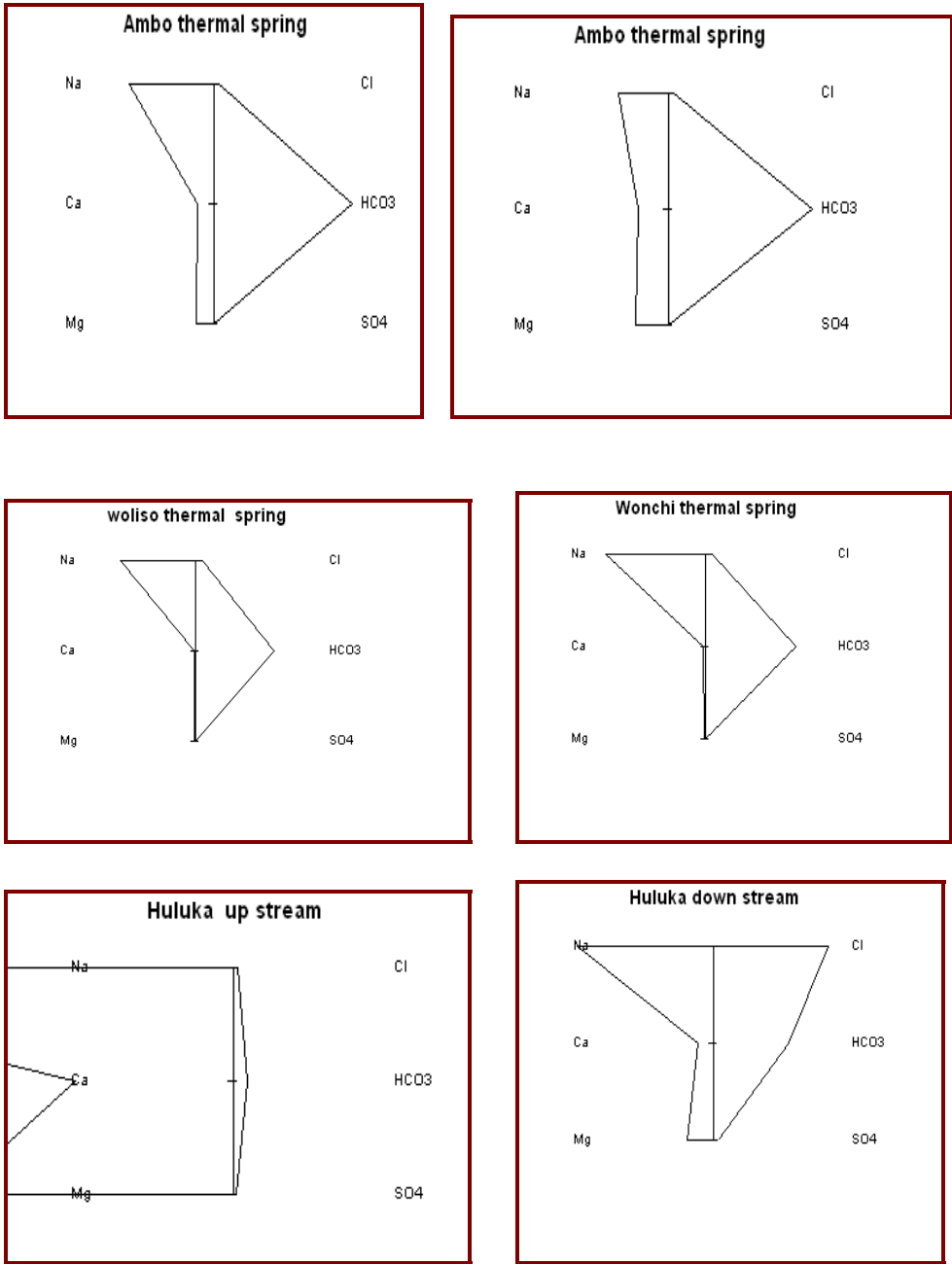


Figure 5.11: Indicates the thermally springs are totally governed by Na-Ca-Mg-HCO<sub>3</sub><sup>-</sup> type it is limited to the western and along the faults that Connects Ambo and Woliso.

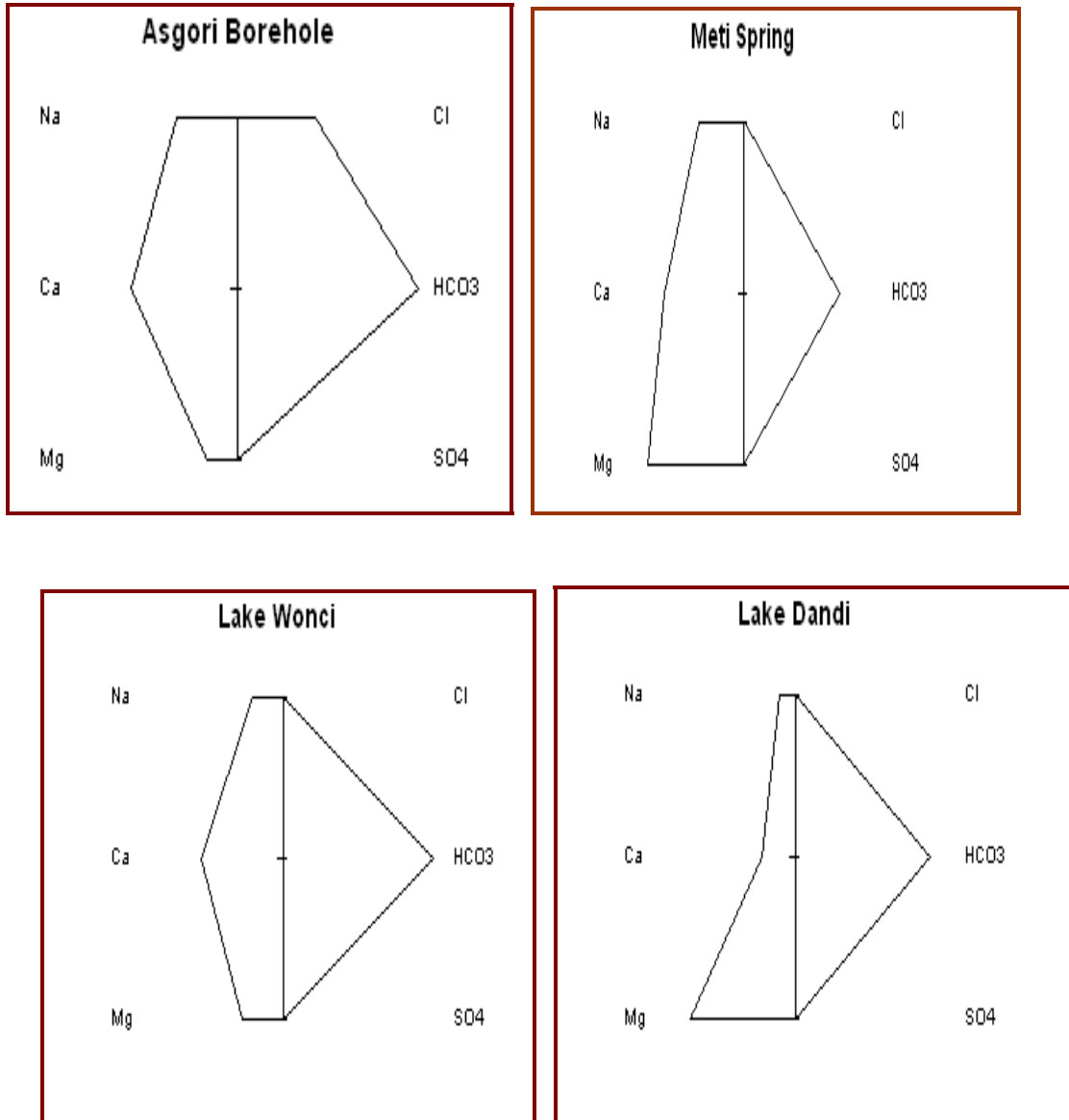


Figure 5.12: Here east west aligned Dandi and Wonchi Lake give rise to different facies it has to do with local Lithological setting.

Though there are various factors that control the hydrogeochemical evolution, geology and tectonic activities are found to be the most influential ones in determining the water type from quality point of view even these factors affect the quantity of both surface water and groundwater.

Chemical data interpretation using AquaChem software indicates two major water types with some exceptions: sodium bicarbonate and calcium bicarbonate type water, exceptionally magnesium bicarbonate. Tamiru Alemayehu and Seifu Kebede (2005) classified the water type of the area as follows: -

1. Na-Ca-HCO<sub>3</sub>, Ca-Mg-Na-HCO<sub>3</sub>
2. Ca-Na-HCO<sub>3</sub>
3. Mg-Ca-HCO<sub>3</sub>

The first type water is observed around the west end of the study area, predominantly limited to the thermal springs which occur following the North-South running faults in between Ambo and Woliso across Wonchi volcanic center. This water is believed to be more evolved owing to its association with the hot spring which is responsible in carrying dissolved solids from the deep-seated aquifer and has involved more reaction. And it can be concluded that all sodium-enriched (sodium bicarbonate) water is limited to the area controlled by the thermal springs system.

Ca-Na-HCO<sub>3</sub> type is noticed in those samples taken from northern, southern, and eastern parts of the study area, relatively outside thermal spring influences. These are shown in the stiff diagrams plotted for some representatives (figure 5.10, 5.11, 5.12).

Magnesium (Mg) rich water is encountered in samples taken from basic rocks. For instance, Meti spring, located east of Ambo at about 8 km, emerges from the fracture of dark basalt. The origin of Mg is attributed to this lithology. Similarly, Dandi lake exhibits high Mg concentration. This might have been linked with the ruminant basic (basalt) rock along the conduit wall from where it is leached out to the crater lake that filled the conduit.

## 6. Ionic Evolution

Both groundwater and surface water may undergo evolution based on certain controlling factors that it encounters along flow path geological nature, meteoric water frequency and chemistry, distance traveled and respective lithology with which contact will be made determine the eleven variables (pH,  $\text{Ca}^{2+}$   $\text{Mg}^{2+}$   $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ -TDS) extent of influence in ionic evolution.

Geological and tectonic activities are the major influential besides those mentioned. From physico-chemical analysis point of view the ionic evolution in the area can be categorized less evolved and highly evolved water. Water samples collected from the high land parts of the area are less evolved and characterized by Ca-Mg-HCO<sub>3</sub> or/ and Ca-Na-HCO<sub>3</sub>. In any case calcium bicarbonate is very dominant in most cold springs, boreholes, streams. Typically belong to east, north and south east with in the area.

In area where dark basalt is extensive laterally and thicker Mg-Ca-HCO<sub>3</sub> type is encountered this is noticed around Meti and Dandi Lake. Summary of water type is given in table 6.1.

Cold springs, bore holes, most surface water are fresh and less evolved which is attributed to meteoric water which flushes in such away lessening concentration of ionic species which suppose to cause evolution along the course. Generally, up land water of the area is uniform and Ca-HCO<sub>3</sub> type seldom Mg-HCO<sub>3</sub> type until it reaches the boundary of thermal spring's emergence where another type ionic evolution takes over.

At thermal spring controlled area the water is seen to be evolving from Ca-HCO<sub>3</sub> type to Na-HCO<sub>3</sub> type here the water is characterized by low pH, high TDS, EC and high partial pressure of CO<sub>2</sub> (Seifu Kebede et al, 2005). The influx of CO<sub>2</sub> from deeper source has played crucial role in maintaining Na-HCO<sub>3</sub> type water. Its possible source is believed to be decarbonation of Mesozoic sedimentary sequence and degassing of magma chamber along the deep-seated faults.

Ca is removed when shallow groundwater is transferred to the deep thermal groundwater. Removal of Ca together with Mg is linked with their fast saturation index. The left over Ca produces travertine deposit in the area silica sinter is formed in similar manner, they are likely from olivine, pyroxenes, plagioclases, and alkali feldspars hydrolysis including the Mesozoic sediments. According to Ferdinad.H(1983) all mineral water occurrences accompanied by the travertine outcrops.

In the area at least we have two water types occur as a result of evolution in between the thermal springs and relatively high altitude surface water together with shallow circulating groundwater.

According to Seifu Kebede et al 2005 in Yerer Tulu Welel Volcanic lineament (YTWVL)  $\delta^{18}O$  is highly depleted composition of the high TDS Na-HCO<sub>3</sub> springs, indicating that recharge must have taken place at higher altitude sources likewise the absence of appreciable amount of tritium in high TDS waters also testifies lack of any modern day meteoric water mixing into them. Implying Na-HCO<sub>3</sub> waters must have followed deeper circulation pathways before they emerge as low temperature thermal waters.

Seldom one can encounter relatively high chlorine (Cl<sup>-</sup>) and Nitrate (NO<sub>3</sub><sup>-</sup>) in some localized area this can be related to pollutant introduction from

households and agricultural practices. Occasional  $\text{SO}_4^{2-}$  occurrences in Ambo area may be related to Gypsum that exists as minor intercalation with the sand stone.

The major ionic evolution involves Ca-Mg- $\text{HCO}_3$  and Na- $\text{HCO}_3$  type the later characterized by High TDS, EC, low pH, high  $\text{CO}_2$ , and  $\text{HCO}_3^-$  while in the other opposite condition prevails.

Water type	Location(source)	Remark	east	North	elevation
Ca- $\text{HCO}_3$	Beshi spring	near boda	402971	972860	2273
Ca-Mg- $\text{HCO}_3$	Becho	becho plain	400317	931223	2148
Ca-Mg- $\text{HCO}_3$	Ginchi Borehole	Ginchi twon	405426	998009	2259
Ca-Mg-Na- $\text{HCO}_3$	Molche	7km north dandi lake	392924	986830	2680
Ca-Na- $\text{HCO}_3$	Tulubolo	Tulubolo Twon	400511	981086	2518
Ca- $\text{HCO}_3$	Wodesa(Homi spring)	5km North of Ambo	374796	1001340	2454
Ca-Mg- $\text{HCO}_3$	Wonchi lake		377722	974031	2890
Mg-Ca-Na- $\text{HCO}_3$	Meti	9km EAST Ambo	389381	991246	2670
Na-Ca- $\text{HCO}_3$	Ambo	AARI	371506	991436	2090
Ca-Na- $\text{HCO}_3$	Borehole Ambo	Ambo twon			
Ca-Na- $\text{HCO}_3$ -Cl	Asgori	10 km East Ambo	395776	992530	
Ca-Na-Mg- $\text{HCO}_3$	Busa	b/n Tulu bolo and Ginchi	406120	970002	2176
Ca-Cl- $\text{HCO}_3$	Hulka down stream part	after ambo twon			
Ca-Na-Mg- $\text{HCO}_3$	Hukoqorke spring	3 km East Ambo	379652	988970	2299
Mg-Ca- $\text{HCO}_3$	lake dandi		389129	978644	2850
Ca-Mg- $\text{HCO}_3$	Kelina stream	near ginchi	409673	999385	2240
Na-Mg-Ca- $\text{HCO}_3$	Ambo thermal spring	Ambo twon	374014	992809	2079
Na-Ca- $\text{HCO}_3$ -Cl	Thermal Spring( hotel)	Cl=40mg/l	373938	993022	2100
Ca-Na-Mg- $\text{HCO}_3$ -Cl	Awaro	Cl=32mg/l	378500	991200	2200
Na- $\text{HCO}_3$	Wonchi thermal spring	near Wonchi	376889	969696	3000

Table 7.1: Water type of the area determined using AquaChem.

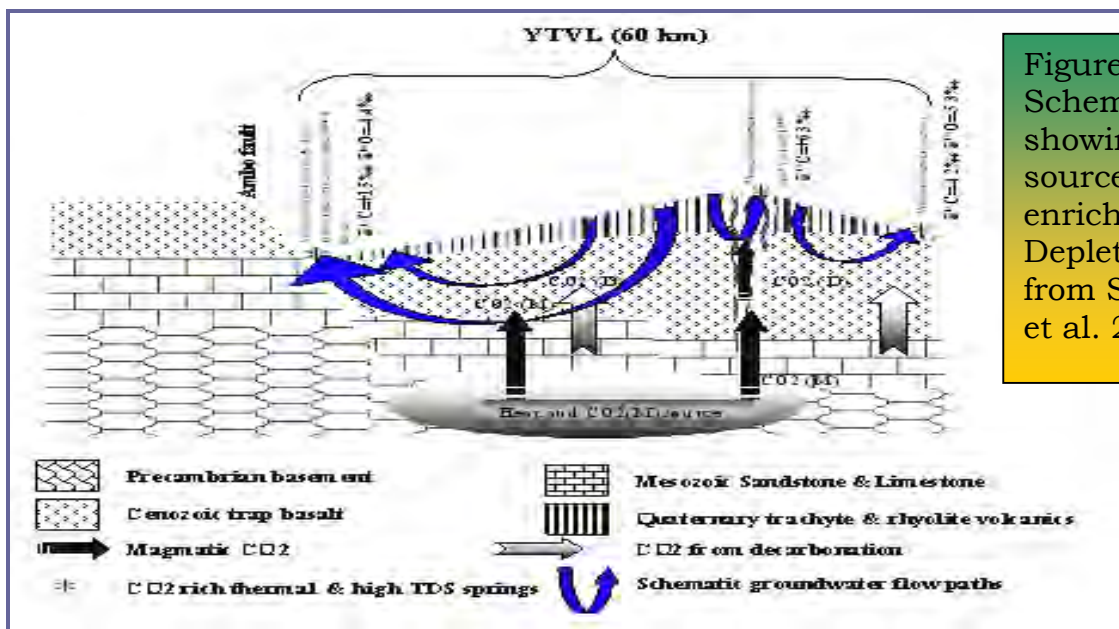


Figure 6.1: Schematic diagram showing  $\text{CO}_2$  source and isotopic enrichment and Depletion (Adapted from Seifu Kebede, et al. 2005)

Strikingly the eastern side of the area with respect to Dandi Wonchi Volcanic centers dose not show thermal springs unlike its counter western part that exist along Ambo and Woliso lineaments. Perhaps this might be attributed to the following hypothesis:-

- Geological formation variation (Pinching out of Mesozoic Sediments in the area).
- Volume and Geometry of cooling magma chamber and its mode of origin.
- Deep seated structures effect,
- Accessible route for Groundwater to and from the chamber.

In the eastern side where ignimbrite unit act as confining formation there is no dense deep seated faulting effect that has significant role in providing passage for hot water in the west margin. Though Geological structures mode of origin categorize them more or less in the same tectonic episodes, the eastern side might have suffered sealing effect as a result of internal and external disturbances.

The lengthy Dandi and Wonchi volcanic center oriented W-E ridge disappear at some point before reaching Becho plain; suggesting the active deep magma chamber similarly restricted with in the same geometrical dimension beneath those volcanic centers.

Absence of Mesozoic sedimentary origin may account for non existence of CO<sub>2</sub> rich water for there is no decarbonation; in association with these points there may be no accessible flow path for now and then movement of groundwater so that it can be carried to and from the deep. Here the Author recommended that farther investigation to be carried out.

## 7. Synthesis

To conceptualize the hydrogeochemical evolution essential scientific interpretation approaches are employed these include:

- ♣ Geological setting characterization
- ♣ Hydrogeological environment zoning
- ♣ Hydrometrology analysis
- ♣ Land use land cover classification
- ♣ Physicochemical data interpretation, etc.

Knowing the geological setting of the area has crucial role to ward understanding of hydrogeochemical evolution of groundwater. Rock water interaction is a kind of processes where by they exchange signature that bears their coexistence in such way inheriting the behavior of each other at the scale of spatial and temporal effect. The time water takes with in the hydrolithology and the spatial availability of both significantly affects the kind of hydrochemistry in that particular environment. The more time spent in the rock the more water will undergo evolution (more ionic species are involved) that is leaching of minerals as function of time is very effective based on the kind of geology. Hence geological setting in the study area is strongly affects the kind of water type from quality point of view.

Hydrogeological condition significance is inevitable in that of determining the evolution of water as it passes through different hydrostratigraphy being controlled by the hydraulic property of the material. The hydraulic property of aquifer governs the passage and storage (residence time) of groundwater. In very permeable unit water easily pass by rapidly implying there is no as such time for water to harvest the minerals from the host rock while water in confined media liable to increase in its chemical concentration. Generally speaking, hydrogeological system of

the area is vital component that governs water physicochemical nature this is because hydrogeology of any area is produced by dozens of natural elements including water, which in turn determine the fate of each other physically and chemically. Normally, hydrochemistry of the area varies as the function of hydrogeological condition that why we have different water type.

Employing Hydrometeorological parameters to study the evolution of groundwater is very meaningful, it is clear that with out the hydrologic cycle concept it is impossible to imagine hydrogeochemistry. In the study are rainfall is believed to be the decisive recharge inducing component, high rainfall record such as 1143.1mm/year even more at some station due to orographic effect, suggesting the freshness of the water is attributed to the high rainfall received which flushes (renews) the surface water and shallow circulating groundwater chemistry.

Moreover the Actual evapotranspiration indicates evaporation is effective in places where water bodies and vegetations are available the consequence has to do with the chemical concentration; more evapotranspiration involves ionic concentration increment in the water.

Classification of land use land cover (LULC) system depicts to what extent hydrogeochemical system of the area can be influenced by the kind of prevailing situation. Fore example nitrate ( $\text{NO}_3$ ) and Chlorine (Cl) presence in detectable scale is a clue that indicates what kind of land use land cover system is there specifically. For instance in water contamination management system, land use land cover classification is mandatory. In the area influence of LULC can be seen against recharge, discharge, contaminant introduction to water from urban and farm lands these and other sequentially affect the evolution of water.

## 8. Conclusion

Several man made and natural factors control the Hydrogeochemical evolution: land use land cover, geology, tectonic activity, and climatological condition, etc.

Geological structures control groundwater and surface water interaction through facilitating recharge and discharge; this is effective in making the distinction between ionic evolutions in the area

The eleven variables (pH,  $\text{Ca}^{2+}$   $\text{Mg}^{2+}$   $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  TDS) are interpreted to describe hydrochemistry and ionic evolution. Groundwater movement (flow direction) is radial on those volcanic centers and assumes well defined east and west direction in relatively low land part of the area; O18 and 2H isotopic depletion in thermal water enrichment in the higher altitudes suggests about the water origin and movement. Normally hydrogeochemical evolution is toward west course; along this path flow there are at least two water types, High TDS Na-HCO<sub>3</sub> rich and fresh (low TDS) Ca-HCO<sub>3</sub> water.

Low pH and high electrical conductivity water is limited to Ambo thermal spring emerging sites, wonchi and Woliso which are connected by NNW and SSE structures. The low pH is attributed to high CO<sub>2</sub> supply from Mesozoic decarbonation and Dandi Wonchi related magma chamber degassing. Travertine and silica sinter deposit are encountered in the area where thermal springs are out poured, the deposits occur owing to drop in temperature, pressure and mixing of thermal springs with fresh water coming from the high altitude ridges. Generally ionic evolution is highly affected by geological condition and deep seating structures.

## 9. Recommendations

- It is advisable conducting integrated geochemistry, isotope and hydrogeological investigation so as to characterize Ionic evolution where by water resources status can be addressed.
- It is better making the distinction boundary between Mesozoic deposits and igneous rocks to know which controls more ionic species constituents with respect to spatial and temporal variation.
- Detail physicochemical, biological and trace element analysis is proper to see extent of pollution from human effect and natural impact.
- Paying attention to structural and tectonic effect is highly recommended which suppose to be in charge of groundwater evolution to larger extent.
- It is recommended to conduct appropriate scientific investigation in the eastern part of the area to see possible reasons that causes absence of thermal springs with respect its counter part Ambo-Woliso thermal springs.

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**Annexes**  
**Hydrometeorology**  
**Temperature**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
max average	27.0	28.7	28.2	28.0	28.0	24.6	22.7	22.6	23.9	25.7	26.5	26.5	26.0
min average	11.4	12.4	13.0	13.3	12.2	11.9	12.1	12.2	11.0	10.1	10.8	10.0	11.7
ambo mean	19.2	20.6	20.6	20.6	20.1	18.3	17.4	17.4	17.5	17.9	18.7	18.2	18.9
													0.0
					Woliso station								0.0
max average	26.6	28.0	27.4	27.6	27.3	23.6	21.3	21.6	23.1	25.2	25.6	25.6	25.2
min average	13.2	14.5	14.1	14.0	13.0	12.8	12.8	13.1	12.3	12.4	13.0	13.0	13.2
Woliso mean	19.9	21.2	20.7	20.8	20.2	18.2	17.1	17.4	17.7	18.8	19.3	19.3	19.2
					Tulu bolo station								0.0
max average	24.3	25.0	25.3	25.5	25.7	24.8	23.3	23.5	23.6	23.3	23.9	23.6	24.3
min average	8.6	8.7	9.7	9.9	9.6	9.8	9.8	9.8	9.3	9.0	8.5	8.3	9.2
tulubolo mean	16.4	16.9	17.5	17.7	17.6	17.3	16.6	16.6	16.5	16.2	16.2	15.9	16.8
													0.0
					Asgori station								0.0
max average	27.5	28.5	29.0	28.4	29.0	27.6	25.0	24.8	25.5	25.8	26.5	26.8	27.0
min average	6.1	7.1	8.8	10.0	9.2	9.7	10.5	10.8	9.6	5.8	4.5	4.8	8.1
Asgori mean	16.8	17.8	18.9	19.2	19.1	18.6	17.7	17.8	17.6	15.8	15.5	15.8	17.5

**Relative Humidity**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ambo Average	50.6	42.4	49.4	51.1	51.6	66.6	72.6	75.0	73.4	57.2	49.4	48.0
Woliso Average	50.2	46.1	51.5	56.9	61.8	76.7	83.3	83.9	78.8	57.9	47.1	47.5

CATCHMENT'S RELATIVE HUMIDITY												No v	Dec
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Mean RH	50.4	44.3	50.5	54.0	56.7	71.7	78.0	79.4	76.1	57.6	48.3	47.8	

	Sunshine duration											
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Woliso Average	8.615	9.54	7.815	7.005	7.745	5.655	4.645	3.6	4.375	7.295	9.18	9.7
Ambo average	8.4	9	7.6	7.1	7.6	4.5	3.675	3.5	4.6	8.85	9.525	9.575
Mean	8.51	9.27	7.71	7.05	7.67	5.08	4.16	3.55	4.49	8.07	9.35	9.64

**Wind speed**

Woliso												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	67.5	65.5	53.2	48.4	32.7	19.7	17.6	16.8	20.7	45.7	65.7	74.9
mean	4.0	3.9	3.1	2.8	1.9	1.2	1.0	1.0	1.2	2.7	3.9	4.4
Ambo												
Total	17	19.3	17.1	16.4	13.1	10.1	7	6.8	7.7	13	15.7	18.1
mean	2.1	2.4	2.1	2.1	1.6	1.3	0.9	0.9	1.0	1.6	2.0	2.3
Catchment mean wind speed												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Catchment mean	3.0	3.1	2.6	2.4	1.8	1.2	1.0	0.9	1.1	2.2	2.9	3.3

**Rainfall**

station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total (mm)
Tulubolo	18.3	18.6	54.2	67.8	78.4	192.9	287.5	277.7	90.6	24.6	7.4	7	1125
Asgori	18.5	32.8	53.6	83.6	67.9	128.1	242.5	239.4	102.2	25.7	6.9	5.3	1006.5
Woliso	23.9	27.4	66.5	84.8	122.8	190.9	271.9	257.3	130.5	40.4	7.6	5.3	1229.3
Busa	21.3	59	55.9	73.7	84.4	179.8	358.2	372.5	164.9	43	10	9.1	1431.8
Wolonkomi	22.8	29.2	66.1	72.4	77.9	154.4	240	234.4	133.7	36	12.2	6.6	1085.7
Ambo	31.87	15.27	52.76	74.65	73.18	149.87	177.2	163.2	87.71	45.83	9.22	11.3	892.09
Ginchi	33.9077	65.93	84.38	105.1	87.46	148.68	238.7	224.3	150.6	32.04	4	16	1191.19
Arithmetic Mean	24.37	35.46	61.92	80.3	84.58	163.52	259.4	252.7	122.9	35.37	8.19	8.66	1137.38

Note: annual total=1137.37mm/year

## Annex Hydrochemistry data

### Water Sample Data

**Water Sample collected for Physico-Chemical Analysis**

Collection date	Code	Kebele	Locality	UtmE	Utm N	Elevation (m)	Ec (uS/cm)	PH	Temp (C°)	Sample source
5/5/2007	Majsho-1	Koromi	Koromi	394506	988270	2669	400	6.65	20.1	Spring
5/5/2007	Bush-2	Hubato	Shone	393704	986667	2669	300	6.25		Spring
5/5/2007	Arbu.ker-3	Hubato	Cheefe kernsa	392904	985837	2670	200		17.9	Spring
6/5/2007	B.Gode-4	Gode	Maja	394620	987611	2670	10	6.23	17.3	Spring
6/5/2007	Regbuq-5	Bollo	Meti	389381	991246	2670	200	6.64	19.9	Spring
2/6/2007	Ds-6	Dagalee gatiraa	Wodesa	375722	999239	2255	557			Spring
3/6/2007	Hs-7	Abbedoyo	Wodesa	374796	1001340	2454	319			Spring
3/6/2007	HDS-8	Abbedoyo	Wodesa	375548	1001130	2485	293			Spring
3/6/2007	LHS-9	Debis	Legahola	375866	995950	1998	1120			Spring
3/6/2007	XHS-10	Ambo	Ambo twon	374014	992809	2079	2570			Spring
3/6/2007	EHS-11	Ambo	Ambotwon	374014	992809	2079	2440			Spring
3/6/2007	HCS_12	Awaro	Hukoqorke	379652	988970	2299	1500			Spring
3/6/2007	HDS-13	Awaro	Hukoqorke	380229	989316	2290	900			Spring
3/6/2007	OHC-14	Awaro	Hukoqorke	380015	989478	2276	902			Spring
3/6/2007	Aqs-15	Awaro	Qora	379445	990905	2202	1020			Borehole
24-May-07	TOS-16	Tulubolo	Tulubolo	412187	957227	2091	420	6.76		Spring
24/6/2007	DB-17	Busa	Busa	406120	970002	2176	627	7.07		Borehole
24/6/2007	BB-18	Bashi	Bashi	402971	972860	2273	456	6.9	24.3	Spring
24/6/2007	B2B-19	bashi2	bashi2	402977	972888	2254	454	7	24.3	Spring
24/6/2007	BD-20	Boda	Boda	399059	979194	2600	112	6.27		Spring
24/6/2007	TB-21	Tuluboda	Oo spring	400511	981086	2518	112	7.02		Spring
24/6/2007	GB-22	Ginchi	Ginchi town	405426	998009	2259	670	7.16	20.8	Borehole
24/6/2007	GS-23	Barodo	Barodo	409673	999385	2240	455	7.54		Spring
24/6/07	BH-24	Barodo	Barodo	409433	999120	2230	600	7.06		Borehole
29/6/07	Wts-25	Woliso TS	Lodge	0387837	094370	2041	2320			

Chemical data

local name	type	source	Na+	K+	Ca <sup>2+</sup>	Mg <sup>2+</sup>	F-	Cl-	NO <sub>2</sub> -	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	CO <sub>3</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>
Shone	CS	Autor	6.67	1.16	10.4	4.28		11.16		2.49	nd		12.2
wodesa	CS	Autor	15	3.1	80.96	12.42	0.95	2.96	tace	1.01	0.53		329.4
wodesa	CS	Autor	6.37		13.39	7.19		10.29		1.79			146.4
ambotwon	TS	Autor	80.33					33.99					1116.3
hukoqorke	CS	Autor	88.26	6.95	9.38	10.53		20.57					573.4
hukoqorke	CS	Autor	71.8	6.33	13.69	7.18		18.83					512.4
qora	CS	Autor	49	12.1	114.4	24.3	1.05	31.78	0.005	5.06	0.074		505.08
tulubolo	CS	Autor	28.5	10.1		6.48	26.4	1.5		2.8	1.38		204.22
Busa	BH	Autor	49.0	10.1	58.1	17.3	1.27	5.96		1.8	22.9		395.28
Bashi	CS	Autor	14.73	2.99	14.97	5.23		10.75		1.08	nd		219.6
ginchi twon	BH	Autor	24	2.5	96.8	21.6	0.19	17.9	0.005	7.2	2.01		386.5
barodo	CS	Autor	8.37		28.18	8.17		9.41		1.04	nd		262.3
Woliso	TS	Autor	266	10.7	3.52	1.62	6.4	38.7	0.015	0.4	8.46	24	667.1
taji galla		WWDSE			2	5	0.29	nd		1.8	1		57.34
wolonkomi		WWDSE	12	2.3	113.9	15.1		15.5		25	8.98		384.3
bodaz		WWDSE			38.4	6.24	0.29			5.28	1	U	33U
becho dilala		WWDSE	9.7	3.3	29.6	8.5	0.15	3.8		7.5	0		136.9
Wonchi	TS	Kashun	348.4	19.8	4.1	1.3		40.1			0.1	0.8	856.4
Qerensa	CS	L	11.966	2.013	24.8	22.08		3	7.48	0.017	nd	0	187.88
Molche	CS	L	0	0	20	19.2		nd	0.0033	1.76	1		56.12
Buqisa	CS	L			21.6	15.84		nd	0.0132	19.36	nd		80.52
Huluka	stream	L			20	21		nd	0.073	5.61	0.6		nd
Chafe	CS	L	32.134	5.407	112	43.2		nd	0.023	5.72	29		610
kilinto	Cs	L	5.536	0.932	120	37.92		nd	0.023	31.68	nd		488
Huluka	stream dow	L	115.105	19.367	11.2	11.52	nd	150	0.403	nd	10		169.58
Wanchi	lake	L	18.383	9.839	11.2	2.4	1.02	8	0.026	6.16	nd		120.78
Sankale	bh	L	336.808	23.874	36.8	78.72	0.53	198	0.046	4.4	4		1091.9
Ambo	BH	L	24.893	4.188	82.4	34.08	nd	6	0.023	16.28	nd		420.9
Hotel	ts	L	182.458	30.699	168	33.6		220	0.0264	151.52	77		585.6
Dule	Cs	L	87.004	14.639	220	55.2		nd	0.023	18.04	625		397.72
tiro	stream	L			80	43.2		nd	0.0165	4.84	7		248.88
Wachani	cs	L	25.134	4.229	58.4	17.76		nd	0.0264	9.24	1		329.4
Dandi	lake	L	10.126	5.419	20	38.4		nd	0.0132	6.6	5		248.88
Ela	cs	L			48	4.8	0.22	nd	0.013	14.08	1		12.2
shamme	cs	L			56	57.69	0.48	nd	0.393	7.04	50		268.4
AARI	bh	L	275.00	29.86	64.00	62.40	0.8	nd	0.036	5.28	1		1281
thermal spring	ts	L	181.448	19.707	180	33.6	0.98		0.003	5.28	1		1183.4
Wolonkomi	DW	wwdse	33	46	140	46	0.6	97			32		436
Ginchi asgori	BH	oroma	28	4.4	44	7.6	0.24	58		1.23	0.83		230.6
ginchi bole	DW	WWDSE	25	4	62	19	0.03	5			44		350
Ginchi Boda	DW	WWDSE	5	9	4	3		4		0.1	13		46
jemjem Ginchi	stream	WWDSE	9	2	30	8	0.2	6			5		145
Awaro	bh	seifu	76.6	11.95	93	30.36	1.1	32		13.2	1.3		564.9
wonchi	cs	seifu	41.1	6.69	6.63	1.26	6.6	3.5			0.7	0.35	163.48
gudar	bh	seifu	35	6.5	46.6	5.8		6		1.32	24	3.06	194
Ambo	ts	seifu	268.1	31.53	45.65	29.83	0.9	27.9		4.8	0.1	0.29	1172
Sankale2	bh	seifu	250	38	75	50	0.8	36		1	13	0.09	1150
ambo	ts	seifu	280	28	74.4	21.9		34			0.1	0.22	692
Ambo ussr	dw	seifu	314	27.5	52.9	39.4	0.5	42.5		2.6	0.1	0.46	<b>1159.00</b>