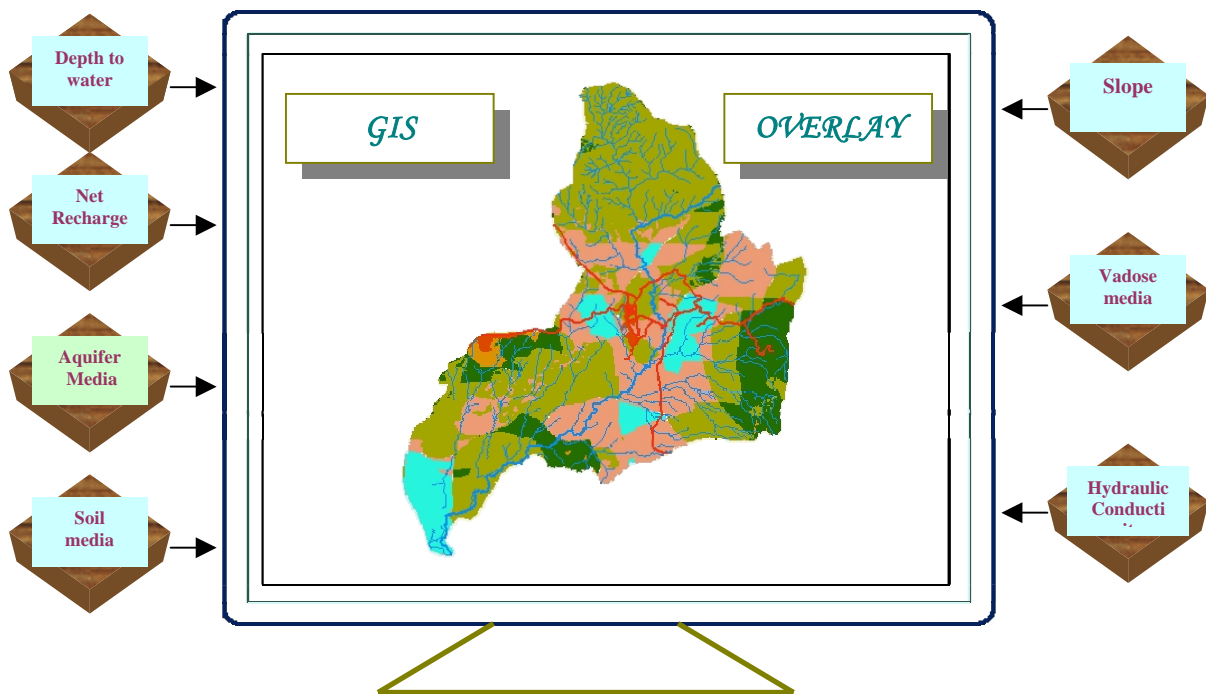


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ADDIS ABABA UNIVERSITY  
DEPARTMENT OF  
EARTH SCIENCES  
FACULTY OF SCIENCE

## GIS-BASED GROUNDWATER VULNERABILITY MAPPING OF HOLETA RIVER CATCHMENT, OROMIA REGIONAL STATE, WEST SHEWA ZONE



A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN  
PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE  
OF MASTER OF SCIENCE IN HYDROGEOLOGY

BY  
ASSAMINEW GEBEYEHU

July, 2007  
ADDIS ABABA

**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
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SCIENCE FACULTY**

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## **ABSTRACT**

The studied area, Holeta River Catchment, lies in the central part of the country, 28 km west of Addis Ababa in Oromia Regional National State. The area is bounded between Latitude 8°53'23" to 9°13'28" North and Longitude 38°20'45" to 38°36'48" East. It is a sub-catchment of upper Awash drainage basin with a total surface area of 508 km<sup>2</sup> and perimeter 125.54 km. It has an elevation range of less than 2060 to 3380 m.a.s.l.

The basaltic lava flows (Alaji and Tarmaber-Megezez formation), Trachytic and Rhyolitic Volcanic rocks, pyroclastic deposits and quaternary Alluvial sediments are major geologic units in the area.

On annual basis, the area has 1094.5 mm, 981.3 mm, 595.8 mm, and 304.2 mm of mean total rainfall, Potential Evapotranspiration (PET), Actual Evapotranspiration (AET), and groundwater recharge respectively. The mean annual temperature of the area is 16.2°C.

Population density of Holeta River catchment varies from 15.83 persons per hectare to 0.52 persons per hectare. The existing land use/land cover patterns in the area are broadly divided into six groups as: Agriculture/grass land area (63.95%), forest land (6.46%), bare rock (1.09%), urban area (0.69%), bushes/shrubs (26.13%), and wetland cover (1.69%) of the total land use cover. The dominant soil types in study area are; cambisols (67%), vertisols (0.78%), and Alluvial soil (0.78%) of the total soil cover. The soil thickness varies from less than 2.1 m to greater than 9.1 m and the major soil texture classified as; silty clay, clay, and sandy loam respectively.

Studies shows that, the major aquifer type of the area are: Alluvial deposits, buried valley deposits, and weathered and fractured basalts.

The major possible pollutant sources of groundwater are; Agricultural activities (both point and non-point sources), municipal/domestic waste disposal, sewage and also health centers, cemeteries, quarry mining, and market places. The groundwater in the area is characterized by mainly Ca-Mg-HCO<sub>3</sub>, Ca-Na-HCO<sub>3</sub>, and Ca-HCO<sub>3</sub>. In analyzed samples the dominant cation is Calcium ion and bicarbonate is the dominant anion. TDS, EC, and pH values range 50mg/l-648mg/l, 84µs/cm-607.8µs/cm, 6-7.99 respectively.

The general objective of the study is to identify and map the groundwater vulnerability to pollution in Holeta River Catchment by using a DRASTIC model with the assistance of GIS (Arc-map) software. In general, in intrinsic DRASTIC map, the vulnerability of groundwater increases from north to south of the catchment. This map revealed that major part (northern) of the catchment lies on medium risk area while the southern tip and central parts of the area are highly/extremely vulnerable to pollution due to high recharge rate, alluvial and highly fractured aquifer media, and gentle slope. Low/very low vulnerable area is quite small in western and eastern parts.

From the specific vulnerability impact map due to population density of the catchment, it is possible to conclude that the both the urban sites (Holeta and Adis Alem) show high vulnerability index to groundwater due to their population size. Where as, major parts of the study area are very low vulnerable to pollution with respect to population density.

Finally, as this work is conducted under serious constraints of resources, I recommend further detail research work to fill the knowledge gap and provide detailed data for future researchers.

## **DECLARATION**

I the undersigned declare that this thesis is my original work and has not been presented for a degree in any other university. All sources of material used for the thesis have been duly acknowledged.

Name: Assaminew Gebeyehu

Signature: \_\_\_\_\_

Place: Addis Ababa University, School of Graduate Studies.

Date of Submission: July, 2007

# **CHAPTER ONE**

## **INTRODUCTION**

### **1.1. Background**

Water quality degradation is one of the major environmental problems of these days. The physical, chemical and biological quality degradation can limit the intended use of water. The fast population growth, uncontrolled urbanization and industrialization, poor sanitation situation, etc cause serious quality degradation of surface and groundwater in particular. So, the quality of groundwater is receiving wide spread attention all over the world; and hydrogeological information is essential to the effective protection and management of groundwater quality.

The quality of groundwater can affect not only our health, but also society and the economy. Groundwater contamination can adversely affect property values, the image of a community, economic development, and overall quality of life we all share. Once groundwater has been contaminated, it is usually very difficult and costly to clean. For many years, it was thought that groundwater was protected from contamination by the layers of rock and soil that act as filters, but contaminants do make their way into the groundwater and affect its quality.

To be more specific, Groundwater is an important resource in much of the Holeta River catchment. It supplies drinking water and other domestic and agricultural use for both rural and urban dwellers in the study area. Protection of the groundwater in the country has become a significant concern. One of the major potential sources of groundwater contamination in the study area is agricultural activity. However, the vulnerability of groundwater in this area to agricultural both non-point and point source pollution as well as other contaminant sources is not well understood.

Even if the impacts of flower farm activities is not well detected in the groundwater yet since it is being practiced recently in the study area, but it is a threat to the groundwater due to uncontrolled discharge of the chemical effluents.

Therefore, it is crystal clear that there should be a protection of the groundwater resource from any pollution threat. To supplement the policy makers on groundwater resources management in this catchment, there must be map-based information that indicates spatial distribution of relatively areas. Hence, this study is initiated to make available this information for the decision/policy makers and professionals who are interested to work on related issues.

The concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against the natural and human impacts, especially with regard to contaminants entering the subsurface environment.

## **1.2. Statement of the problem**

With increasing demand and reliance on groundwater from a growing population and agricultural activity comes the need to increase efforts to protect and manage the resources.

The impact of human on surface and groundwater is increasing with the development of agricultural activity and population size in the Holeta River catchment. The currently identified problem, which is going to be applied in the indicated geological set-up and hydrogeological settings, is believed to meet the objectives mentioned.

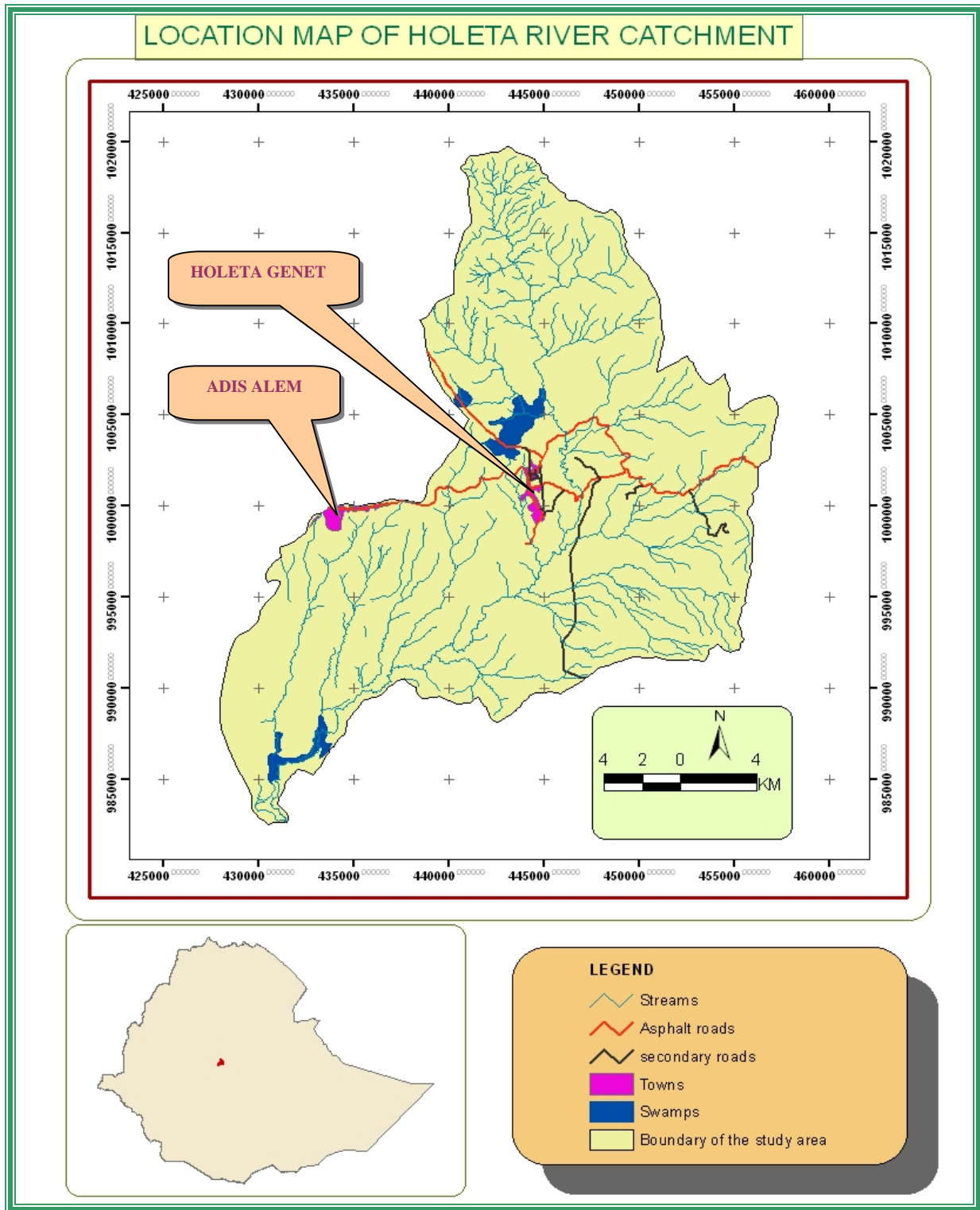
There is a need to compile the groundwater data into information to enable more effective management decision-making regarding the resource. As well, a method of identifying and prioritizing aquifers for different types of management attention is becoming essential in an era of limiting budget resources.

This work is, therefore, planned to address and cater groundwater degradation by anthropogenic sources of pollutants which is critical problem to the society's resources and which is consistently facing development planners with regard to groundwater management. Furthermore, in order to conduct development in harmony with groundwater regime in particular, and the environment in general, the concerned development needs to have such comprehensive groundwater vulnerability map, which is used easily by other professionals.

### **1.3. Location, Aerial Extent, and Accessibility**

Holeta River catchment is located in the central part of Ethiopia, 28 km west of Addis Ababa in Oromia Regional National State, West Shewa Administrative Region. The area is bounded between Latitude 8°53'23" to 9°13'28" North and Longitude 38°20'45" to 38°36'48" East.

It is delineated based on surface water divide located in upper Awash basin. It comprises parts of the two administrative woredas; Welmera and Ejere with a total surface area of 508 km<sup>2</sup> and perimeter 125.54km. It is accessible from Addis Ababa by main asphalt road stretching to Welega. Many other secondary roads are available for inter-site movements/traverses (Figure 1.1).



**Figure 1.1. Location map of Holeta River Catchment.**

## 1.4. Objectives

### 1.4.1 General Objective

To identify and produce a map groundwater vulnerability to pollution in the Holeta River catchment and to assess the risk for groundwater pollution through adopting the DRASTIC model with Geographic Information System(GIS) mapping of water supply aquifers.

### 1.4.2. Specific objectives

- To identify areas which are more likely to be susceptible to groundwater contamination relative to one another.
- Identifying the possible sources of pollutant in the study area.
- Evaluating and mapping the seven parameters in the DRASTIC model, named:
  - D**=Depth to water table,
  - R**=Net **R**echarge,
  - A**=**A**quifer media,
  - S**=**S**oil media,
  - T**= **T**opography/Slope,
  - I**= **I**mpact of Vadose Zone media, and
  - C**= Hydraulic **C**onductivity of the aquifer.
- Characterizing the aquifers in the catchment.
- To study the hydrogeology, hydrochemistry, and groundwater flow direction within the catchment.
- To produce the Intrinsic and specific vulnerability map.

## 1.5. Methodology

To meet the above specified objectives of the research project, the empirical model known as the DRASTIC model developed by the National Water Well

Association under a cooperative agreement with the United States Environmental Protection Agency (Aller et al., 1987; Evans and Meyers, 1990) to assess relative groundwater pollution susceptibility using hydrogeologic factors with GIS was adopted. The below mentioned related approaches have been used to assess the groundwater vulnerability.

- ❖ Characterization of the chemistry of water samples collected from different sources within and adjacent to the catchment.
- ❖ Characterization of the meteorological elements and hydrological conditions of the catchment and its surroundings.
- ❖ Plotting all developed water schemes on 1:50,000 topographic maps.
- ❖ Measurement of EC, Ph, TDS, and Temperature of water samples.
- ❖ Interpretation of Landsat satellite images in regional scale.
- ❖ Characterization of various contaminants within the catchment.
- ❖ Understanding of the geologic and hydrogeologic set-ups of the catchment and adjacent catchments through observation of borehole logs from well completion reports, water well sitting reports, pumping test reports, irrigation scheme study reports, and water scheme inventory reports.

### ***1.5.1. Data integration***

The following figure 1.2. Shows data flow and procedures followed to prepare the seven DRASTIC base maps for the final aquifer vulnerability analysis.

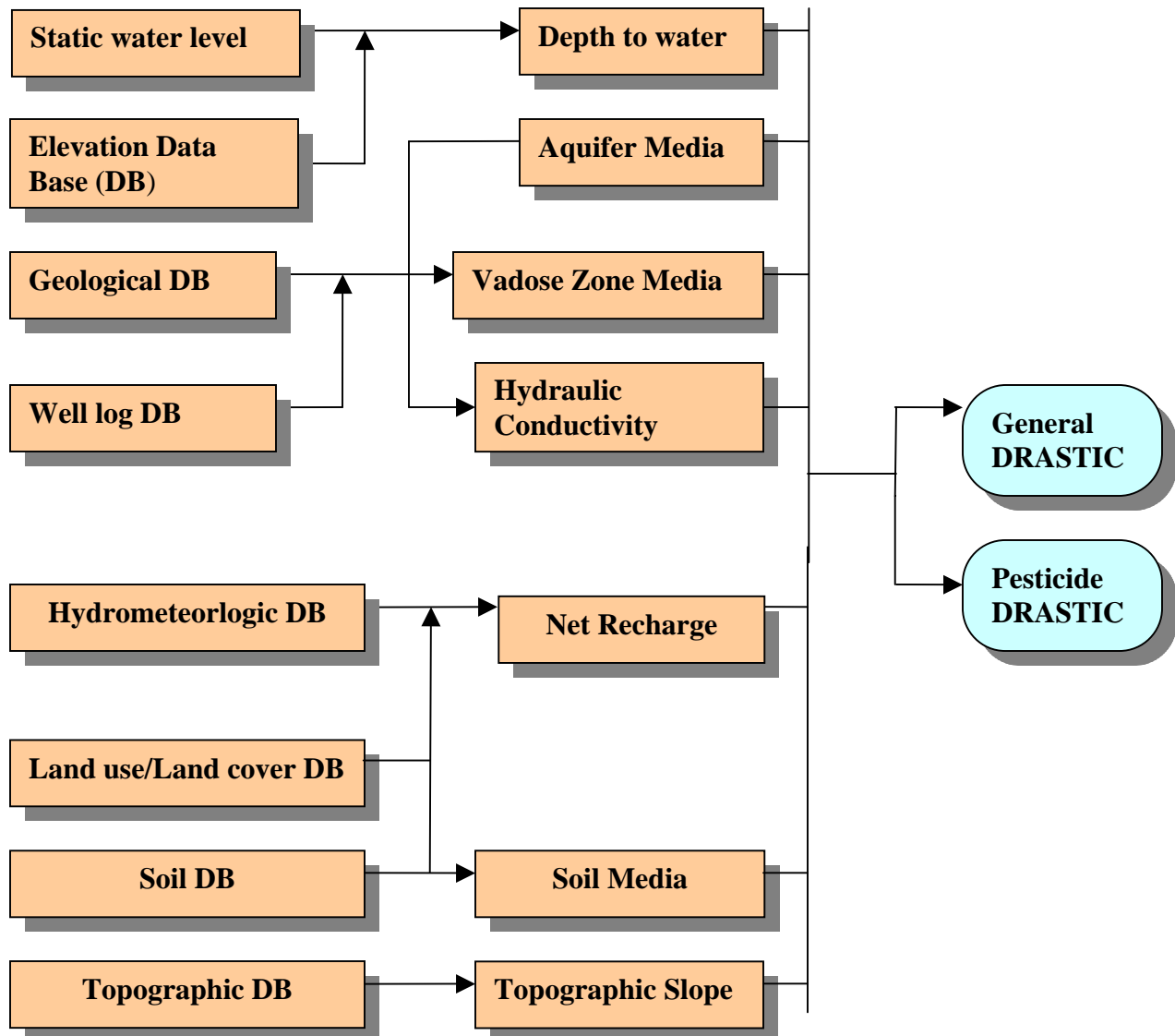


Figure 1.2. Data integration and Procedures Followed For groundwater vulnerability mapping

In this thesis GIS (Arc GIS 9.1) is used as a tool for aquifer vulnerability mapping. Groundwater vulnerability is determined by assigning a weight based on rating for different ranges of the values. The typical ratings range from 1 to 10 and the weights from 1 to 5.

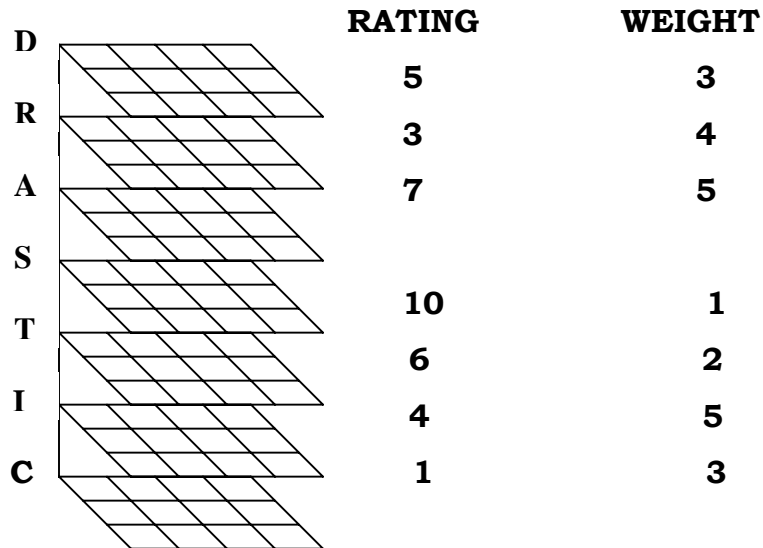
**1.5.2. Procedure to Evaluate Groundwater Vulnerability**

First of all the seven thematic maps are produced for each hydrogeological settings which make up the acronym DRASTIC, and each DRASTIC factor is assigned a relative value of Ratings shown in Table 8.1 (page 117-118).The value obtained is multiplied by its respective weight, and the seven layers or products are summed to obtain the DRASTIC index ( $D_i$ )(equation1.1). That means the additive-overlay processes in the corresponding data layer values(ratings) for a particular cell are multiplied by an important coefficient (weight) to produce a composite score called vulnerability index (Dereje Nigussa,2003). The equation for determining the DRASTIC index is:

$$D_i = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \text{ ----- (1.1)}$$

Where, D, R, S, T, I, and C are the seven parameters stated before, and r=rating value= weight.

The following schematic diagram (fig.1.3) shows how the DRASTIC index is computed for a single pixel.



**Vulnerability Index=5\*3+3\*4+7\*5+10\*1+6\*2+4\*5+1\*3=107**

Figure 1.3. Additive Overlay procedure to compute DRASTIC index.

Once a DRASTIC index has been computed, it is possible to identify areas which are more likely to be susceptible to groundwater contamination relative to one another. The higher the DRASTIC Index, the greater the groundwater pollution potential. The DRASTIC Index provides only a relative evaluation tool and is not designed to provide absolute answers. Therefore, the numbers generated in the DRASTIC index and in the pesticide DRASTIC cannot be equated (Aller et.al., 1987).

### **1.6. Application of Results**

- Vulnerability maps can help planners and regulators make informed, environmentally sound decisions regarding land use and groundwater protection.
- Vulnerability maps are a good tool to make local assessment of groundwater vulnerability potential, to identify areas susceptible to contamination, to design monitoring networks, and evaluate groundwater contamination, particularly non-point contamination.
- They are also helpful for educating and informing planners, managers, and decision- and policy-makers about groundwater protection, risk of contamination, and contamination prevention.
- The results can also be used to educate the public in the study area about groundwater being part of a large, interconnected ecological system.
- It also helps for similar studies in the adjacent areas and region which possess similar geological, hydrogeological and climatic conditions.
- The result will also be used as a data source for the future researchers.

### **1.7. Previous Works**

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 hydrogeological point of view. The investigation carried out so far in the area are either to general (on a regional scale ) or hydrogeological and geophysical investigations for specific institutions, organizations, private limited companies and town water supply for locating borehole sites with out considering all the catchment areas.

Among the important geological and hydrogeological investigations within the catchment and its environs are: unpublished thesis on water resources potential evaluation of the Holeta River catchment by Ketema Wogari (2006). And also, unpublished thesis on GIS-based Groundwater vulnerability assessment in Akaki River Catchment, Addis Ababa by Dereje Nigussa (2003). UNEP/ UNESCO Report on Hydrogeology, water quality and the degree of groundwater vulnerability to pollution in Addis Ababa by Tamiru Alemayehu, et al.,(2005).The feasibility study of surface and groundwater for the water supply of Holeta Genet by Norconsult (Norconsult, 1999). Groundwater investigation at south of Holeta town, Ethio AGRI-CEFT pvt. Ltd. co., by water well drilling enterprise consultancy division (WWDE, 2003).Hydrogeological Report of Holeta area for the purpose of locating borehole site for Holeta Mulugeta Buli Military Training camp, Ministry of Defense by Water Works Design and Supervision Enterprise (WWDSE, 2004). Construction Rock materials assessment project in areas around Finfinne, Adama and Ambo (Draft report on Geology and construction material potential of area around Finfinne that includes Holeta area (Gelana Gadissa et al; 2003).

## CHAPTER TWO

### GENERAL OVERVIEW OF THE STUDY AREA

#### 2.1. Climate

Climatic elements such as precipitation, temperature, humidity, sunshine, and wind are affected by geographic location and altitude. Seasonal classification over the study area is thus mainly based on the average rainfall distribution pattern over the year, and the seasonal distribution of rainfall over the area is governed by the position of the Inter-Tropical Convergence Zone (ITCZ).

According to this, the study areas is characterized by three distinct seasons and are locally known as “Bega” (October-January), “Belg” (February-May), and “Kiremt” (June-September). Therefore, the rainfall pattern in the area has two distinct peaks during a year that is a short rainy seasons in months of February / March-May and long Rainy Seasons in moths of June/ July-September (fig. 2.1 ) (Daniel Gemechu, 1977) and has the mean annual rainfall of 1094.5mm.

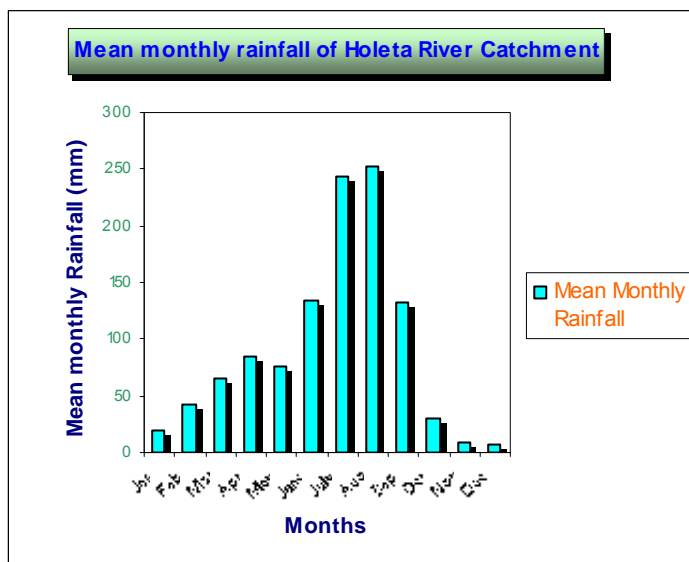


Figure 2.1 Rainfall Pattern over the Study area.

The fact that altitude in the catchment ranges between below 2060m to 3380m, it is possible to observe that the study area lies in Temperate (Woina Dega) of 54% and cool temperate (Dega) of 46% climatic zones. Hence therefore, the mean annual temperature of the area is 16.2°C.

## 2.2. Demography

Understanding of the human population dynamics is extremely important when considering the impact of various human activities upon the various water supply sources. Holeta River catchment had a population of 72231 in 1999 (CSA, 1999), which grew to 1103797 by 2007 according to Wored's agricultural and Health Center offices. Moreover, the population size indicated 65.4% increases from that of 1999. The average population density of Holeta River Catchment is 2.7 persons per hectare and that of urban and rural parts of the study area are 13.2 and 1.99 per ha, respectively. The highest and the lowest population density of the catchment are 15.83 per hectare in Addis Alem and 0.52 persons per hectare in Wetabecha minjaro. Total population size of the study area is given in Table 2.1 and Figure 2.2 and the current population density with respect to their kebeles and towns are given in figures 2.3 and 2.4

Kebele/Town	Population
Ula Foyeta	3554
Teleho	3911
Dufa	214
Burkusami Rob Gebeya	3777
Nano Genet	5558
Holeta Genet	17289
Ula Silasse	1751
Haro Boki	5166
Ade Simbirti Kotu	1345
Ilala Gojo	7521
Wajitu Harbu	2194
Dawaf lafto	2202
Tulu wato Dalecha	1492
Nano Suba	2371
Geresu Sida	2862
Wechecha	1874

Berfeta 1 <sup>st</sup>	3423
Berfeta 2 <sup>nd</sup>	7808
Menagesha Kolobo	3172
Wetabecha minjaro	421
Addis Alem	11540
Chiri	3781
Bolongo	1924
Telbo	2726
Tulu Korma	667
Amaro	4762
Hora	2294
Kusaye	2016
Indode	2764
Total	1103797

Table 2.1 Population distribution within the study area.

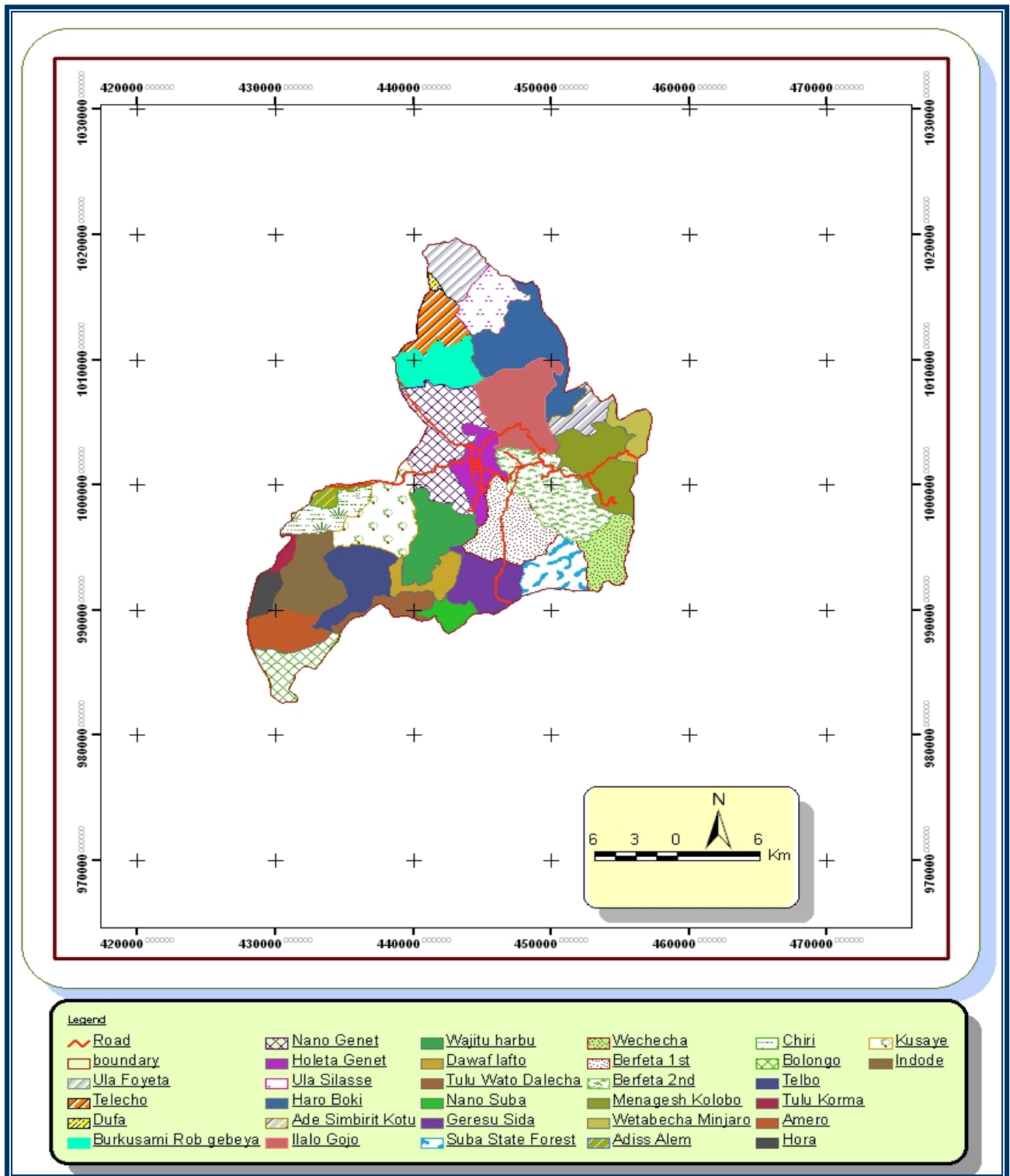


Figure 2.2 Map of the study area (source: School Map and Primary Planning Project, SMAPP project, 2007).

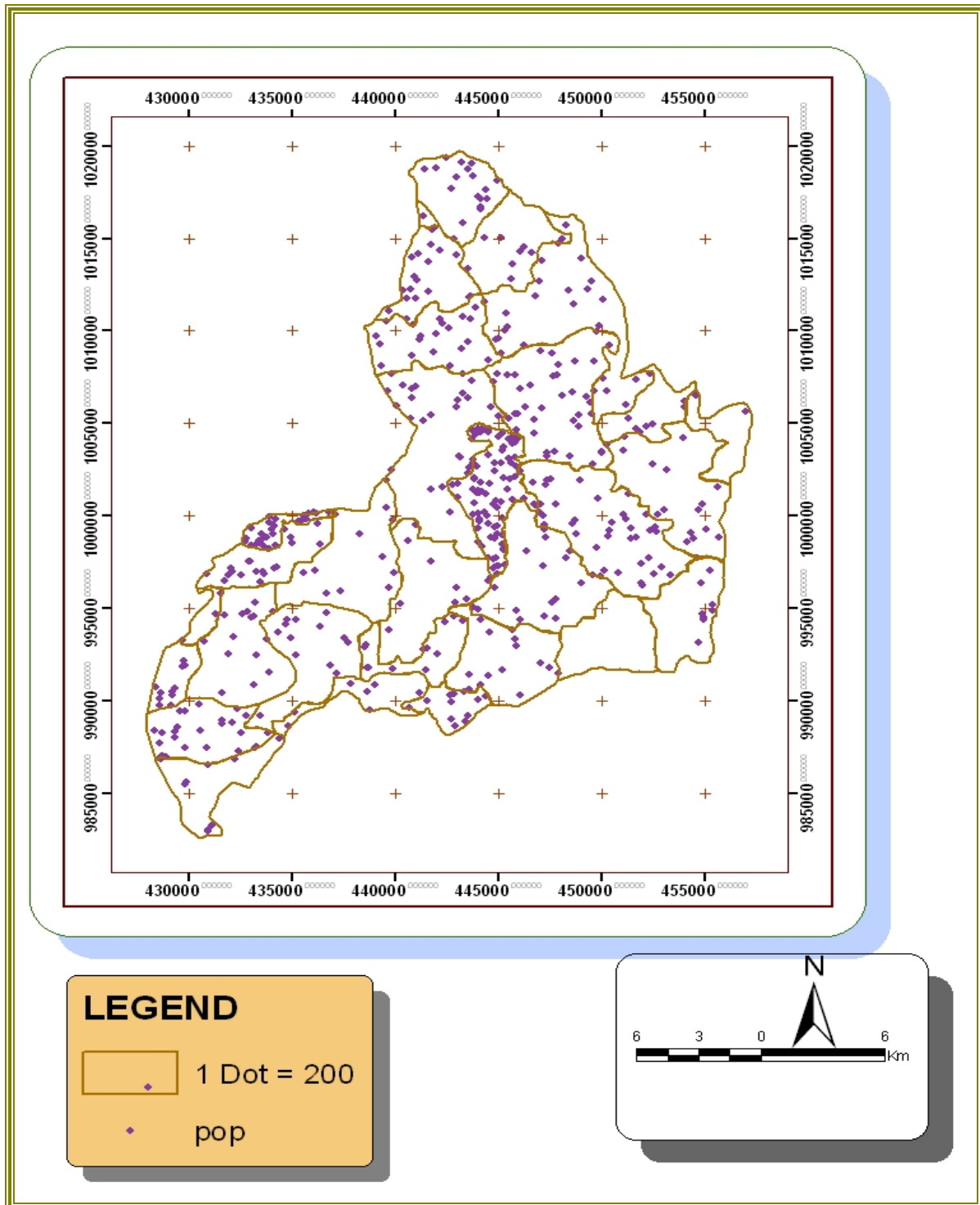


Figure2.3 Population density map (1Dot=200 people)

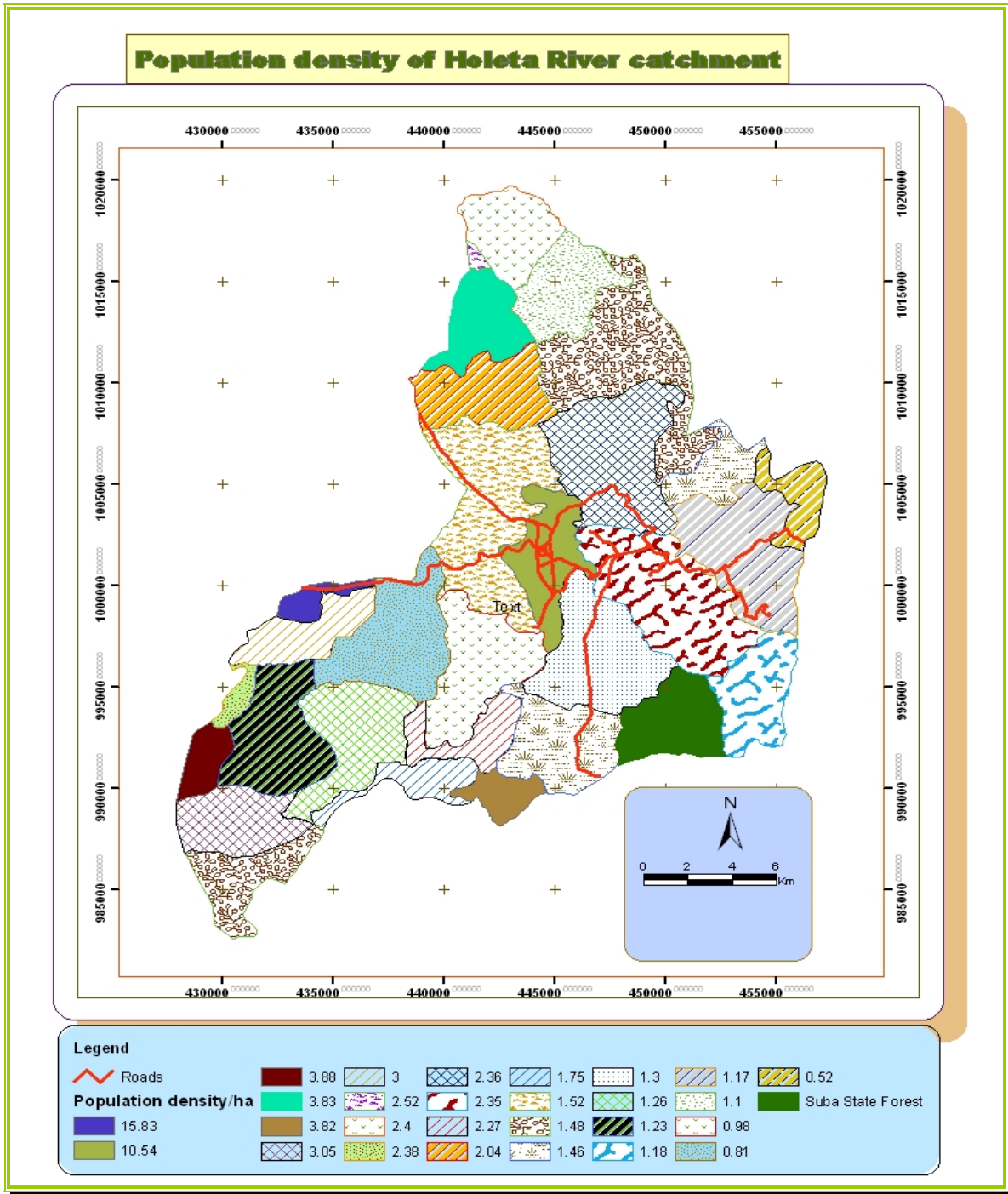


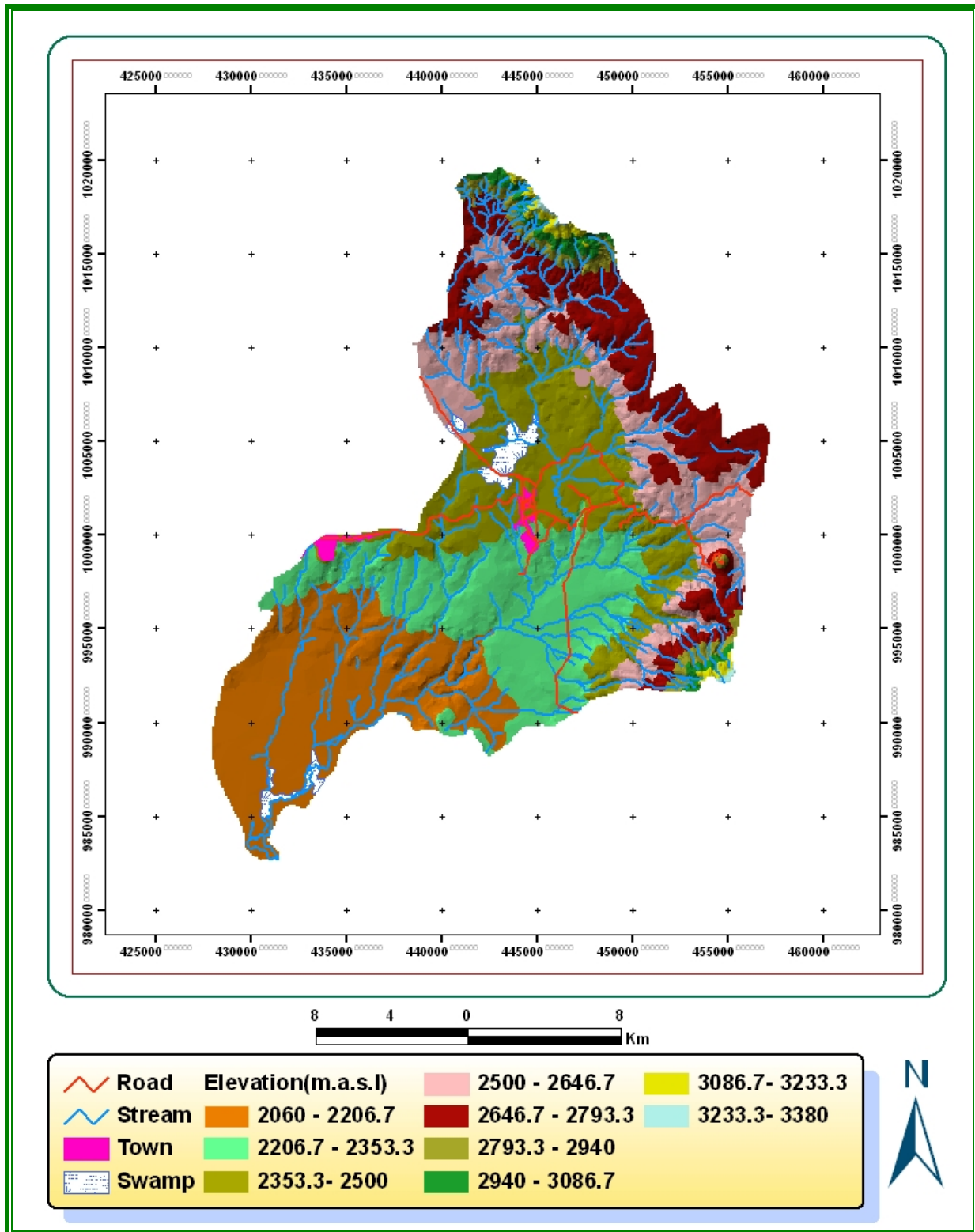
Figure 2.4 Population density of the study area (Pop/ha).

## **2.3. Physiography, Drainage, and Land use/land cover**

### ***2.3.1 Physiography***

Holeta River catchment is located partly in the western Ethiopia rift escarpment and partly in the western Ethiopia highland plateau. The present physiographic setting of the catchment is the result of volcano-tectonic activity that forms the plateau and the rift. Later erosion and river dissection has contributed to the existing rugged landform. Two major types of land forms generally characterize the study area: volcanic ridges and hills surrounding the catchment at its northern and eastern, with flat land forms in central, western, and southern part. The general slope of these central and western plain is toward the south. Holeta river catchment has an elevation range of less than 2060m.a.s.l. to 3380m.a.s.l. (topographic map of scale 1:50, 000, EMA, 1973-1986) at Wechecha and Fo-ota mountain ranges, and the confluence of Holeta and Awash River respectively (Figure2.5).

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. Similarly, the eastern part of the study area is also a mountainous land comprised by high lands of Menagesha-Wechecha ridges made up of silicic rocks (Ketema Wogari, 2006)



**Figure 2.5 Drainage and Topographic (in m.a.s.l) map of Holeta River Catchment**

### **2.3.2. Drainage**

One major river form Holeta River catchment that is Holeta River and its tributaries. This river is one of the tributaries of Awash River. Fo-ota and Wechecha mountain Ranges form the surface water divide between northern and eastern parts of the study area. The other volcanic centers forms the surface water divide between the study area and other adjoining hydrographic basins in the upper Awash River basin.

Various factors affect the pattern and density of drainage in the study area. Among these are: rainfall, slope, vegetation, rock type and tectonics are important ones. Accordingly, in the central and western parts of the catchment where rainfall is high, vegetation is dense, and topographic elevation is high; drainage forms steep narrow gorges. In addition to these, tectonized basaltic and rhyolitic rocks produced parallel and/or dendritic drainage patterns. Therefore, the catchment is characterized by both dendritic and parallel drainage pattern (Figure2.5).

It is commonly known that the higher the permeability the lower the drainage density, and higher the drainage density higher the surface runoff. The drainage density of the Holeta River catchment is given by:

$$D_d = P_c / A_c$$

$$D_d = 125.54\text{Km} / 508\text{Km}^2 = \underline{0.25\text{km}/\text{km}^2}$$

Where,  $D_d$  is Drainage density of the catchment,  $P_c$  and  $A_c$  are perimeter and Area of the catchment respectively.

### **2.3.3. Land use/Land cover**

Land can be put to different uses based on the suitability of its different physical land resources, demand, climate, location, etc. the existing land use patterns in the catchment were broadly divided in to six groups: agricultural/grass land, forest, urban area and its associated different

uses, bushes/shrubs, bare rock and water bodies by Gelana Gadissa (2005) (Figure 2.6).

The agricultural/grass land cover a large part of the area that is in central, northern, western, and southern parts. The eastern part of the study area that is Wechecha mountain range is almost covered by forests. Most eastern parts of the study area are also covered by bushes/shrubs. Accordingly, the areal extent and proportions of each land/land cover is given in table 2.2.

Table 2.2 Land use/Land cover of Holeta River Catchment.

<b>No.</b>	<b>Land use/Land cover</b>	<b>Area(km<sup>2</sup>)</b>	<b>Area (%)</b>
1	Agriculture/ grass land	325.96	63.95
2	Forest	32.9	6.46
3	Bare Rock	5.55	1.09
4	Town	3.50	0.69
5	Bushes/Shrubs	133.20	26.13
6	Wetland	8.57	1.68
<b>Total</b>		<b>509.68</b>	<b>100</b>

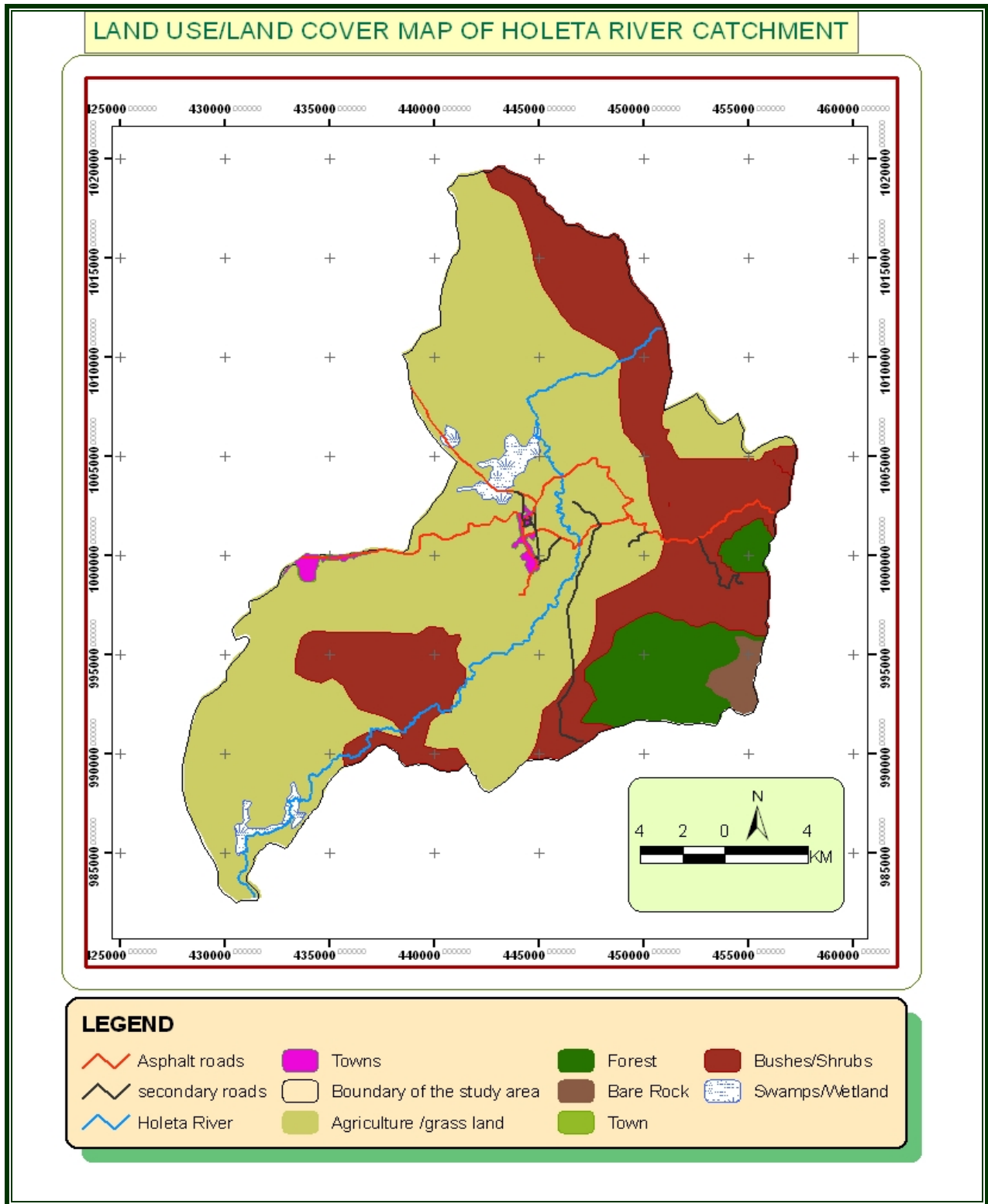


Figure2.6 Land use/Land cover Map (modified after Gelana Gadissa, 2005)

#### **2.3.4. Soil**

The variation in the characteristics of soils resulted in variations and water holding capacity. Climate, topography, parent material, maturity and biological activities are the major controlling factors that control soil formations. The resulting porosity and permeability of soil, on the other hand, control the vertical as well as horizontal movements of contaminants by surface- and sub-surface waters (Tamiru Alemayehu et al., 2005).

The soil development in the study area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products either remain in places and form residual soils or are transported and deposited to form alluvial deposits in low-lying areas. Meanwhile, the difference observed in the type and development of soils in the catchment is mostly depends on the topography, parent materials and the degree of weathering.

Although there is significant difference in the degree of weathering on the slopes, mostly the soils are highly eroded and result in thin soil cover along most parts of the divide lines of the catchment. In the localities where the topography is plain to gently sloping (central and southern parts) the area is covered by relatively thick soils (Figure2.7).

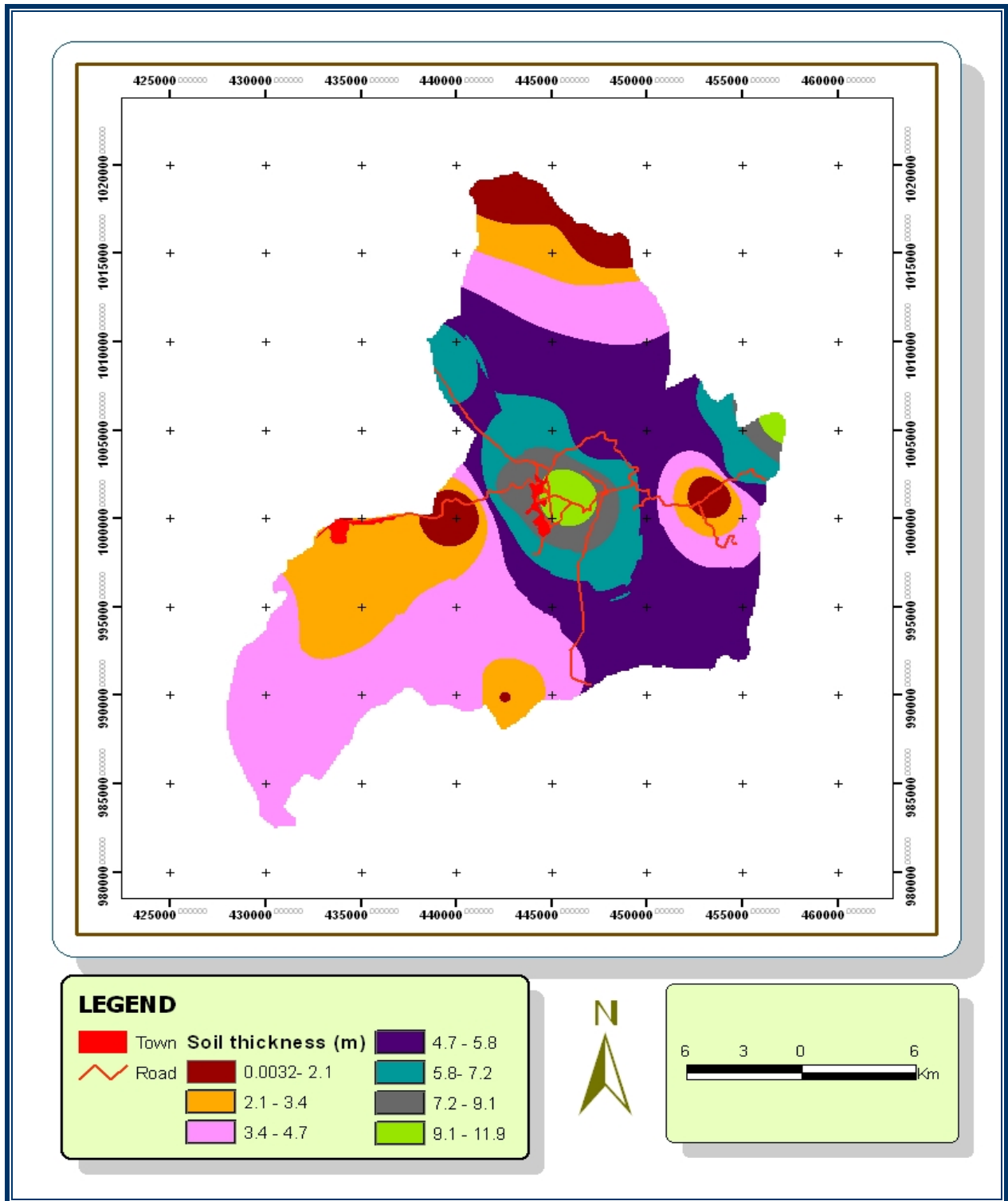
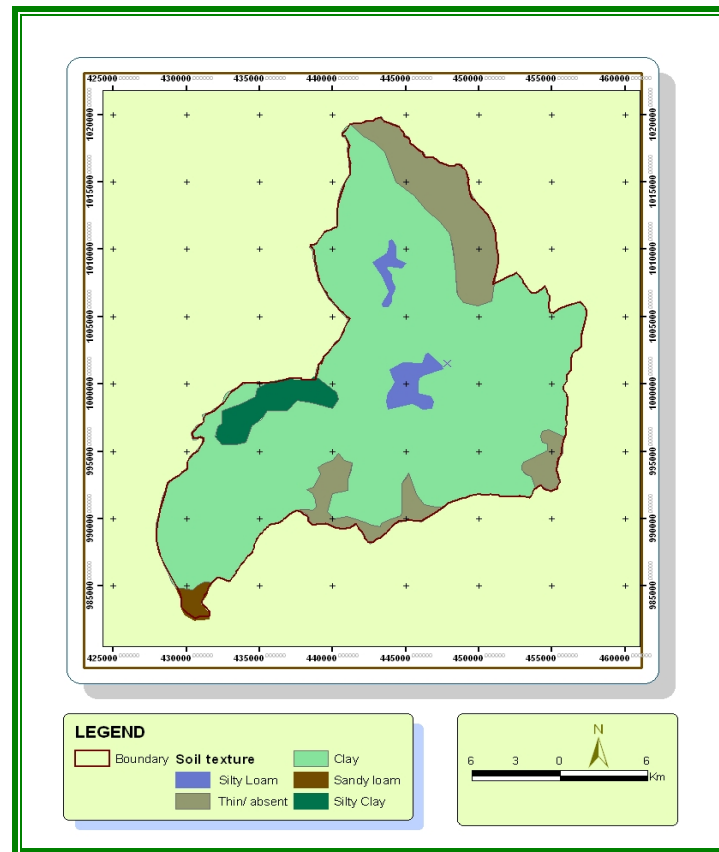


Figure 2.7 Soil thickness map of Holeta River Catchment

According to Holeta Agricultural Research Institute, the grain size distribution in the area shows that the residual soil in the central part of the catchment, has 7.5% clay, 51.25 Silt %, and 41.25 % sand which is categorized as silty loam. In eastern and southern tip of the catchment have 4.5% clay, 51.25% silt and 41.25% sand and classified as silty clay and sandy loam (Soil textural classification chart, 1951), respectively (Figure2.8).

In general, two types of soils dominate the study area, cambisols (Red clay Soil), in the northern, eastern, western, and central parts and vertisols (black cotton soil), in the central and southern parts of the catchment (Figure2.9). Accordingly, the proportions of each soil type are as follows: vertisols(16.9%), Cambisols (67.4%), and alluvial Soil (0.78%).of the total area.



**Figure 2.8 Soil Texture map**

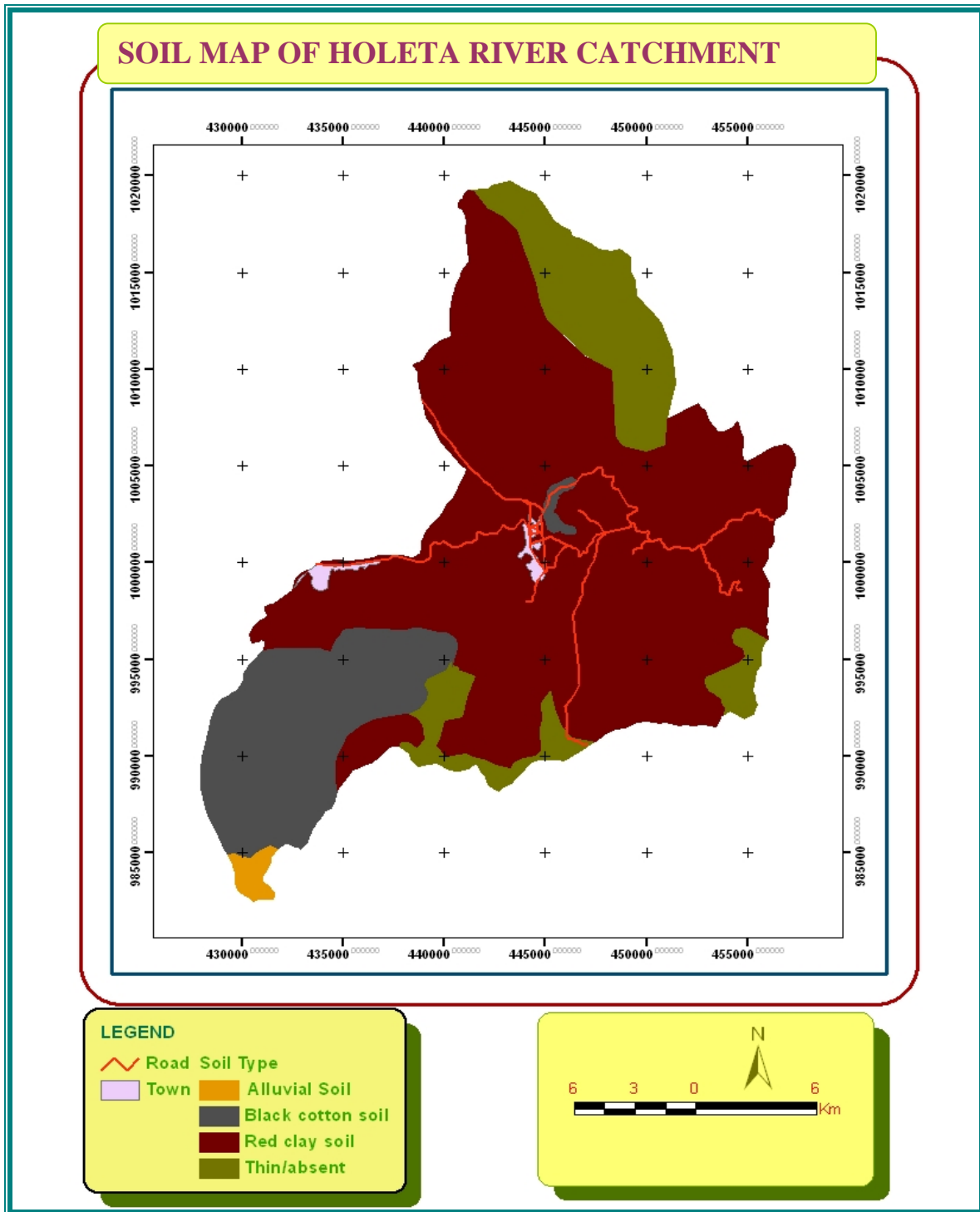


Figure2.9 Soil Type Map

## **CHAPTER THREE**

### **GEOLOGICAL SETTINGS**

#### **3.1. Regional Geology**

The study area is situated in the central part of Oromia, West Shewa Administrative Region, Welmera and Ejere Districts. 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 Formation ( $PNa_a$ ), and Tarmaber-Magazaz formation (Ntb) (Ketema Wogari, 2006).

The post rift volcanic and sediments include Adama group, Afar group Wonji 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 ( $p_{1a}$ )**

According to Ketema Wogari, 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 Ashangi Formation occurs in an old northwesterly trending rift system now buried under young volcanic and partially eroded away (Zanettin et al., 1978; 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; Seifemichael 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, 1979; Kazmin et al., 1980). The Aiba Basalts occur in north Shawa of northwest Oromia (Mengesha Teferra 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 M.Y. 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, Zanettin et al., 1978 and Kazmin et al. (1980, 1981) recognized analogous 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 (Jones and Rex, 1974; Kuntz et al., 1975; Morbidelli et al., 1975; Zanettin et al., 1978; Morton et al., 1979; Kazmin et al., 1980). 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 Teffera 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., 1974)

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.

Therefore, 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 Teffera 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 plaesols 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<sub>a</sub>) (Figure3.1).

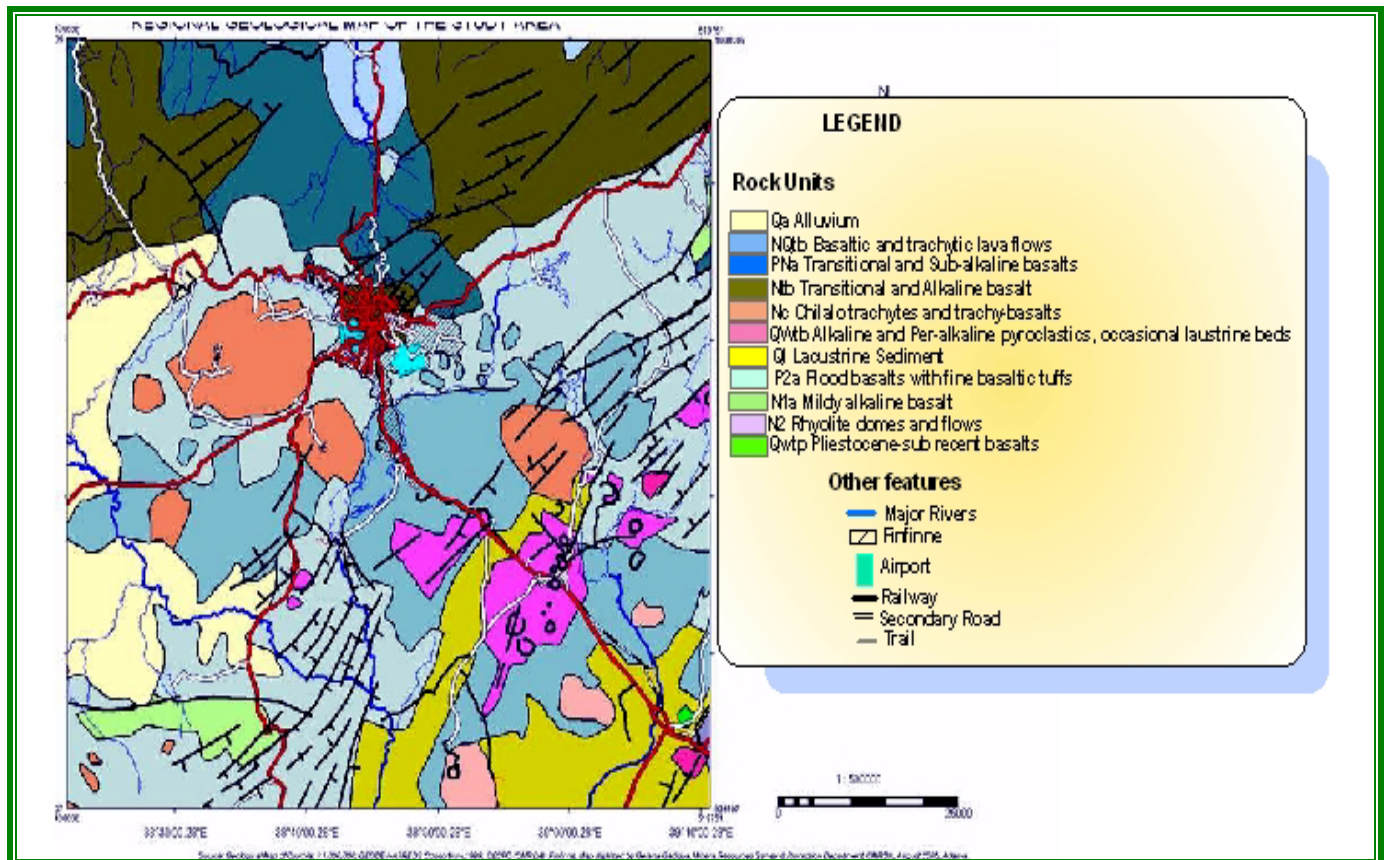


Figure3.1 Regional Geology map (Source: Gelana Gadissa, 2005)

## **3.2 Geological setting of the study area**

According to Ketema Wogari (2006), 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<sub>1a</sub>), 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 silty-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 3.2).



Figure 3.2:-Wetherd part of Alaji basalt south west of Menagesha (source: Ketema Wogari, 2006)

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 palaeosol 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 porphyritic and mostly aphanatic. It is highly fractured, columnar 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 3.3). 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 Holeta town. More than two basaltic flows can be recognized at this place separated by reddish clay pale soil of about 0.5-m thickness.



Figure 3.3 Spheroidal Weathering of Alaji basalt (adopted from Ketema Wogari, 2006)

#### **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 paleosol 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 catchment. This Fo'ata mountain range formed of Tarmaber-Megezez basalt is the source of most head stream waters of the catchment in general and Holeta River in particular. This basalt covers 15 % of the total area of the catchment.



Figure 3.4 Fo'ata mountain range covered by Tarmaber megezez basalt  
(Adopted from Ketema Wogari, 2006)

### **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 catchment, because of the mentioned reason (not extensive) and observed as patches of out crops in several places of the catchment. 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 (Figure3.5).



Figure 3.5 Columnary jointed Ignimbrite used for Dimension Stone

### **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 (Figure3.6). 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 3.6 Arrows indicating Southern portion of the study area covered by Alluvium deposit (Adopted from Ketema Wogari, 2006) .

### 3.3 Geological Structures

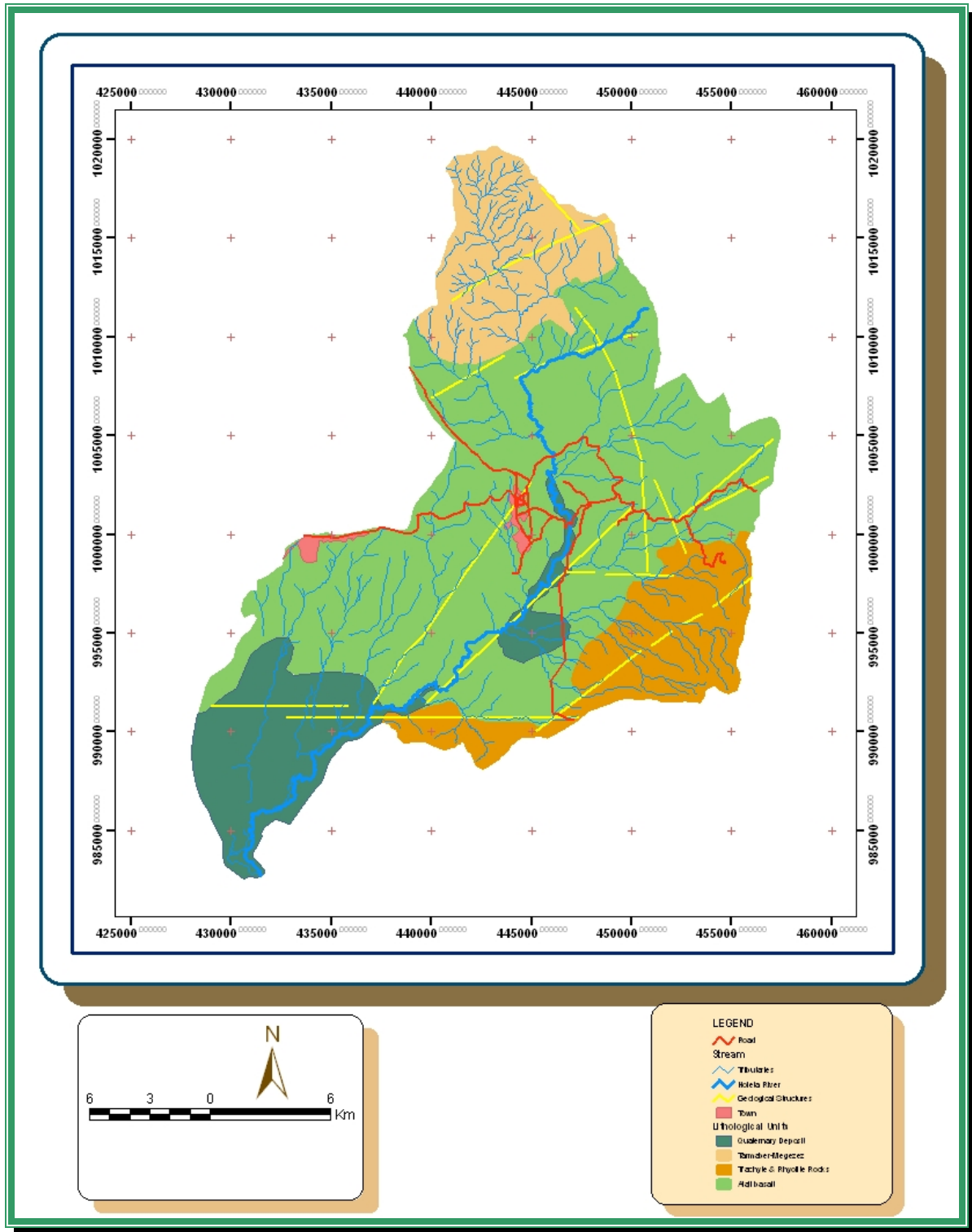
In the study area the occurrences of faults, joints and other structures with in the different volcanic rocks were reported by different professionals and consultants carried out some studies for the purpose of productive well site locations for different organizations institutions and flower farming 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 (Figure3.7).

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 Wechecha, 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 catchment (Ketema Wogari, 2006).



**Figure3.7** Geological map of Holeta River catchment (Adopted from: Ketema Wogari, 2006)

## **CHAPTER FOUR**

### **HYDROMETEOROLOGY**

#### **4.1. General**

Hydrometeorology is a science which links hydrology and meteorology. It studies the hydrological cycle which involve processes in the atmosphere and at the earth's surface (Shaw, 1985). Hydrometeorology data are required to determine the water balance of a certain basin for developing and managing its water resources. The most useful hydro meteorological elements are precipitation, evapotranspiration, sunshine hours, air temperature, and relative humidity, soil moisture and stream discharge (runoff), etc.

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#### **4.2. Meteorological parameters**

There are nine meteorological stations within and around the study area. There is only one station, located at Holeta Agricultural Research Institute. The other adjacent stations; Addis Alem, Teji, Sebeta, Ensilale, Boneya, Enchiny, Kimoye, and Addis Ababa Bole are selected from their geographical distribution point of view (Figure 4.1). The overall meteorological parameters available in the study area are; rainfall, temperature, relative humidity, wind speed, and sunshine duration. Accordingly, average of the nine stations meteorological (climatological) data has been used for the study area (Table 4.1).

The climatological data together with Holeta River, gagging near Holeta Genet town are the basis to determine the water balance of the catchment. The analysis results of the climatological data are presented in the following sections.

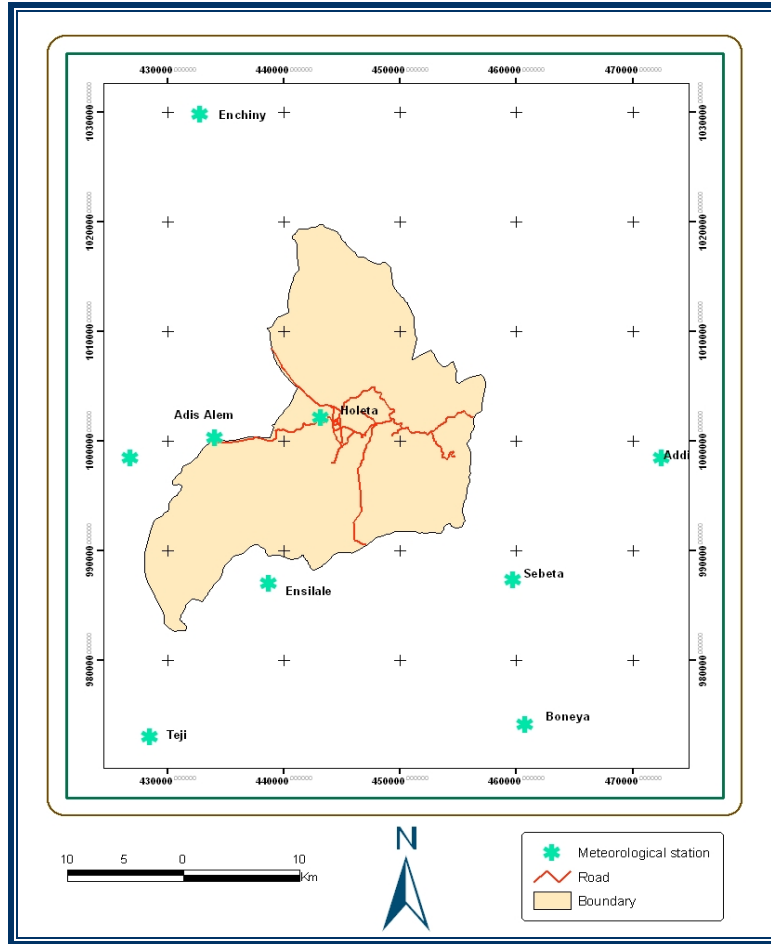


Figure 4.1. Location map of meteorological stations

Table 4.1 Meteorological Stations within and around Holeta River catchment

No.	Station	UTM (m)		Altitude(m.a.s.l)
		Latitude	Longitude	
1	Holeta	443220	1002172	2000
2	Adis Alem	434058	1000343	2240
3	Sebeta	459690	987412	2240
4	Addis Ababa Bole	472523	998456	2324
5	Kimoye	428560	998510	2200
6	Teji	430440	972917	2110
7	Boneya	463554	987408	2310
8	Ensilale	435870	987443	2205
9	Enchiny	432800	1029750	2690

### 4.2.1. Seasonality of Rainfall

The areal pattern of the seasonality of rainfall in the study area determined by analyzing long term mean monthly rainfall data for nine stations in and around the catchment.

Precipitation is the most commonly measured meteorological data. In this study, from 1965 to 2005 monthly total rainfall records of nine stations are used to analyze monthly mean rainfall, mean annual rainfall, rainfall coefficient and areal depth of precipitation. The mean monthly and annual mean rainfall as recorded by National Meteorological Services Agency (NMSA) at the stations Holeta, Addis Alem, Teji, Kimoye, Addis Ababa Bole, Boneya, Sebeta, Enchiny, and Ensilale are shown in Table 4.2 and Figure 4.2.

Table 4.2 Mean Monthly Rainfall in Nine Stations and Holeta River Catchment (Pm) (mm)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual Total	Mean monthly
Holeta	32.8	75.7	91.9	111.1	108.4	181.2	305.5	365.9	217.9	33.1	11.9	10.3	1545.6	128.8
Addis Alem	20.6	40.2	67.9	77.9	76.9	136.6	243.0	251.9	142.2	35.6	14.8	11.0	1118.7	93.2
Addis Ababa Bole	13.7	36.4	62.5	90.8	73.4	116.1	230.6	236.8	132.5	32.1	5.7	5.1	1035.7	86.3
Enchiny	22.5	28.5	73.2	71.4	69.6	131.5	254.7	236.2	129.3	46.5	20.1	11.9	1095.5	91.3
Kimoye	15.5	41.1	73.7	90.0	78.9	132.3	205.0	211.9	110.2	23.7	5.6	5.7	993.5	82.8
Sebeta	15.2	58.4	79.6	108.4	105.6	181.8	323.5	363.0	140.9	39.9	8.7	6.5	1431.4	119.3
Boneya	12.2	29.4	41.6	62.7	51.7	100.3	208.4	191.4	113.9	15.0	3.3	4.9	859.6	71.6
Ensilale	17.0	29.1	46.9	68.8	54.2	101.1	204.7	192.6	100.6	18.8	10.3	2.7	846.7	70.6
Teji	17.6	36.1	54.3	78.8	70.9	121.3	221.2	215.7	97.5	23.9	5.6	5.4	948.3	79.0
<b>Holeta catchment</b>	<b>18.6</b>	<b>41.7</b>	<b>65.7</b>	<b>84.4</b>	<b>76.6</b>	<b>133.6</b>	<b>244.1</b>	<b>251.7</b>	<b>131.7</b>	<b>29.8</b>	<b>9.5</b>	<b>7.1</b>	<b>1094.5</b>	<b>91.2</b>

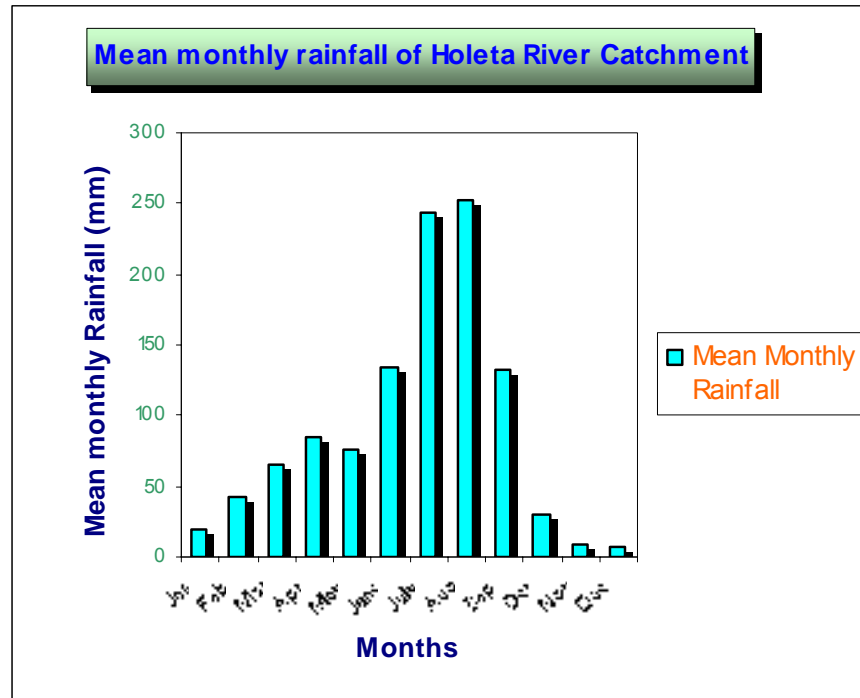


Figure 4.2 Mean Monthly rainfall of the study area.

To compare the monthly distribution of rainfall at these stations, the method employed here was adapted from a study of precipitation for the Awash River basin (Daniel Gemechu, 1974). This involved the calculation of “Rainfall Coefficient” for each month of the study area, the coefficient being the ratio between the mean monthly rainfall and one-twelfth of the annual mean of the total rainfalls.

$$RC = P_m / (P_a / 12)$$

Where, RC= Rainfall Coefficient

$P_a$ = Annual weighted rainfall of the area, which is 1349.07mm

$P_m$ = Mean monthly weighted Rainfall (Obtained by Thiessen Polygon method)

In this study, a month was distinguished “rainy” if the rainfall coefficient is 0.6 or over. The term “a small rain is employed to refer to those months with a rainfall coefficient of 0.6 to 0.9; and the term “big” rainy months are further

classified into three groups; those with “moderate concentration” of rainfall (coefficient of 2.0-2.9); and those with “very high concentration” of rainfall (coefficient of 3.0 and above). And if the rainfall coefficient is less than 0.6, the months are classified as dry seasons. This scheme of classification is presented in Table 4.3.

Table 4.3 Rainfall Coefficient of Holeta river catchment.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
* P <sub>m</sub> (mm)	27.03	61.69	80.52	99.60	94.62	160.76	277.23	316.50	180.60	30.67	11.26	8.60	1349.07
RC	0.24	0.52	0.72	0.89	0.84	1.43	2.47	2.82	1.61	0.27	0.10	0.08	
Season	Dry	Dry	Rainy	Rainy	Rainy	Rainy	Rainy	Rainy	Rainy	Dry	Dry	Dry	
Amount	-	-	Small	Small	Small	Big	Big	Big	Big	-	-	-	
Concentration	-	-	-	-	-	Moderate	High	High	moderate	-	-	-	

\*P<sub>m</sub>= Monthly weighted rain fall calculated by Thiessen polygons method

On the basis of the above classification, as depicted in table 4.3, the catchment is characterized by two rainy seasons and five dry months during the year. The two rainy seasons in total have seven months; March, April, May, June, July, August, and September. The first rainy season occurs during the months of March, April, and May. The rains are small, and account for 20.7% of the average annual rainfall of the catchment. The second big rainy season occurs from June to September, and accounts for 69.5% of the average annual rainfall of the area.

The big rainy seasons occur in June and September is moderate in concentration, whereas, in July and August it occurs in high concentration.

The catchment is characterized by five dry seasons. They occur during the months starts from October ends in February. The amount of rainfall that occurs during these five months of dry seasons in total accounts for 9.75% of the average annual rainfall of the catchment. The study area has not experienced a very high concentration of rainfall.

#### **4.2.2. Determination of Areal Depth of Precipitation**

In water budget studies, it is necessary to know the average depth of precipitation over a study catchment. 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 catchment (Fetter, 1994).

Because of the non-uniform distribution of the precipitation gauges and variation of topographic textures, the Thiessen polygon, Arithmetic mean and Isohyetal methods are selected for quantifying reliable and representative values of areal depth of precipitation.

##### **4.2.2.1. Arithmetic mean method**

Arithmetic mean method is the simplest one for evaluation of mean uniform distribution of rainfall of a basin. It is the mean of all the rain gauges that are located on relatively flat topography and closely and evenly spaced. Since only two stations (Holeta and Addis Alem) are located very close to each other, the estimated average uniform precipitation ( $P_A$ ) is computed as follows:

$$P_A = \sum_{i=1} P_i / n = \frac{1545.6+1118.7}{2} = \mathbf{1332.2mm}$$

Where  $P_A$  = average rain fall the total area

$P_i$  = Measured precipitation at a given station and time

$n$  = Number of rain gauges.

Therefore, an annual areal precipitation depth computed from Arithmetic method is **1332mm**.

#### 4.2.2.2. Isohyetal Method

Considering the non-uniformity of the land, variation of topographic of the area (2060-3380 m.a.s.l), Isohyetal method is selected. This analyzed by interpolating rainfall depth of equal value over the area interest (Figure4.3). Accordingly, the annual precipitation in the catchment is equal to 1227.94mm (Table4.4).

Table 4.4 Isohyetal method of calculating the annual rainfall in Holeta Catchment

<b>Isohyet (mm)</b>	<b>Estimated EUD</b>	<b>Net Area (km<sup>2</sup>)</b>	<b>Percent of Total area</b>	<b>Weighted Precipitation (mm)</b>
<b>(A)</b>	<b>(B)</b>	<b>(C)</b>	<b>(D)</b>	<b>( B*D)</b>
891-1000	945.5	40.7	8.01	75.7
1000-1109	1054.5	81.4	16.03	169.04
1109-1218	1163.5	75.4	14.80	172.2
1218-1327	1272.5	198.6	39.10	497.5
1327-1436	1381.5	73.9	14.60	201.7
1436-1545	1490.5	37.9	7.50	111.8
Total		507.9	100.00	<b>1227.94</b>

Where, EUD is Effective Uniform Depth of Precipitation

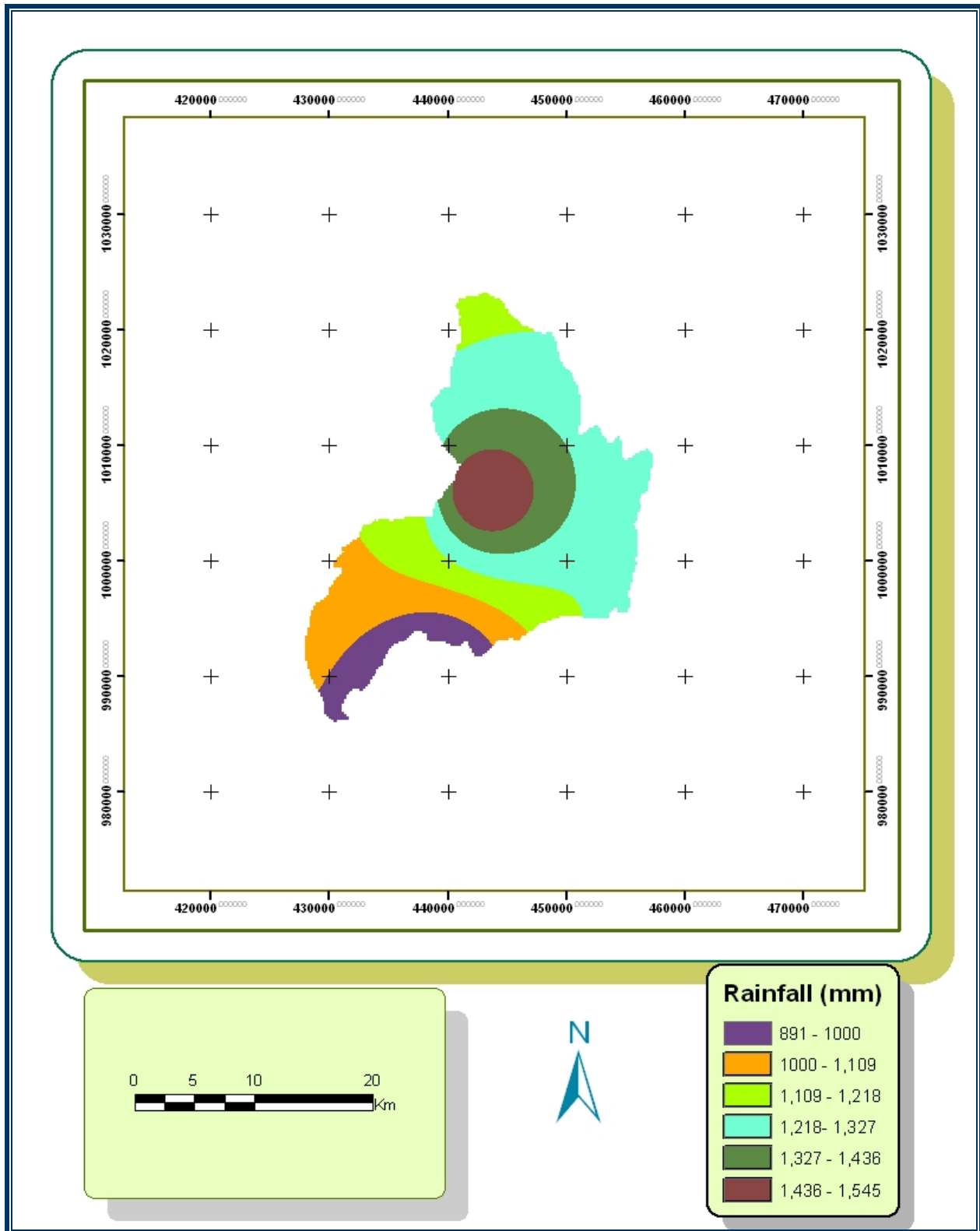


Figure 4.3 Isohyetal Map of Holeta River Catchment

#### 4.2.2.3. Thiessen polygons

This method provides a good result for non-uniformly distributed rain gauges over the area for both flat and hilly terrain by determining a weighted factor for each gauge. Even though nine stations are considered to construct Thiessen polygon, only five stations (Holeta, Addis Alem, Ensilale, Kimoye and Sebeta) are used for computing weighted annual rainfall (Figure4.4).

The method is given by:

$$P_A = \sum P_{i-1,i} a_{i-1,i} / A_t$$

Where,  $P_A$  = the average depth of Precipitation

$P_{i-1,i}$  = rainfall between isohyets  $i-1$  and  $i$

$a_{i-1,i}$  = area enclosed by successive isohyets of  $i-1,i$

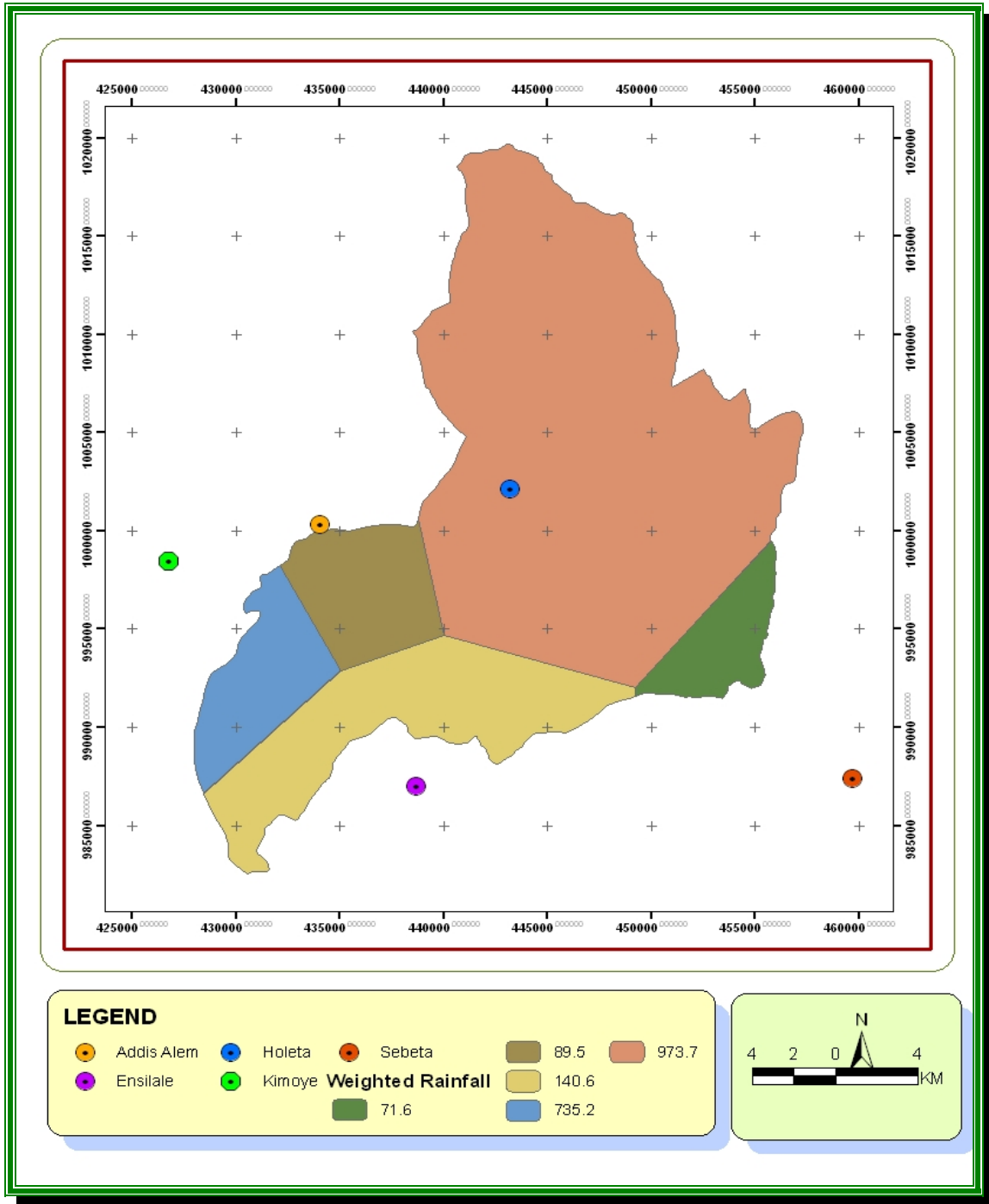
Using the method, the computed annual rainfall of Holeta River Catchment is 2010.6 mm (Table4.5).

Table 4.5 Thiessen polygon method to calculate the annual rainfall of Holeta River Catchment

Stations	Station Precipitation (mm)	Net area (Km <sup>2</sup> )	Percent of Total Area (%)	Weighted Precipitation (mm)
	<b>(A)</b>	<b>(B)</b>	<b>(C)</b>	<b>(A*C)</b>
<b>Holeta</b>	1545.6	320.0	63.0	973.7
<b>Addis Alem</b>	1118.7	40.6	8.0	89.5
<b>Kimoye</b>	993.5	37.8	7.4	73.5
<b>Sebeta</b>	1431.4	25.5	5.0	71.6
<b>Ensilale</b>	846.7	84.1	16.6	140.6
<b>Total</b>		508.0	100.0	<b>1348.9</b>

Table 4.6 Monthly weighted rainfall amount by Thiessen polygon method

Stations	Net area (Km <sup>2</sup> )	% of Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Mean	SD	Min	Max
Holeta	320	63.0	20.7	47.7	57.9	69.9	68.3	114.2	192.5	230.5	137.3	20.9	7.5	6.5	973.9	81.2	73.3	6.5	230.5
Adis Alem	40.6	8.0	1.6	3.2	5.4	6.2	6.2	10.9	19.4	20.2	11.4	2.9	1.2	0.9	89.5	7.5	6.7	0.9	20.2
Kimoye	37.8	7.4	1.15	3.0	5.5	6.7	5.8	9.8	15.2	15.7	8.2	1.8	0.4	0.4	73.5	6.1	5.3	0.4	15.7
Sebeta	25.5	5	0.76	2.92	3.98	5.42	5.28	9.09	16.18	18.15	7.05	2.00	0.44	0.33	71.6	6.0	5.9	0.33	18.15
Ensilale	84.1	16.6	2.82	4.83	7.79	11.42	9.00	16.78	33.98	31.97	16.70	3.12	1.71	0.45	140.6	11.7	11.3	0.45	
Total	508	100	27.03	61.69	80.52	99.60	94.62	160.76	277.23	316.50	180.60	30.67	11.26	8.60	1349.07	112.42	102.2	8.6	316.5
Average			<b>5.41</b>	<b>12.34</b>	<b>16.10</b>	<b>19.92</b>	<b>18.92</b>	<b>32.15</b>	<b>55.45</b>	<b>63.30</b>	<b>36.12</b>	<b>6.13</b>	<b>2.25</b>	<b>1.72</b>	<b>269.81</b>	<b>143.69</b>	<b>20.4</b>	<b>1.72</b>	<b>63.3</b>
SD			<b>8.58</b>	<b>19.78</b>	<b>23.40</b>	<b>28.04</b>	<b>27.64</b>	<b>45.97</b>	<b>76.99</b>	<b>93.68</b>	<b>56.69</b>	<b>8.27</b>	<b>2.98</b>	<b>2.68</b>	<b>394.58</b>	<b>32.88</b>	<b>29.7</b>		



**Figure 4.4 Theissen polygon map of Holeta River Catchment**

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, Isohyetal method, and Thiessen methods are 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 these methods is 1303.01 mm.

### 4.2.3. Temperature

In the study area, as in all other places of Ethiopia, the altitude of the sun is always high, making solar radiation intense. Temperature is high during the day and is considerably reduced at night causing the daily range of temperature to be large. Temperature data are the major factor in computing potential evapotranspiration of the area.

From 1980 to 2005 monthly mean maximum and minimum temperature as recoded by the NMSA at the stations of Holeta, Addis Alem, Kimoye, and Addis Ababa Bole are used to calculate representative monthly and annual average temperature of the area. Accordingly the average monthly and annual maximum and minimum temperatures of the catchment are shown in Table4.7 and Figure4.5.

The mean annual minimum temperature of the study area is 8.4 °C and the mean annual maximum temperature is 24.1°C. The mean annual air temperature of the area is 16.2°C.

Table 4.7 Mean Monthly Temperature of Holeta River catchment

Months	Jan	Feb.	Mar	Apr.	May	Jun	Jul	Aug	Sep.	Oct	Nov	Dec	Ann.Av.	SD
<b>M.M.Max. Temp.</b>	25.5	25.6	25.7	25.5	25.7	23.7	21.7	21.8	22.3	23.0	24.2	24.3	24.1	17.8
<b>M.M.Min.Temp.</b>	6.5	7.9	9.3	9.7	9.7	9.4	10.0	10.3	9.5	7.5	5.8	5.1	8.4	7.7
<b>M.M. Temp.</b>	<b>16.0</b>	<b>16.7</b>	<b>17.5</b>	<b>17.6</b>	<b>17.7</b>	<b>16.5</b>	<b>15.9</b>	<b>16.0</b>	<b>15.9</b>	<b>15.3</b>	<b>15.0</b>	<b>14.7</b>	<b>16.2</b>	14.9

Where, M.M.Max. Temp. is mean monthly maximum temperature;  
M.M.min.Temp is mean monthly minimum temperature; M.M.Temp.is mean  
monthly air temperature.

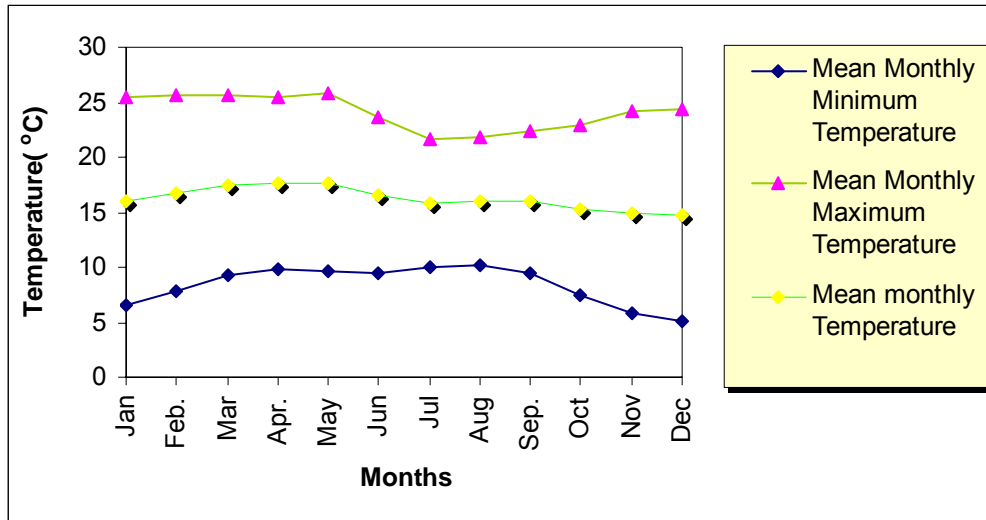


Figure 4.5 Mean air Temperature of Holeta River catchment

Figure 4.6 shows long-term temperature and rainfall relation for the catchment. Even though the maximum air temperature occurs in May, high temperature values are observed during the rainy seasons. Months in the rainy seasons are warmer than months in dry seasons. The minimum temperatures as well as rainfall are also occurring almost in similar range of months.

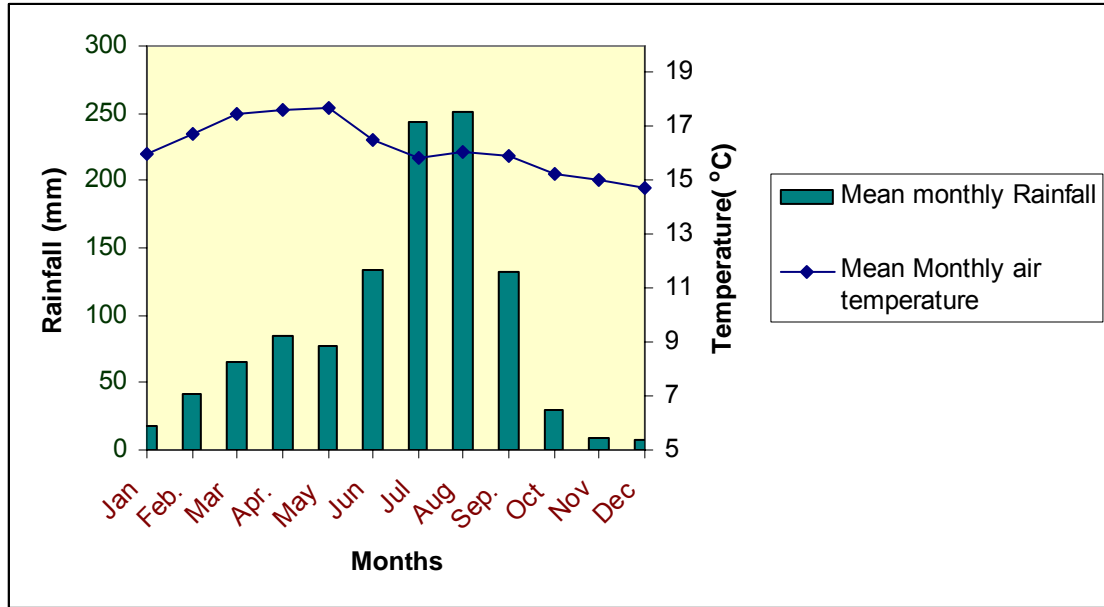


Figure 4.6 Temperature and Rainfall Relation Ship

#### 4.2.4. Wind Speed

The movement of air and moisture transfer depends on wind speed and turbulence. Evaporation has a direct relation wind speed and turbulence (Shaw, 1988; Tamiru Alemayehu and Tenalem Ayenew, 2001). Wind speed and air temperature removes water vapor molecules from the air in contact with the water holding surface and enable evaporation to proceed at maximum rate governing with the existing main factors, temperature and humidity condition.

In this study, Wind speed data measured at height of 2m above the ground surface and recorded from 1988-2003 is analyzed from the Holeta station, located in the center of the catchment. The mean monthly wind speed data is shown in Table 4.8. The magnitude varies from 1.4-0.8 m/sec. Wind speed is relatively low, especially in the rainy season (July- September).

#### 4.2.5. Sunshine Duration

Monthly sunshine hours were collected from Holeta meteorological Station. The data were recorded from 1981 to 1998. The mean monthly sunshine hours of

the area are given in the table4.8. The maximum sunshine hour is recorded in December (9.1 hours) whereas the minimum one is in August (3.13 hours). Generally, the maximum sunshine hours are found in dry months whereas the minimum are in very highly rainy months.

#### 4.2.6. Relative Humidity

Relative humidity is the relative measure of the amount of the moisture in the air to the amount needed to saturate the air at the same temperature  $e_d/e_a$  represents as a percentage (Shaw, 1985).

$$RH = (e_d/e_a) * 100$$

Where, RH is Relative humidity

$e_d$  is actual vapor pressure at the dew point,  $T_d$

$e_a$  is saturated vapor pressure at air temperature,  $T_a$

Hence therefore, the relative humidity data (%) was taken from Holeta meteorological station. The data was recorded from 1980-1997. The mean monthly values were computed and are given in the table4.8 below. The maximum and minimum relative humidity is found in August (82.8%) and December (53.0%), respectively. This maximum and minimum value is also within very highly rainy month and dry month, respectively. In general the highest humidity values are found in the rainy months whereas the lowest values are in the dry months.

Table4.8 Mean Monthly wind speed, relative humidity, and sunshine hour.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average	SD
W.S(m/s)	1.05	1.2	1.3	1.2	1.3	1.1	0.85	0.8	0.9	0.95	1.4	1.1	<b>1.09</b>	1.01
R.H (%)	53.7	55.1	54.7	61.7	54.1	71.1	81.7	82.8	77.4	59.4	55.1	53.0	<b>63.5</b>	58.1
S (Hrs)	8.53	7.93	7.18	6.47	7.19	5.51	3.14	3.13	4.86	7.92	8.98	9.1	<b>6.7</b>	6.1

Where: S is Sunshine Hours; R.H. is relative humidity; and W.S is wind speed.

### **4.3. Runoff**

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

Both perennial and/or intermittent streams and perennial rivers exist in the catchment. The hydrological characteristics of the catchment is described by the Holeta river that discharges all the run off from the catchment. 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 streams in the upper part of the catchment. These streams merge together on the middle of the catchment and cover relatively large area of the drainage basin.

Kebi, Bobe, Welenso and Karsa drain the catchment 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 draining the east –west oriented ridges on the north side of the catchment show such drainage pattern where as, streams that drain the south west of the catchment do have parallel drainage pattern. The catchment has a forth order river net work (Ketema Wogari, 2006).

#### 4.3.1. 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 gaged near Holeta Genet town is used in the total runoff analysis of the catchment (Table 4.9).

The mean annual discharge of the Holeta River at the road crossing (119 km<sup>2</sup>) is 1.7 m<sup>3</sup> / sec or total Annual flow of 55 Mm<sup>3</sup>. This results in an average unit discharge of about 14.3 l/s /km<sup>2</sup>. 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 m.a.s.l) is expected to be higher than in the town (2380 m.a.s.l) 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

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Mm <sup>3</sup>	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 <sup>3</sup> /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	20.3
mm	5.8	5.9	5.8	6.9	7.1	12.8	88.9	170	118	19.9	9.9	5.9	<b>456.9</b>

Figure4.7- Shows the monthly rainfall-runoff relationship. Runoff is concentrated from July to September. This runoff represents more than 80% of the annual runoff

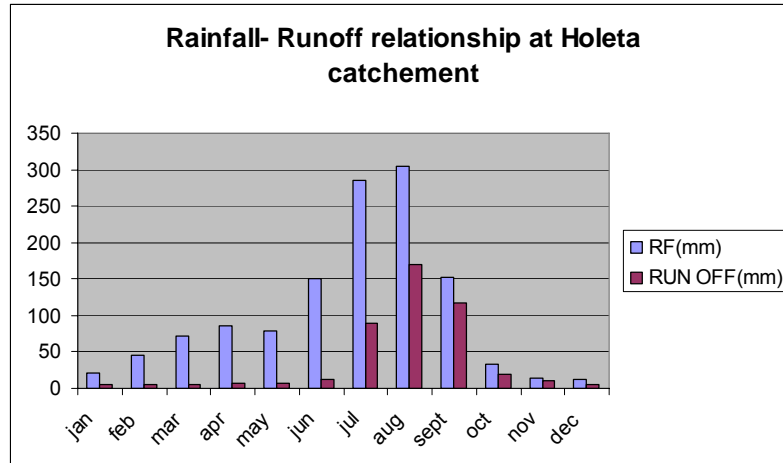


Figure 4.7 Rainfall-Runoff relationships at Holeta catchment.

Actually in this paper the base flow separation software programmer method described by Lynne and Hollick (1979) and Nathan and McMahon (1990) 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  $1.7\text{m}^3/\text{sec}$  56% ( $0.952\text{m}^3/\text{s}$ ) is a contribution from the base flow and 44% ( $0.748\text{m}^3/\text{s}$ ) is a contribution from overland flow.

The yearly volume of base flow is spread over the catchment area above the gaging station ( $119\text{km}^2$ ) in order to estimate the minimum depth in mm of recharge to ground water in the given catchment area which is 252mm. This results in an average unit ground water recharge of  $81\text{l/s/km}^2$ .

In reality, the amount of recharge or infiltration with in the same catchment 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 catchment area despite the variation from one location to another.

Hence for this particular study area, the total catchment 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 (Ketema Wogari, 2006).

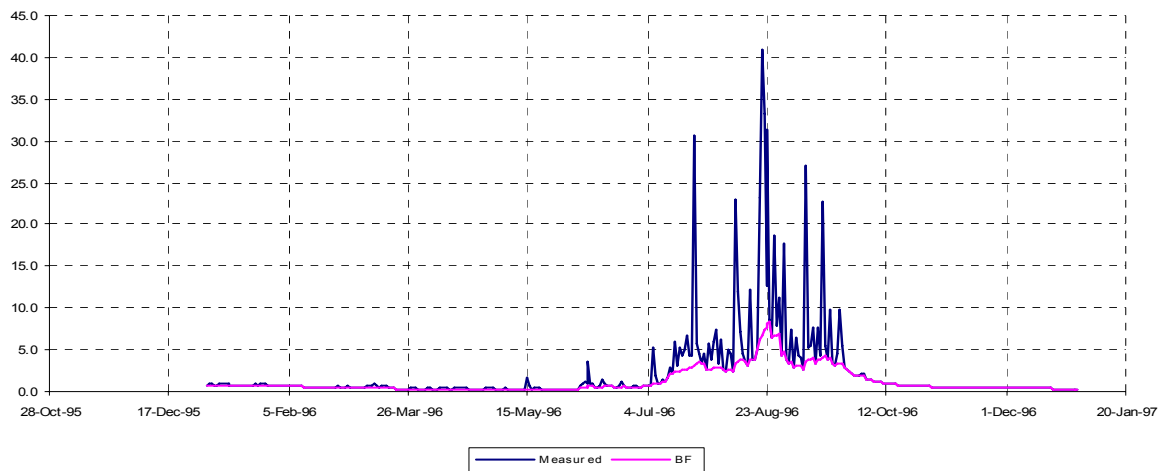


Figure 4.8 Hydrograph base flow separation (Adopted from: Ketema Wogari, 2006)

#### 4.4. 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. Therefore, 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. Therefore, evapotranspiration has been computed using the recorded data of meteorological stations of the catchment employing the Penman, Thornthwaite and Mather empirical formulae, as well as using satellite imageries by adopting SEBAL algorithm.

**4.4.1. 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 Ayenew and Tamiru Alemayehu, 2001). PET has a positive relation with temperature, sunshine, and wind speed but has a negative relation ship with air humidity.

**4.4.1.1 Penman modified method**

For calculating potential evaportanspiration there are different formulae but for this research, Penman modified method and adjusted Thorentnwaite 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:

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

Where the extra subscript ‘t’ signifies inclusion of transpiration effects.

$$H_T = 0.75R_1 - R_o \text{ ----- 4.2}$$

Where;  $\gamma$  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  $0.35[0.5 + u_2 / 100] (e_a - e_d)$ ) the coefficient 0.5 being replaced by 1 to allow for extra roughness.

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

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 south of  $54 1/2^{\circ}N$ , (Shaw. 1988) is equal to:

$$f_a(n/N) = (0.16 + 0.62 n/N)\text{-----4.4}$$

The empirical equation for the outgoing reduction takes the form:

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

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, silty 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). Therefore by averaging the above albedo the value of ' $\gamma$ ' is taken as 0.23. The calculated annual potential evapotranspiration of the study area according to penman is 1273.6 mm (Table 4.10).

**4.4.1.2 Thornthwaite method**

Thornthwaite 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):

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

Where m is the month 1, 2, 3..... 12, and N<sub>m</sub> is the monthly adjustment factor related to hours of daylight, T<sub>m</sub> is the monthly mean temperature °C (Table 4.7), I is the heat index for the year, given by:

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

And:  $a=6.7 \times 10^{-7} \quad \beta = 7.7 \times 10^{-5} I^2 + 1.8 \times 10^{-2} I + 0.49$

The calculated annual PET of Holeta river catchment as of Thornthwaite is 688.9mm (Table 4.10).

From the above two results, the PET obtained from Thornthwaite method seems to be representative. Penman modified method overestimates the value. Therefore, for further analyses the catchment’s PET is assumed to be 688.9mm.

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

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly
<b>P.m</b>	107.2	109.9	131.8	130.5	121.9	95.5	83.4	84.7	91.5	110.6	103.6	102.9	1273.6
<b>T.w</b>	51.8	56.6	64.8	82.2	67.4	60.2	54.3	54.1	51.9	48.7	48.5	48.6	688.9

#### 4.4.2. 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 methods employed in this paper are that developed by Thornthwaite and Mather (1957) method and SEBAL approach.

**4.4.2.1. 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);

$$AET = PET \times f(AW/AWC) \text{-----} 4.7$$

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 three major groups of soil type (Clay, clay loam and sandy loam) with average 200 mm of water at field capacity, 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 (Table 4.10) is calculated using Thornthwaite and Mather (Ding man, 1994) standard soil water balance model. In puts to Thornthwaite model consists of monthly value of rain fall, P<sub>m</sub> (Table 4.2), and potential evapotranspiration, PET<sub>m</sub> from Thornthwaite method (Table4.10).

Alley (1984, in Dingman), found out that if in a given month P<sub>m</sub>>PET<sub>m</sub>, the value of soil moisture at the end of that month, S<sub>m</sub>, is found as:

$$S_m = \min \{[(P_m - PET_m) + S_{m-1}] S_{mm}\} \text{ -----4.8}$$

If P<sub>m</sub><PET<sub>m</sub>, a soil moisture deficit develops or increases. The soil moisture for this case is given as:

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

The monthly actual evapotranspiration,  $AET_m$  is then found as:

$$AET = PET \text{ if } P_m > PET \text{-----4.10 Otherwise,}$$

$$AET_m = P_m + S_{m-1} - S_m \text{-----4.11}$$

Using this method and the potential evapotranspiration from Thornthwaite method, the actual evapotranspiration (AET) of the study area is **596.76 mm/year** (Table 4.11).

**Table 4.11:- Estimation of Actual Evapotranspiration, AET by using Thornthwaite-Mather method.**

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly
Pm	18.6	41.7	65.7	84.4	76.6	133.6	244.1	251.7	131.7	29.8	9.5	7.1	1094.5
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	-33.18	-14.91	0.88	2.24	9.22	73.4	189.79	197.6	79.75	-18.9	-39.01	-41.52	405.36
Ac.p.wl	-117.6	-124.5	-	-	-	-	-	-	-	-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	4.93	49.98	58.42	82.16	64.78	60.20	54.3	54.10	51.95	45.4	38.73	32.81	596.76
D	46.85	6.63	6.4	0	2.6	0	0	0	0	3.3	9.78	15.81	91.37
S	0	0	0	0	0	30.59	189.79	197.6	79.75	0	0	0	497.73

Where, 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.

In order to have reasonable value of AET for the study area, the average value, which is 456.1mm/year obtained from the two different methods (Thornthwaite method and SEBAL approach) 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. Therefore, the Average AET value, which is 456.1mm/year, will be taken for any further water balance calculation of Holeta catchments.

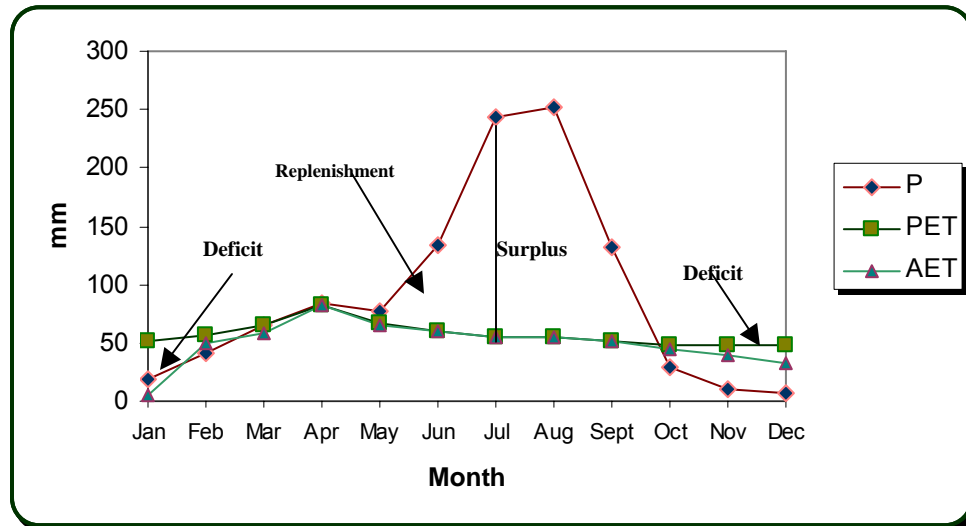


Figure 4.9 Monthly water balance plot for Holeta River catchment

#### 4.4.2.2 Using SEBAL model with remotely sensed data

Remote sensing is an indirect evapotranspiration measurement technique; it involves using a set of equations in a strict hierarchical sequence to convert the spectral radiances measured by satellites or air planes in estimates of actual ET (Water watch, 2007).

SEBAL model demonstrates that remote sensing is a direct method to estimate ET without a prior knowledge on soil, crop, and management conditions. Evapotranspiration is related to the surface –energy balance, which reads as;

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

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

Therefore, the actual Evapotranspiration is calculated using MODIS, NDVI and other related satellite imagery data with their respective algorithms; annual AET is calculated and obtained with cell size of 100X100 for the study area on the basis of land use/land cover (Figure4.10). So, the mean annual AET is 315.4mm.

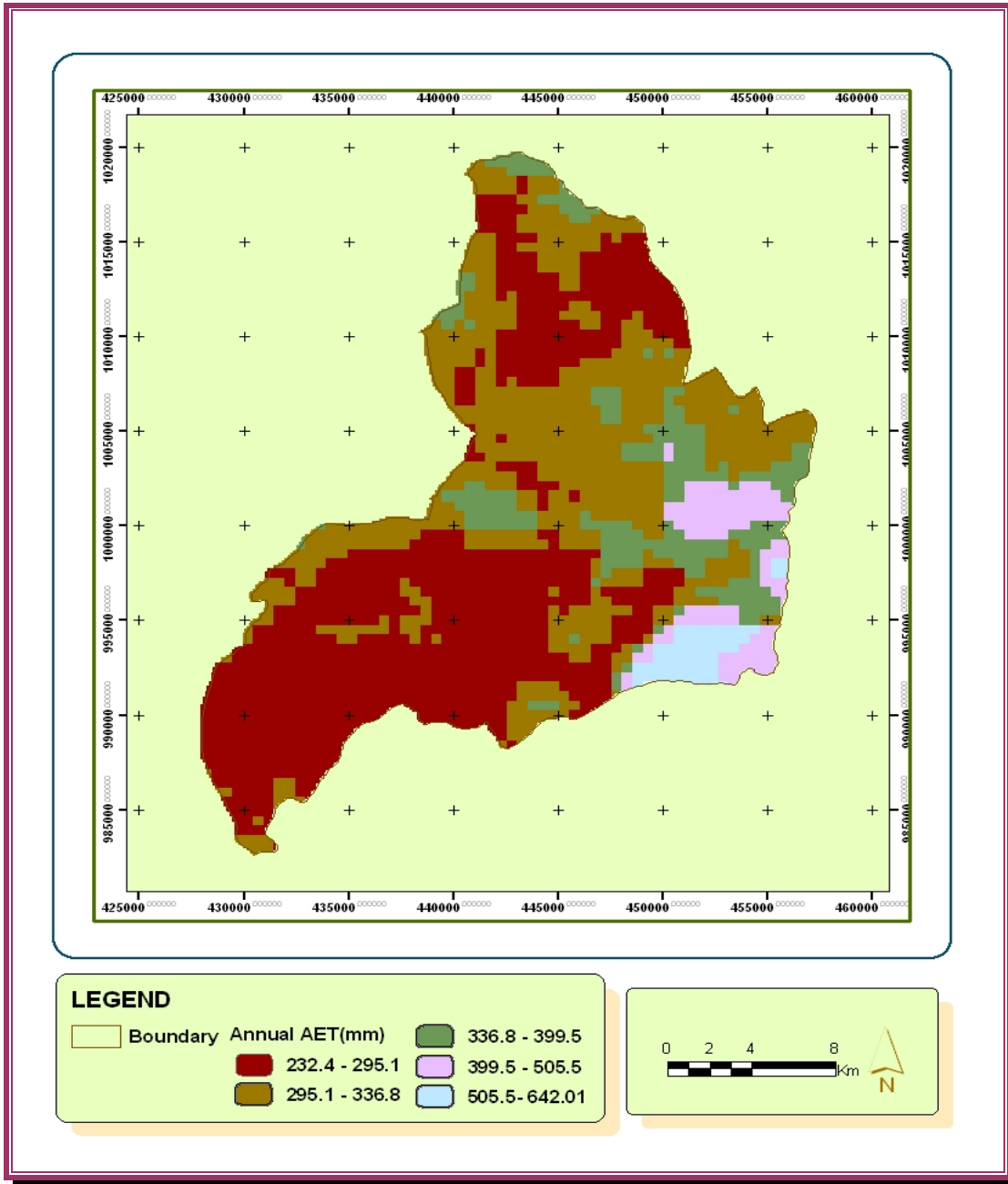


Figure 4.10 Actual Evapotranspiration map of Holeta River Catchment

## **4.5. Groundwater Recharge estimation**

Ground water 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.

### ***4.5.1 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 Mm<sup>3</sup> of the total 227 Mm<sup>3</sup> per year and the annual runoff is 100 Mm<sup>3</sup> per year (Figure 4.8).

### ***4.5.2. 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 catchment, 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 catchment (basin) is assumed as a close basin based on the detailed field observation around the water divide of the basin from Fo'ata, and Wechecha. 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.

$$\text{Inflow} = \text{out flow} + \text{change in storage.}$$

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:

$$P + G_i = AET + SRO + R + G_o + \Delta S$$

Where;  $G_i$  = Ground water in flow  $G_o$  = Ground water out flow  $\Delta s$  = 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:

$$P = AET + SRO + R$$

$P$  = precipitation (1303.01) annually

$AET$  = annual actual evapotranspiration (456.1mm)

$SRO$  = annual surface runoff (456.9mm)

$$R = P - AET - SRO = \mathbf{390.01mm}$$

Therefore, the amount of recharge in Holeta catchment is calculated as 160 mm. 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 catchment is good for ground water percolation.

## **CHAPTER FIVE**

### **HYDROGEOLOGY**

#### **5.1 General**

The groundwater circulation and the dispersion of pollutants depend on the hydrogeological characteristics of the material such as porosity, permeability, transmissivity, etc. The origin, flow and chemical constitute of groundwater is controlled by the type of lithology, distribution, thickness and structure of hydrostratigraphical units through which it moves. The stress from tectonism and weathering govern the hydrogeochemical characteristics of earth material (Tamiru Alemayehu et al., 2005).

#### **5.2. Hydrostratigraphic units**

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

##### ***5.2.1 Quaternary alluvial sediments.***

This sediment pertains to river valleys and southern plain areas of the catchment 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 (HTBH1) drilled in Holeta river valley, reveled the thickness of about 20 meters (Figure 5.1). A shallow well drilled at Geresu Seda well n<sub>01</sub> 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.

However, from field observation and geological log, the top part of the alluvial deposit is mainly clayey, and the observation of drilled well yield observation indicates that the sediment varies lithologically from fine to coarse material at depth (Ketema Wogari, 2006).

### **5.2.2 Buried valley deposit.**

Thick gravel and sand deposit of an old river was observed at Holeta test well (HTBH1) 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 HTBH1 is about 70 meters (Figure 5.1). 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 coarse to fine. The geologic log of HTBH1 indicates this (Figure 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 be 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 (Ketema Wogari, 2006).

Holeta Borehole (HTBH1)		
UTM (m)		Elivation (m)
X	Y	
446080	1002870	2388

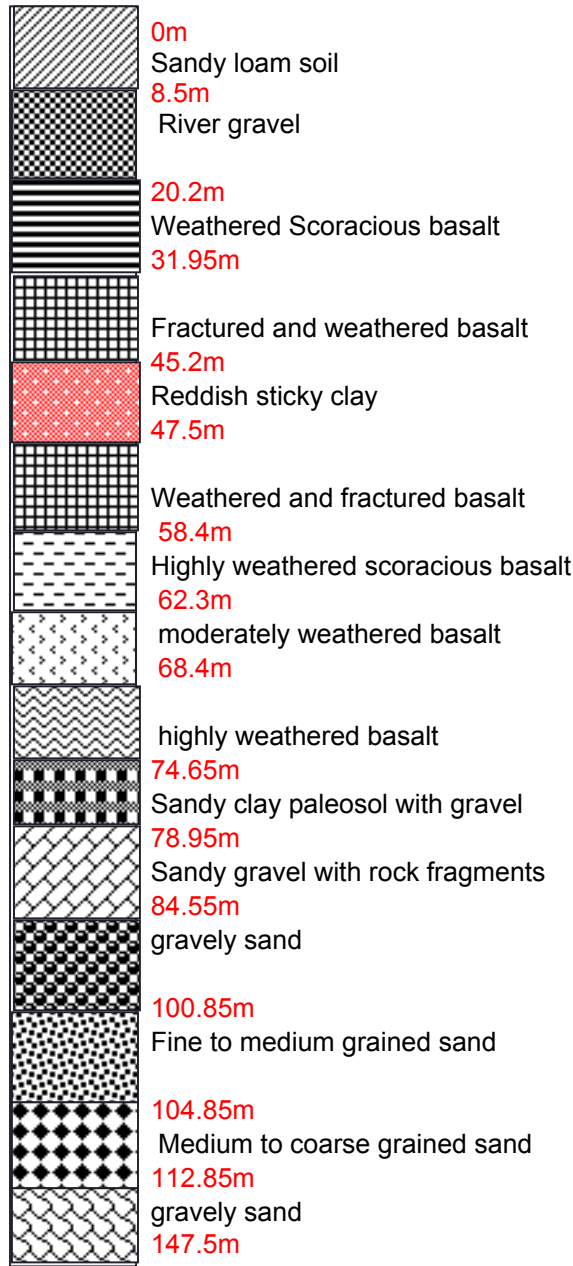


Figure 5.1 Lithological log of Holeta Bore hole (not to scale).

### **5.2.3 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 within the rock matrix. The primary and secondary openings which make the rock porous and pervious are 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 lithological features observed are considered to be favorable.

In the catchment 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 whereas those basaltic lava flow constituting the elevated lands such as Fo'ota range, Fo'ota mintile area Simbrti kotu area and Dagu Dufa area are highly weathered and where 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 scoriaceous and

vesicular. Therefore 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).

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 catchment 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 interbedded 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 catchment most of the important water bearing zone are observed blow 80 meters from the ground surface (Figure 5.2). 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.

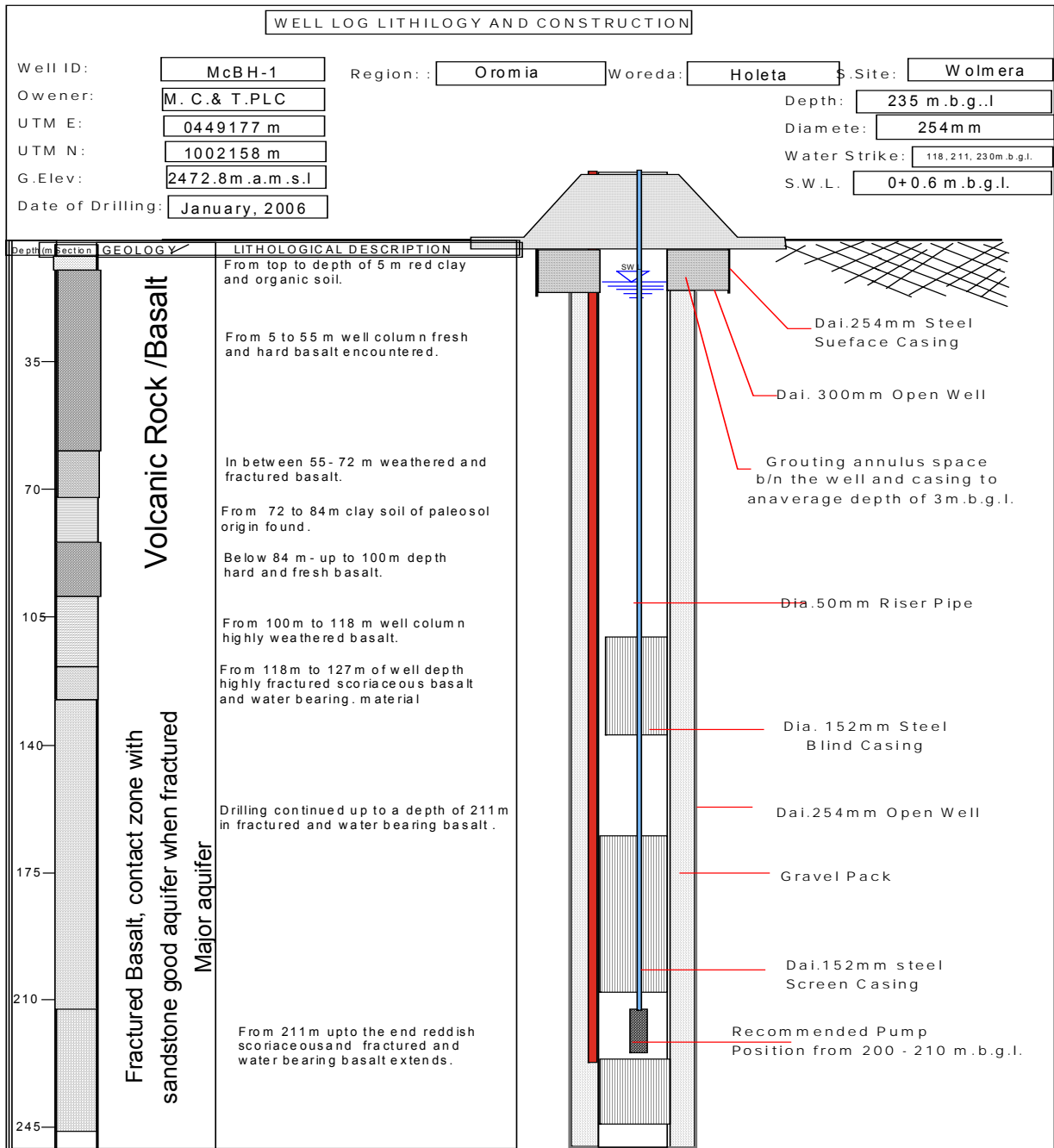


Figure 5.2. Lithological log of Macro P.L.C (not to scale).

### **5.3 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 groundwater recharge and discharge areas. Flow lines can be drawn 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 ground water, 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 catchment are Fo'ota mountain range, Fo'ota mintile area, simbrti kotu area, and Daku Dufa area in the northern part and Menagesha-Wechecha mountain chain in the eastern part of the catchment, which are also located at higher elevation (Figure5.3). These high lying areas get high rain fall compared to its surrounding low lying area.

Ground water recharge can take place due to rain fall 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 catchment, 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 catchment, because of upper layer is mainly clayey in nature the possibility of recharge due to direct precipitation on the potential site is relatively small. Ground water due to infiltration from the rivers is possible but it can not be considered as major recharge mechanism.

The discharge areas of the catchment 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 catchment 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 catchment has the recharge area in the basin divide and the discharge area at the valley bottom (Figure5.3). Several boreholes, shallow wells, Hand dug wells and springs observed (inventoried) in the catchment confirm this situation.

In general, recharge to the aquifer systems comes from precipitation and loss from ephemeral streams. (Ketema Wogari, 2006).

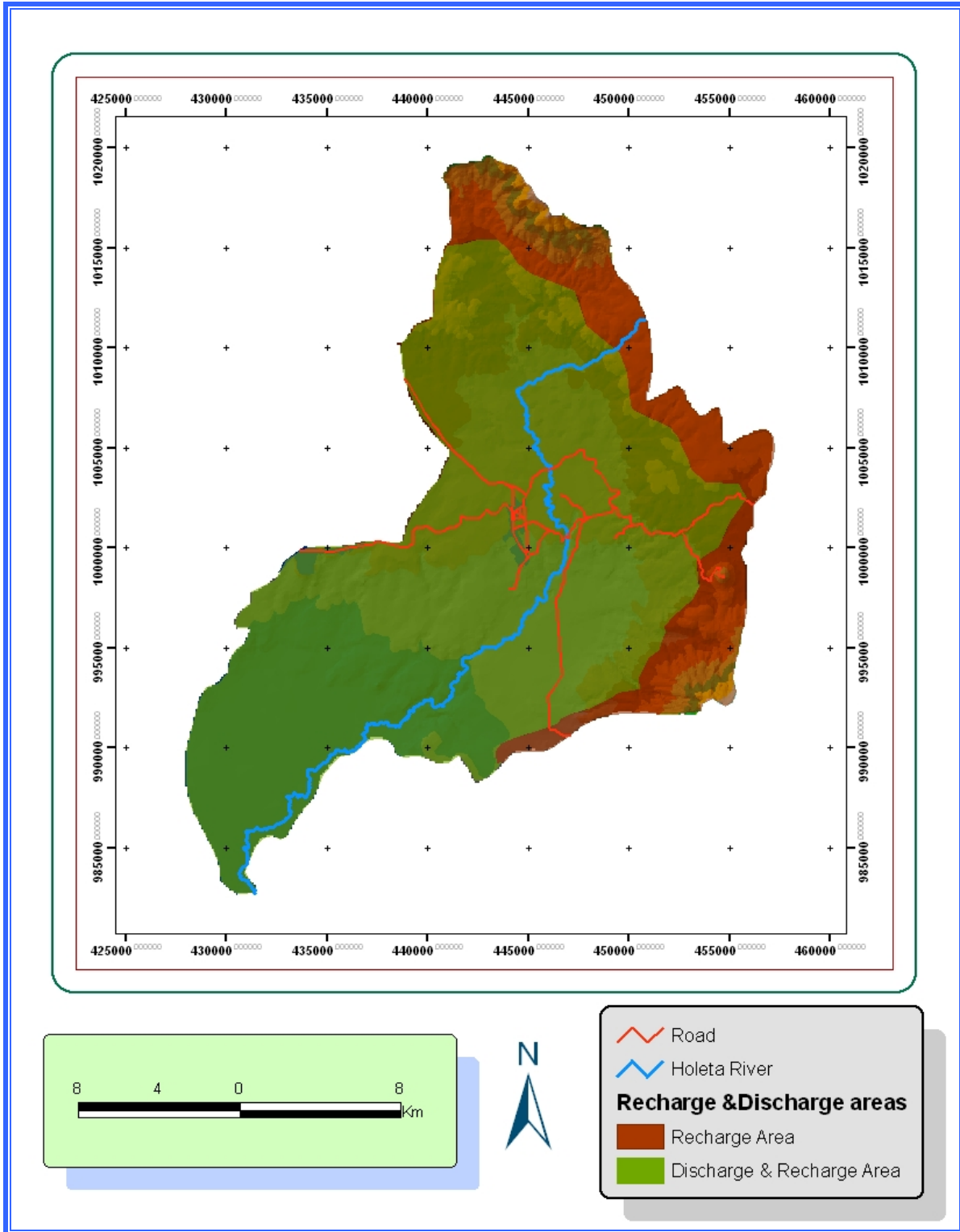
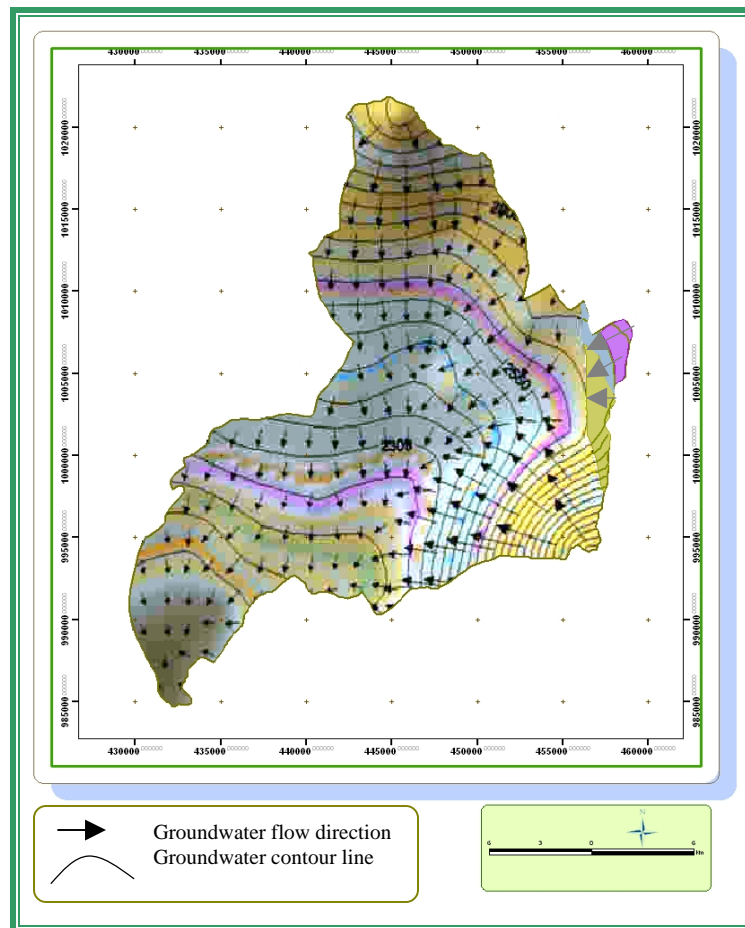


Figure 5.3 Recharge and Discharge Map (Modified After Ketema Wogari, 2006)

## 5.4 Groundwater flow

The study of groundwater flow direction is essentially the identification of the movement of contaminants, once they enter the groundwater from high grounds. The elevation of water level in boreholes (for shallow or unconfined aquifer) is used to determine the general direction of groundwater flow in the study area.

The groundwater flow direction (Figure 5.4) is dominated by north-south and east-west flow. The flow lines converge towards the southern parts of the study area. In general, the groundwater movement is sub-parallel to the surface water flow direction and more or less controlled by the topography of the area. The confined aquifers found in the catchment were not considered for the piezometric analysis.



**Figure 5.4** Gundwater flow pattern (For shallow aquifer) in Holeta River Catchment

## 5.5 Springs

Spring is a concentrated discharge of ground water 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.

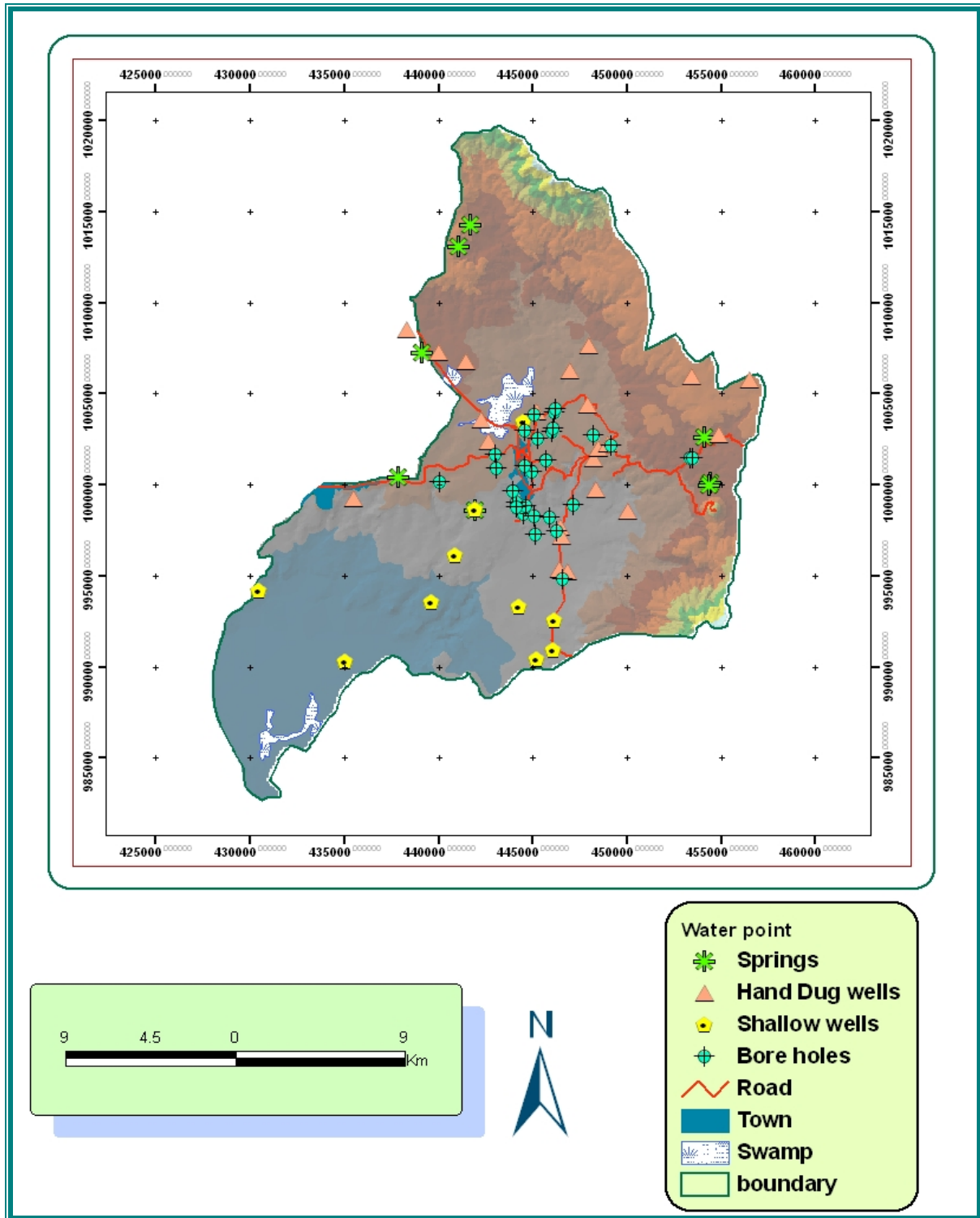
Generally, in the study area there are only cold (gravity) springs. Taking in to consideration their mode of origin, the dominant springs are contact and/ or depression springs. For the first case there are many conditions under which it can occur: permeable layer over laying an impermeable layer e.g. 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 (Ketema Wogari, 2006).

Some springs are observed and recorded in the study area and presented on the following table 5.1 and location of different water points found in the catchment are presented in Figure 5.5 as well.

**Table: 5.1 Types and location of some springs in Holeta catchment  
(source: Ketema Wogari, 2006).**

<b>Name of springs</b>	<b>Coordinate</b>	<b>Elevation</b>	<b>Q(l/s)</b>	<b>Type</b>
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.



**Figure 5.5 Location map of Water points**

## **5.6 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. 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 scoriaceous 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.

### ***5.6.1 Alluvial deposits***

Though the thickness of alluvial deposit is not well known and varied from place to place, the test bore hole (HBHT1) 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. 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 (Ketema Wogari, 2006).

### ***5.6.2. Buried valley deposit***

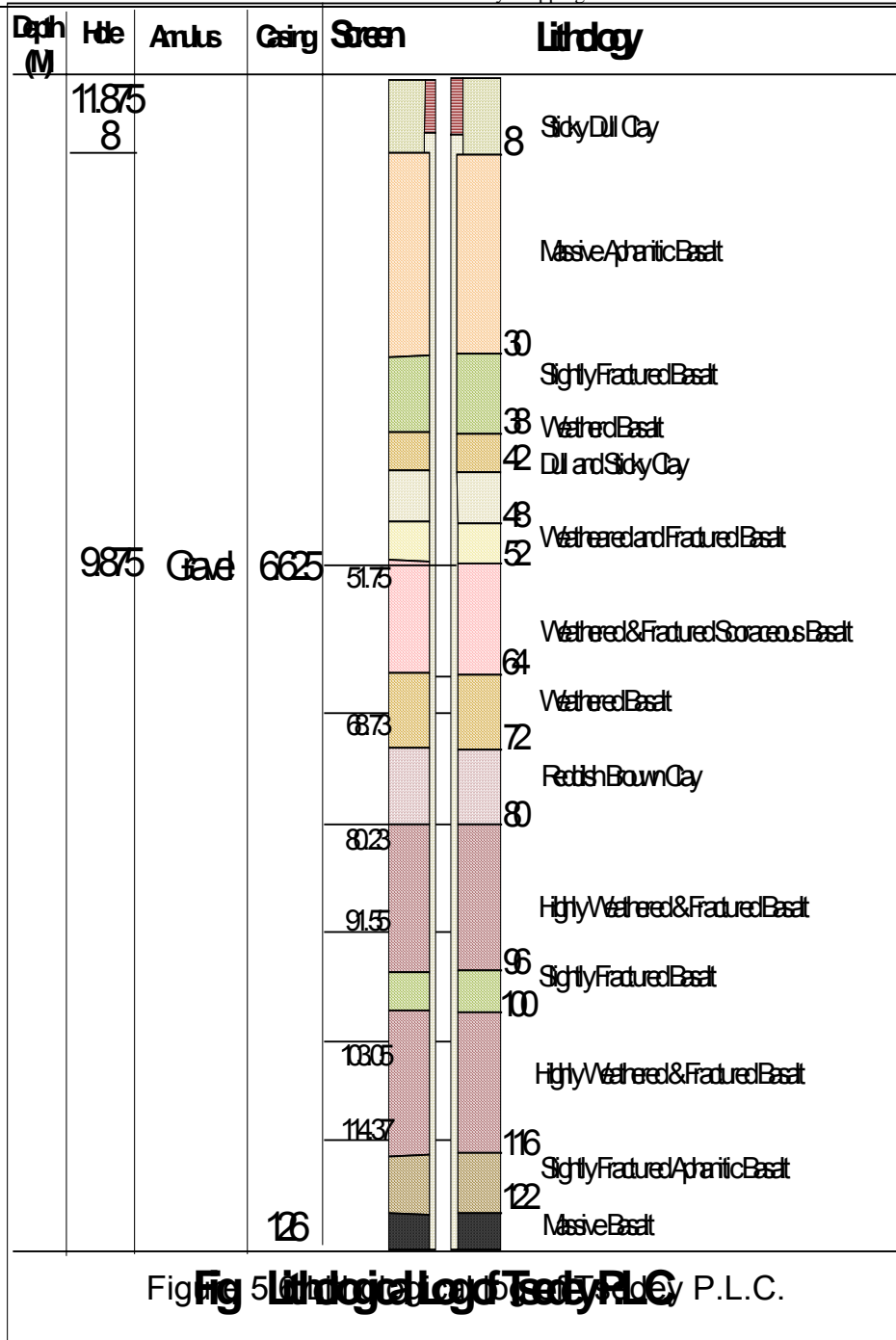
As indicated above thick gravel and sand deposit of an old river was observed at Holeta test well (HBHT1) under laying the basalt. The thickness of this deposit at this well is about 70 meter. From the borehole log the gravel is well sorted at some section and found mixed with sand at other sections. The sand deposit varies from coarse to fine. The Lithological log of HBHT1 indicates this (Figure5.1). The old river is assumed to be a large river, to form alluvial deposit of such thickness. This aquifer formation is found to form the deep/ or confined aquifer.

### ***5.6.3 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 catchment are to this aquifer formation showing different productivity. The variation in productivity is related to degree of weathering and fracturing, and penetration of the required depth of aquifer. 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 (Figure5.6). 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.



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 reinforce the indirect hydro geological observations, other methods such as geological / litho logical well logging and pumping test data analysis were employed.

Recently (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 catchment. Therefore, 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 catchment areas (Figure 5.8). 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 (Ketema Wogari, 2006).

Therefore, 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 5.7). Thus, they have very high ground water potential ( $>10$  l/sec). The main aquifer is fractured and weathered basalt / or fractured and weathered scoraceous basalt (Table5.2)



Figure 5.7 weatherd and fractured Alaji basalt (Adopted from Ketema Wogari, 2006)

**Table 5.2 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. 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 depressional 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 catchment and southern portion have moderate ground water potential with average well yields 5-10 l/s. Here is

also identified similar fractured basalt unit and also alluvial deposit as an aquifer.

Table 5.3 Representative Wells of moderate productivity.

	Yosef Rirdu 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)		
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 Undifferentiated 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 upstream area of Gale and west of the catchment portion (around Adis Alem) have low ground water potential i.e. 2-5 l/s, where, massive basaltic hydrostratigraphic unit dominates.

Table 5.4 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 eastern periphery of the catchment has poor groundwater potential (<2l/s), that attributed to the presence of massive Rhyolitic and Trachytic lava flows. However, the upper wreathed parts of these rocks are source of hand dug wells and most of the sprigs which are used as water supply for local commun

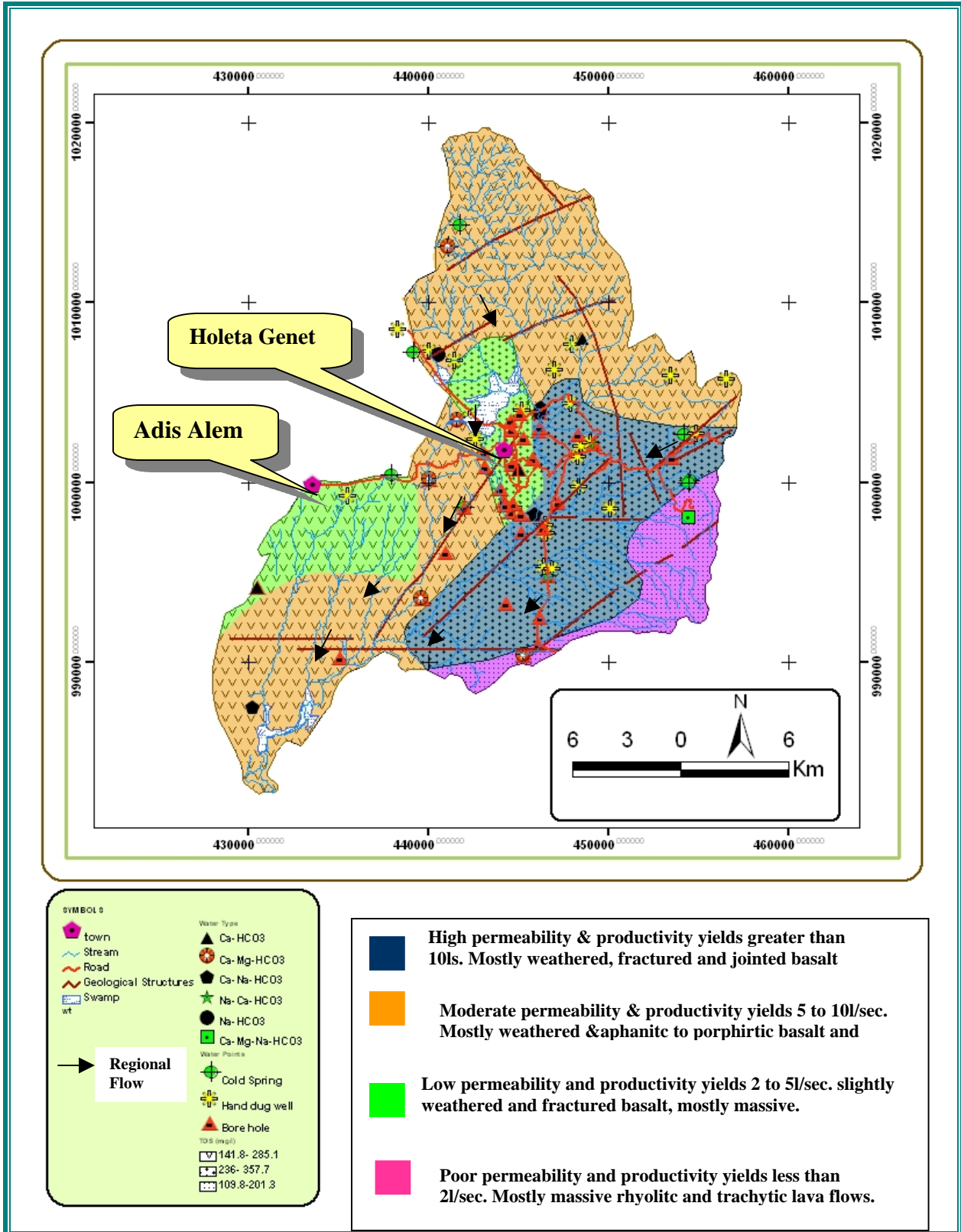


Figure 5.8 Hydrogeological map of Holeta River catchment (Modified after Ketema Wogari, 2006)

## **CHAPTER SIX**

### **HYDROCHEMISTRY**

The chemical composition of natural water is the result of both natural processes and cultural effects as a consequence of human activities. The occurrence of basic and acidic volcanic rocks, major tectonic discontinuities and highly variable topography are the major water quality controlling factors. Besides, urbanization, agricultural activities and associated development features for more than a century in the catchment have significantly changed the chemical constituents of surface and groundwater. Water entering the subsurface from different sources may remain temporarily as a continuous body or in several distinct water-bearing zones. The resulting physical and chemical properties of groundwater are most importantly related to its relationship within the media which the water encountered, and its residence time. In addition to the natural factors, major changes in the chemical constituents of groundwater have resulted from the human activities. The type and concentration of dissolved constituents governs the usefulness of groundwater for various purposes. Therefore, it is necessary to determine the composition of groundwater before the water can be used for the intended purpose.

To understand the general chemistry variation (spatial variation) and the possible sources for variation (natural or anthropogenic), water samples (mostly from shallow or unconfined aquifer, springs and river) have been used for chemical analysis and physical parameters were measured on site during field work.

## **6.1. Physical Parameters**

The physical parameters analyzed for the water samples to evaluate the field conditions of the groundwater chemistry are: TDS, Water temperature, EC and pH of different water sources that is, boreholes, hand dug wells, river, and springs within the study area using water quality measurement kits.

### ***6.1.1 pH and water Temperature***

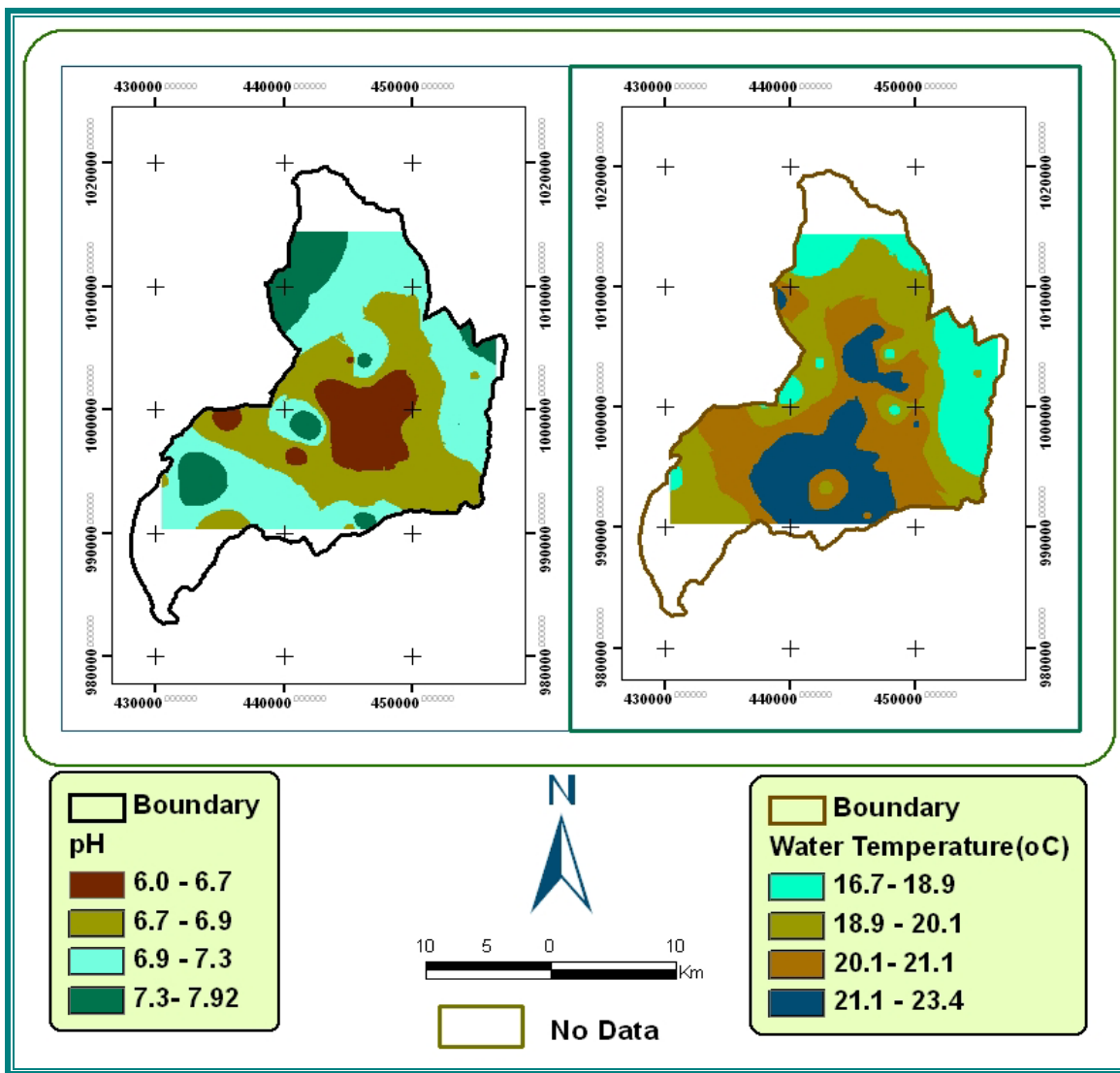
The pH of an aqueous system is a measure of the acid-base equilibrium achieved by various dissolved compounds. In most natural waters it is controlled by the carbon dioxide-bicarbonate-carbonate equilibrium system (WHO, 1984). Accordingly, the measured pH values ranges between 6 and 7.99, and are mostly associated with the high bicarbonate contents of the water. However, the highest value (7.99) measured from Holeta River and Hand dug wells are associated with water points that receive wastes directly from human activities. Where as, the lower values are measured from shallow wells, and Holeta river, hand dug wells and springs during high rainy month (August). Figure 6.1 shows spatial variation in pH in the study area.

Water temperature is an important factor that determines water suitability for human and agricultural use, industrial applications, and aquatic ecosystem functioning. Water temperature can affect the dissolved oxygen content. The temperature of water is mainly controlled by climate.

A number of parameters such as, turbidity, color, odor, etc--- are affected by temperature directly or indirectly. Temperature also affects pH, electric conductivity, the rate of chemical reaction as well as the concentration of

the reactants and the products, and solubility of gases in the water (Ketema Wogai, 2006).

In the study area the water temperature of the samples ranges from 16.7 °C to 24.7°C on site. In general, the temperature of the water samples show progressive increase from north to south and from east to west in the direction of groundwater flow path. This is due to the regional flow system in the mentioned direction (Figure 6.1).



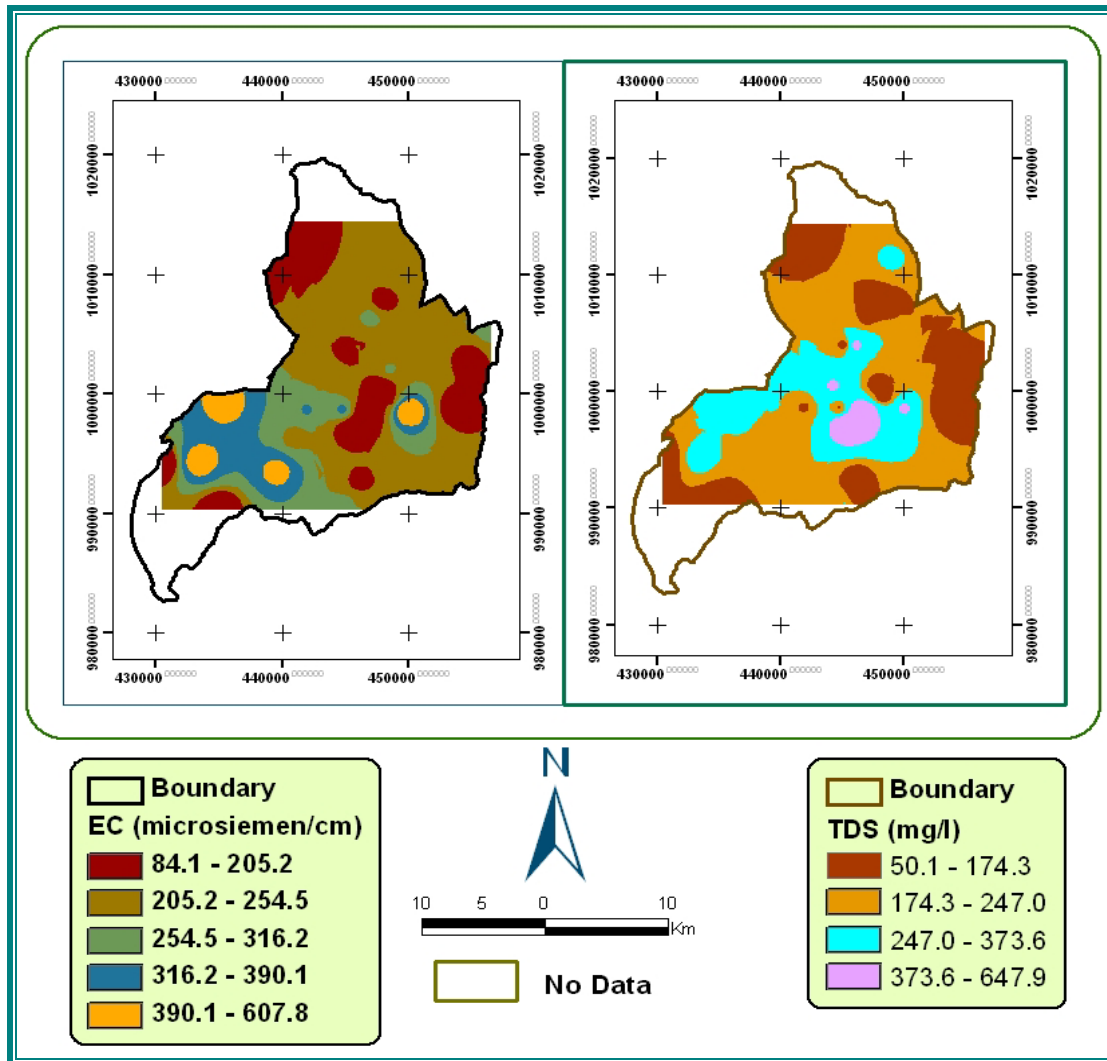
**Figure 6.1. Spatial variations in pH and Water temperature**

### **6.1.2 Total Dissolved Solids (TDS) and Electrical Conductivity (EC)**

Total dissolved solids (TDS) include all solids that are dissolved in water, whether ionized or not. According to USA EPA (1976) the principal ions contributing to total dissolved solids are; bicarbonate, chloride, sulphate, nitrate, sodium, calcium and magnesium.

From the water quality analysis of the area, the TDS values ranges from 50mg /l for groundwater to 648mg/l for Holeta River. In general, Holeta river water that is contaminated with different wastes possesses high TDS value. According to their total dissolved solid concentration, the water in the catchment has been categorized under fresh water (those having less than 1000mg/l of TDS). Hence, TDS value shows an increase trend along the flow path (Figure6.2).

Electrical conductivity (EC) is directly related to the TDS values. The presence of dissolved minerals in water gives the ability to conduct electricity. EC is often expressed in terms of mili siemens (ms) or micro siemens per centimeter (0s/cm). The more salts are dissolved in the water; the higher is the value of EC. EC does not give specific information about the chemical species present in water, but it gives a determination of TDS. In calculating approximate TDS values from EC, the relationship most commonly used is  $KA=S$ , where  $A=0.59$ ,  $K$ =specific conductance in mhos/cm, and  $S$  is dissolved solids in mg/l (Hem, 1985).



**Figure 6.2 Spatial variations in EC and TDS of the study area.**

### 6.2. 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.

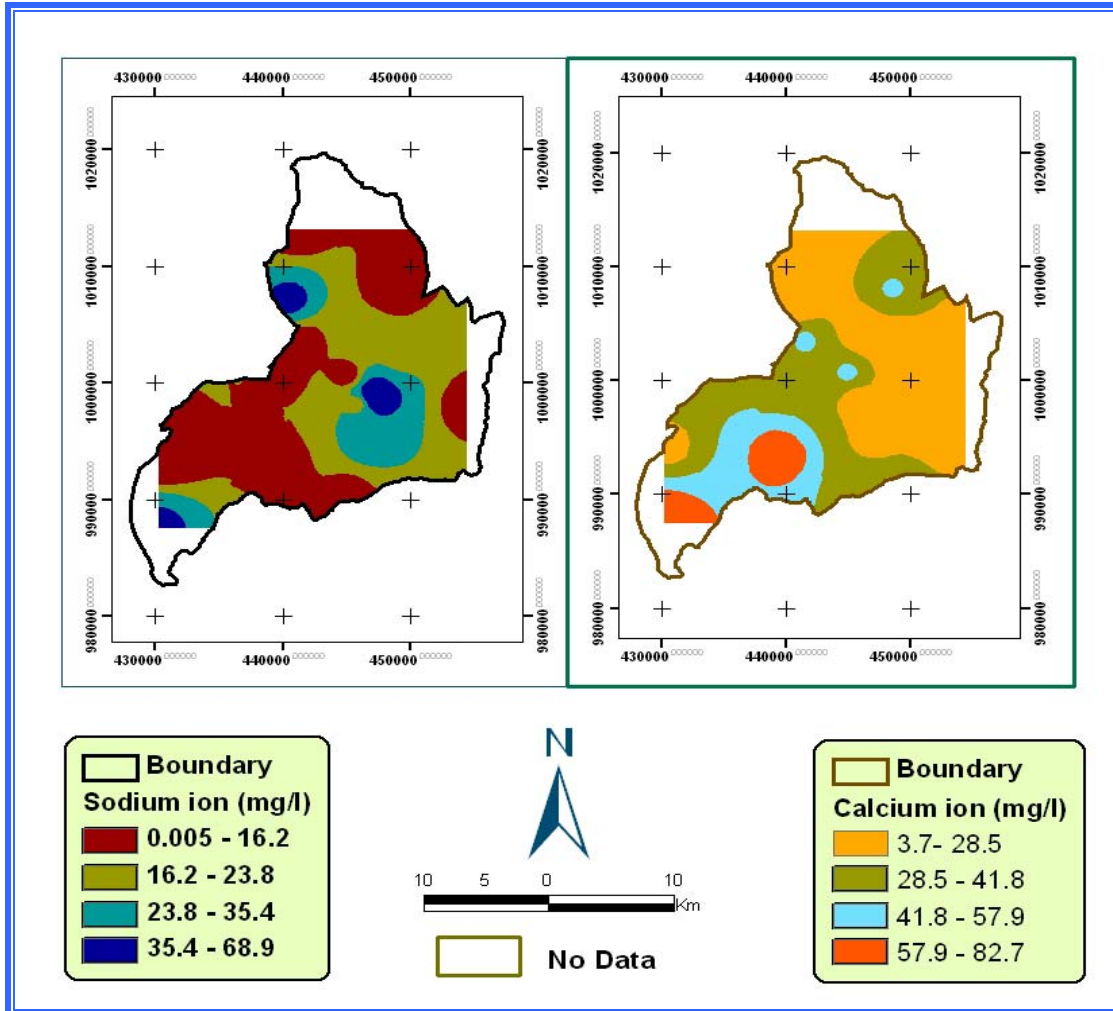
### **6.2.1. Cations**

In the majority of the samples the dominant cation is calcium. The concentration varies from 3.7mg/L up to 82.7 mg/L. The higher value of calcium is observed for sample taken from Amero well south of Adis Alem town. And the lower value is observed for sample taken from Tulukorma Shallow well Southwest of Adis Alem. Generally, the calcium ion progressively increases from north to southwest of the study area. This is due to that, the groundwater gets more time to interact with rocks in contact along the regional flow path from northern recharge area to southwester parts of the catchment (Figure 6.3). 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 Wechecha-Menagesha mountain ranges, suggesting the lithology from which they emerge is relatively acidic rock (Trachyte). Human activities 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 (western part of the area), 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 shallow no2) to 37.4 mg/L (for sample taken from Holeta River).

Magnesium in the area is possibly derived from the weathering of ferromagnesian minerals such as olivine, biotite, hornblende and augite.



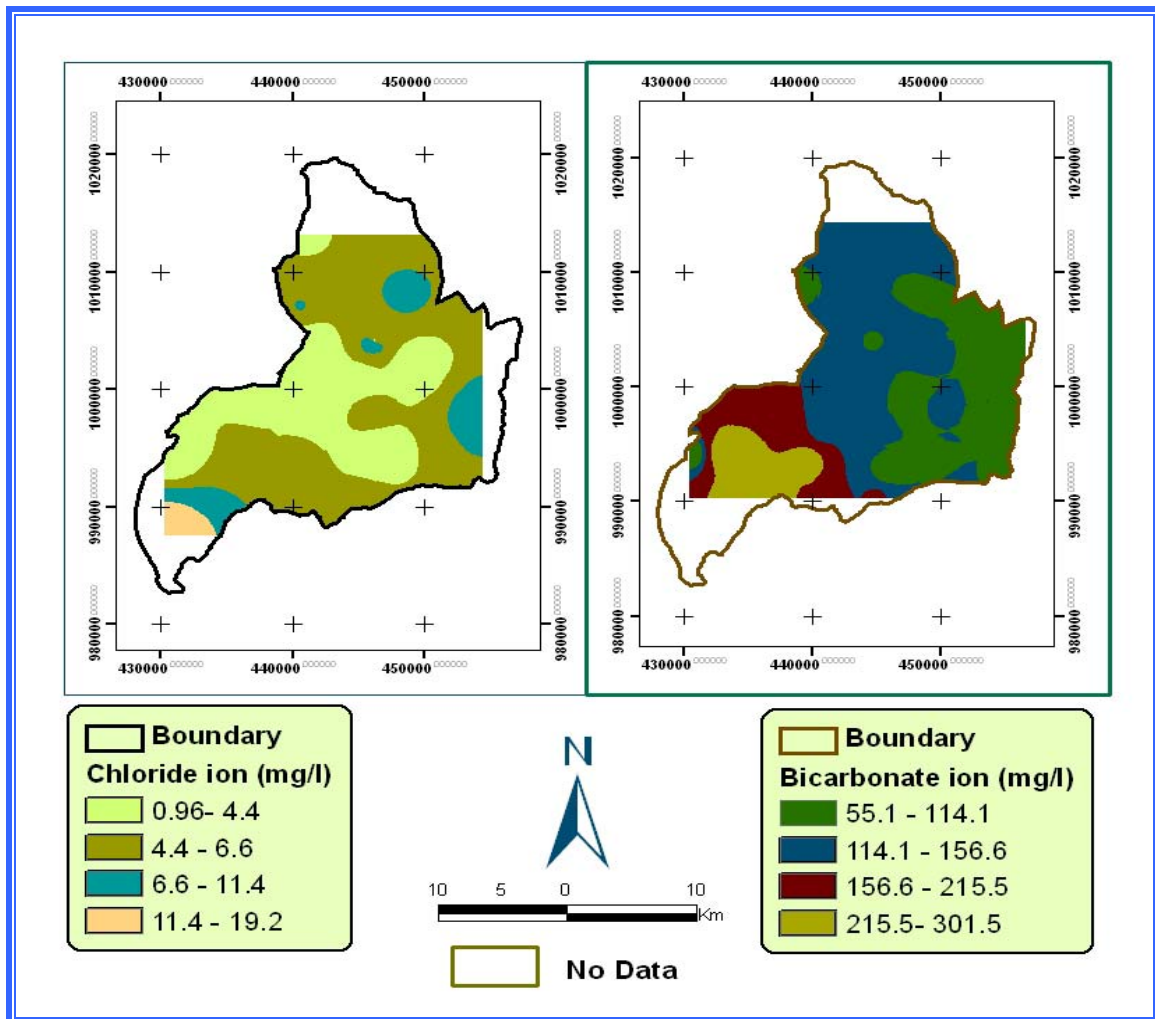
**Figure 6.3 Spatial variations of both Na and Ca ions of the catchment.**

### 6.2.2 Anions

The predominant major anions in all the analyzed samples are bicarbonate. It varies from 55.1 mg/L for Tulukorma shallow well to 301.4mg/L for Andode shallow south of Adis Alem town. 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 (1966). The high bicarbonate content in the area could be

from the atmospheric gas and CO<sub>2</sub> in the soil. Generally, the amount of bicarbonate ion increases from east (Wechecha mountain range) to southwest (Plain land below Adis Alem town) of the study area (Figure 6.4).

Carbonate and chloride contents are significant in some samples even though they are much lower than objectionable amount. Chloride ion presents in all natural waters, but mostly the concentrations are low (Hem, 1985). Chloride ion ranges from 0.96mg/l to 19.2mg/l, which generally shows an increment from central to southern part of the area (Figure 6.4). Sulfate content is very low in almost all of the samples collected.



**Figure 6.4 Spatial variations of Cl and HCO<sub>3</sub> ions in the area**

### **6.3 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 nitrate concentrations in some samples are relatively significant though it is below the maximum permissible contaminant level, which according to WHO (1984) drinking water quality standard is 50 mg/l.

The relatively higher  $\text{NO}_3^-$  value (20.24 mg/L) observed in some shallow wells and springs in the study area is attributed to the agricultural practices (Figure 6.5). Most shallow wells and springs are located at a downstream 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. And, the high nitrate concentration may be related to waste disposal

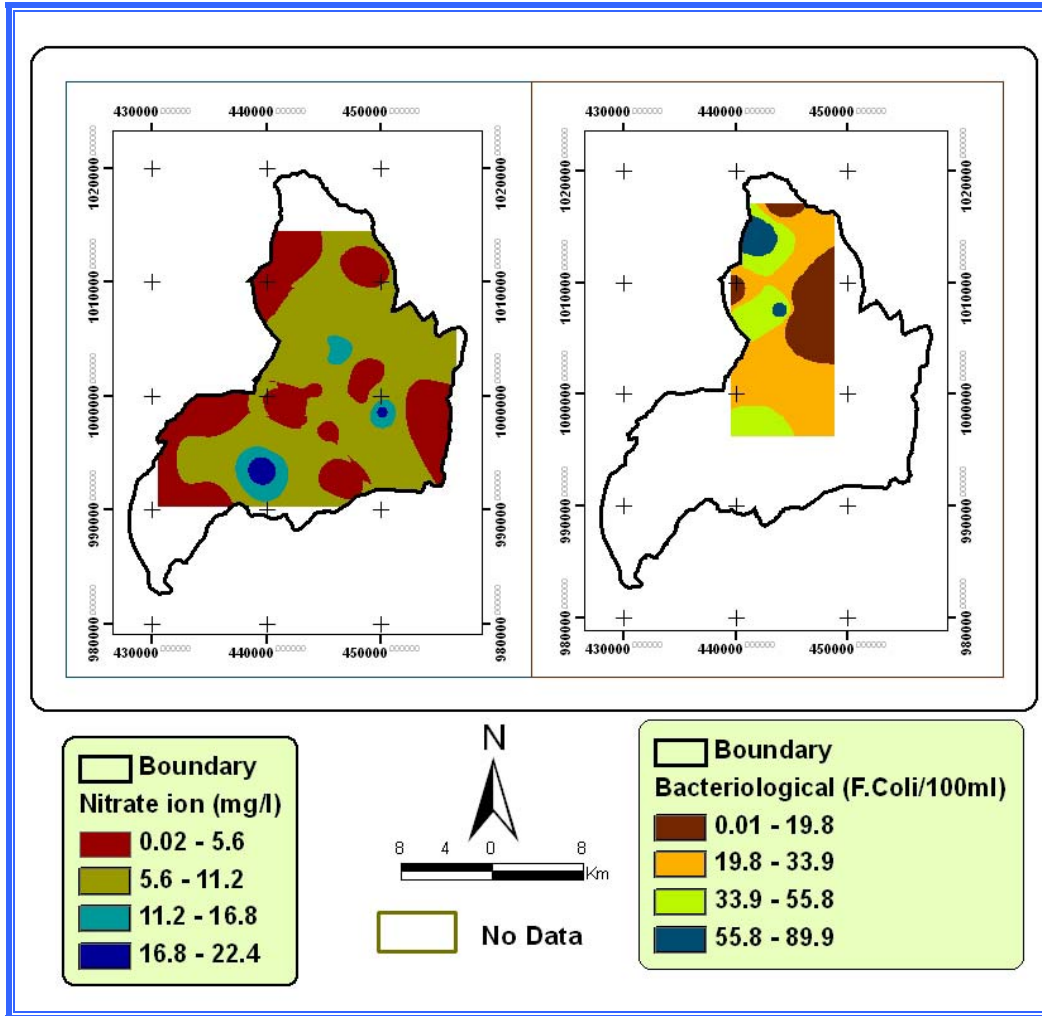
### **6.4 Bacteriological**

.In the study area, only fourteen bacteriologically analyzed data of hand dug wells are obtained particularly in some parts of the northern and central of the area. Accordingly, most of the dug wells (77% of the total analyzed wells) have found to be not potable, since they had high bacterial load (Table 6.1). From this on can deduce that, the shallow groundwater system in the catchment is so susceptible to anthropogenic effect. That is, water wells are not well protected from wastes and other pollutant sources because of improper design, lack of awareness of the local people how to protect the water source from being contaminated, etc. Generally, from

the analyzed samples, the northern part of area has high bacterial load (55.7 F.coli/100ml -89.9F.coli/100ml). See Figure 6.5.

Table 6.1 Bacteriological analysis

No.	Source	Locality	UTM(m)		Bacteriological (F. Coli/100ml)
			X	Y	
1	Hand dug well	Gulole	441972	1014070	90
2	“	Agota	443960	1016909	6
3	“	Gegebso	439595	1008960	Nil
4	“	Haro	448786	1009244	Nil
5	“	Arifeta	445805	1008250	Nil
6	“	Guenet Church	445663	1006121	1
7	“	Goro Mosque	449496	1003423	Nil
8	“	Mulugeta Baruda	446515	1004985	Nil
9	“	Illala gojo	445237	1006688	6
10	“	Taticha	444102	1007398	80
11	“	Dolio	440837	1006972	51
12	“	Shola Genet	440269	1002146	30
13	“	Wajitu fiche	441688	996183	42
14	“	Dawa & tsebel	441972	991925	Nil



**Figure 6.5 Spatial variation of nitrate ion and bacteriological**

### 6.5 Water Types

Water type classification of the water samples collected from all sources found within the catchment is made to observe the major water groups along the flow path by using a piper diagram graphical presentation method.

According to their spatial relationship and source type, they have classified into different water types. Samples taken from all water sources are generally showed Ca-Na-HCO<sub>3</sub> to Ca-HCO<sub>3</sub> water type (Figure 6.6)

Samples taken from deep wells from central part show in general Ca-Mg-HCO<sub>3</sub> and Ca-Na-HCO<sub>3</sub> to Ca-HCO<sub>3</sub> water type (Figure 6.7). Similarly samples taken from hand dug wells of western, eastern and central parts are generally showed Na-Ca-HCO<sub>3</sub> and Ca-Mg-HCO<sub>3</sub> to Ca-HCO<sub>3</sub> water type (Figure 6.8). And, similarly that include the springs and shallow wells in the northern, eastern, western, southern and southwestern parts of the catchment show Na-Ca-HCO<sub>3</sub>, Ca-Na-HCO<sub>3</sub>, Ca-Mg-HCO<sub>3</sub> to Ca-HCO<sub>3</sub> (Figure 6.9 and 6.10).

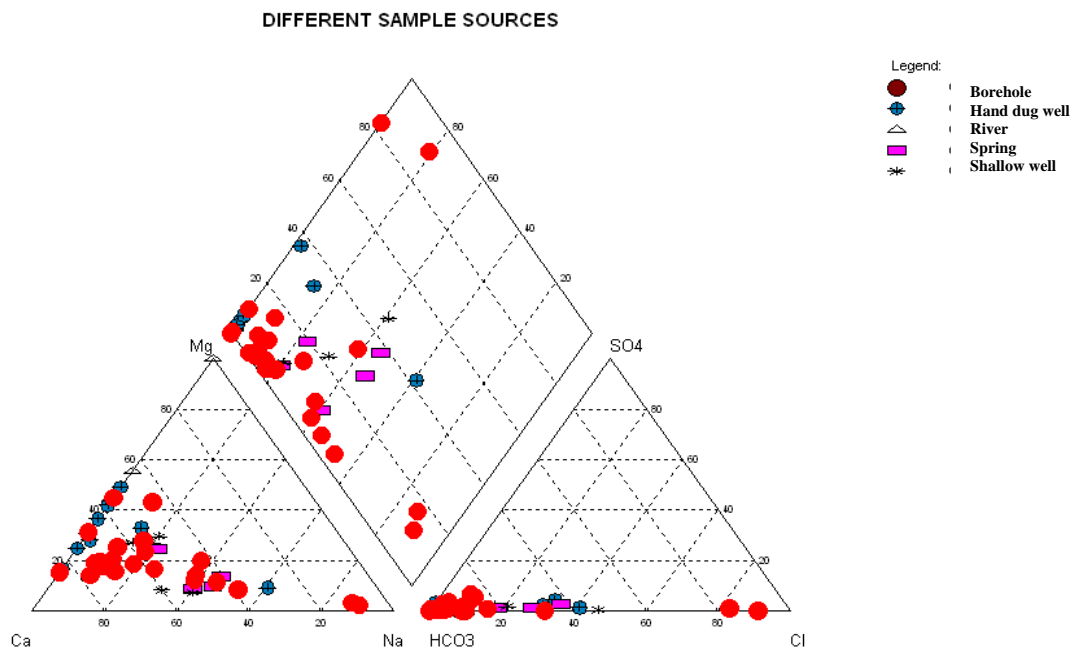


Figure 6.6 Piper plot for all water samples analyzed from different sample sources

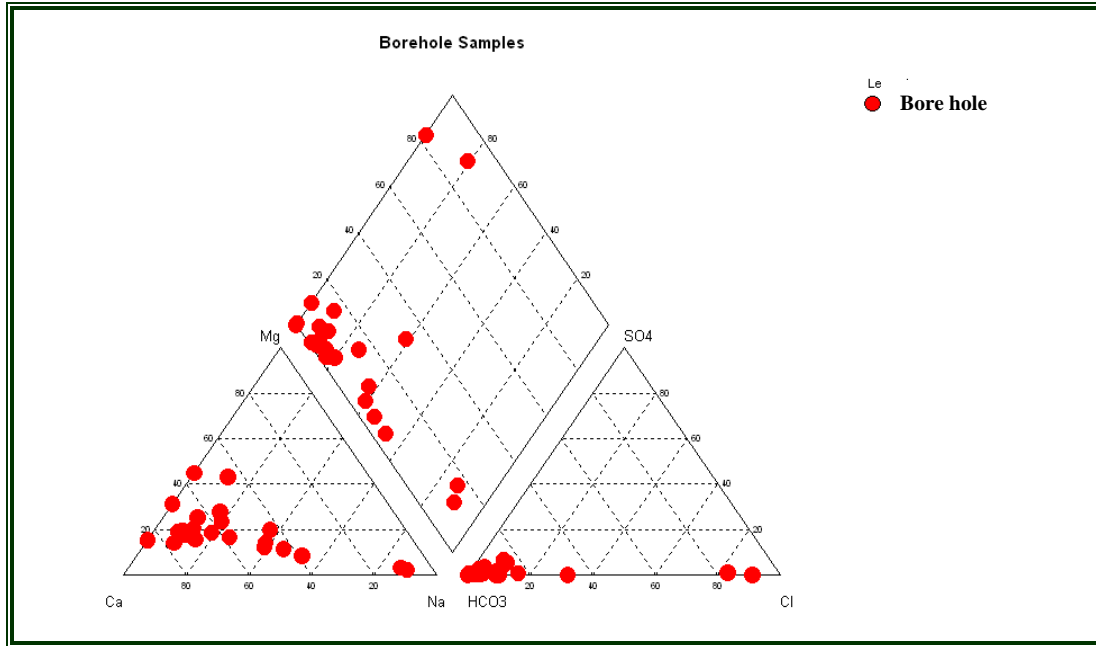


Figure 6.7 Piper plot for bore holes from central part of the area

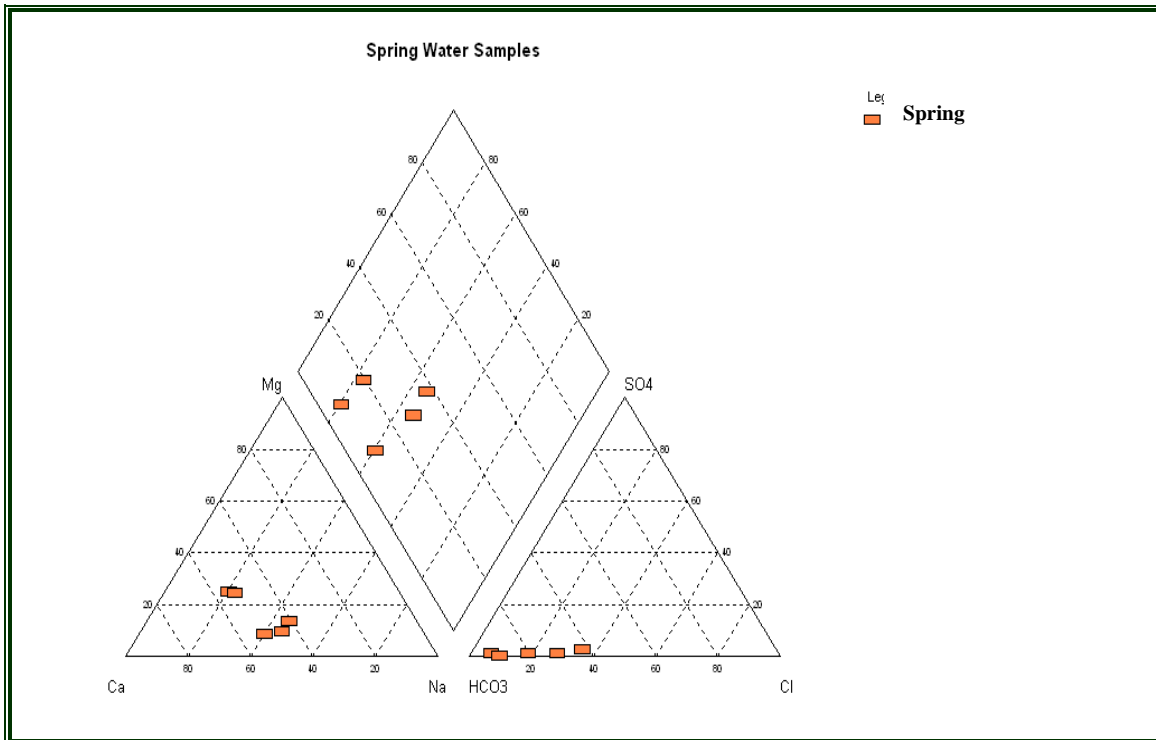


Figure 6.8 Piper plot for spring water samples

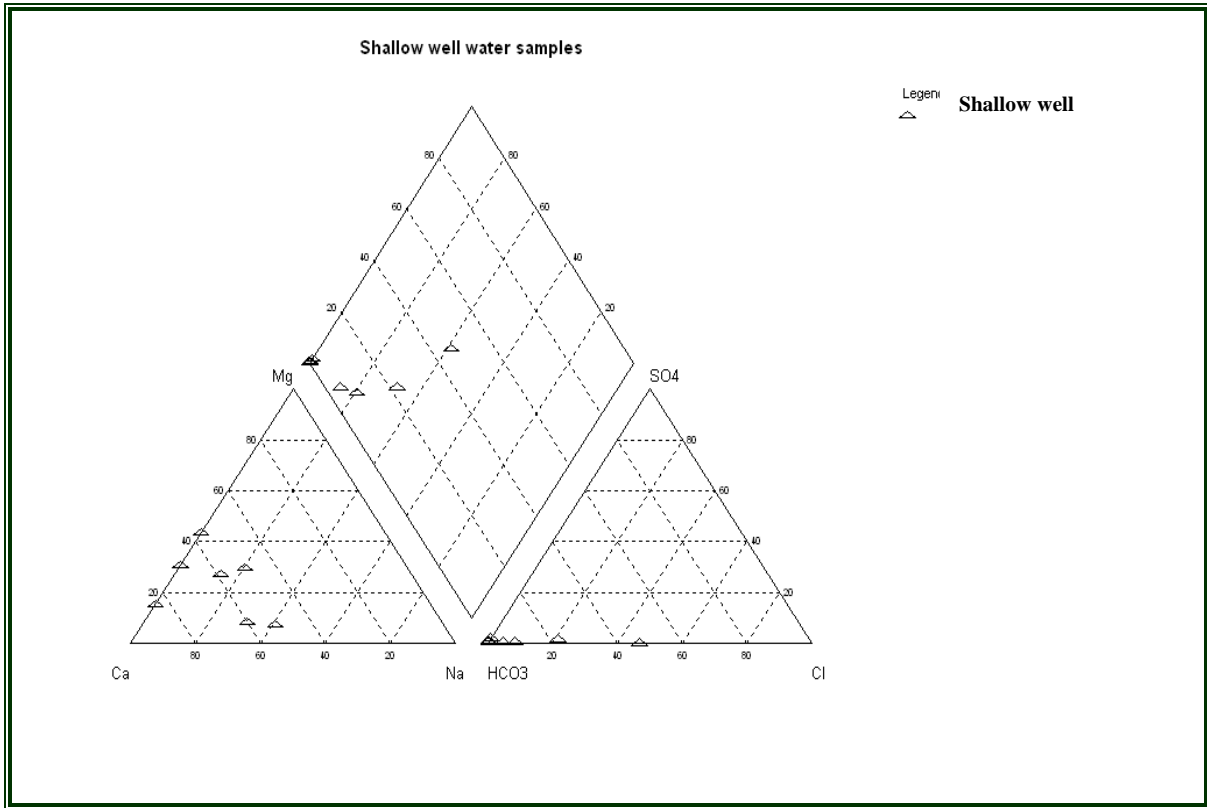


Figure 6.9 piper plot for shallow well water samples

## **CHAPTER SEVEN**

### **POSSIBLE SOURCES OF POLLUTANTS**

Like in many sectors of the developing countries of the world, economic development usually does not take in to consideration the possible impact it has on the environment. On the other hand, absence of proper environmental management practice paralleling economic development may lead to an irrecoverable environmental degradation.

There are numerous sources of pollutants that could deteriorate the quality of water resources. In most developing countries sources of pollution from domestic, agricultural and industrial activities are unregulated. Likewise, in Holeta River catchment, where there is as such no environmental protection practice there are a number of pollutant sources that continuously deteriorate the quality of surface and groundwater. Based on observation made during field visits and analytical results, the following pollution sources have been considered as major categories of sources of pollutants in the study area. These are agricultural activities and solid wastes. Meanwhile, in the catchment a number of cemetery (grave yard), health centers, and market areas contribute to the deterioration of the water environment. Unfortunately, no industries are found currently in the study area, but I have located in Figure 7.1 the proposed industry site on the new master plan of Holeta Genet town. The distribution and major activities of hazard centers are summarized below.

#### **7.1 Agricultural Pollution**

In most part of the study area, crop production and animal husbandry are being carried out for a long of time and recently flower farming is being practiced widely. Agricultural activities in the catchment are practiced on

individual or cooperative basis. The common practices in the study area are to breed animals in small plots of land with in the compound and farming of small plots of land using primitive methods is the leading activity. Due to high density of cattle, large amounts of wastes are accumulated in unmanaged way and unsafe areas. Within the catchment there are a lot of grazing animals and use fertilizer to plant 'Teff', and other cereals that have potential impact on the quality of the groundwater.

Uncontrolled addition of chemical fertilizers to the soil in order to increase the yield, in the study area, can be lost during the rainy season by rapid surface runoff where we can have a sloppy area and in relatively flat terrain they migrate in to the subsurface with the percolating water.

Of the three main nutrients in fertilizers, Urea ( $\text{CO}(\text{NH}_2)$ ) is the one that most commonly causes contamination of groundwater beneath agricultural land (Freeze et al., 1979). Nitrate is generally much more mobile in subsurface flow system than any other fertilizer component. Cation exchanges cause potassium to have low mobility in most non-fractured geologic materials (Tamiru Alemayehu et al., 2005). The water samples taken from shallow groundwater around Holeta (central of the catchment) contain above 8.36mg/l nitrates. Thus, the presence nitrate can be attributed to the intensive use of fertilizer usage in the farmlands of the area.

### ***Flower (Rose) Farming***

Among agricultural activities, flower (Rose) farming is most recently being practiced widely in the study area. Since it is confined in green houses, it is considered to be as a point source of pollutant. Green houses can affect the actual Evapotranspiration (AET) in it, i.e. they reduce the amount of AET by 50% of the total amount outside of it (Water watch, 2007). Therefore, this can facilitate the recharge rate in side the green house.

Within the catchment, there are numerous green houses of Rose farming that can have adverse effect on the quality of groundwater due to uncontrolled discharge of chemical effluents. They are mostly concentrated in central part of the catchment (Figure 7.1).

These farms use various toxic and hazardous chemicals for fungicide, acaricide, and insecticide. Such as, Oscar, Previcur, Dynamic, Pegasus Mangister, Roviral, Cilitac, Mitag, and Mancozeb which composed of mostly copper sulphate and ethyldibromide. Most of them apply these chemicals on their product at least twice a week on the basis of environmental conditions, and they discharge the chemical effluents by mixing with water in to an excavated pit of about 2m depth unsafely, which is so dangerous that they can easily percolate and pollute the groundwater on the basis of hydrogeological settings. Once they enter the groundwater system, they can easily migrate in the direction of flow path to southern part of the catchment.

## **7.2. Solid Waste Disposal**

The solid waste (refuse) from both urban and rural areas includes wastes generated by domestic house holds, commercial centers, and local institutions. Wastes produced indirectly from agriculture and other source is discussed under their respective sources. Addis Ababa Administration Region Health Regulation (Legal Notice no. 1/ 1986) defined solid waste as “ anything discarded as public sweepings, food remains, ash, vegetables and grass remains, cigarette butts, papers of various sorts, discarded glass, metals, plastics, dead animals and the like that posses environmental health risks”.

Currently, both in urban and rural areas of the catchment, all possible open spaces seem to be used as official waste disposal sites. That is why it

is uncommon to observe uncollected waste heaps distributed all over the catchment. Open areas, quarries, streams and ditches within the study area are full of wastes coming from several sources. The problem becomes severe in the areas where there is a setting up of markets where people gather mostly. Consequently the areas become a breeding ground for viruses, bacteria and parasites. Outbreak and transmission of diseases as consequences of this poor sanitation remains to be a recurrent phenomenon in the catchment for a long period of time.

In urban areas (Holeta genet and Addis Alem), people dump their domestic and commercial wastes in undersigned excavated pit and open sites located in the outskirts of the towns by using carriage mostly. Whereas, in rural areas, domestic wastes are dumped in nearby streams, quarries, and open sites.

Open dumps are the oldest and located wherever land is available without regard to safety, health hazards and aesthetic degradation. Diseases such as, acute respiration, skin rushes, brocho-pneumonia and gonococcal infection are related to the improper waste management (Tamiru Alemayehu et al., 2005). It is known that leaching of the waste by percolating water is one of the most significant possible source of surface and groundwater pollution. Leachate contains large number of inorganic, organic and toxic constituents. The amount of leachates becomes high when there is high amount of rainfall (June, July and August) and the groundwater level consequently rises.

### **7.3. Sewage**

The term sewage refers to water whose quality is degraded as a consequence of human activities. The discharge of untreated sewage into

surface water can lead to organic pollution. Holeta River catchment has on any sewerage system both in urban and rural areas. Therefore, people connect their sewerage system (open ditches) to nearby water courses. And the streams receive untreated sewage from toilets, and other related sources.

In general, inefficient (or lack) of waste collection and disposal, lack of concern among responsible bodies to the available resources and the current illegal dumping practices threaten the sanitary situation of both urban and rural areas of the catchment more than ever. The problem will continue and will become sever in the coming years unless sound corrective and protective measures are taken.

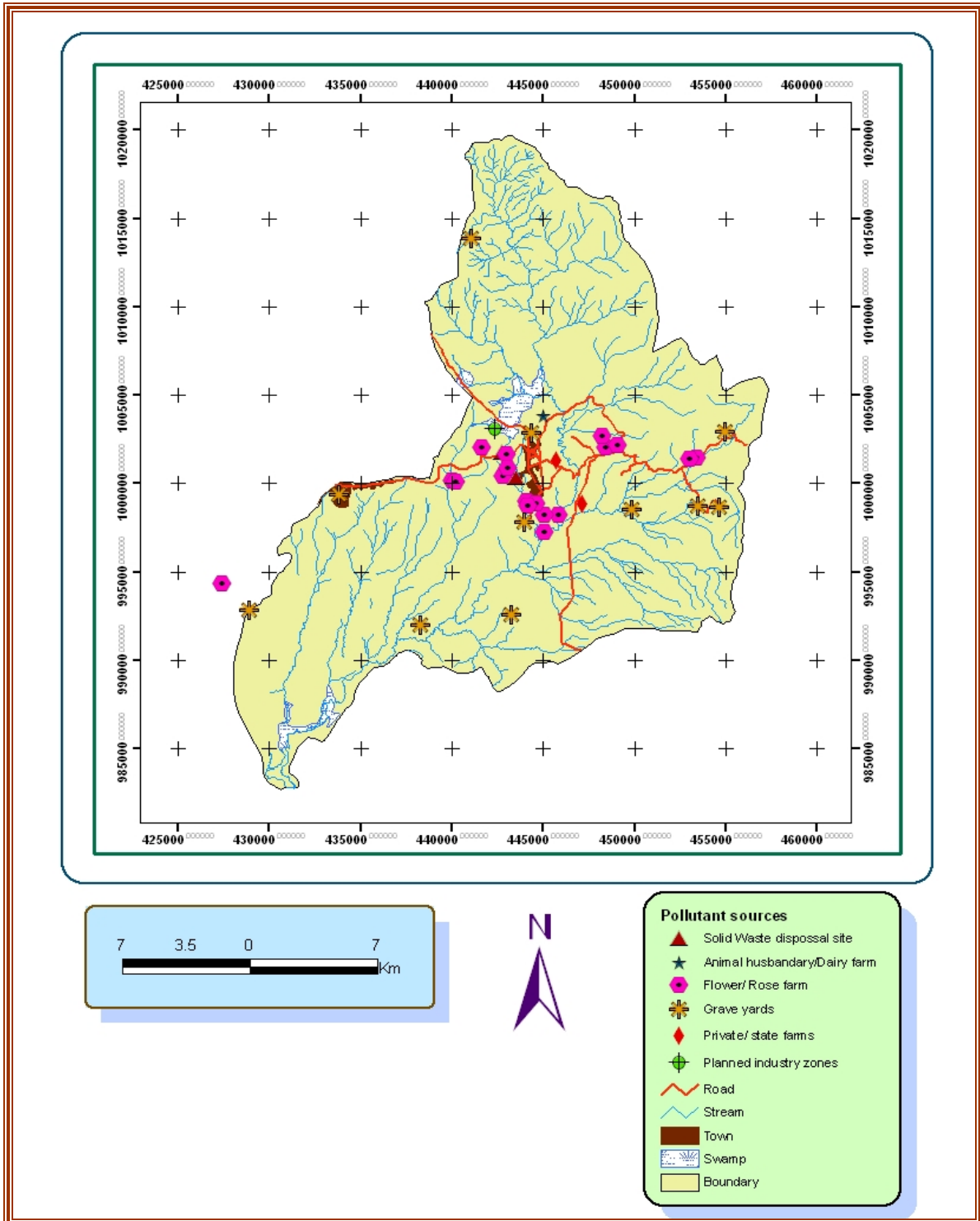


Figure 7.1 Location map of Possible Pollutant Sources

## **CHAPTER EIGHT**

### **GROUNDWATER VULNERABILITY MAPPING AND ASSESSMENT CONCEPT**

#### **8.1. General**

The concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against human and natural impacts, especially with regard to contaminants entering the subsurface environment. That means the soil-rock-groundwater system may provide a degree of protection against contamination of groundwater by ‘self-purification’ or natural attenuation’ (Zaporozec, 2001). Thus, the intrinsic (natural) groundwater vulnerability could be described as the ‘relative inability’ of the soil-rock-groundwater system to protect its water against contamination. As a result some land areas are more vulnerable to groundwater contamination than others this situation is due to the potential for contaminant attenuation possessed by earth materials (Dereje Nigussa, 2003).

Water pollutants do not always enter the groundwater system instead the pollutants tend to be removed or reduced in concentration with time and distance traveled. Rate of pollution attenuation depends on the type of pollutants and on the local hydrogeological situations. More over, mechanisms of pollution attenuation include filtration, sorption, chemical processes, microbiological decomposition and dilution (Tamiru Alemayehu et al., 2005). Like wise, Civita and De Maio, (1998) considered the soil /overburden and the unsaturated zone as the first and the second defiance lines respectively. Thus, an important element in assessing groundwater resources is the investigation of aquifer exposure to contamination. The evaluation of the potential exposure of groundwater

resources to contamination is termed as vulnerability. Thus, the preparation of aquifer vulnerability map is a key consideration and become a forecasting tool and via the planning processes a prevention tool and an identifier of action priority list (Civita and De Maio, 1998).

Le Grand (1964) developed an empirical point count system to evaluate the potential pollution from a given source. A new model (DRASTIC) was built up to assess aquifer vulnerability by United States Environmental protection Agency (Aller et al., 1987) directly derived from Le grand ideas.

The intrinsic (natural) vulnerability map is based on the assessment of various natural factors or attributes, such as soil, unsaturated zone, aquifer properties, and recharge rate that enter into the determination of the vulnerability of groundwater. The application will be acquired when intrinsic vulnerability of a certain area is associated with danger sources. In this case one is considering integrated vulnerability, which is defined by the interaction of intrinsic vulnerability of hydrogeological system and danger sources. Specific vulnerability is the evaluation of groundwater for every type and class of contamination and for every mechanism of contamination. This type of evaluation needs a rather long time (Tamiru Alemayehu et al., 2005).

## **8.2. Ranges, Ratings and Weights analysis in DRASTIC Model**

DRASTIC factors use a numerical ranking to assess groundwater pollution potential in hydrogeologic settings. The system consists of three parts, which are designated as: *ranges*, *ratings*, and *weights*. Each DRASTIC factor has been divided into either ranges or significant media type, which have a significant impact on pollution potential. Ranges for each DRASTIC factor have been evaluated with respect to the other factors

in order to determine the relative significance of each range with respect to pollution potential (Napolitano, 1995). The ranges for the model have been assigned a subjective rating, which varies between 1 and 10 (Table 8.1). For these factors; D, R, S, T, and C have been assigned one value per range, while the other two, A and I, have been assigned a “typical” rating and a “variable” rating. The variable rating permits the user to choose either a typical value or to adjust the value based on more specific knowledge (Aller et al., 1987). In this study, the typical rating is applied.

Two relative weight strings (varying from 1 to 5) have been assigned to each DRASTIC factor in order to determine the relative importance of each factor. The most significant factors assigned weights of 5 and a weight of 1 for the least significant factors. The two strings as shown in table 8.1 are weights for the “general or normal” DRASTIC and “Agricultural or Pesticide” DRASTIC. Agricultural DRASTIC was developed to reflect the effect of herbicides and pesticides. According to the authors Aller et al., (1987) weights are constant and cannot be changed. And the ratings assigned for each DRASTIC parameter are the same for both the Normal DRASTIC index and the pesticide DRASTIC index.

According to Aller et al., (1987), once a DRASTIC index has been computed, it is possible to identify areas which are more likely to be susceptible to groundwater contamination relative to one another. The higher the DRASTIC index, the greater the groundwater pollution potential. The DRASTIC index provides only a relative evaluation tool and is not designed to provide absolute answers.

Table 8.1. Assigned ranges, ratings and weights for DRASTIC factors (Aller et al., 1987).

Factors	Weight		Range	Rating	Typical Rating
	General (Normal)	Agricultural (Pesticide)			
<b>*Depth to Water(m)</b>	5	5	2.5-9.9	8	
			9.9-15.1	5	
			15.1-22.1	4	
			22.1-30.8	3	
			30.8-38.3	2	
			38.3+	1	
<b>*Net Recharge(mm)</b>	4	4	170-350	5	
			350-400	7	
			400-600	8	
			600+	10	
<b>Aquifer Media</b>	3	3	Massive Shale	1-3	2
			Metamorphic/Igneous	2-5	3
			Weathered metamorphic/ Igneous	3-5	4
			Glacial Till	4-6	5
			Bedded sandstone, limestone, and shale sequence	5-9	6
				4-9	6
			Massive sandstone	4-9	8
			Massive Limestone	2-10	9
			Sand and gravel	9-10	10
			Basalt Karsts limestone		
<b>Soil Media</b>	2	5	Thin or Absent	10	
			Gravel	10	
			Sand	9	
			Peat	8	
			Shrinking and/or aggregated clay	7	
				6	
			Sandy loam	5	

			Loam	4	
			Silty loam	3	
			Clay loam	2	
			Muck		
			Non-shrinking and non-aggregated clay	1	
<b>*Topography/ slope (%)</b>	1	3	0-2.8	10	
			2.8-8.5	9	
			8.5-14.8	8	
			14.8-21.9	7	
			21.9-29.7	6	
			29.7-38.2	5	
			38.2-48.8	4	
			48.8-96.2	3	
			96.2+	1	
<b>Impact of the Vadose Zone Media</b>	5	4	Confining layer	1	1
			Silty/clay	2-6	3
			Shale	2-5	3
			Limestone	2-7	6
			Sandstone	4-8	6
			Bedded limestone, sandstone, shale	4-8	6
			Sand and gravel with significant Silt and Clay	4-8	6
			Metamorphic/igneous	2-8	4
			Sand and gravel	6-9	8
			Basalt	2-10	9
			Karst limestone	8-10	10
<b>*Hydraulic Conductivity (m/s)</b>	3	2	$4.72 \times 10^{-7}$ - $4.72 \times 10^{-5}$	1	
			$4.72 \times 10^{-5}$ - $14.16 \times 10^{-5}$	2	
			$14.16 \times 10^{-5}$ - $33.04 \times 10^{-5}$	4	
			$33.04 \times 10^{-5}$ - $4.72 \times 10^{-4}$	6	
			$4.72 \times 10^{-4}$ - $4.72 \times 10^{-3}$	9	
			$4.72 \times 10^{-3}$ +	10	

*\* Modified DRASTIC approach is followed to rate depth to water, net recharge, Topography, and Hydraulic conductivity.*

### **8.3. Definition and Significances of the DRASTIC parameters**

In the following paragraphs definition of each DRASTIC layer will be discussed together with their significances in potential assessment.

#### **8.3.1. Depth to Water (D)**

Depth to Water represents the depth of the topographic surface and it gives an idea of the minimum distance that a pollutant has to travel to reach the saturated zone. In other words, it is the depth or thickness of the material through which a contaminant travels before reaching the aquifer. Depth to water table is important because it provides the maximum opportunity for oxidation of the contaminant by atmospheric oxygen. As the depth to water increases generally, there is a great chance for attenuation to occur because deeper water level implies longer times.

#### **8.3.2. Net (effective) Recharge**

Net recharge is the amount of water, which infiltrates from the ground surface to the aquifer on annual basis. This recharge water is thus available to transport a contaminant vertically to the water table and horizontally within the aquifer. The net recharge is the difference between total precipitation and the cumulative loss by direct runoff and effective Evapotranspiration. The vulnerability of an aquifer to groundwater contamination is in large part a function of the susceptibility of its recharge area to infiltration. Areas that are replenished at a high rate are generally more vulnerable to pollution than those replenished at a slower rate. In addition, it controls the volume of water available for dispersion and dilution of the contaminant in the vadose and saturated zones.

### **8.3.3. Aquifer media**

An aquifer is defined as a subsurface rock unit that will yield sufficient quantities of water for use. Aquifer media is based on lithology and refers to consolidated or unconsolidated rock, which serves as an aquifer (Aller et al., 1987). Aquifer media governs the route and path length which a contaminant must follow within the aquifer. Textural and formation features of the saturated zone control the pollutant diffusion within the aquifer. That is the route that the contaminant will take can be strongly influenced by fracturing, porosity, or by an interconnected series of openings which may provide preferential pathways for groundwater flow.

### **8.3.4. Soil Media**

Soil is the portion of the unsaturated zone characterized by significant biological activity. It is an open three-phase accumulator and transformer of matter and energy sub-system, which is developed via the physical, chemical, and biological alterations of the bottom litho types and of the organic matter they made of. It is considered as the first defense-line of the hydrogeological system (Civita and De Mario, 2002). The characteristics of the soil influence the amount of potential dispersion, the purifying process of contaminants, and the ability of contaminants to move vertically into the vadose zone. The presence of fine-textured material such as silts and clays can decrease relative soil permeability and block contaminant migration.

### **8.3.5. Topographic Slope**

Topographic slope is an important factor in vulnerability assessment as it governs the amount of surface runoff produced, the precipitation rate and displacement velocity of water (or a fluid and/or hydro-vectored contaminant) Civita and De Maio (2000). It refers to the slope variability of the land surface. Furthermore, the slope may be a genetic factor of the soil

type and thickness that indirectly facilitate the attenuation potential of the hydrogeological system. It also determines the extent of runoff of the pollutant and the degree of settling sufficient for infiltration. Areas with steep slopes, having large amount of runoff and smaller amounts of infiltration, are less vulnerable to groundwater contamination (Napolitano, 1995). Contrary to this; topography influences soil development and therefore have an effect on contaminant attenuation.

### ***8.3.6. Impact of the Vadose Zone media***

Vadose zone is defined as the unsaturated zone from the ground surface to the top of the aquifer (for unconfined aquifer); and for confined aquifer the vadose zone is defined all unsaturated and saturated zones between the ground surface and the top of the confined aquifer (Napolitano, 1995). The type of vadose zone media determines the attenuation characteristics of the material including the typical soil horizon and rock above the water table. The media also controls the path length and routing, thus affecting the time available for attenuation and the quantity of material. In short, it is defined as the zone above the water table that is unsaturated or discontinuously saturated (Lee, 2002). The type of vadose media determines the attenuation characteristics of the material below the typical soil horizon and above the water table. Biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization and dispersion are all processes that may occur within this media.

### ***8.3.7. Hydraulic Conductivity of the Aquifer***

This parameter refers to the ability of the aquifer materials to transmit water, which in turn, the rate at which the groundwater will flow under a given hydraulic gradient. It also controls the rate at which a contaminant moves away from the point at which it enters the aquifer (Aller et al., 1987). Hydraulic conductivity is controlled by the amount and

interconnection of void space within the aquifer which may occur as a consequence of intergranular porosity, fracturing and bedding planes. Hence, high hydraulic conductivity is associated with higher pollution potential.

## **CHAPTER NINE**

### **MODELING AND APPLICATION OF DRASTIC WITH GIS ON THE HOLETA RIVER CATCHMENT**

#### **9.1. DRASTIC Approach and GIS**

Geographic Information System (GIS) is used with DRASTIC model in this study. GIS is a tool for storing, manipulating, retrieving and presenting both spatial and non-spatial data in a quick, efficient and organized way.

When DRASTIC was proposed for the first time, its formulation did not take the advantage of advanced GIS technique (Napolitano, 1995). The method was primarily developed for manual overlay of semi-quantitative data layers (Vrba and Zaporozec, 1994). According to the earlier works in Napolitano (1995) many authors (Evans and Meyers, 1990; Cavallin and Giullano, 1992; Rundquist et al., 1991) used DRASTIC with raster-based GIS because the vulnerability index defined as an equation of linear combination of a linear combination equation (1.1) given in chapter one can be calculated with the overlay operation available in GIS.

Many researchers agree why they use GIS for aquifer vulnerability assessment is recommended:

- Storage of a large amount of georeferenced data and of the attributes;
- Data processing with interpolation of spatial data, rating of variables with appropriate weighting and calculation of a final vulnerability index by digital overlaying of raster data layers;
- Out put of large data sets;
- Frequent update of time-dependent data sets in a flexible and comfortable way

- Use of several technique of parameter coding to apply and compare different scenarios or strategies.

## 9.2. Data Sources

Various data inputs pertaining to seven DRASTIC parameters must be available for data base construction. All pertinent secondary data were collected prior to the primary data collection. The main data both primary and secondary, used for this work are given in Table 9.1.

Data	Data Source	Data Format	Scale
Drainage, Contour lines	Topographic map (EMA)	Map Coverage/ Vector	1:50,000
DEM (Digital Elevation Model)	Contour of topographic Map (EMA)	Grid (Raster) map	1:50,000
Slope	Elevation Contours (generated from TIN image)	Grid	1:50,000
Geology	Oromia Mineral Resources Development agent, OMRDA, 2005	Map (Coverage)	1:50,000
Land Sat image	Water watch, 2007		
soil	From this research and Holeta agricultural research institute (HARI)	Map and Tables	1:50,000
Land use	OMRDA, 2005	Map Coverage	1:50,000
Well data	Ketema, 2006, Drilling companies	Tables and reports	
Climatological data	National Meteorological Services agency	Tables	
Water Chemistry	Ketema, 2006, from this research and drilling companies	Tables and Reports	

Table 9.1. The major data sources used

### 9.3. Data Construction and Structure for Attribute Data

Attribute data were stored in a spreadsheet using Microsoft using Microsoft Excel while spatial data have been directly digitized and analyzed into a GIS using Arc Map and ERDAS.

The topographic base maps of 1:50,000 scale produced by the Ethiopian mapping Agency (EMA) in 1982 were used to digitize elevation contours, drainage and other related features. The base maps used for the production of topographic data and hydrographic network of the area are (Figure 9.1.): Adis Alem, Addis Ababa NW, Addis Ababa SW and Teji. The topographic base maps with contour interval of 20m were used for the construction of the Digital Elevation Model (DEM). Tin and Slope were extracted from the DEM at the same resolution.

Adis Alem 0938 C4	Addis Ababa NW 0938 D3
Teji 0838 A2	Addis Ababa SW 0838 B1

Figure 9.1. Topographic sheets used for the study

Lithological logs were used to classify aquifer media, type of vadose Zone and depth of Soil profiles. Based on the borehole database, the hydraulic conductivity of the aquifers was estimated using the ranges presented in Freeze and Cherry (1979). Under the borehole database, the aquifer media has attributes of geographic coordinates, depth to top of the aquifer media types, type of aquifer, confining unit and finally rating value of the upper aquifer media. The vadose media has attributes of location and coordinate,

significant media type, total vadose thickness and average rating for the materials constituting the vadose zone. Similarly, soil media was derived from boreholes data to reinforce the grain size distribution analysis conducted by different authorities and/ or organizations. It has attributes of qualitative description of soil type, thickness of overburden and rating. The thickness of overburden I simply to indicate the depth of the soil with similar color and texture up to the bedrock or soil of another color and/or texture according to the lithologic log description.

#### **9.4. Sources of Errors**

The vulnerability mapping process is highly subjected to errors that can vary the results. Actually the output quality depends on the type of data, efficiency of interpretation etc. The main sources of errors in Groundwater vulnerability assessment expected to occur in the analysis are:

1. Errors in Obtaining Data (Accuracy in locating sites collection and handling, Laboratory preparation and analysis, interpretation results)
2. Errors due to spatial and temporal variability (Random sampling error, Rationalization, extrapolation, interpolation, etc.)
3. Errors in computerization (Digitizing) and storage of Data (data entry, data variability, change in format, etc.)
4. Inefficiency in data manipulation
5. Final classification of vulnerability classes

#### **9.5 Model Output**

The data incorporated in GIS resulted in polygons that are identified as shape files and grids. For the seven DRSASTIC parameters the resulting shape files and grids are presented in Figures 9.2-9.8.

**9.5.1. Depth to water table**

Depth to water table can be computed either by converting all water level observation data to water levels below land surface by using topographical base maps and draw isobaths or lines of equal depth to groundwater or by using computer we can subtract the static Water level from the DEM. The water level map of the catchment is obtained by interpolating water level data of shallow (unconfined) aquifer.

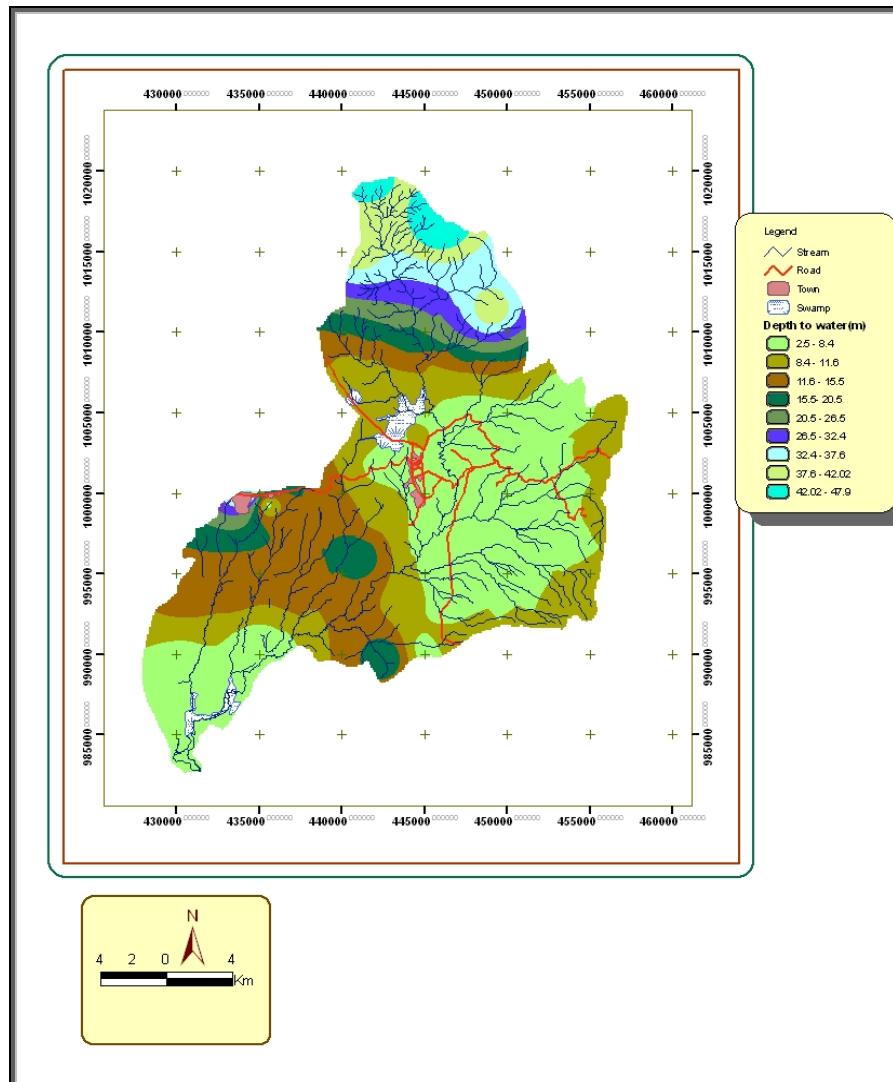


Figure 9.2. Water level Map

### 9.5.2. Net Recharge

The net recharge values for the study area are obtained by subtracting runoff value and actual Evapotranspiration values from precipitation values of the catchment. Actual Evapotranspiration on different parts of the study area is determined by using SEBAL algorithm (Water Watch, 2007) on the basis of vegetation index and land (Figure 4.10). Annual runoff value (456.9mm) and Isohyetal map for precipitation which are determined and discussed on chapter four respectively are used to calculate the net recharge values on different parts of the catchment.

Accordingly, the vector map of net recharge is produced with the values obtained:

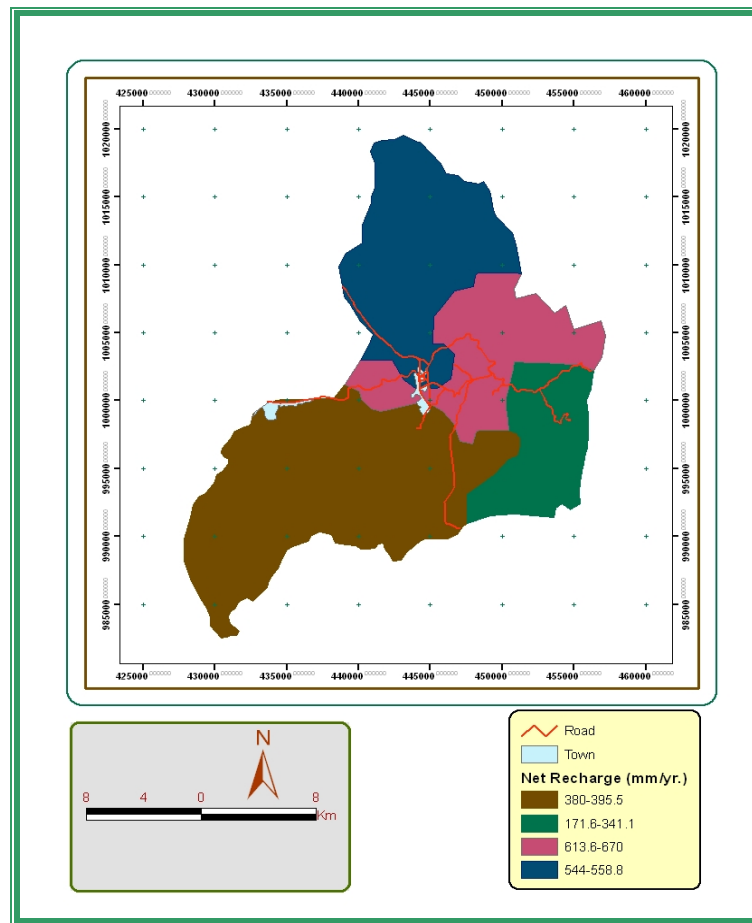


Figure 9.3. Net Recharge map

### 9.5.3. Aquifer Media

The general procedure is similar to that of vadose zone rating. The rating of the aquifer media assigned based on point (well) data were transformed in to vector map of aquifer media. Each polygon corresponding to a geological unit is assigned the mean value of the data points falling in it (see table 8.1.). Thus the upper aquifer (unconfined aquifer) material was used in rating of aquifer media and hydraulic conductivity as well.

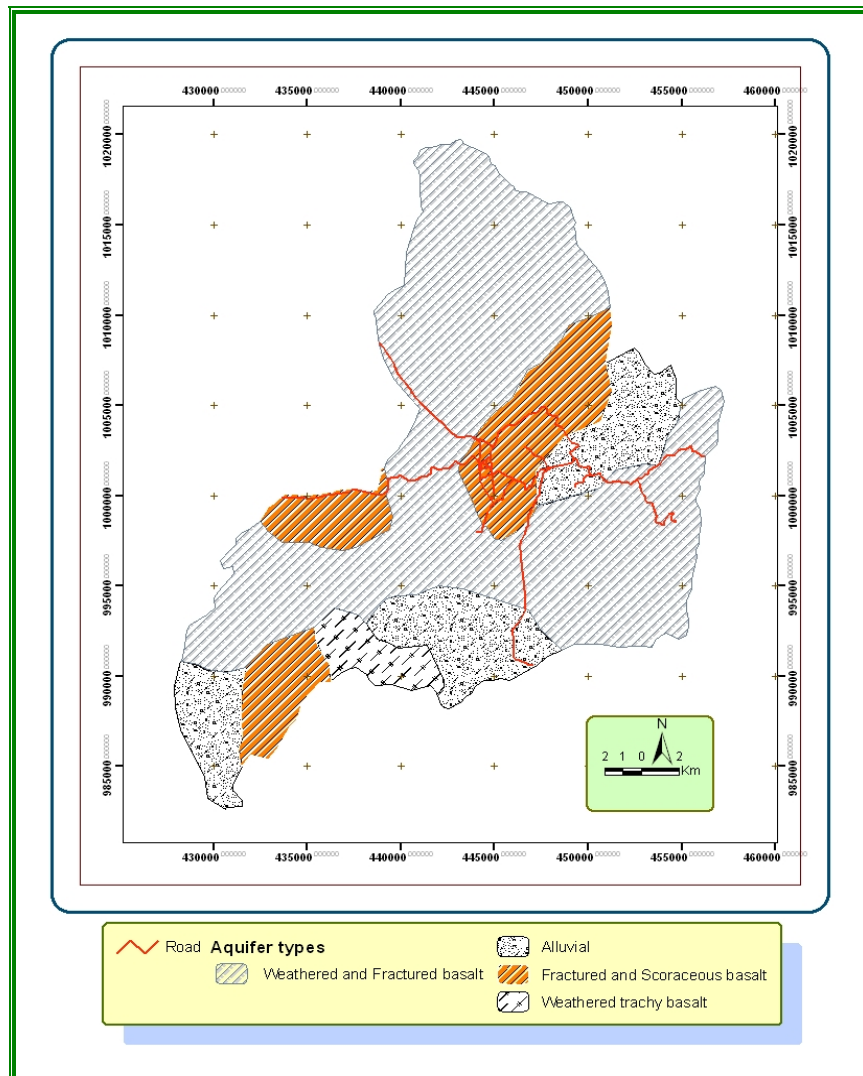


Figure 9.4 Aquifer type map

### 9.5.4. Soil Media

Soil map for this study is produced during the field work and modified after Ketema Wogari, 2006. During data gathering for this research, however, soil texture or grain size distribution analysis data were collected. Therefore, grain size distributions obtained at each location were classified using US soil Conservation Service (US SCS) (1951) soil texture classification method for these point data (Annex 6). After textural classification the soil map is assigned this texture for latter rating. And also, the soil thickness map (Figure9.5) is produced by interpolating point data obtained from Lithological logs and measured during field work. Hence therefore, the soil media map is developed by overlaying both the thickness and textural map of soil and averaging the ratings given to both maps.

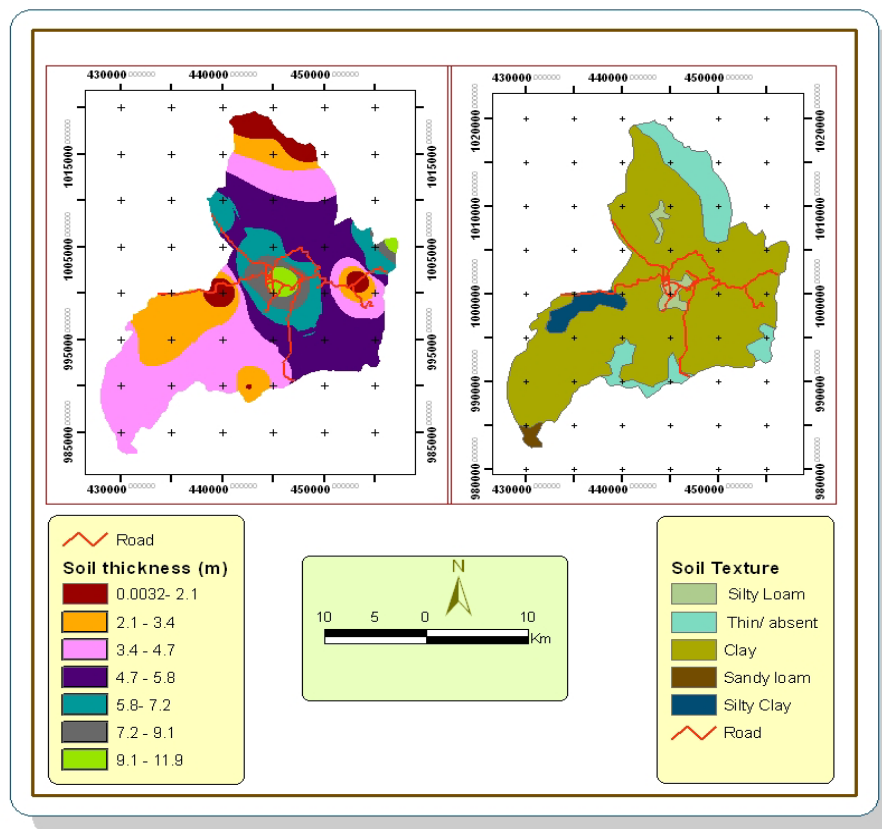


Figure 9.5. Soil texture and soil thickness maps

### 9.5.5. Topographic Slope

The Digital Elevation model, DEM, is used for the construction of the slope map. The DEM is developed from 20m interval digitized contour lines from a base map of 1:50,000 scale, and used to extract the slope. The slope map shows very high variability ranging between 0% and 96.1%.

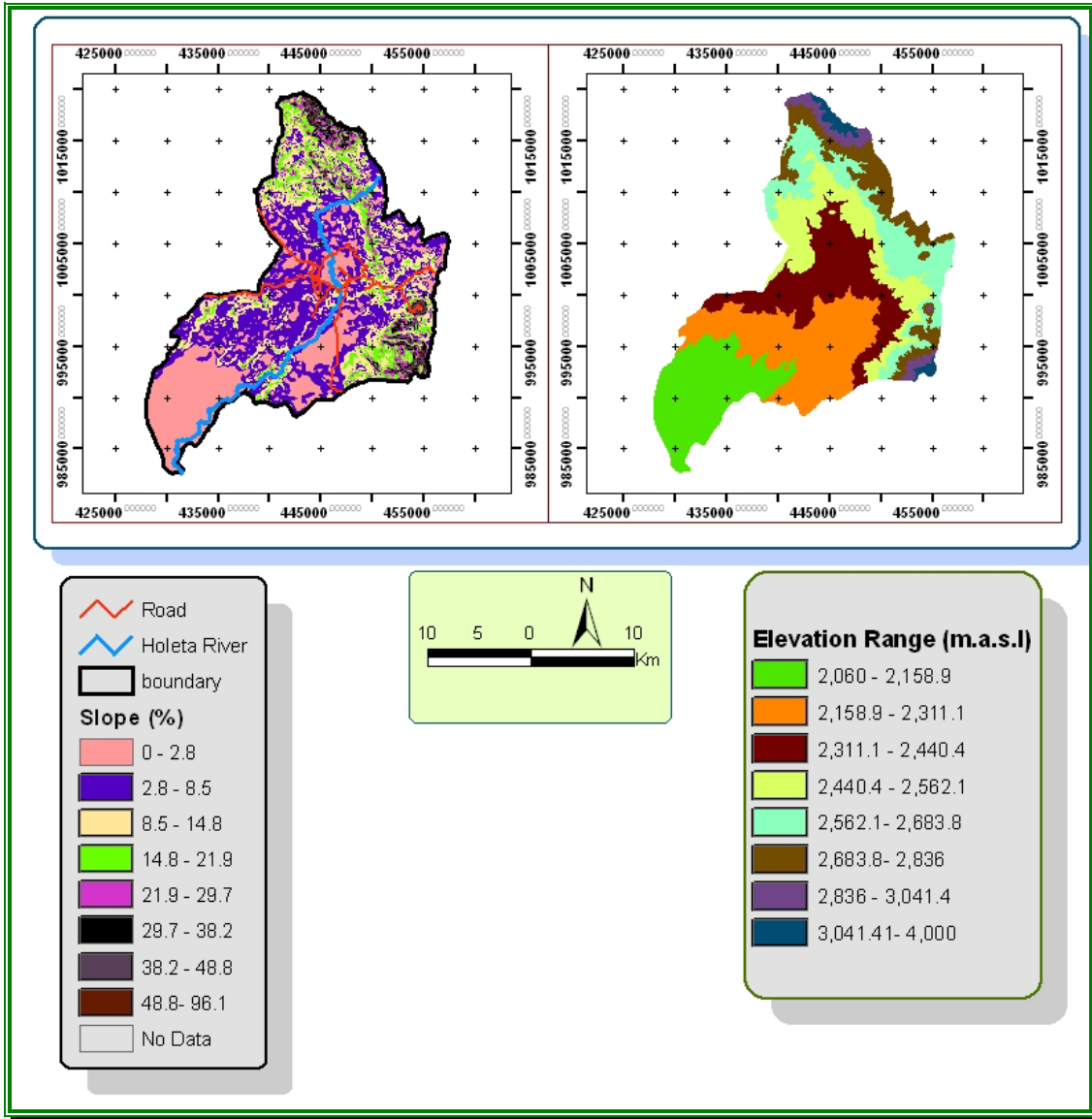


Figure 9.6. Topography and Slope map of the catchment

**9.5.6. Impact of the vadose zone media**

The vadose zone of the study area was developed by overlaying the vadose zone thickness map which is produced by interpolating point data obtained from Lithological logs and vadose type map. And, the rating was computed by averaging the rating values assigned for both maps.

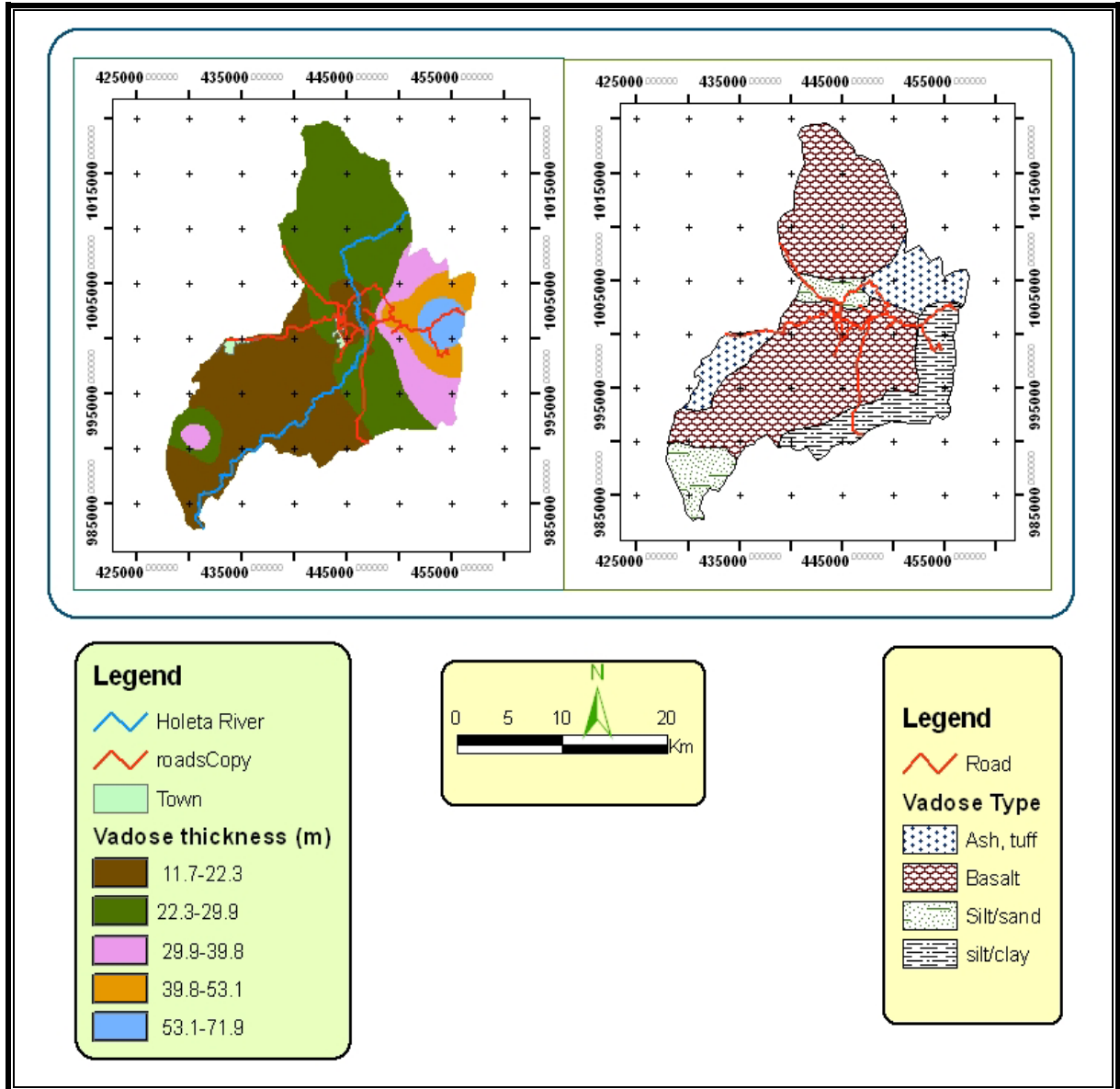


Figure 9.7. Vadose Type and Thickness map

### 9.5.7. Hydraulic Conductivity

In this study, hydraulic conductivity data are not sufficient for mapping. Thus, using the geologic database, hydraulic conductivity, which depends largely on the rock type and degree of weathering, was estimated according to the ranges given by Freeze and Cherry (1979) (Annex 5). The obtained rating values were overlaid on the geologic map and geologic units were assigned the mean values of the rating values that fall in it.

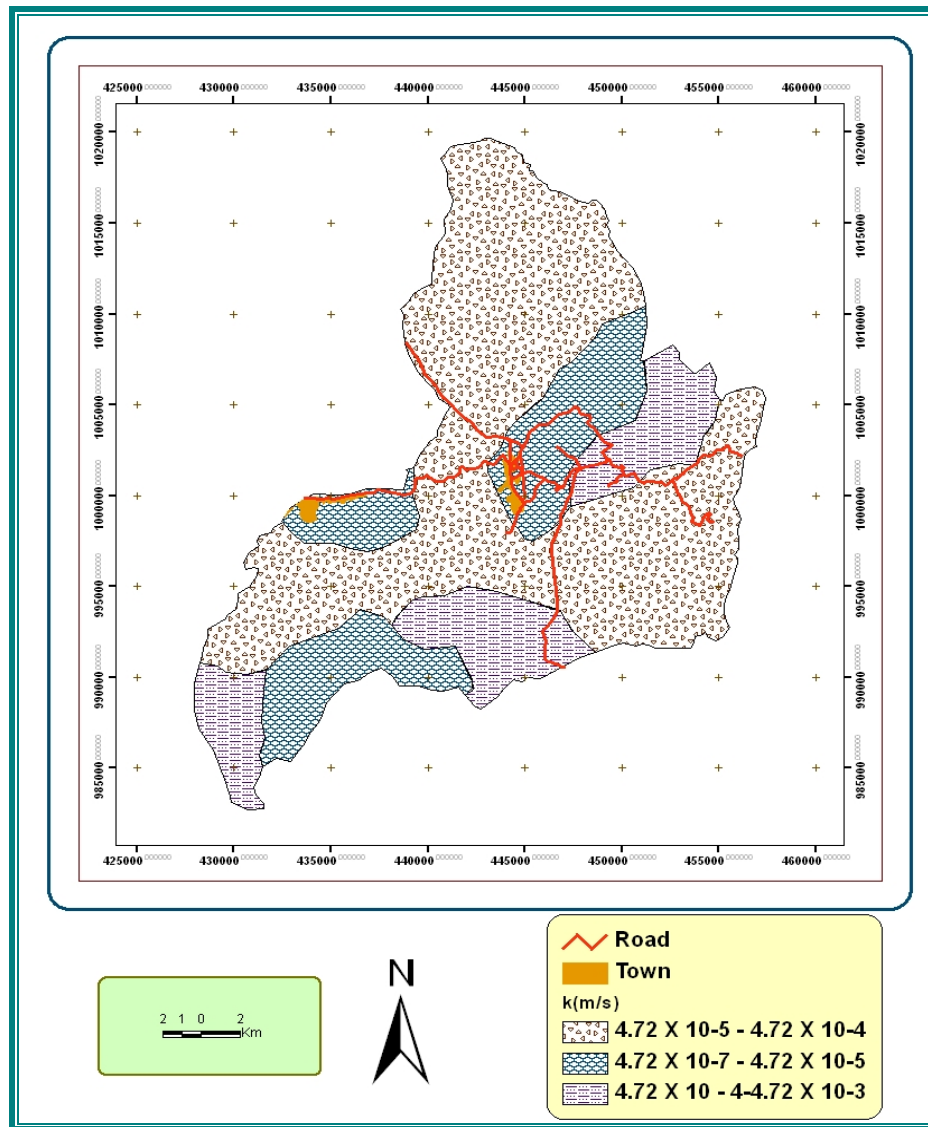


Figure 9.8. Hydraulic conductivity map

## 9.6. Results and Discussions

The shape files have been converted into grid (Raster) files where the cell size is 100X100. The results are given in figures 9.9 to 9.15.

### 9.6.1. Intrinsic Vulnerability Map

By overlaying the seven DRASTIC parameters the intrinsic vulnerability map (Figure 9.16) was generated using Arc map 9.1. The procedure employed is, as phenomenological presented in chapter one, Figure 1.3.

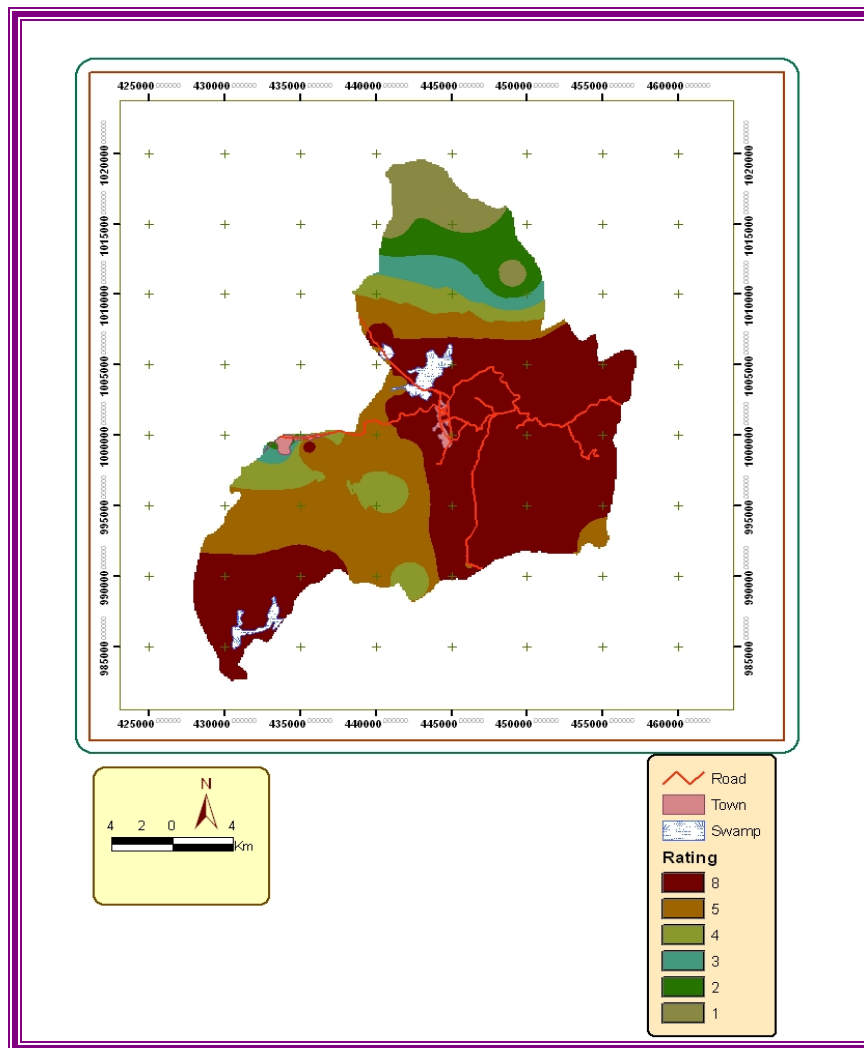


Figure 9.9. Rating result for Depth to water table (D).

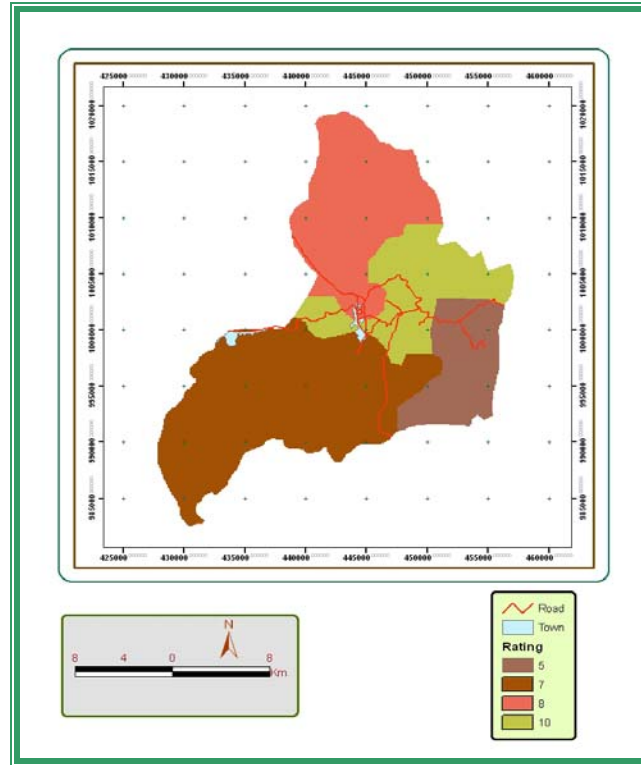


Figure 9.10 Rating Result for Net Recharge (R)

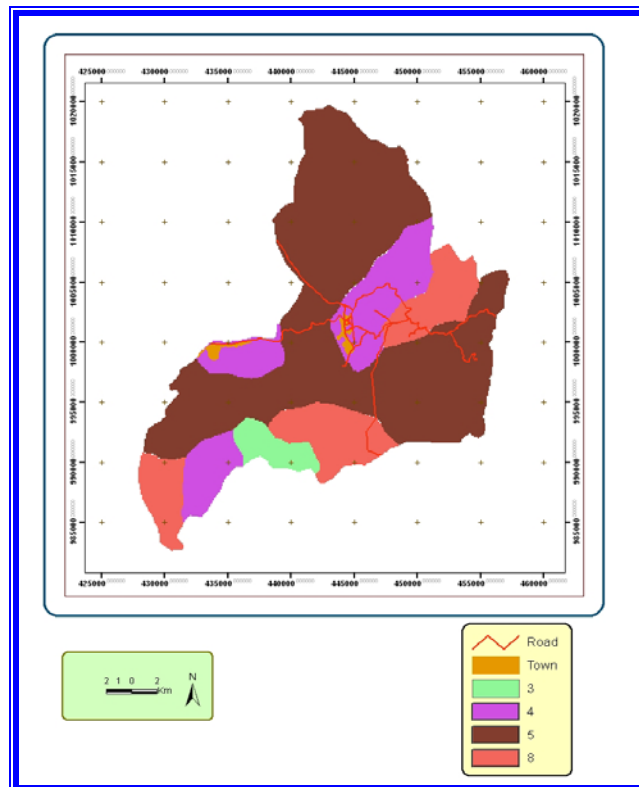


Figure 9.11 Rating result for Aquifer media (A)

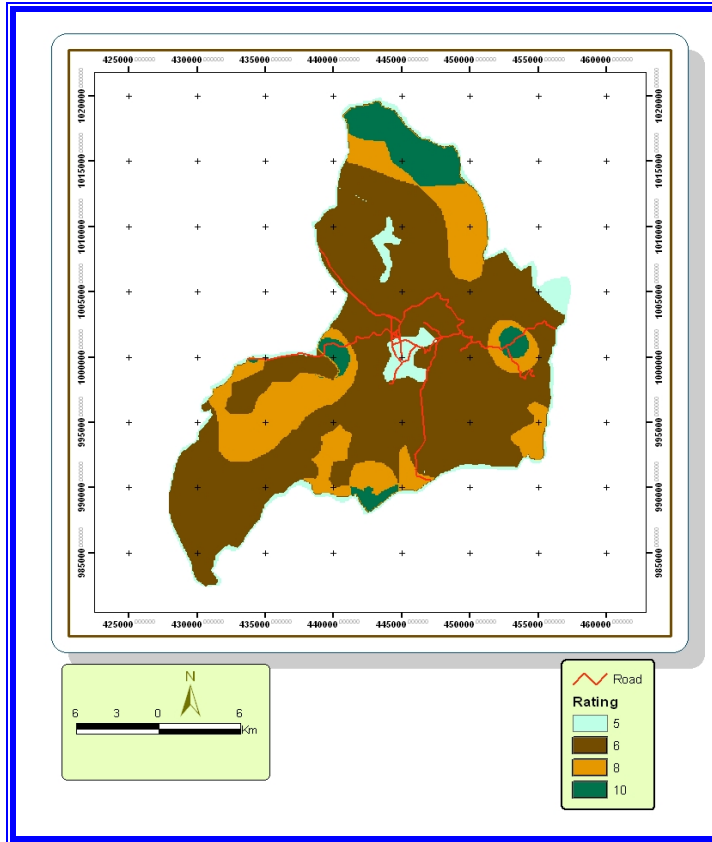


Figure 9.12 Rating result for soil media (S)

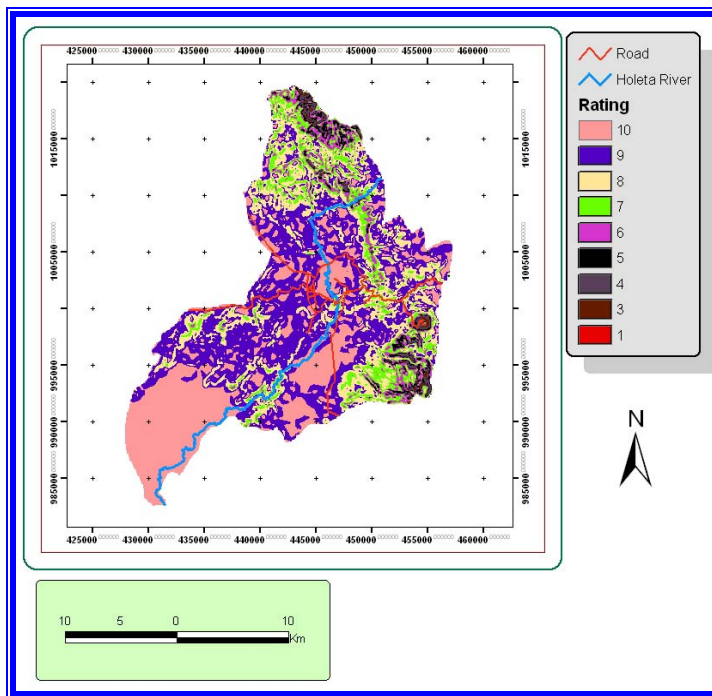


Figure 9.13 Rating result for slope (T)

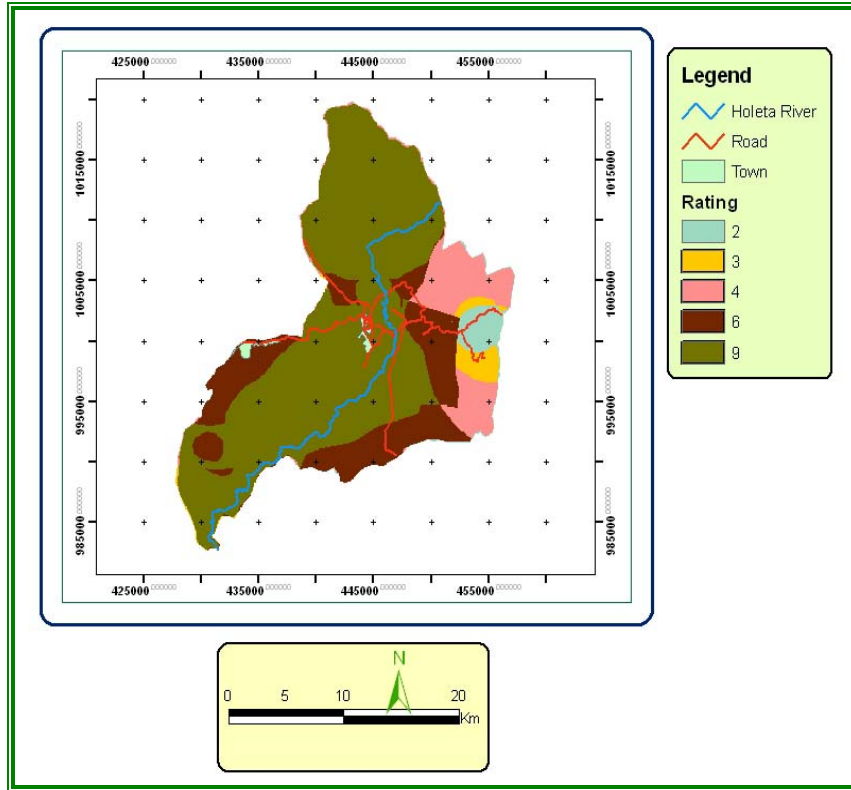


Figure 9. 14 Rating result for Impact of Vadose media (I)

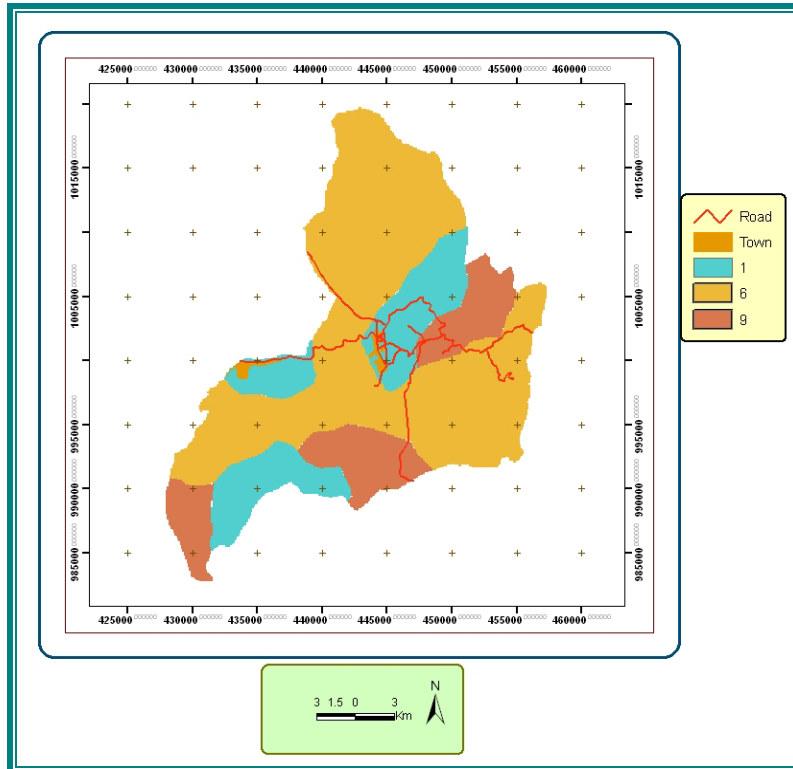


Figure 9.15 Rating result for Hydraulic Conductivity (C)

Hence therefore, from the above data layers “General/Normal” and “Pesticide” DRASTIC maps are produced (Figure 9.14 and 9.15). The resultant DRASTIC index values from equation 1.1 by employing overlay analysis are as follows: the minimum normal/ general DRASTIC index is 93-114 and the maximum normal/ general DRASTIC index is 177-198; where as, the minimum and maximum pesticide DRASTIC index is 119-139 and 198-218 respectively.

The final DRASTIC values have been grouped into very low, low, moderate, high, and very high pollution potential classes. These classes only represent the relative pollution potential within the study area. In terms of normal DRASTIC index extent, 93 to 114 is classified as indicating a very low pollution potential, 114 to 135 is classified as indicating a low pollution potential, 135 to 156 is classified as having a moderate pollution potential, 156 to 177 is classified as having a high pollution potential, and 177 to 198 as very high. The pesticide DRASTIC map is classified similar to that of normal DRASTIC map except for the range of the index values; 119-139, 139-159, 159-178, 178-198, and 198-218 classified as very low, low, moderate, high, and very high respectively.

Generally, groundwater is highly vulnerable in southern and central part of the study area because of high rating values of depth to water, net recharge, aquifer media, hydraulic conductivity, soil and impact of vadose zone media, and slope. That means these areas with very high index values are characterized as relatively high pollution potential. Only in western part of the catchment around Addis Alem town is classified as very low to pollution of the groundwater resources in general DRASTIC assessment. This is due to very low recharge rate as a result of thick soil cover and relatively deep groundwater. Areas with high and moderate pollution potential to groundwater cover significant parts of the area.

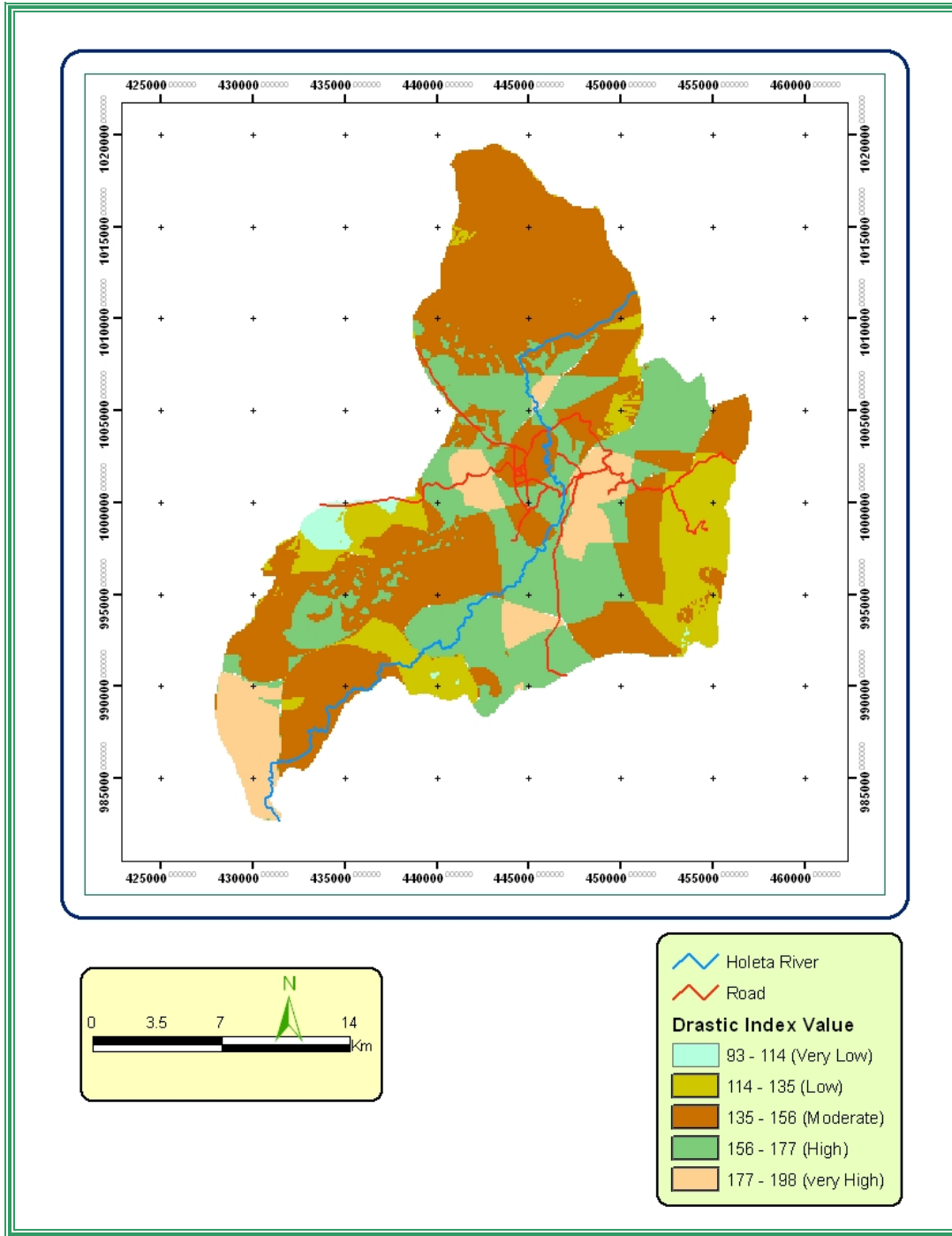


Figure 9.15 Intrinsic Vulnerability map for Holeta River Catchment

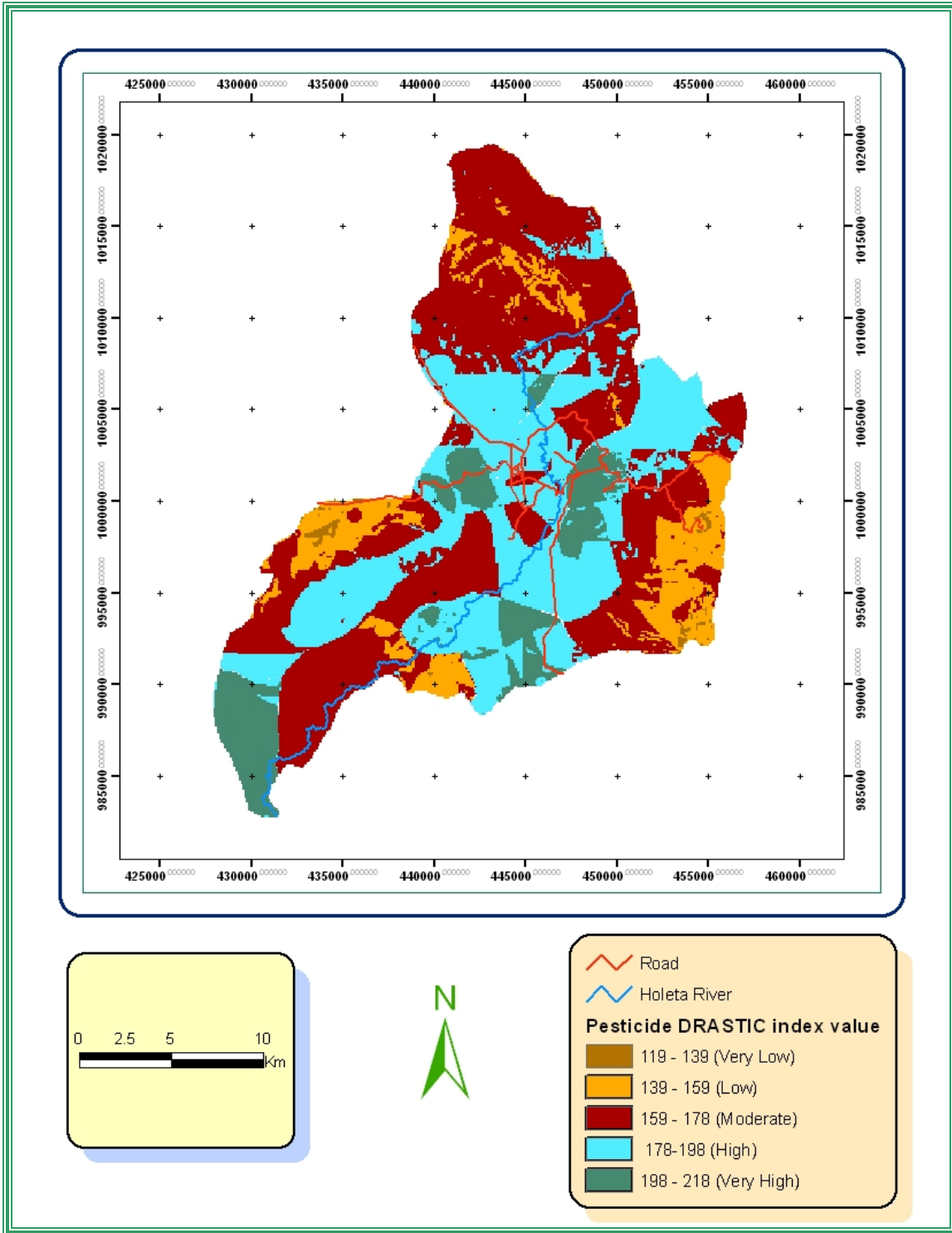


Figure 9.16 Pesticide Drastic map of Holeta River Catchment

### **9.6.2. Specific Vulnerability**

Specific vulnerability is assessed in terms of the danger of the groundwater system becoming exposed to certain contaminant load. The major attribute involved in assessing specific vulnerability is population density and flower farming. The more densely populated area has greater potential of the groundwater system and areas occupied or covered by a lot of green houses of flower farming are more susceptible to groundwater pollution than areas not covered.

The map indicates that rural kebel located in the northern, southern, and southern part (Telecho, Tulukorma, Hora, Indode and Nano suba) and Holeta and Addis Alem towns exhibits high to very high risk due to high population density(Figure9.17). And, Figure 9.18 shows that whether the green houses are sited on safest area of the catchment or not under natural hydrogeological settings. Therefore, most of the green houses found in the study area located on moderately and highly vulnerable parts of the catchment i.e. central part of the study area.

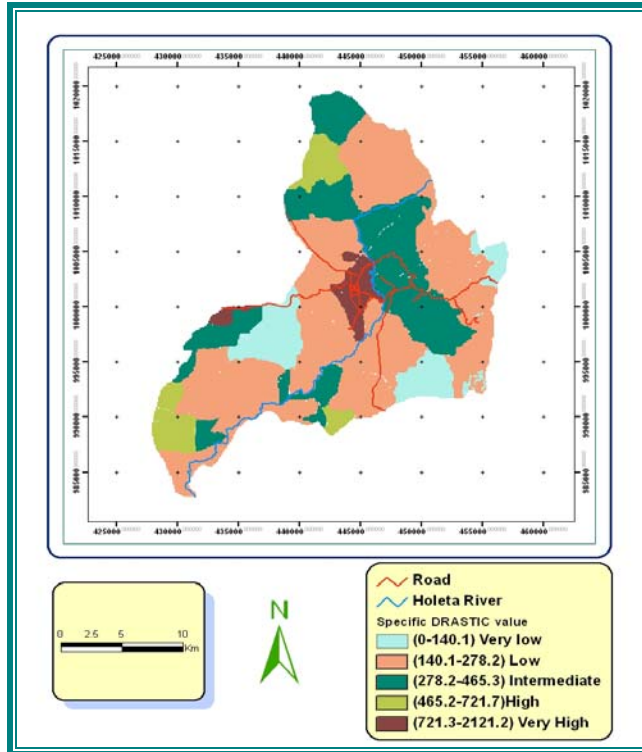


Figure 9.17 Degree of Impact on groundwater due to population density.

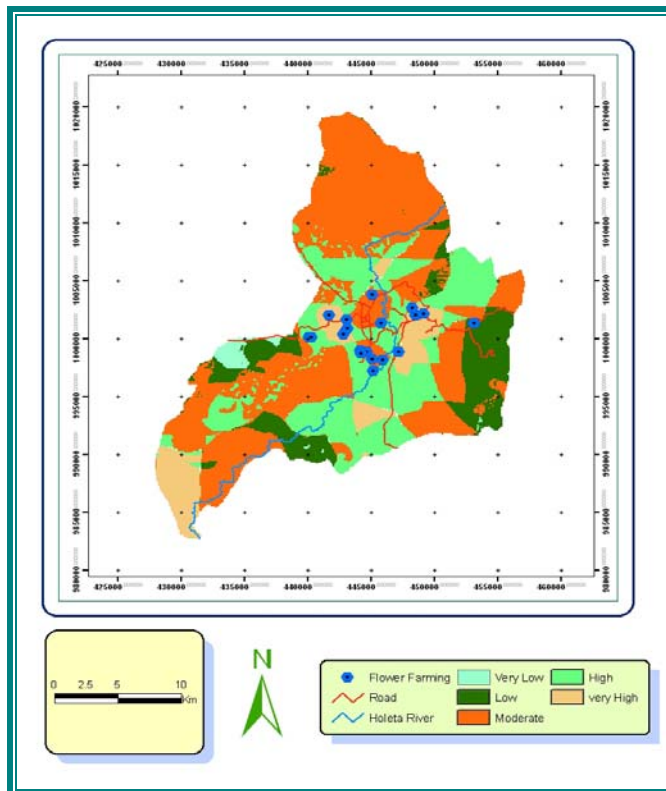


Figure 9.18 Degree of impact on groundwater due to flower farming

## **CHAPTER TEN**

### **SYNTHESIS**

Groundwater vulnerability mapping of Holeta River catchment is conceptualized that, the study area is characterized by high elevation ranges that can affect the runoff and even the infiltration rate of the pollutants. Therefore one of the parameters in the acronym DRASTIC, topography or slope of the catchment is obtained from elevation ranges. Groundwater system in sloppy areas will be less susceptible to pollution than plain lands.

Specific vulnerability is assessed in terms of the danger of the groundwater system becoming exposed to certain contaminant load. The major attributes involved in assessing specific vulnerability include: land use/land cover and population density. Hence therefore, in this study, demography is considered to evaluate and produce the specific groundwater vulnerability mapping in the catchment due to the impact of population density.

One of the parameters in the acronym DRASTIC is soil. Soil is so crucial in determining and assessing the groundwater vulnerability by using various parameters. Accordingly, in this thesis a combination of soil texture and soil thickness were used to produce both the normal and pesticide DRASTIC maps.

The local geological settings of the area are important to understand the major Lithological and structural distribution within the catchment. And it also helps to recognize the major aquifer and vadose zone types of the area. Therefore, in order to determine the major aquifer type, which is one of the parameters of the DRASTIC model, it was identified and

extrapolated from understanding of the local geological settings of the area.

Hydro meteorological parameters are essential in determining the water balance of the catchment as well as, in this particular study; it helps to evaluate the major inputs of net recharge, such as precipitation, actual Evapotranspiration, and runoff of the study area. Once these parameters are obtained, it is possible to evaluate one of the DRASTIC parameters “effective recharge” of the catchment.

Hydrogeology determines the major hydrostratigraphic succession of the study area. The major aquifer (A) and vadose (I) or unsaturated zone types has been determined from the Lithological logs of various boreholes. Hydraulic conductivity (C) as well as depth to water table (D) has also been evaluated from understanding of hydrogeology in combination with physiography of the catchment.

The chemical composition of natural water is the result of both natural and cultural effects as a consequence of human activities. That is, changes in the chemical constituents of groundwater have resulted from human activities in addition to natural factors. Therefore, to understand the changes in quality of groundwater due to the impact of human as well as natural process, it is important to discuss the hydrochemistry of the catchment. And it also helps to understand the adverse effect of agricultural activity and other pollutant sources on groundwater in particular.

## **CHAPTER ELEVEN**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **11.1 Conclusions**

Water quality degradation is one of the major environmental problems in Holeta River catchment and its environs. Hence, determination of the degree of vulnerability to pollution based on hydrogeological factors is important for policy and decision makers. Therefore, the primary goal of this study was to perform an aquifer vulnerability assessment of the water supply aquifers of the study area using a DRASTIC approach assisted by GIS software. To apply the DRASTIC system; hydrometeorology, topography, drainage, borehole data, geology, soil. Land use/land cover database were constructed. Using the aforementioned database, hydrogeological factors such as depth to water, net recharge, aquifer media, soil media, slope, and hydraulic conductivity were extracted and the DRASTIC is applied.

The results suggest that this approach can assess the possible pollution potential of the study area and generate information that is readily usable by agencies and concerned bodies. The groundwater vulnerability map is ideal for use in future land-use planning studies and exclude areas, where potential contamination may occur. It also helps to avoid future contamination of the groundwater by considering the vulnerability of an area before high-risk activities are allowed to take place. Thus, information of non-point and point sources of potential pollutants, including population, livestock and pesticide usage will be needed for the risk analysis of groundwater pollution. The main sources of pollutants that deteriorate the quality of water in the study area are; wastes generated from domestic activities, health centers and other institutions, and agricultural activities including the flower farming which is a point-source.

There is a spatial variation in EC, TDS, and pH in groundwater based on the contaminant input.

The intrinsic vulnerability mapping of the water supply aquifers of Holeta river catchment revealed that major part (northern) of the catchment lies on medium risk area while the southern tip and central parts of the area are highly/extremely vulnerable to pollution due to high recharge rate, alluvial and highly fractured aquifer media, and gentle slope. Low/very low vulnerable area is quite small in western and eastern parts. Generally, vulnerability of groundwater increases from north to south parts of the area. Regarding pesticide vulnerability index, northern part and some parts of southern lie on medium risk areas while the central and southern parts of the catchment are highly to extremely vulnerable for pesticides under natural hydrogeological settings.

From the specific vulnerability impact map due to population density of the catchment, it is possible to conclude that the both the urban sites (Holeta and Adis Alem) show high vulnerability index to groundwater due to their population size. Where as, major parts of the study area are very low vulnerable to pollution with respect to population density.

This study provides information on groundwater resource management, and also indicates that apart from its resource value, groundwater could be considered as a constraint for development activity within the catchment where it is near to the earth's surface.

## 11.2 Recommendations

- ❖ Based on the vulnerability index map produced in this paper, it is important to review existing potential contamination sources, and carefully plan future land use/ development/ activities located in the relatively vulnerable to groundwater system in the catchment. Otherwise, through time we are going to have polluted groundwater as a result of high loading of pollutant at even naturally less susceptible zones.
- ❖ For further validation of the maps using seasonal water level, hydrochemical, natural/ artificial tracer analysis is recommended.
- ❖ The current water management should include the groundwater resources management with much attention to the very high/ high vulnerability units.
- ❖ To understand very well the hydro-/litho-/ stratigraphic sequence and estimate the hydraulic parameters for each aquifer systems, an objective oriented project of core-barrel drilling and pumping test of the multi-layer aquifers separately required. Detailed geophysical and structural study should also be conducted to validate the assessment more.
- ❖ Detailed net recharge estimation will be required by using different methodologies/approaches, as this is one of the basic hydrogeological parameters affecting pollutant transport, and amount of safely and economically available exploitable groundwater resources in the catchment.
- ❖ Further possible groundwater contamination inventory for the aforementioned objectives and for the purpose of groundwater quality monitoring.
- ❖ The groundwater modeling approach of mapping is recommended to be included in the DRASTIC approach package with further research and manual development.

- ❖ Comprehensive risk assessment is recommended to be done by analyzing the contamination scenario and toxicity including detailed analysis of the behavior and degree of toxicity of chemicals used by flower farming.
- ❖ As depicted in specific vulnerability mapping before, most of the Rose farming practice is concentrated in central part of the catchment, which is a high/very high risk area. Therefore, it is recommended that, they should take good care of both the surface and groundwater resources by using appropriate amount of chemicals to their products, so that the chemicals can not percolate through the soil horizon to the saturated zone, and by not discharging their effluents in the nearby surface water bodies as well as in undesigned excavated pits.
- ❖ Awareness creation on groundwater vulnerability to pollution among the decision/ policy makers and planners to give an impulse to environmental thinking and public concern will be of an important risk averting strategy for future groundwater pollution protection within the catchment. In addition, it is important to educate the local people how to protect our groundwater system from pollution with particular emphasis on waste disposal and management as well as proper use of pesticides and/or chemical fertilizers.

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## Annex-1 Climatological Data

Element: monthly total Rainfall in mm

Coordinate: Long. 38°30', Lat. 09°05'

Station:Holeta

Elevation: 2000m.a.s.l.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aver.
1962	X	X	X	0	70.9	84.6	152.1	107.6	184.3	29.9	45.8	31.7	
1963	45.2	67	86	181.9	121.3	248.4	280.2	187	93.4	0	9.2	67	115.6
1964	0	7	37.9	69.1	75.9	280.8	373.8	329.4	263.7	49.3	0	28.6	126.3
1965	31.1	7.3	64.1	49.9	63.4	160.9	271.9	396.4	190.4	8.3	22.9	0	105.6
1966	7.7	65.5	97.8	155.3	2.5	65.7	295	387	491	78.9	26.8	0	139.4
1967	0	29	497.4	716.1	1196.9	1023.5	1333.1	1401.5	1195	381	13	0	648.9
1968	362	780.5	432.7	256.5	9.8	400.2	152.5	661.5	300.9	6.5	2.5	0	280.5
1969	44.4	435.7	64.7	42.4	68.5	84.1	204	285.9	139.2	0	14.9	0	115.3
1970	34.2	69.3	30.7	41.7	7.7	139.6	83.6	255.5	392	64.4	0	13.1	94.3
1971	30.2	0	155.2	160	215.6	335.5	415.2	628.7	314	29.2	12.1	0	191.3
1972	43.3	190.2	126.9	334.7	110.9	222	520.6	529.8	256	0	44.3	55.4	202.8
1973	15.3	0	2.1	82.6	160.1	297.5	522.1	536.1	335.9	60.3	0	12	168.7
1974	0	24.2	137.2	68.7	131.3	111	248.8	151.2	156.6	4.3	0	0	86.1
1975	0	5.2	20.2	79.4	68.4	124.2	271.9	270.8	216.5	13.9	0	0	89.2
1976	5.9	9.8	58.3	67.4	63	118	236.1	346.3	97.9	5.3	14.4	1.0	85.3
1977	185.9	45	28.2	41.9	80.1	444.6	778.7	821	247.5	25.2	154.5	15.3	239.0
1978	0	44.5	204.1	60.9	62.5	206.9	304.1	562.6	217.1	53.2	0	0	143.0
1979	46.6	78.7	56.5	93.6	61.5	110.4	224.8	264.5	145.4	13.2	0	14.5	92.5
1980	30.3	33.1	70.3	69.7	95.2	148.4	229.4	329.9	169.0	45	0	0	101.7
1981	34.3	64.5	111.3	107.7	122	145.8	449.5	663.5	572	14.4	0	7.5	191.0
1982	61.7	61.9	124.3	83.4	192.2	173.4	341.2	256.8	167.6	53.1	51.5	39.8	133.9
1983	19.9	49.9	120.4	126.6	219.1	87.5	241.2	284.1	101.9	23.8	3.9	22.7	108.4
1984	0	0	41.8	8.5	141.6	178.5	258.3	221.8	106.1	0	0.6	13.1	80.9
1985	15.2	0	47.7	49.1	48.5	45.6	257.3	281.9	105.1	21.1	4.1	0	73.0
1986	0	51.2	88	135.5	89	157.9	243.9	279.4	144	11.9	0	0	100.1
1987	2.4	77.3	112.1	92.4	137	86.2	182	261.8	112.9	19	1.4	21.4	92.2
1988	9.3	80.7	5.2	90.1	21.1	107	203.7	283.7	239.5	29.9	0	0.2	89.2
1989	4.8	86.9	78	69.8	8.3	74.9	240.7	279.3	117.5	3	0.3	21	82.0
1990	0.5	101.3	34.9	95.4	55.5	131.8	262.4	338.2	155.7	8	0	0.9	98.7
1991	21.1	74.8	118	21.3	37.2	89.9	232.1	229	172.5	2.6	0.3	5.8	83.7
1992	57.4	33.5	58.8	95	34.6	115.4	190.9	312.6	135.1	36.3	0.6	1.4	89.3
1993	18.2	83.8	3.8	127	59.3	103.1	210	276.1	214.3	26.5	0	0	93.5
1994	0	2.3	86.7	85.9	25.7	107.3	216.4	203.3	149.7	0	34.8	0	76.0
1995	0	84.6	41.9	123.8	81.3	91.6	196.9	264.5	82.1	15.5	0	34	84.7
1996	0	8.5	94.1	58.4	55.4	183.8	213.9	236.4	120.7	5.3	0	4.2	81.7
1997	15.3	0	21.1	95.4	13.5	95	233.2	193.1	40.5	46.5	23.6	1.0	64.9
1998	52.7	42.3	25.7	62.2	42.7	103.8	238.1	159.2	75.0	29.0	3.4	0	69.5
1999	18.9	4.6	15.8	12.7	31.0	105.1	144.8	169.5	27.0	41.5	0.0	0.0	47.6
	1213.8	2800.1	3400.0	4110.7	4010.8	6705.3	11302.4	13539.3	8060.6	1225.3	439.1	379.9	4765.6
Ave.	32.8	75.7	91.9	111.1	108.4	181.2	305.5	365.9	217.9	33.1	11.9	10.3	128.8

Station: Adis Alem  
 Element: Monthly Total Rainfall in mm  
 Geographic coordinate: 38°24'(long.), 09°03'(lat.)  
 Altitude: 2240m

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1964	0	3.5	80.1	76.1	88.9	156.7	22.3	145.9	124.4	38.5	0.6	15.3
1965	20.8	1.5	33.4	73.1	16.2	85.5	216.2	232.9	101.8	53.2	23.5	0
1966	3	87.3	72.6	180	49	148.7	293.3	397.7	160.5	30.5	8	0
1967	0	2	53	86	118	100.5	266.8	266.5	181	94.5	7.5	0
1968	0	131	18	180.5	39	179.5	257	377	184.5	13	0	0
1969	106	63	175	185	57	200	429	353	156	21	15	0
1970	41.5	89	124	44	74.5	149.5	397.5	307	198	51	0	1.5
1971	3	0	57	79	173	226.5	233	303.5	183.5	27.5	16.5	23
1972	28	71.5	60.8	152.5	70.8	116.2	215.5	160.5	156.5	1.5	17.5	0
1973	5.3	0.0	1.3	41.4	94.8	161.2	254.5	261.9	176.9	37.0	0.0	4.1
1974	0	25	132.8	11.1	110.5	97	241.2	281.6	150.6	2	0	0
1975	0	8.2	25.5	121	52	150.9	274.9	288.6	182.9	35.1	0	0
1976	20.5	4.1	50.8	54.5	89.5	96.8	266.1	295.9	104.2	17.8	19.3	2.5
1977	61.3	28.5	98	22	115.6	134	241.5	223.5	176.2	206	186.1	9
1978	7	56	49.5	39.5	41	163.5	315.1	231.2	232.1	75.5	2	25.5
1979	71.4	100	94.5	69	61	137	237	296	184.5	22	0	38
1980	33	45	62	69	69	138	215	236	138.4	1.7	8.1	0
1981	0	87.5	141	98.2	75.6	88	241.6	267	267	12	9	47
1982	52	49	42	65.5	70.9	65.5	228	256	59	64	112	40
1983	18	65	29	102	145.3	66.0	147.2	4	136.6	29.6	14.6	42.5
1984	2.5	0	32	12	138	157.6	157.4	150.5	109.5	3	8.1	8
1985	10	0	8	59.2	50	98.5	170	168.5	86.9	61.1	11	0
1986	2.5	64.3	105	89	148	138	193	179	121	16	3	4.5
1987	78	44.4	106	52	127	89	129	122	88	13	0	5.5
1988	11	35.5	9	55	13.9	117	182	242	127	21	0	0
1989	32	61	28	104	38.9	126.2	250.2	256	210	10.5	0	24
1990	9.6	131.6	55	55.8	105.1	111.5	187.6	342.8	196.5	13	0	7
1991	0	79.8	102.6	43.9	16.8	144.6	307.4	350.8	193.6	0	0	24.1
1992	41	50.7	72.4	85.5	33.7	75.1	323.1	385.4	234.3	36.3	5.4	8.2
1993	10.2	12.5	14.4	116.8	88.9	168.6	359.7	367.3	168.1	44.3	0	0
1994	0	0	34.5	44.8	37	218	304.8	225.1	141.2	0	17.5	0
1995	0	39.5	47.1	144.9	94.5	245.1	393.5	352.3	136.8	6.4	0	15.6
1996	0	7.9	129.5	70.1	160.4	163.2	371.9	326.6	123	6.2	0	2.2
1997	23.5	0	17.6	65.9	23.7	87.1	243.1	164.1	86.1	58.8	82.2	0.5
1998	53.2	86.5	107.4	67.3	101.1	198.1	289.5	251	154	53.9	13.9	0
1999	29.5	3.3	28.6	13.5	72.6	197.5	255	299.8	46.8	125.6	0	0
2000	0	0	12.5	103.1	135.4	168.1	266.6	238.1	186.8	28.4	17.4	29.2
2001	0	0	169.4	28.2	124.3	233.9	309.7	265	43.3	21.4	0	0
2002	48.6	83.8	77.8	26.4	35	174.5	333.1	275.3	38.8	0	0	34.9
2003	24.8	19.8	173.2	96	2.1	49.5	156	224.4	87.7	0	8.8	22.2
2004	17.5	27.6	70.5	144.6	69.9	143.2	190.4	212.5	172.5	171.8	11.3	0
2005	14.2	15.2	139.2	55.1	96.9	93.4	218.8	224	99	21.9	12.5	0
Total	904.7	1770.4	2989.5	3428.9	3385.6	6009.0	10692.4	11084.8	6257.7	1565.0	651.5	484.0
Ave.	20.6	40.2	67.9	77.9	76.9	136.6	243.0	251.9	142.2	35.6	14.8	11.0

Station: Addis Ababa Bole

Element: Monthly Total Rainfall in mm

Geographic coordinate: 38°45'(long.), 09°02'(lat.)

Altitude: 2324m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1965	0	0	42.5	58.7	6.2	16.8	168.9	231.9	45.7	64.2	6.4	0.5	53.5
1966	12.4	73	6.9	72.9	0.4	139.4	165.2	287.9	111.6	41.9	0	0	76.0
1967	0	6.2	75.8	107.1	145.6	134.7	263.9	208.9	232.9	20.1	38.9	0	102.8
1968	1	149.9	37.8	302.1	15	110.5	180.5	155.4	128.6	4.9	0.8	0	90.5
1969	67.5	109.2	153.5	95.8	123.5	128.2	226	300	109.3	0	0.3	0.1	109.5
1970	0	52.3	176.4	39.5	31.5	61.7	340.6	311.3	165.5	2.9	0	0	98.5
1971	7.2	0	36.8	67.9	154.1	123.1	303.4	300.7	161.3	8.4	4.2	16	98.6
1972	7.7	103.4	82.4	162.8	83.3	91.4	268.9	152	134.1	3.2	6.4	0	91.3
1973	0	0	0	25.3	68.8	117.6	266.3	333.7	130.8	31.1	0	74.6	87.4
1974	0	15.7	6.4	5	142.2	140.3	269.8	237.4	203.3	10	0	0	85.8
1975	5.7	0	26.7	79.2	8.6	112.9	292.7	155.2	128.8	29.5	0	0	69.9
1976	23.6	9.2	50.4	99.1	129.2	106.3	249.7	236.9	102.3	0	78.3	3.4	90.7
1977	64	46.8	95.2	76.5	104.8	151.7	222.8	300.3	168.5	227.1	9.3	0	122.3
1978	0	71.6	28.9	92	46.2	101.6	162.3	244.5	195.8	44.8	0	0	82.3
1979	91	7.2	91	31.4	139.5	119.9	249.2	164.2	85	15.2	0	5.8	83.3
1980	23.6	26.8	64.3	74.3	44.4	129.1	268.1	214.8	118.6	0	0	0	80.3
1981	0	42.6	217.5	79	18.4	56.9	273.9	256.1	162.5	24.7	0	2.7	94.5
1982	26.6	96.4	90.2	48.1	73.5	63.6	220.3	221.6	142.8	19	40.7	4.9	87.3
1983	12.4	41.2	28.9	113.7	186.9	56.1	217.9	213.7	202.2	35.9	0	1.5	92.5
1984	0	0.4	11.6	11.6	135	334.2	313.7	180.4	98.8	0	0	0	90.5
1985	35.1	0	49.1	130.3	92.8	110.9	209.8	260.8	168.6	29.8	0	0.4	90.6
1986	0	37.6	56.2	216.6	37.7	175.2	167.9	223.3	107.4	31.6	0	2.5	88.0
1987	0	49.1	180.1	85.7	154.6	71.9	155.9	98.1	57	16.6	0	0.4	72.5
1988	4.7	33.4	6.7	157.9	34.7	93.2	181.4	265.3	187.3	57.3	0	0	85.2
1989	3.4	33.7	58.4	143.3	0	88.1	218.1	318.6	150	36.8	0	7.9	88.2
1990	3.2	161.1	60.4	144.5	25.2	48.3	204.2	413.4	143	46.1	2.1	0	104.3
1991	0.2	29.6	134.1	15	7.7	107.5	279.4	287.9	123.1	4.4	2.1	0	82.6
1992	14.5	28	35	58.6	55	82.2	254.8	223.3	157	64.4	2.2	0.4	81.3
1993	11.7	52.1	11.6	168.3	91.5	157.2	209.5	291.7	190.1	24.1	0	0	100.7
1994	0	0	52.9	70	31.7	112.9	242.2	199.3	100.9	0.5	11	0	68.5
1995	0	81.3	73.3	140.3	95.9	78.2	165.1	256.9	97	0	0	28.6	84.7
1996	20.5	5.8	126.2	95.4	128.1	289.7	346.3	312.7	211.4	0.2	0.4	0	128.1
1997	29.1	0	22.1	66.8	44.8	128	257	160.7	94.7	58.6	15.3	0	73.1
1998	66.6	40	43.8	99.8	197.7	153.4	270.7	236.8	173.4	139.4	0	0	118.5
1999	4.4	0	35	17.8	30.5	104.6	294	270.5	62.8	127.1	0	0	78.9
2000	0	0	17.6	109.7	95.2	102.1	192.9	221.9	157.5	19.6	7.5	0	77.0
2001	0	10.3	165.3	14.8	106.7	163	274.4	179.1	107.3	10.6	0	0	86.0
2002	30.6	25.9	79.4	36.6	49.6	109	213.9	233.6	72.6	0.5	0	32.8	73.7
2003	4.8	34.1	48.9	121.9	33	128	226.4	238.4	130.2	4.6	0	33.3	83.6
2004	26.1	11.7	32.4	104.2	7	120.6	240.6	230.1	122.1	50	0	0	78.7
2005	55.9	13.6	41.4	116.2	170.6	159.1	174.3	244.1	77.6	25.8	7.2	0	90.5
Total	562.5	1492.0	2562.1	3724.3	3007.6	4759.2	9453.7	9709.2	5434.4	1315.7	233.1	210.0	3538.7
Ave.	13.7	36.4	62.5	90.8	73.4	116.1	230.6	236.8	132.5	32.1	5.7	5.1	86.3

Station: Teji

Element: Monthly Total Rainfall in mm

UTM: 430440(long.),972917(lat.)

Altitude: 2110m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1974	0	23	74.4	2.9	68.8	85.4	214.9	228.5	144.4	3	0	0	845.3
1975	0.4	11.8	51.6	66.8	64.9	93.8	257.2	165.5	171.9	10	0	0	893.9
1976	15	0	16.9	55.3	89	169.3	153.6	190.1	72.4	11.3	25.3	18.7	816.9
1977	60.1	77.1	77.6	61.4	73.9	133.2	202.8	205.8	66.2	204.8	5.5	0	1168.4
1978	1.6	53.3	57.6	75.5	59.1	168.3	273.6	229.8	141.9	1.5	0	6.8	1069.0
1979	81.5	36.3	74.2	68.4	111.7	113.3	181.4	251.1	82.3	27.4	0	11.1	1038.7
1980	15.6	28.8	32.6	71.2	26.2	126.5	273.9	245.8	106.2	36.7	0	0	963.5
1981	0	24.8	113.5	125.4	198	60.4	239	179.3	131.1	5.3	0	0	1076.8
1982	35.5	46.7	28	77	48.3	97.8	239.2	226.1	49.9	26.7	42.9	5.6	923.7
1983	13.1	100.1	43.3	137	9.8	61.4	248.6	178.8	53.1	0	0	0	845.2
1984	0	19.8	11.6	3.7	147.2	214.8	242.1	148.8	131.9	0	0	0	919.9
1985	17.1	0	21	64.7	43.7	54.9	283.3	234.4	116.6	3.8	0	4.7	844.2
1986	17.9	18.3	62.3	144.9	105.3	180.7	197.5	188.4	76.7	6.9	0	0	998.9
1987	0.9	46.2	133.4	94.7	128.8	55.7	90.7	207.5	48.3	11.7	0	0.8	818.7
1988	7.6	71.9	10.8	156.1	4.3	120.4	249.3	289.2	226.4	26.3	0	0	1162.3
1989	0.4	92.5	49.6	72.2	6.1	71.5	245	246.6	114.1	5.8	0	17.6	921.4
1990	0	149.6	74.5	79.1	30.4	101.7	251.1	210.6	81.3	11.8	0	0	990.1
1991	0	53.1	140.3	3.1	34.7	96.9	221.7	261.8	129.3	1.8	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	149.9	100.1	92.9	234.7	288.8	97.3	22	0	2.5	1093.6
1994	0	0	34.8	36.8	28.4	197.8	185.4	241.6	128.8	0	13.3	0	866.9
1995	0	41	18.2	98.2	65.7	66.1	223.8	179.4	46.5	1.3	0	48.6	788.8
1996	53.3	2.3	99.8	95	71.9	113.2	219.3	208.3	72.5	3.6	1.9	0	941.1
1997	12.7	0	28.7	131.9	29.3	96.1	187.9	143.9	63.7	48.1	48.6	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	1140.3
1999	4.9	0	44.2	5.8	45.2	97.5	242.4	218	98.2	76.5	0	0	832.7
2000	0	0	13.9	94	74.3	94.4	186.6	212.5	148.7	10.8	29.3	1.6	866.1
2001	2.3	1	95.5	14.9	164.7	182.9	214.5	120.3	64.6	3.3	7.7	0	871.7
2002	14.3	10	63.1	38	45.7	139.8	210.5	214.3	48.9	0	0	26.5	811.1
2003	29.3	21.1	80.6	153.7	48	158	229.8	267.4	84.3	0	0.2	9.6	1082.0
2004	20.1	6.4	22.2	129.5	28.5	163	209.2	216.9	72.6	68.5	0	0	936.9
2005	21.9	8.1	72.6	55.2	171.4	213.7	237.9	235	72.3	15.7	0	0	1103.8
Total	564.1	1156.0	1737.8	2520.0	2268.0	3881.4	7079.9	6902.0	3119.1	765.3	179.3	173.9	30346.8
Ave.	17.6	36.1	54.3	78.8	70.9	121.3	221.2	215.7	97.5	23.9	5.6	5.4	948.3

Station: Kimoye

Element: Monthly Total Rainfall in mm

Geographic coordinate: 38°24'(long.), 09°02'(lat.)

Altitude: 2200m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1981	0	10.8	366.8	310.1	80.8	149.7	401.7	249.9	157.2	0.6	0.3	5	1732.9
1982	22.2	42.9	63.1	124	97.7	96.3	39.8	264.5	48.6	22.3	5.6	1.7	828.8
1983	41.3	102.9	38.6	166.7	210.4	141.9	198.1	294.6	224.1	36.2	6.5	0.5	1461.8
1984	0	0	31.7	0.1	109.7	135.3	113.1	192.5	89.2	1.4	1.6	0.2	674.7
1985	5.8	0	14	50.8	73.4	97	226.9	215.4	84.3	19.3	16.9	0	803.8
1986	0	38.6	74.7	94.5	98.9	115.9	178.9	194.9	60.9		0	0	859.9
1987	1.9	33.9	178.2	145.4	107.8	56.5	241.1	151.4	69.5	6.3	0	0	992.0
1988	4.2	76.2	15.2	81.3	27.8	189.1	101.6	223.2	201	26.9	0	0	946.5
1989	0	111.7	117.8	80.7	39.3	143.3	198.9	173.0	129.7	9.4	0.0	0	1003.7
1990	0	80.8	17.9	74.7	79.1	141.2	222.8	253.3	127.8	18.1	1.3	4.8	1021.8
1991	7.4	87.2	66.9	7.9	51.7	106.9	274.2	259.6	105	0	0	0.1	966.9
1992	25.3	130.5	73.8	71.3	59.7	123.3	169.9	225.8	103.7	94.7	9.9	16.2	1104.1
1993	21	49.3	8.9	133.8	177.2	96.4	219.1	237.4	142.9	56.7	0	0	1142.7
1994	0	0	43.1	56.6	27.5	141.2	187.7	219	140.6	3.2	16.9	0	835.8
1995	0	58.9	59.6	156.8	47.6	89.7	241.9	254.8	124.9	0	0	15.4	1049.6
1996	53.5	0	159.5	54.1	78.2	109.4	297.8	215.7	145.3	3.4	2.9	2.4	1122.2
1997	23.4	0	20.4	37.2	24.7	89.6	248.1	149.8	59.1	40.5	47.5	1.9	742.2
1998	49.5	38.8	108.6	65.5	121.3	263.4	177.4	203.3	149.5	63.4	5	0	1245.7
1999	16.1	0	15.4	28.5	45.5	113.7	211.3	196.8	56.9	85.1	0	0	769.3
2000	0	0	3.7	60.9	80.5	123.6	223	207.5	135.3	48.9	9.6	53.9	946.9
2001	11.3	0	161.6	24.5	151.8	137.8	247.8	213.7	49.7	14.1	1.9	0	1014.2
2002	38.2	21.8	64.8	49	53.4	189.2	193.4	198	21.1	0	0	32.8	861.7
2003	24.3	99.3	37.8	104.9	14.2	154.8	184.1	165.8	121.6	1.6	4.7	1.9	915.0
2004	26	2.2	26.8	180.1	36.5	169.5	120.4	125.6	97.0	14.0	3.7	0.0	801.7
Total	371.4	985.8	1768.9	2159.4	1894.7	3174.67	4919.005	5085.4	2644.8661	568.62	134.31	136.784	23844
Ave.	15.5	41.1	73.7	90.0	78.9	132.3	205.0	211.9	110.2	23.7	5.6	5.7	993.5

Element; Monthly Rainfall in mm

Region; Shoa

Station; Enchiny

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1983	8.5	52	71	97.8	253.6	119.1	312.7	338.9	140.6	27.6	45.7	4.3	1471.8
1984	0.6	0	0	0	0	35.4	188.2	110.8	262.7	0.2	0	0	597.9
1985	0	19.4	0	0	0	159.3	171.5	68.3	59.5	38.4	12.2	17.7	546.3
1986	0	11.1	97.9	39.9	52.6	91.0	154.8	111.6	116.6	9.7	39.8	11.6	736.5
1987	3.6	24.3	234	95.2	164.4	124	161	207.3	68.5	17.6	0	0.8	1100.7
1988	3.8	24.3	12.6	38.7	10.0	85.7	136.6	186.8	71.2	28.5	0.0	0.0	598.3
1989	38.9	105	14.4	75.8	19.2	129.4	250.5	298	121.2	54.9	0.0	8.8	1116.1
1990	15.1	79.6	40.1	45.9	67.0	93.6	136.8	221.1	90.7	31.6	0.0	4.8	826.1
1991	48.4	40.3	103	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	1281.4
1993	1.9	53	31.6	200.6	79.3	146.3	270.4	235.7	269.6	70	1.5	9	1368.9
1994	6.9	8.1	100.3	34.2	70.4	231.2	330.3	222.7	148.7	12.7	11.6	0	1177.1

1995	0	12.2	73.7	134.4		91.5	338.8	233.3	117.2	10	12.7	59.1	1082.9
1996	82.9	21.8	163.6	93.8	99	191.7	310.3	341.3	122.2	21.9	37.1	3.8	1489.4
1997	49.3	0	25.6	100	89	123.3	306.1	218.1	98.7	151.2	101.4	16.3	1279.0
1998	46	19.4	66.2	18.4	119.5	195	348.2	304.4	170	113	13	0	1413.1
1999	16.7	9.3	22.6	22.5	41	90.4	274.7	319.1	88.8	136.5	1.3	1.8	1024.7
2000	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	48.4	126.1	171.1	308.9	207	121.2	38.5	3.4	8.6	1276.6
2002	62.3	5.5	121.1	32	20.6	163.1	222.6	305.1	154.2	0	0	53.2	1139.7
Total	450.6	570.9	1463.5	1428.2	1392.9	2630.9	5093.1	4724.8	2585.1	930.7	401.0	238.7	21910.4
Ave.	22.5	28.5	73.2	71.4	69.6	131.5	254.7	236.2	129.3	46.5	20.1	11.9	1095.5

Station: Sebeta

Element: Monthly Total Rainfall in mm

Geographic coordinate: 38°38'(long.), 08°56'(lat.)

Altitude:  
2240m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1975	0	2.2	28.5	85.9	33.2	76.9	182.1	134.4	174.8	2.7	0	3.4	724.1
1976	0	4.3	48.8	172	85	103.3	273.4	280.2	55.8	7.7	30	15.6	1076.1
1977	46.4	17.9	64.8	43.2	60.9	162	283	144.1	35.2	332.7	15.1	0	1205.3
1978	11.7	7.2	41.9	38.3	32.8	106.2	159.2	141.5	151.4	11.6	0	0	701.8
1979	90.6	14.4	23.5	63.9	57.7	181.4	170.2	55.1	15.6	0	4.8	0	677.2
1980	0	32.1	17.2	19.5	39.5	146.5	343.2	287.9	45.9	0	0	0	931.8
1981	0	61.2	141.8	57.9	0	197.5	220.1	215.7	112.8	0	0	0	1007.0
1982	17.9	13.9	22	10.5	7.5	80.8	213.6	252	78	50.6	43.4	19.2	809.4
1983	23.6	43.1	114.5	110.5	224	71.5	179.5	227.8	48.4	10.6	0	6	1059.5
1984	0	8.8	21.8	0	34.8	170	65.8	48.5	50.7	0	0	0	400.4
1985	0	10.8	31.9	179.1	80.2	156.5	595.6	578.3	293.1	64.4	23.8	0	2013.7
1986	0	262.3	86.4	151.2	493.4	494.6	344	1311.4	172.1	63.9	0	0	3379.3
1987	0	190.3	640.1	237.7	411.7	529.6	461.6	711.5	175.2	48.2	27.3	0	3433.2
1988	20.4	367.7	15.2	336.7	59.5	682.1	1565.5	1169.5	536.8	108.7	0	0	4862.1
1989	3.3	203.9	102.2	355.5	19.4	109.8	305.1	550.4	213.3	19	0	2.1	1884.0
1990	0	157.9	18.6	115.8	33.5	74.3	245.6	220.5	139.2	23.8	4.2	0	1033.4
1991	2.6	24.4	109.6	28.8	22	101.9	207.6	243.5	120.5	16.3	0	0	877.2
1992	41.4	51.3	46.4	41.3	70.6	92.9	205.2	415.2	251.1	119.9	11.7	6.9	1353.9
1993	25.4	136.2	38.6	413.6	338.4	216.1	525.8	1089	295.6	52.4	0	0	3131.1
1994	0	0	135.7	102.1	147.4	220.1	427.7	316.7	114.7	0	15.5	0	1479.9
1995	0	48.2	39.9	211.2	207.8	69.1	530.4	314.9	103.8	7	0	18.8	1551.1
1996	26	0	111.7	63.2	281	341.1	404.6	431.8	130.6	0	0.2	0	1790.2
1997	30	0	33.2	53.5	11.7	274.7	196.5	197.2	50.9	0	61.7	0	909.4
1998	69.6	3.4	15	30.3	101.8	129.9	214.5	217	105.8	48.9	0	35.5	971.7
1999	0	23.3	48.2	14	56.8	114.3	217	220.8	77.8	102.1	1.1	1.3	876.7
2000	0	0	3.2	75.7	37.3	96.1	173.7	182.7	217	26.8	21.1	24.6	858.2
2001	0	0	158	11.1	156.4	114.7	281.3	163.6	64.6	20.5	0	0	970.2
2002	25.4	47.2	129.8	31.8	30.6	81.3	173	251	113	0.6	0	21.1	904.8
2003	3	5.8	52.6	76.4	13.6	122.7	279.9	327.4	118.2	1.2	0	39.2	1040.0
2004	17.2	15.2	46.3	122.8	19.4	136.6	261.5	189.7	166	55.9	0	0	1030.6
Total	454.5	1753	2387.44	3253.5	3167.9	5454.47	9706.245	10889	4227.9	1195.5	259.9	193.7	42943
Ave.	15.2	58.4	79.6	108.4	105.6	181.8	323.5	363.0	140.9	39.9	8.7	6.5	1431.4

Station: Ensilale

Element: Monthly Total Rainfall in mm

Geographic coordinate: 38°58'(long.), 09°10'(lat.)

Altitude: 2205m

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1965	2.1	0	43.9	41	14.6	40.9	187.2	229.7	115.6	29.9	3.7	0	708.6
1966	2.1	105	38.6	91.8	2.3	120.4	211.7	251.8	143.5	21.8	5.9	0	994.9
1967	0	4.8	50.4	50.8	90.9	83.8	255.7	193.4	120.3	18.9	116.5	0	985.5
1968	0	54.2	42.2	152.6	30.2	149.4	177.3	162.4	109.3	1.6	0	0	879.2
1969	66.2	79.4	75.1	135	37.6	111.1	193.7	207.2	48.3	0	13.9	0	967.5
1970	29.6	63.2	93.1	40.3	52.2	69.1	292.9	220.4	148.1	3.1	0	0	1012.0
1971	23	0	45.1	40.2	95.3	112.5	279.7	211	148.5	1.4	0.5	5.4	962.6
1972	15.1	35.7	40.9	103.5	32.1	71.2	179.8	90.6	73.5	0.7	1.6	7.6	652.3
1973	6.8	0.0	1.0	26.3	68.3	115.1	224.9	169.0	123.0	8.7	0.0	2.3	745.3
1974	0	32.6	102.8	7.1	116.8	97.5	195.2	171.2	97.9	3.4	0	0	824.5
1975	1.2	6.8	22.4	79.9	48.6	140.7	197.6	194.4	148.3	10	0	0	849.9
1976	11.9	8.7	20.4	55.1	60.4	132.7	143.8	132.3	53.6	19	23.5	0	661.4
1977	67.7	48.5	94.5	53.8	58.3	110.3	200.3	268.1	53.4	164.7	1.4	0	1121.0
1978	41.6	48.1	39.6	44	21.4	122.9	55.4	197	142.5	18.3	0	4.6	735.4
1979	67.3	0	47.7	47.8	62	119.6	124.8	177.2	73.7	16.2	0	0	736.3
1980	29	34.7	59.7	75.5	60.5	100.2	231.5	175.1	69.8	12.2	6	0	854.2
1981	0	14.6	189.8	48.8	31.3	58.9	235.7	187.1	130.2	21.4	0	0	917.8
1982	22.3	29	38.4	65.9	46.2	55.4	226.3	223.8	106.3	34	29.3	3.4	880.3
1983	3.1	62	49.2	93.9	127.4	40.7	217.1	101	28.2	0	0	0	722.6
1984	17.2	1.2	8.1	6.3	102.6	130.9	155.9	184.3	109.5	0	0	8.2	724.2
1985	15	0	19.1	68.6	66.3	50.9	215.5	246.7	149	17.5	1.7	0	850.3
1986	0	29.0	23.9	78.9	44.2	68.3	148.1	159.5	90.6	5.6	0	0	647.9
1987	2.3	39.9	27.4	55.5	73.4	45.1	113.4	136.2	74.7	5.8	0.2	3.1	577.1
1988	2.7	26.7	9.8	125.9	10.7	117.3	138.5	265.6	164.7	52.1	0	0	914.0
1989	7.8	77.8	88.3	48.7	7.8	67.9	235.6	283.3	4.5	6.7	0	15.8	844.2
1990	0	67.5	24.3	104.9	18.8	101.2	230.3	207.8	128.1	7.4	0	0	890.3
1991	0.7	35.6	100.7	2.6	42.7	76.9	221.5	196.8	157.5	2.5	0	1.4	838.9
1992	13.5	40.4	21.6	35.2	27.6	92.2	157.7	231.3	49.8	47.3	0	0.8	717.4
1993	10.4	86.6	0.5	64.8	45.1	74.9	161.8	143.1	144.2	28.2	0	0	759.6
1994	0	0	42.7	57.1	62	140.7	293.9	237.9	126	0	64.3	0	1024.6
1995	0	45.8	14.3	136.4	48.8	77.2	217.4	207.8	50.9	2.3	0	17	817.9
1996	42.6	8.9	110.8	89.5	60.3	236.4	241.6	211.7	130.4	8.5	0.1	0	1140.8
1997	14	0	20	115.8	16.7	75.6	262	124	72.7	37.3	26.4	0	764.5
1998	103.4	46.3	21.8	74.6	73.4	95.6	299	240.9	81.4	0	0	0	1036.4
1999	4.8	0	15.1	19.3	32	119	223.1	224.4	70.9	78.4	0	2.3	789.3
2000	0	0	1.1	104.9	81	65.3	181.2	242.1	113.1	14.9	119.6	24.2	947.4
2001	0	21.5	71.5	8.4	82.7	129.6	210.3	126.5	95	23.9	0	0	769.4
2002	46.8	6.1	66.2	40.2	54.6	137.7	226.4	153.3	37	2.4	0	12.7	783.4
2003	14.1	29.1	67.9	90	22.7	123	267.7	207.3	135.7	8.6	0	0	966.1
2004	6.2	0.2	34.9	178.7	28.7	125	163.4	141.6	102.3	16.8	0	0	797.8
2005	7.5	3.5	36.2	59.5	163.9	141.1	198.7	162.1	102	19.1	6.6	0	900.2
Total	697.9	1193.4	1921.1	2819.1	2222.4	4144.2	8393.5	7896.9	4124.0	770.5	421.2	108.8	34713.1
Ave.	17.0	29.1	46.9	68.8	54.2	101.1	204.7	192.6	100.6	18.8	10.3	2.7	846.7

Station: Boneya

Element: Monthly Total Rainfall in mm

Geographic coordinate: 38°40'(long.), 08°56'(lat.)

Altitude: 2310m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1974	0	30.9	104.4	1.3	146.1	58	241.1	192.6	157.1	0	0	0	931.5
1975	0	0.1	0.5	87.1	70.1	159.3	276.2	151	171	18.8	0	0	934.1
1976	20	22.8	65.4	90.4	71.1	61.5	124	185.7	66.5	6.8	31.4	39.3	784.9
1977	47.5	9.1	99.7	125.9	33.2	193.1	271.9	370.3	43.4	164.8	15.4	0	1374.3
1978	2.2	95.8	38.9	103.3	35.1	127.8	141.2	235.6	164.4	12.5	0	1.6	958.4
1979	126.9	8.7	104.4	44	72.5	97.4	219.7	153.7	127.9	10	0	12	977.2
1980	18.2	24.3	36.3	66.3	20.9	78.1	311.4	189.9	137.5	2	0	0	884.9
1981	0	4	65.7	112.1	39	11	185.6	206.4	113.7	0	0	0	737.5
1982	20.5	43.5	54	20.2	100.5	55.8	178.9	299.2	127.9	57	16.9	1.9	976.3
1983	32.6	38.3	34.1	107.4	207.5	67.1	208.6	321.3	113	15.9	0.7	0	1146.5
1984	0	0	0	0	4.9	93.9	227.8	236.8	82.1	0	0	40.9	686.4
1985	8.7	0	24.6	85.6	96.6	85.3	347.9	291.2	110.1	1.7	0	0	1051.7
1986	2.5	109.6	57.8	111.2	50.9	162.4	199.1	136.1	150.7	0	0	9.7	990.0
1987	0	72.2	122.1	73	106.1	55.2	168.7	213.3	271.1	1.3	0	0	1083.0
1988	4.6	118.3	3.9	102.6	11.4	156.9	452.4	247.5	253.9	1.1	0.0	0.0	1352.7
1989	2.9	82.3	20.1	107.9	11.1	69.2	252.2	209.5	125.8	0.3	0.0	0	881.3
1990	0	116.2	21.4	72.7	27.6	148	224.3	279.8	73.1	2.3	0.0	0.0	965.5
1991	5.2	40.4	88	1.7	5.8	201.9	253.5	279.1	167.9	2.8	0	4.5	1050.8
1992	10.8	11.2	10.6	50.7	38.1	137.9	169.6	289.8	115	23.7	0	1.5	858.9
1993	0	64	0	50.8	47.3	132.4	263.3	203	107.6	12.9	0	0	881.3
1994	0	0	53.9	32.5	26.3	112.9	251.7	253.3	70	0	1.9	0	802.5
1995	0	35.1	24.7	129.8	76.2	47.2	181.3	134.2	70.1	0	0	19.7	718.3
1996	11.1	0	101.9	114.6	89	148.4	359.9	167.8	147.3	0	0	0	1140.0
1997	1.9	0	16.9	61	46.7	72.1	87.8	123.5	30.1	35	22.3	0	497.3
1998	25.6	9.4	37	27.2	63.3	99.4	154.3	108.2	119.4	0	0	0	643.7
1999	0	0	18.6	0	18	94.6	187.7	201.6	79.5	79.9	0	0	679.9
2000	0	0	0	36.5	48.4	78	154.9	129.9	114.9	7.9	13.4	0	583.9
2001	0	0	49.6	9.7	90.4	146.8	168.3	108.5	58	0	0	0	631.3
2002	17.5	11.1	18.3	15.1	24.8	75.6	144	122.2	46.1	0	0	14.7	489.4
2003	14.2	7.5	34.1	48.5	5.8	66.8	146.7	124.8	108.4	0	0	6.8	563.6
2004	25.1	0	35.2	75.4	18.3	70.1	84.2	67	6	8.5	0	0	389.8
Total	377.5	911.3	1288.1	1944.3	1602.5	3108.3	6459.3	5933.5	3529.6	465.2	102.0	152.6	26646.9
Ave.	12.2	29.4	41.6	62.7	51.7	100.3	208.4	191.4	113.9	15.0	3.3	4.9	859.6

Station: Holeta Research

Element: Monthly mean Maximum Temperature(°c)

Geographic coordinate: 38°29'(long.), 09°04'(lat.)

Altitude: 2380m

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean
1980	22.9	25.3	24.5	24.3	24.4	22.6	19.5	19.4	20.4	21.5	22.6	23.2	22.55
1981	24	24.2	22.5	22.4	24.6	24.5	19.6	19.3	19.6	21.4	22.2	22.6	22.24
1982	22.5	22.7	23.9	22.9	23.3	23.3	19.7	18.6	20.1	20.7	21.3	21.8	21.73
1983	22.7	23.6	24.2	23.1	22.7	22.4	21.1	19	20.1	21.3	22.2	22.4	22.07
1984	23.2	24.6	25.3	26.3	23.6	21.2	19.4	19.9	20.6	22.6	23.1	22.7	22.71
1985	23.6	24.2	24.6	22.7	23.3	23.4	19	19	20.1	21.4	22.5	22.8	22.22
1986	23.7	23.9	23.4	22.2	23.8	20.8	20.2	19.5	20.4	21.8	22.8	23	22.13
1987	22.9	23.6	22.5	22.6	22.6	22	20.9	20	21.5	22.6	23.3	23.5	22.33
1988	23.6	23.7	26	24.4	25.5	22.1	18.7	19.4	19.9	21.3	22	22.3	22.41
1989	24.4	22.2	23.2	21.6	24.1	22.6	19.4	19.1	19.2	20.6	22.5	22.1	21.75
1990	23	X	22.8	23.1	24.6	22.2	19.8	19.5	20.1	21.9	22.8	23.1	22.08
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	22.63
1992	22.4	22.6	24.8	24.6	24.3	22.5	19.4	18.9	19.7	21	21.7	X	21.99
1993	23	22	25.1	22.4	22.9	21.6	19.6	19.4	19.3	21.5	22.4	23	21.85
1994	24.1	25.1	24.4	24.1	25.1	21.4	19	19.3	20.6	22.3	22.5	23.1	22.58
1995	X	X	X	X	X	X	X	X	X	X	X	X	X
1996	X	25.1	23.9	23.2	23.5	20.7	19.9	19.4	20.4	22.3	X	X	22.04
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
1998	23.8	24.4	24.8	X	X	X	X	19.7	X	X	X	22.4	23.18
1999	X	25.1	X	X	X	X	X	X	X	X	X	X	25.1
Total	554.6	550	553.5	517.1	552.2	510.7	467.9	481.5	482.6	538.6	466.7	497.4	
mean	26.4	25	25.2	24.6	25.1	23.2	20.3	21.9	21.0	21.5	23.3	23.7	

Station: Holeta Research

Element: Monthly mean minimum Temperature

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean
1980	4.2	6.7	7.9	8.6	8	8.4	9.5	9.4	8.3	5.2	3.1	0.6	6.66
1981	3.3	4.2	9.2	9.4	7.5	6.9	9.7	10	8.8	4.3	1.5	1.3	6.34
1982	5.7	8.3	6.3	9.2	8.9	6.9	8.9	9.5	8.1	5.5	5.4	4.4	7.26
1983	3	7.4	9	9.7	10.3	8.4	9.7	10.7	8.8	6.3	4	4	7.61
1984	4.1	3.8	8.6	9.4	9.7	9.2	8.7	8.3	7.4	2.2	3	1.8	6.35
1985	2.5	3.3	7	9	7.7	6.8	8.3	8.9	7.3	4.5	1.9	2.6	5.82
1986	2.1	6.3	6.2	9.1	8.2	8.5	8.6	8	7.1	3.4	1.3	2.1	5.91
1987	2.4	6	10.1	8.2	8.8	7.8	8.8	9.7	7.8	5.6	2.2	3	6.70
1988	4.7	8.5	5.6	8.8	6.9	8.3	10.4	9.9	8.9	5	1.9	2.7	6.80
1989	2.1	5.1	6.5	8.8	6.4	7.3	9.2	9.1	8	4.3	1.9	5.9	6.22
1990	2.8	X	7.2	8.5	7.7	7.3	9.3	9.2	8.5	4.3	3.5	0.7	6.27
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	6.61
1992	5.7	8.6	8.2	8.2	8	7	9	10.6	7.5	5.9	3.1	X	7.44
1993	5.6	7.4	4.4	9.6	8.3	8.3	9.1	8.6	7.7	5.8	1.8	1	6.47
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	5.69

1995	1.3	5.8	7	9.8	7.6	6.5	8.6	9.1	6.3	3.4	1.8	3.3	5.88
1996	X	3.5	7.8	7.5	7.3	8.2	8.7	8.3	7.1	3.5	X	X	52.9
1997	5.6	1.1	7.3	8.1	6.6	8.4	8.4	8.4	7.2	6.4	5.6	X	6.65
1998	6.1	7.8	8.8	X	X	X	X	9.3	X	X	X	-1.6	6.08
<b>Total</b>	<b>83.8</b>	<b>127.7</b>	<b>177.3</b>	<b>194</b>	<b>180.6</b>	<b>185.9</b>	<b>229.5</b>	<b>239.4</b>	<b>194.2</b>	<b>122.4</b>	<b>52.9</b>	<b>42.7</b>	
<b>mean</b>	<b>3.5</b>	<b>5.6</b>	<b>7.4</b>	<b>8.4</b>	<b>7.9</b>	<b>7.7</b>	<b>9.2</b>	<b>9.2</b>	<b>7.8</b>	<b>4.7</b>	<b>2.4</b>	<b>1.9</b>	

Station: Adis Alem

Element: Monthly mean Maximum Temperature(°c)

Geographic coordinate: 38°24'(long.), 09°03'(lat.)

Altitude: 2340m

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1998	24.7	25.3	25.1	27	24.4	25.1	21.8	20.6	21.4	22.4	23.1	23.3
1999	23.8	26.2	24.3	24.2	25.2	23.8	21.2	20.8	23.3	22.3	23	24
2000	23.1	23.3	24.5	24.9	24.2	23.9	23.2	21.1	22	24.1	24.1	24
2001	24.1	25.3	24.7	23.6	23.9	23.1	21.8	21.6	23.4	24.4	24.2	24.3
2002	24.5	24.8	24.8	26.9	28.2	25.9	23.1	21.8	23.4	24.1	25	23.9
2003	24.8	24.5	26.2	26	27.8	23.4	20.7	20.8	22.3	25.5	26.1	25.7
2004	27	26.4	27.1	25.2	27.1	24	21.3	21.5	22.3	23.8	24.7	
2005	24	27.9	26.5	25.3	24.5	23.7	21.6	22	22.8	18.9	24	25.4
<b>Total</b>	<b>196</b>	<b>203.7</b>	<b>203.2</b>	<b>203.1</b>	<b>205.3</b>	<b>192.9</b>	<b>174.7</b>	<b>170.2</b>	<b>180.9</b>	<b>185.5</b>	<b>194.2</b>	<b>170.6</b>
<b>mean</b>	<b>24.5</b>	<b>25.5</b>	<b>25.4</b>	<b>25.4</b>	<b>25.7</b>	<b>24.1</b>	<b>21.8</b>	<b>21.3</b>	<b>22.6</b>	<b>23.2</b>	<b>24.3</b>	<b>24.37</b>

Station: Adis Alem

Element: Monthly mean Minimum Temperature(°c)

Geographic coordinate: 38°24'(long.), 09°03'(lat.)

Altitude: 2340m

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1998	9.6	11	11.2	11.8	11.5	10.8	11	11.8	10.3	8.6	4.4	2.7
1999	5.9	6.6	9.3	9.2	10.1	9.9	10	9.9	9.6	8.5	4.5	4.4
2000	4.5	5.1	7.2	7.4	7.5	9.4	9.5	9.5	9.6	7.8	5.7	9.1
2001	5.7	6.2	6.9	6.9	7.5	9.3	9.3	10.2	10.8	7.3	5.6	5.5
2002	6.9	9.1	7.3	8.5	9.5	9.2	9.9	9.4	7.6	6.3	6	8.7
2003	5.7	7.3	9.2	9.1	9.7	9.5	9.8	10.6	11.1	12.7	15.1	15.3
2004	13.5	12.6	14.1	12.8	14.9	12	9.8	10.5	12.8	12.4	13	
2005	11.3	14.1	13.7	12.8	13.4	11.9	9.9	11.3	12.9	12.3	8.2	2
<b>Total</b>	<b>63.1</b>	<b>72</b>	<b>78.9</b>	<b>78.5</b>	<b>84.1</b>	<b>82</b>	<b>79.2</b>	<b>83.2</b>	<b>84.7</b>	<b>75.9</b>	<b>62.5</b>	<b>47.7</b>
<b>mean</b>	<b>7.9</b>	<b>9.0</b>	<b>9.9</b>	<b>9.8</b>	<b>10.5</b>	<b>10.3</b>	<b>9.9</b>	<b>10.4</b>	<b>10.6</b>	<b>9.5</b>	<b>7.8</b>	<b>6.8</b>

Monthly Sunshine Duration

Station Addis Ababa 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
<b>Ave.</b>	<b>8.8</b>	<b>9.0</b>	<b>7.9</b>	<b>6.8</b>	<b>7.9</b>	<b>6.0</b>	<b>3.8</b>	<b>4.2</b>	<b>6.0</b>	<b>8.5</b>	<b>9.4</b>	<b>9.8</b>	<b>7.3</b>

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
<b>Ave.</b>	<b>8.7</b>	<b>8.9</b>	<b>7.4</b>	<b>5.9</b>	<b>7.3</b>	<b>5.0</b>	<b>2.7</b>	<b>2.8</b>	<b>2.8</b>	<b>5.2</b>	<b>8.6</b>	<b>9.45</b>	<b>6.4</b>

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
<b>Ave.</b>	<b>76.1</b>	<b>69.9</b>	<b>74.9</b>	<b>72.6</b>	<b>75.2</b>	<b>85.8</b>	<b>91.4</b>	<b>90.7</b>	<b>87.8</b>	<b>74.9</b>	<b>68.1</b>	<b>77.6</b>	<b>78.7</b>

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
<b>Ave.</b>	<b>45.5</b>	<b>40.4</b>	<b>47.8</b>	<b>45.9</b>	<b>44.5</b>	<b>58</b>	<b>70.9</b>	<b>70.9</b>	<b>61.4</b>	<b>43</b>	<b>40.6</b>	<b>46.3</b>	<b>51.4</b>

**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
<b>Ave.</b>	<b>46.2</b>	<b>37.1</b>	<b>46.2</b>	<b>50</b>	<b>47.3</b>	<b>63.9</b>	<b>75.7</b>	<b>76.125</b>	<b>65.9</b>	<b>47.4</b>	<b>42.9</b>	<b>47.6</b>	<b>53.9</b>

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

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
<b>Ave.</b>	<b>88.7</b>	<b>86.6</b>	<b>86.6</b>	<b>88.1</b>	<b>83.7</b>	<b>92.8</b>	<b>94.4</b>	<b>95.2</b>	<b>94.5</b>	<b>90.5</b>	<b>91.6</b>	<b>91.6</b>	<b>90.4</b>

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
<b>Ave.</b>	<b>36.1</b>	<b>38.9</b>	<b>38.1</b>	<b>46.2</b>	<b>37.9</b>	<b>55.5</b>	<b>70.6</b>	<b>71.3</b>	<b>63.4</b>	<b>40.6</b>	<b>33.5</b>	<b>32.3</b>	<b>47.0</b>

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
<b>Ave.</b>	<b>36.3</b>	<b>39.9</b>	<b>39.4</b>	<b>50.8</b>	<b>42.6</b>	<b>64.9</b>	<b>80</b>	<b>81.8</b>	<b>74.4</b>	<b>47</b>	<b>40.1</b>	<b>35.2</b>	<b>53.0</b>

## Annex-2 Hydrochemical Analysis

### Insitu measured Hydrochemical data

S/N	Identity	Source	Easting	Northing	Alt(m)	Ph	Eh (mv)	T(°C)	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

Annex -3 Hydrochemistry Data (Laboratory Results)																									
Locality	Scheme	x	y	Elevation	Date	Ph	TDS(mg/l)	EC(µs/cm)	T°(oC)	Na+	Ca++	K	Mg++	NH4+	CU++	Fe++	Mn++	Cl-	NO3-	NO2-	F-	HCO3	CO3=	SO4	PO4-3
Jerba sefer	HDW	435539	999256	2301	31/5/07	6.62	299.0	453	453					0.04	0.01	0.24	0.3		0.176			197.6	0	8	5.4
Markos	HDW	450099	998555	2358	4/6/2007	6.85	401.3	608	21.2					0.46	0.06	0.8	0.1		18.92			139.1	0	30	4
Minjaro	HDW	456560	1E+06	2705	5/6/2007	7.9	198	300	18.1					0.03	0.01	0.03	0.2		9.24			75.64	0	7	6.2
Sademo	HDW	448521	1E+06	2425	5/6/2007	6.53	175.56	266	22.6					0	0	1.13	0		0			144	0	4	1.5
Rob Gebeya	HDW	438346	1E+06	2590	6/6/2007	7.99	192.1	291	22.8					0.05	0.02	0.07	0.4		3.8			104.9	0	1	2.9
Cheshire home	HDW	454903	1E+06	2614	5/6/2007	6.95	113.19	171.5	19.2					0.03	0	0.05	0		6.1.6			64	0	0	2.4
Telecho	SOS	441081	1E+06	2661	31/5/2007	7.68	131.9	199.9	18.2					0.03	0.01	0.13	0.1		3.52			136.6	0	0	6.7
Menagesha mariyam	Sprig	453642	998774	2527	4/6/2007	7.54	123.6	187.2	18.8					0.13	0.01	0.24	0.2		3.96			139.1	0	2	3.4
Holeta River	Upstream	446106	1E+06	2661	6/6/2007	7.68	131.9	199.9	18.2					2.26	0	1.35	0		28.6			202.5	0	35	7
Sademo2	HDW	447915	1E+06	2360	27/10/2001	6.5	70	140	19.3		18		6	0	0.01	0.3	0	0	4.4	0.01	0.21	97.6	0	0	0.01
W/Choke	HDW	447992	1E+06	2480	29/10/2001	6.8	90	180	19.5		24		4.8	0	0	0.3	0.003	0	6.16	0.003	0.09	85.4	0	0.5	0.02
Welmera gojo	HDW	446993	1E+06	2420	27/10/2001	7	140	285	21.5		40		4.8	0	0	0.02	0	0	7.04	0.033	0.16	134.2	0	1	0.17
Hoita/02	HDW	444303	1E+06	2352	29/10/2001	6	400	790	21.7		40		13.92	0.03	0	0.02	0	0	4.84	0.003	0	115.9	0	0	0.16
Holeta/01	HDW	445225	1E+06	2409	29/10/2001	6.6	97	195	22.1		32		18.72	0	0	0.07	0.001	2.3	8.36	0.02	0.14	85.4	0	0.2	0
	spring	453665	998796	2572		6.75		148		7.4	15	4.2	4.2					10			0.12	76		<1	<1
	spring	441080	1E+06	2673		7.42		162		6.4	15	1.3	4.2					4			0.23	96			<1
	spring	451757	1E+06	2644		7.05	130	260		32.2	36	0.3	3.6		0.04	0.04	0.004	12	20.24		0.24	189.1	12	Nil	0.2
	SW	445271	990389	2225		6.88	248.8	306		10	36	3.4	10					5	7.5		0.41	184		<1	
	SW	440925	996210	2269		6.58	183.1	226		10.5	22.5	1.9	8					7	9.3		0.16	133		<1	
	SW	439642	993516	2190		7.14	222	444		43.7	72	2.3	6		0.06	0.03	0.001	40	22.4		0.39	256.2	42	4	0.28
	SW	446181	992508	2258		6.84	84	168		25.3	28	2.4	2.4		0.3	0.16	0.002	28	2.2		0.5	54.9	54	Nil	0.22
	BH	446266	1E+06	2372		7.96	158	229		21.5	23.5	0.8	3.57			0.03	0.1	3.84	12.76		0.37	134.7		0.8	
	BH	444997	1E+06	2354		7.16	204	284		8.1	47	1.8	7.14			0.03	0.1	3.84	12.76		0.37	134.7		0.8	
	BH	444626	1E+06	2366		7.51	190	277		9.2	44.5	1.3	8.16			0.01	0.1	2.88	8.8		0.27	178.6			
	BH	445942	998199	2250		8.28	144	192		18	18.5	2	5.1			0.04	0.1	5.76	11.4		0.06	107.4	4.8	1.6	
	BH	445773	1E+06	2417		7.49	232	324		9.6	48.7	2.1	11.73			0.01	0.1	4.8	13.64			205		0.8	
	BH	440079	1E+06	2410		8.12	174	253		11.7	33.6	2.2	10.2			0.01	0.01	1.92	6.6		0.13	147.4	9.6	0.5	
	BH	446170	1E+06	2385		8.7	104	208		18.4	20		3.6		0.06	0.02	0.001	10	11.44		0.55	36.6	66		0.22
	BH	446632	994813	2241		7.6	148			30	25	1.7	4			0.2	0.1	3	4.43		0.09	124		<1	
	River	446802	997431	2255		6.35	84	168			49.6		37.44		0.03	0.02	0.4		7.92		0.09	67.1	27	1	0.25
	River	445415	997168	2216		6.48	106	212			68		25.92		0.05	0.01	0.6		3.96		0.09	67.1	27	2	0.25
	River	445415	997168	2380		6.85	117	234			88		28.32		0.07	0.01	0.8		3.42		0.06	101.3	42	Nil	0.19

Annex4- Lithological Logs of Water points in the study area.							
	Water point	Bore hole	Borehole	Bore hole	Borehole (Artesian)	Shallow well	Shallow well
	ID	HTBH1	TSBH2	AABH3	WGBH4	HBSW1	TLNW2
UTM(m)	X	446080	447200	434160	447394	449048	435090
	Y	1002870	998889	1000153	1004331	1011411	990265
	Location	Holeta town	Tsedey PLC	Adis Alem town	Welmera Goro	Haro Boki	Telbo
	Elevation (m)	2388	2294	2333	2432	2729	2073
	Depth of well (m)	174.5	126	147	110	59.8	50
	SWL (m)	2.2	0		0		
Geologica Formations	Litho 01 (Depth)	sandy loam soil (0-8.5)	clay (0-8)	Red clay soil (0-2)	Brown clay (0-5)	Brown clay (0-4.6)	black cotton soil (0-4)
	Litho 02 (Depth)	River gravel (8.5-20.2)	Massive aphanetic basalt (8-30)	weathered scoria (2-6)	weathered basalt (5-10)	highly weathered basalt (4.6-6.9)	highly weathered basalt (4-14)
	Litho 03 (Depth)	scoracious basalt (20.2-31.95)	slightly fractured basalt (30-38)	Scoracious basalt (6-22)	scoraceous basalt (10-15)	fractured basalt (6.9-13.8)	Reddish clay soil (14-20)
	Litho 04 (Depth)	Fractured & weathered basalt (31.95-45.2)	weathered basalt (38-42)	Fractured scoraceous basalt (22-26)	Slightly weathered aphanetic basalt (15-20)	highly weathered basalt (13.8-18.4)	weathered vesicular basalt (20-28)
	Litho 05 (Depth)	Reddish sticky clay (45.2-47.5)	sticky clay(42-48)	fracture trachy basalt (26-42)	Weathered vesicular basalt (20-25)	weathered greyish basalt (18.4-23)	Scoraceous basalt (28-50)
	Litho 06 (Depth)	Weathered & fractured basalt (47.5-58.40)	weathered & fractured basalt(48-52)	fractured scoraceous basalt (42-44)		slightly fractured basalt (23-25.3)	
	Litho 07 (Depth)	Highly weathered scoracious basalt (58.4-62.3)	weathered & fractured scoracious basalt(52-64)	massive basalt (44-46)	Paleosol (25-27.5)	Highly weathered basalt (27.5-30)	slightly weathered basalt (25.3-27.6)
	Litho 08 (Depth)	Mod. Weathered basalt (62.3-68.4)	weathered basalt (64-72)	fractured scoraceous basalt (46-89)	Mod. Weathered scoraceous basalt (30-35)	massive basalt (27.6-32.2)	
	Litho 09 (Depth)	Highly weathered basalt (68.4-74.65)	Reddish brown clay (72-80)	Trachy basalt (89-90)	mod. Weathered & fractured basalt (35-70)	weathered & fractured basalt (32.2-59.8)	
	Litho 10 (Depth)	sandy clay paleosol (74.65-78.95)	Highly weathered & fractured basalt (80-96)	Fractured scoraceous basalt (90-147)	Massive basalt (70-76)		
	Litho 11 (Depth)	Sandy gravel with rock fragment (78.95-84.55)	Slightly fractured basalt (96-100)		Mod. Weathered scoraceous basalt (76-107.5)		
	Litho12 (Depth)	gravely sand (84.55-100.9)	Highly weathered & fractured basalt (100-116))		Fresh basalt (107.5- 110)		

		Continue					
	Water point	Shallow well	Shallow well	Shallow well	Shallow well	Shallow well	Shallow well
	ID	NSSW3	NSSW4	AMSW5	TKSW6	ADSW7	ADSW8
UTM (m)	X	442576	440616	429422	430519	430696	433369
	Y	989827	989882	988550	994178	991052	994260
	Location	Nano Suba	Nano Suba	Amero	Tulu korma	Andode	Andode
	Elevation (m)	2198	2200	2072	2137	2076	2124
	Depth of well (m)	38	50	37	45.6	50	59.8
	SWL (m)						
Geological Formations	Litho 01 (Depth)	Reddish silt (0-2)	Black cotton clay(0-4)	Black cotton clay(0-4)	Black cotton clay(0-4)	Black cotton soil (0-2)	Black cotton soil (0-2.3)
	Litho 02 (Depth)	Grey silt sediment (2-10)	Brown silt (4-14)	Brown silt (4-10)	Ash (4-8)	Basaltic gravel (2-4)	Highly fractured basalt (2.3-9.2)
	Litho 03 (Depth)	weathered basalt (10-14)	Reddish silt (14-20)	Sandy sediment (10-18)	Weathered tuff (8-22)	Weathered basalt (4-10)	Highly weathered basalt (9.2-18.4)
	Litho 04 (Depth)	Brown sandysediment (14-19)	Highly weathered trachy basalt (20-26)	Fractured sandstone (18-28)	Brown clay (22-26)	Fresh basalt (10-12)	paleosol (18.4-20.7)
	Litho 05 (Depth)	Grey sand (19-22)	Highly weathered basalt (26-34)	weathered tuff (28-37)	Weathered basalt (26-30)	Paleosol(12-14)	Fractured and weathered basalt (20.7-27.6)
	Litho 06 (Depth)	Weathered vesicular basalt (22-32)	Pumice (34-46)		Fractured basalt (30-42)	Slightly weathered basalt (14-22)	Paleosol (27.6-32.2)
	Litho 07 (Depth)	Weathered scoraceous basalt (32-38)	Sandy sediment (46-50)		Paleosol(42-45.6)	Gravelly basalt (22-28)	Fractured and weathered basalt (32.2-41.4)
	Litho 08 (Depth)					silty basalt (28-34)	Fractured basalt (41.4-47.3)
	Litho 09 (Depth)					Gravelly basalt (34-40)	Slightly weathered&fractured basalt (47.3-59.8)
	Litho 09 (Depth)					Highly weathered and fractured basalt(40-42)	
Litho 10 (Depth)					Gravelly basalt (42-50)		



**Annex-7 Types and location of water points in the study area**

Code	Locality	UTME	UTMY	Elevation	Schem typ	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 giyrgis2	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		

### Annex- 8 Pollutant sources

x	y	z	type
443618	1000335	2360	solid waste
442833	1001754	2410	"
443294	1000886	2378	animal husbandary/dairy farm
442852	1000414	2377	Rose ethiopia flower farm
441714	1002055	2434	euro flower farm
448521	1002021	2425	flower farm
444168	998992	2288	agriservice flower
445168	997226	2239	direhighland farm
445099	1003816	2400	dairy farm
445942	998199	2394	metrolux flower
443050	1001649	2403	garad flower
445773	1001323	2388	HARI
443132	100869	2386	arsis flower
445114	998215	2385	top international flower
444677	998888	2306	ama flower
444209	998733	2283	agri service farm
448290	1002698	2413	kurtusi flower
440079	1000151	2410	ethio dream
449177	1002158	2472	macro flower
453522	1001417	2556	jordan r. herbs
447200	998889	2294	tseyedey fruit
440280	1000112	2354	garad flower
453145	1001365	2551	menagesha flower
427491	994310	2119	supra flor itech p.l.c.
455088	1002928		gefesa michael graveyard
444451	1002892		genet gebriel
433899	999345		adis lem mariyam
443318	992555		gave yard
454714	998677		menagesha medahnealem
453543	998703		menagesha maryam
449935	998559		markose
444060	997847		genet medahenealem
438345	991985		dawa & lafto
441153	1013888		telecho gebriel
428969	992813		layi gyorgis

