ADDIS ABABA UNIVERSITY
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WATERRESOURCES POTENTIAL EVALUATION OF HOLETA RIVER CATCHEMENT CENTERAL OROMIA, WEST SHEWA

A THESIS SBMITTED TO THE SCHOOL OF GRADUATE STUDIES
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Table of contents

List of Tables

List of Figure

List of Annexes

Abstract

The study area lies in the central part of the country, 45 km west of Addis Ababa, in Oromia National Regional state. It is a sub catchement of upper Awash drainage basin with a total surface area of 515 km^2. Currently the need for water is highly increasing due to increasing population, irrigation practices, and agricultural based industry (particularly flower farming) in the area. Thus the main objective of this research is to study the status of water resources potential in the catchement. It is generally characterized with two major types of land forms: volcanic ridges and hills surrounding the catchement at its northern and eastern, part with flat land areas in central, western and southern part with humid climatic conditions and rivers that flow towards south.

The basaltic lava flows (Alaji and Tarmaber Megeze formation); Trachyitic and Rhyolitic volcanic rocks, phyroclastic deposits and Quaternary Alluvial sediments are major geologic units in the area.

On annual basis, the area has 1253.3mm; 748.2 mm, and 310.6 mm of mean total rainfall, Actual Evopotranspiration (AET), and groundwater recharge respectively, and is found under moisture surplus where by, precipitation satisfy soil moisture demand.

The groundwater recharge from the annual precipitation in the area is very high. The Holeta River catchement is wide and very long. The land slope with in the catchement is very gentle. The outcrops in the area are highly fractured and jointed. Local minor faults and regional fractures are densely distributed in the area. There fore, recharge to the groundwater from the local precipitation with in the catchement is found to be high, so that groundwater storage of the area having alluvial sediments, weathered and fractured basaltic rocks and scoracious basalts as main aquifer and highly weathered basalt (paleosoil) layer as confining (barrier) is very high.

The main recharge area of the study catchement are Fo’ata mountain range, Fo’ata mintile area Simbirtu kotu area, in the northern part, and Wechecha Menagesha mountain chain in the eastern part of the catchement, which are also located at higher elevation. These high lying areas get high rain fall compared to its surrounding low-lying area. Moreover, the groundwater movement in most places sub- parallel to the surface water flow and more or less controlled by the topography of the area.

According to the hydro geological investigation under taken with in the catchement and as it has been revealed also from the yield of wells, the catchement is categorized in to four permeability and productivity zones. The high permeability and productivity areas (yield ≥ 10 l/s), moderate permeability and productivity (yield 5-10 l/s) low permeability and productivity (yield 2-5 l/s), and poor permeability and productivity (yield < 2l/sec).

The water samples analyzed in the area have 15.5 ^{o}c to 24.7 ^{o}c and less than 1000 mg/l of temperature and TDS respectively, eventhough they show progressive increase along the flow path. In all analyzed samples calcium is the dominant cation and bicarbonate is the dominant anion. The water in the catchement is mainly of $Ca\text{-}Mg\text{-}HCO_3$, $Ca\text{-}Na\text{-}HCO_3$ and $Ca.HCO_3$. Almost all the analyzed water samples are with in the limit of acceptable value of WHO (World Health organization) water quality standards for water supply and irrigation.

In general the current water resource potential (quantity and quality) of the catchement for domestic, agricultural, and industrial is evidently enormous. How ever the long term sustainable use of this resource requires an integrated effort of all concerned professionals and departments and the inhabitants of the whole population of the catchement and its surroundings as to how to use and protect the soil- water- forest system in the catchement as it is very decisive in the fate of the future generation.

Chapter one: - Introduction

1.1 Back ground

Water is an essential ingredient of all life. Among other substances gifted by nature, water is the basic and most precious one that makes up our earth's system next to air. Water plays a major role in virtually every aspect of the human life. The importance of this resource for water supply aspect is very clear and besides its supply aspect, it has social, political, economical as well as esthetic values.

Every attempt toward environmental protection and regulation is by no means successful without the basic knowledge of the water sector. Civilization and development never be possible with out proper utilization of this environmental deterministic and vital resource. Henceforth, it is mandatory and nonnegotiable to have basic knowledge of this resource by every one primarily the local water authorities so that effective use, management and conservation of the resource could be adopted and universal water problem related to its occurrence, distribution and contamination can be solved.

As the countries water supply coverage and other developmental activities are still require high effort, the study of water resource potential evaluation is the most practical method to solve this problem. Many studies on the ground water geology of an area make no attempt to evaluate how much water is available for use. In the absence of this attempt it is impossible to plan the development and management strategy of water resources which is very crucial for the economic development of the country in general and the study area in particular.

Currently the need for water is highly increasing due to increasing population, irrigation practices and agricultural based industry (particularly flower farming) in the area. The main reason for the increase of population and concentration of flower farming private limited companies in the Holeta River catchement is due to the nearness of the area to the Bole International Air port as the newly constructed Addis Ababa-Ambo Asphalt road minimizes the distance from 45 km to 28 km, and favorable soil and air condition of the area for the flower farming industry.

According to Oromia Investment Promotion Agency, so far more than thirty seven flower farming private limited companies are present in the study area and still the question is arising. Though the area is highly in need of water due to the above mentioned reasons and other developmental activities, the catchement lacks a detailed geological, hydrological (hydro geological), and hydro chemical study in order to lunch developmental activities using ground water.

1.2 Objective of the study

The ultimate objective of this research is to provide basic information to investors and decision makers about the status of water resource potential in the catchement.

The specific objectives of the study are to:

- Produce geological and hydrogeological map of the area at the scale of 1:50,000.
- Estimate total subsurface storage capacity of the catchement.
- Identify recharge and discharge zone of the catchement.
- Determine ground water flow directions.
- Establish physical parameters of the aquifers Transmissivity (T), Hydraulic conductivity (k), specific capacity, etc.
- Analyze spatial variation of hydrochemistry.
- Asses and evaluate the possible sources of water pollution (it there is any).
- Delineate potential sites for development.
- Suggest possible future sustainable utilization of the surface water and ground water resources.

1.3 Methods and materials

For the achievement of the objective i.e. water resources potential evaluation, the following methods and materials were employed.

- Review of previous works in the study area (geological, hydro geological, geophysical, and well completion reports)
- Examination of different maps and aerial photos of the area
- Geological and hydro geological field survey
- The 1:50,000 scale topographic map and Magellan GPS-15were used for navigation during the field work so that accurate locations of the observations data on the base

map were made and different types of final maps are compiled with 1:200,000 scale (such as: soil, land use/ land cover, geological, and Hydro geological maps).

- Physico-chemical analysis was carried out for representative samples collected from different sources. A total of five spring's four shallow wells, three hand dug wells, eight deep wells and three streams were collected.
- P^H meter of mode Hi 9025 microcomputer and TDS metre of model ISO 9001 manufactured by Hanna instrument company, and conductivity meter of model HD 8706 manufactured by delta OHM company and Thermometer.

1.4 Previous work

Unlike other parts of the country such as the Rift zones, High land plateau areas in general and Holeta area in particular is less investigated both from geological and hydro geological point of view. The investigation carried out so far in the area are either to general (on a regional scale) or hydro geological and geophysical investigations for specific institutions, organizations, private limited companies and town water supply for locating bore hole sties with out considering all the ctchement areas.

Among the important geological and hydro geological investigations are: the feasibility study of surface and ground water for the water supply of Holeta Genet town by nor consults (norconsult, 1999). Ground water investigation at south of Holeta Town, Ethio AGRI-CEFT Pvt. Ltd. Co., by water well drilling enterprise consultancy division (WWDE, 2003). Hydro geological Report of Holeta area for the purpose of locating bore hole site for Holeta Mulugeta Buli Military Training Camp, Ministry of Defense by water works Design and supervision Enterprise (WWDSE, 2004). Construction Rock materials assess mint project in areas around Finfinne, ADAMA and AMBO (Draft report on Geology and construction material potential of areas around Finfine that includes Holeta area (Gelana Gadissa etal; 2003).

Chapter two: - General overview of the study area

2.1 Location and aerial extent

The study area, Holeta River catchement, is located in the central part of the country, 45 km west of Addis Ababa in Oromia National Regional state, west Shewa Administrative Region. The area is bounded between latitude 8^o 53’ 75” to 9^o 14’ North and longitude 38^o 21’ 40” to 38^o 36’ 14” East.

It is delineated based on water divide/ river catchement located in upper Awash basin. It includes part of two administrative districts, Welmera and Ejere with a total surface area of 515 km^2 (Fig 2.1).

2.2. Population

The population of study area as of 2003 was 134,858 (office of Finance and Economic Development for West Shewa zone). Using the national annual population growth rate of 3% the projected population as of the year 2006 will be 146995 out of this about 85% are living in rural while the rest are urban dwellers.

Table 2.1 Human population of the study area

Sex	2003		
	Urban	Rural	Total
Male	19403	46949	66352
Female	20933	47573	68506
Total	40336	94522	134,858

According to West Shewa zone Agricultural Development Department 2003/2004 live stocks in the study area is estimated to be 349374 (Table 2.2).

Table 2.2:- Live stock in the study area.

No	Type of animals and Poultry	Total
1	Cattle	147222
2	Sheep	84273
3	Goats	13342
4	Poultry	97495
5	Horses	7042
6	Asses	12465
7	Mules	154

Source: - Office of Agricultural development for Welemera district.

2.3. Socio Economic activity: - According to West Shewa Zone planning and Economic Development Department 2003, Agriculture is the primary socio economic activity of the community of the study area. Wheat, Barley, Teff, Maize and sorghum are the major Cereal crops cultivated in the area which accounts for about 78% of the total crops. They grow under conditions of temperature that ranges from 18-25^{o}c. Cumbisols and luvisols which are located in most parts of the study area are comfortable for these crops to grow. Pulses and oil crops, accounts for 22% of the total cultivated area.

In general, the economic activity of the community is mainly a mixed type of farming. Population pressure is much higher in the study area because of the presence of thick fertile soil and favorable climate condition for crops to grow. As a result, the land in this area is intensively cultivated with major cereal crops mentioned above.

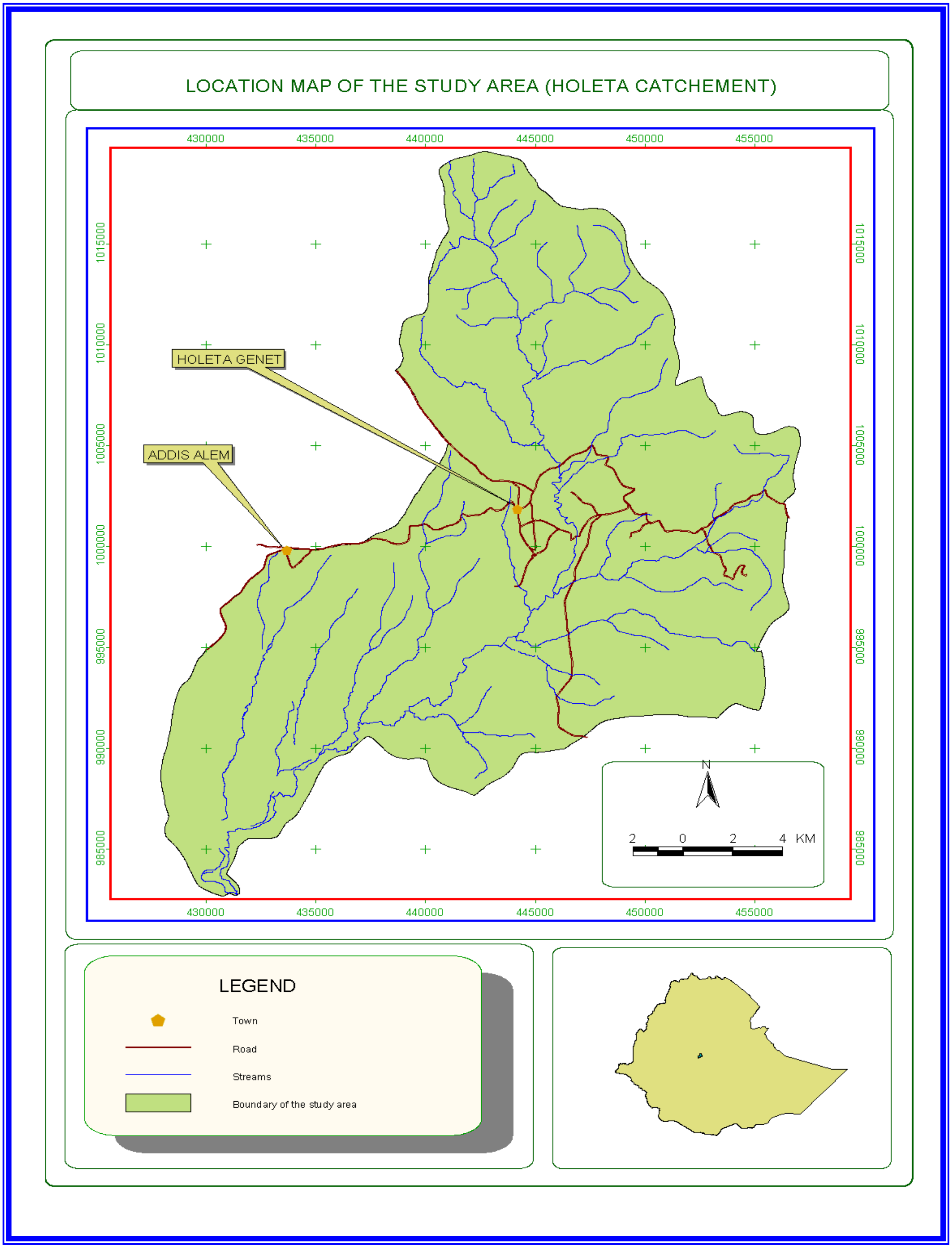


Figure 2.1 Location Map

2.4 Physiography

Holeta catchement is located partly in the western Ethiopian rift Escarpment and partly in the western Ethiopian high land plateau. The morphology of the study area is a direct reflection of the different volcanic strategic successions, tectonic activities and the action of erosion between successive lava flows. Two major types of land forms generally characterize the study area: volcanic ridges and hills surrounding the catchement at its northern and eastern, with flat land areas in central, western, and southern part. The general slope of these central and western plain is toward the south. The highest and lowest elevation is estimated to be about 3385m.a.s.l.and 2060m.a.s.l. at Wachacha mountain range and the confluence of Holeta and Awash River respectively.

The Northern part of the area is formed by an east- west oriented elevated land that is considered to be fault escarpment, and from which a number of streams emerge. This fault escarpment also acts as a surface water divide. Similarly, the eastern part of the study area is also a mountainous land comprised by high lands of menagesha- Wachacha ridges made up of silicic rocks.

The area is characterized by dendritic and parallel d rainage pattern (Figure2.2).

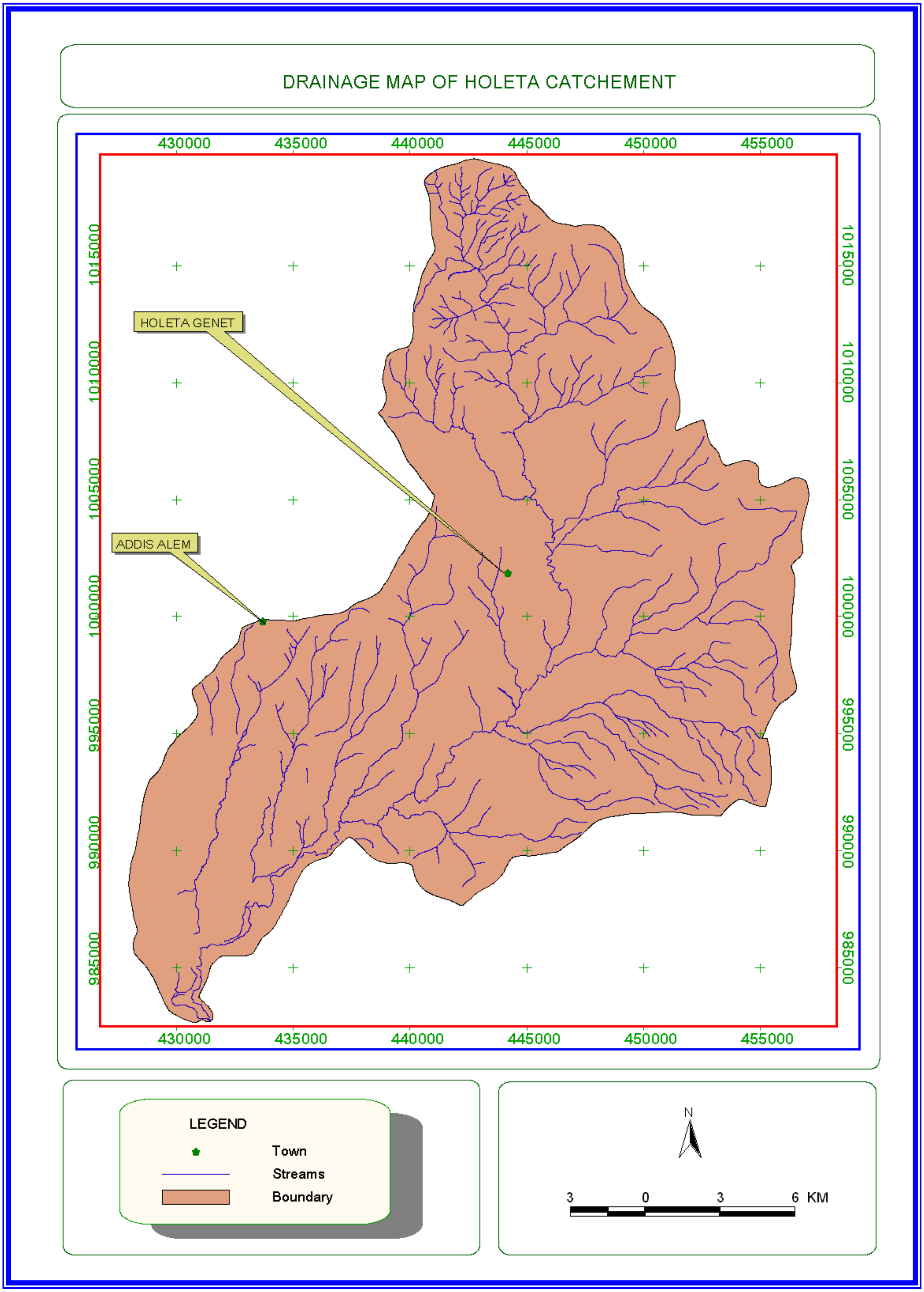


Figure 2.2 Drainage Map

2.5 Climate

Based on rainfall, the climate of the area can be categorized in to two broad seasons: the dry season (winter) and the wet season (summer) with autumn and spring receiving a slight amount of rain. The total annual rainfall in the area is 1253.3mm on average; and the mean annual temperature is 14.4 ^{o}c.

The maximum and minimum recorded temperatures are 24.5 and 2.0 ^{o}c respectively in May and December.

From Agro climatic point of view the study area is divided in to two: cool temperate (Dega) 46% (237km^2) and temperate (Weina Dega) 54% (278km^2).

2.6 Soil

Taking in to account the climate physiographic geology and other factors responsible for soil formation and development the fallowing soil types have been identified in the study area. Along the divide lines of the catchement thin layers of soil were developed. In the central part of the catchement the layer of the soil is relatively thick. Accordingly there are three types of soils found in the study area (Figure2.2).

1. **Chromic and orthic luvisols: -** This soil types covered most part of northern, north eastern, eastern, and western parts of the study area. But they differ in that the northern and western ones are developed on basic volcanic rocks, where as in the north eastern and eastern elevated lands such as Menagesha, Wechecha and Wato Dalecha, the soils are derived from intermediate (trachytic) lava flows. This type of soil covers 78 % of the study area.

2. **Chromic and pellic vertisols:-**Mostly found on flat areas of the central part of the catchement, which is dominantly comprised by black cotton soil. This type of soil constitutes about 15 % of the total area.

3. **Sandy-silly clay soil: -** Soils in the southern plain land area of the catchement are more of sandy silly nature unlike the central tract of land, which is dominantly comprised by black cotton soil. This type of soil is derived from transported materials of elevated lands of the study area and deposited at the southern part (bacho plain) and along stream and river courses. It covers about 7 % of the total area.

   To sum up, one may categorize the soil in the study area from hydro geological point of view in to those that have high permeability (Sand dominated soils) and those that have low permeability (clay dominated soils). Accordingly areas to the south and along stream covers and Northern part of the study area (thin soil cover) are those of the first c ategory, where as the central flat planar areas are of the second category.

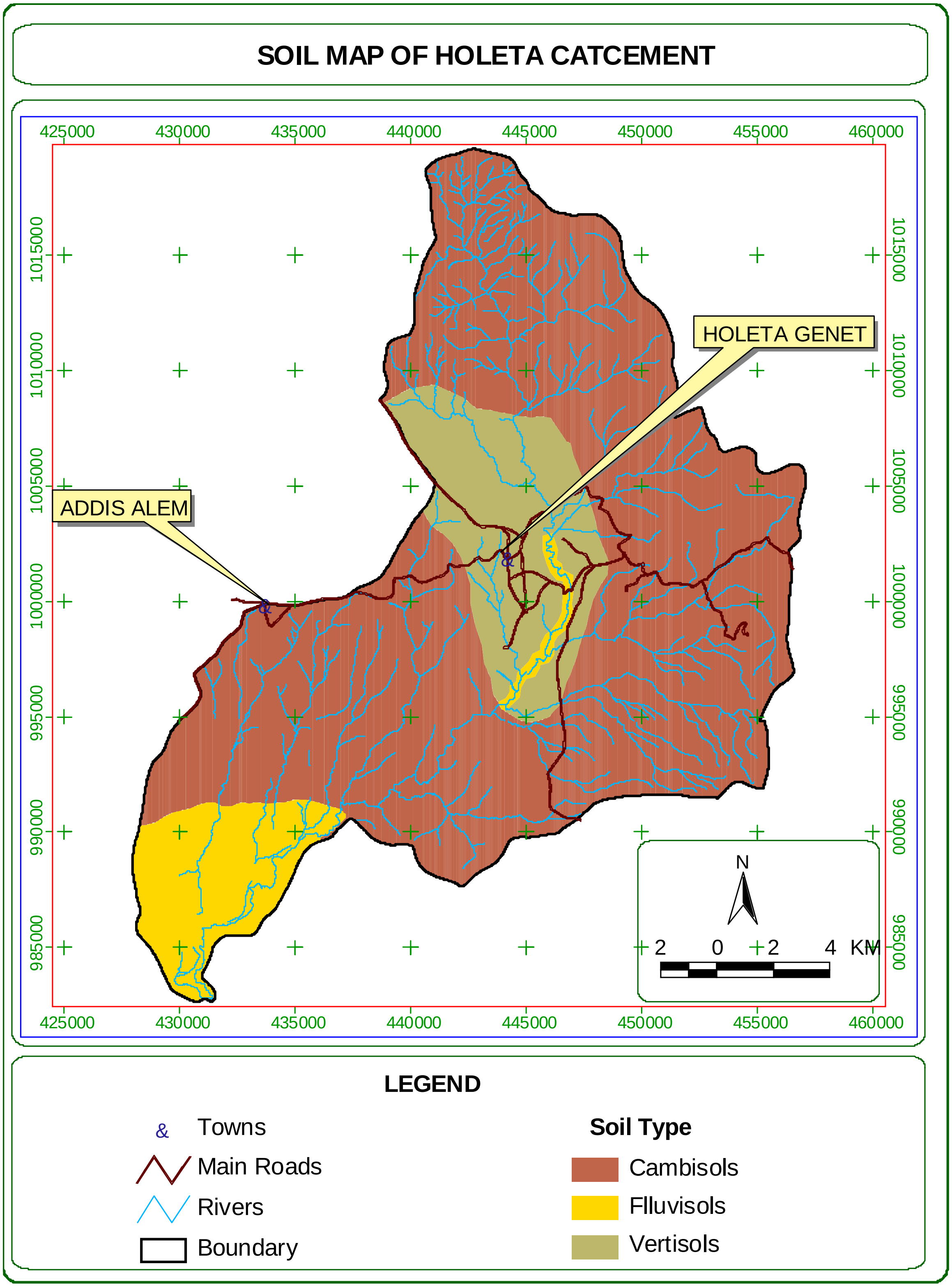


Figure 2.3 Soil map of the study area

2.7 Land use and land cover

Apart from in convenient areas for farming such as hills and /or ridges as well as areas reserved for grazing and state forests, the majority of the study area is covered with cereal, pulses and oil crops (Figure 2.3).

Vegetation: **-** The catchement was highly vegetated area in the past yeas but now a day because of increased farmland, deforestation and increased population pressure, the species and types of vegetation is decreased, major type of natural vegetation found in the catchement are wood land and shrub and bush. There are also man made and natural protected forest in the catchement.

One can categorize the vegetation cover of the area in to grass lands, shrubs and forests along the ridges watersheds. The forest part is almost classified under Eucalyptus and coniferous which are planted artificially. The coniferous forest originally covered the northern central and southern highlands of the study area. This has revealed by the relicts observed at the mentioned areas. However, due to human interference the original vegetation has been destroyed and there are no more forests or brood leafed trees. There are vast areas of pasture and few trees.

The eastern part of the study area i.e. Wachacha Menagesh Mountain range is almost covered by natural and artificial trees. The North East and some West central part of the catchement are covered by Eucalyptus tree and shrubs.

In general the land use land cover of the study area is summarized as follows (Table 2.3).

No	Description	Area(km^2)	%
1	Land under crops	339	65.83
2	Land covered by vegetation	101	19.64
3	Grass land	23	4.49
4	Assigned for other purposes	52	10.02
Total		515	100

Source:- Office of Agricultural Development for Welmera district

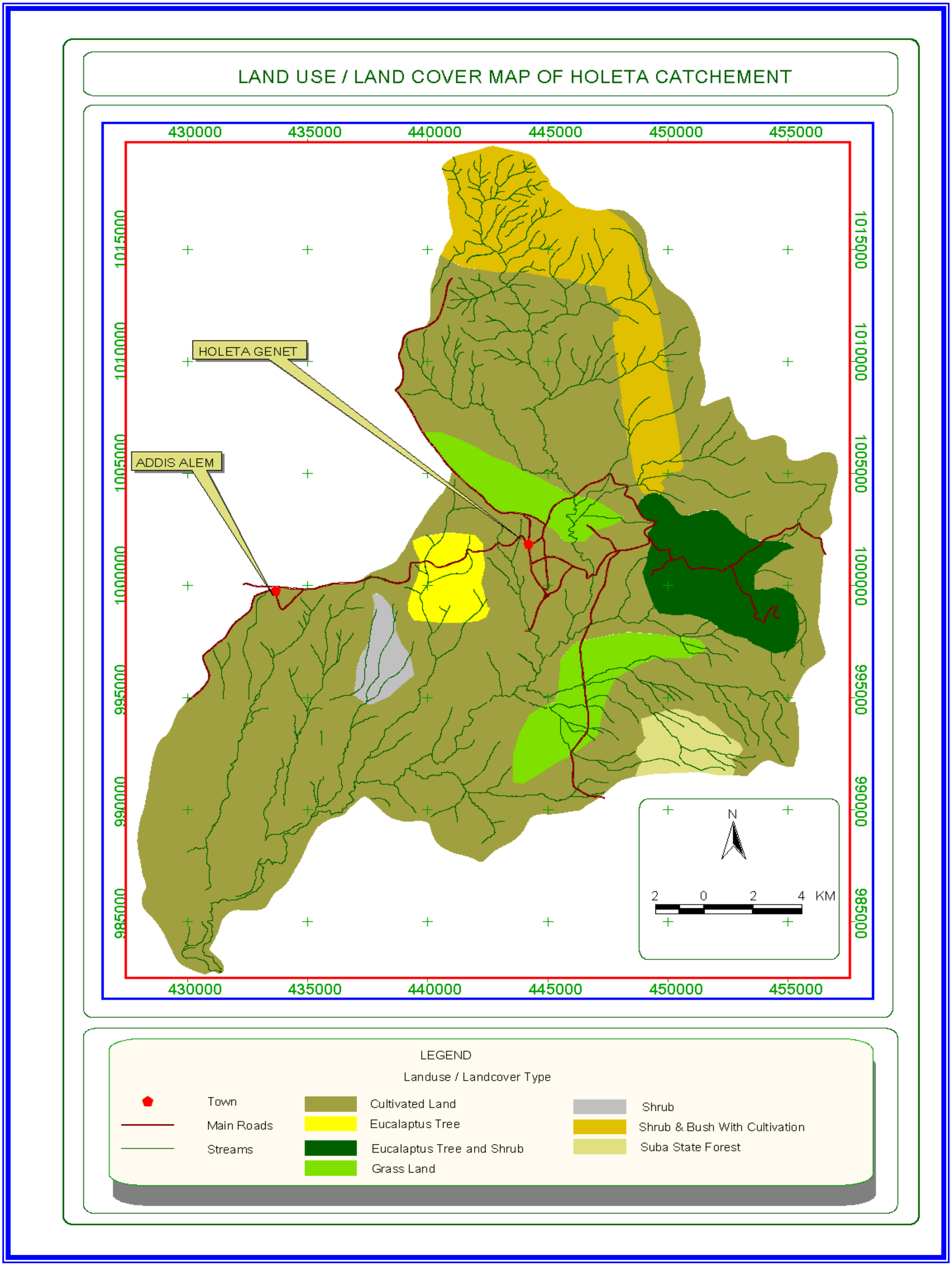


Figure 2.4 Land use / Land cover Map

Chapter III: –Geology

3.1 Regional Geology

The study area is situated in the central part of Oromia, West Shewa Administrative Region, welmera District. Regional geological setting of this area consists of two major rock groups, namely pre Rift volcanic succession, and Rift/ Post Rift volcanic products and sediments. The pre-Rift Groups are parts of the thick volcanic succession, mainly basalt, in the Trap-series volcanism of Tertiary period, with Fissural and / or central modes of eruptions. They include Ashangi Formation (p_1a), Aiba Formation (P_2a), Alaji Fomation (PNa_a), and Tarmaber-Magazaz formation (Ntb).

The post rift volcanic and sediments include Adama group, Affar group Wanji group, Quaternary plateau basalts (Qb) and Alluvial and Lacustrine Deposits.

Details of the regional geology as extracted from previous workers' reports (mainly from a compilation work of GEODEV-AFREDS PLC. Consortium (1999), Geology and Mineral Resource Section), are provided in the following subsections.

3.1.1 Ashangi Formation (p_1a)

An extensive development of fissural and central type eruptions in pre-Tertiary Period produced a thick succession of the Trap-Series Basalts that formed the northwestern and southeastern Ethiopia plateau. Blanford (1869) assigned the name Ashangi Group that he considered to have formed during Mesozoic, the oldest basalts of the Ethiopia plateau. Currently the term "Ashangi Basalts" has been used to describe several hundreds of meters thick highly weathered basalts of the Ethiopia plateau (Zanettin 1993).

It is now generally accepted that in the Ethiopia Plateau, the Trap Series was formed in the course of two clearly separate cycles of eruptions, namely the Ashangi Cycle (50-35 MY), the older part, and the younger post Ashangi Cycle (32-15MY) (Zanettin 1993).

The Asangi Formation occurs in an old northwesterly trending rift system now buried under young volcanic and partially eroded away (Zanettin et al., 1978b; Zanettin 1993). It is made of transitional basalts with tholeiitic affinity.

The Ashangi Basalts are exposed in North Shawa and Jimma Zones (Merla et al., 1973; Berhe et al., 1987). It consists mainly of several hundreds of meters to a kilometer thick of strongly weathered, tilted basalts with rare trachyte, rhyolited and pyroclastic intercalations. It is commonly intruded by dolerite sills and dykes. Its upper part contains lacustrine deposits containing lignite seams.

3.1.2. Aiba Formation

Aiba Basalts represent part of the second major cycle of fissural basalt volcanism on the northwestern plateau after the Ashangi Formation (Zanettin and Justin-Visentin 1973). This new cycle began with the emission of huge volumes of lava, flooding the pen plain surface of the Ashangi Basalts. The Aiba Basalts whose age is 36-25 MY old are typical transitional basalts, very homogenous in composition. They are generally followed by the Alaji Volcanics, represented by interlay red silica rocks and transitional basalts, but sometimes only by silicic rocks, mostly slightly per alkaline rhyolites.
They range in thickness from 200 to 600 meters. They are generally aphyric and compact in places showing clear stratification and contain rare basic tuffs (Kazmin et al., 1980; Kazmin, 1979). The Aiba Basalts occur in north Shawa of northwest Oromia (Mengesha et al 1996). Here it overlies the Ambaradam Formation.

Analogous to the Aiba Basalts occur in the southwest of Oromia and adjoining areas, where similar K-Ar age to Aiba Basalts of 34-30 MY have been reported (Davidson and Rex, 1980). They are mapped together with the Alaji Formation (PNa). The Aiba Basalt flow, however, are missing in the southeastern plateau.

The Aiba Basalts are commonly jointed, aphyric or porphyritic with plagioclase and olivine phenocrysts.

3.1.3 Alaji Formation

The Alaji Formation was first identified by Zanettin and Justin-Visentin (1973) on the central Oromia Plateau. Later, Kazmin et al. (1980, 1981) and Zanettin et al (1978a) ecognized anlogous unit on the southeastern plateau and in the southern segment of the Rift section of Oromiya. The Alaji Formation occurs in both the northwestern and southeastern parts of escarpment of the Rift system. In central part of the Rift the Alaji Basalts are covered by thick accumulations of younger silicic volcanic rocks and may possibly are missing in some segments of the Rift (Kazmin et al 1981). This has been proved near Kalla village north of Buttajira town. The actual extent of the area, where the pre-Rift succession is missing is not known yet (Kazmin, 1981).

The Alaji Formation is overlain by Taramber- Magazaz Formation (Ntb), and is overlapped by younger volcanic units, where Tarmaber Formation is missing. Absolute age determinations place the Alaji Formation between 30-13 MY (Kuntz et al., 1975; Morbidelli et al., 1975; Kazmin et al., 1980; Zanettin et al., 1978; Morton et al., 1979; Jones and Rex, 1974). In southeastern plateau and northern Oromia a succession of up to 800 meters thick Alaji Basalts, dominantly aphyric flood basalts, lies unconformably on the eroded surfaces of the Mesozoic sedimentary succession (Kazmin et al., 1978, 1981). It rests mostly on the Cretaceous Sandstone of Ambaradom Formation, where it is missing it overlies the Urandab Formation or as direct fault contact with the Hamanlei

Formation. In Northwestern Plateau of Northwestern Oromia, North Shawa Zone, it lies either on the Aiba or Ashangi Formations. In southwest Oromia, Jimma Zone, a thick succession of sialic volcanic flows, pyroclastic and subordinate intercalated basalt flows dominate the upper part of the pre- Rift volcanic succession (Omo-Gibe Project, 1996; Mengesha et al., 1996).

3.1.4. Tarmaber-Magazaz Formation

The fissural Alaji volcanism was followed by central volcanism, which formed large volcanoes decreasing in age from north to south (Zanettin, et al., 1967; Zanettin, 1993). This change in volcanic regime in space and time is matched by change in lava composition, from transitional basalts to alkali basalts and basanites (Zannettin, 1993). On the north western and southeastern Oromia plateaus, the fissural eruptions of the Ashangi, Aiba and Alaji Formations were followed by the central type volcanism which built up the large shield volcanoes of the Mt Ras Dashen, Abuna Josef, Guna Choke, Guasssa, Bashillo, Salale, Tarmaber, Magazaz, Mengistu, Arba Guggu and others (Zanettin et. al., 1974a)

In the northwestern part of the Oromia plateau the shield volcanoes become progressively younger from north to south (Zanettin et al., 1976b; Zanettin, 1993) and the central type volcanism took place between 26 and 16 MY ago. The age of the shield volcanoes of the southern part of the Oromia, plateau ranges from 16 to 13 MY.

These two shield volcanoes having an age of (26-16MY) and (16-13MY) are named Tarmaber- Guassa Formation and Tarmaber- Magazaz Formation (Ntb) respectively. They are named after volcanisms that formed the Tarmaber, Guassa and Magazaz Mountains northeast of Finfinne. Basalts from Tarmaber Mountain are dated 13 MY old (Kazmin, 1979). Mohr (1967) established a lower Miocene age of (24.3. MY) For the Ras Dashen mountain basalts, and for the Dasse-Bati area central volcanoes 28 to 24 MY age.

There fore, the classification Tarmaber Guassa Formation for the shield volcanoes of the name Tarmaber Magazaa Formation for the younger shield volcanoes with an absolute age range of 16 to 13 My in southern part of the northwestern plateau and the southeastern part of the Oromia plateau became essential (Kazmin, 1979; Zanettin et al., 1967; Menagesha et al., 1996).

In contrast to the tholeiitic and mildly alkaline nature of the underlying fissural basalts, the Tarmaber Basalts are typically alkaline in nature (Kazmin, 1981). Usually individual flows are easily recognizable particularly in areas where plaeosols and scoraceous horizons developed in many places between flows (Kazmin, 1979). In general, the Tarmaber Basalts and their equivalents have much fresher appearance than the underlying stratoid basalts of Alaji Formation (PN_a).

3.2 Geological setting of the study area.

The geological setting of the study area consists of two major rock groups, classified in this study based up on their special distribution and mode of formation. They are Plateau Basalts, and Rift Volcanic and Sediments (Figure 3.1). Wider scope of the geology in most of the cases is as provided in the Regional Setting described earlier. Detail things of the map units and corresponding rock associations, emphasizing ideas and observation absent or less satisfactory in the Regional Geology Part, is given in this section of the report. Stratigraphic nomenclatures of some of the map units in this work area adopted from reports of earlier workers, in order to enhance clarity and reduce possible confusion in this report. The map units are presented in a decreasing order of eruption and/ or deposition age, as judged from field observation supported by the already constructed stratigraphy by previous workers.

3.2.1 Plateau Basalts

3.2.1.1 Alaji Basalt

All the central and western parts of the study area underlain by this basalt unit of pre-rift succession known in this study as Alaji Basalt (P_1a), name of the map unit being adopted from previous works in the regional geology.

This unit forms gently undulating landforms, usually covered by relatively thick soil in plain areas. Weathered material of the unit virtually looks like volcanic ash of light gray to white and fine-grained silly-clay soft matrix with surrounded weathering remnant boulders of the basalt; the basalt has a white weathering. This is typically noted in between Menagesha and Holeta (Figure 3.1).

Figure 3.1:-Wetherd part of Alaji basalt south west of Menagesha

Alaji Basalt directly overlies the Aiba Basalt which in turn is overlain by Tarmaber-megezez formation of younger volcanism. Contacts of the units are usually marked by a horizon up to a meter thick reddish brown palaeosoil material.

Alaji Basalt of the map area consists of massive and more of aphanitic thick basalt layer at its lower part, and commonly sub rounded boulders of porphyritic (olivine and plagioclase phenocrysted variety at top. Good exposure of this rock unit is seen around stream beds and banks.

Alaji basalt of the study area is porophyritic and mostly aphanatic. It is highly fractured, columinary jointed and weathered. Weathering and fracturing is prominent in all the area. Basaltic boulder formed by exfoliation is found in situ in some places (Figure 3.2). As observed during fieldwork, the top part of the basalt is vesicular, where the underlying basalt is aphanites or porphyritic indicating the escape of gas from the surface during cooling process. Apart from high textural variation, different flows are also observed at a quarry near Kurkufa hill, about 12 km north of the Holota town. More than two basaltic flows can be recognized at this place separated by reddish clay pale soil of about 0.5-lm thickness.

Figure 3.2 Spheroidal Weathering of Alaji basalt

3.2.1.2 Tarmaber –Megezez Formation

Another map unit known in this study as Tarmaber megezez formation is found overlaying the Alaji basalt and exposure is well identified in the northern part of the study area forming highly rugged and outstanding topography. Fo'ata mountain range on the northern part is typically formed of this basalt, which has vast extension towards west through inchini area in Ada'a Barga and Meta Robi areas out of the study boundary. Contacts of the units are marked by the presence of up to 1m thick reddish brown paloesosoi horizons that have discontinuous nature of occurrence.

The basalt has greenish brown to greenish dark color in fresh, where as dirty-looking dark pale brown in weathered surfaces.

The rock unit is found covering all the northern recharge area of the catchement. This fo'ata mountain range formed of Tarmaber Megezez basalt is the source of most head stream waters of the catchement in general and Holeta River in particular. This basalt covers 15 % of the total area of the catchement.

Figure 3.3 Fo'ata mountain range covered by Tarmaber magezez basalt

3.2.2 **RIFT/ Post-Rift Volcanics and sediments.**

3.2.2.1 Trachytic and Rhyolitic Rocks

A number of large central (shield) volcanoes of mostly trachytic formation occur along the eastern part of the study area. These include Wachacha, Menagesha and Wato Dalecha. They generally form mountain ranges and domes /plugs, with highly rugged surfaces characterizing the larger volcanoes of Wachacha Menagesha, and Wato Dalecha.

As noted in the trachyte formation of Wachacha, the component rock grade from more trachytic to rhyolites, as one goes from base of the mountain to its top, where a number of volcanic necks and plugs occur at its vent.

The rock generally is porphyritic with large euhedral phenocrysts of feldspar. Jointing due to cooling of the magma, and complex flow fold structure commonly occur in the rock.

Trachytic rock of this work was mapped as part of chilallo Formation (NC) in previous works of regional studies. Age of eruption ranges from 4.5-3.0 my according to reports of the earlier works indicated in the Regional Geology part.

3.2.2.2 Pyroclastic deposits

Though they are not mapable unevenly distributed (erratic) patches of ignimbrite sheets having less than 10m thickness and usually of smaller aerial extent are observed deposited on top of plateau basalt (Alaji basalt) of the study area. These rocks are considered to be erosion remnant and /or independently deposited parts of the tufts of Nazeret Group. There fore they are not considered for further discussion as they are not important from hydro geological point of view for this particular catchement, because of the mentioned reason (not extensive) and observed as patches of out crops in several places of the catchement. Even if it is not extensive the rock forms typical columnar joint structure of mostly vertical and some times sub horizontal orientation.

However the ignimbrite of the study area is used as small quarry for dimension stone (masonry). Here, the rock is simply extracted using hand equipment such as hammer and crowbars.

3.2.2.3 Quaternary (Alluvium) Deposit (Qa).

Quaternary sediments of fluvial origin are widely distributed all over the southern portion of the study area, which is part of the Bacho plain and along the streams and river valleys (Figure3.5). The alluvial deposits area mostly recent and are deposited as a result of transport of sediments from down wash of sloppy area.

The Alluvium Deposit (Qa) consists mainly of sand, silt and clay.

Figure 3.5 Southern portion of the study area covered by Alluvium deposit.

3.3 Geological Structures

In the study area the occurrences of faults, joints and other structures with in the different volcanic rocks were reported by different professionals and consultants carried out some studies for the purpose of productive well site locations for different organizations institutions and flower farming PLCS such as (nor consult, 1999), (WWDSE, 2004) and (WWDE, 2004).

The area is affected by tectonic events occurred in Ethiopia. Structural movements related to the rift system are prominent and are considered important during ground water investigations. NS, NE, EW and NW trending fractures and faults are observed in the area. Some of these fractures and faults are regional and clearly visible on remote sensing images and in the field.

The Holeta river valley is an example of valley formed along NS trending fractures while its tributaries are formed mainly along NE and EW trending fractures.

The alignment of Wachacha, Menagesha, and Wato Dalecha volcanic plugs and / or domes along NE-SW trend may also suggest their eruption along structures related to the rift system. Certainly the violent but sluggish extrusion of these viscous lavas to surface must have strained shattered and fractured the country rocks i.e. mainly the Nazeret group ignimbrite and basalts.

This has been confirmed from the well logs in the area particularly wells around Menagesha which have high yield of groundwater potential, and consequently classified as high permeability and productivity zone relative to other parts of the catchement.

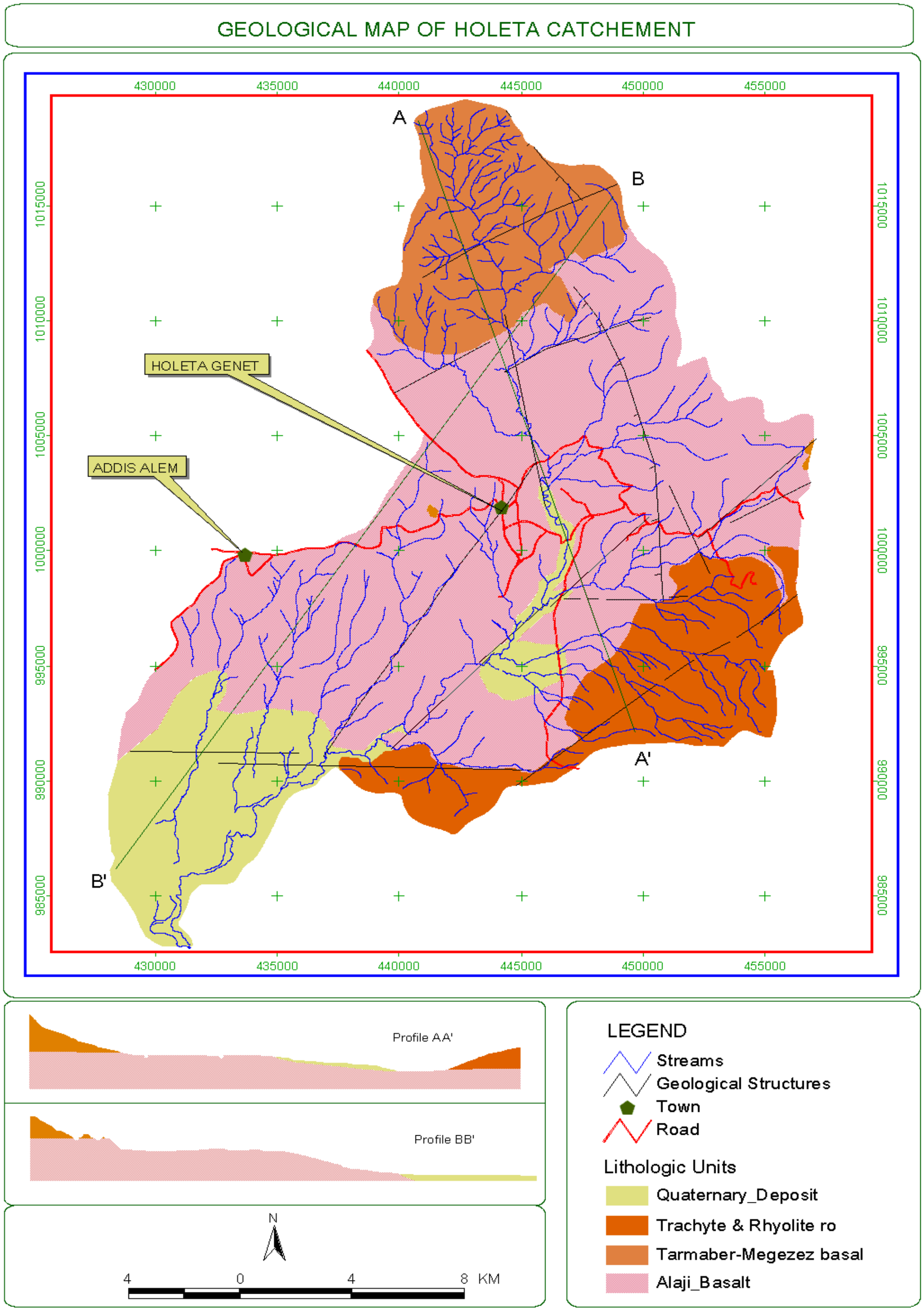


Figure 3.6 geological map

Chapter Four- Hydrometeorology

4.1 Meteorological parameters.

There are seven meteorological stations within and adjacent the study area. Two of them, Holeta and Adis Alem are located with in the study Area. The other five stations; Inchini, Intoto, Adis Ababa bole, Sebeta and Tej are selected adjacent stations from their geographical distribution point of view. Accordingly, average of the seven stations meteorological data (climate logical data) have been used for the study area. As climate is an aggregate of environmental conditions involving heat, moisture, and motion, the chief climatic factors that establish the hydrologic features of a region in the tropics are the amount and distribution of precipitation and the effects of wind, temperature, solar radiation, and humidity on evapotranspiration. Of the seven stations present with in and adjacent the study area only Holeta and Adis Ababa Bole are the 1st class, the others are not.

The climatologicall data together with Holeta River gagging near Holeta Genet town and Awash River gagging near Awash Belo data are the basis to determine the water balance of the study area. The analysis results of the climatologicall data are presented in the following sections.

4.1.1 Rainfall characteristics

The monthly average rainfall shows a unimodal pattern with the heavy rains between June and September. Owing to high temperatures near the equator, the lower layers of air are heated. It thus expands and rises rapidly producing a lower pressure belt known as the Inter Tropical Convergence Zone (ITCZ). ITCZ is the major rain causing mechanism and its movement in the north ward direction brings moisture from the South Atlantic Ocean. This results in the big kiremt rainfall in most parts of Ethiopia. Because of the location of

Holeta river catchments, in the central high lands of Ethiopia, ITCZ reaches late and leave early in this area, which explains the short rainy season (June-September). The small rains originate from Indian Ocean brought by south easterly winds. Though short seasoned, the amount of annual rainfall is high in the study area. The average monthly rainfalls are shown in table 4.1and Figure 4.1 There fore, the rainfall amount, particularly in kiremet, is reliable in this area.

Tables 4.1 mean monthly rainfall (mm) of the study area.

Mo	Jan	Feb	mar	Apr	may	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Ave.	21.1	44.7	72.1	85.4	79.2	150.9	285.3	304.3	151.4	32.5	14.0	12.4	1253.3

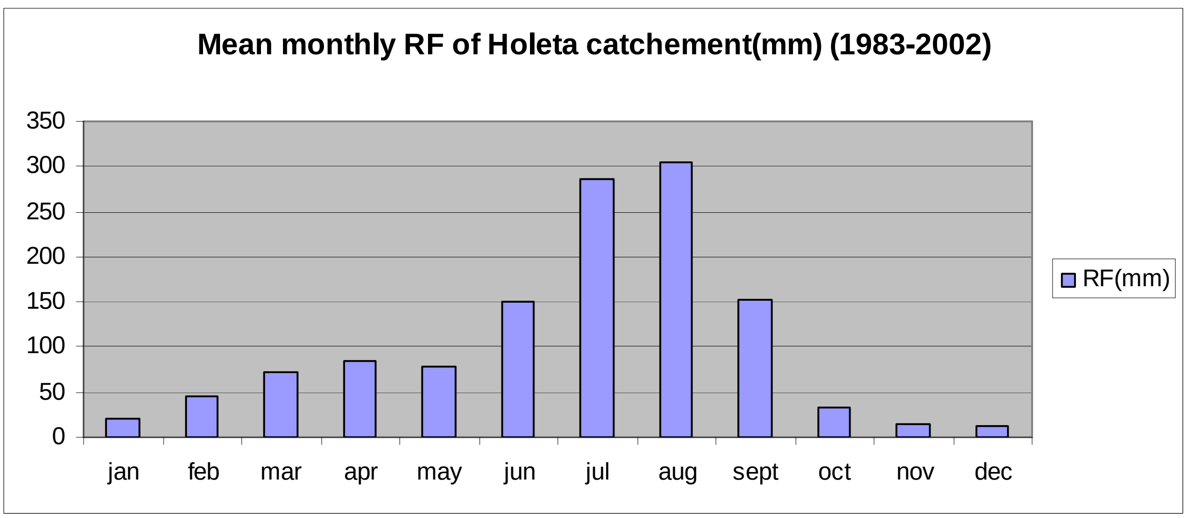


Figure4.1 Mean monthly rainfall of Holeta catchement.

The distribution of rainfall in the study area is more or less similar to that of the Ethiopian central plateau. Based on temporal rainfall distribution, generally two main seasons can be identified for the study area: the dray and the wet season. More quantitative seasonal category based on rainfall distribution can be explained by using the rainfall coefficient (R.C) which is the ratio between mean monthly rainfall and one twelfth of the annual mean of the total rainfalls (Daniel Gamachu, 1977).

$$R.C. = \frac{12Pm}{Pa}$$

Where R.C= rainfall coefficient

Pa = Annual total rainfall of the area, which is 1253.3 mm

Pm = Mean monthly rainfall

Table 4.2 mean monthly rainfall (Pm) and rainfall coefficient (R.C) for the study area.

Month	Jan	Feb	mar	Apr	may	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Pm(mm)	21.1	44.7	72.1	85.4	79.2	150.9	285.3	304.3	151.4	32.5	14.0	12.4	1253.3
R.C	0.202	0.428	0.690	0.817	0.758	1.445	2.732	2.914	1.449	0.311	0.134	0.118	

Based on R.C values the following precipitation category can be made for Holeta catchments.

- Dry month (R.C < 0.6): October, November, December, January and February.
- Rainy month (R.C ≥ 0.6): This can be further grouped in to the following
    - Small rain (0.6 – 0.9) March, April and may.
    - Big rain (≥ 1.0)
        - ❖ Moderate concentrations (1.0 – 1.9) : June and September
        - ❖ High concentrations (2.0 – 2.9) July and August.
        - ❖ Very high concentration (≥ 3.0)

4.1.2 Determination of Aerial Depth of precipitation.

In water budget studies, it is necessary to know the average depth of precipitation over a study catchement. This may be determined for time periods ranging from the duration of part of a single storm to a year. The data are generally measurements of precipitation and / or equivalent snow fall at a number of points through out the catchement (Fetter, 1994).

Precipitation over certain durations for a given basin is rarely produces uniform rain fall depth with relative to otters.

There fore using different rain fall depth of different stations found in the target study and the adjacent area, the representative aerial depth of rain fall over the whole area is analyzed. Accordingly Arithmetic mean and isohayetal method is selected, considering the non uniformity of the land and variation of topographic textures of the area and the average of them has been used for explanation purpose. An annual aerial precipitation computed from the average of arithmetic and isohyets is 1253.3 mm.

4.1.2.1 Arithmetic mean method

Arithmetic mean method is the simplest one for evaluation of mean uniform distribution of rain fall of a basin. It is the mean of all the rain gages located with in the area of interest (will son, 1983). Since only two stations (Holeta and Adis Alem) are located with in Holeta River catchments, the estimated average uniform precipitation (PA) is computed as follows

$$PA = \sum_{i=1}^{n} Pi / n$$

Where PA = average rain fall the total area

Pi = Measured precipitation at a given station and time

n = Number of rain gauges.

An Annual aerial precipitation computed from Arithmetic method is 1261.5 mm.

4.1.2.2 Isohyetal method.

Considering the non uniformity of the land, variation of topographic features of the area (2060-3385masl) isohyetal method is selected.This method is analyzed by joining rain fall depth of equal value over the area of interest (Figure 4.2). According to this method the annual precipitation in the basin is equal to 1245.08 mm (Table4.3)

Table 4.3:– Ishohyetal method of calculating rain fall in Holeta catchement

Isohyet (mm)	Estimated EVD	Net Are (km^2)	Percent of total area	Weighted rain fall(mm)
100-1050	1025	3.89	0.76	7.79
1050-1100	1075	10.88	2.11	22.68
1100-1150	1125	21.72	4.23	47.59
1150-1200	1175	75.38	14.63	171.90
1200-1250	1225	112.23	21.79	266.93
1250-1300	1275	209.22	40.62	517.91
1300-1350	1325	81.75	15.87	210.28
Total		515.07	100.00	1245.08

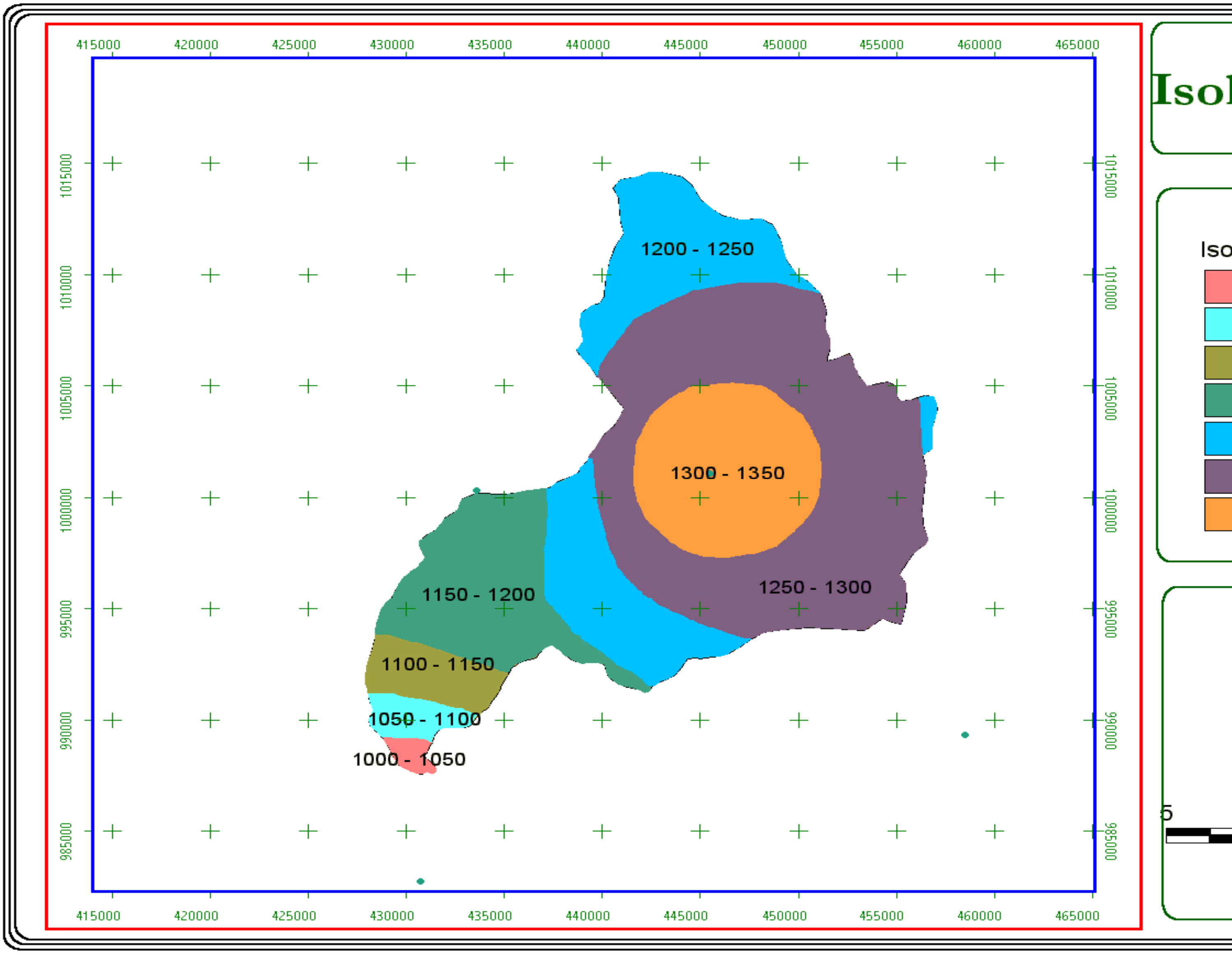


Figure 4.2 Isoheytal Map

4.1.3 Temperature

High daily temperature associated with longer sunshine hours duration and clear sky increases evapotranspiration. Temperature data are the major factor in computing potential evapotranspiration of an area. Temperature in the tropics is constantly high; the annual range, year to year variability, is low. Altitude is the major factor in reducing temperature in the tropics as compared to the high in coming solar radiation. The Annual series of mean, maximum and minimum temperature of Holeta river catchment for the period 1988-1997 is shown the Appendices. (Analyzed from Sebeta, Holeta, Adis Alem and Inchini stations) Accordingly the average monthly temperatures are shown in. table 4.4. Maximum temperature occurs in March, April may and minimum in November & December.

Table 4.4 – Monthly average temperature in ^{o}c of the study area.

Mo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Y.Av
Max	23.2	23.7	24.4	23.4	24.5	22.4	19.5	19.5	20.4	22.6	22.3	22.7	22.4
Min	3.8	5.7	7.1	8.5	7.4	7.8	9.3	9.2	7.6	4.5	2.4	2.0	6.3
Ave	13.5	14.5	15.8	15.9	15.9	15.1	14.4	14.4	14.0	13.6	12.4	12.4	14.4

4.1.4 Wind Speed

Wind speed data are important for computing potential evapotranspiration of an area. High wind speed induces more evapotranspiration. The annual monthly series of wind sped for the study area is shown the appendices.

Wind speed data for the study area is analyzed from the Holeta station, located in the center of the catchement. So it is wise to use data from this station as it has high

Influence from geographical point of view. The mean monthly wind speed data is shown in Table 4.5. The magnitude varise from 1.4 – 0.8 m/sec wind speed is relatively low, especially in the rainy season (July-September).

Table 4.5- Average monthly wind speed (mille) of the study area (1994-2003).

Mo	Jan	Feb	mar	Apr	may	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Ave	1.05	1.2	1.3	1.2	1.3	1.1	0.85	0.8	0.9	0.95	1.4	1.1

4.1.5 Sunshine duration

Solar radiation is the primary source of energy of the process of change at the health's surface and in the atmosphere. Mean daily sunshine hours durations is shown in table 4.6-. It is analyzed from Holeta station. Sunshine hours duration is maximum in December and minimum in August at the mid of rainy season.

Table 4.6- Average daily sunshine hours duration for Holeta catchement (1994-1998)

Mo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly Ave.
Ave	8.7	8.9	7.4	5.9	7.3	5.0	2.9	2.8	2.8	5.2	8.6	9.5	6.4

4.1.6 Relative humidity.

Relative humidity, the water vapor contained in the atmosphere, is expressed as the percentage of the ratio of actual to saturation vapor pressure. Evaporation takes place more rapidly in to dry air than in to air with a high relative humidity. The monthly average relative humidity data is shown in Table 4.7. It varies from 53 % in December to 83 % in August. Relative humidity is maximum following the rainy season.

Table 4 .7:-Average relative humidity (%) of Holeta catchment (1994-2003)

Mo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly Ave.
Av	53.7	55.1	54.7	61.7	54.1	71.1	81.7	82.8	77.4	59.4	55.1	53.0	63.5

4.1.7 Climate Classification

According to Thornthwite method of climate classification, where the precipitation analyzed month by month is just adequate to supply all the water that would be needed for maximum evapotranspiration in the course of a year, the moisture index is considered to be Zero. The moisture index is calculated from rainfall and PET data as follows:

$$Im = 100^{*} (s-d)/n\ (\%)$$

Where,

Im = moisture index

S = moisture surplus (rainfall – PET), yearly total

d = moisture deficiency (PET – rainfall), yearly total

n = PET, yearly total

Danial Gemechu (1977), Aspects of Climate and Water Budget in Ethiopia, give ranges of Im to define climatic types or moisture regions by quoting Barry and Chorley (1968) as follows:

Im	**Climatic (Moisture) Region**
Over 100	Per humid
20-100	Humid
0 to 20	Moist Sub humid
-33 to 0	Dry Sub humid
-67 to -33	Semi Arid
-100 to -67	Arid

Table:4.8- Mean monthly moisture balance at Holeta Genet

Mo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
R.F	21.1	44.7	72.1	85.4	79.2	150.9	285.3	304.3	151.4	32.5	14.0	12.4	1253.3
PET	79.48	83.26	98.34	106.34	94.68	77.85	68.85	69.37	71.74	79.63	76.04	75.81	981.25
R-P	-58.38	-38.56	-26.24	-20.94	-15.48	73.05	216.45	234.93	79.66	-47.13	-62.04	-63.41	272.05

For Holeta River catchement Im as calculated by the above procedure is 55, which results in a classification of humid climate. Likewise according to UNESCO 1979 world climatic classification (P/PET) is equal to 1.3 which results also in a classification of humid climate. However, the moisture surplus, which generates the high runoff, is only occurs during the kiremt (June-September) season. River flows in other months occur as a result of the groundwater storage of rainfall during Kiremt.

Figure:4.3-Shows the moisture balance (rainfall-PET) relation ship of Holeta River catchement where rainfall is in excess of PET during the rainy season.

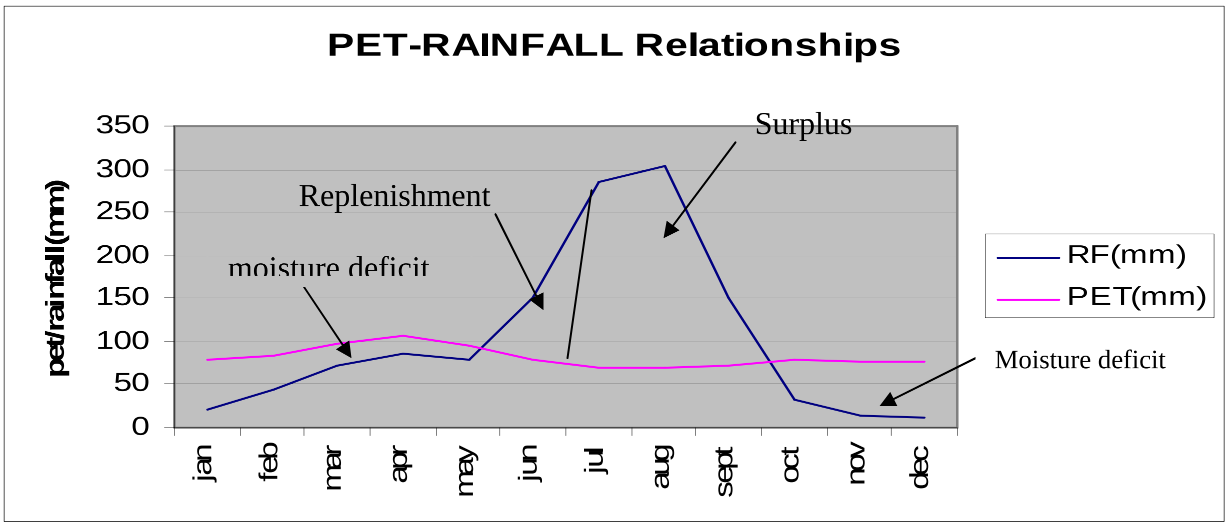


Figure: 4.3- Moisture balance at Holeta River cachement

4.2 Runoff

Holeta River catchement is one of the sub-catchement of upper Awash River basin. Rivers and streams are the only surface water body that found in the study area.

Both perennial and intermittent rivers and streams exist in the catchement. The hydrological characteristics of the catchement is described by the Holeta river that discharges all the run off from the catchement. The river originates in the mountain at around 3200 m.a.s.l north of the study area.

Botoru, Melkara, Sole, Keta and mintile are the perennial stream in the upper part of the catchement. These streams merge together on the middle of the catchement and cover relatively large area of the drainage basin.

Kebi, Bobe, Welenso and Karsa drain the catchement in the eastern part and finally join Holeta. Generally most of the streams drain in North south and east west direction.

The prevailing drainage pattern in the area is a dendritic type. Especially all the streams daring the east –west oriented ridges on the north side of the catchement show such drainage pattern where as, streams that drain the south west of the catchement do have parallel drainage pattern. The catchement has a forth order river net work.

Mean monthly and annual flows.

Water that drains across the basin in to a stream channel as overland flow and ground water contribution to a stream as base flow collectively known as runoff. The 22 years (1975-1997) river discharge of Holeta River gagged near Holeta Genet town is used in the total runoff analysis of the catchement (Table 4.8).

The mean annual discharge of the Holeta River at the rood crossing (119 km^2) is 1.7 m^3 / sec or total Annual flow of 55 Mm^3. This results in an average unit discharge of about 14.3 l/s /km^2. This is a fairly high yield and an indication of a good amount of rainfall in the area. The runoff coefficient at Holeta Genet is about 36% i.e. ratio of run off to rainfall. Rain fall at the mountain (3200 masl) is expected to be higher than in the town (2380 masl) and the large elevation drop in relatively short distance (about 15 km) results in a high runoff coefficient.

Table 4.9:- Mean monthly flows, Holeta River at Holeta Genet

Mo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Mm^3	0.69	0.70	0.69	0.82	0.85	1.52	10.5	20.2	14.1	2.36	1.18	0.70	55
m^3/s	0.25	0.25	0.25	0.30	0.30	0.56	3.62	7.58	0.92	5..52	0.45	0.26	1.7
mm	5.8	5.9	5.8	6.9	7.1	12.8	88.9	170	118	19.9	9.9	5.9	456.9

Figure: 4.4- Shows the monthly rainfall-discharge relationship. Discarge is concentrated in July to September. This discharge represents more than 80% of the annual discharge.

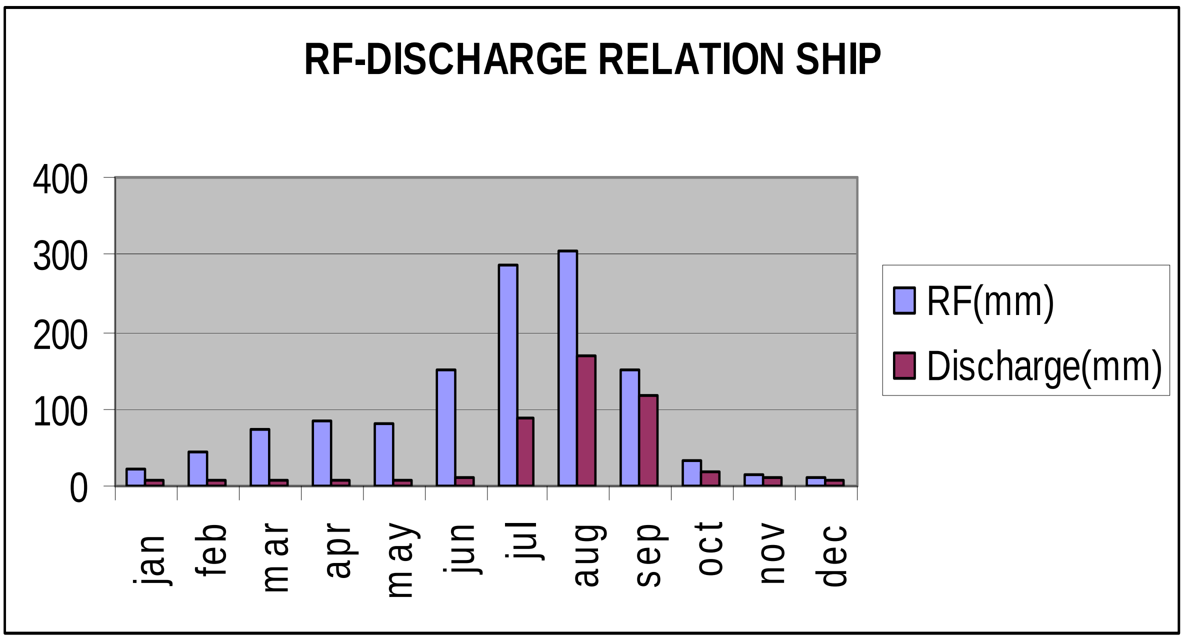


Figure: 4.4- Rainfall-Discharge relationship at Holeta catchement.

Actually in this paper the base flow separation software programme method described by Nathan and macmahon (1990) and Lyne and Hollick (1979) is used to separate the base flow and runoff component of the mean annual flow. In this spread sheet the time interval of the measured rainfall and discharge in the river should be the same.

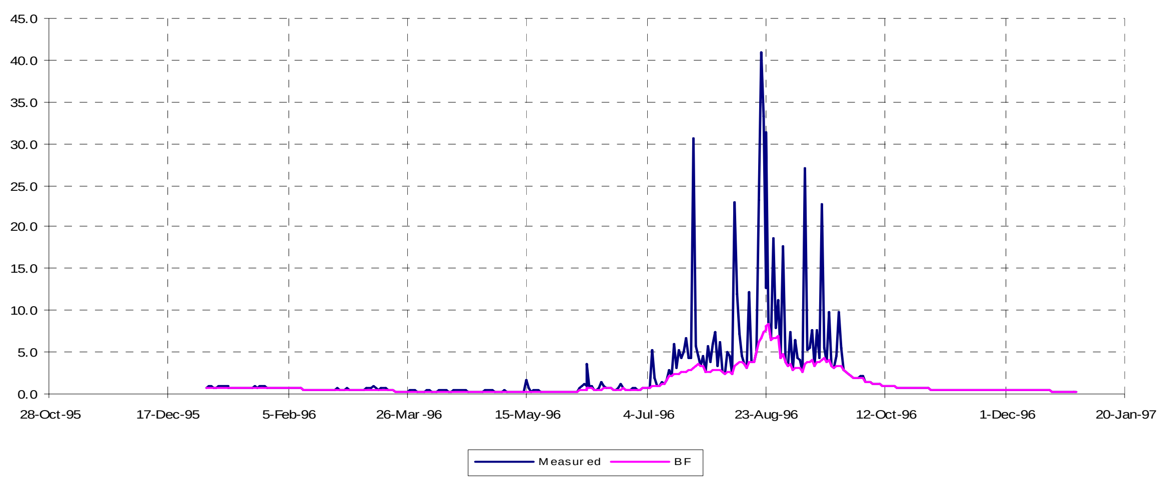
Accordingly, from the mean annual flow of 1.7m^3 /sec 56% (0.952m^3/s) is a contribution from the base flow and 44% (0.748m^3/s) is a contribution from overland flow.

The yearly volume of base flow is spread over the catchement area above the gagging station (119km^2) in order to estimate the minimum depth in mm of recharge to ground water in the given catchement area which is 252mm. This results in an average unit ground water recharge of 8l/s/km^2.

In reality, the amount of recharge or infiltration with in the same catchement varies from one location to another depending on the topography, soil cover, vegetation cover, the rock type, structure and the intensity of rainfall at each location. Therefore, the recharge value which is estimated by the above method is an average for the catchement area despite the variation from one location to another.

Hence for this particular study area, the total catchement area is small and the variation of the mentioned parameters from one location to another is not significant so, the estimated recharge fairly represent the study area.

FIGURE:4.5-HYDRO GRAPH BASE FLOW SEPARATION



4.3 Evapotranspiration

Evapotranspiration E_t is the process of water loss from a vegetated land surface by evaporation plus transpiration (Shaw, 1988). The evaporation from a vegetated surface is a function of available energy, net radiation, the temperature of the surface and air, the saturation deficit, the wind speed, and the available soil moisture. There fore, the assessment of transpiration loss takes in to account the water available to the plant in the rooting zone of the soil.

In the study area, there is no direct measurement value of evaporation from open water body or pan evaporation. There for evapotranspiration has been computed using the recorded data of meteorological stations of the catchement employing the pen man, Thorenthwaite and Turc empirical formulae.

4.3.1. Estimation of potential evapotranspiration (PET).

PET is defined as the evapotranspiration which would occur under unrestricted availability of water to a fully vegetated surface (Shaw, 1988) or it is the maximum possible evaporation under given meteorological conditions (Tenalem and Tamiru, 2001). PET has a positive relation with temperature, sunshine, and wind speed but has a negative relation ship with air humidity.

4.3.1.1 Penman modified method

For calculating potential evaportanspiration there are different formulae but for this research, Penman modified method and adjusted Thorenthwaite are used based on the available data. Resulting from his experience, Penman produced a formula which was later modified by MAFF (1967, in Shaw) to allow the condition under which evaporation plus transpiration takes place form a vegetated surface which is given by:

$$PET = \frac{(\Delta/\gamma) H_T + E_{at}}{(\Delta/\gamma) + 1} \quad 4.1$$

Where the extra subscript t signifies inclusion of transpiration effects

$$H_T = 0.75R_1 - R_o \quad 4.2$$

Where: γ is the reflective coefficient for incident radiations or the Albedo of the basin that depends on the nature of the surface? For the specific study area, this is taken as 0.23 assuming majority of land cover of the study area as short grass surface. The term E_{at} is very similar to E_a (Which is equal to $0.35[0.5 + u_2 /100](e_a - e_a)$) the coefficient 0.5 being replaced by 1 to allow for extra roughness.

$$E_{at} - 0.35 (1+u_2/100)(e_a-e_d) \quad 4.3$$

The empirical equations for the incoming and outgoing radiation in the energy term H_T are given by R_1 (1-r) = 0.75 R_a f_a (n/N), and f_a (n/N) for the study area within latitudes sough of $54/2^0$N,

(Shaw. 1988) is equal to:

$$f_a(n/N) = (0.16 + 0.62\, n/N) \quad 4.4$$

The empirical equation for the outgoing reduction takes the form:

$$R_o=\sigma T^4 (0.47-0.075\sqrt{e_d}) (0.17 + 0.83n/N) \quad 4.5$$

Albedo (short wave-reflection coefficient) of any basin can vary widely with time of day, season, latitude and cloud cover. In the absence of knowledge on crop the value of r(reflection coefficient), is recommended to be 0.23 (Maidment, 1993, in Shaw)

In the study area, the average and dominant crops, forests, soil and grass are cereal crops, clay soil, silly soil, Eucalyptus tree, grass and pasture and bare soil with their Albedo 0.25, 0.13, 0.3 0.2, 0.25 and 0.22 respectively (Dunne and Leopold, 1978) and maidment

(1993). There fore by averaging the above albedo the value of γ is taken as 0.23. The calculated annual potential evapotranspiration of the study area according to penman is 1273.55 mm Table (4.10).

4.3.1.2 Thornthwaite method

Thorn Waite produced a formula for calculating PET based on temperature with an adjustment being made for the latitude location and number of daylight hours. This method uses air temperature as an index of energy available for evapotranspiration, assuming that air temperature is correlated with the integrated effects of net radiation and other controls of evapotranspiration, and the available energy is shared in fixed proportion between heating the atmosphere and evapotranspiration (Dunne and Leopold. 1978).

The equation is given by (Shaw, 1988)

$$PET_m = 16\ N_m\ (10T_m/I)^a \text{ mm} \qquad 4.6$$

Where m is the month 1, 2, 3...... 12, and N_m is the monthly adjustment factor related to hours of daylight, T_m is the monthly mean temperature ^{0}C (Table 4.3), *I* is the heat index for the year, given by:

$$I = \sum i_m = \sum(T_m/5)^{1.5} \qquad \text{for m=1... 12}$$

And:

$$a=6.7\text{x}10^{-7}\ I^3 - 7.7\ \text{x}10^{-5}\ I^2 + 1.8\text{x}10^{-2}I+0.49$$

The calculated annual PET of Holeta river catchement as of Thorenthwaite is 688.95mm (Table 4.10).

For estimation of potential evopotranspiration of the study area, the average of the two methods; penman and thorenthwaite; have been used and the result is presented in table 4.10.

Table 4.10:-Average potential evapotranspiration (PET in millimeter) of the study area from thoranthwaite and penman methods.

Mo.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly
P.m	107.17	109.9	131.83	130.52	121.98	95.50	83.38	84.63	91.52	110.56	103.57	102.99	1273.55
T.w	51.78	56.61	64.82	82.16	67.38	60.20	54.31	54.10	51.95	48.70	48.51	48.62	688.95
Ave	79.48	83.26	98.34	106.34	94.68	77.85	68.85	69.37	71.74	79.63	76.04	75.81	981.25

4.3.2. Actual evapotranspiration (AET)

AET is that amount of water lost through evapotranspiration under the existing field condition. A value of actual evapotranspiration (AET) over a basin is often obtained by first calculating the potential evaporation plus transpiration (PET), and then modifying the answer by accounting for the actual soil moisture content (Shaw, 1988). The term actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under the existing field conditions (Dunne and Leopold, 1978). The majority of the water loss due to evapotranspiration takes place during the winter months (dry hot seasons in Ethiopian case) while little loss is during the summer (wet cold season in Ethiopian case). Always actual evapotranspiration is less or equal to potential evapotranspiration. When the vegetation is unable to abstract water from the soil, then the actual evapotranspiration becomes less than potential.

Various approaches exist for the determination of Actual evapotranspiration. The method employed in this paper is that developed by thornthwaite and Mather (1957) and Turc method.

4.3.2.1. Thorenthwaite and Mather soil water balance model.

When the soil is saturated, it will hold on more water. In this condition, actual evapotranspiration is equal to potential evapotranspiration (Shaw, 1988). If there is no rain to replenish the water supply, the soil moisture gradually becomes depleted by the demand of vegetation to produce a soil moisture deficit (D). As soil moisture deficits increases, actual evapotranspiration becomes increasingly less than potential evapotranspiration. The values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation. When the moisture supply becomes limiting, the computed potential rate is modulated by a factor that depends up on the amount of water in the soil. The relationship can be expressed as (Dunne and Leopold, 1978);

$$AET=PET x f\,(AW/AWC) \qquad 4.7$$

Where AET and PET are actual and potential rates of evapotranspiration respectively, f ( ) is some function of the term inside the parentheses, AW is the available soil moisture which is equal to soil moisture content minus permanent wilting point times the rooting depth of vegetation (cm), AWC is the available water capacity of soil which is equal to field capacity minus permanent wilting point times rooting depth of vegetation (cm).

Penman (1950, in Shaw introduced the concept of 'root constant' that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constants (Dunne and Leopold, 1978). Therefore, to evaluate actual evapotranspiration over a basin area, the proportions of different types of vegetation covering the basin must be known.

Accordingly, the study area has been classified in to two major groups of soil type (Clay loam and sandy-silty loam) with average field capacity of 200 mm, and the types of rooting depth of vegetation cover are taken 1m on average, which are often cereal crops such as wheat, Barley, Maize, and Sorghum and Grass, Shrubs and Wood lands. Based on these categories and available meteorological data, the actual evapotranspiration is calculated using thorenthwaite and mother (Ding man, 1994) standard soil water balance model. In puts to thorenthwaite model consists of monthly value of rain fall, pm (Table 4.1), and potential evapotranspiration, PETm (Table4.10) and (Table 4.11).

Alley (1984, in Dingman), found out that if in a given month P_m>PET_m, the value of soil moisture at the end of that month, S_m, is found as:

s_m=min {[(p_m-PET_m)+S_m-1]S_{mm}} 4.8

If P_m<PET_m, a soil moisture deficit develops or increases. The soil moisture for this case is given as:

$$S_m=S_{m-1}\exp\left[\frac{(PET_m - P_m)}{S_{max}}\right] \qquad 4.9$$

The monthly actual evapotranspiration, AET_m is then found as:

AET=PET if P_m>PET 4.10

AET_m=P_m+S_{m-1} –S_m Otherwise 4.11

Using this method and the potential evapotranspiration from penman method, the actual evapotranspiration (AET) of the study area is 904.09 mm/ year (Table 4.11a). And based on the evapotranspiration values obtained by Thorenthwatite method, the calculated actual evapotranspiration (AET) is 652.04 mm/ year (Table 4.11b).

When the result obtained by these two methods compared, the potential as well as the actual evapotranspiration calculated by thorenthwaite method is smaller than the analyzed by penman method.

Table 4.11:- Estimation of Actual evapotranspiration, AET by using Thornthwaite-mather method.

Mo.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly
P	21.1	44.7	72.1	85.4	79.2	150.9	285.3	304.3	154.4	32.5	14	12.4	1253.3
PET	107.17	109.9	131.83	130.52	121.98	59.5	83.38	84.63	91.52	110.56	103.57	102.99	1273.55
P.PET	-86.07	-65.2	-59.73	-45.12	-42.78	55.4	201.92	219.67	62.88	-78.06	-89.57	-90.59	
Ac.p.wl	-344.29	-409.49	-469.22	-514.34	-557.12	-	-	-	-	-78.06	-167.63	-258.22	
Sm	35.76	25.81	19.15	15.28	12.34	67.74	200	200	200	135.37	86.50	54.99	
ΔSm	-19.23	-9.95	-6.66	-3.87	-2.94	55.4	132.26	0.00	0.00	-64.63	-48.87	-31.51	
AET	40.33	54.65	78.76	89.27	82.14	95.5	83.38	84.63	91.52	97.13	62.87	43.91	904.09
D	66.84	55.25	53.07	41.25	39.84	0	0	0	0	13.43	40.7	59.08	369.46
S	0	0	0	0	0	0	69.66	219.67	62.88	0	0	0	352.2

a. PET determined by using pan man method.

Mo.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly
P	21.1	44.7	72.1	85.4	79.2	150.9	285.3	304.3	154.4	32.5	14	12.4	1253.3
PET	51.78	56.61	64.82	82.16	67.38	60.20	54.31	54.10	51.95	48.70	48.51	48.62	689.14
P.PET	-30.68	-11.91	7.28	3.24	11.82	90.7	230.90	250.2	102.45	-16.2	-34.51	-36.22	
Ac.p.wl	-117.6	-124.52	-	-	-	-	-	-	-	-16.2	-50.71	-86.93	
Sm	143.13	134.85	142.13	145.37	157.19	200	200	200	200	184.4	155.17	129.46	
ΔSm	-13.67	-8.28	7.28	3.24	11.82	42.81	0.00	0.00	0.00	-15.6	-29.23	-25.71	
AET	34.77	52.98	64.82	82.16	67.38	60.20	54.3	54.10	51.95	48.1	43.23	38.11	652.04
D	17.01	3.63	0	0	0	0	0	0	0	0.6	5.28	10.51	37.03
S	0	0	0	0	0	47.89	230.90	250.2	102.45	0	0	0	631.44

b. PET determined by using Thorenthwite method.

* P= precipitation, PET =Potential Evapotranspiration, AC.P.WL.= accumulated potential water loss, SM= Soil moisture, ΔSM= change in soil moisture, AET= Actual evapotranspiration, D=soil moisture deficit, and S=annual moisture surplus.

4.3.2.2 TURC METHOD

The method determines the annual actual evapotransipiration (AET), directly from two meteorological parameters, precipitation and temperature.

It is an empirical formula developed based on data from various catchements of different climates, and hence could be applied in humid or arid climates, either hot or cold, Shaw (1988). It is given by the formula:

$$AEP= (P)/ (\sqrt{} [0.9+ (P/L)^{2}]$$

Where AET= Actual evapotranspiration of a year in mm.

P= Annual mean precipitation in mm.

T= Annual mean temperature in ^{o}c

L= 300+25T +0.05 T^{3} in mm.

For the study area P and T are 1253.3 mm and 14.4 ^{o}c respectively.

Hence, L=809.3mm and the value of ATE becomes 688.46 mm/year.

In order to have reasonable value of AET for the study area, the average value, which is 748.20 mm/year obtained from the three different methods (Thorenthwaite, Penman, and Turc) is used. Because during the calculation of AET employing various methods, some parameters that may affect evapotranspiration are either estimated or totally neglected. Hence, if the value from a single method is used, either over estimation or under estimation of AET of the area could possibly occur. There fore, the Average AET value, which is 748.20mm/year, will be taken for any further water balance calculation of Holeta catchement.

4.4:- Groundwater recharge estimation

Groundwater recharge can be defined as the entry of water in to the saturated zone of water made available at the water table surface together with the associated flow away from the water table with in the saturated zone (Freez and cheery 1979). The central core of this thesis is estimating the amount of recharge in the basin which plays a great role in determining different developmental activities related with water. To estimate ground water recharge, different techniques of estimation have been deployed.

4.1 Base flow separation method

This method is possible to do either by hydrograph method or using soft ware. The hydrograph method is either under estimate or over estimate where as the soft ware is used to estimate reasonable amount of recharge by taking in to account of surficial characteristics of the basin.

There fore, the best method of separating base flow from the total flow of Holeta river is soft ware separation method. This method considers surface characteristics of the basin as an in put in addition to the in put data of daily flow of the river. Accordingly, the amount of base flow of Holeta river is obtained as 127 mcm of the total 227 mcm per year and the annual runoff is 100 mcm per year (Figure).

4.2 Water balance method of the basin

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, fiver basin, etc) over a specified period (Tenalem Ayenew and Tamiru Alemayhu, 2001). For natural catchement, measurement of the precipitation and river discharge may be made satisfactorily with some degree of precision. But the measurement of ground water movements in to or out of the drainage area can not be made easily.

In this study of water balance, the catchement (basin) is assumed as a close basin based on the detailed field observation around the water divide of the basin from fo'ata, and wachacha. This condition made the evaluation relatively simple in avoiding the subsurface and surface movement of water across the defined water shade boundary. There fore water balance of the basin is represented by the general equation. Inflow=out flow + change in storage.

Here, the inflow includes precipitation and ground water inflow where as the out flow includes surface run off, ground water out flow, Evapotranspiration and change in storage. The general water balance equation is:

$P=AET+SRO+R\pm\Delta S$

Where; Δs =change in storage.

But change in storage in annual case is almost negligible and is assumed to be zero. Ground water in flow is assumed to be equal to ground water out flow. Then finally, the study area will have a water balance equation of:

$P=AET+SRo+R$

P=precipiation (1253.3) annually

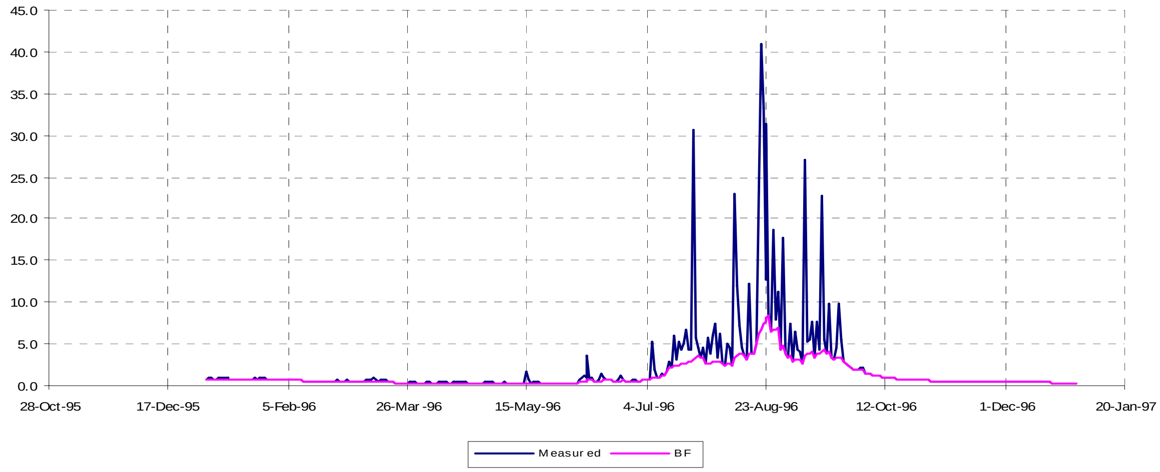
AET=annual actual evapotranspiration (748.2mm)

SRO=annual surface runoff (194.5mm)

R=P-AET-SRO=310.6mm

There fore, the amount of recharge in Holeta catchement is calculated as 160 mcm. Of this amount of recharge 79% leaves the basin in the form of base flow. The above result shows that recharge, AET and SRO are 24%, 60% and 16% respectively of the total rainfall which indicates that the topography of the basin is good for ground water percolation.

FIGURE:4.5-HYDRO GRAPH BASE FLOW SEPARATION



Chapter Five: Hydrogeology

5.1 General

The occurrence, distribution and movement of groundwater is a function of many variables such as meteorological, physiographical and geological formations. The behavior of geological materials toward the interaction, storage and transmission of sub surface water constitute the basic part of hydrogeology. Some materials can store & transmit water (aquifer). Others can only store but do not transmit (aquiclude); still others neither store nor transmit water (aquifuge). These properties of geological materials depend on litho logy, structure, grain size, sorting, cementing materials and the degree of cementation, degree of weathering, tectonics, etc. Both lateral and vertical extent, shape and distribution of the geological formation play a role in the hydrogeology of an area. The presence of permeable geological formation is not enough for the storage of the ground water. Thus bottom confining bed that can hold up the subsurface water and the later confining bed (barrier) in case of a ground water discharge at the foot of cliffs are important in limiting the occurrence of ground water.

There fore understanding of the hydrogeology of a given area require in formation of both surface and subsurface geology and structure in addition to hydro meteorological physiographical factors.

Even though the hydro geological parameters mentioned above are interrelated and dependent, it is vital to discus each of them separately to clearly understand the fate of each factor in controlling the occurrence of water resources of the catchement in general and ground water in particular.

5.2 Meteorological effect on groundwater occurrence.

The primary factor for the occurrence of ground water is precipitation which is the in put for both surface and subsurface waters. Rain fall is the main source for recharge. Major part of West Shewa in general and the study area in particular are rich from rain fall point of view. Areas receiving high annual rain fall will have high ground water potential (1253.3mm) for study area. In general areas with frequent, long-lived and less intensity of rain fall will have high infiltration (recharge) to the ground water. While areas with short lived; very intense and infrequent rain fall pattern will aggravate runoff and hinders infiltration. Hence the meteorological effect on ground water flow system of the study area is promissing.

5.3 Geologic effect on groundwater occurrence.

Geological formations and its associated structures: - The nature and distribution of aquifers and acquitards in geological system are controlled by litho logy stratigraphy and structure of geologic deposits and formations. In this context, the litho logy implies the physical makeup, including the mineral composition, grain size, and grain packing of sediment or rocks that makeup the geological system. The stratigraphy describes the geometrical and age relations between the various lenses, beds and formations in geologic system of sedimentary origin (Jackson, 1970). Structural features encompass the geometric properties of the geologic system produced after deposition by deformation or crystallization. This includes beddings, fractures, joints, faults, cleavages folds and unconformities.

The presence of regionally high permeability conduit; due to the weathering and fracturing of the volcanic rock to ground surface cause the presence of regional flow systems. The presence of regional flow systems in the study area have been conformed by the increase of TDS and relatively rise in temperature along the flow direction. Had there been no regional flow system in the study area water samples taken at different localities along the flow wouldn't show substantial chemical variation due to the increase of rock water interaction with flow direction.

Geology will have paramount role in governing the amount, movement and storage of ground waters. Areas having porous, permeable and deeply weathered and associated geological structures such as faults, Joints fractures, will be good aquifers while areas lacking this are aquiclude. In this context, the geological formation having wide extent of geological structures such as faults, Joints, fractures, bedding, cavities and lineaments are favorable for the storage, and circulation of groundwater. Hence the study area is characterized by this nature of geology and geological structures and is considered to be promising in this regard.

5.4 Topographic effect on groundwater occurrence.

Geomorphologic features of an area significantly determine the amount of recharge to groundwater. It can promote either surface run off or infiltration depending on the nature of land slope and configuration. Flat planar gentle slope topography promotes the rate of recharge to subsurface and retard runoff. Area with ragged topography and steep slope favors runoff while hinders recharge to ground water.

The study area has regional aquifers fed by recharge in the rock out crop areas of the surrounding north and east mountain ranges. The area is characterized by a chain of ridges mainly oriented east- west in the north and north-south in the east and the central, west and south of the study area is characterized by a flat topography covering about 80% of the total area. Hence facilitate infiltration (recharge) than runoff.

Depending up on the drainage basin topography and basin shape geometry, flow system may be regional, local, and intermediate. For regional flow system the surface area where recharge takes place is quite small in relation to the volume of water stored in that region of the aquifer (Fetter, 1996). Hence the study area is characterized by this nature of topography where the surface are of recharge are much less in relation to the volume ofstored in the aquifer indicating the prevailing of regional flow system in the area.

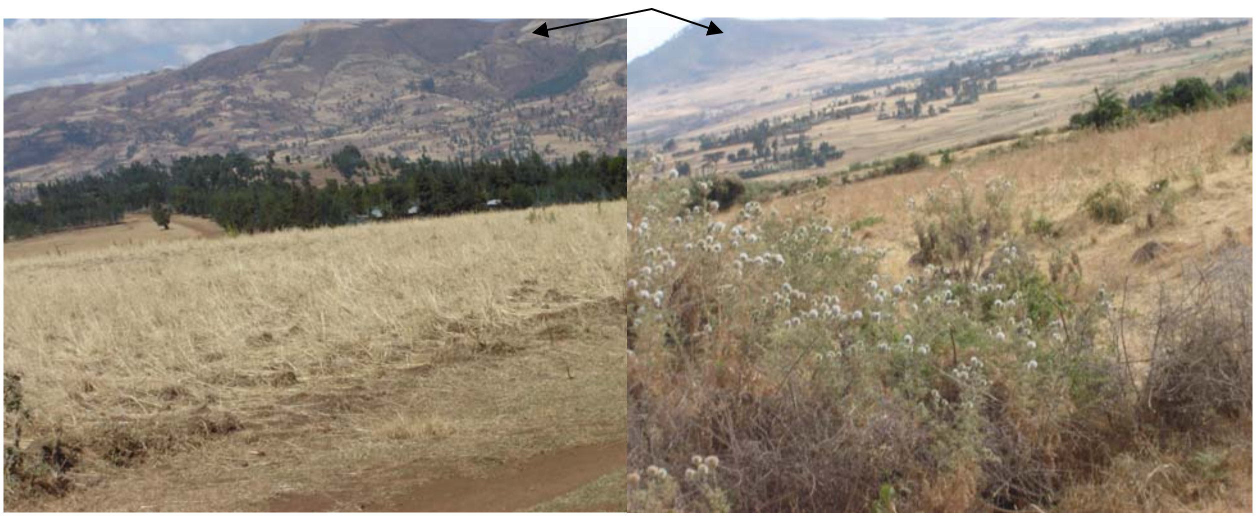


Figure: 5.1 Fo’ata (left) and Wacaca (right) Mountain range

5.5 **Land cover affecting groundwater occurrence**.

Soil type and vegetation cover is another factor that determines and controls the amount of recharge to the ground water as well as ground water chemistry (Freeze_and cherry, 1979). Area with thick soil covers having deep rooted vegetation will promote infiltration while areas with bare lands and thin soil cover enhance more surficial erosion. In this regared most part of the study area is covered with thick soil and deep rooted vegetation even though the increasing of population pressure, the ongoing decline of annual precipitation, deforestation, and misuse of land is currently observed in the catchment.

Generally, the groundwater potential, circulation and distribution are the ultimate cumulative effects of climate, geology, geomorphology land cover and human intervention with natural ecology.

Accordingly the study areas groundwater potential reserve varies from low, medium to high depending on the degree of weathering and fracturing of basaltic flows and deposition of Alluvial sediments extent and thickness. Meteorological stations located with in and around the study area indicates, meteorological elements such as rain fall, temperature, sunshine duration, wind speed & Relative humidity slightly varies from station to station depending on topographical elevation. Geology and Geomorphology of the discharge area is almost similar. The potential resource of groundwater is highly related to the degree of weathering and fracturing, presence of alluvial deposits and buried river gravels and sands.

5.6. Hydro stratigraphic units

From field hydro geological study of the area, geophysical investigations and the well log of several wells drilled in the catchament, the major hydrostratigraphic units can be categorized in to the following: Quaternary alluvial sediments,buried valley deposit,fissured,and fractured trachyte and basalts.

5.6.1 Quaternary alluvial sediments.

This sediment pertains to river valleys and southern plain areas of the catchement and deposited as a result of transport of sediments from dawn wash of sloppy area. The alluvial soil is dark and clayey in the areas of lower topographic relief. It generally consists of clay, silt and sand. Though the thickness of alluvial sediment is not well known and varies from place to place, the test bore hole (HT1) drilled in Holeta river valley, reveled the thickness of about 20 meters. A shallow well drilled at Geresu Seda well no1 has penetrated about 36 meter of the alluvial sediment deposited in the valley. This indicates that at least the alluvial deposit at this place is about 36 meter. From this, it can be deduce that if the alluvial sediment is fully penetrated significant amount of water may be obtained.

How ever, from field observation and geological log the top part of the alluvial deposit is mainly clayey, and the observation of geophysical investigation and drilled well yield observation indicates that the sediment varies litho logically from fine to coarse material at depth. Hence, exploitation of ground water in this unit must consider careful subsurface investigation in delineating coarse loose sediment such as sand and gravel. Generally, the maximum yield of well is expected in the zones where coarse sediment deposition takes places.

5.6.2 Buried valley deposit.

Thick gravel and sand deposit of an old river was observed at Holeta test well (HT1) underlying the basalt of considerable thickness (Nor consult, 1999). The alluvial deposit varies from sand to fine pebble or very coarse gravel. The thickness of this deposit at HT1 is about 70 meters (Table5.1). However, the bore hole didn't penetrate this formation to its full thickness because the contractor was not able to drill further. From the bore hole log the gravel is well sorted at some section and found mixed with sand at other sections. The sand deposit varies from course to fine. The geologic log OF HT1 indicates this (Table 5.1). The old river is assumed to be a large river, to form alluvial deposit of such thickness. Considering the thickness the area extent of the deposit can also large. The continuation of the old river can not be defined from the only test well HT1. Hence, the thickness and extent of this aquifer formation can not be known. However, it may continue along the course and valley of the current Holeta River.

5.6.3 Fissured and fractured volcanic rocks

The most widely distributed other possible aquifer in the study area is the basaltic rock formation. Generally, the permeability and productivity of such rocks is a function of both primary and secondary structures with in the rock matrix. The primary and secondary openings which make the rock porous and pervious is formed during and after the cooling process. Interconnected vesicles, and fractures caused by buckling of the partly congealed lava, voids between successive flows, are some of the features that may give high permeability to the rock body. In the Holeta catchment, the textural, structural and litho logical features observed are considered to be favorable.

In the catchement two units of basaltic rock formations are identified as discussed under the geological setting of the study area. They are the tarmaber megeze formation and the Alaji basalt. The basaltic lava flow exposed at northern part of the study area (tarmabar megezez formation) occupies the elevated land as compared to those exposed in the gentle and flat plain (Alaji basalt) of the study area. But their macroscopic structures as well as other surface features such as fracturing, degree of weathering and vegetation cover can group them under similar hydrostratigraphic unit. Basaltic lava flows exposed in stream cuts/or those that cover the plain area show high degree of cooling fractures but they are moderately weathered where as those basaltic lava flow constituting the elevated lands such as fo'ota range, Fo'ota mintile area simbrti kotu area and Dhagu Dhufa area are highly weathered and were the un weathered one is observed, it shows high degree of cooling fractures. Hence, the lack of one criterion can be compensated by another bringing them under similar hydrostratigraphic unit.

Several boreholes drilled in the catchment indicate that the basalts of the study area are highly fractured and in several places they are scoracious and vesicular. There fore they have a high permeability and productivity.

. The typical examples are wells drilled at Jordan River herbs, Tsedy Plc, Macro, metrolux flower etc.(Yield>10l/s).

Figure: 5.2- Macro artesian well

Although most of the Ethiopian volcanic high lands have good ground water reserve, in places finding water is not straight forward. This is exemplified by the dry wells observed in the Holeta cathement with in the same geological and Geomorphological setting. The local variation in the ground water reserve is often related to the presence of continuous hard massive volcanic stratigraphy. Often high land aquifers are associated with weathered volcanic rocks interbeded with river gravels forming multilayer aquifers.

In places close to major rivers the shallow water bearing formations are alluvial deposits. In all cases the most important water bearing zones in the high lands may not exceed 50 to 80 m below ground surface (Tenalem Ayenew, 2004). This is may be true in most parts of the Ethiopian volcanic high lands. However in Holeta river catchements most of the important water bearing zone are observed blow 80 meters from the ground surface (Figure 5.5). From this one can conclude that the occurrence, accumulation, circulation and distribution of ground water in volcanic rocks are site specific and difficult to generalize. In these areas the main ingredient in ground water investigation is often large scale analysis of both primary and secondary structures.

Table 5.1 Lithological log of Holeta borehole1 (HT1).

Depth (m)	S.W.L (m)	D.W.L (m)	Yield (l/s)	Depth at which water is encountered
174.5	2.2	87	10	45,57and74
Geological well logging	0-8.5 m sandy loam soil 8.15-20.2m River gravel 20.2-31.95 m Mode.weathered scoracious basalt 31.95-45.2 m Fractured and weatherd basalt 45.2-47.5 m Reddish sticky clay 47.5-58.4 m Weathered and fractured basalt 58.4-62.3 m High.weathered scoracious basalt 62.3-68.4mMod.Weathered basalt 68.4-74.65m High. Weathered basalt 74.65-78.95m Sandy clay palaeosoil with gravel 78.95-84.55m Sandy gravel with rock fragments 84.55-100.85m gravely sand 100.85-104.85m Fine to medium grained sand 104.5-112.85m Medium to coarse grained sand 112.5-147.5m Gravely sand			

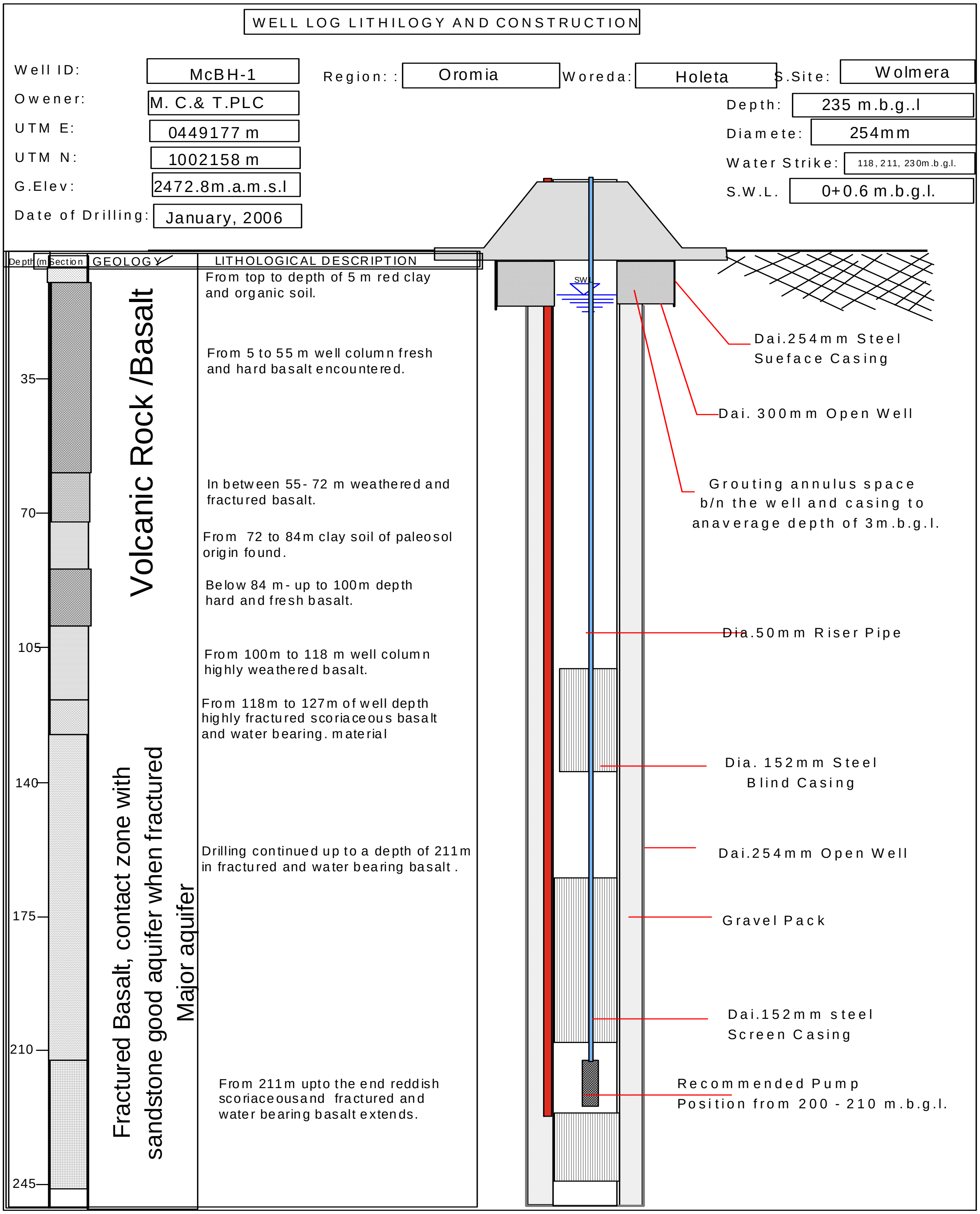


Figure 5.3 well log of macro

5.7 Recharge and Discharge Areas

Recharge areas are usually in topographical high places; discharge areas are located in topographic lows. In the recharge areas, there is often a rather deep unsaturated zone between the water table and the land surface. Conversely, the water table is found either close or at the land surface in discharge areas (Fetter, 1994).

Flow lines on a flow net tend to diverge from recharge areas and converge to ward discharge areas. This convergence will not occur if the discharge zone is large. This is exemplified by the study area. A water table contour map can often be used to locate ground. Water recharge and discharge areas. Flow lines can be drown on the basis of ground water contours, crossing them at right angles.

In the field, vegetation and surface water can sometimes be used to locate discharge areas. There may be some physical manifestation of the discharging groundwater, which can take the form of springs, seep, lake, or stream. The presence of vegetation common to wet soils may be indicative of discharge areas.

Accordingly, the main recharge areas of the study catchement are Fo’ota mountain range, Fo’ota mintile area, simbrti kotu area, and Dhaqu Dhufa area in the northern part and menagesha-wechecha mountain chain in the eastern part of the catchement, which are also located at higher elevation (Figure5.6). These high lying areas get high rain fall compared to its surrounding low lying area.

Figure: 5.4- Fo’ota mountain range of the main recharge area

Groundwater recharge can take place due to rainfall at the mentioned recharge area that is far from the discharge area (potential site), through direct infiltration of the precipitation in to the aquifer system in the basin, and through infiltration of river water in to the aquifer specially during the rainy season. The other possible recharge is due to direct recharge on the potential site itself. However, in most of the basin, because of upper layer is mainly clayey in nature the possibility of recharge due to direct precipitation on the potential site is relatively small. Groundwater due to infiltration from the rivers is possible but it can not be considered as major recharge mechanism.

The discharge areas of the catchement lie in the central North east, west and south of the study area. That is almost all parts of the gentle and flat plain of the catchement covering about 80% of the total area. The surface area where recharge to the regional flow system takes place is quite small in relation to the volume of water stored in the region of the aquifer (discharge areas). Hence the catchement have the recharge area in the basin divide and the discharge area at the valley bottom (Figure5.7). Several boreholes, shallow wells, Hand dug wells and springs observed (inventoried) in the catchament confirm this situation.

In general recharge to the aquifer systems comes from precipitation and loss from ephemeral streams. Precipitation-hence, recharge increases to the north and east. As these are also topographical high areas, regional ground water flow is away from them, to the south west.

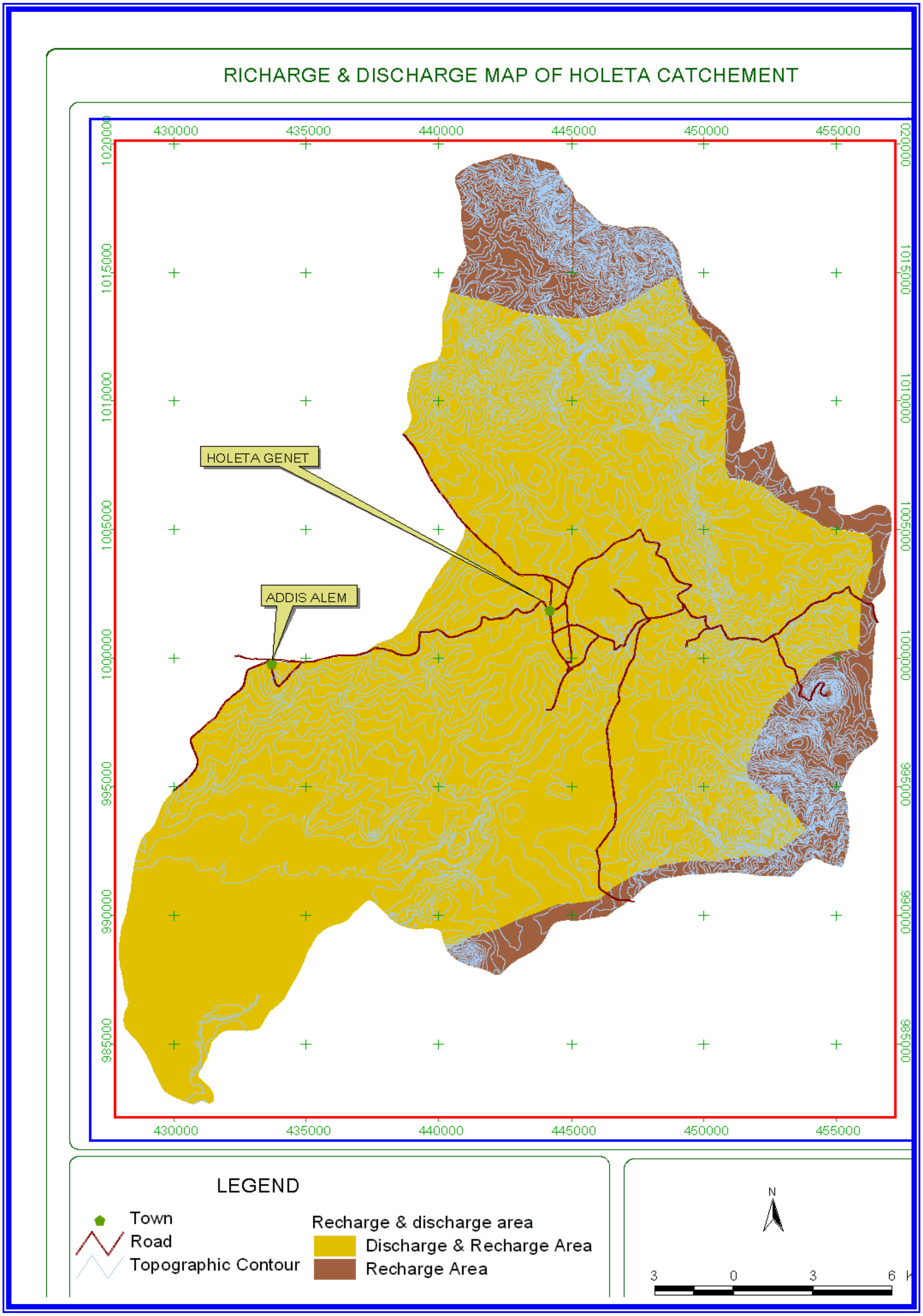


Figure 5.5 Recharge & Discharge Map

5.8 GroundWater flow.

It is desirable, wherever possible, to determine the position of the water table and the direction of groundwater movement. To do so, it is necessary to determine the altitude, or the height above the datum plane, of the water level in well. How ever in most areas, general but very valuable conclusion about the direction of groundwater movement can be derived from observation of land surface topography.

Gravity is the dominant driving force in groundwater movement. Under natural conditions, ground water moves “down hill” until, in the course of its movement, it reaches the land surface at a spring or through a seep along a side or bottom of a stream channel.

Thus, if we ignore minor surface irregularities, in the study area we find that general slope of the land surface is to ward the sough west, suggesting that the groundwater flow is in the same direction.

To know the actual groundwater flow it requires sufficient data of water tables in the study area. Accordingly several water level measurements were collected and the ground water elevations were calculated and ground water contour map has been constructed using the Arcview 3.2 to verify and present the resulting water level contours distribution.

However, not every well is useful, for this purpose some water supply wells are open borings in rocks that include both aquifers and confining beds. Other water supply wells may have more than one well screen, each indicating a different aquifer. Since the water level in such well is a reflection of the heads in several different units and not one specific unit, they are not useful in making water level maps (Fetter 1994).

Accordingly in the construction of ground water level contour map of the study area phereatimetric map errors are introduce due to the following major problems: lack of access for water level measurements, accuracy introduce in the measurement of ground elevation (altitude), occurrence of multilayer aquifers with different pressure, and water level data taken at different times.

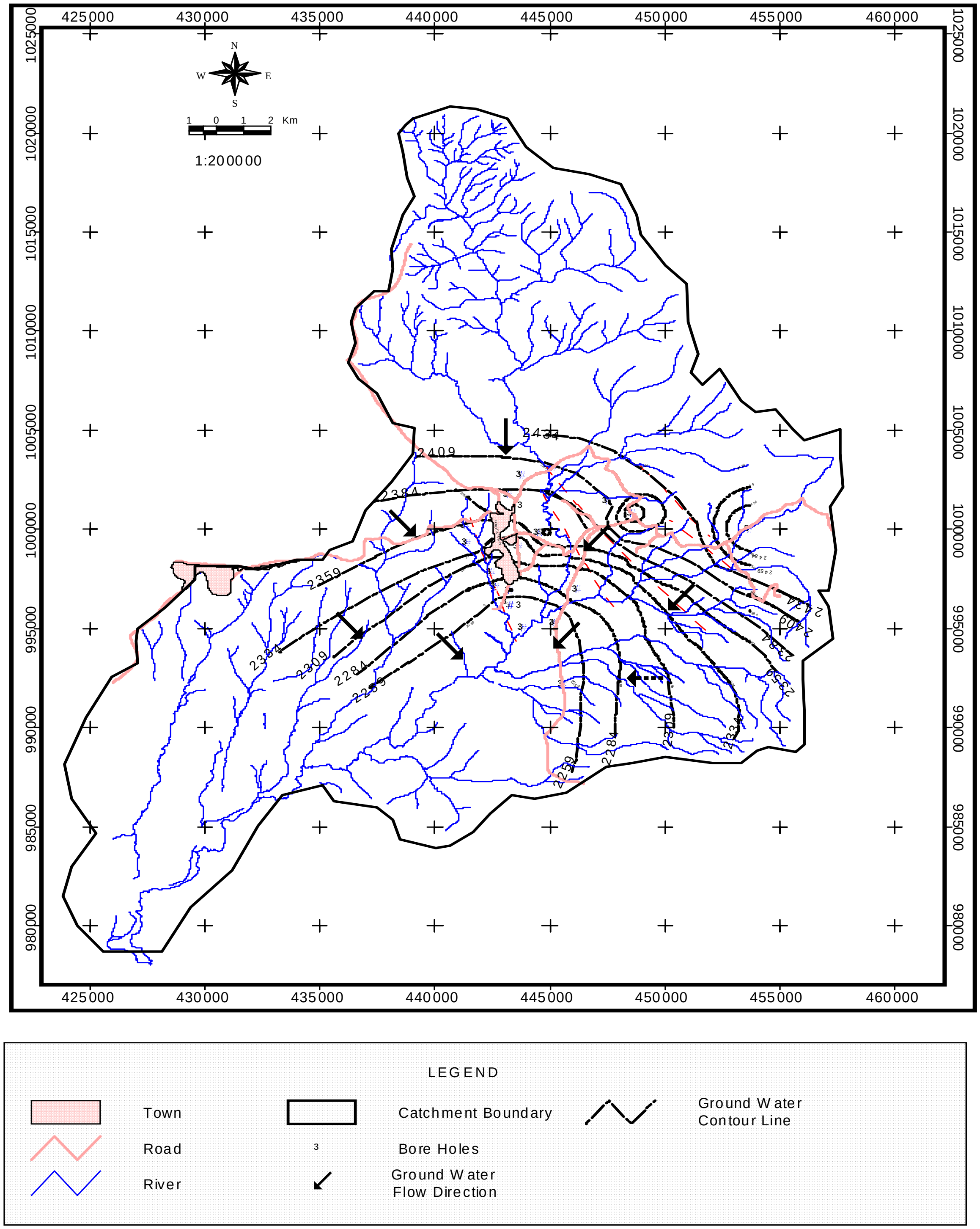
In order to make a groundwater level map, one needs water level readings made in a number of wells, each of which is open only in the aquifer of interest. But in many areas of the country in general and the study area in particular, it is very difficult to get wells which fulfill the mentioned requirements fully. On top of this it is also difficult to get evenly distributed wells which represent the whole catchement. In Holeta cachement even though there are several wells drilled they are concentrated only at the center of the study area (around Holeta Genet town).

There fore, these conditions force the researcher to construct the groundwater level contour map and groundwater flow direction based on the available data at least to see the general trend of the ground water flow direction besides the problems introduce because of the above mentioned problems and constraints.

As such the generalground water flow of the catchement is towards south from north and towards south west from east via to the Awash River reflecting the same general slope of the land surface (Figure5.8).

If the surface topography has well defined local relief, a series of local groundwater flow system can form in humid regions. This is due to the fact that topographic relief causes undulation in the water table. A local ground water flow system has the recharge area at a top and its discharge area at an adjacent topographic low (Fitter 1994). In this regard the study area has no well defined local relief, apart from the minor local relief observed at the north part of the catchement suggesting the ground water flow system of the catchement is relatively regional.

Figure: 5.9 GROUND WATER LEVEL CONTOUR MAP AND FLOW DIRECTION



5.9 Springs

Spring is a concentrated discharge of groundwater appearing at the ground surface as a current of flowing water (Todd, 1980). Spring also can be defined as any natural surface discharge of water large enough to flow in small rivulet; discharge smaller than this is called surface seepage (Devis and Dewiest, 1966). A number of parameters may be employed to classify springs. Such as based on magnitude of discharge, type of aquifer, chemical characteristics, water temperature, direction of water migration, relation to topography, and geologic structure.

Generally, in the study area there are only cold (gravity) springs. Taking in to consideration their mode of origin, the dominant springs are contact and/ or depression springs. For the first case there are many conditions under which it can occur: permeable layer over laying an impermeable layer e.g. presence of paleosol with in fractured and/ or weathered sequence of lava flow, or the same lithology but different degree of weathering and/ or fracturing.

In addition to contact and depression springs, joint springs or fracture springs are also present in the study area.

Some springs are observed and recorded in the study area and presented on the following table.

Table: 5.2 Types and location of some springs in Holeta catchement.

Name of springs	Coordinate	Elevation	Q(l/s)	Type
Kimoye (HSP1)	437919 E 1000411N	2397	1.5	Contact
Menagesha mariam (HSP 2)	441957E 0998620 N	2572	1	Depression
Kolobo (HSP3)	454152 E 1002643 N	2610	1.5	Depression
Yubo (HSP 4)	439169 E 1007250N	2555	0.5	Depression
Telecha (Hsp5)	441080 E 1013103N	2673	3	Contact
Gajoo	441757 E 1014339 N	2644	2	Contact
Tsedey Farm	463370 E 996912 N	2501	1	E-W Fracture
Yesus tebel	454438 E 999971 N	2600	1.7	Depression
Beite	454469 E 1000092 N	2519	3	Depression
Burka Abaduka	459444 E 989690 N	2562	2	Depression
Roghe	457026E 981375 N	2087	10	E-W Fracture

As indicated on the table several springs emanate from the intersection of the water table with the valley and fractures.

5.10 Geophysical investigation

In the catchement geophysical surveying was carried out by different organizations and consultants to up grade the knowledge of the subsurface condition regarding geology and hydrogeology by indirect interpretation.

These electrical resistivity survey was carried out mainly to supplement the hydro geological investigation with the aim of assessing favorable potential ground water site for bore hole drilling and to determine the provisional drilling depth of the boreholes to be drilled.

The geophysical surveying employed was both vertical electrical sounding of wenner and schlumberger type configuration.

One of the most essential steps for ground water investigation is collection of available data (if any) that expresses the surrounding ground water conditions. Thus a total of ten vertical electrical soundings (VES) data were collected and the VES result is related to the litho logy and well yield of the boreholes drilled in the vicinity of the VES survey areas. A calibration model for aquifer of the study area in particular and similar geological, physiographical, and climatological areas in general is then suggested which can serve as a starting first hand information for further study and research.

According to, VES surveys carried out in the study area and as has been reveled from the results and interpretation different geo-electrical layers (three to seven layers) were identified for investigated depth. These different geo-electrical layers interpreted from the VES survey more or less indicated the alternating formation of permeable and less permeable units in the catchement i.e. Topsoil, silty or sandy clay sediments, moderately weathered basalt, highly weathered basalts (paleosols), highly weathered and /or fractured basalts, slightly weathered basalts, massive basalts etc. Which are more or less encountered in the litho logical well logs observed in the catchement. There fore during the interpretation care must be taken as the one that revels low apparent resistively value is not always necessarily the saturation zone (ground water potential zone); because due to the presence of clay the layer resistivety might be very low. In such cases ground water experts should consider the general hydro geological parameters, the thickness and depth of that layer, and if possible supported by additional geophysical surveys. Thus from the interpreted results of VES survey and the encountered litho logy of the wells shown in figures and appendices the geophysical investigation could be helpful to supplement the hydro geological investigation of a region to delineate ground water potential zone and target drilling depths.

Summary of the location of VES points and interpreted results are shown here under (Table5.3)

No	Survey area	Coordinate	point elevation (m)	layer	Resivty (ohm-m)	Thickness (m)	depth (m)	Probable lithology
1	Inside the army camp	044465E 1000545 N	2367	First second third Fourth	12 6 13 95	1 32 51 -	1 33 84 -	Topsoil Clayey/ silt sediments Highly w. basalt moderately weathered and/or Fractured basalt
2	Along the grovel rood to old town	0445057E 1000545 N	2367	First second third Fourth	14 8 31 13 102	1.2 4.3 25 47 -	1.2 6 30 78 -	Topsoil/ Compacted Topsoil/ Compacted Moderately weathered basalt Highly weathered and/or fractured Moderately weathered basalt
3	Along the grovel rood to old town	0445017E 1000937 N	2358	First second third Fourth	76 19 5 10 52	1.2 4 5 40 -	1.2 5 10 50 -	Coarse and compact soil Coarse sediment soil Fine sediment Highly weathered and or Fractured basalt Moderately weathered basalt
4	South west of the camp	0444228E 0999532 N	2310	First second third Fourth	16 5 9 56	1.4 1.2 47 -	1.4 2.5 50 -	Silty / clayey sediment “ “ “ Highly weathered and/ or fractured basalt Mod weathered and /or fractured basalt

Table continued

No	Survey area	Coordinate	point elevation (m)	layer	Resivty (ohm-m)	Thickness (m)	depth (m)	Probable lithology
5	South of Holeta	444750 E 980500 N	2340	First	9.7	1.1	1.1	Top soil
				Second	2.3	0.9	1.9	"
				Third	9.6	4.6	6.6	"
				Fourth	52	37.5	44	Slightly weathered basalt
				Fifth	45.1	118.3	162.3	Weathered v. basalt (Saturated)
				Sixth	90.3	45.8	208.1	Slightly weathered / fractured basalt
				Seventh	148.3	-	-	Massive basalt
6	Holeta Diary farm	-	-	First	34.2	1.7	1.7	Topsoil
				Second	12.1	21.8	23.5	Saturated alluvial deposit
				Third	54.7	36.3	59.7	Saturated fractured and weathered basalt
				Fourth	19.9	52.4	112.2	Buried river deposit
				Fifth	84.8	-	-	Slightly weathered basalt
7	Holeta Near BH4	-	-	First	50.6	1.3	1.3	Top soil
				Second	8.5	8.4	9.8	Auvial deposit
				Third	28..7	38.9	48.7	Fractured and weathered basalt
				Fourth	48.2	-	-	Moderately weathered basalt

Table continued

No	Survey area	Coordinate	point elevation (m)	layer	Resistivity (ohm-m)	Thickness (m)	depth (m)	Probable litho logy
8	Holeta farm	-	-	First	12.5	0.7	0.7	Silly/ clayey sediment
				Second	6.3	2.9	3.6	"
				Third	17.8	9.4	13	"
				Fourth	11.1	11.5	24.5	"
				Fifth	53.9	-	-	Fractured and weathered basalt
9	Holeta-kuwi			First	32.3	2.9	2.9	Top soil
				Second	13.2	21.4	24.3	Alluvial sediment
				Third	49.4	-	-	Fractured and weathered basalt
10	Holeta Godicha			First	39.9	1.5	1.5	Top soil
				Second	10.0	4	5.5	Alluvial sediment
				Third	17.7	4.9	10.4	"
				Fourth	8.4	10.4	20.8	"
				Fifth	33.0	58.0	78.8	Fractrered and weathered basalt
				Sixth	16.5	106.9	185.7	Butied river deposit
				Seventh	65.7	-	-	Slightly weathered basalt

Note:-1-4 (WWSDSE, 2004) 6-10 (Nor consult, 1999)

5 (WWDE, 2003)

Table 5.2 shows the results of different VES (VES 1-10). The interpretation of the sounding curve delineates four to seven resistivity layers. If one considers VES 1, it shows four major resistivity layers. The first layer has a resistivity of 12 ohm-m and thickness of 1 mater. It represents the top soil. Below the top most layer a low resistivity (6 ohm-m) layer with a thickness of 32 m is found, which may be interpreted as representing clayey/ silty sediment. The third geoelectric layer is marked by a resitivity value of 13 ohm-m having a thickness of 51 meter. This horizon presumably represents highly weathered and/or fractured basalt. The fourth layer is characterized by high resistivity value (95 ohm-m), it is found at a depth of 84 meters. The relatively high resistivity value of this horizon may indicated the moderately weathered and/or fractured nature of the volcanic rock, it could be water bearing.

As indicated from the table above almost all of the VES results show shallow depth of investigation apart from those carried out at south of Holeta (WWDE, 2003), which show about 208 meter and above depth of investigation and north of Holeta (Godicha) (Norconsult, 1999).

This VES no 10 with a low resistivity value (16.5 ohm.m) on the sixth layer (185 meter depth) and which was interpreted as buried river deposit with a thickness of about 100 meter may suggest the continuation (extension) of buried bally deposit observed at Holeta test well one (HBH1). as it was carried out along the Holeta river valley up stream of HBH1.

From the table the vertical electrical sounding (VES) conducted in Holeta river catchement of the interpreted apparent resistivity data shows generally low resistivity value i.e. below 100 ohm meter except two showing > 100 ohm meter. The resistivity value trend shows moderate value at the top, low at the middle and again moderate at depth. Apart from the dry soil at the top, most part of the formation indicated as low resistivity value and can be interpreted as saturated alluvial deposit, while the moderate resistivity value indicated saturated fractured and weathered basaltic rock formation and buried river deposit of various origin and the high resistivity value (>100) may be attributed to massive basalt.

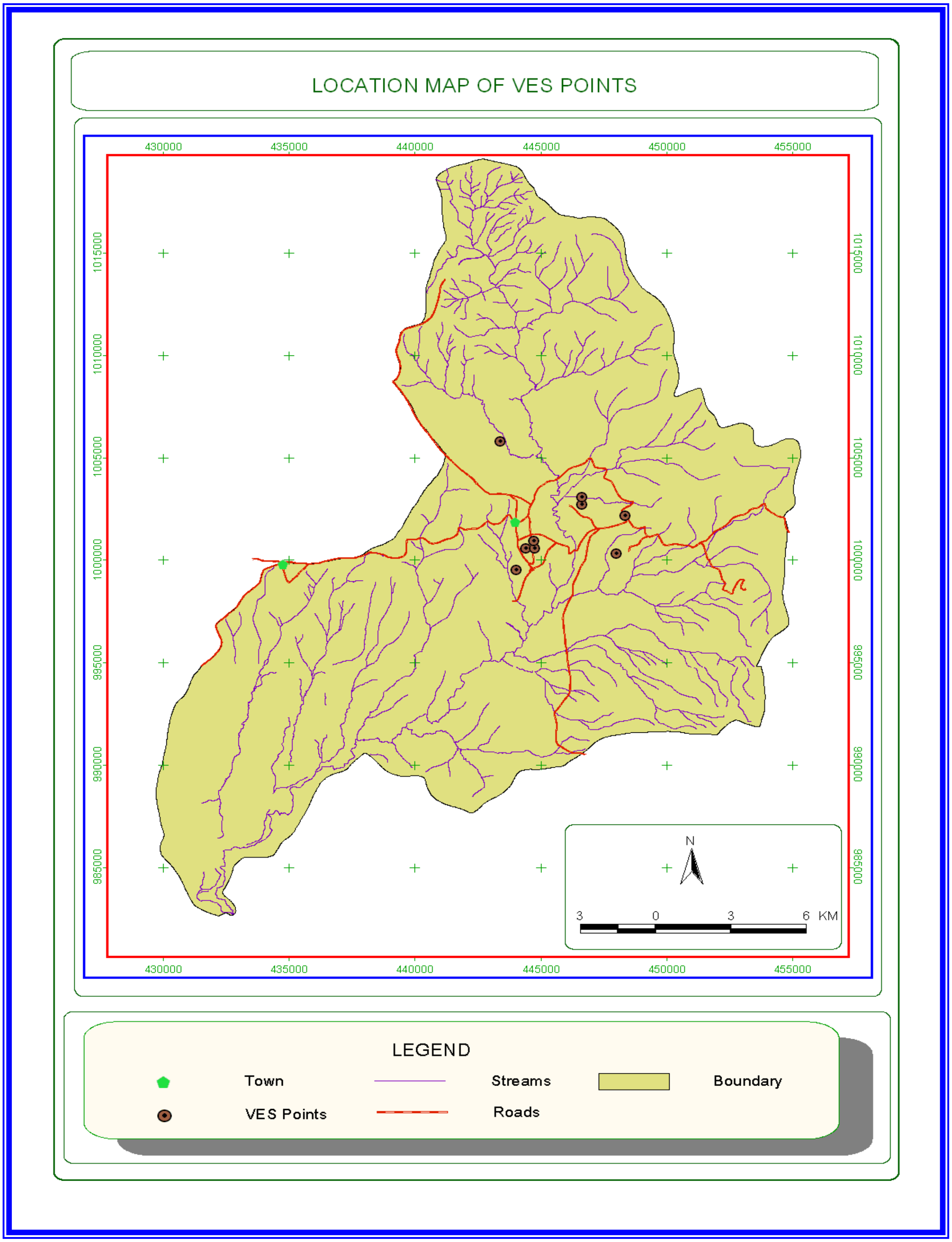


Figure5.8 VES Point Map

5.11 Aquifer characteristics

An aquifer is a hydro geological formation that stores and transmits a significant quantity of water in such a way that a reasonable amount of water can be abstracted from it economically. It is both a hydro geologic & hydrodynamic system that can be defined by the following quantifiable characteristics, Detay (1997).

- Its dimension (geometry) and boundary conditions that give rise to its volume.
- Its hydrodynamic, hydro chemical and hydro biological behavior respectively characterizing water storage and transmission, geochemical interaction, and biological purification of the aquifer.

Geological, hydro geological and hydro geochemical investigations are the most important sources of data for knowing such aquifer characteristic. Under this section more emphasis is given to the hydro geological investigation, particularly well data in order to define the hydrodynamic or hydraulic parameters of aquifers in the study area.

Based on the hydrological investigation as well as the existing well data, the main aquifers identified in the study area are the alluvial deposits along streams, buried valley deposits, weathered and fractured scoraceous basalt and weathered and fractured basalt. Each of the aquifer type in the study area will be treated separately to show their few specified characteristic even though most aquifer characteristics of the catchment reflects multilayer aquifers rather than aquifer characteristics of each layer

Alluvial deposits

Though the thickness of alluvial deposit is not well known and varied from place to place, the test bore hole (HBH1) drilled in Holeta river valley reveled the thickness of about 20 meters. A shallow well drilled at Geresu seda well no 1 has penetrated about 36 meters and a deep well drilled for metrolux flower plc encounter about 10 meters. From this, it can be deduce that if the alluvial sediment is fully penetrated significant amount of water may be obtained. However it is impossible to characterize the hydraulic parameters of this aquifer independently as it is not pump tested separately.

According to the data from these wells, the alluvial deposit is found to form a shallow aquifer and the clay soil forms the upper confining layer.

Buried valley deposit

As indicated above thick gravel and sand deposit of an old river was observed at Holeta test well (HBH1) under laying the basalt. The thickness of this deposit at this well is about 70 meter. How ever the bore hole didn't penetrate this aquifer formation to its full thickness because the contractor was not able to drill further (Nor consult, 1999). From the borehole log the gravel is well sorted at some section and found mixed with sand at other sections. The sand deposit varies from coarse to fine. The geologic log of HBH1 indicates this (Figure5.3). The old river is assumed to be a large river, to form alluvial deposit of such thickness.

Considering the thickness, the area extent of the deposit can also be large. The continuation of the old river can not be defined from the only test well. Hence the thickness and extent of this aquifer formation can not be known. Howe ever it may continue along the course and valley of the current Holeta River. This aquifer formation is found to form the deep/ or confined aquifer.

Weathered and fractured basalt

There are several springs that emerge from basaltic lava flow and trachytic lava flow in the study area. This shows the basaltic lava flow and trachytic lava flow are an aquifer at least for the shallow ground water/ or it forms unconfined aquifer in their top weathered parts. Besides this, there are many hand dug wells, shallow wells and deep wells that are drilled to this aquifer (especially basalt lava flow) tapping ground water. Almost all wells drilled in the catchement are to this aquifer formation showing different productivity. The variation in productivity is related to degree of weathering and fracturing, penetration of the requited depth of aquifer and well construction and completion, etc.

According to data from the wells the basaltic lava flow is found to form multilayer aquifers: the shallow/ unconfined aquifer and the deep / or confined aquifer. Paleosol / or clay soil form the upper and middle confining layer and massive basalt form the bottom confining layer (Figure5.9). But most of the wells are still in partial penetration of the aquifers. These are exemplified by HBH 1, Metroluxe, Garad, etc.

Deep wells drilled revealed that two confined aquifers both of which are comprised by fractured and weathered basalt, and with some scoracious basalt exist in the study area. The aquifers are encountered at different depths in different well. However most of the main aquifers are encountered below 80 meters.

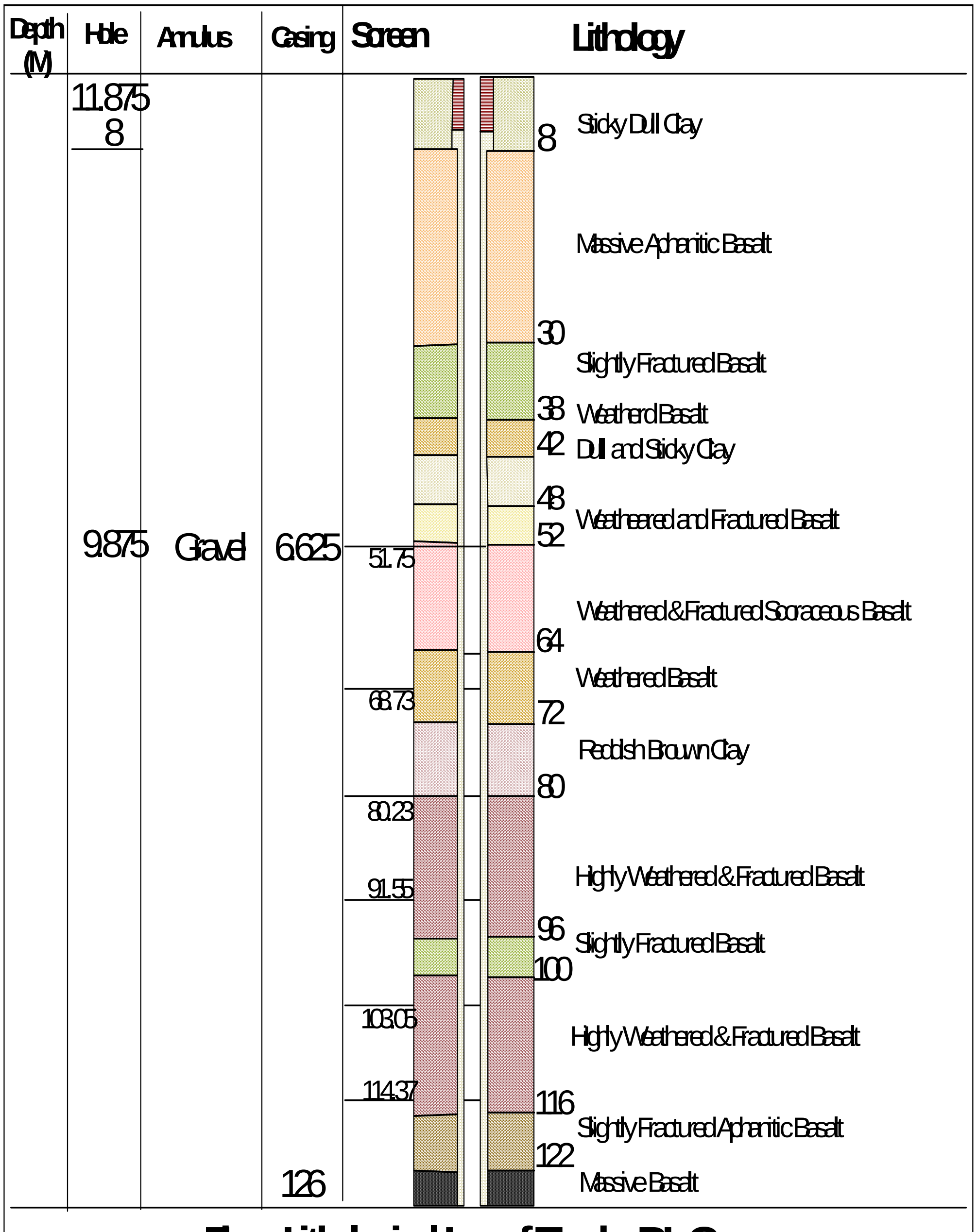


Fig. Lithological Log of Tsedey P.L.C

Figure 5.9

The geological/ litho logical descriptions and field observations are very important tools in the assessment of the aquifer productivities. Hydro geological field observations such as the distribution and magnitude of spring discharges, the degree of fracturing to the rock units, the thickness of the formations, the grain size rounding and sorting, the clay proportions, the type and degree of cementation and the extent of weathering are some of the significant field observations which provided indirect evidence as to whether a rock unit is likely to be an aquifer of poor, low, moderate or high productivity. In order to re in force the indirect hydro geological observations, other methods such as geological / litho logical well logging and pumping test data analysis were employed.

Recent (2003-2005) drilled wells for different organization and flower farming PLC with their geological /litho logical, pumping test, and physico chemical test data's were available in the study catchement. There fore the analysis of these data's with hydro geological field observations provided a basis for estimation of yield specific capacity and Transmissivity values which after a simple statistical treatment were used to rank the aquifers in to poor, low, moderate, and high productivities relative to the catchement areas. When the results obtained from the pumping test data and the field hydro geological observations were compared, they matched quite well in most cases and in those few cases were they did not match the necessary changes were made in the ranking.

Over all physical identification of geological parameters, air photo and remote sensing interpretations, geomorphologic description, interpretation of geophysical data, drilled wells, pump test and chemical analysis have been used to delineate the study area according to their hydro geological characteristic and relative ground water productivity. In general about 50 drilled wells, 20 pumping test and more than 25 hydro chemical analyses have been considered in classifying the area according to their relative ground water productivity (figure)

Therefor, the north east portion of the study area such as areas around Menagesha, Tseday PLC and the area found in the down stream part of Holeta river and towards the confluence of Holeta and Gale are covered with basaltic flows (Alaji basalt) having deep weathering and fracturing (figure). Thus,they have very high ground water potential (>10 l/sec). The static water level is also shallow as compared to the rest of the catchement (0-10m). As it has been reveled form the litho logic description of some wells in this high groundwater potential zone, the main aquifer is fractured and weathered basalt / or fractured and weathered scoraceous basalt (Table 5.4).

Figure 5.10 weathered and fractured Alaji basalt

Table 5.4 Representative well of high productivity (Jordan River herbs PLC)

Depth (m)	S.W.L (m)	D.W.L (m)	Yield (l/s)	Depth at which water is encountered
115.3	57.84	59.1	14.6	72 to 86 and 98-107
Geological well logging	0-4 m Highly weathered aphanatic basalt 12-24 m Massive aphanatic basalt 24-40 m Reddish brown sticky clay 40-56 m Massive aphanatic basalt 56-72 m reddish sticky clay 72-86 m Fractured basalt 86-90 slightly fractured basalt 90-94 Weathered and fractured basalt 98-107 Weathered and fractured scoracious basalt 107-115.25 Massive basalt			

The trap basalt (Tarmaber megezaz formation of the Northern recharge area is deeply weathered with various associated geological structures formed by different episodes of flow will infiltrate rain water at fastest rate to the subsurface (Figure5.1). Like wise the formation underlying this basaltic out crop is Alaji basalt, which is also weathered and fractured as observed from field hydro geological observations and drilled wells and covering the flat gentle plain of the catchment facilitates the percolation of infiltrated water to the ground.

The central (along the stream courses) and south portion of depress ional low laying land of the study area is deposited by sand, silt and clay (alluvial sediments) transported from adjacent high land with thickness varies from 12 to 36 meter. This formation has good shallow ground water reservoirs and also deep ground water potential as the alluvial sediments facilitate percolation (recharge) to the deep basaltic flow aquifer.

Therefore the northern parts of the catchament and southern portion have moderate ground water potential with average well yields 5-10l/s. Here is also identified similar fractured basalt unit and also alluvial deposit as an aquifer.

Table 5.5 Representative wells of moderate productivity.

	Yosef Firdu Flower Farm	Ethio-Dream Pvt. Ltd. Co.
Depth (m)	100	112
SWL.(m)	4089	0
DWL.(m)	28.5	13.5
Depth at which water is encountered(m)	72,96	102
Yield (l/s)	6	6
Geological well logging	0-4m Brown color clay 4-8m Dark color, slightly weathered massive basalt 8-28m Dark color Fresh basalt 28-36m Red clay soil 36-50m Brown clay soil 50-60m Red clay soil 60-72m Undiferentiated rock fragment intercalated with brown clay 72-80m Highly weathered scoracious baslt 80-84m Fractured basalt 84-92m Undifferentiated rock fragment 92-96m Fresh basalt 96-100m Dark color fractured basalt	0-4m Vesiculated basalt 4-14m Massive fresh basalt 14-20m Slightly fractured basalt 20-40m Fresh basalt 40-44m Clay 44-72m Fresh basalt 72-78m Clay 78-92m Slightly fractured basalt 92-102m Fresh basalt 102-112m Fractured basalt

The area upstream of Gale and areas west of the catchement portion (around Adis Alem) have low ground water potential i.e. 2-5 l/s. In the area up stream of Gale massive basaltic unit dominates the subsurface geology.

Table 5.6 Representative wells of low productivity.

	Garad Plc	IAR
Depth (m)	130	101
SWL.(m)	24	23.3
DWL.(m)		38.06
Depth at which water is encountered(m)	100	45-56, 74-86, 88-92
Yield (l/s)	3.3	3.5
Geological well logging	0-8m Topsoil clay 8-12m Boulder basaltic origin 12-26m Highly weathered material 26-34m Fresh basalt 34-54m Highly weathered material 54-74m weathered material 74-100m Fresh basalt 100-130m Undifferentiated material	0-12m Sticky dull gray clay 12-16m Highly weathered basalt 16-20m Sticky clay 20-28m Weathered and fractured basalt 28-34m Slightly fractured basalt 34-42m Moderately fractured basalt 42-56m Weath and fract. Scoraceous basalt 56-57m Clay 57-64m Aphanitic basalt 64-66m Reddish brown soil 66-74m Aphanitic basalt 74-86m Fractured basalt 86-88m Sticky dull clay 88-92m Scoria 92-96m Highly weathered materials 96-101m Aphaniti basalt

Finally, the areas eastern peripheries of the catchement have poor ground water potential (<2l/s) as the area, underlies mostly by massive Rhyolitic and Trachytic lava flows. However, the upper wreathed parts of the rocks in the catchement are used for hand dug wells and most of the sprigs of the area used as water supply for rural communities are the result of this weathered part of the basaltic and trachytic lava flows.

In practice it is very difficult to get similar productive wells even with in a short distance difference especially in volcanic rock terrains. Thus the classified aquifers indicate the success rate of tapping the mentioned ranges of ground water with in the delineated areas.

5.11.1 Estimating aquifer transmissivity form specific capacity data.

There is a large body of data on the specific capacity water wells. Aquifer tests are usually not performed when water wells are drilled. However, the well is normally test pumped for at least a few hours and/or days the yield and maximum drawdown are recorded. The yield of the well divided by the draw down is called the specific capacity. Typical unit are m^3/day/m of drawdown or l/s/m of draw down.

Razack and Huntley (1991) established a formula in studying the relationship between transmissivity and specific capacity in an alluvial ground water basin in morocco. They analyzed 215 data pairs where tarnsmissivity and specific capacity were known for a well (Fitter, 1994). Then they were able to find an empirical relation ship between the two parameters, which had a correlation coefficient of 0.67. This relation ship can be expressed as:

$$T=15.3(Q/ho\text{-}h)^{0.67}$$

Where: T-transmissivity (m^2/day)

Q=pumping rate (m3/day)

Ho-h- draw down (m)

From this they conclude that the relation best estimates the specific capacity and consequently aquifer transmissivity. Thus it is wise to use this relation ship to have a relatively reasonable value of T. Accordingly, the following transmissivity values are estimated based on this relation and summarized here under below (Table 5.7).

Table: 5.7 **Estimation of Transmissivity from specifie capacity for some wells in Holeta River catchement.**

BH Name	Code	Coordinate Easting	Northing	Depth (m)	Elev (m)	SWL (m)	Pumping Test rate (l/s)	DWL (m)	Draw down (m)	Transmissivity (m^2/day)	Specific Capacity (l/s/m)	Hydrolic Coundctivity (m/day)	Aquifer thiknes (m)
Jordan	HBH 21	453387	1001417	115.3	2556	57.84	14.6	59.1	1.26	1567	11.59	55.18	28.4
Rose Eth.Plc	HBH 6	444577	998364	252	2290	81.7	4	203.7	122	30.74	0.03	1.02	30
Yosef Firdu				100		4.89	6	28.5	23.61	121.22	0.25	12.12	10
Garad Plc	HBH 10	443050	1001649	130	2397	24	3.3						28.7
Top Plc	HBH 13	445114	998215	100	2285	5.9	5.6	6.2	0.3	2156.6	18.6	89.83	24
Ammh Plc	HBH 14	444677	998808	100	2306	21.3	5.6	53.38	32.08	92.59	0.17	3.86	24
Ethio.dirme	HBH 19	440079	1000151	112	2410	0	6	13.5	13.5	175.1	0.44	14.59	12
Tsedy Plc	HBH 26	447200	998889	126	2294	0	14	45.36	45.36	138.47	0.31	3.55	39
Metrolux	HBH 9	445942	998199	99	2250	0	14	2.54	2.54	952.2	5.51	39.66	24
IAR #1	HBH 11	445773	1001323	74.5	2388	30.35	3.1	37.4	6.86	177.75	0.45		23
TOWN W.Sup.	HBH 1	446080	1002870	147.5	2388	2.2	8.3	87	84.8	64.89	0.1		
TOWN W.Sup.	HBH 2	446170	1003930	90	2385	7	5.7	65.3	48.8	73.32	0.12		
IAR #2		445300	1002500	101	2388	23.3	3.5	38.06	14.76	116.65	0.24	5.18	22.54
Roge	HBH 28	446632	994813	100	2240	4.5	5	10.5	6	250.29	0.75		30
Guntuta	HBH 27	446338	997431	110	2256	14	5	48	34	85.14	0.15		30
Ethio agriceft #1	HBH 36	444750	980500	90	23400	7.36	6.5	15.53	8.17	260.38	1.26	8.68	30
Ethio agriceft#2	HBH37			98		7.2	5	27.98	20.78	116.85	0.24	2.54	46
Mulugeta Buli #1	HBH 38	443984	999625	150	2305	28.8	3.5	69	41.74	57.7	0.08	1.37	42

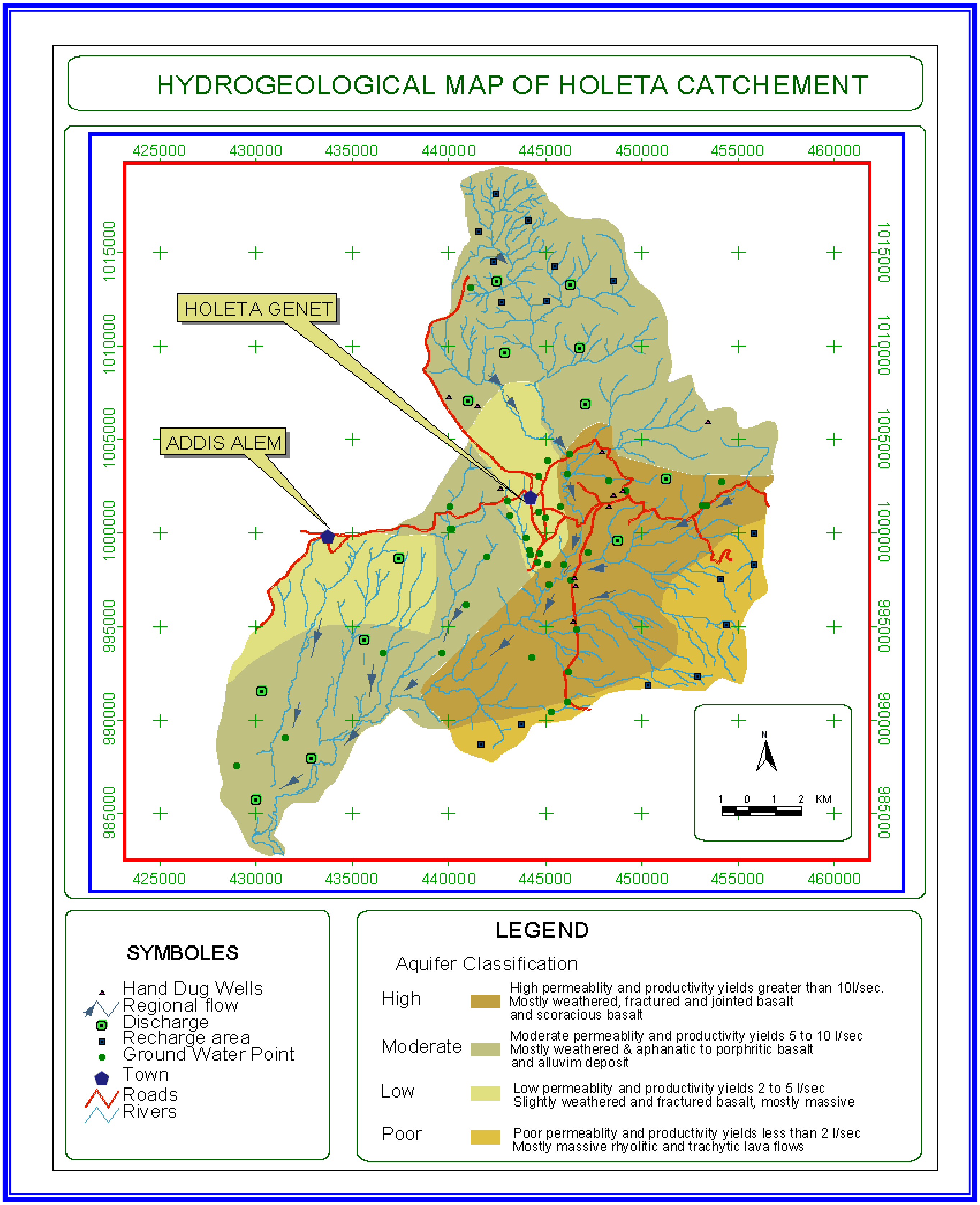

HYDROGEOLOGICAL MAP OF HOLETA CATCHEMENT
425000
430000
435000
440000
445000
450000
455000
460000
1015000
1010000
1005000
1000000
995000
990000
985000
HOLETA GENET
ADDIS ALEM
N
1 0 1 2 KM
SYMBOLES
Hand Dug Wells
Regional flow
Discharge
Recharge area
Ground Water Point
Town
Roads
Rivers
LEGEND
Aquifer Classification
High
High permeablity and productivity yields greater than 10l/sec.
Mostly weathered, fractured and jointed basalt
and scoracious basalt
Moderate
Moderate permeablity and productivity yields 5 to 10 l/sec
Mostly weathered & aphanatic to porphritic basalt
and alluvim deposit
Low
Low permeablity and productivity yields 2 to 5 l/sec
Slightly weathered and fractured basalt, mostly massive
Poor
Poor permeablity and productivity yields less than 2 l/sec
Mostly massive rhyolitic and trachytic lava flows

Figure 5.11

CHAPTER SIX: - HYDROCHEMISTRY

6.1 General

For most of its uses, the chemical properties of water are as important as the physical properties and available quantity. The mineral composition of the ground water reservoir, the ground water flow patterns in the basin and the length of time the water have been in contact with different rock formations influence area variations in chemical characteristics of water. In other words, the chemical composition of natural water is derived from many different sources of solutes, including gases and aerosols from the atmospheres, weathering and erosion of rocks and soils, solution and precipitation reactions occurring below the surface and cultural effects resulting from the human activities. The solute taken up or precipitated and the amount present in the solution are influenced by many environmental factors, especially climate, structure and position of rock strata and biochemical effects associated with life cycle of plants and animals, both microscopic and macroscopic (Hem, 1992).

Interpretation of hydrochemical data has vital uses. Information regarding water quality, water quantity, hydraulic interconnections, mixing of different water types, depth of circulation, location of recharge, and some of pollution can be easily obtained from thorough analysis of physiochemical data.

To know the general chemistry variation (spatial variation) and the possible sources for variation (natural or man made activities), water samples have been taken for chemical analysis and field parameters were measured at field in the catchment.

6.2 Sampling techniques and analysis

Natural water is sampled in view of carrying out various analyses on it. In the study area more of the samples are collected from different water supply schemes that are found with in the basin and few samples from rivers to compare parameters among different sources. A total of twenty three samples have been collected: Five samples from springs, four samples from Shallow wells, three samples from Hand Dug Wells, eight samples from Deep Wells, and three from Rivers. Each sample is taken with a one liter polyethylene plastic bottle. Representative samples were taken from each water sources and at different locations (figure). The samples are analyzed in the laboratory of Oromia water resources development bureau, Ethiopian Geological survey and ministry of water resources.

The analysis is made for major actions and anions, tow trace elements, and silica. Field and laboratory measurements of PH, EC, TDS and Temperature have been conducted. The accuracy of the analytical results of the chemical data was examined for analytical error prior to the interpretation. Those data with in the limit of acceptable error (< 5%) used for the purpose of data processing.

Reaction errors are determined as a method to asses data quality. The sum of actions equals the sum of anions in each solution. The deviation from such equality provides a way to assess the data quality.

The equations were: $$RE = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}}$$

Where RE is reaction error and $\sum$ is the summation.

Accordingly most secondary dates collected from the study area were not used for analysis as their reaction error is greater than 5%.

6.3 Organoleptic parameters

Organoleptic parameters characterize the aesthetic values of water. They include color, odor, turbidity and taste. The existence of an objectionable situation in one of these properties of water have to be tested whether they meet some standards or not for specific water use. Except taste, other properties have been tested for the collected samples from the study area.

The presence of organic or inorganic suspended matter such as clay, silt, colloidal organic particles in water cause turbidity. Turbidity is an expression of certain light scattering and light absorbing properties of water. It has two main effects in water: cause an objectionable taste or appearance to consumers, reduce the effectiveness of disinfectants by providing protection to micro organisms, WHO (1984). Its guideline value, according to WHO (1984) is 5 NTU. When samples taken from different sources in the study area compared among each other for the turbidity, it ranges from nil to 120 NTU. High value of turbidity is observed for HSW2. This is may be due to the well head construction problem observed during the sampling period.

Odor in water is usually caused by the presence of organic matter in it. All the samples collected for the investigation are tested to be odorless. Color of the water samples ranges from nil units to 107 units. The maximum is observed for river.

6.4 Physicochemical parameters.

The physicochemical parameters analyzed for the water samples are categorized in to two: those that have been measured both on the field and in the laboratory and those that have been only analyzed in the laboratory. For that reason the measurement of PH, Redo

– potential (Eh), Temperature (T), total dissolved solids (TDS) and Electrical conductivity (EC) are made both at the field and laboratory, (Annex 2).

6.4.1 P^H

P^H is a measure of the hydrogen ion concentration of the water. The P^H of water indicates whether the water is acid or alkaline. Drinking water with a P^H of between 6.5 and 8.5 is generally considered satisfactory. Acid waters tend to be corrosive to plumbing and faucets, particularly if the P^H is below 6. Alkaline waters are less corrosive.

The P^H value of the samples in the study area ranges from 6.27 to 8.7. The lower values measured for hand dug well (HHDW11) and the higher value is for sample from borehole (HBH2) (table 5.2).

The P^H values of the water samples analyzed in the laboratory and measured on the field (6.27-8.7) and (6.62-7.7) respectively are mostly associated with the high bicarbonate of the water.

6.4.2 Temperature.

Water temperature is an important property that determines water suitability for human use, industrial applications and aquatic ecosystem functioning. Water temperature can affect the dissolved oxygen content, an important water characteristic that strongly affects many aquatic organisms. The temperature of water is controlled primarily by climate.

A number of parameters such as turbidity, color, odor, etc are affected by temperature directly or indirectly. Temperature also affects PH, electrical conductivity, the rate of chemical reaction as well as the concentration of the reactants and the products, and solubility of gases in the water.

In the study area the water temperature of the samples ranges from 15.5c^o to 24.7c^o on the field. In general, the temperatures of the water samples show progressive increase from North to south in the direction of flow paths. This increase of temperature indicates the regional flow system in the mentioned direction.

6.4.3. Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

The term TDS describes all solids (usually mineral salts) that are dissolved in water. The TDS is usually measured in mg/l. Water naturally contains a number of different dissolved in organic constituents. The major cations are calcium, magnesium, sodium and potassium: the major anions are chloride, sulfate, carbonate, and bicarbonate. Although not in ionic form, silica can also be a major constituent. These major constituents constitute the bulk of the mineral matter contributing to total dissolved solids. In addition there may be minor constituents present, including iron, manganese, fluoride, nitrate, strontium and boron. Table 6.1 gives a classification scheme for water based on the total dissolved solids (Fetter, 1994).

The presence of these chemical constituents gives water the ability to conduct electricity. Thus, the electrical conductivity (EC) of water is an indirect measure of its dissolved constituents. In practice, EC is often expressed in terms of mill siemens (ms) and micro siemens. The TDS and the EC are in a close connection. The more salts are dissolved in the water; the higher is the value of the electric conductivity. EC does not give specific in formation about the chemical species present in water, but it gives a determination of TDS, which is an acceptable indicator for water quality.

In calculating approximate dissolved solids values from EC the relation ship most commonly used is KA=S where A=0.59, K=specific conductance in mhos/cm, and S is dissolved solids in mg/L (Ham, 1992).

TABLE 6.1- Classification of water based on total dissolved solids.

Class	TDS(mg/2)
Fresh	0-1,000
Brackish	1,000-10,000
saline	10,000-100,000
Brine	>100,000

All water samples collected from the study area have a TDS value of less than 1000 mg/L. Hence, they are all fresh water even though they show a progress increase along the flow path.

6.4.4 Major cations and anions.

The major cations and anions that have been analyzed for the collected samples are calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, and chloride.

Cations

In the majority of the samples the dominant cation is calcium. The concentration varies from 15 mg/L up to 88 mg/L. The higher value of calcium is observed for sample taken from Holeta River south of Holeta Genet town (HR3). And the lower value is observed for sample taken from springs at the foot of wachacha mountain range. The higher calcium can be derived from the weathering of the plagioclase feldspar and pyroxene mineral groups that are the rock forming minerals of basalt. Sodium is the second highest cation in some samples particularly for those shallow wells and sprigs taken at the foot of wacacha-menagesha mountain ranges, suggesting the litho logy form which they emerge is relatively acidic rock (Trachyte). Human activates can also have a significant influence on the concentration of sodium in surface water and ground water. For this effect the reuse of water for irrigation commonly leaves a residual that is much higher in sodium concentration than was the original water. This has been confirmed from the deep well drilled at the center of Tsedey farmig PLC, which is the oldest irrigation practice in the study area in reusing of water for irrigation and consequently in much higher sodium concentration from samples collected for physicochemical analysis (69 mg/ L).

Another major cation is magnesium. Its value varies from 2.4 mg/L (for Holeta sallow no2) to 33.4 mg/L (for sample taken from HR1). Magnesium in the area is possibly derived from the weathering of ferromagnesian minerals such as olivine, biotite, hornblende and augite.

Anions

The predominant major anions in all the analyzed samples are bicarbonate. It varies from 36.6 mg/L for Holeta Bore hole (HBH2) to 280 mg/L for Holeta Hand Dug well seven (HHDW7). Most bicarbonate ions in ground water are derived from the carbon dioxide from the atmosphere, carbon dioxide in the soil, and the solution of the carbonated rocks, Davis (19966). The high bicarbonate content in the HHDW7 could be from the carbon dioxide from the atmosphere and co_2 in the soil as most of the shallow wells and springs in the area have more or less similar bicarbonate content.

Carbonate and chloride contents are significant in some samples even though they are much lower than objectionable amount. However sulfate content is very low in almost all of the samples collected.

6.4.5 Minor ions.

All the ions other than those mentioned under the major ions obtained from the results of chemical analysis of the water sample, such as fluoride, Nitrate, iron, and manganese are considered as minor ions.

Both surface and ground water in the area generally shows lower concentration of the mentioned minor ions. However nitrated concentration in same samples are relatively significant though it is below the maximum permissible contaminant level (MPCL), which according to WHO (1984) drinking water quality standard is 50 mg 12.

The relatively higher No_3 value (22.44 mg/L) observed in some sallow wells and springs in the study area is attributed to the agricultural practices. Most shallow wells and sprigs are located at a down stream of extensively cultivated farmland. In this case both the synthetic fertilizers and the manures should have their own contribution as people use both in up grading the soil fertility of their farm land in the area.

6.4.6 Other chemical parameters

Hardness

The term “hardness” may be one of the oldest words in use to describe a property of water. Ever since the use of soap become prevalent, people noticed that, depending on the water source, different amount of soap were needed to produce suds. Water requiring more soap was culled hard water: that is, suds were hard to produce. Rain water, on the other, hand, required

Hardness in water is caused primarily by calcium and magnesium cations, although some heavy metals such as iron and manganese also consume soap. Hardness of water may be divided in to two types, carbonate and non carbonate. Carbonate hardness includes that portion of the calcium and magnesium that combines with bicarbonate and the small amount of carbonate present. This was once called temporary hardness because it can be removed by boiling, which precipitates calcium and magnesium carbonate and sulfate minerals. Hardness is usually expressed in terms of calcium carbonate.

None carbonate hardeners is the difference between total hardness and carbonate hardness. None carbonate hardness can not be removed by boiling and thus termed as permanent hardness.

According to WHO (1984), the degree of hardness of drinking water can be classified in terms of its equivalent ca co_3 concentration. Water is said to be soft, medium hard, hard and very hard when the value in hardness is 0-60, 60-120, 120-180 and greater than 180 mg/l respectively.

But it should be realized that there exist different ranges of values for the classification of water based on hardness. Accordingly water that is considered to be soft by one classification criterion can be of a medium hard in another.

As has been observed from the results of the chemical analysis, the water in the area have a total hardness of greater than 65 mg/L. The highest, 336 mg/L is obtained for HR3. Generally the ground water of the study area varies from medium hard to very hard based on the above classification.

Among the water samples collected in the catchement the lowest hardness value was found in ground water. This is due to parts of the bicarbonate changes to carbonate which then reacts with calcium and magnesium ions, resulting in ca and mg carbonate scale (Driscol, 1995).

For some of the collected samples, total alkalinity has also been determined. Alkalinity is caused by $co_{3,}$ HCo_3, OH anions. The predominance one over the other depends on PH. between PH 4.5 and 8.2, it is dominantly caused by HCO_3; above PH 9.0, OH constitute a significant component; and below PH 4.5, HCO_3 is changed to $H_2CO_{3.}$ For most of the analyzed samples, the total alkalinity is similar with the bicarbonate anion indicating that it is mostly caused by bicarbonate; hence, even one may call it as bicarbonate alkalinity.

6.5 Presentation of Results of chemical Analyses.

The tabular presentation of chemical data is an ambiguous to understand and interpret, especially, if there are many samples. Hence, there exist various methods of graphical presentation of chemical analysis of water. The graph facilitates for easy understanding, interpretation, comparison and also classification of water samples. They can be either a single sample diagram or many samples diagram. Some of the common graphical methods of presenting hydro chemical data that will be discussed here are the piper tri-linear diagram, the stiff pattern diagram, and scholler semi logarithmic diagram. All the three methods consider mainly the major cations (Ca^2, mg^{2+}, and $Na^+ + K^+$) and major anions (HCO_3, CO_3^{2-}, Cl^- and SO_4^{2-}). Of the three graphical methods, the piper trilinear diagram is most widely used for interpretation and classification of water, and will be discussed as follows.

PIPER TRI Linear Diagram.

The concentration in meq/l of major cations and anions from different water points analyzed in the area are plotted in the piper diagram (Fig 6.1) . From the diagram four kind of water can be identified: $Ca\text{-}Mg\text{-}HCO_{3,}$ $Ca\text{-}Na\text{-}HCO_3$,$Ca\text{-}HCO_3$ and $Na\text{-}Ca\text{-}HCO_3$ .The $Ca\text{-}Mg\text{-}HCO_3$ dominate the area.

Most of the bore hole water belongs to the $Ca\text{-}Mg\text{-}HCO_3$ and $Ca\text{-}HCO_3$ plots, where the percentage of carbonate and bicarbonate is constant and the cation calcium and magnesium show more or less equally abundant. The relative abundance of the ions can be related to geochemical reactions taken place as the water comes in contact with different minerals.

The plots of spring water points in the tri-liner diagram shows the dominance of bicarbonate ions,with variation in composation of Na and Ca.The resalting water type also vary from $Na\text{-}Ca\text{-}HCO_3$ to $Ca\text{-}Na\text{-}HCO_3$ .The relative aboundance of the cations indicates the dissollution of minerals that constitute either basic or acidic volcanic rocks.

6.6 Water Quality Assessment

Water quality guideline is established to protect the health of users and thus eliminate adverse effect or reduce to a minimum of water constituents harmful to health and well-being of the users. A guideline value represents the level or concentration of constituents that ensure aesthetically pleasing water that does not result in any significant risk to the consumers. In this context, quality refers to fitness for purpose. Hence, for practical purpose, it is very useful to assess and evaluate the quality of water resources of the area in concern for various purposes. Hence, for practical purpose, it is very useful to assess and evaluate the quality of water resources of the area in concern for various purposes. Basically, it is difficult to establish universally accepted single water quality standard but it varies from place to place and country to country.

Water guide line for drinking purpose is established taking into consideration the socioeconomic status, availabilities of alternative water resources, geographical location

(Climate condition) and dietary condition of the people (Fetter, 1994). Although the guideline values describe a quality of water that is acceptable for lifelong consumption, the guidelines should not be regarded as implying that the quality of water is degraded to the recommended level.

One of the main objectives of hydro chemical characterization of waters of the study area is to evaluate the quality of the water resources. Therefore, in the assessment of water quality, it needs to identify the purpose for which the quality is referred to. Accordingly, water quality for drinking is different from that for irrigation and industry. The quality of water in Holeta River catchement is assessed for two principal purposes: drinking and agriculture.

6.6.1 Drinking water quality

Water qualities for purpose mentioned above are evaluated with comparison to the standards.

Drinking water quality guidelines provide abase for decision-making:

- Approval of new water supply sources
- Watershed protection
- Disinfection of treatment plants, detection of sources of pollution
- Regulation of chemical substances
- Cleaning of water storage facilities

In this particular water quality assessment, two water quality standards; WHO, and EU; has been used for comparison purpose with the water quality of the study area (Table 6.2).

Table 6.2:- Drinking water quality standard

Constituents	WHO	EU	Study area
P^H	7	7	6.27-8.7
Color (TU)	15	20	Clear
TDS (mg/1)	1000	500	70-232
Total alkalinity as $CaCO_3$,(mg/l)	500	-	95-280
Total Hardness as $CaCO_3$,(mg/g	300	-	65-336
Calcium hardness as $CaCO_3$,(mg/l)	300	-	-
Na (mg/l)	200	150	2.2-69
K(mg/l)	10	-	0.3-4.2
Ca(mg/l)	100	-	15-72
Mg(mg/l)	30	-	2.4-37.44
Cl(mg/l)	250	25	1.92-70
SO_4(mg/l)	250	250	0.53-4
F(mg/l)	2.5	-	0.06-0.5
No_3(mg/l)	50	50	2.2-22.4
Mn(mg/l)	0.1	0.05	0.001-0.8
Fe(mg/l)	0.3	0.2	0.01-0.2

From the above table ground water in the study area has constituents with in the range of WHO and EU water quality standards. Thus the area has fresh ground water that is very favorable for drinking purpose that could be used directly with out the need for chemical purification.

6.6.2 Agricultural water quality

Water quality, soil types, and cropping practices all play a role in successful irrigation. Good quality water permits maximum yields consistent with proper soil and water management. Study of soil types determines the infiltration rates that can be expected for certain soils, thereby providing some guides to the amount of leaching of mineral salts that can be anticipated; leaching is essential to reduction of salinity in top soils. Equally important, the tolerance for certain elements must be determined before specific crops can be selected.

Water quality problems in irrigation include salinity and toxicity. Excessive salinity occurs when there is an accumulation of salts in top soils. These salts can affect crop production because crop roots, especially in the upper root zone, have great difficulty extracting enough water and nutrients from saline solution. Soil permeability can be reduced significantly by the buildup of salts in the soil, zone. Consequently, crop production is limited because sufficient water can not reach the root zone. Toxicity is also a problem in maintaining good yields. Some waters contain high enough concentrations of certain elements to retard or even eliminate the growth of some plants. Boron, chlorides, and sodium are common toxic substances.

Sodium has far –reaching effects on soils. Most sodium in natural water originates with the release of soluble products during the weathering of plagioclase feldspars (Davis and Dewiest, 1966). In addition, minor amounts of sodium may come from the mineral halite (table salt).

Of particular consequence is the ratio of sodium to calcium and magnesium. When sodium-rich water is applied to soil, some of the sodium is taken up by clay; the clay gives up calcium and magnesium in exchange. This reaction, called Base Exchange, alters the physical characteristics of soil and can even lead to growth retardation. Clay that takes up sodium becomes sticky and slick when wet and has low permeability. When dry, the clay shrinks in to hard clods that are difficult to cultivate. Even worse, high concentrations of sodium salts can produce alkali soils in which little or no vegetation can grow. On the other hand, when the same clay carries excess calcium or magnesium ions, it tills easily and has good permeability.

If irrigation water contains calcium and magnesium ions sufficient to equal or exceed the sodium ions, enough calcium and magnesium is retained on clay particles to maintain good tilth and permeability. These waters serve well for irrigation, even though the total mineral content may be quite high.

The importance of sodium led to the adoption of a method to measure the effect of sodium ions. In 1954 the United States Salinity Laboratory proposed that the sodium effect be calculated by the sodium adsorption ratio (SAR method). The SAR is calculated from the following equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Where sodium calcium, and magnesium are in mill equivalents per liter from the water analysis.

According to Todd (1980 and references there in), the water quality evaluation for irrigation based on SAR and EC are as follows.

Water class	Excellent	Good	Fair	Poor
SAR	< 10	10-18	18-26	>26

Water class	Excellent	Good	Permissible	Doubtful	Unsuitable

Ec(μs/cm)	<250	250-750	750-2000	2000-3000	>3000

In order to evaluate water quality for irrigation from salinity and sodium hazard point of view for the study area, the parameters have been measured and calculated as shown in table 6.3. Accordingly, all water samples show low sodium hazard, and they are all below 10, which is of an excellent quality. And from salinity point of view, the quality varies from excellent to good.

Table.6.3 SAR and Ec for water samples of Holeta catchement.

Sample code	HBH1	HBH2	HBH3	HBH4	HBH9	HBH11	HBH19	HHDW7	HHDW3
Ec ((μs/cm)	229	208	284	277	192	342	253	280	140
SAR	1.09	0.99	0.29	0.33	0.96	0.32	0.45	0.45	2.49

Sample code	HSP2	HSP3	HSP4	HSP 5	HSP6	HSW2	HSW4	HSW6	HSW7
Ec ((μs/cm)	148	260	204	162	260	168	306	226	444
SAR	0.44	0.83	1.52	0.38	1.37	1.23	0.38	0.48	1.33

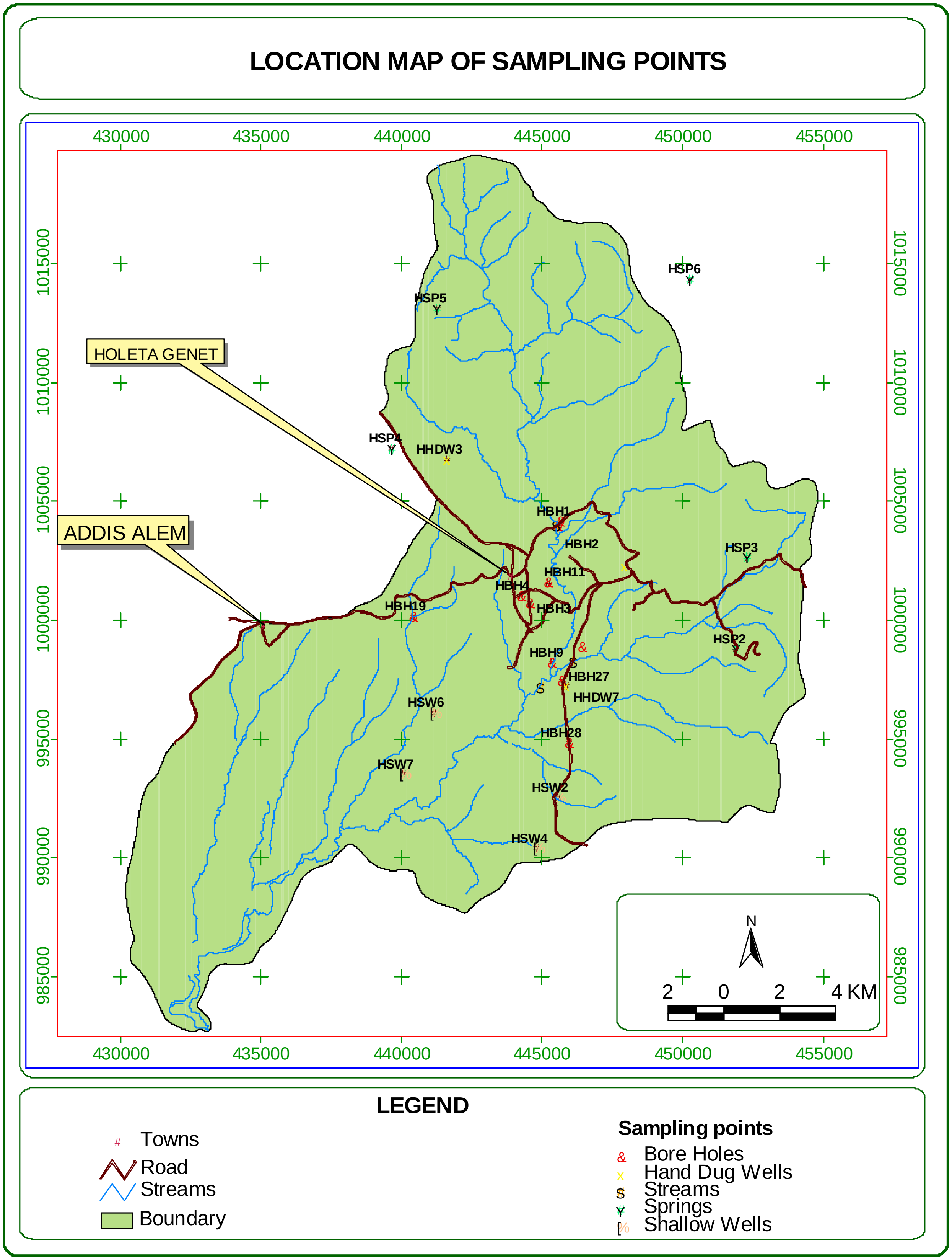


Figure 6.2 Sampling Points Map

Chapter Seven: - Conclusion and recommendation

7.1 Conclusion

Indirect investigations from field observations of the hydrography, cause of springs, type of vegetation cover, degree of fracturing of the rocks, in addition to direct data on boreholes, geologic logs, pumping tests, hydrochemistry, river flows, etc, revel that the water resource potential of the study area both surface and subsurface are enormous.

The study area is located in upper Awash drainage basin, and it is bounded to the north by Abay drainage basin, to the east and west by Akaki and Berga river catchments of the same upper Awash drainage basins respectively. The area comprises rugged mountains dissected by streams at its northern and eastern and flat lands and plains at its central, western and southern. The general slope of the land is two ward the south. It is characterized by denderitic and parallel drainage pattern with a fourth order stream net work.

The amount of recharge from rainfall to ground water was estimated from a hydrograph base flow separation soft ware program mentioned in the previous chapter (under hydro meteorology) so that the total annual ground water reserves replenished in the catchement is known. It is estimated that the annual recharge to ground water from rainfall is about 24% of the mean annual rainfall of the catchement. In other words the annual recharge to ground water is estimated to be about 160Mm^3/year. The estimation takes the higher figure of the recharge estimated by Testaye chernet (1993) indicating that the catchement has high infiltration capacity (depending on the permeability of the rocks, topographic conditions, soil type, vegetation cover and high annual precipitation, etc).

There are a number of hydro stratigraphic units in the catchement. There is a surfical aquifer system, an upper confining unit, the upper weathered and fractured aquifer, a middle confining unit, the lower weathered and fractured basalt and scoracious basalt aquifer, and a lower confining unit. In other words there exists multi layer aquifer system in the area. They are the upper unconfined aquifer and two confined aquifers at different depths (three layers).

The Holeta river catchement is reach in both shallow and deep ground water. The sallow ground water is attributed to the presence of shallow alluvial sediments and alternative pervious and impervious layers and weathered top part of the basaltic and Trachytic rocks and the deep ground water is because of deep weathered and fractured basaltic rocks and the regional fractures connecting the valley to the recharge areas (mountainous areas). These have been confirmed by the presence of several and dug wells and springs at the northern and eastern part of the catchement, and several productive deep wells in the central part.

Hence from the field hydro geological study of the area, geophysical data investigations and the well log of several wells drilled in the catchement the main aquifers are identified they are quaternary alluvial sediments, Buried valley deposits, fissured and fractured basalt, and scoracious basalt.

Most of the wells drilled in the catchement reveal that they are not pentrating to the full depth of the aquifer. Thus they are in partial penetration of the aquifer.

The Holeta catchement has two major recharge zones. The northern portion of the catchement is recharged in the out crop area of Fo'ata mountain range covered by Tarmaber Magezez formation, where the elevations are 3000 to 3200 meter above sea level. Recharge to the aquifer also occurs in a zone found east of the catchement (Wacacha-Menagesha mountain range). This is an area of high topography with relatively receiving high rain fall.

Water flows from the recharge areas, following the regional hydraulic gradient, and discharge to the potential sites (valley bottoms). There is also lesser amount of recharge from down ward leakage through the vast area of the catchement.

The hydrogeologic characteristics of the study area aquifer materials vary widely because of the differing extent of weathering and fracturing distribution of the volcanic rocks. The yield varies from less than 1.5 l/s to more than 14 l/sec and averages 8 l/sec. Transmissivity varies from 30 to 2156 m^2/day and averages 382m^2/day. Hydraulic conductivity varies from 1.02 to 90 m/day and averages 20 m/d specific capacity varies from 0.08 to 18.67 l/s/m and averages 2.5 l/s/m.

The predominant water type in the study area is a bicarbonate type. The Ca-Mg-HCO_3 dominates the area, followed by Ca-Na-HCO_3. In addition to these there are also Na-Ca-HCO_3 and Ca-HCO_3 types indicated by the analysis in the area.

Ground water of the area has low content of Total Dissolved Solids (TDS). The content of TDS is between 100 and 500 mg/l.

Concerning water quality, the basin has no any water sources having values of parameters above the permissible limit for water supply and irrigation. So far, there is no industry that can pollute both surface and ground water in the catchement.

7.2 Recommendation

- Most of aquifers of the catchement are partially pent rated. Thus to establish the depth of wells and aquifer thickness and consequently the actual yield and transmissivity of the aquifer of the study area drilling should penetrate to the full depth of the aquifer thickness. In most cases to the depth of 250 meters.

- As has been observed from the drilled wells high yield of the boreholes are related to the presence of structures. Hence careful fracture trace analysis is deeply required rather than simply locating well sites only at the low laying areas.
- The current demand of water in the catchement is highly increasing and wells are concentrated around the Holeta Genet town. As most of aquifers of the catchement are confined and semi confined cone of depression extends fast, hence well interference would occur. There fore careful well site locations are crucial to minimize the likely occurrence of this interference.
- Regular monitoring of the water levels should be conducted, as the effects of climatic variations and ground water drafting could be reflected in the water level data
- To carry out further studies and researches data availability and data quality is a pre requisite. The current situation of data establishment and organization in the country in general and the study area in particular would not inciate researchers and professionals to carry out further study and researches. There fore this crucial and important isuses of Hydrological and Hydrological data's and others which are either purposely generated or which result from drilling activities conducted for different developmental works should be collected and organized properly by the concerned organization so that the data can be available for valuable studies and research.
- In general, the water resource potential of the area for domestics industrial and agricultural is evidently enormous. One of the basic requirements for a wide planning and utilization of the water resources is the promotion of hydro geological and hydrological studies and research. The water resources development should be coupled with environmental protection and it should be also preceded a companied by continuous studies.

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Annex-1 Climatological datas

Element: Monthly Rainfall Inmm
Region: SHOA
Station TEJI

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1989	0.4	92.5	49.6	72.2	6.1	65.4	227.9	236.6	114.2	5.8	0.0	17.6	888.3
1990	0.0	149.6	74.5	79.1	30.4	101.7	251.1	210.6	81.3	11.8	0.0	0.0	990.1
1991	0.0	53.1	140.3	3.1	34.7	96.9	221.7	261.8	129.3	1.8	0.0	18.3	961.0
1992	43.7	60.1	61.3	87.1	76.4	124.3	122.8	235.4	89.5	56.3	4.6	1.5	963.0
1993	5.1	100.3	0.0	149.9	100.1	92.9	234.7	288.8	97.3	22.0	0.0	2.5	1093.6
1994	0.0	0.0	33.7	36.8	28.4	197.8	185.4	241.6	128.8	0.0	13.3	0.0	865.8
1995	0.0	41.0	18.2	98.2	65.7	66.1	223.8	179.4	46.5	1.3	0.0	46.6	786.8
1996	53.3	2.3	99.8	95.0	71.9	113.2	219.3	208.3	72.5	3.6	1.9	0.0	941.1
1997	12.7	0.0	28.7	131.9	29.3	96.1	187.9	143.9	63.7	48.1	48.6	0.0	790.9
1998	89.8	52.4	29.7	70.6	68.2	135.7	310.2	232.1	87.2	64.4	0.0	0.0	1140.3
1999	4.9	0.0	44.2	5.8	45.2	97.5	242.4	218.0	98.2	76.5	0.0	0.0	832.7
2000	0.0	0.0	13.9	94.0	74.3	94.4	186.6	212.5	148.7	10.8	29.3	1.6	866.1
2001	2.3	1.0	95.5	14.9	164.7	182.9	214.5	120.3	64.6	3.3	7.7	0.0	871.7
2002	14.3	10.0	63.1	38.0	45.7	139.8	210.5	214.3	48.9	0.0	0.0	26.5	811.1
2003	29.3	21.1	80.6	153.7	48.0	158.0	229.8	267.4	84.3	0.0	0.2	9.6	1082.0
Ave.	**17.1**	**38.9**	**55.5**	**75.4**	**59.3**	**117.5**	**217.9**	**218.1**	**90.3**	**20.4**	**7.0**	**8.3**	**925.6**

Element: Monthly Rainfall in mm
Region: Shoa
Station: Addis Ababa Bole

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1989	3.4	33.7	58.4	143.3	0.0	88.1	218.1	318.6	150.0	36.8	0.0	7.9	1058.3
1990	3.2	161.1	60.4	144.5	25.2	48.3	204.2	413.4	143.0	46.1	2.1	0	1251.5
1991	0.2	29.6	134.1	15.0	7.7	107.5	279.4	287.9	123.1	4.4	2.1	0.0	991.0
1992	14.5	28.0	35.0	58.6	55.0	82.2	254.8	223.3	157.0	64.4	2.2	0.4	975.4
1993	11.7	52.1	11.6	168.3	91.5	157.2	209.5	291.7	190.1	24.1	0.0	0.0	1207.8
1994	0.0	0.0	52.9	70.0	31.7	112.9	242.2	199.3	100.9	0.5	11.0	0.0	821.4
1995	0.0	81.3	73.3	140.3	95.9	78.2	165.1	256.9	97.0	0.0	0.0	28.6	1016.6
1996	20.5	5.8	126.2	95.4	128.1	289.7	346.3	312.7	211.4	0.2	0.4	0.0	1536.7
1997	29.1	0.0	22.1	66.8	44.8	128.0	257.0	160.7	94.7	58.6	15.3	0.0	877.1
1998	66.6	40.0	43.8	99.8	197.7	153.4	270.7	236.8	173.4	139.4	0.0	0.0	1421.6
1999	4.4	0.0	35.0	17.8	30.5	104.6	294.0	270.5	62.8	127.1	0.0	0.0	946.7
2000	0.0	0.0	17.6	109.7	95.2	102.1	192.9	221.9	157.5	19.6	7.5	0	924.0
2001	0.0	10.3	165.3	14.8	106.7	163.0	274.4	179.1	107.3	10.6	0.0	0	1031.5
2002	30.6	25.9	79.4	36.6	49.6	109.0	213.9	233.6	72.6	0.5	0.0	32.8	884.5
2003	4.8	34.1	48.9	121.9	33.0	128.0	226.4	238.4	130.2	4.6	0.0	33.3	1003.6
Ave.	**12.6**	**33.5**	**64.3**	**86.9**	**66.2**	**123.5**	**243.3**	**256.3**	**131.4**	**35.8**	**2.7**	**6.9**	**1063.2**

Element: Monthly Rainfall in mm
Region: Shoa
Station: HOLETA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1962	17.0	41.3	50.1	0.0	70.9	84.6	152.1	107.6	184.3	29.9	45.8	31.7	815.3
1963	45.2	67.0	86.0	181.9	121.3	248.4	280.2	187.0	93.4	0.0	9.2	67.0	1386.6
1964	0.0	7.0	37.9	69.1	75.9	280.8	373.8	329.4	263.7	49.3	0.0	28.6	1515.5
1965	31.1	7.3	64.1	49.9	63.4	160.9	271.9	396.4	190.4	8.3	22.9	0.0	1266.6
1966	7.7	65.5	97.8	155.3	2.5	65.7	295.0	387.0	491.0	78.9	26.8	0.0	1673.2
1969	44.4	435.7	64.7	42.4	68.5	84.1	204.0	285.9	139.2	0.0	14.9	0.0	1383.8
1970	34.2	69.3	30.7	41.7	7.7	139.6	83.6	255.5	392.0	64.4	0.0	13.1	1131.8
1971	30.2	0.0	155.2	160.0	215.0	335.5	415.2	628.7	314.0	29.2	12.1	0.0	2295.1
1972	43.3	190.2	126.9	334.7	110.9	222.0	520.6	529.8	256.0	0.0	44.3	55.4	2434.1
1973	15.3	0.0	2.1	82.6	160.1	297.5	522.1	536.1	335.0	60.3	0.0	12.0	2023.1
1974	0.0	24.2	137.2	68.7	131.3	111.0	248.8	151.2	156.6	4.3	8.9	8.0	1050.2
1975	0.0	5.2	20.2	79.4	68.4	124.2	271.9	270.8	216.5	13.9	0.0	0.0	1070.5
1976	5.9	9.8	58.3	67.4	63.0	118.0	236.1	346.3	172.1	18.4	11.4	10.0	1116.7
1977	185.9	45.0	28.2	41.9	80.1	444.6	778.7	821.0	247.5	25.2	154.5	15.3	2867.9
1978	0.0	44.5	204.1	60.9	62.5	206.9	304.1	562.6	217.1	53.2	0.0	0.0	1715.9
1979	46.6	78.7	56.5	93.6	61.5	110.4	224.8	264.5	145.4	13.2	0.0	14.5	1109.7
1981	34.3	64.5	111.3	107.7	122.0	145.8	449.5	663.5	572.0	14.4	0.0	14.5	2299.5
1982	61.7	61.9	124.3	83.4	192.0	173.4	341.2	256.8	167.6	53.1	51.5	39.8	1606.7
1983	19.9	49.9	90.2	126.1	219.1	87.5	241.2	284.1	92.6	23.8	3.9	22.7	1261.0
1984	0.0	0.0	41.8	8.5	46.6	178.5	260.3	221.8	106.1	0.0	0.6	13.1	877.3
1985	15.2	0.0	47.7	49.1	48.5	45.6	257.6	281.9	104.6	21.1	4.1	0.0	875.4
1986	0.0	51.2	88.0	139.1	88.5	160.4	243.9	279.4	142.0	11.9	0.0	0.0	1204.4
1987	2.4	77.3	112.1	95.7	136.5	87.1	182.0	261.8	107.6	19.0	1.4	27.4	1110.3
1988	10.3	80.7	7.8	89.6	21.1	108.0	291.6	263.7	239.9	31.9	0.0	0.2	1144.8
1989	7.1	86.9	78.0	69.8	8.3	74.9	240.7	279.3	117.5	3.0	0.3	21.6	987.4
1990	0.5	163.5	34.9	95.4	55.5	131.8	242.4	338.2	165.5	8.0	0.0	0.9	1236.6
1991	21.1	74.8	118.0	21.3	37.2	89.9	232.1	229.0	172.5	2.6	0.3	5.8	1004.6
1992	57.4	33.5	58.8	95.0	34.6	115.4	190.9	312.6	135.1	36.3	0.6	X	1070.2
1993	18.2	83.8	3.8	127.0	59.3	103.1	210.0	271.6	214.3	26.5	0.0	0.0	1117.6
1994	0.0	2.3	86.7	85.9	25.7	107.3	216.4	203.3	149.7	0.0	34.8	0.0	912.1
1995	X	84.6	41.9	123.8	81.3	91.6	196.9	264.5	82.1	15.5	0.0	34.0	1016.2
1996	X	8.5	94.1	58.4	55.4	183.8	213.9	236.4	120.7	5.3	X	X	976.5
1997	15.3	0.0	21.1	95.4	13.5	95.0	233.2	193.1	40.5	46.5	23.6	X	777.2
Ave.	**24.8**	**61.0**	**72.1**	**90.9**	**79.0**	**151.9**	**285.7**	**330.3**	**198.3**	**23.3**	**14.7**	**14.5**	**1346.7**

Element; Monthly Rainfall in mm
Region; Shoa
Station; Enchiny

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1983	8.5	52.0	71.0	97.8	253.6	119.1	312.7	338.9	140.6	27.6	45.7	4.3	1471.8
1984		0.0	0.0	0.0	0.0	35.4	188.2	110.8	262.7	0.2	0.0	0.0	597.3
1985	0.0	19.4	0.0	0.0	0.0	159.3	171.5	68.3	59.5	38.4	12.2	17.7	546.3
1986	0.0	11.1	x	x	x	x	x	x	x	x	39.8	11.6	62.5
1987	3.6	24.3	234.0	95.2	164.4	124.0	161.0	207.3	68.5	17.6	0.0	x	1099.9
1988	x	x	x	x	x	x	x	x	x	x	x	x	
1989	38.9	105.0	14.4	75.8	19.2	129.4	250.5	298.0	121.2	54.9	x	x	1107.3
1990	x	x	x	x	x	x	x	x	x	x	x	x	
1991	48.4	40.3	103.0	24.9	28.1	116.2	316.8	265.1	108.9	43.5	8.4	27.5	1131.1
1992	55.8	47.2	64.7	143.5	75.5	150.8	207.6	267.1	142.6	69.2	50.4	7.0	1281.4
1993	1.9	53.0	31.6	200.6	79.3	146.3	270.4	235.7	269.6	70.0	1.5	5.7	1365.6
1994	6.9	8.1	100.3	34.2	70.4	231.2	330.3	222.7	148.7	12.7	11.6	0.0	1177.1
1995	0.0	12.2	73.7	134.4		91.5	338.8	233.3	117.2	10.0	12.7	59.1	1082.9
1996	82.9	21.8	163.6	93.8	99.0	191.7	310.3	341.3	122.2	21.9	37.1	3.8	1489.4
1997	49.3	0.0	25.6	100.0	89.0	123.3	306.1	218.1	98.7	151.2	101.4	16.3	1279.0
1998	46.0	19.4	66.2	18.4	119.5	195.0	348.2	304.4	170.0	113.0	13.0	0.0	1413.1
1999	16.7	9.3	22.6	22.5	41.0	90.4	274.7	319.1	88.8	136.5	1.3	1.8	1024.7
2000	0.0	0.0	26.1	182.2	77.7	122.8	346.3	263.1	111.9	55.8	62.5	4.5	1252.9
2001	9.9	38.5	195.0	48.4	126.1	171.1	308.9	207.0	121.2	38.5	3.4	8.6	1276.6
2002	62.3	5.5	121.1	32.0	20.6	163.1	222.6	305.1	154.2	0.0	0.0	53.2	1139.7
Ave.	**25.4**	**26.0**	**77.2**	**76.7**	**79.0**	**138.9**	**274.4**	**247.4**	**135.7**	**50.6**	**23.6**	**13.8**	**1168.6**

Element Monthly Total Rainfall in mm
Region SHOA
station SEBETA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1989	3.3	203.9	102.2	355.5	19.4	109.8	305.1	550.4	213.3	19.0	0.0	2.1	1884.0
1990	0.0	157.9	18.6	115.8	33.5	74.3	245.6	220.5	139.2	23.8	4.2	0.0	1033.4
1991	2.6	24.4	109.6	28.8	22.0	101.9	207.6	243.5	120.5	16.3	0.0	0.0	877.2
1992	41.4	51.3	46.4	41.3	70.6	92.9	x	x	251.1	119.9	11.7	6.9	733.5
1993	25.4	136.2	38.6	413.6	338.4	216.1	525.8	1089.0	295.6	52.4	0.0	0.0	3131.1
1994	0.0	0.0	135.7	102.1	147.4	220.1	427.7	316.7	114.7	0.0	15.5	0.0	1479.9
1995	x	x	x	x	x	69.1	530.4	314.9	103.8	7.0	0.0	18.8	1044.0
1996	26.0	0.0	111.7	63.2	281.0	341.1	404.6	431.8	130.6	0.0	0.2	0.0	1790.2
1997	30.0	0.0	33.2	53.5	11.7	274.7	196.5	197.2	50.9	0.0	61.7	0.0	909.4
1998	69.6	3.4	15.0	30.3	101.8	129.9	214.5	217.0	105.8	48.9	0.0	35.5	971.7
1999	0.0	23.3	48.2	14.0	56.8	114.3	217.0	220.8	77.8	102.1	1.1	1.3	876.7
2000	x	0.0	3.2	75.7	37.3	96.1	173.7	182.7	217.0	26.8	21.1	24.6	858.2
2001	0.0	x	158.0	11.1	156.4	114.7	281.3	163.7	64.6	20.5	0.0	0.0	970.3
2002	25.4	47.2	129.8	31.8	30.6	x	173.0	251.0	113.0	0.6	0.0	21.1	823.5
2003	3.0	5.8	52.6	76.4	13.6	122.7	279.9	327.4	118.2	1.2	0.0	39.2	1040.0
Ave.	**17.4**	**50.3**	**71.6**	**100.9**	**94.3**	**148.4**	**298.8**	**337.6**	**141.1**	**29.2**	**7.7**	**10.0**	**1307.3**

Element: Monthly Rainfall in mm
Region: Shoa
Station: Addis Alem

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	rly Ave.
1989	32.0	61.0	80.0	104.0	38.9	126.2	250.2	256.0	210.0	3.7	0.0	22.0	1184.0
1990	9.6	131.6	55.0	55.8	96.1	111.5	187.6	342.8	196.5	13.0	0.0	0.0	1199.5
1991	0.0	79.8	102.6	43.9	16.8	142.6	370.4	350.8	193.6	0.0	0.0	23.5	1324.0
1992	41.0	50.7	72.4	85.5	32.7	75.1	323.1	385.4	234.3	36.3	5.4	8.2	1350.1
1993	10.0	12.3	13.4	116.8	88.9	168.6	359.7	367.3	168.1	44.3	0.0	0.0	1349.4
1994	0.0	0.0	34.5	40.8	43.0	218.0	250.4	228.1	155.6	0.0	17.5	0.0	987.9
1995	0.0	39.5	47.1	144.9	92.2	244.6	392.5	352.3	136.8	6.4	0.0	15.6	1471.9
1996	46.1	7.9	107.1	70.1	160.4	163.2	371.9	326.6	123.0	6.2	0.0	2.2	1384.7
1997	21.5	0.0	17.6	70.1	23.7	88.1	243.1	164.1	86.1	58.8	79.2	0.0	852.3
1998	61.1	86.8	107.4	67.3	101.1	208.1	289.5	251.0	154.0	53.9	21.9	0.0	1402.1
1999	29.5	3.3	26.6	74.6	13.5	197.5	255.0	262.2	46.8	116.6	0.0	0.0	1025.6
2000	0.0	0.0	12.5	108.1	135.4	168.1	266.6	238.2	186.8	33.6	17.4	29.2	1195.9
2001	0.0	0.0	169.4	28.2	124.3	233.9	309.7	265.0	43.3	21.4	0.0	0.0	1195.2
2002	0.0	84.1	59.2	0.0	0.0	145.9	139.9	103.2	38.4	0.0	0.0	62.4	633.1
2003	0.0	65.8	109.6	84.1	0.0	173.1	226.0	232.1	165.3	11.0	6.6	4.0	1077.6
Ave.	**16.7**	**41.5**	**67.6**	**72.9**	**64.5**	**164.3**	**282.4**	**275.0**	**142.6**	**27.0**	**9.9**	**11.1**	**1175.6**

Element Monthly Temperature Maximum
Regio: SHOA
Station: Addis Ababa Bole

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1994	24.4	25.7	25.9	26.1	26.7	23.1	21.2	20.8	22.0	23.3	23.5	23.5	23.9
1995	24.2	24.5	25.1	23.9	25.2	23.8	21.0	21.5	22.3	23.8	24	23.9	23.6
1996	24.6	26.4	25.0	24.7	24.4	21.1	20.2	21.4	22.1	23.6	23.3	23.0	23.3
1997	23.4	25.2	26.0	24.5	26.8	24.9	21.7	21.9	23.3	23.1	x	24.2	24.1
1998	24.3	25.0	25.4	26.6	25.2	24.7	22.3	21.9	21.9	22.2	22.8	23.2	23.8
1999	24.7	26.7	25.5	27.6	26.9	24.6	20.5	20.6	22.1	21.9	22.7	22.7	23.9
2000	24.3	25.4	27.3	25.6	25.4	23.0	21.5	20.5	21.0	22.5	22.9	23.8	23.6
2001	24.0	25.2	24.0	26.0	24.3	22.4	21.4	20.2	22.9	24.6	24.2	24.1	23.6
2002	24.1	26.2	25.6	26.7	27.0	25.0	23.0	21.7	22.4	24.3	24.2	23.7	24.5
2003	24.3	26.2	26.3	25.1	26.8	24.5	21.2	20.8	21.9	23.7	23.6	23.3	24.0
Ave.	**24.2**	**25.7**	**25.6**	**25.7**	**25.9**	**23.7**	**21.4**	**21.1**	**22.2**	**23.3**	**23.5**	**23.5**	**23.8**

Element Monthly minimum Temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YeaAve.
1994	5.0	7.4	10.6	10.8	10.9	11.9	11.6	11.2	9.6	10.0	6.6	4.9	9.2
1995	5.2	9.5	10.5	12.0	11.1	10.2	11.4	11.5	10.0	8.3	6.3	7.9	9.5
1996	9.2	7.8	11.1	10.5	11.1	11.3	11.1	11.0	9.8	7.1	6.3	5.7	9.3
1997	9.3	6.1	10.6	11.2	11.1	11.7	11.3	11.5	10.6	10.0	x	6.6	10.0
1998	9.8	11.7	12.0	12.1	12.6	11.2	11.7	11.5	11.0	9.2	4.7	3.4	10.1
1999	6.7	7.3	10.4	10.4	10.5	10.3	10.5	10.4	9.9	9.2	5.4	5.6	8.9
2000	5.5	5.8	10.2	12.3	11.1	10.1	11.0	10.7	10.6	8.9	6.9	8.7	9.3
2001	6.7	7.8	11.0	10.9	11.3	10.4	11.1	11.6	9.8	8.2	5.9	6.4	9.3
2002	7.6	8.6	10.8	11.4	12.0	11.0	11.2	10.8	10.5	8.9	6.5	9.5	9.9
2003	8.5	9.8	10.3	11.8	11.4	10.9	11.5	11.9	11.4	8.2	7.4	6	9.9
Ave.	**7.4**	**8.2**	**10.8**	**11.3**	**11.3**	**10.9**	**11.2**	**11.2**	**10.3**	**8.8**	**6.2**	**6.5**	**9.5**

Element Monthly Maximum Temperature In0c

Region: SHOA

Satation Holwr r I.A.R

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearl Ave.
1988	22.9	23.7	26.0	24.4	25.5	22.1	18.7	19.4	19.9	28.2	22.0	22.3	
1989	22.4	22.2	23.2	21.6	24.1	22.6	19.4	19.1	20.0	21.3	22.5	22.1	21.7
1990	23.0	x	22.8	23.1	24.6	22.2	19.8	19.5	20.1	21.9	22.8	23.1	22.1
1991	24.2	23.9	23.3	24.4	25.9	23.8	19.5	19.8	20.9	22.2	20.9	22.7	22.6
1992	22.4	22.6	24.8	24.6	24.3	22.5	19.4	18.9	19.7	21.0	21.7	x	22.0
1993	23.0	22.0	25.1	22.4	22.9	21.6	19.6	19.4	19.3	21.5	22.4	23.0	21.9
1994	24.1	25.1	24.4	24.1	25.1	21.4	19.0	19.3	20.6	22.3	22.5	23.1	22.58
1995	24.0	24.4	24.5	22.6	24.0	23.6	19.4	19.7	20.6	22.6	23.4	22.8	22.6
1996	x	25.1	23.9	23.2	23.5	20.7	19.9	19.4	20.4	22.3	x	x	22.0
1997	22.9	24.7	25.6	23.6	25.3	23.4	20.2	20.3	22.1	22.4	22.5	x	23.0
Ave.	**23.2**	**23.7**	**24.4**	**23.4**	**24.5**	**22.4**	**19.5**	**19.5**	**20.4**	**22.6**	**22.3**	**22.7**	**22.4**

Element Monthly Minimum Temperature In0c

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearl Ave.
1988	4.7	8.5	5.6	8.8	6.9	8.3	10.4	9.9	8.7	5.0	0.2	0.3	6.4
1989	2.1	5.1	6.5	8.8	6.4	7.3	9.2	9.1	8.0	4.4	1.9	5.9	6.2
1990	2.8	x	7.2	8.5	7.7	7.3	9.3	9.2	8.5	4.3	3.5	0.7	6.3
1991	4.6	7.2	8.5	7.9	7.6	8.4	10.1	9.6	7.9	3.4	1.5	2.6	6.6
1992	5.7	8.6	8.2	8.2	8.0	7.0	9.0	10.6	7.5	5.9	3.1	x	7.4
1993	5.6	7.4	4.4	9.6	8.3	8.3	9.1	8.6	7.7	5.8	1.8	1.0	6.5
1994	1.6	3.9	8.3	7.9	7.3	8.1	9.9	9.1	6.6	2.5	2.6	0.5	5.7
1995	1.3	5.8	7.0	9.8	7.6	6.5	8.6	9.1	6.3	3.4	1.8	3.3	5.9
1996	x	3.5	7.8	7.5	7.3	8.2	8.7	8.3	7.1	3.5	x	x	6.9
1997	5.6	1.1	7.3	8.1	6.6	8.4	8.4	8.4	7.2	6.4	5.6	x	6.6
Ave.	**3.8**	**5.7**	**7.1**	**8.5**	**7.4**	**7.8**	**9.3**	**9.2**	**7.6**	**4.5**	**2.4**	**2.0**	**6.3**

Elemen: Monthly Maximum Temperatu
Region: SHOA

Station: AddisAlem

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearl Ave.
1997	x	x	x	x	x	x	x	21.0	21.3	23.4	20.7	25.2	22.3
1998	24.7	25.2	25.1	27.1	25.3	25.2	22.1	20.6	21.5	22.4	23.6	23.3	23.8
1999	23.8	26.2	24.3	24.2	25.2	23.8	21.2	20.8	23.3	22.3	23.0	24.0	23.5
2000	23.9	24.1	25.6	24.9	24.2	24.0	23.2	21.2	22.0	24.1	24.1	23.8	23.8
2001	24.1	25.5	24.7	23.6	20.0	23.3	21.9	21.2	23.5	24.4	24.3	24.4	23.4
2002	24.6	24.8	24.9	26.9	28.2	26.0	23.1	21.8	23.4	24.2	24.9	23.9	24.7
2003	24.8	24.6	26.2	26.1	27.8	23.3	20.7	20.8	22.3	25.6	26.1	25.7	24.5
Ave.	**24.3**	**25.1**	**25.1**	**25.5**	**25.1**	**24.3**	**22.0**	**21.1**	**22.5**	**23.8**	**23.8**	**24.3**	**23.7**

Elemen:
Region: SHoA

Station: Addi Alem

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearl Ave.
1997	x	x	x	x	x	x	x	10.5	9.9	9.3	4.7	7.0	8.3
1998	9.6	11.0	11.2	11.9	11.5	10.9	11.0	11.8	10.3	8.6	4.4	2.7	9.6
1999	5.6	6.6	9.2	9.2	10.1	9.9	10.0	9.9	9.6	8.5	4.5	4.3	8.1
2000	4.5	5.2	7.3	7.5	7.5	9.4	9.5	9.5	9.7	7.8	5.7	4.7	
2001	5.7	6.3	7.0	6.9	4.1	9.3	9.3	10.3	8.6	7.7	5.6	5.5	7.2
2002	7.0	7.3	7.3	8.6	9.6	9.2	9.9	9.5	7.6	6.4	6.1	8.7	8.1
2003	5.7	7.3	9.3	9.2	9.7	9.5	9.8	10.6	11.1	12.7	15.1	15.5	10.5
Ave.	**6.4**	**7.3**	**8.6**	**8.9**	**8.8**	**9.7**	**9.9**	**10.3**	**9.5**	**8.7**	**6.6**	**6.9**	**8.5**

Monthly Sunshine Duration

Station Addis Abaaba Bole

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1992	6.9		7.9	7.1	7.7	5.8	3.9	2.6	4.7	7.8	8.5	8.7	6.5
1993	8.0	6.8	9.7	4.8	7.0	6.0	4.4	5.4	4.6	8.6	10.3	10.3	7.2
1994	10.5	9.8	7.6	7.7	8.7	4.4	3.1	3.8	6.4	10.2	9.3	10.2	7.6
1995	13.3	9.0	8.1	5.5	8.3	7.4	3.8	4.1	6.2	9.4	10.3	9.6	7.9
1996	7.8	10.0	7.2	7.5	7.2	4.5	3.7	4.5	5.8	9.6	9.1	9.8	7.2
1997	7.2	10.7	8.1	6.5	9.2	6.9	4.4	4.8	8.6	7.7	7.9	9.9	7.7
1998	7.9	7.5	7.0	8.5	7.2	6.7	3.6	3.9	5.7	5.9	10.3	10.4	7.1
Ave.	**8.8**	**9.0**	**7.9**	**6.8**	**7.9**	**6.0**	**3.8**	**4.2**	**6.0**	**8.5**	**9.4**	**9.8**	**7.3**

Element: Mean Monthly sun shine hour

Region: Shoa

Station: HOLLETA IAR

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1994	9.8	9.3	7.2	6.5	7.5	4.1	2.5	X	X	X	8.7	9.8	7.3
1995	10.1	8.6	8.0	4.7	7.6	6.6	2.7	3.0	3.0	4.5	9.6	8.8	6.4
1996	x	9.1	6.8	6.4	6.0	4.0		2.8	2.8	4.4	8.5	9.2	6.0
1997	6.7	10.3	8.3	6.0	7.9	5.3	3.0	3.1	3.1	6.6	7.4	X	6.2
1998	8.0	7.3	6.9	X	X	X	X	2.4	2.4	X	X	10.0	6.2
Ave.	**8.7**	**8.9**	**7.4**	**5.9**	**7.3**	**5.0**	**2.7**	**2.8**	**2.8**	**5.2**	**8.6**	**9.45**	**6.4**

Element Monthly Mean Relative Humidity at 0600 L.S.T

Region Shoa

Station Addis Ababa Bole

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1994	66	64	80	79	75	93	97	95	94	73	83	88	82.3
1995	88	85	87	92	83	89	94	x	x	x	x	x	88.3
1996	90	85	89	87	88	96	91	93	91	83	80	77	87.5
1997	85	67	76	47	74	86	94	94	89	88	x	88	80.7
1998	88	86	x	81	85	88	94	x	92	92	83	x	87.7
1999	69	56	77	66	73	82	92	x	x	x	x	x	73.6
2000	57	65	46	57	73	83	87	87	85	78	62	72	71.0
2001	69	69	79	74	79	83	89	90	83	68	62	72	76.4
2002	75	59	73	69	69	81	88	88	83	59	51	80	72.9
2003	74	63	67	74	53	77	88	88	85	58	56	66	70.8
Ave.	**76.1**	**69.9**	**74.9**	**72.6**	**75.2**	**85.8**	**91.4**	**90.7**	**87.8**	**74.9**	**68.1**	**77.6**	**78.7**

Element **Monthly Mean Relative Humidity at 1200 L.S.T**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1994	25	28	42	42	36	64	80	82	67	37	57	54	51.2
1995	53	59	58	71	62	62	75	76	65	50	43	52	60.5
1996	56	59	65	54	63	74	71	72	65	39	41	37	58.0
1997	52	30	41	47	35	50	70	68	55	55	x	47	50.0
1998	53	52	x	45	51	55	71	x	64	55	37	x	53.7
1999	38	27	48	32	30	52	74	63	58	x	x	x	46.9
2000	39	39	28	36	48	57	66	66	64	50	41	42	48.0
2001	44	38	58	43	50	58	67	71	56	40	38	42	50.4
2002	46	35	48	43	42	56	65	69	56	28	27	57	47.7
2003	49	37	42	46	28	52	70	71	64	33	41	39	47.7
Ave.	**45.5**	**40.4**	**47.8**	**45.9**	**44.5**	**58**	**70.9**	**70.9**	**61.4**	**43**	**40.6**	**46.3**	**51.4**

Element **Monthly Mean Relative Humidity at 1800 L.S.T**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1994	25	22	35	40	31	73	82	85	71	36	60	57	51.4
1995	53	55	59	76	65	64	75	x	x	x	x	x	63.9
1996	56	58	70	58	65	79	80	78	74	48	44	38	62.3
1997	48	25	34	49	35	54	73	70	59	60	x	53	50.9
1998	55	44	x	49	53	63	76	x	73	69	41	x	58.1
1999	40	27	48	36	42	57	78	75	63	x	x	x	51.8
2000	55	39	38	55	47	62	69	73	70	56	57	42	55.3
2001	40	34	51	45	60	68	72	76	60	42	34	42	52.0
2002	44	30	43	42	44	65	73	73	58	32	26	59	49.1
2003	46	37	38	50	31	54	79	79	65	36	38	42	49.6
Ave.	**46.2**	**37.1**	**46.2**	**50**	**47.3**	**63.9**	**75.7**	**76.125**	**65.9**	**47.4**	**42.9**	**47.6**	**53.9**

Element: Monthly Mean Rel.Hu
at 0600 L.S.T Holleta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1988	92	87	78	83	77	93	94	94	95	92	91	90	88.8
1989	93	87	91	92	77	90	93	93	94	90	93	94	90.6
1990	88	90	93	88	87	95	92	94	95	89	93	93	91.4
1991	87	91	86	78	85	92	94	98	94	90	90	94	89.9
1992	95	96	89	91	86	94	97	98	96	95	92	95	93.7
1993	91	93	86	94	95	95	97	97	97	93	92	87	93.1
1994	78	77	88	89	83	96	97	98	96	89	92	94	89.8
1995	87	85	89	93	85	91	95	95	95	89	92	92	90.7
1996	x	81	89	86	86	95	94	93	93	88	89	85	89.0
1997	87	79	77	87	76	87	91	92	90	90	92	x	86.2
Ave.	**88.7**	**86.6**	**86.6**	**88.1**	**83.7**	**92.8**	**94.4**	**95.2**	**94.5**	**90.5**	**91.6**	**91.6**	**90.4**

Element: Monthly Mean Rel.Hu
at 1200 L.S.T Holleta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Ave.
1988	36	36	26	43	33	56	75	71	66	45	28	27	45.2
1989	38	37	40	49	31	49	65	68	63	39	30	45	46.2
1990	30	53	45	46	38	56	69	67	66	34	33	26	46.9
1991	31	40	41	31	31	50	73	71	61	35	27	33	43.7
1992	43	52	40	44	36	55	72	77	64	47	35	39	50.3
1993	46	53	32	60	55	65	71	72	70	51	39	31	53.8
1994	28	32	40	44	37	61	72	73	64	35	35	29	45.8
1995	30	40	40	58	45	50	73	74	64	38	31	34	48.1
1996	x	25	44	44	44	65	68	71	63	35	31	27	47.0
1997	43	21	33	43	29	48	68	69	53	47	46	x	45.5
Ave.	**36.1**	**38.9**	**38.1**	**46.2**	**37.9**	**55.5**	**70.6**	**71.3**	**63.4**	**40.6**	**33.5**	**32.3**	**47.0**

Element: Monthly Mean Rel.Hu
at 1800 L.S.T Holleta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
1988	35		25	46	29	63	82	81	82	50	31	28	49.3
1989	36	34	44	55	33	57	80	79	74	44	33	51	51.7
1990	27	59	44	49	45	71	78	81	78	42	42	27	53.6
1991	30	44	44	31	29	56	86	84	70	40	34	39	48.9
1992	47	57	37	49	50	64	77	86	75	57	43	44	57.2
1993	47	57	37	66	62	79	84	85	84	57	44	34	61.3
1994	28	27	44	49	40	75	82	86	75	40	45	29	51.7
1995	34	37	41	63	54	60	78	81	71	47	38	33	53.1
1996	x	26	47	51	53	71	80	80	74	40	36	32	53.6
1997	43	18	31	49	31	53	73	75	61	53	55	x	49.3
Ave.	**36.3**	**39.9**	**39.4**	**50.8**	**42.6**	**64.9**	**80**	**81.8**	**74.4**	**47**	**40.1**	**35.2**	**53.0**

Annex-2 Hydrochemical analyses

Insitu measured Hydrochemical data

S/N	Identity	Source	Easting	Northing	Alt(m)	Ph	Eh (mv)	T(^oC)	TDS(mg/l)	EC(μS)	Date
1	HSP1	SPG	437919	1000411	2397	6.45	47.5	18.8	98.6	162	5/6/2005
2	HHDW1	HDW	442318	1003599	2462	6.69	35	18.5	107.8	644	5/6/2005
3	HSW1	SW	441580	1003443	2447	7.15	10	20	165.5	276	5/6/2005
4	HHDW2	HDW	442649	1002185	2439	7.06	15.3	19.7	164.9	276	5/6/2005
5	HHDW3	HDW	441486	1006779	2519	6.62	38.2	19.8	41.8	68.4	5/6/2005
6	HHDW4	HDW	440060	1007305	2550	7.04	16.5	17.7	77.4	129.3	5/6/2005
7	HHDW5	HDW	448288	1001423	2393	6.68	35.6	19.9	79.7	132.7	6/6/2005
8	HHDW6	HDW	446495	997676	2259	6.7	33.2	20.6	140	237	6/6/2005
9	HHDW7	HDW	446551	997200	2256	6.98	17.5	20.4	171.2	278	6/6/2005
10	HHDW8	HDW	446459	995334	2234	6.94	22.2	22.4	161.6	275	6/6/2005
11	HHDW9	HDW	446897	995227	2253	6.97	19.1	20.6	253	409	6/6/2005
12	HHDW10	HDW	448514	1002015	2420	6.89	28.7	21.6	107.4	182.3	6/6/2005
13	HHDW11	HDW	448988	1002253	2449	7.06	15.7	20.8	166.7	278	19/06/05
14	HSW2	SW	446181	992508	2258	6.9	22.6	21.6	128.6	215	19/06/05
15	HSW3	SW	446120	990922	2249	7.11	12.5	21.5	186.6	309	19/06/05
16	HSW4	SW	445271	990389	2225	6.98	18.9	22.5	183.3	313	19/06/05
17	HSW5	SW	44286	993301	2247	6.89	23.5	19.8	94.3	152.9	19/06/05
18	HSW6	SW	440925	996121	2269	6.86	26.7	23.4	13.9	234	21/06/05
19	HSW7	SW	439642	993516	2190	7.13	11.3	22.4	274	463	21/06/05
20	HSW8	SW	441957	998620	2307	7.13	9.2	22	208	344	21/06/05
21	HSP2	SPg	453665	998796	2572	6.94	26.4	15.5	88.3	150.3	21/06/05
22	HHDW12	HDW	453467	1005964	2707	6.67	33	17.1	49.5	85.4	21/06/05
23	HSP3	SPg	454152	1002643	2610	6.97	17	17.9	157.2	246	21/06/05
24	HSDW13	HDW	447922	1004383	2421	6.95	18.3	18.3	220	368	21/06/05
25	HSP4	SPg	439169	1007210	2555	7.07	13.3	19.9	106	169.6	21/06/05
26	HSP5	SPg	441080	1013103	2673	7.04	15	16.8	94.4	162.2	21/06/05
27	HSP6	SPg	451757	1014339	2644	7.03	14.9	17.2	165	272	21/06/05
28	HBH1	BH	446170	1003930	2385	7.7	27.8	19.7	133.2	217	21/06/05
29	HBH2	BH	447196	998889	2278	7.58	17.7	24.7	140.7	235	21/06/05
30	HBH3	BH	440208	1000112	2354						

Laboratory chemical result

Code	HSP2	HSP5	HSP3	HSP4	HSP6	HSW4	HSW6	HSW7	HSW2	HHDW7	HHDW11	HHDW3
Source	Spg	Spg	Spg	Spg	Spg	Sw	Sw	Sw	Sw	HDW	HDW	HDW
UTM x	453665	441080	454152	439169	451757	445271	440925	439642	446181	4E+05	448988	441486
y	998796	1013103	1E+06	1E+06	1014339	990389	99621	993516	992508	1E+06	1E+06	1E+06
Altitude(m)	2572	2673	2610	2555	2644	2225	2269	2190	2258	2256	2449	2519
Turbidity(NTU)	nill	nill	nill	4	1			nill	120			7
Color(pt.co)	nill	nill	nill	21	10			4	1310			82
Odor	odorless	odorless	odorless	odorless	odorless			odorless	odorless			odorless
PH	6.75	7.42	6.93	6.52	7.05	6.88	6.58	7.14	6.84	6.95	6.27	6.66
TDS(mg/l)			331	230	130	248.8	183.1	222	84	226.1		70
Ec(ms/cm)	148	162	260	204	260	306	226	444	168	280	81	140
Tot. Alka. ($caco_3$)			185	145	175	150.8	109	280	135	136.9		110
Tot. H.($caco_3$)			120	85	105	131	89	205	80	115.2		65
Sio_2	31	32	40	46	40	47	32	40	40	43	16	40
Co_2	25	8				41	55			33	29	
Cations (mg/l)												
Na^+	7.4	6.4	46	32.2	32.2	10	10.5	43.7	25.3	11	2.2	46
K^+	4.2	1.3	1.5	3.1	0.3	3.4	1.9	2.3	2.4	1.7	0.8	
Ca^{2+}	15	15	36	28	36	36	22.5	72	28	33	7.5	20
Mg^{2+}	4.2	4.2	7.2	3.6	3.6	10	8	6	2.4	8	2.8	3.6
Cu^{2+}			0.08	0.04	0.04			0.06	0.3			0.05
Fe^{2+}			0.01	0.03	0.04			0.03	0.16			0.04
Mn^{2+}			0.001	0.001	0.004			0.001	0.002			0.001
Cr^{2+}			0.11	0.1	0.12			0.11	0.12			0.22
Aions (Mg/l)												
OH^-			nill	nill	nill			nill	nill			nill
Cl^-	10	4	40	30	12	5	7	40	28	5	7	50
No_3^-		3.1	10.56	7.92	20.24	7.5	9.3	22.4	2.2	7.1	10.2	7.92
F^-	0.12	0.23	0.22	0.32	0.24	0.41	0.16	0.39	0.5	0.38	0.08	0.08
HCO_3^-	76	96	176.9	91.5	189.1	184	133	256.2	54.9	167	27	122
Co_3^{2-}			24	42	12			42	54			12
So_4^{2-}	<1	<1	2	3	nill	<1	<1	4	nill	<1	<1	2
Po_4^{3-}			nill	0.56	0.2			0.28	0.22			0.02

Code		**HBH1**	**HBH3**	**HBH4**	**HBH9**	**HBH11**	**HBH19**	**HBH2**	**HBH26**	**HBH28**	**HBH27**	**HR1**	**HR1**	**HR3**
Source		**BH**	**BH**	**BH**	**BH**	**BH**	**BH**	**BH**	**BH**	**BH**	**BH**	**RV**	**RV**	**RV**
UTM	x	446266	444997	444626	445942	445773	440079	446170	47196	446632	446338	446802	445415	446109
	y	1004147	1000718	1001034	998199	1001591	1000151	1003930	998889	994813	997431	998262	997168	1003977
Altitude(m)		2372	2354	2366	2250	2417	2410	2385	2278	2240.4	2256.2	2255	2216	2380
Turbidity(NTU)								2	3			14	4	23
Color(pt.co)								18	22			107	55	81
Odor								odorless	odorless			odorless	odorless	odorless
PH		7.96	7.16	7.51	8.28	7.49	8.12	8.7	801	7.6	6.97			
TDS(mg/l)		158	204	190	144	232	174	104	109	148	186.8	6.35	6.48	6.85
Ec(ms/cm)		229	284	277	192	324	253	208	218			84	106	117
To. Alk.($caco_3$)		110.4	148.8	146.4	88	168	136.8	140	160	101.6	119.7	168	212	234
To.H.($caco_3$)		73.4	146.7	144.6	67.1	169.8	125.8	65	65	78.8	987	95	200	118
Sio_2								48	46	20	57	176	278	336
Co_2												51	51	51
Cations (mg/l)														
Na^+		21.5	8.1	9.2	18	9.6	11.7	18.4	69	30	11			
K^+		0.8	1.8	1.3	2	2.1	2.2		1.9	1.7	3.1			
$^{2+}$		23.52	47.04	44.52	18.5	48.72	33.6	20	20	25	28	49.6	68	88
Mg^{2+}		3.57	7.14	8.16	5.1	11.73	10.2	3.6	3.6	4	7	37.44	25.92	28.32
Cu^{2+}								0.06	0.1			0.03	0.05	0.07
Fe^{2+}		0.025	0.014	0.012	0.04	0.01	0.012	0.02	0.01	0.2	0.2	0.02	0.01	0.01
Mn^{2+}		0.1	0.1	0.1	0.1	0.1	0.01	0.001	0.001	0.1	0.1	0.4	0.6	0.8
Cr^{2+}								0.13	0.12			0.04	0.04	0.04
Anions (Mg/l)														
OH^-												nill	nill	nill
Cl^-		3.84	1.92	2.88	5.76	4.8	1.92	10	70	3	4			
No_3^-		12.76	16.28	8.8	11.4	13.64	6.6	11.44	8.36	4.43	4.43	792	3.96	3.52
F^-		0.37	0.07	0.27	0.06		0.13	0.55	0.24	0.09	0.25	0.09	0.08	0.06
HCO_3^-		134.69	181.54	178.61	107.36	204.96	147.38	36.6	12	124	146	67.1	146.4	101.26
Co_3^{2-}					4.8		9.6	66	36			27	48	42
So_4^{2-}		0.79	0.53	0.53	1.58	0.79	0.53		nill	<1	<1	1	2	nill
Po_4^{3-}								0.22	0.1			0.25	0.25	0.19

Annex-3 Types and location of water points in the study area

Code	Locality	UTME	UTMY	Elevation	Scheme type	Depth	SWL	Yield
HBHI	Townw.supply1	446266	1004147	2388	BH	147.5	2.2	7
HBH2	Townw.supply2	446155	1003073	2388	BH	90	7	5
HBH3	Townw.supply3	444997	1000718	2356	BH	91.2	37.5	
HBH4	Military camp	444626	1001031	2366	BH		40	0.5
HBH5	Agriservice flower	444168	998992	2288	BH	98	7.20	5
HBH6	Rose flower	444577	998364	2290	BH	140		2
HBH7	Dire high land	445168	997226	2239	BH	98	00	14
HBH8	Dairy farm	445099	1003816	2400	BH	130	30	7
HBH9	Metrolux flower.	445942	998199	2394	BH	99	00	14
HBH10	Garad flower	443050	1001649	2403	BH	130	24	3.3
HBH11	ARI	445773	1001323	2388	BH	74.5	30.35	3.1
HBH12	Arsi flower	443132	100869	2386	BH	116	30	2
HBH13	Top international	445114	998215	2385	BH	100	5.90	5.6
HBH14	Ama flower	444677	998888	2306	BH	100	21.3	5.6
HBH15	Mulugeta Buli	444642	1002960	2427	BH	66	49.4	2
HBH16	Mulugeta Buli	443984	999625	2306	BH	70	10	3.7
HBH17	Agri service farm	444209	998733	2283	BH		702	
HBH18	Kurtusi flower	448290	1002698	2413	BH	78	10.2	
HBH19	Ethio Drim	440079	1000151	2410	BH	112	00	6
HBH20	Macro flower	449177	1002158	2472	BH	220	00	
HBH21	Jordan R.herbs	453522	1001417	2556	BH	115.3	57.84	14.6
HBH22	Nano gelgel	441584	1003445	2453	BH	50	11	
HBH23	Rob gebeya	437892	1008952	2587	BH	13	4	
HBH24	Wajitu1	436632	993521	2186	BH	39	11.7	1
HBH25	Wajitu2	440926	996120	2273	BH	27		
HBH26	Tseday fruit	447200	998889	2294	BH	126	00	14
HBH27	Guntuta	446338	997431	2256	BH	125	13.2	5
HBH28	Roge	446632	494813	2240	BH	80	1	5
HBH29	Gole liben	446125	990938	2259	BH	50		
HBH30	Geresu seda1	446166	992510	2261	BH	50	7	
HBH31	Geresu seda2	446120	990922	2249	BH	50	13	2
HBH32	Kawo giyrgis1	445271	990389	2225	BH	50	5	

HBH33	Kawo giyorgis2	439642	993516	2190	BH			
HBH34	Garad PLC	440280	1000112	2354	BH	167	94	4.5
HBH35	Menagaesha flower	453145	1001365	2551	BH	115	73	16
HBH36	Choke kebele	448532	1008047	2525	BH	50		
HSW1	Garasu Seda1	444286	993301	2247	SW	58		
HSW2	Garasu Seda 2	446181	992508	2258	SW	50		
HSW3	Kawo 1	446120	990922	2249	SW	50		
HSW4	Kawo 2	445271	990389	2225	SW	50		
HSW5	Suba 1				SW	42		
HSW6	Suba 2				SW	42		
HSW7	Wajitu Fitche	440925	996121	2269	SW	54		
HSW8	Harbu Bishoftu	441957	998620	2307	SW	15		
HSW9	Dhawana	439642	993516	2590	SW			
HSW10	Lafto Wajitu				SW		11	
HSW11	Gegel Kuyu	444580	1003443	2447	SW	54	9	
HSW12	Cheshire Home				SW	15.5		
HHDW1	Kolobo	442318	1003599		HDW	12		
HHDW2	Kolobo	442649	1002385	2439	HDW	7		
HHDW3	Bakaka	441486	1006779	2519	HDW			
HHDW4	Xaxechaa	440060	1007305	2550	HDW	11		
HHDW5	Xaxechaa	448288	1001423	2393	HDW	7		
HHDW6	Xaxechaa	446495	997676	2259	HDW	605		
HHDW7	Chafee	446551	997200	2256	HDW	8.9		
HHDW8	Roqe Aba/W/Mari.	446459	995334	2234	HDW	10		
HHDW9	Rogee	446897	995227	2253	HDW	11		
HHDW10	Dadamo Guxii	448514	1002015	2420	HDW	7		
HHDW11	Dadamo Guxii	448988	1002253	2449	HDW	9		
HHDW12	Sibrii qoree	453467	1005964	2707	HDW	8.5		
HHDW13	Welmara	447922	1004383	2421	HDW	10		