ADDISS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF EARTH SCIENCES

GROUNDWATER POTENTIAL EVALUATION
&
HYDROCHEMISTRY OF SULULTA CACTHMENT

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS IN HYDROGEOLOGY

BY:

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ABSTRACT

Sululta catchment is located in the north part of Addis Ababa with east north-south stretch of $9^0$05' 01''N to 9^0 18' 45''N latitude and east west stretch of 38^0 33' 15''E to 38^0 50' 45'' E longitude. It is a sub-catchment of Abay drainage basin with a total area of about 480.80 km^2.

The main rock outcrops in the catchment are alluvial deposit of Quaternary age, basaltic, trachytic, rhyolitic lava flows & pyroclastic deposits of Tertiary age.

From long term mean monthly rainfall data annual precipitation of the catchment is calculated as 1201.31 mm per year. The potential and actual evapotranspiration for the catchment are 959.81 mm and 684.82 mm respectively. The area has an estimated overland flow of 178mm/year. Hence, the area's annual recharge value is 342 mm/year. When the value of annual base flow is subtracted 132mm/year depth of water is being added to the groundwater reservoir. This value is very important to categorize the groundwater development of the catchment exactly knowing the entire groundwater withdrawal per year.

The vertical electrical survey (VES) interpreted results, borehole logs, pumping test and qualitative interpretation have indicated that the upper 3-20 meters in most part of the central plain area is potential for hand dug well and shallow groundwater. This same area is potential for borehole of maximum depth 120 following the main fracture zones. The main aquifer in catchment is fractured and/or weathered basaltic lava. Hand dug wells are potential sources of water in the area where quaternary alluvial deposits followed by thick weathered basaltic lava. Even though, the yield is low to moderate both rhyolitic and trachyatic flow are aquifers near the Intoto ridge.

Based on the qualitative and quantitative analysis of aquifer characteristics the catchment is categorized into three permeability zones. The high permeable zone has transmissivity greater than 22 m^2/day and the yield of wells is 2 to 4 l/sec with partial penetration. The low permeable zone have trasmissivity less than 5.5 m^2 /day and yield less than 1 l/sec. the formation mapped as moderate permeable zone has values of transmissivity and yield between these zones.

The water in the catchment is mainly of Ca- Mg-HCO_3-CO_3 and Ca- Na-HCO_3-CO_3 water type. In most samples percentage of Ca^{2+}+Mg^{2+} is greater than Na^++K^+. The TDS obtained for the catchment is generally below 256mg/l and maximum EC is 540 microsiemens (μS). Redox Potential (Eh) is generally positive nearby the recharge area and gradually decreases downstream part of the catchment.

Concerning water quality, except for turbidity, color and bacteria the rest parameters are within the limit of acceptable value of WHO (World Health Organization) water quality standards for water supply, irrigation and industries excluding trace elements. Hand dug well shows the bacterial pollution because of its shallow water table.

CHAPTER I

1. INTRODUCTION

1.1. BACKGROUND

Water is an essence food and basic component of life. The need for water is strongly ascending and ha a diversified purpose, which is not only important for drinking purpose but is also vital for an development activities. It gets more complex due to population growth, urbanization an industrialization. Any development is related either directly or indirectly with water utilization.

In spite of its huge water resources, Ethiopia is frequently affected by drought and the people are nc food secured. These problems, to some extent, are related to under utilization of the existing wate resources. It is obvious that for the full utilization of existing water resources good understanding c hydro-geological system that controls the evaluation of potential water resources of a catchment i highly important. Such understanding could also help water managers to understand the impacts c climatic variability and aquifer pumping on water resources.

Groundwater is a precious and most widely distributed resource of the earth and unlikely any othe mineral resources it gets in annual replenishment from the meteoric precipitation. At present one fift of all the water used in the world is obtained from the groundwater resources (Raghunath, 1987). In a area where surface water is not available, groundwater is the second alternative for irrigation purpose i the demand for the irrigation and groundwater potential is promising without negative environmenta effect.

To use water for drinking purpose, the water should be analyzed in terms of quantity, and quality. B doing so, obtaining healthy, productive and prosperous community will be the final output of supplyin potable water. As that water supply needs chemical, physical, and bacteriological analysis, irrigatio water also needs hydrochemical analysis for different major cations and anions.

Water which is absolutely pure is not found in nature; even water vapor condensing in the air contain solids, dissolved salts, and dissolved gases. As condensed water falls, it sweep up other material fror the air, and becomes more contaminated on reaching the ground, running on the surface an percolating through the various strata of the soil and rock. Some contamination may be removed b passage through the soil as the result of infiltration and adsorption and exchange reactions; some may be removed in the surface water by sedimentation and biological activity; specific engineered processes in the treatment plants may remove some of them.

The activity of using water especially for irrigation is low. The paper is addressing the effective utilization of the water resources of the catchment by giving due attention to the potential water resources and recommending possible developmental activities. Generally, the project gives detailed hydrological, hydrochemical and hydrogeological study in order to launch developmental activities using groundwater and groundwater in the catchment. It is believed that this research will play important role toward the sustainable use of water resources in the catchment.

1.2. OBJECTIVES OF PAPER

The general objective is to conduct a groundwater potential evaluation and hydrochemistry of the study catchment.

SPECIFIC OBJECTIVES

1. Contribution of precipitation to the groundwater is analyzed
2. Studying hydrochemistry of natural waters.
3. To assess and evaluate possible sources of water pollution (if there is any)
4. Studying hydrogeological condition of the study area.
5. To determine groundwater flow direction in the catchment
6. To delineate potential sites for groundwater development
7. Integrating resistivity survey method for identifying deep weathered and fractured zones for groundwater potential.
8. To suggest possible feature sustainable utilization of surface and groundwater.

1.3 PREVOIUS WORKS

The previous studies made on the Sibilu includes: preliminary identification of regional water resources by Addis Ababa Water & Sewerage Authority (AAWSA) project study II, 1984; feasibility study by SEURECA (French consultant) associated with British consultant – Sir Alexander and Patress, (1991) and part of the detail investigation by AE-HBT Joint Venture which was interrupted without finalized report.

Morin and Parry (1971) investigated the geotechnical properties of Ethiopian volcanic soils, to which the studied area is included. The regional geology of the area was described by many authors: Mohr (1967, 1971), Zanettin *et al.* (1973, 1974, and 1977), Kazmin *et al.* (1975), Morton *et al.* (1979), and Haile Sellase Girmay and Getaneh Assefa (1989). Trufat Hailemariam, January 2001, did Geotechnical and engineering geological investigation of Sibilu Dam site, Reservoir, and catchment area. Girma Wolderufael, June 1999, did engineering geological study of the proposed Intoto tunnel. There are many water supply studies carried out by Oromia Water Resources Bureau for the purpose of site selection for borehole, spring development, and hand dug well constructions.

1.4 METHODOLOGY

Different investigation methods which are useful to provide information regarding the groundwater potential evaluation, and hydrochemistry have been conducted. These include:

- Arial photo interpretation, field geological and hydrogeological investigations and various relevant data completions and review of literatures and books.
- Analysis of the topographic map (1:50,000) for the drainage map.
- Preparing of geological map based on the site investigation and published reports
- Site investigation to map the soil and different land use land cover maps
- Locating different water points by GPS for spatial distribution and mapping purpose
- Taking photography of water points and land feature condition and rock outcrop (especially structures)
- Conducting of vertical electrical survey at different area of the catchment
- Collecting hydro meteorological, soil, land cover, water points inventories, well log, and pumping well results etc.

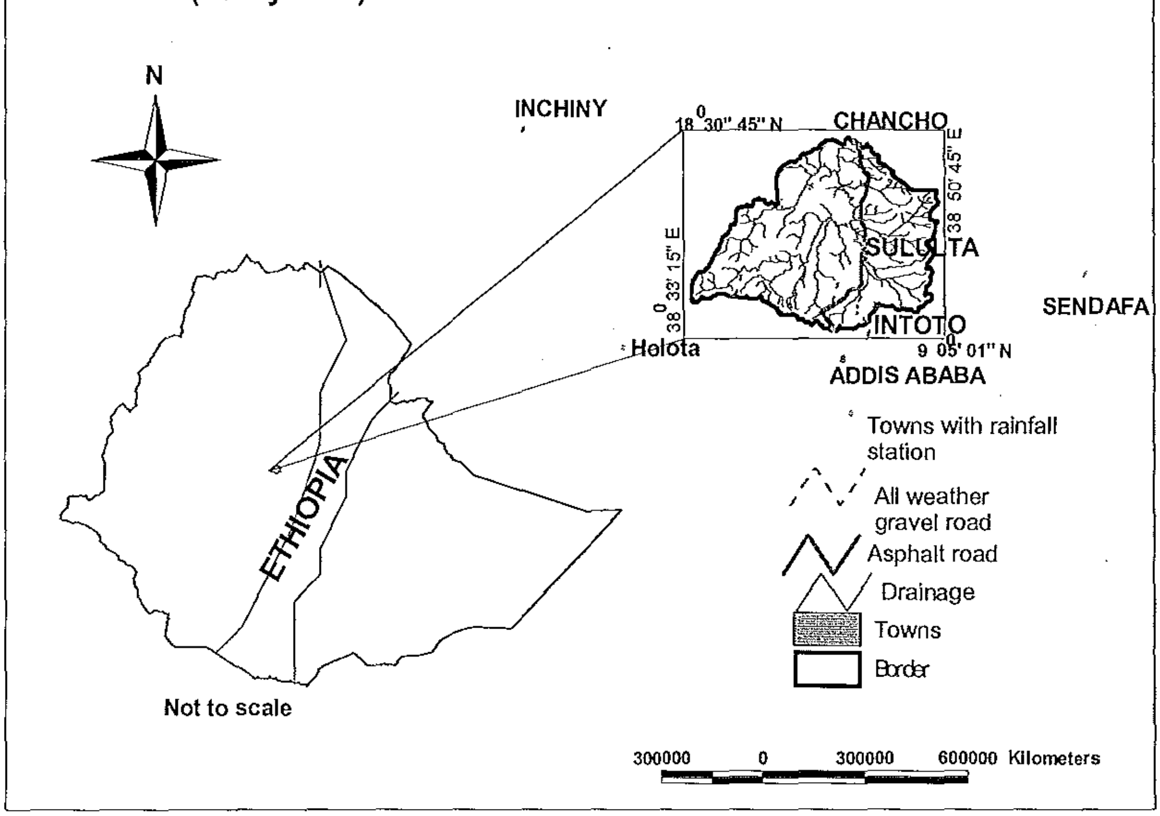
CHAPTER II

2. GENRAL OVERVEIW OF THE STUDY AREA

2.1 LOCATION AND ACCESSIBILITY

Sululta catchment is located in the northern part of Addis Ababa and south of Chancho town. Intoto silicic is found in the Central part of Ethiopian plateau bounded by Rhyolitic ridges to the south and basaltic (Alaji) ridge to the east. The basin is enclosed within the geographical co-ordinate of $9^0$05' 01''N - 9^0 18' 45''N latitude and 38^0 33' 15''E - 38^0 50' 45'' E longitude. It covers a total area of about 480.8 km^2. With respect to the main asphalt road that connects Gojjam with Addis Ababa, more proportion of the catchment lay in the western part and the rest in east direction longitudinally. The location and drainage map of the basin is shown in Figure 2.1.

Fig. 2.1 Location map of the Sululta Catchment (Study Area)



The main asphalt road passes through the middle of the basin and provides good access to the area. Additionally, all weather gravel roads drive in the upper part of the catchment along the Intoto ridges and near Chancho town to west part of the catchment. Different subsidiary dry weather roads give access for most of water supply schemes in the basin. In general the study area is accessible.

2.2 PHYSIOGRAPHIC SETTING

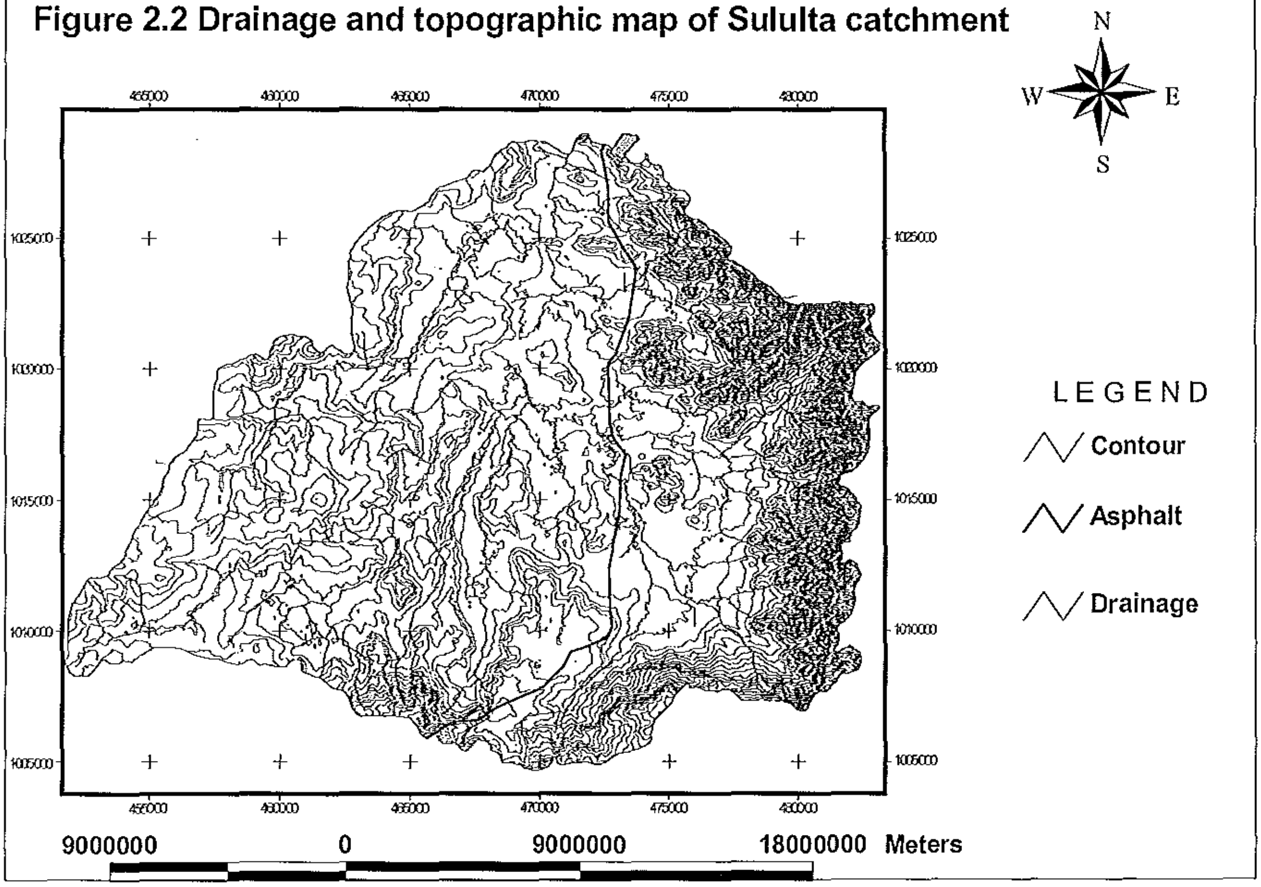
The catchment area lies in the central part of Ethiopian plateau in the southeastern of Abay basin. In this direction, the area covers the uppermost catchment of Abay basin and drain to the north direction. Except fewer scattered hills and ridges, most of the catchment is nearly flat and surrounded by continuous rhyolitic and basaltic ridges to the south and east respectively i.e. it is dominated by flat plain with undulating topography.

The elevation generally drops to the northwest direction. Parts of the catchment that fall on the Intoto ridges have higher elevation than the northwestern one. The peak altitude is estimated to be about 3230m at Ilani Welebabo ridge and the lowest is 2530m above sea level at the mouse of the basin (Sibilu river).

The streams in the catchment flow to the upper part to the northwest direction. Few streams however drain the catchment in this part somewhat north direction, sub-parallel to each other. In the middle of the catchment most the streams merge together and result Sibilu River and generally drain northeastern and northwestern direction. Finally the catchment discharges the entire surface water through Sibilu River.

Generally, the major river draining in the area is Sibilu. It is a tributary of Muger River, which is one of the main tributaries of Abay. The Sibilu River meanders in the flat topography of Sululta plain. Where the topography is more irregular, the drainage pattern develops like a branching tree, referred as dendritic drainage pattern in the southern and western portion of the catchment. Probably due to local tectonic effect, the composite landform shows more or less parallel, N-S running perennial rivers with all intermittent and short dendritic tributaries.

Figure 2.2 Drainage and topographic map of Sululta catchment



2.3 CLIMATE

The Sululta catchment has the same general climatological characteristics as that of Addis Ababa. Globally it is a part of tropical humid climatic region, which is characterized by warm temperature and high rainfall.

The broad climatic characteristics of the studied area, with its alternating wet and dry seasons, are determined largely by the annual movements across the country of equatorial low pressure zones caused by the convergence of dry north-easterly winds with moist winds of the south-easterly or south-westerly origin. During October to February when northeasterly winds persist long periods of dry weather are experienced. Between February and the ends of April the weather becomes more unsettled and a convergence of moist southeasterly air stream causes light rains –commonly referred to the "Belge Rains". The main rains falls between June- September when moist winds from the Atlantic and Indian oceans converge over the Ethiopian highlands. Thus the year is characterized by a major rainy season four months long, from June to September, during which about 65% of the Annual rainfalls, followed by a dry season four months long until the end of January and the major rainy season from February to the end of April (Admasu Gebyehu, 1996).

2.4 SOIL

There are different soil types in the catchment; the variations are attributed mainly to the parent materials and topography. Along the divide lines of the catchment thin layers of soil were developed. In the central part of the catchment the layer of the soil is relatively thick.

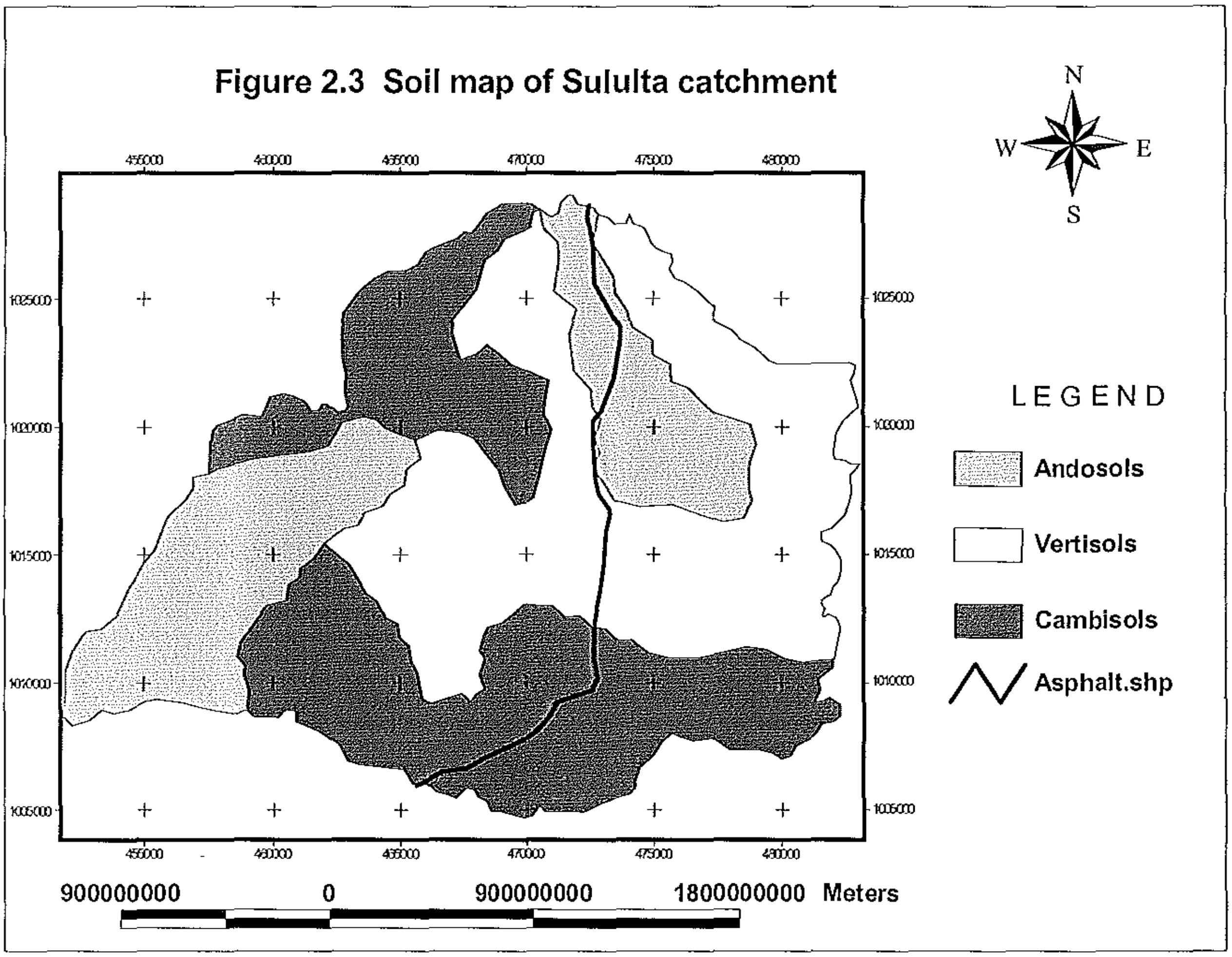


Figure 2.3 Soil map of Sululta catchment

This is a natural process facilitated by the degradation of rock into somewhat disorganized sediments or fragmented materials, which is finally formed different soil horizons comprising the soil profile. Geomorphology and climate, within a given parent material, drainage and vegetation types, are the major controlling factors in the soil formation (Graef, 1996).

In the studied catchment, the volcanic terrains are subjected to high rainfall and temperature in described landforms, which explains the suitable conditions for distinct chemical weathering to produce clay soils. Many researchers have been done in tropical soils to model the interrelation between the different controlling factors and the product soil material by different authors. Tricart, (1972) tried to relate the annual rainfall amount with clay soil in sloped, well-drained basaltic terrains of the humid tropics region. Jenny (1964) also described the annual temperature and clay contents of the soil in different drainage conditions of basic Tertiary basaltic rocks (cited in Tricart, 1972). In Ethiopian plateau especially in the northwest of Addis Ababa, there was a study conducted by Thompson, (1965) to define the relationship between volcanic clay soils with the existing climatic conditions. Also Morin and Parry (1971) studied geotechnical properties of Ethiopian volcanic soil related with their formation and controlling factors.

The clay formation of the studied catchment is controlled by climate, nature of the source material, topography, drainage, vegetation cover and time; like any other catchment. Its topography can broadly grouped under sloped area around the watershed boundary and the remaining plain. The drainage can be related with its topography i.e. the sloped part with well-drained conditions, which favor extreme leaching while the plain is poorly drained which facilitates limited leaching. So all these conditions lead to tell the type of clay mineral formation, i.e. kaolinite and halloysite in the well-drained area due to extreme leaching (Morin and Parry, 1971) but in poorly drained areas the formation of montimorillonite is favored, in the swampy plateau and plain (Grim, 1968) and the left over be laterites. Illite is favored in the immediate leaching process especially in tropics (Grim, 1974).

Locally classified that there are three major types of soils in Sululta catchment. These are vertisols (black clay soil), cambisol (red clay soil), and andosol (gray soil) (Oromia Finance and Economic Development Bureau), Figure (2.3).

1. VERTISOLS: -Mostly found on flat areas. It has poor drainage. Difficult to work on it when dry, moreover, when there is too much moisture. This type of soil constitutes about 37.2 % of the total area.

2. CAMBISOL: - Found on sloppy in few places on flat areas. Since such type of soil is found on sloppy areas, it is exposed to erosion. This soil covers about 55.7 % of the total area of the catchment.

3. ANDOSOL: -The locally named Bole soil approximately covers about 21.3 % of the total area.

2.5 LAND USE / LAND COVER

Except areas that are inconvenient for farming the majorities are covered with cultivation. Grazing land and tree plantation are the other land cover categorized in the basin as major element. Grass & grazing, eucalyptus tress with shrubs and rock exposure and few settlements, and cultivated land including homestead tree and settlement are 21.3%, 23% and 55.7% respectively (Figure 2.4). Almost the entire plain areas are used for its grass and grazing. Residential areas are found either as town/ or villages or as sparse settlements of family/ or relatives. Densely populated settlements are more concentrated near the steep landforms and on the flat topped ridges between plain areas.

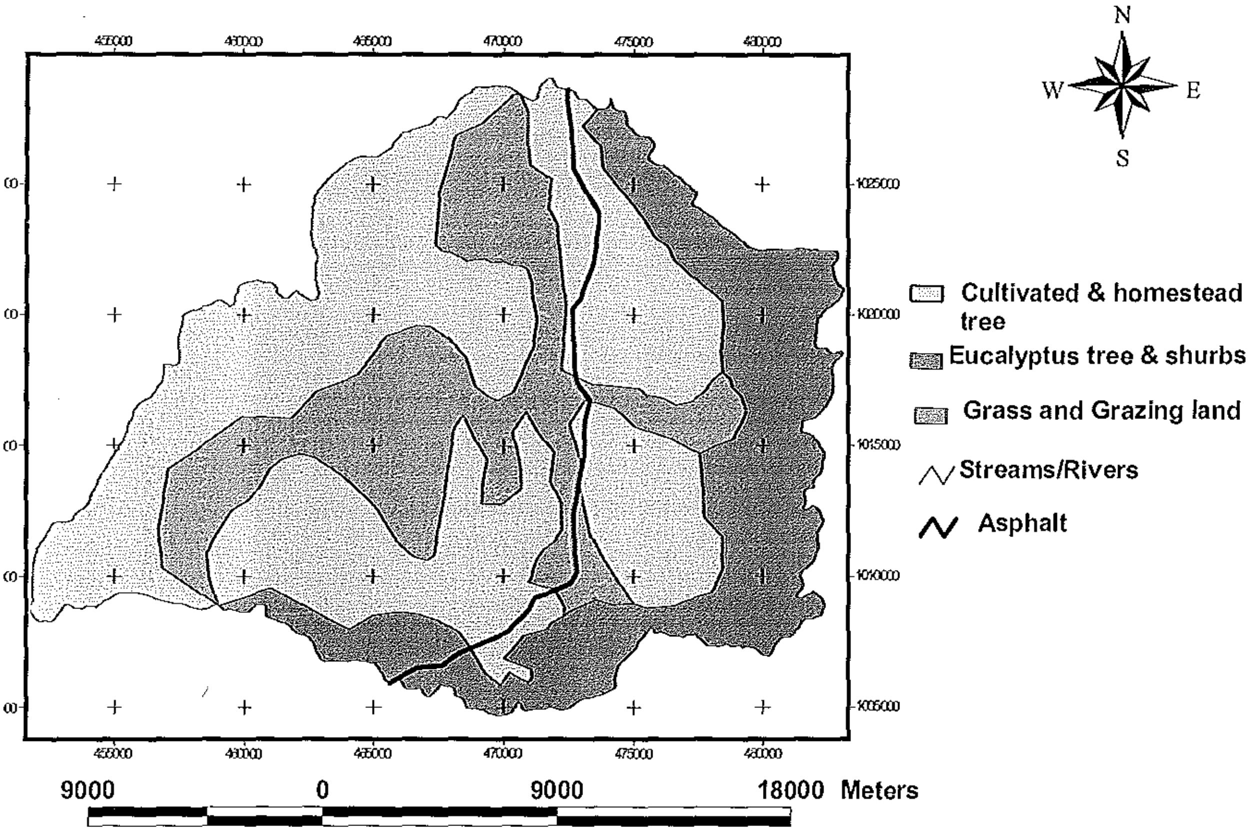
One may categorize the vegetation cover of the area into three groups: grass lands, shrubs, and forests along the ridges / watersheds. The forest part is almost classified under Eucalyptus and shrubs (valleys and rocks also found).

2.6 VEGETATION

Eucalyptus trees are seen around homestead and on sloppy areas. In the study area, there is one plantation forest owned by Addis-Beha fuel wood project. This forest covers about 114 Km^2. It also includes one cooperative forest and the homestead and bushes (not totally mapped on the land cover because of scattering growth).

The vegetation cover is mostly concentrated in the mountainsides of Intoto as Eucalyptus and Acacia tree together with scattered bushes and minor other kind of plants. The northern plain part of the catchment is mainly a pastures and alternating crops with few scattered trees (Figure 2.4).

Figure 2.4 Land use- land cover map of Sululta catchment



CHAPTER III

3. GEOLOGY

3.1 Regional Geology

The study area is located in the Shoa plateau, which is made of tertiary volcanic rocks belonging to th trap series. It is situated in the western margin of the Main Ethiopian Rift and consists of differen volcanic rocks that vary from basic to acidic in composition.

Different researchers have been studied the geology of Addis Ababa and its surroundings both locall and at regional scale. As the works by Mohr (1967, 1971), Zenettin et al. (1973,1974, 1977), Kazmin e al. (1975), Morton et al. (1979) the described rock units reveals the Miocene –Pleistocene volcani succession ranging from older plateau volcanic to younger Rift volcanic.

The volcanic rocks belonging to the trap series include Ashangi group and shield group. These rocks have been considered to be related with extensive fracturing that occurred synchronously and immediately following the uplift of the Arabo Ethiopian swell (Mhor, 1971; Kazmin, 1975)

ASHANGI GROUP (Paleocene- Oligocene- Miocene): This broad group is classified into alkali olivine basalt and tuffs, rare rhyolites, and dolerite sills and gabbro-diabase intrusive. As a formation it is explained as alkali olivine basalt, pyroclastics and rare rhyolite injected by doleritic sills, acidic dykes and gabbro-diabase intrusion.

SHIELD GROUP (Miocene): It is composed of alkali olivine basalt, tuff and agglomerates. The alkali olivine basalt in this group shows amygdaloidal textural features. The volcanic rocks thought to be younger than the rocks of the trap series are Magdala and Afar group.

These younger volcanic rocks may be related with the rift system faulting and occur within the rift and along the adjacent plateau (Mohr, 1971; Kazmin, 1975).

MAGDALA GROUP (upper Miocene- Pleistocene): It is an association of rhyolites, trachytes, rhyolitic and trachytic tuffs inter bedded with lava and agglomerates of basaltic composition i.e. ignimbrites, agglomerates and basalts.

AFAR GROUP (Miocene- Pleistocene): This group consists of basalts, subordinate acid (silicic rocks) and ignimbrite.

The Sululta basin comprises of volcanic rocks belonging to the Ashangi group of the trap series. This rock also found in the southern and central part of this specific basin. The rocks of Shield group of trap series are exposed to the west and east of the basin whereas the southern boundary of the catchment constituted by the rocks of the Magdala group.

3.2 LITHOLOGICAL UNITS

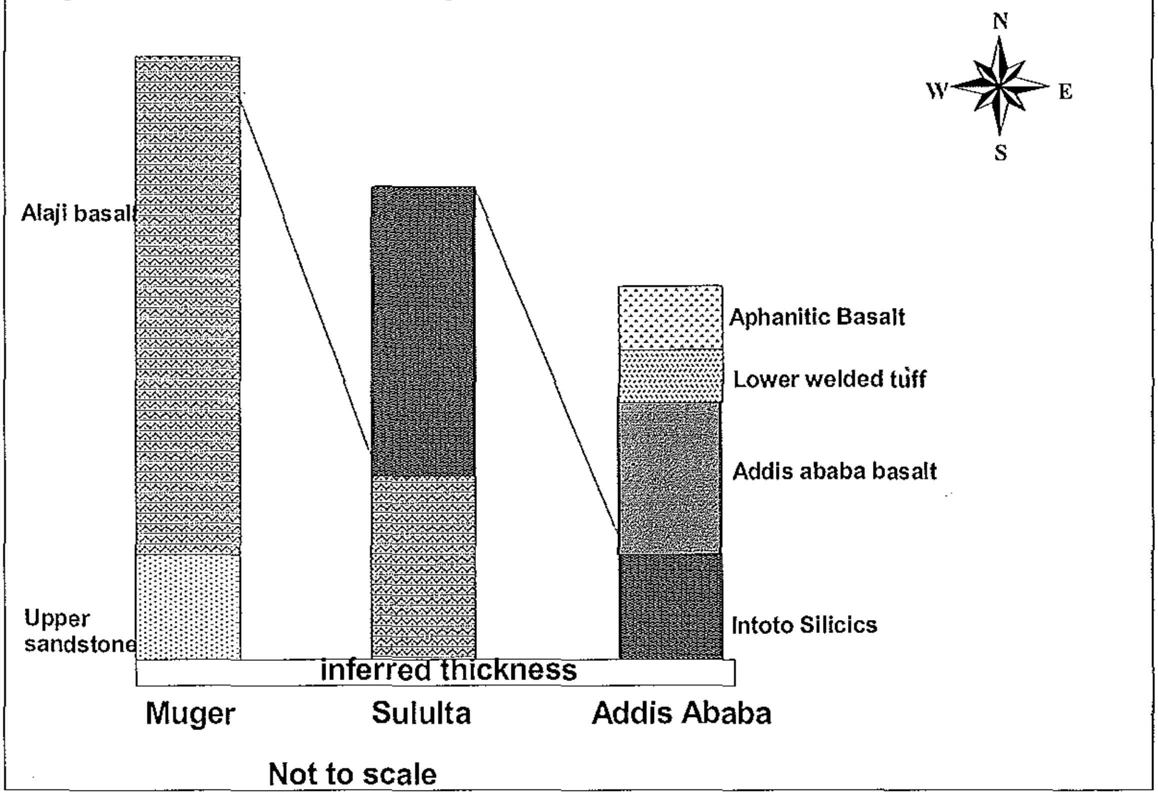
The geology and the volcanic sequences of most of the Central and Southern part were systematically explained with the analog of the geology of the Addis Ababa by Morton et al. (1979); and Haile Sellase Girmay and Getaneh Assefa (1989), Haile Sellase Girmay and Getaneh Assefa (1989) described the stratigrphy of the area starting from Sululta to Nazareth. By suggesting the Miocene –Pleistocene volcanic successions they redefined the lithostratigraphic units as follows from bottom to top (Fig.3.2):

- Alaji basalts
- Intoto Silicic
- Addis Ababa Basalt
- Nazareth groups
- Bofa basalts

I. ALAJI BASALTS

This rock group covers the crest of the Intoto hills which is the divided basin of the Sululta catchment in the southern limits and the plain of Sululta (Zanettin et al., 1974). Haile Sellase Girmay and Getaneh Assefa 1989 also explain the extension of this rock unit from the Intoto hill to the North. Mainly this unit consists of basalt that varies in texture from highly porphyritic to aphanatic. Its major composition is labradorite, andesite, pyroxene and Magnetite.

Figure. 3.1 SKetch of lithologic section and correlation



Trachyte: The trachytic lava flows outcrop on the top of Intoto ridges and foothills, exposed on the farming hills and valleys. It is light gray when it is fresh. It shows a quite uniform texture. It is very fine to fine grained and rarely is constituted by visible phenocrystes of orthoclase, sanidine, oligoclase, and magnetite within a groundmass of plagioclase iron oxide and minor quartz and mafic minerals. With its textural resemblance the trachytic rocks of the northern catchment may be complied in this stratigraphic unit.

IGNIMBRITE (WELDED TUFF): are incorporated with the above two flows forms a gentle slope and probably occurs as a lens within the rhyolite. It is moderately weathered and crystal fragments are scattered through a matrix of ash. They are welded and characterized by columnar jointing. They are usually composed of sanidine, rebeekite, anothoclase, quartz and unidentified volcanic fragments (Haile Sellase Girmay and Getaneh Assefa 1989). The Intoto silicics is unconformably overlain by Addis Ababa basalt on the foothills of Intoto ridges and underlain by Alaji basalt. The Intoto silicics are dated 21 m.y by Morton (1974) and 22 m.y by Morton et al. (1979). Thus from the general stratigraphy established by Zanettin et al. (1974) both rhyolite and trachyte of the Intoto silicics be to the Miocene Alaji rhyolite and basalt' sequences.

III. ADDIS ABABA BASALTS

In the catchment, the oldest visible rock posts dating the silicics are the Addis Ababa basalts. The which is mainly present in the central part of the Addis Ababa town, exposed in the Sululta pla underlain by Intoto Silicics. It is vesicular (vesicles filled with calcite) and of labradorite-bytow olivine and augite as phenocrystes. The groundmass is made up of andesine, labradorite, oli magnetite and pyroxene (Haile Sellase Girmay and Getaneh Assefa 1989). With its textural simil the northern catchment vesicular basaltic rock may be grouped in this stratigraphic unit.

IV. NAZARETH GROUP

The units identified in this group are denoted as ignimbrite (lower welded tuff), aphanitic basal upper welded tuff. Out of these only ignimbrite is exposed in the Sibilu catchment (Haile Se Girmay and Getaneh Assefa 1989).

IGNIMBRITE: it is also named as lower welded tuff. It outcrops as a small discontinuous bo Sululta plain. It is glassy with abundant fiamme and has columnar joints. The age of this rock as by Morton et al. (1979) at Sululta is 5.4 m.y. This age overlap with the period of Wechecha vol 4.6 m.y. Wechecha is located 15 km west of Addis Ababa and probably the sources of ignimbrite catchment (Morton et al., 1979).

3.3 GEOLOGICAL STRUCTURES

In the Sululta catchment and adjacent area, different authors reported the occurrences of faults and other structures within the different volcanic rocks (Zanettin et al., 1977, Haile sillase (1985).

A great fault is running east west Via Kassam River, and it cuts across the western rift esc (northern Addis Ababa) and uplifted its northern block (Zanettin et al., 1977) at about 8 m.y a fault marks the outer boundary of the western Ethiopia rift margin immediate north of Addis Ababa – Ambo road (Zanettin et al., 1977). The Intoto silicics confined along this fault and form a ridge. It bounds the Sululta catchment in the South. The fault has a down throw to the south in the catchment area (Haile sellase Girmay, 1985).

The structural features, which are inferred in the catchment, are obtained from 1: 50,000 aerial photographs of the area. These lineaments include straight contacts between various rock unit, sudden and straight lithologic contacts, straight river courses and aligned topographic features (Trufat Hailemariam, 2001). These lineaments are grouped in to four sets of orientation i.e. NW-SE, NE-SW, E-W, and N-S (Fig. 3.1)

NW-SE and NE-SW lineaments are the most abundant ones. They are straight topographic alignments and straight river course. E-W lineaments are observed along Intoto Ridges as fault scarp traces between the rhyolite-basalt and Rhyolite- ignimbrite (Trufat Hailemariam, 2001). N-S lineaments are observed in the western part of the Catchment which is traced in the basalt.

3.4 LITHOLOGIC CHARACTERISTICS OF CATCHMENT

I. BASALTIC LAVA FLOWS

It outcrops on most of the hills and the riverbeds and occurs as thick lava flow or as thin band intercalating with pyroclastic deposits. In the hand specimen the rock is dark-to-dark gray, very fine to medium grained. It shows different degree of weathering from fresh to strongly weathered and fractured basalt, and also shows local spheroidal weathering.

The basalt exhibits different types of textures i.e. aphanitic, scoracieous, vesicular, and halo-crystalline basalts. The rock is also affected by various sets of joint systems including columnar joints, minor fractures, and lineaments and occasionally shows flow banding (Trufat Hailemariam, 2001).

II. TRACHYTIC LAVA FLOWS

This rock unit is found exposed in the northern part of the area covered by rhyolitic rock unit. The trachyte is light gray in color; fine grained with some phenocryrsts composed of essentially feldspar and minor mafic minerals, and rarely contains amygdule filled with calcite (Trufat Hailemariam, 2001). It is slightly to highly weathered. It is affected by systematic joint sets including columnar joints.

III. RHYOLITIC LAVA FLOW

It is exposed at the top and foot of Intoto ridge. The outcrop is very visible at the road cut and highly eroded stream cut places. The features and the characteristic of this rock are already explained under the regional stratigraphic units.

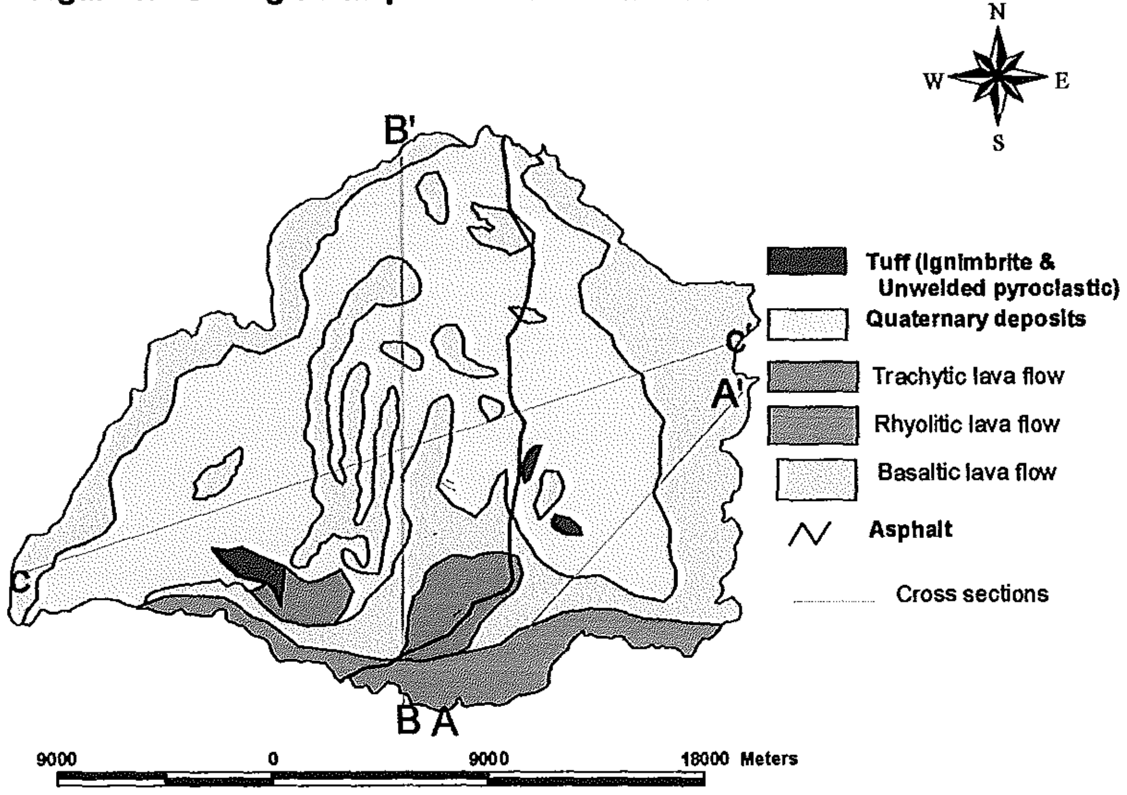
IV. PYROCLASTIC DEPOSITS

It is found exposed intercalated the basaltic rock at Ochi & Asere ridge. This rock unit is highly friable. It composed of tuff, agglomerate and locally scoria. The tuff is fine grained, light to pinkish gray in color, friable to compact rock composed of largely ash-sized particles including aggregates of quartz grains (Trufat Hailemariam, 2001). The scoria lenses that are highly vesicular and in places filled with calcite and quartz usually found in tuff. The agglomerates consist of welded aggregates of scoraceous (commonly basaltic) rock fragments.

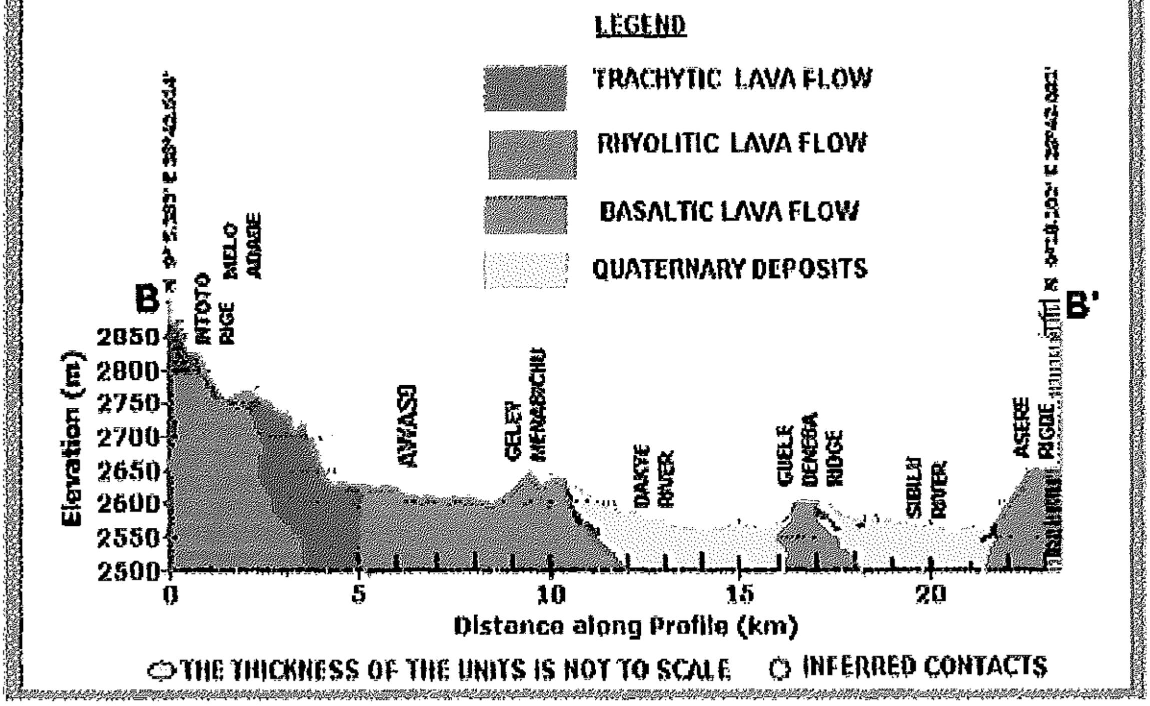
V. QUATERNARY DEPOSITS

It includes residual soils, alluvial and colluvial deposits. The residual (elluvial) deposits ranging in size from silt to clay are observed in the western and southern part of the catchment. They are formed from the weathering of trachyte and basalt. Alluvial deposits that range in size from gravel or silt to clay cover flood plains of the rivers and tributary streams. The gentle slope areas are commonly covered with colluvial deposits in the limited area of the quaternary deposits.

Figure 3.2 Geological map of Sululta catchment



GEOLOGICAL CROSS SECTION ACROSS B - B'



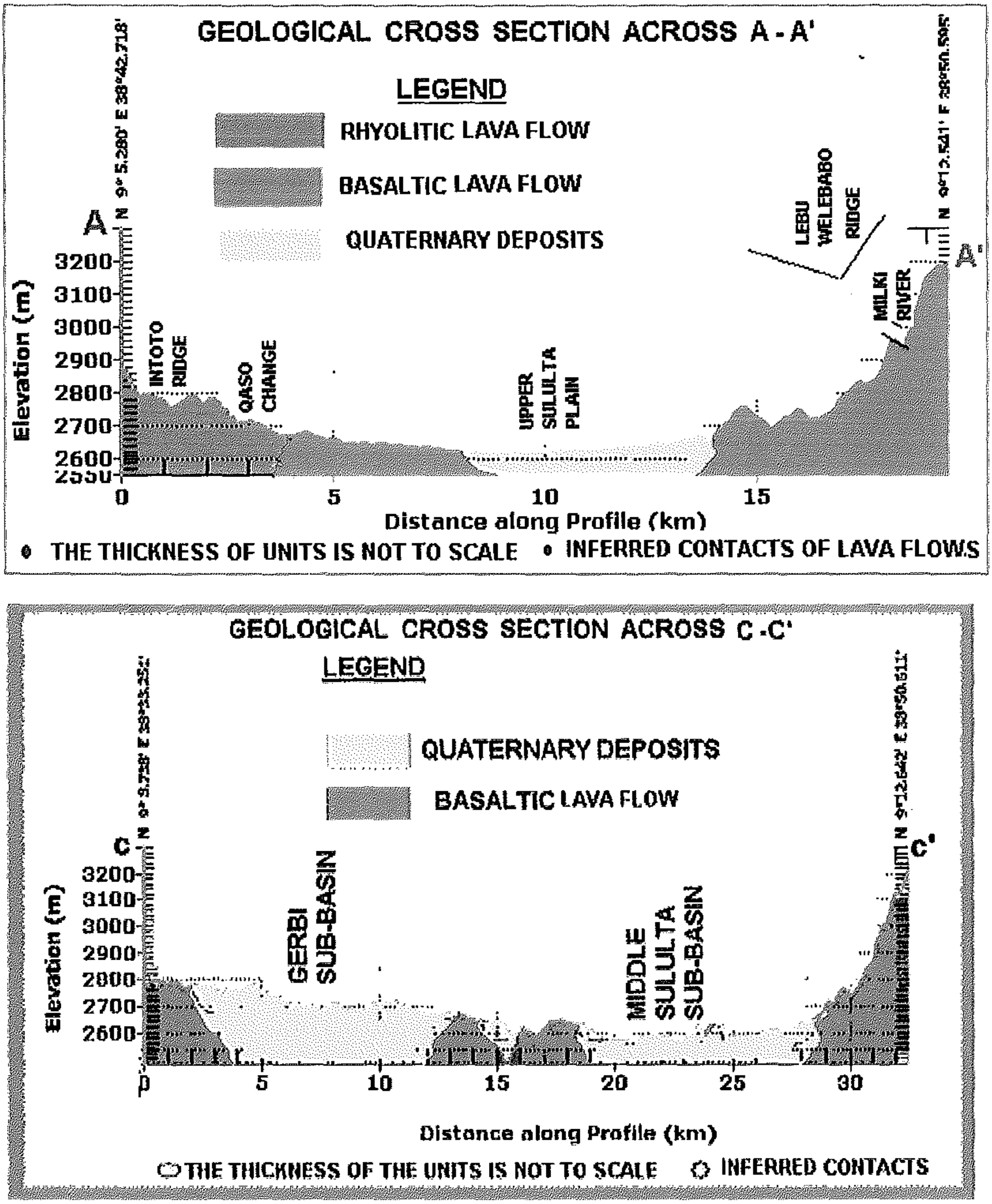


Figure. 3.3 Geological cross sections

CHAPTER IV

4. HYDROMETEOROLOGY

Hydrometeorology describes atmospheric processes that used for the study of water resource evaluation of the earth. Its broader definition was given by the World Meteorological Organization (WHO) in stating that hydrometeorology is deals with the atmospheric and land phases of the hydrologic cycle with the emphasize on the inter-relation ship involved (Jayarami, 1992).

4.1 METEOROLOGICAL PARAMETERS

In the Sululta catchment there is only one meteorological station located at Sululta town. It records fully the rainfall, minimum and maximum temperatures. The Intoto and Chancho observatories are the others relatively nearby available stations (Annex 4.1). No any observatory other than Addis Ababa and Fitche that records all parameters and most of them are class three & four. They record mainly rainfall and temperature. The overall meteorological parameters available for the study area are: rainfall, temperature, relative humidity, wind speed, & duration of sunshine. For different stations the duration over which the parameters are averaged varies.

For the analysis of various hydrologic cycle components, long-term meteorological data have been taken from ENMSA (Ethiopian national meteorology service agency) for the stations distributed in the study area and in the vicinity.

Of all the components of hydrological cycle the elements of precipitation is the most commonly measured. It would appear to be a straightforward procedure to catch rainfall as it falls. The rainfall obtained from a single rain gauge station is known as the point rainfall or station rainfall.

4.1.1 RAINFALL CHARACTERISTICS

Being located in tropical region, rainfall is the main form of precipitation in the country. There are two main sources of rainfall in Ethiopia: the Atlantic equatorial westerly wind, and the southerly and easterly Indian Ocean air currents. The first source supplies rainfall to the highlands as well as western lowlands of the country mainly due to orographic effect whereas the southerly and easterly air currents

Table 4.1 long terms mean monthly rainfall (mm) of the four stations in and around the Catchment with average rainfall estimated by Theissen method

s.no	Jan	Jeb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Chancho	26.2	25.9	63.8	80.3	62.6	170.0	363.4	350.9	171.3	19.9	7.6	9.8	1351.6
Holota	14.1	54.0	56.1	84.8	50.3	104.9	219.4	259.3	132.7	19.8	5.6	7.0	1008.0
Intoto	14.7	38.8	62.0	84.5	65.0	138.3	309.2	341.7	145.1	145.1	24.1	10.5	1244.0
Sululta	14.1	21.3	79.5	72.5	55.4	166.0	297.7	293.8	130.5	16.1	8.1	4.6	1159.5
Aver. Theissen method	16.5	26.6	72.6	76.5	58.0	159.2	307.6	310.0	140.5	18.25	8.25	6.51	1200.3

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

Month	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pm(mm)	16.46	26.59	72.57	76.5	57.97	159.2	307.58	310.07	140.54	18.23	8.27	6.48	1200.31
R.C.	0.165	0.266	0.725	0.765	0.580	1.591	3.075	3.100	1.405	0.182	0.083	0.065	
Designation	Dry	Dry	Rainy	Rainy	Dry	Rainy	Rainy	Rainy	Rainy	Dry	Dry	Dry	

The study area has six months of rainy and dry season. It is getting very high rainfall concentration during the months of July and August. The months of June and September are categorized under moderate rainfall concentration and the rest rainy seasons are with short rains (Figure 4.2).

4.1.2 DETERMINATION OF AERIAL DEPTH OF PRECIPITATION

Precipitation over certain duration for a given basin is rarely produces uniform rainfall depth over the entire area. Certain gauges may record maximum rainfall depth with relative to the others. Using different rainfall depth of different stations found in the target study basin and the adjacent area, the representative aerial depth of rainfall over the whole area is analyzed. The three methods to arrive at an approximate average depth of rainfall are:

1. Arithmetic mean method, 2. Thiessen polygon method, and 3. Isohyetal method

Arithmetic mean is the simplest one for evaluation of mean uniform distribution of rainfall of a basin. It is the mean of all the rain gauges located within the area of interest (Wilson, 1983). Since only one station is located within Sululta catchment, the estimated average uniform precipitation is the same to the mean annual precipitation of the Sululta station over the given period, which is about 1159.54 mm.

Except at the watershed areas this method is applicable to estimate the average aerial distribution of precipitation. The method is accurate if the area is flat and the gauges are distributed uniformly over the area and the variation of the individual gauge record from the mean is not too large (Shaw, 1988 & Jayerami, 1996).

Thiessen polygon is other method used for the estimation of the uniform distribution of precipitation over a basin. This method is more reliable for non-uniform gauge distribution. It is based on the size of the area within the drainage basin that is closest to a given rain gauge (Figure 4.3).

The method is given by $$P = \frac{A_1P_1 + A_2P_2 + \cdots A_nP_n}{\sum A_i}$$

Where P—average aerial depth of rainfall

$P_1, P_2 \ldots P_n$ = mean annual rainfalls recorded at each rain gauge stations

A_1, A_2, A_n - - - Polygonal areas around each stations with in the basin

Using this method the result obtained is 1200.31mm (Table 4.3)

Table 4.3 Theissen polygon method to calculate annual rainfall of Sululta Cathcment.

Station	Mean Annual rainfall (mm)	Area of influence (km^2)	Weighted area (%)	Weighted rainfall (mm)
Sululta	1159.54	290.2	60.35	699.73
Intoto	1243.96	74.2	15.43	191.94
Holota	1008	25.9	5.39	54.29
Chancho	1351.6	90.5	18.82	254.36
Total		480.8	100	1200.31

The third method is an Isohyetal method analyzed by joining rainfall depth of equ
the area of interest (Figure.4.4). According to this method the annual precipitation i
equal to **1210.08** mm (Table 4.4).

Table 4.4 Isohyetal method of calculating annual rainfalls in Sululta Catchment

Isohyetal range (mm)	Average Isohyetal value (mm)	Enclosed area Km^2	Weighted area (%)	Weighted rainfall (mm)
<1150	1125	13.5	2.81	31.59
1150-1200	1175	229.6	47.75	561.11
1200-1250	1225	161.3	33.55	410.97
1250-1300	1275	41.2	8.57	109.26
1300-1350	1325	33.7	7.01	92.87
1350-1400	1375	1.5	0.31	4.29
Total		480.8	100.00	1210.08

The effective annual depth of precipitation in the study area is calculated by using the
methods and the result is given by the intermediate value which is obtained by Theiss
Therefore, the annual precipitation in the basin is 1201.31 mm (The average the thr
close to this value).

4.1.3 TEMPERATURE

The temperature is recorded continuously on three stations. At Chancho station the
obtained and the Holota record is not considered in this study because the influ
significant on the target area.

From the daily temperature of all the days in the month, the mean minimum and
temperature of the Sululta and the nearby Intoto station were computed to represen
area (Figure 4.5).

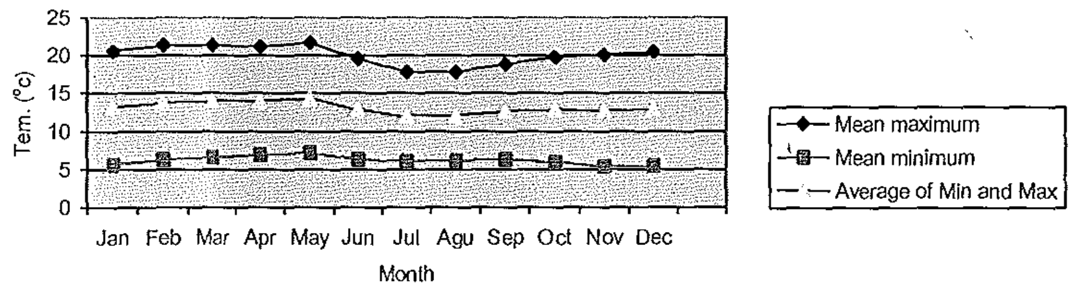
The Chart below elucidates the temperature decrease with increase of elevation. Intot
bit at higher elevation and both mean minimum and maximum temperature records ar

less than that of Sululta. The average value of the mean monthly maximum and minimum of the two stations were considered to characterize the temperature of the Sululta catchment.

Table 4.5 Minimum and Maximum temperature of the two stations and the average for the study catchment

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec
Intoto	Max (°c)	19.0	19.9	19.9	19.4	20.0	18.2	15.9	15.8	16.7	18.0	18.5	18.7
	Min (°c)	7.9	8.6	8.9	9.2	9.8	8.5	8.0	8.1	8.3	8.0	7.4	7.4
Sululta	Max (°c)	22.2	22.8	22.9	23.0	23.4	20.9	19.7	19.8	20.9	21.6	21.7	22.0
	Min (°c)	3.5	3.9	4.3	4.5	4.5	4.1	4.2	4.3	4.3	3.7	3.3	3.4
	Mean of max	20.6	21.4	21.4	21.2	21.7	19.6	17.8	17.8	18.8	19.8	20.1	20.4
	Mean of Min	5.7	6.3	6.6	6.9	7.2	6.3	6.1	6.2	6.3	5.9	5.4	5.4
Average of min and max		13.2	13.8	14.0	14.0	14.4	12.9	12.0	12.0	12.6	12.8	12.7	12.9

Figure 4.5 Monthly mean min & max temp of the two staions and the average of min and max for the catchment



4.1.4 SUNSHINE

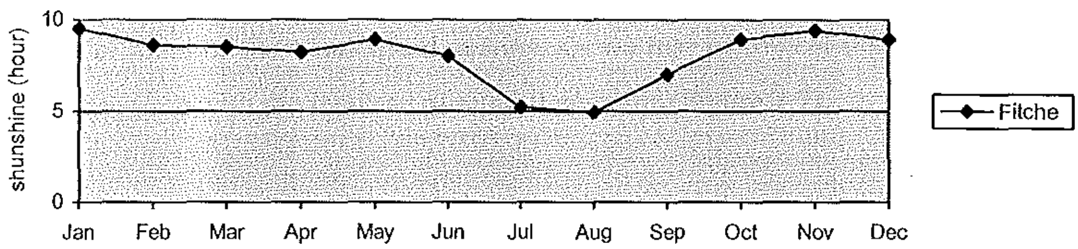
It is the main evaporation factor and has a direct relationship with evaporation. The data is available only for Addis Ababa and Fitche observatories that are under class I recording category. These stations are located in the south and north of the study area respectively and assumed that only the Fitche station can represent the study area (Table 4.6).

Table 4.6 the mean monthly sunshine estimated for the study area from Fitche station

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fitche	9.0	8.6	8.5	8.2	8.5	8.0	5.2	4.9	7.0	8.6	9.4	8.9

The area gets maximum and minimum sunshine hours during the month of November and August respectively. This condition is a reflection of the maximum and minimum cloud cover in the different months of the season. During rainy season the cloud coverage is greater and mean monthly sunshine is relatively small (Figure 4.6).

Figure.4.6 Variation of the estimated sunshine duration for the study area



4.1.5 RELATIVE HUMIDITY

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature (Shaw, 1988). Mean relatively humidity analyzed for the catchment from Sululta (relatively short period record) station.

The mean monthly relative humidity attains the maximum in the months of July, August, & September and the minimum value is during November (Table 4.7). In general, this change is related to the rainy season and dry season of the country in which it raises during summer (Kirmet).

Table 4.7 Relative humidity of the Sululta catchment analyzed from Sululta station

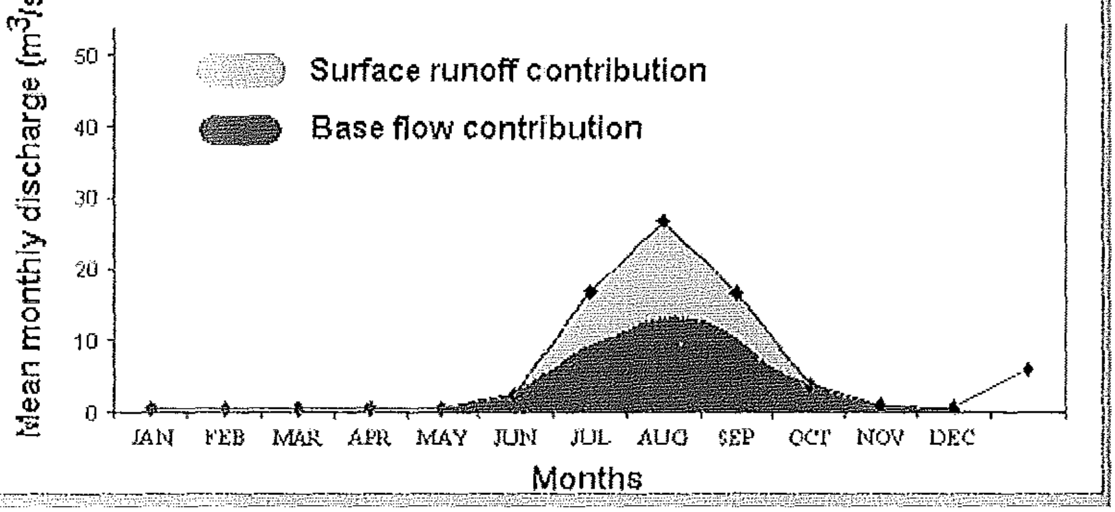
	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sululta	1200lst	65.6	66.6	69.8	71.2	68	69.8	73	73.9	78.1	67.6	65.9	62.2
	1800lst	66.2	66.4	68.2	69.4	67	69.6	74.2	71.8	71.6	67.8	55.5	55.7
	Ava.	65.9	66.5	69	70.3	67.5	69.7	73.6	72.9	74.9	67.7	60.7	59.0

approximates the base flow, especially, for humid climate. Therefore by considering monthly minimum stream flow as a base flow, it has been subtracted from the monthly total runoff to get the component that forms over land flow. Actually, in this paper, the graphic separation (tangent method) of the surface runoff and base flow of the two components used for analysis and showed that 54% of the flow is contributed by base flow.

388mm x 0.54 = 210 mm

388mm x 0.46 = 178mm, Therefore, the mean annual surface runoff is 178 mm.

Figur 4.8 Hydrograph of Sibilu river at mouse & base flow separation



There are various factors that control runoff; among them are soil infiltration capacity, physiography, vegetation, land use, climate, and soil type. Catchment with steep slope, less permeable soil and sparse vegetation cover could have higher runoff value than a similar catchment with gentle slope, more permeable soil and dense vegetation cover other factors being similar for the two catchments. Therefore, the south and eastern part pf the catchment are prone to high runoff than the central and western part of the catchment.

4.3 EVAPOTRANSPIRATION ESTIMATION

Evapotranspiration is the total of all water that leaves a region through direct evaporation from surface water bodies, snow, and ice plus that which is evaporated after passing through the vascular systems of plants (transpiration), (Dingman 1994). Evapotranspiration is one of the most complicated hydrologic processes and needs more elaborate treatment.

Evapotranspiration is generally depends on the different factors: climate (temperature, wind speed, relative humidity, solar radiation, barometric pressure, etc), plant physiology, water quality, etc. The nature of evaporating surface affects evaporation by modifying the wind pattern. Over a rough irregular surface, friction reduces wind speed but has a tendency to cause turbulence and the evaporation is affected predominately by a horizontal velocity (Shaw, 1988).

In the study catchment, there is no direct measurement value of evaporation from open water body or pan evaporation. Therefore the different formulated methods are used for evapotranspiration estimation. The applicability of these different methods are limited by availability of different required parameters, and some methods are site specific; i.e. they are valid only under a given climatic zone.

4.3.1 POTENTIAL EVAPOTRANSPIRATION

I. PENMAN METHOD

For calculating potential evapotranspiration the evaporation rate formula was modified (MAFF, 1967) to allow the condition under which evaporation plus transpiration takes place from a vegetated surface (Shaw, 1988) and it is given by

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

t, extra subscript which denotes the effect of transpiration

$$H_t=R_I(1-r)-R_o \qquad \text{--------------------------------------(2)}$$

Where r=the reflective coefficient for incident radiations Albedo, from the basin depending on the nature of the surface. This value usually varies between 0.15-0.25, 0.05-0.45, and 0.05 respectively for close ground crops, bare lands, and water surface, Subramanya (1988). Thus for the study basin it is assumed to 0.21.

Where, PET = potential evapotranspiration (mm/month), t_a = mean monthly air temperature (^{o}c), J= Heat index = $\sum(t_{ai}/5)^{1.514}$

$$a= 675 \times 10^{-9} J^3 - 771 \times 10^{-7} J^2 + 1792 J^{-5} + 0.49239$$

The potential evapotranspiration calculated by this method is 590.6 mm/years which very small with respect that calculated based on the Penman method. The values of evapotranspiration of the months are close to each other in this method than the one obtained by Penman. Almost the evapotranspiration obtained by Thornthwaite method is the reflection of the variation of the mean monthly temperature. The estimated average value the two methods which is 959.81 mm/year taken for the Sululta catchment.

4.3.2 ACTUAL EVAPOTRANSPIRATION

Actual evapotranspiration is the real evapotranspiration that takes place under the existing moisture. A value of actual evapotranspiration (AET) over a catchment is obtained by first calculating the potential evapotranspiration plus transpiration (PET), that is assuming an unrestricted availability of water, and the modifying the answer by the actual soil moisture content (Shaw, 1988). It is the amount of water lost under the field conditions. The value of actual evapotranspiration becomes larger during dry period and less during rainy period of the year. Always actual evapotranspiration is less or equal to potential evapotranspiration.

I. THORNTHWAITE AND MATHER SOIL WATER BALANCE MODEL

When soil is saturated, it will hold no more water. Therefore, under this situation actual evapotranspiration is equal to potential evapotranspiration (Shaw, 1988). The soil moisture gradually depleted if there is no rain to replenish water that lost from the soil and produce soil moisture deficit (SMD). As the soil moisture deficit increases, the actual evapotranspiration becomes much lower than potential evapotranspiration. The soil types and the different land covers like vegetation are the main controlling factors.

Therefore to evaluate the actual evapotranspiration the proportion of vegetation cover with its soil moisture and soil type of the catchment must be known. The study area is classified in to three major groups of soil types with vegetation cover.

Thornthwaite and Mather soil water balance model is used to calculate the actual evapotranspiration based on the available meteorological data and soil and vegetation categories. The vegetation and soil cover of the catchment area is estimated as follows:

1. On the steep land: the soil and vegetation types are clay loam with matured forest and covers 154.5 km^2
2. On composite landform: the soil and vegetation types are silty loam with deep rooted shrubs and covers 132.8 km^2
3. on the gently sloping and level lands: the soil and vegetation types are clay loam with shallow rooted crops and covers 195.7 km^2

The parameters for this method are, rainfall (p) and potential evapotranspiration (PET) (Dingman, 1994). The soil-water storage capacity is designated by single value of Smax (maximum soil moisture) and an initial value of soil moisture by So.

Alley (1984), if for a given month Pm>PETm, the value of the soil moisture at the end of the month, Sm, is found as:

$$S_m = \min [((P_m - PET_m) + S_{m-1}), S_{max}] \text{ ------------------------------------ } (11)$$

If Pm<PETma soil moisture deficit develops or increases. The soil moisture under this condition is given as:

$$S_m = S_{max} \exp\left[- \frac{PET_m - P_m}{S_{max}} \right] \text{ -- } (12)$$

The monthly actual evapotranspiration (AET) is then found as

$$AET = PET \quad \text{if } Pm > PETm \text{ ------------------------- } (13)$$

$$AET = Pm + Sm\text{-}1 - Sm \quad \text{otherwise ------------------------- } (14)$$

Using this method and the potential evapo-transpiration from Penman method, the actual evapotranspiration of the area is 826.83mm/year and the amount of water that the basin gain from surplus is 359.44 mm.

Based on the evapotranspiration values obtained by Thronthwaite method, the calculated actual evapotranspiration is 585.63 mm/year and the amount of water that the basin gains from surplus is 614.81mm/year.

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

II. TURC METHOD

The method determines the annual actual eavapotranspiration, AET directly from meteorological parameters, precipitation and temperature. It is an empirical formula developed based on the data from various catchments of different climates, and hence could be applied in humid or arid climates, either hot or clod, Shaw (1988).

It is given the formula:

AET= (P)/[√ (0.9 + (P/L) ^{2}], Where AET = Actual evapotranspiration, P = annual mean precipitation in mm, T= annual mean temperature in ^{0}c.

$$L= 300 + 25\ T + 0.05T^{3} \text{ in mm}$$

The annual mean precipitation and mean temperature for the study site are 1200.13 mm and 13.2 ^{0}c respectively. Hence, L calculated and equal to 745 mm. The value of AET becomes 642 mm per year.

4.4 WATER BALANCE

By water balance it is meant equating/ or balancing the amount of water inflow and outflow for a given system, such as a hydrogeologic system, over a given area; hence it is a dynamic system, Detay (1997). The hydrogeologic system can be a drainage basin/or catchment, groundwater basin, soil layer, or any surface water reservoir (natural or artificial).

The basic assumption that considered is the surface water divide coincides with the surface drainage basin. Therefore, other than the water that is percolated within the limit of the surface water divide, there is no inter-flow (inflow or out flow) of groundwater.

The basic equation of water balance is: **Inflow=outflow $\pm$ ΔS**

For the study area, the main inflow component is precipitation, but the outflow components are evapotranspiration and runoff assuming all other components such as water abstraction by human for other purposes to be negligible. The change in storage can be considered to be zero if the water balance is made by taking water year/ or hydrologic year. Hence, the value of ΔS will be negligible/ or zero since the calculation is to be made annual basis.

4.4.1 INFILTRATION

Among the several components allowing to estimate the hydrological balance of certain catchment , infiltration is not directly evaluated. In fact infiltration is mostly estimated by means of indirect calculations which into account precipitation, evapotranspiration and runoff, as I=P-ET-R, Where I=infiltration, P=precipitation, ET=Evapotranspiration, R=Runoff

The main factors affecting infiltration are rainfall intensity; size, shape and arrangement of soils; porosity and permeability of rocks; vegetation cover; soil moisture content and the amount of available water.

In the studied area the main types of infiltration are:Direct infiltration of water during rain events, Infiltration through fractures and joints, & Infiltration from runoff through perennial and intermittent stream channels, I=1200.13mm-684.82mm-388mm=127mm/year (excluding base flow)

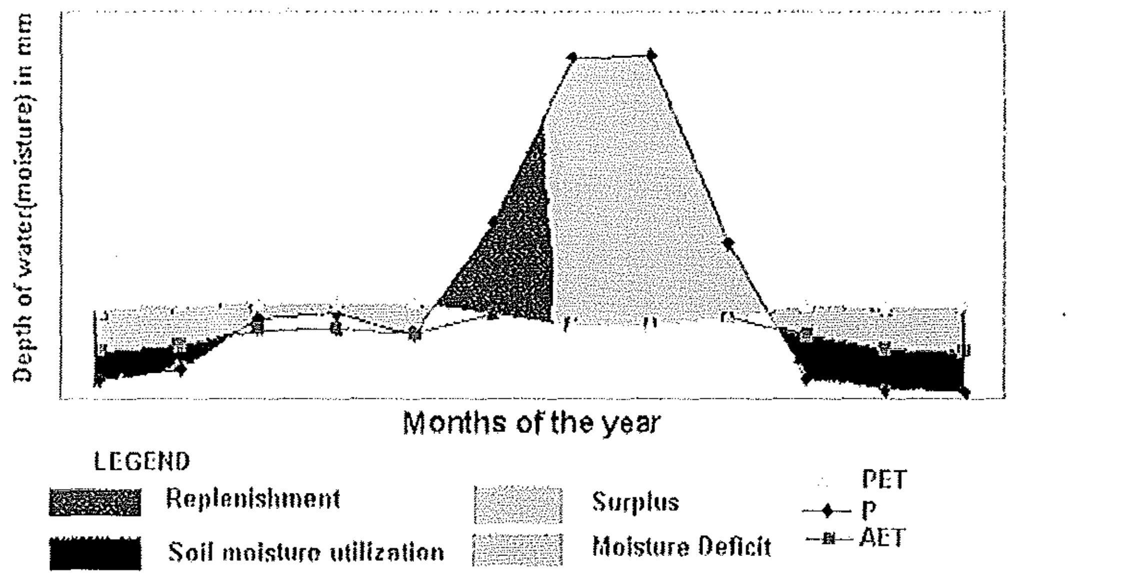
4.4.2 SUMMARY OF THE WATER BALANCE

The different results of AET obtained by different methods are shown below:

1. Thornthwaite-Mather method (PET from Penman method), AET=826.83 mm/year
2. Thornthwaite-Mather method (PET from Thornthwaite method), AET=585.63mm/year
3. Turc method: AET=642mm/year

The average value of the three methods considered fair to represent the AET of the catchment, and it is 684.82mm/year. The area has a total annual precipitation of 1200.13 mm, and an estimated overland flow of 178mm/year. Hence, the area's annual recharge value is 342 mm/year. When the value of annual base flow is subtracted 132mm/year depth of water is being added to the reservoir. This value is very important to categorize the groundwater development of the catchment exactly knowing the entire groundwater withdrawal per annual.

Figure 9 Comparsion of precipitation (p), potential (PET) and actual (AET) evapotranspirations of Sululta catchment



CHAPTER V

5.HYDROGEOLOGY

5.1 GENERAL

Hydrogeology can be defined as the study of groundwater with particular emphasis given to its chemistry, mode of circulation and relation to the geologic environment (Devis & Dewiest, 1996). The behavior of geological materials toward the interaction, storage and transmissions of subsurface water constitute the basic part of hydrogeology. Geological materials, therefore, can be categorized into aquifer, aquiclude and aquifude based on the transimissivity and hydraulic properties.

The lateral and vertical extent, shape, and the distribution of geological formation are also play a great role in the characterizing the hydrogeology of an area. The presence of permeable geological formation is not enough for the storage of the groundwater. Thus bottom-confining bed that can hold up the subsurface water and the lateral confining bed (barrier) in case of groundwater discharge at the foot of cliffs is important in limiting the occurrence of groundwater.

Therefore, understanding of the hydrogeology of a given area require information of both surface and subsurface geology and structure in addition to hydrometeorological factors. In area where the subsurface information is not sufficient, geophysical data can support the interpretation of the subsurface condition.

In many areas, especially in most part of our country it is difficult to get a documented well data that could describe the lithology and aquifer characteristic fully. To characterize aquifer quantitatively the boreholes density and spatial distribution is other required condition. In most cases, therefore, hydrogeological description or interpretation is made by qualitative analysis of an area based on the surface information and other important data. The presence or absence of springs, degree of weathering, thickness of the formation, sorting, and degree of cementation, etc are used for qualitative evaluate the permeability of geological formation.

In the study area, there are some boreholes drilled for the towns and rural water supply. Their location is limited along one line longitudinally and only very shallow dug wells (3-20m depth) are abundant in the catchment. Almost all the wells are shallow to medium in depth and not to the full depth extent of the geological formation.

5.2 HYDROSTRATIGRAPHIC UNITS

Based on the well log of different wells found in the catchment and the geology of the area, the major hdrostratigraphic units can be categorized into the following: Slightly to highly fractured and weathered Rhyolite and Trachyte, Slightly to highly fractured and weathered basalt, Pyroclastic deposits (welded & unwelded tuff), and Quaternary deposits (Alluvial material).

5.2.1 RHYOLITE AND TRACHYTE

It is obvious that the groundwater storage of the volcanic rocks is attributed to its primary and secondary hydro-structures. The structures include vesicles, joints (due to weathering, tectonic or cooling processes), lava tubes, and voids between successive flows.

These rocks covered most part of the recharge zones near and on the Intoto ridges. Macroscopic structures as well as other surface features such as fracturing, jointing and cracks are dominant. The joints in many exposures are aligned parallel to each other with narrow spacing of the major joints in different orientations (Figure 5.1).

The lithological log of the Guto Weserbi well 1 & 2 confirm the existence of depth weathering of these rocks. The highly weathered part is relatively has clay size (Figure 5.8), which is low transimssitive water bearing formation.

The rhyolitic lava has large area coverage with respect to trachyitic lava. The later shows moderate weathering and jointing. The fracturing and weathering intensity of these rocks decrease with depth (from well log and from surface rock outcrop).

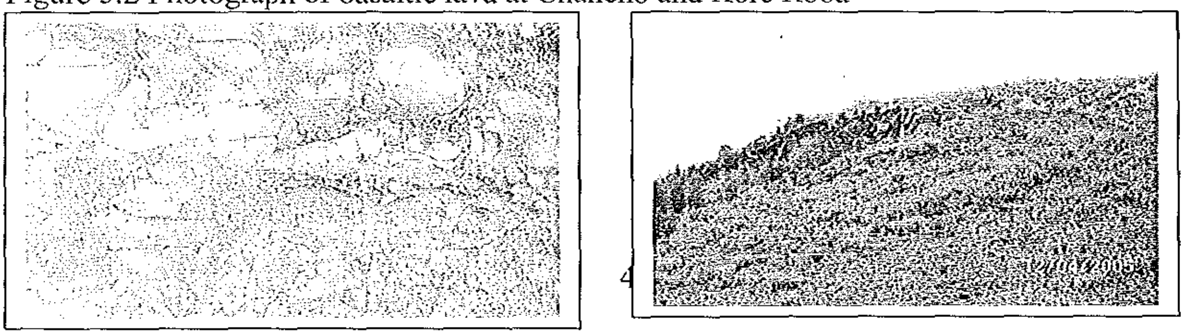
Figure 5.1 Photograph of Rhyolitic lava at Intoto

5.2.2 BASALTIC LAVA

This rock is the most dominant lithology within the Sululta catchment. The distinctive hydro geological feature of volcanic rock is the significant primary porosity in the form of interstices in vesicular varieties. Filling up sometimes considerably reduces the vesicular porosity of basalts with minerals like zeolites and silica to form amygales. On the other hand, porosity may be increased by circulating water unsaturated with respect to certain constitutes. In the study area, especially basaltic aquifer is located beneath the alluvial deposit located in the central plain area of the catchment characterized by vesicular structures. In some area it is found filled with secondary minerals washed from the overlain alluvial deposits.

Different exposures of basaltic lava show secondary porosity. Weathering, cracks and jointing, and fracturing are the common types of secondary structures which increase the porosity and permeability of the formation. Highly fractured as well as weathered basaltic lava exposures are common along the ridges and on areas prone to land degradation. Figure 5.2 shows the picture of basaltic rocks taken from Chancho and Kore Roba ridges. As the surface exposures indicate the degree of weathering and fracturing is high. However, for comparison the well lithologic logs of Kore Roba and Chancho boreholes show the fracturing and weathering degree decreases with depth. The thickness of the different formation is indicated on the lithological correlation the wells.

Figure 5.2 Photograph of basaltic lava at Chancho and Kore Roba



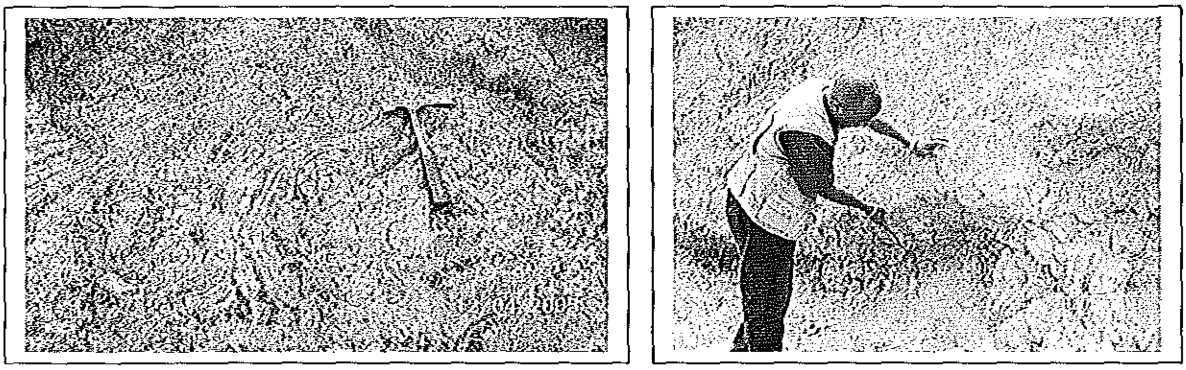
5.2.3 PYROCLASTIC DEPOSITS

Pyroclastic rocks associated with law flows are generally porous but not very permeable except blocky, coarse material near volcanic vents and tuffs that have been reworked by water, Devis (1966).

The pyrolcatic deposits in the study area are mainly comprised by unwelded and welded tuffs. It covers areas around Intoto and some part in the center of the catchment in between the basaltic lava layer (Figure 5.3).

The lithologic logs of the Guto weserbi well 1 & 2, Sululta and Chancho indicate that the pyroclastic deposits found intercalated in both acidic and basic lava flows (Figure 5.8). This deposit in the acidic lava is more porous than in basic lava, however, the hydraulic properties might be the reverse. The tuff is highly friable. The hydrogeological significance of this unit shows a spatial variation of grain size as one goes from Intoto to Chancho. In Chancho areas it is clay size. Except in areas where this rock is exposed as large outcrop, in many places intercalated between the rhyolitic and basalitic lava and mostly it is unwelded type. The thickness of this rock varies from 5 to 15m as log data of different wells indicate.

Figure 5.3 Photograph of welded and unwelded tuff at Intoto

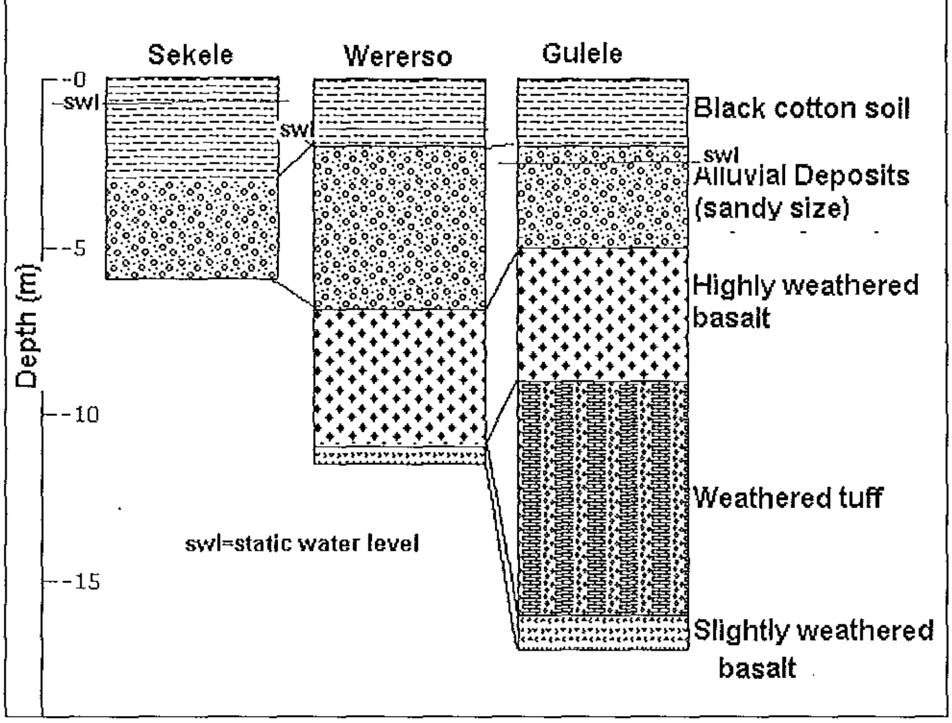


5.2.4 ALLUVIAL DEPOSITS

Recent alluvial deposits cover most of the central part of catchment overlying the basalitic lava. It is the result of weathering and erosion from the upstream elevated landforms. This material is generally unconsolidated and the thickness ranges from 3 to 12 m (hand dug log and deep erosion cut exposures). The thickness of the wreathed zone depends on climate, topography etc.; it may be under favorable circumstances reach a depth of several tens of meters. The upper layer of the alluvial materials in most area is clay size and sticky nature with high moisture holding capacity (hand dug wells, Figure 5.4b). The lower reaches of weathered zone contain the more coarse particles. In this way the transition zone may be more permeable than both the upper layers of the weathered zone and the slightly fractured underlying rock. This alluvial deposits and weathered rock is 4 to 5 m thick in erosion cut areas (Figure 5.4a)

Figure 5.4a Photograph of alluvial/weathering product of acidic lava at Weserbi

Figure 5.4b Lithological log data of Hand dug wells



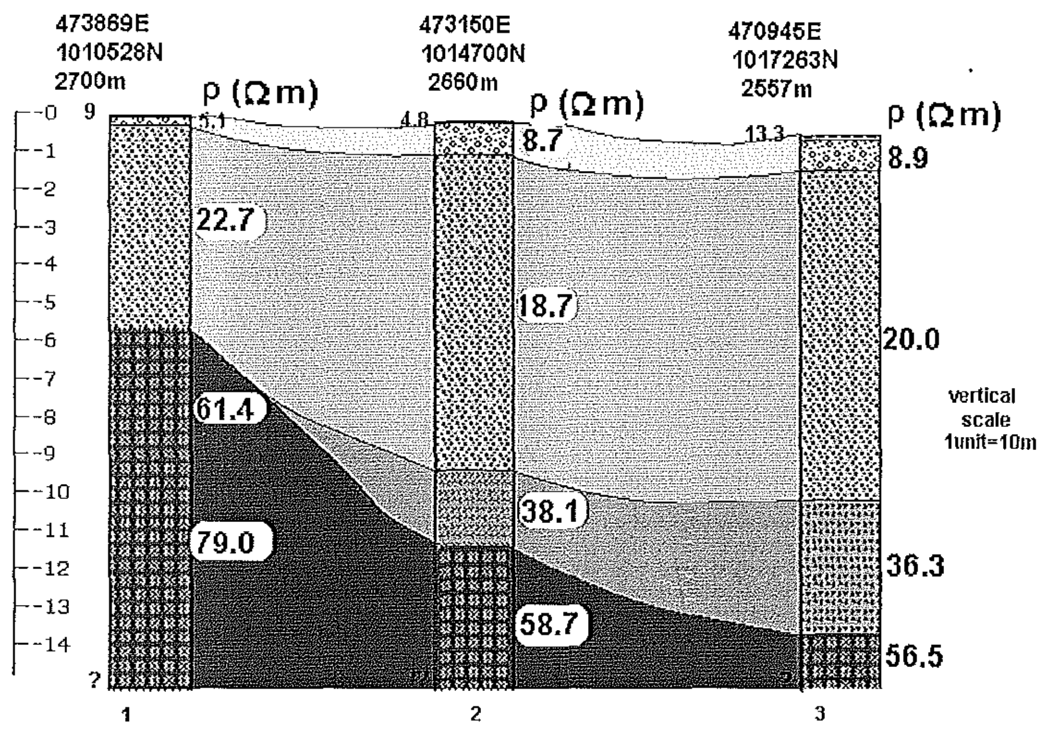
5.3 ELECTRICAL RESISTIVITY METHOD

5.3.1 INTRODUCTION & GENERAL PRINCIPLES

Geophysics has evaluated from the realization that variations in the physical properties of rocks in situ give rise to variations in physical quantities which may be measured at a distances from the rocks themselves, either at the earth's surface or above it. Interpretation of geophysical measurements allows saying some thing about the subsurface properties of earth materials.

Resistance is the property that impedes the flow of current through a material. Electrical resistance is a function of both the material type and the electrical current flow geometry. When electricity passes through the earth, it encounters resistance to its flow from the soil/rock materials. The resistance offered to the current flow is dependent on the mineralogy, particle arrangement, water content and salinity of the underlying earth layers (Woods, 1994).

Figure5.5 Geoelectric cross section near Sululta town

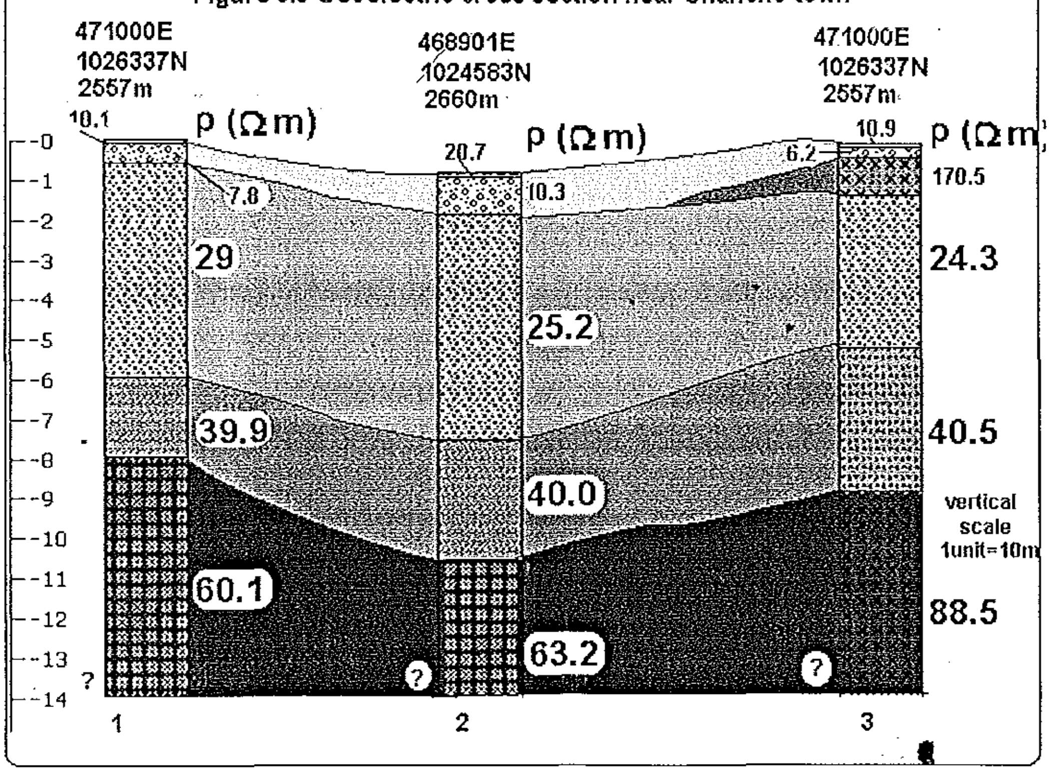


Resistivity is governed by Ohm's Law, which states that the change in potential across a resistor is oportional to both the current and the resistance. It is a fundamental property of the material is independent of geometry.

=V/I, where R is the resistance, V is the voltage and I is the current. For a given material being measured and inversely proportional to its cross-sectional area $R = \rho L/A$ or $\rho = RA/L$, where ρ is the characteristic resistivity of the geologic medium, A is the unit cross-sectional area and L is its length. Unit of resistivity are usually given in ohm - meters.

Resistivity values are obtained by two different surface exploration methods. The first of these, called electrical sounding, involves vertical exploration. In this procedure, a series of stations are established and careful depth soundings are taken. These soundings are later transferred to a vertical cross-section (Figure 5.5 to 5.7). By evaluating the resistivity values, an understanding of subsurface materials can be developed. This exploration method is especially useful for estimating the depth of sand, gravel bedrock or water bearing strata, or for estimating the thickness of selected formations, weathering thickness, fracturing and other primary or secondary structures of hard rocks.

Figure 5.6 Geoelectric cross section near Chancho town



In soils or rocks, the flow of an electrical current occurs through, the pore water which acts as a conductor, and the soil or rock which may act as a conductor or an insulator/resistor depending upon the nature of the mineral.

Hence, the nature of the pore water as well as the mineral will affect the resistivity. Resistivity can provide information about soil/rock type. For example, clay will conduct electricity through both the pore water and the clay itself, whereas a sand will transmit current primarily through its pore water.

The second resistivity exploration technique is called electrical profiling. As in the case of sounding, numerous stations are selected. Resistivity measurements are then made, this time for the same depth, at each station.

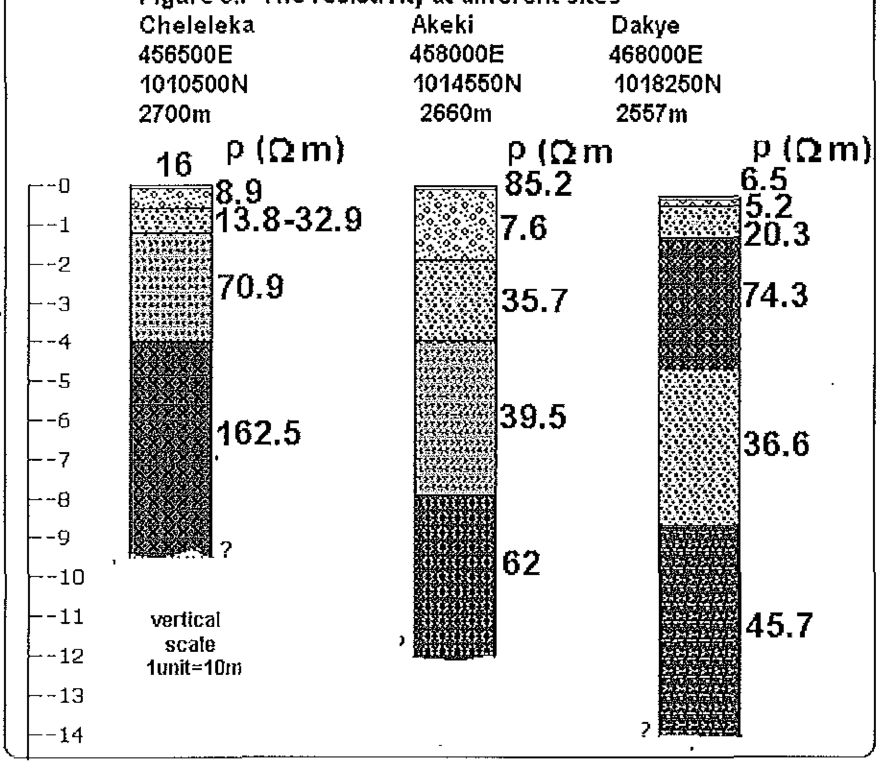


Figure 5.7 The resistivity at different sites

5.3.2 SELECTION OF THE METHOD

The paper presents the use of electrical resistivity test as an investigation tool to supplement the borehole data. The technique is time saving and is particularly useful in the current scenario of fast track projects in the groundwater exploration.

Used in conjunction with boreholes, the electrical resistivity test can confirm continuity of the various strata and the depth of the layers.

The aim of the investigation was to assess the groundwater potential in the unconfined and confined aquifer, estimate the depth and to supplement the other constraint data such as hydraulic properties of formation for mapping. Electrical resistivity surveys were carried out in the field for locating the availability of water (Figure 6.4).

To evaluate the stratigraphy to the required depth of about 120m at three fields namely Sululta town, Chancho and some specific points in western part of the catcment along Denba stream trace, it was decided to conduct electrical resistivity tests (Figure 5.8).

For groundwater investigation purposes, resistivity testing can provide information regarding lithology and can be correlated with borehole information (Figure 5.5 – 5.7).

5.3.3 INTERPRETATION OF STRATIGRAPHY & AQUIFER CONDITION

The true resistivity values have been interpreted to assess the nature of the strata. After careful evaluation of the stratigraphy, range of measured values and comparison with published values, an assessment was made of the probable range of resistivity values in each of the different mediums (soil & rock layers) at the project sites. The following table presents the ranges used for interpretation (Table 5.1).

As can be seen, some of these ranges overlap. Interpretation was done by comparing the adjacent borehole data with the resistivity test results so as to develop a profile consistent with the anticipated stratigraphy at the location.

It is cautioned here that these ranges could vary even for similar nature of rocks depending upon moisture content, level of groundwater, degree of compactness, mineralogy and other factors. The ranges will, therefore, have to be developed on site after careful review of data and comparison with borehole information.

Generalized surface profiles along the centerline of the three proposed areas are presented in Figure 6.4. The stratigraphy is shown on these illustrations beyond the depth investigated by the boreholes is obtained by interpolating and projecting the geo-electric section along the centerline of the selected roots (Figure 5.5 – 5.8).

Based on this evaluation, the stratigraphy at the required location is generated. The parameters required for the analysis is interpreted by comparison with the borehole data and the hydro geological assessment of the trend of values. The result is used in aquifer characterization of the cathchment with other parameters as indicated under the hydrogeology part (Figure 5.8 & 5.14).

Figure 5.8 Survey sites (VES) locations

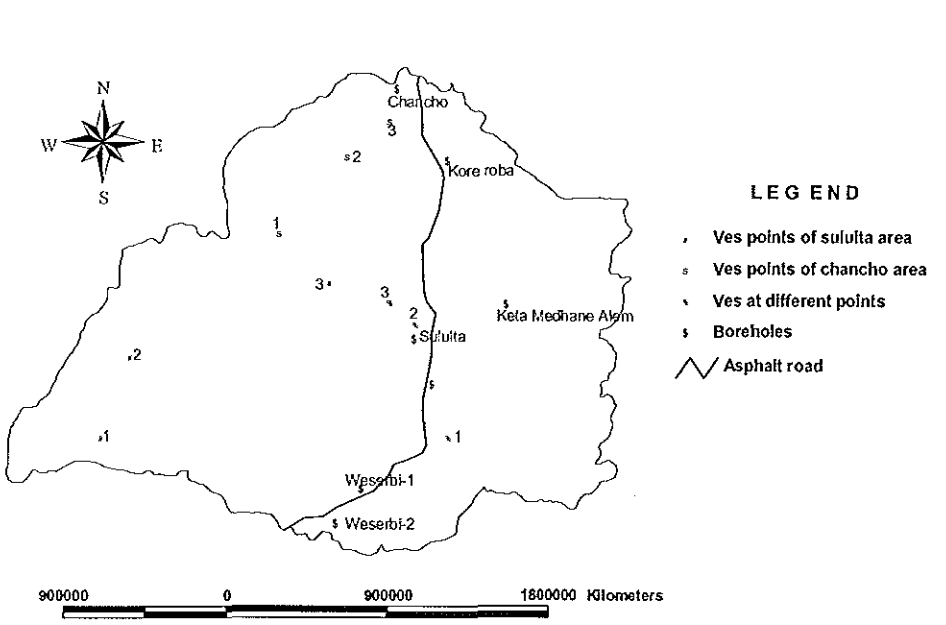


Table 5.1 Interpreted lithology and aquifer condition

True Resistivity, ohm-m	Interpreted Stratigraphy	Interpreted aquifer condition
4-20	Top soil	High moisture containing to dry soil
5-12	Alluvial deposits/Quaternary (silt to gravel size)	Saturated unconfined aquifer, productive for hand dug well
15-30	Highly weathered & fractured basalt, rhyolite, trchyacte & tuff	Saturated unconfined aquifer productive for boreholes
31- 50	Slightly fractured basalt, rhyolite, trchyacte & ignimbrite	Aquitard to Acquiclude
> 50	Relatively fresh basaltitic layer	Aquifuge

5.4 AQUIFER CHARACTERISTIC

An aquifer is a hydrogeological 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.

In the various formations the variation in the groundwater storage, transmission and yield are the basis for the classification of the aquifer. Lithology, topography, areal coverage, degree of fracturing, grain size, roundness and sorting type are considerable affects the aquifer characteristics. Therefore, geological formations of an area are classified according to their relative hydraulic properties as aquifers of very high, high, moderate, low, and very low permeability and productivity. Aquifers with low productivity have limited groundwater resource.

Permeability, the degree of interconnectedness between pore spaces and fractures within a or sediment deposit. It is measure of the capacity of a porous material to transmit fluids.

A. PERMEABILITY (K) is largely a function of: (1) Grain size, size of pore space (2) Shape of grains/shape of pore space (3) Degree of interconnected pore space

B. HYDRAULIC CONDUCTIVITY = is a measure of rate of transmission of fluids horizontally through aquifer, essentially another term for permeability.

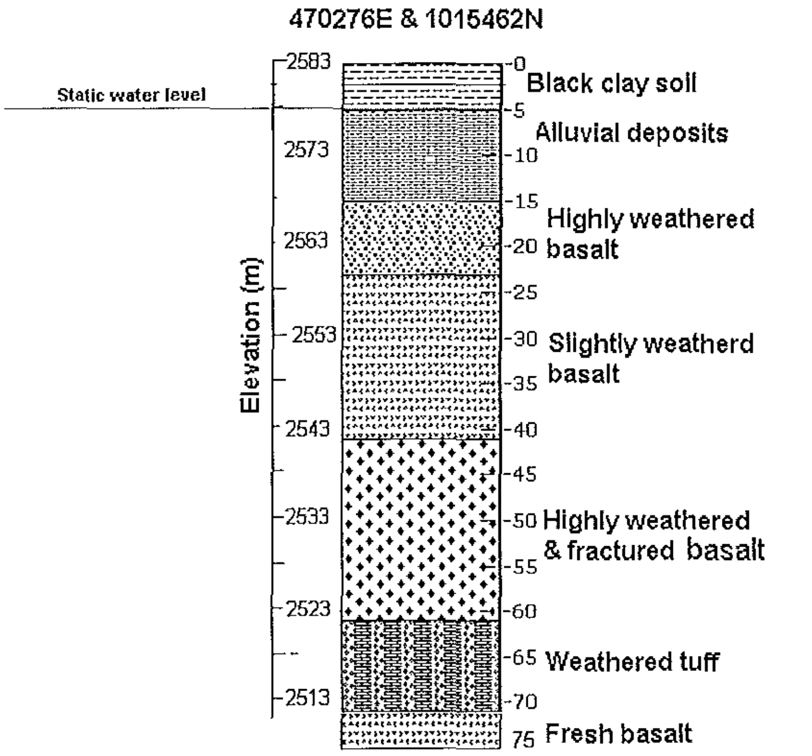
In general, groundwater is not usually static but flow through rock. The flow to wells and productivity of water wells is measured by hydraulic parameters. These values are obtained from pumping tests. Therefore, the study area is mapped into three main zones based on its hydraulic properties (transmissivity) and interpretation of the lithologic sample of the well logs, interpretation of the geo-electric sections, physical descriptions, and land use- land cover analysis of the catchment.

5.4.1 HIGH PERMEABILITY ZONE

It includes part of the catchment, especially around Sululta town extending northwest direction to Chancho town following the fracture trace of the streams. Alluvial deposits on the top and slight to highly weathered & fractured basalt with intercalation of tuff covered the area (Figure 5.9 & 5.10).

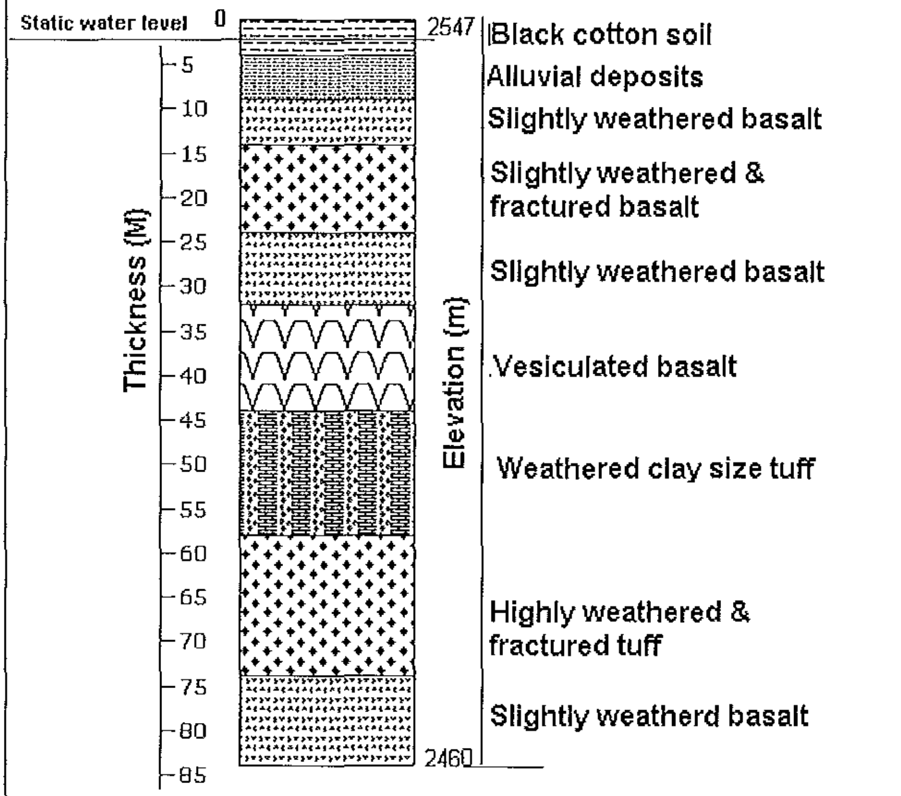
Columnar joints and strong weathering characterize basaltic rock of the area. It is also highly fractured. The layers of rocks are separated from each other by Scoraceous soil horizons (or paleosol) and ignimbrite intercalations. Due to the above-mentioned characters these rocks exhibit both primary and secondary porosity. In some horizons the paleosoil are made up of clay and may act as confining layers and barriers

Figure 5.9 Lithological log data of Sululta Borehole



The above-mentioned characteristics are favorable conditions for these rocks to become the best water bearing formation. But where there is thick soil cover and clay size alluvial deposits the rate of infiltration becomes minimum. The elevated portion of the catchment is affected by high runoff. However, the lower part of the catchment is relatively plain and gets time for the groundwater infiltration from runoff. The boreholes drilled in this formation have a discharge in the ranges of 2 to 4 l/sec. As the resistivity survey in the catchment indicates; most wells with partial penetration of the aquifer. The ranges of the transmissivity of wells in this zone are from 27.4 to 34 m^2/day (Chancho & Sululta wells respectively).

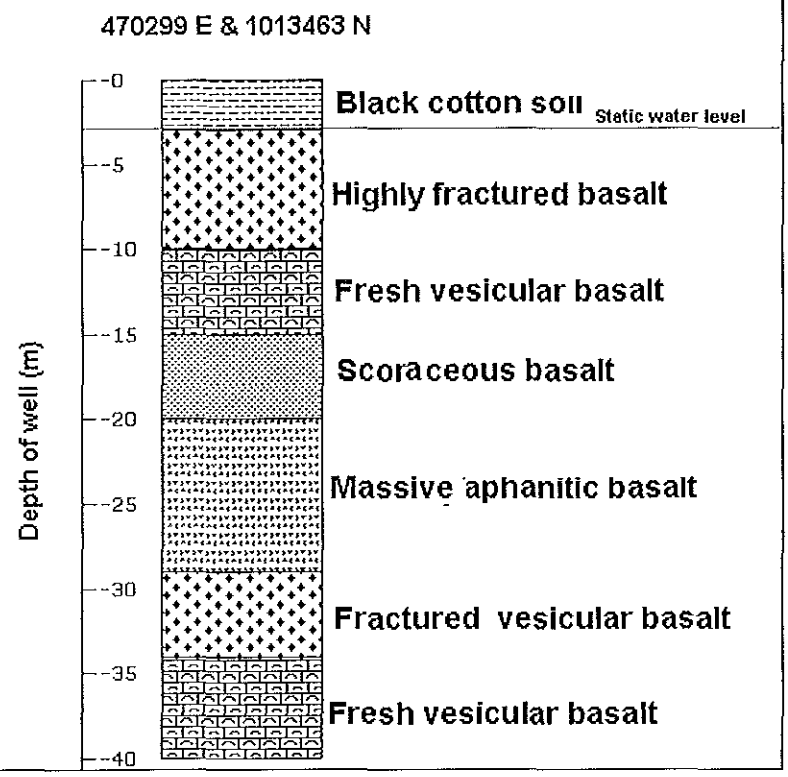
Figure 5.10 Lithological log data of Chancho Borehole
471404E & 1027963N



5.4.2 MODERATE PERMEABILITY ZONE

Area between the divide basin and the high permeable zone are categorized under this zone. Almost the same lithology covered this area and area's classified under high permeability zone. The main difference is that most of the areas here are relatively steep slope. Additionally, the lateral extension of aquifer is sometimes limited in some direction because of ridges and impermeable layers (Figure 5.11). It has higher elevation than the lower central part of the catchment. The transimissivity estimated from Kajima well (17.6 m^2/day) and extrapolated for the rest zone based on the lithologic logs and qualitative interpretation.

Figure 5.11 lithologic log data of Kajima well

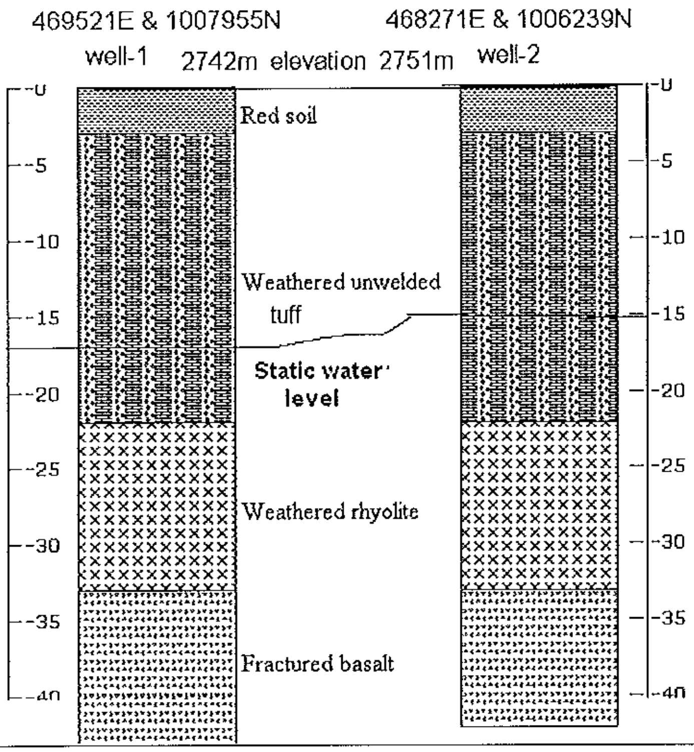


5.4.3 LOW PERMEABLE ZONE

It includes upper parts the study catchment and areas near Sululta town that covered by proclastic rocks. It is both the recharge and discharge zone. In general this area is covered with rhyolite, trachyte, and both welded and unwelded tuff which known mostly by their moderate to low permeability (Figure 5.12).

They are jointed, fractured, and mountain forming. Due to the presence of joints and fractures these rocks have good secondary porosity and could have acted as good water bearing formations but their mountainous morphology and higher topography is more suitable for runoff than infiltration. The aquifers in this rock are semi-confined and shallow depth in the ranges of 30 to 50 m. According to the geological well logging of Guto Weserbi well 1 & 2, the aquifer has moderate yield in the ranges of 0.5 to 1 l/sec. The pumping test result evaluation gave the transmissivity values about 1.12 to 4.49 m^2/day. Therefore, the aquifer is classified under low permeability.

Figure 5.12 Lithological log data of Guto Weserbi W-1 & 2



5.4.4 VERY LOW & IMPERMEABLE PERMEABLE FORMATION

Slightly weathered to non-weathered or fresh basalt has low permeability to impermeable. Formation of such type is characterized by a massive basalt flow, non-fractured and exposed on the surface. Extreme surface runoff is favored on this formation by prohibiting rainwater entrance to the ground (infiltration).

It is mainly found in extreme eastern part and northeastern parts of the catchment. It is prone to high runoff. Hand dug wells are not productive in this zone. Groundwater assessment in such areas has to be with good identification of fracture traces from aerial photograph, satellite images, etc. Like the other zones it is not mapped because found as small portion within different area of the catchment with the above-indicated conditions.

5.5 RECHARGE AND DISCHARGE ZONE

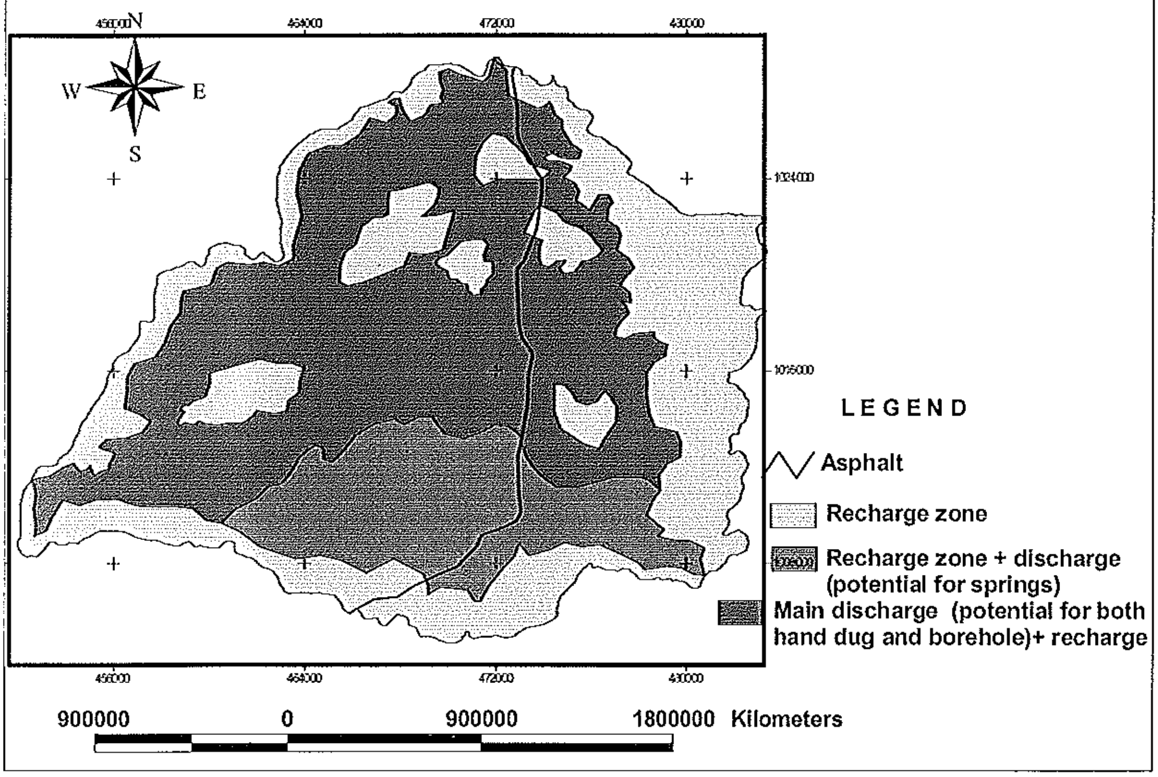
Recharge area is usually in topographically high places where as discharge areas are located in topographic lows. In the recharge areas there is often a rather deep unsaturated zone between the water table and the land surface. Conversely, the water table is found either close to or at land surface in discharge areas. In the field, vegetation and surface water can sometimes be used to locate discharge areas. There may be physical manifestation of the discharging groundwater, which can take the form of springs, seeps, lake, or stream and water indicator vegetations (Fetter, 1994).

The main recharge areas of the study catchment are the elevated parts that are found at the peripheries of the catchment. These areas are the Intoto ridges and connected ridges of the eastern and northeastern part with other basaltic domes in the central and western part of the catchment. Different streams start from this topographically elevated areas flow down to join the main river in the central part of the catchment.

The study catchment lays in the northern part of the main water divide of Awash and Abay basin and therefore, the area is expected to get recharge mainly from direct precipitation. In the central and extreme downstream part of the catchment, however, expected to be fed with recharge from the streams along the limited fracture lines. This condition mostly occurs during the dry period with the decrease of the water table. In the elevated areas the spring discharge fluctuation occur from rainy season to dry period indicates the direct recharge condition from direct precipitation.

The discharge areas are some part of the southern topographically elevated areas close to Intoto and the central vast plain of the catchment. Intoto ridge is both recharge and discharge zone. Different springs and borehole confirm this situation. The central part of the catchment has different boreholes and hand dug wells that indicate its better discharge areas (Figure 5.13).

Figure 5.13 Recharge -Discharge & potential Zones

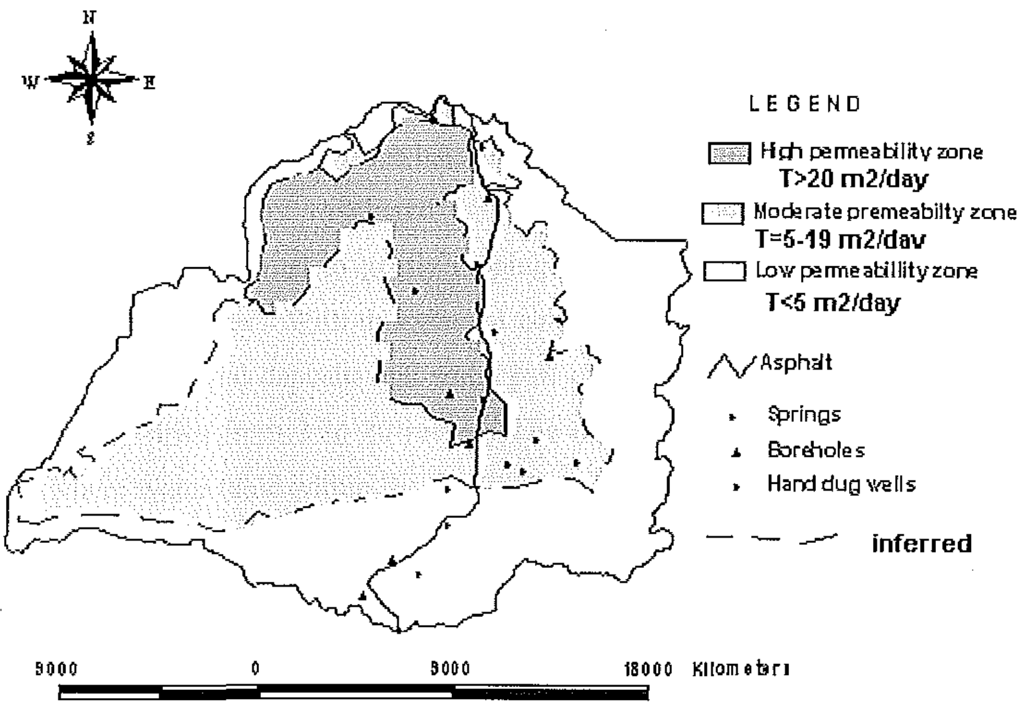


5.6 GROUNDWATER FLOW DIRECTION

Ground water is a continuous movement from recharge to a discharge area in accordance with laws governing water flow in the lithosphere. The laws give the rate of energy loss against resistance from the flow medium (Sen, 1995). Therefore, the known law called Darcay's law governs the flow of water. The law states that 'the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path (Todd, 1980).

Groundwater flow in the study area follows the topography. Most flows are similar to the regional groundwater flow direction that almost parallel to the major fracture traces of the main streams. However, local flow directions at shallow depth are found in small sub-basin catchment due to local structure and local trend of the slope. The regional groundwater flow is north direction. While the local shallow groundwater flows are vary between NW & NE directions (similar to drainage direction).

Figure 5.14 The premeability zonesof the sululta catchment



5.7 WATER POINTS

Three types of water points are to be discussed under this title. These are boreholes (drilled wells), hand dug wells, and springs. Some those with known geographical coordinate are located on the map (Figure 5.14).

5.7.1 BOREHOLES

In the study catchment there are about 13 bore holes. Most of them are drilled around Sululta town, private companies for their water supply demand for constructions and industrial purposes, see figure 5.10 for their spatial distribution of some of the wells). It was discussed in the lithological and aquifer characterization topic.

CHAPTER VI

6. HYDROCHEMISTRY

6.1 GENERAL

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

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

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

6.1 WATER SAMPLE COLLECTION, ANALYSIS, AND DATA EVALUATION

In the study area more of the samples are collected from different water supply schemes that found within the basin and few samples from rivers and unprotected springs to compare parameters among different sources. Totally 25 water samples are collected from boreholes, hand dug wells, springs and rivers/ streams. Each sample is taken with a one –liter polyethylene plastic bottle. Representative samples were taken from each water sources and at different locations

(Figure 5.13). The samples are analyzed in the Laboratory of Oromia water Bureau, Ethiopian Geological Survey, and Addis Ababa Water & Sewerage Authority.

The analysis is made for major cations and anions, few trace elements, and silica. Field and laboratory measurements of pH, EC, TDS, Eh, and Temperature have been conducted. The accuracy of the analytical results of the chemical data was examined for analytical error prior to the interpretation. Those data within the limit of acceptable error (≤5%) used for the purpose of data processing.

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

$$RE = \frac{\sum cations - \sum anions}{\sum cations + \sum anions},$$

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

Those data with reaction error greater than 5% were omitted from data processing. The 32 primary data were fulfilled the requirement while most of the secondary data were not analyzed fully for the different parameters as well as failed for their reaction error greater than 5%. 11 water samples from borehole, 10 water samples from hand dug wells, and 5 and 6 samples for rivers/streams and springs respectively.

6.2 ORGANOLEPTIC PARAMETERS

These parameters include those that characterize the aesthetic values of water. Color, odor, taste and turbidity are classified under this group. Except for test the other parameters were measured.

The presence of organic or inorganic suspended matter such as clay, silt, colloidal organic particles in the water cause turbidity. Turbidity is an expression of certain light scattering and light absorbing properties of water. Turbidity has often been associated with unacceptable tastes and odours. The maximum acceptable concentration (MAC) for turbidity in water entering distribution system is 1 nephelometric turbidity unit (NTU), established on the basis of health

In the study area the water temperature of the samples ranges from 16.1 to 22.2 ^{0}c on the field. In general, the temperature of the water samples is within narrow variation for each water sources. To some extent the water samples collected near the Intoto ridges are less than 20 ^{0}c and the surface water and those found at relatively low elevation exhibit a bit higher temperature.

6.3.4 CHEMICAL NATURE OF THE WATER SAMPLES

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

A. CATIONS

Calcium is the most dominant cation of most water samples. In all the samples the percentage of calcium is the highest with relative to the other three major cations. Sodium is the second highest cation in some samples. Generally the sum of Calcium and magnesium ranges from 50 to 94 % with respect to the sum of sodium and potassium which ranges from 16 to 50 % meq/l of the cations. In borehole the sum of % meq/l of Ca and Mg varies from 57 to 90 while for sum of Na and K ranges from 10 to 23 %. For hang dug wells, rivers/streams, and springs the values of %meq/l (Ca+Mg) and %meq/l (Na + K) vary from 50 –94 & 16- 50, 62-74.4 & 23.6- 38, and 65-89.1 & 9.9 –35 respectively.

B. ANIONS

The predominant major anion in all the analyzed samples, except two, is bicarbonate. Carbonate is significant in some samples, how ever; both sulphate and chloride are rare in most samples.

6.3.5 CHEMICAL NATURE OF DIFFERENT WATERS

A. BOREHOLE WATER

Seven borehole water samples have been used in data processing. Three boreholes are with Ca^{2+}-$HCO3^{-}$ type and the other two are Ca^{2+}-Mg^{2+}-$HCO3^{-}$ and Ca^{2+}-Na^{+}-$HCO3^{-}$type. Sululta borehole that is found in the middle of the basin is with Ca^{2+}-Na^{+}-$HCO3^{-}$-$CO3^{2-}$ type. Guto Weserbi well located along Intoto ridge is a Ca-CO3 type (Figure 6.2 & 6.3).

B. **HAND DUG WELLS**

Totally nine samples were analyzed. 77.7 % water samples are Ca^{2+}-Na^{+}(Mg)-$HCO3^{-}$($CO3^{2-}$) types. Two-water samples with high concentration of NO3 an Cl, and water types are Ca^{2+}-Na^{+} $CO3^{2-}$-$No3^{-}$ and Ca^{2+}-Na^{+}-$HCO3^{-}$-Cl^{-} (Annex 6.2 & Figure 6.2 & 6.3).

C. **RIVER WATER**

The chemistry of running water varies between regions and reflects the local geology and climate. Chemical characteristics are dependent on the mineral makeup of the drainage basin, the solubility of different minerals, chemical content of dust, land use practices, and the effects of stream life on dissolved substances. Rainwater, containing appreciable amounts of ions originating from sea spray, air pollutants, and dust, also contributes to the chemical makeup of waterways.

Only four chemical analyses of river waters are done along the course from upper catchment to the mouse of the river. The rivers are draining the upper quaternary deposit of the plain area more proportionally. Chemical behavior is almost similar and Ca-Na-HCO_3-CO3 at the upper and middle. Finally the sample obtained at the mouse of the Catchment is with the Ca-Na-Mg-HCO_3-CO3 type (Figure 6.2 & 6.3).

D. SPRINGS

The hydrochemical signature of spring is almost similar to that of Hand dug wells. The water is mainly Ca- Mg-HCO_3-CO3 and Ca- Na-HCO_3-CO3 water type. In all the samples percentage of Ca^{2+}+Mg^{2+} is greater than Na^{+}+K^{+} (Figure 6.2 & 6.3).

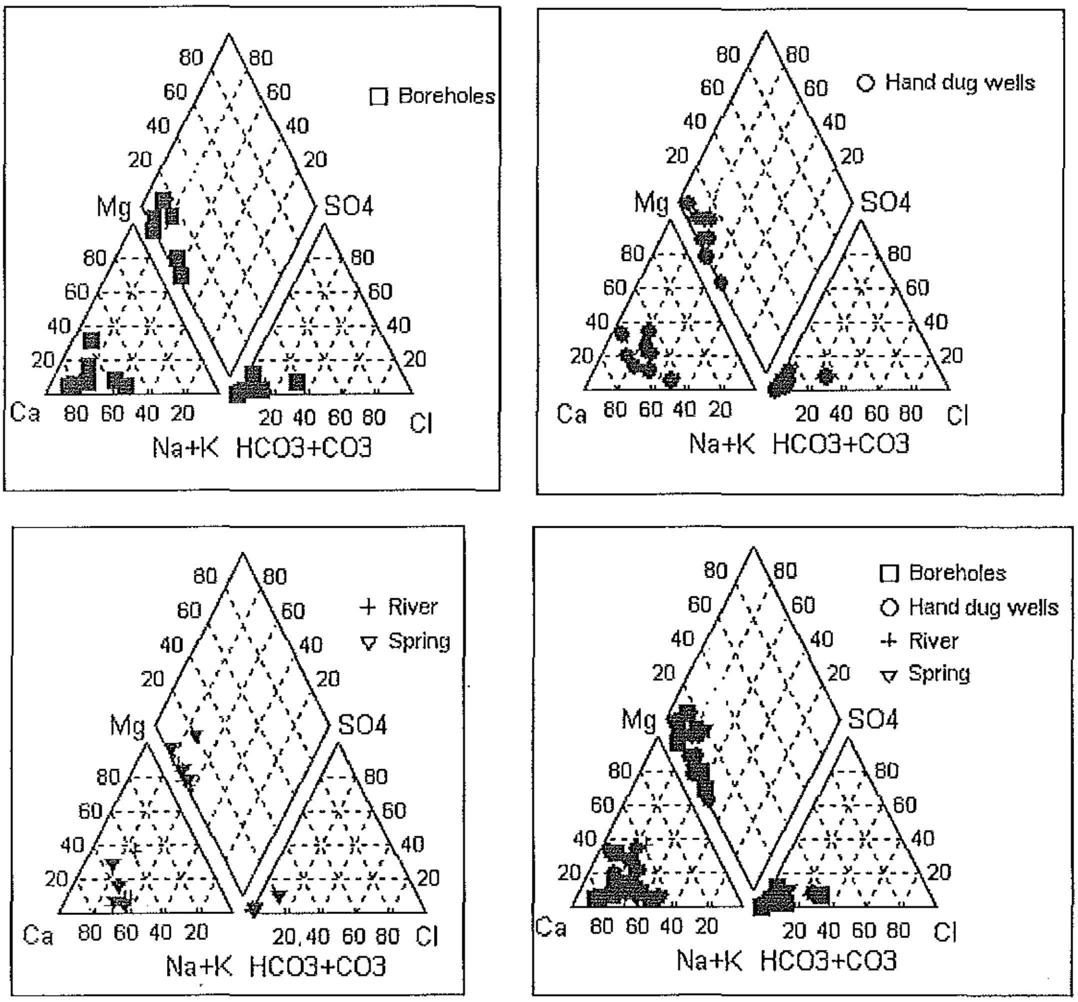
6.3.6 PRESENTATION OF ANALYTICAL RESULTS

There exist various method of graphical presentation of chemical analysis of water. The graph facilitates the easy understanding, interpretation, comparison, and also classification of water samples. They may be either of a single or many sample diagram.

A. PIPER TRI-LINEAR DIAGRAM

Chemical analyses of ground water in this study were classified by a graphical technique described by Piper (1944); percentages of mill-equivalents of the major cations and anions are plotted on tri-linear diagrams and projected onto a common diamond-shaped. The cation comprise Ca^{2+}, Mg^{2+}, and $Na^+ + K^+$; and the anions $HCO3^- + CO3^{2-}$, Cl^-, and $SO4^{2-}$ (Figure 6.2).

Figure 6.2 Piper tri-linear diagram for water samples



B. STIFF (PATTERN) DIAGRAM

The method uses a scale for concentration of ions in meq/l along the x-axis. The ions are arranged along the y-axis in such a way that the cattions (Ca^{2+}, Mg^{2+}, and Na^+) to the left of the center of the plotting scale, and the anions are to the right of it. The diagram has been used to represent some of the water samples from each of the water source (Figure 6.3).

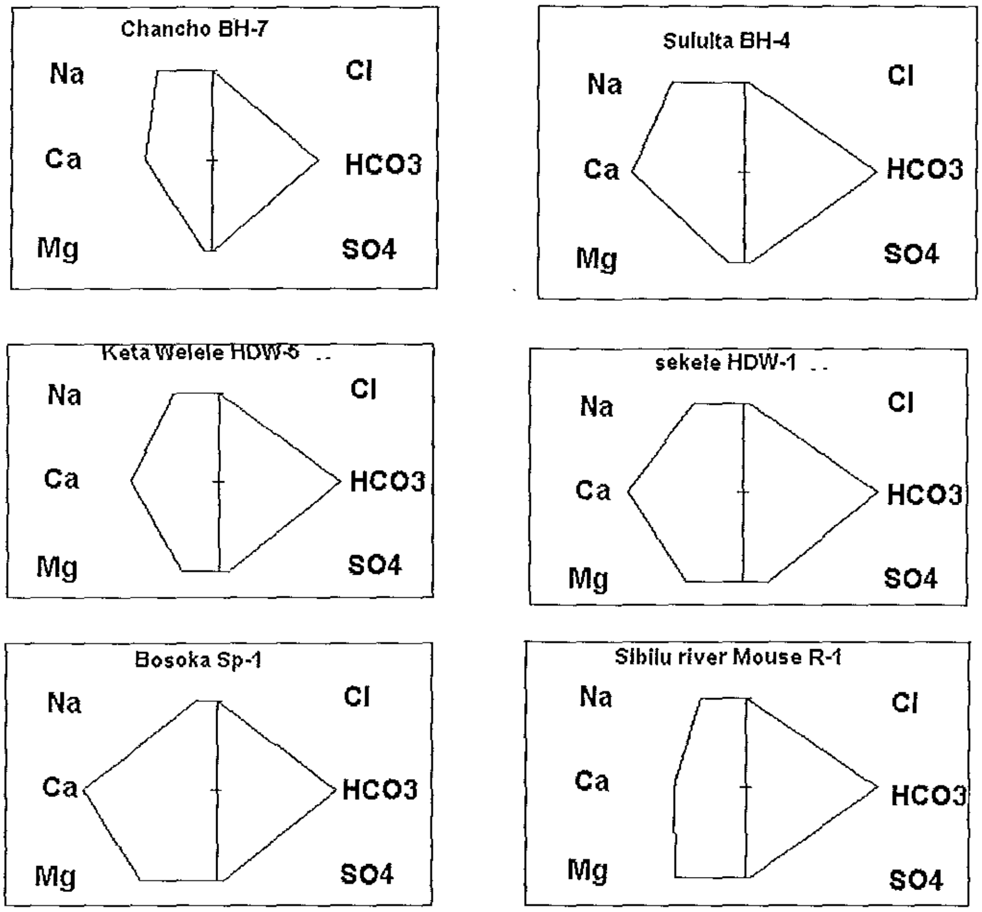


Figure 6.3 Stiff (pattern) diagram for some water samples for each sources

6.3.7 TOTAL DISSOLVED SOLID (TDS) AND ELECTRICAL CONDUCTIVITY (EC)

The term TDS describes all solids (usually mineral salts) that are dissolved in water. The TDS is usually measured in mg/L. Ions like calcium, magnesium, sodium bicarbonate, carbonate, sulphate, iron and etc. may comprise the TDS of water. In natural waters, these ions are present in balanced proportions that are determined by equilibrium between the solution and the geologic formation. The presence of these chemical constituents gives water the ability to conduct electricity. Thus, the electrical conductivity (EC) of water is an indirect measure of its dissolved constituents. In practice, EC is often expressed in terms of millisiemens (mS) and microsiemens (μS). The TDS and the electrical conductivity are in a close connection. The more salts are dissolved in the water, the higher is the value of the electric conductivity (Figure 6.4). EC does not give specific information about the chemical species present in water, but it gives a determination of TDS, which is an acceptable indicator for water quality.

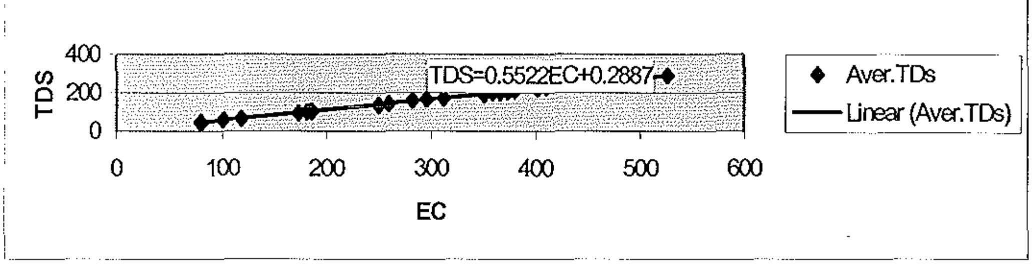


Figure 6.4 A plot showing the relation between TDS and EC of the waters of the Catchment

6.3.8 HARDNESS

In water, hardness is a measure of the total concentration of calcium and magnesium ions, and, to a lesser extent, the salts of other minerals. Calcium and magnesium enter the water via the action of carbonic acid. As water and carbon dioxide react, carbonic acid is produced and dissolves calcium and magnesium from carbonate rocks (e.g., limestone, dolomite).

What constitutes "hard water" has been variously described. A generally accepted classification for hardness as mg/l of CaCO3 is described in Brown, Skougstad, and Fishman (1970) as follows:

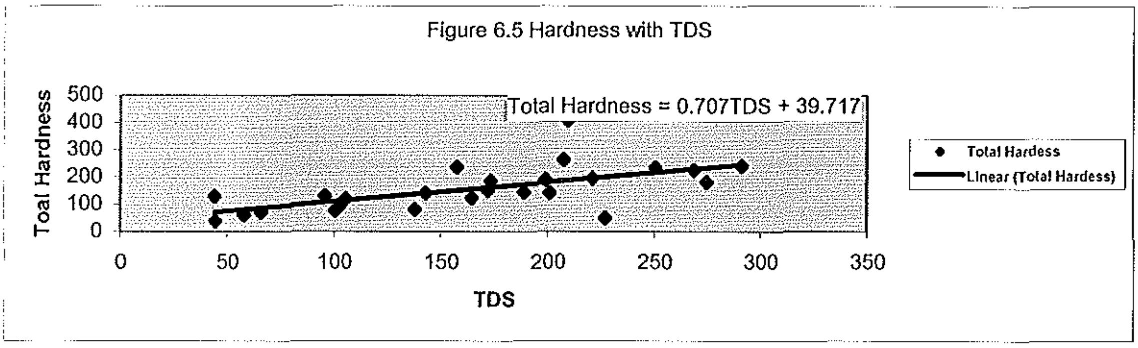
0 to 60 = soft, 61 to 120 = moderately hard, 121 to 180 = hard, and 181 and above = very hard.

Although not a health concern to humans, hard water can be detrimental to home and industrial water systems. Hard water increases the amount of soap or detergent needed to lather and leaves scaly deposits on containers and plumbing. Hardness levels above 500 mg/l are not desirable for domestic use.

Samples of the study area have more $Ca^{++} + Mg^{++}$ so that also hardness of water is one factor of water quality. In general, it is relatively high for borehole and small for spring water.

Table 6.1 classifications of the Water sample of Sululta by hardness

%of sample	Description
12	Soft
20	Moderately Hard
32	Hard
36	Very Hard



In the study catchment the samples have been categorized based on the hardness and shown as follows by table 6.1 and almost increase with Total Dissolved solids (Figure 6.5)

6.4 WATER QUALITY

The source of any water supply determines the kinds and amounts of its impurities. There are tremendous variations in the quality of water from area to area. In some cases there are variations in quality even on a day-to-day basis.

It is almost impossible to find a source of water that will meet basic requirements for specific water use. Generally natural water interacts with environment, and also it is affected by anthropogenic material. Generally, these requirements are: free of disease-producing organisms, colorless, clear, & odorless hand good tasting, non-corrosive and free of objectionable gases and staining minerals, and plentiful and low in cost.

A given quality of water that is unacceptable for one function may prove satisfactory for another. For example, exceptionally hard water that may be objectionable for laundering and bathing may be satisfactory for sprinkling the lawn. Determination of the water quality based on its physical, chemical and biological characteristic is helpful in determining the suitability of particular water for a certain use. A point of interest here is to discuss the suitability of surface and groundwater of the Sululta catchment for specific uses like drinking and agriculture. Industrial water use is quite diverse and water quality requirements vary greatly for different industries. Hence, discussions will only be limited to the above uses only.

6.4.1 Water quality for public supply

Before directly addressing the suitability of surface and ground waters of Sululta for drinking purpose, it is of great importance to first discuss guidelines or standards developed for such purpose.

Authorized legal bodies like WHO (World Health Organization) have established certain guidelines or standards for drinking water quality which can generally be used as a framework of water quality activities. In the mean time, different countries have also set their own standard. Here, the analysis results are compared with the standards developed by Ethiopia & WHO.

Table 6.2 maximum allowable concentrations of water quality variables for drinking water (Tebbutt, 1998 and Adane, 1999)

Variable	WHO Guideline	Ethiopian Standard
Color	15	50
Total Dissolved Solids (mg/l)	1000	1500
Turbidity (NTU)	5	25
PH	6.5 – 8.5	7 – 8.5
Ammonia (mg/l)	-	0.1
Nitrate (mg/l)	50	50
Phosphorus (mg/l)	-	-
Sodium (mg/l)	200	-
Chloride (mg/l)	250	600
Sulphate (mg/l)	250	400
Fluoride (mg/l)	1.5	1.5
Cyanide (mg/l)	0.07	0.05
Arsenic (mg/l)	0.01	0.05
Cadmium (mg/l)	0.03	0.01
Chromium (mg/l)	0.05	0.05
Copper (mg/l)	2	1.5
Iron (mg/l)	0.3	1.0
Lead (mg/l)	0.01	0.1
Manganese (mg/l)	0.1	0.5
Mercury (mg/l)	0.001	0.001
Nikel (mg/l)	0.02	-
Zinc (mg/l)	3	15
Faecal coliform (E.Coli)/100ml	0	0
Total coliforms /100ml	0	0

According to Harvey (1982), water that is to be used for drinking must meet high standards of physical, chemical and biological purity. The water should be appetizing, clear, transparent, colorless, odorless and constant temperature. Water samples taken from the study area have low values of the different water quality parameters for each of the water supply sources. For example, both nitrate and fluoride are within the permissible limit and therefore for water supply purposes only the physical parameters needs to be improved in some water supply sources. In other words, hand dug wells have turbidity and color above the standard limit.

6.4.2 WATER QUALITY FOR IRRIGATION

The development and maintenance of successful irrigation projects involve not only the supplying of irrigation water to the land but also the control of salt and alkali in the soil. The quality of irrigation water, irrigation practices, and drainage conditions are involved in salinity and alkali control. Soil that was originally non saline and non alkaline may develop saline and alkaline character if excessive soluble salts or exchangeable sodium are allowed to accumulate in the soil as the result of improper irrigation or soil-management practices, or inadequate drainage.

In areas of sufficient rainfall and ideal soil conditions the soluble salts originally present in the soil or added to the soil with water are carried downward by the water and ultimately reach the water table. The process of solution and transportation of soluble salts by water moving through the soil is called "leaching." If the amount of water applied to the soil is not in excess of the amount needed by plants, there will be no downward percolation of water below the root zone and mineral matter will accumulate at that level. Impermeable zones in the soil near the surface can retard the downward movement of water, resulting in water logging of the soil and deposition of salts. Unless drainage is adequate, attempts at leaching may not be successful, because leaching requires the free passage of water through and away from the root zone.

The characteristics of water for irrigation that seem to be most important in determining its quality are: (1) total concentration of soluble salts; (2) relative proportion of sodium to other principal cations (magnesium, calcium, and potassium); (3) concentration of boron or other elements that may be toxic to plants; and (4) the bicarbonate concentration, under some conditions, as related to the concentration of calcium plus magnesium.

The total concentration of soluble salts in irrigation water can be adequately expressed in terms of electrical conductivity for purposes of diagnosis and classification (Table 6.3).

The relative proportion of sodium to other cations in irrigation water usually has been expressed simply as the percentage of sodium among the principal cations.

According to the U. S. Department of Agriculture the sodium-adsorption ratio (SAR), used to express the relative activity of sodium ions in exchange reactions with soil, is a better measure of suitability of water for irrigation with respect to the sodium (alkali) hazard (Table 6.3). Sodium percentage and the sodium-adsorption ratio may be determined respectively by:

$$\%Na = \frac{(Na+K)100}{Ca+Mg+K+Na}$$

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

The sodium-absorption ratio may be determined also by use of the nomogram shown in Figure 6.9. Accordingly, SAR is computed for the rivers, springs, shallow and deep wells and the results show low SAR values well below 10. This indicates low sodium hazard in which reduction in soil permeability and hardening of soil is not serious. Hence, the surface and ground water of the Sululta catchment can generally be considered as suitable for irrigation purpose with respect to sodium hazard.

In water having a high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated as a result of evaporation and plant transpiration. This reaction ordinarily does not go to completion, but when it does, there is a reduction in the concentration of calcium and magnesium, and, therefore, a relative increase in sodium. The calcium and magnesium are precipitated as carbonates, and any residual carbonate or bicarbonate is left in solution as sodium carbonate. The potential amount of such residual sodium carbonate may be computed $(Na_2CO_3) = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$, where the ionic concentrations are expressed as milliequivalents per liter or equivalents per million. The relative value is given in the table 6.3 and high for dug wells and boreholes than springs and rivers.

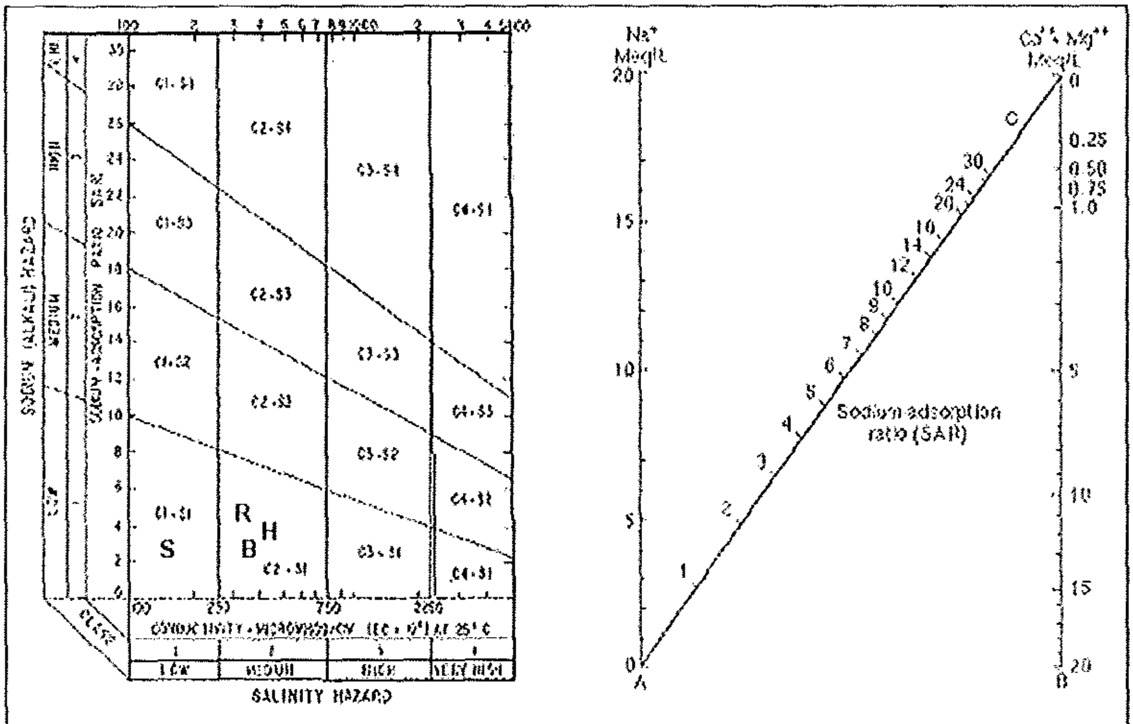
Table 6.3 Quality classification of water for irrigation

Water class	Percent sodium	Specific conductance micro seimen per centimeters
Excellent	<20	<250
Good	20-40	250-750
Permissible	40-60	750-2200
Doubtful	60-80	2200-3000
Unsuitable	>80	>3000

Table 6.4 Average values of the parameters for irrigation

Sources	Na%		SAR		EC		Residual sodium-Carbonate	
		Water class		Water class		Water class		
Springs	28.25	Good	3.32	Low hazard	166.6	Excellent	88.02	
Rivers	37.15	Good	5.42	Low hazard	280.25	Good	151.0 3	
Hand dug wells	29.82	Good	4.64	Low hazard	362.3	Good	158.0	
Boreholes	25.31	Good	3.76	Low hazard	315.4	Good	147.9	

Figure 6.6 Diagram showing suitability of water for irrigation & Nomogram for determining sodium-adsorption ratio of water respectively



B-Borehole, H-Hand dug, S-spring, and R- River

6.3.3 WATER POLLUTION

Within the study area, the common possible sources of pollution are agricultural activities and municipal wastes. Industrial sources of pollution are totally absent in the basin except those areas now started for flower production. Agricultural sources include animal wastes, fertilizer and soil amendments, and pesticides. In general, the main pollutant of water sources are related to the intense fertilizer usage and the animal waste distributed in the catchment. The public and individual dry latrines are the other pollutant sources around Chancho and Sululta towns.

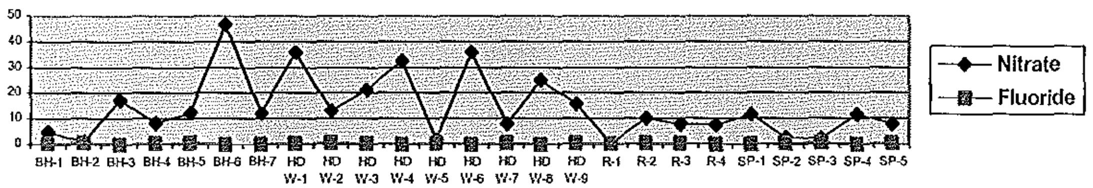
A. NITRATE

Drinking water high in nitrate is potentially harmful to human and animal health. Potential sources of nitrate include septic systems, animal waste, commercial fertilizer, and decaying organic matter. Shallow wells are susceptible to nitrate contamination because there is less soil and rock to serve as a filter between the soil surface and the ground water supply. Nitrate contamination levels may vary with time of year depending on the source of the pollutant. The average value of nitrate in the boreholes, springs, and hand dug wells, and rivers/streams is 14.59, 20.98, 6.49 & 7.13 mg/l respectively (Figure 6.7).

B. FLUORIDE

Fluoride is quite mobile under most geochemical conditions. In water, stability is limited by the formation of fluorite (CaF_2), high F^- concentration will thus occur in low Ca- water. The occurrence of Fuoride is often linked with volcanic activities, geothermal activities and granite rocks. Thermal high pH waters can be expected to have especially high concentration (Redda, 2002).

Figure 6.7 The vaiation of nitrate and fluoride



Shallow wells and cold springs contain low fluoride concentration than the deep ground water system. Areas, which are devoid of thermal springs, contain small amount of fluoride in water. The fluoride concentrations seem to increase from escarpments towards the rift center discharge zone (Tamiru Alemayehu, 2000). In the study area it is low and the minimum and maximum values are 0 to 0.8 mg/l (Figure 6.7).

C. BACTERIA

While the vast majority of bacteria are not harmful, certain types of bacteria cause disease in humans and animals. Examples of waterborne diseases caused by bacteria are: cholera, dysentery, shigellosis and typhoid fever.

Concerns about bacterial contamination of water led to the development of analytical methods to measure the presence of waterborne bacteria. Coliform bacteria have been used to assess the quality of water and the likelihood of pathogens being present. Although several of the coliform bacteria are not usually pathogenic themselves, they serve as an indicator of potential bacterial pathogen contamination. It is generally much simpler, quicker, and safer to analyze for these organisms than for the individual pathogens that may be present. Fecal coliforms are the coliform bacteria that originate specifically from the intestinal tract of warm-blooded animals (e.g, humans beavers, racoons, etc.).

Table 6.5 The microbiological water quality of water sources

s.no	Site	Source	Total coliforms MPN per 100ml	Escherchia coli MPN per 100ml
1	Orgogo	Stream	1,300,000	2,300,000
2	Bosoka	Spring	<1	<1
3	Gometa	Hand dug well	7000	7000
4	Chancho	Borehole	<1	<1

Human sources of bacteria can enter water via either point or non-point sources of contamination. Point sources are those that are readily identifiable and typically discharge water through a system of pipes. Towns with sewerage may not have enough capacity to treat the extremely large volume of water sometimes experienced after heavy rainfalls. At such times, treatment facilities may need to bypass some of the wastewater. In the study area the source of bacteria is both related to the human and cattle population in the area. Hand dug well shows the bacterial pollution because of its shallow water table.

CHAPTER VII

7. WATER RESOURCES EVALUATION

7.1 GENERAL

The techniques of water resources evaluation require an understanding of the concept of hydrologic parameters. Water resource evaluation of the catchment is mainly used to answer the following question.

The best field, proposed pumping scheme on the regional water level, long term yielding capacities of the aquifer, influence of proposed development on the components of water cycle, the volume of water in storage and leaving the storage, the distribution of surface and groundwater and their interaction, the potential pollution sources and extent with future forecast based on the existing trend and potential for small scale irrigation.

7.2 GROUNDWATER POTENTIALS AND CONTROLS

A complexity of factors - hydrogeological, hydrological and climatological, controls the ground water occurrence and movement. The precise assessment of recharge and discharge is rather difficult, as no techniques are currently available for their direct measurements. Hence, the methods employed for groundwater resource estimation are all indirect. Ground water being a dynamic and replenishable resource is generally estimated based on the component of annual recharge, which could be subjected to development by means of suitable groundwater structures.

For quantification of groundwater resources proper understanding of the behaviour and characteristics of the water bearing rock formation known as Aquifer is essential. An aquifer has two main functions - (i) to transit water (conduit function) and (ii) to store it (storage function). The Groundwater resources in unconfined aquifers can be classified as Static and Dynamic. The static resources can be defined as the amount of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resources can be defined as the amount of groundwater available in the zone of water level fluctuation. The replenishable groundwater resource is essentially a dynamic resource which is replenished annually or periodically by precipitation, irrigation return flow, canal seepage, tank seepage, influent seepage, etc.

The study catchment is in Abay basin separated by main divide line of Intoto ridge from Awash basin. Interflow of groundwater from adjacent basins to the study basin very insignificant.

7.3 GROUNDWATER AND SURFACE WATER INTERACTION

Streams that receive groundwater discharge are gaining streams. Streams that allow water to seep into groundwater are known as losing streams. In any catchment, surface water (River or stream) is either gaining or losing stream. The typical stream of a humid region receives groundwater discharge (gaining stream). The study area generally categorized under gaining streams in which along the total length of the stream profile the discharge of streams increase. . Along the ridges many streams appear because of base flow results of groundwater as spring. In some part stream also dry because of the limit in groundwater supply as base flow, and thus discontinued stream occur

During dry period the flow of many streams become very small as one goes upstream from the mouse of the catchment. The groundwater is lost from the aquifer to the streams along the stream profiles. The water table rises and falls according to the season and the amount of rain that has occurred during a particular months of the year. Stream flow during dry period is limited to the middle and lower most part of the catchment as dry period continues. In other word, most of the streams in the upper recharge zone have no flow during the months of January to May. In middle and lower most catchment even though the amount is small the groundwater feed the streams and sustain the river flow of the catchment.

7.4 PRECIPITATION VERSUS POTENTIAL FOR INFILTRATION & RUNOF

Surface runoff, refers to all the waters flowing on the surface of the earth, either by sheet flow or by channel flow in rills, gullies, streams, or rivers (Hydrology Handbook, 1996). Overland flow occurs as a result of infiltration-excess overland flow, and saturation overland flow. Infiltration-excess flow occurs when the precipitation intensity exceeds the rate of water infiltration into the soil. This process is affected by several factors such as rainfall intensity, soil type and land cover. Runoff-contributing areas are usually characterized by low-permeability soils (clayey soils), sparse vegetation and high intensity rainstorms. The purpose of this study is to estimate the potential runoff-contributing areas in a Sululta catchment.

Factors such as soil type, watershed surface properties (elevation, slope, and geology), land cover, and climate (rainfall intensity and duration) affect runoff and determine the potential of an area to yield surface water. Cropland and urban land uses are usually characterized with higher runoff due to increased soil compaction and sparse vegetation, which decreases soil permeability. Grassland and woodland usually have lower runoff than cropland and urban land due to accumulated organic matter on the surface, dense root systems and greater rainfall interception.

The major soil units' mapping is given in the chapter two under soil classification obtained from woreda agricultural office. The permeability of the soil condition is qualitatively identified and in hill slope areas the rocks are well-fractured and permitting infiltration than the plain areas covered with clay soil. Actually the slope is the main factor controlling infiltration than permeability because the boundary in southern and eastern part is highly slope

7.5 HYDROGEOLOGICAL ANALYSIS

7.5.1 GEOLOGICAL MAPPING

This will involve the conduct of rapid reconnaissance to follow-up semi-detailed geological mapping of the project site giving emphasis to areas with geohydrological concerns (e.g. potential groundwater-bearing rocks or horizons) as identified from the interpretations of available aerial photographs, and published or unpublished papers. Actual mapping will be centered on weathering, fracturing, creeks, rivers and alluvial deposits.

Sululta is a catchment having different geological and topographic set-up, giving rise to divergent ground water situations in different parts of catchment. The prevalent rock formations, ranging from basic to acidic lava and quaternary alluvial deposits, which control occurrence and movement of ground water, are widely varied in composition and structure. Similarly, not too insignificant, are the variations of landforms, from the rugged mountainous terrains of southern (Intoto ridge) and eastern to the flat alluvial plains of the central part of the catchment.

7.5.2 WATER POINT/SPRING SOURCES INVENTORY

Table 7.1 water schemes

s.no	Site name	Scheme	s.n	Site name	Scheme
1	Asere Koshe	Spring	22	Goro dima	Spring
2	Asere Ali	Hand dug well	2	Satellite	Hand dug well
3	Jelise	Spring	24	Wererso keta	Hand dug well
4	Michile	Borehole	25	Gullele-1	Hand dug well
5	Gometa	Hand dug well	26	Bekele Alemu	Hand dug well
6	Kore Roba	Borehole	27	Gullele-2	Hand dug well
7	Fiche Gelela	Spring	28	Sakela-1	Hand dug well
8	Intoto camp	Hand dug well	29	Sakela-2	Hand dug well
9	Weserbi-1	Borehole	30	Sakela-3	Hand dug well
10	Weserbi-2	Borehole	31	Sakela-4	Hand dug well
11	Weserbi-Guto	Spring	32	Madrisa	Hand dug well
12	Mene Karshe	Spring	33	Genda bale	Hand dug well
13	Kalwa	Spring	34	Koso bare-1	Hand dug well
14	Damota	Spring	35	Koso bare-2	Hand dug well
15	Wele Babo-1	Hand dug well	36	Weresa	Spring
26	Wele Babo-2	Hand dug well	37	Chancho-1	Borehole
17	Wele Babo-3	Hand dug well	38	Chancho	Hand dug well
18	Wele Babo-4	Hand dug well	39	Sululta	Borehole
19	Wele	Hand dug well	40	Honey moon	Borehole
20	Keta Medhane Alem	Borehole	41	Flower farm	3-Borehole
21	Aluminum industry	Borehole	42	Chancho-2	Borehole

This activity concentrates on spring sources and well inventory, which are key elements in the groundwater resource assessment to be undertaken within the project area. The inventory aspect involves measurement of the water level in wells, spring yield, either developed or undeveloped, its location, elevation, well depth, water level or depth-to-water casing and other pertinent hydrologic information including the physico-chemical quality testing of spring water and deep well discharges. The water table in the catchment is 0.5 –2m at the lower discharge areas (Chancho-1=2m, Chancho=0.5m), 2-6 m in the middle (Sululta=5m, Kore roba=2m and Hajima=3m), and relative deep at recharge zone (Weserbi-1=15m & Weserbi-2=17m). The springs have yield in the range of 0.2 to 4 l/sec(Bosoka spring). High discharge springs are found at the contacts between different lava flow, Bosoka spring emerges at the contact between trachyitic and basaltic lava flows. Table 7.1 shows the inventory report of the 1996 water schemes of the Sululta-Mulo woreda (Woreda Water Resources Desk).

7.5.3 GEO-RESISTIVITY SURVEY

Resistivity survey or VES is to be employed in various localities of the study area that show or express potential groundwater availability. This will be done to supplement the information available on the hydrogeological conditions in the study area. The selection of the sites for VES points is to be based on planned development of water system facilities, hydrogeological conditions, proposed major fractured and weathered formation, together with the initial findings of the well inventory and the geologic mapping activity described above.

The VES interpreted results have indicated results have indicated that the upper 3-20 meters in most part of the central plain area is potential for hand dug well and shallow groundwater. This same area is potential for borehole of maximum depth 120 following the main fracture zones.

7.5.4 AQUIFER CONDITION AND YIELD

The topography and rainfall virtually control runoff and ground water recharge. The high relief areas of the southern & eastern regions occupied by the Intoto ridges, with steep topographic slope, and characteristic geological set-up offer high run-off and little scope for rainwater infiltration. The groundwater potential in these terrains is limited to intermountain valleys, which is mainly a function of the highly fractured weathered acidic lava.

The large alluvial plains extending over a distance of 15 kms following the streams from Sululta to Chancho, constitutes one of the largest and most potential groundwater reservoir in catchment. The aquifer systems are thin alluvial deposits for most of the hand-dug wells in the catchment. The boreholes data confirms that the aquifer systems are thin alluvial deposits and thick weathered & fractured basaltic & welded tuff, hydraulically interconnected and moderate to high yield. To the south of this area all along the Intoto foot hills, occur the fracture lineaments that favor recharge, and springs with discharge between 0.5 to 4 l/sec are out flowing condition.

Rugged topography, weathered and fissured nature of the rock formations, combine to give rise to discontinuous aquifers, with limited to low yield potentials. The near surface weathered rock forms important groundwater reservoir, and the source for circulation of groundwater through the underlying fracture systems. In the middle and lower part of the catchment, deep weathered & fractured rock, abandoned river channels generally contain adequate thickness of porous material, to sustain groundwater development under favourable hydrometeorological conditions. Generally, the potential water saturated fracture systems occur down up to 100 m depth, and in cases yield even up to 4l/sec.

7.6 SMALL SCALE IRRIGATION POTENTIAL OF THE CATCHMENT

The paper is to address the possibility to use irrigation in the study catchment (The paper focused on small based on the discharge data of Sibilu). The study catchment comprised of four streams and one main river flowing along the plain areas of Sululta. In the area there is only one traditional irrigation field cultivating vegetarian crop by using Bosoka(4l/sec) spring.

The other streams are simply flowing by passing the plain of Sululta. Excess water from cattle demand is therefore has to be used for small-scale irrigation to increase the self-food sufficiency of the households in the vicinity.

Small-scale irrigation can be defined as irrigation, usually on small plots, in which small farmers have the controlling influence, using a level of technology which they can operate and maintain effectively. Small-scale irrigation is, therefore, farmer-managed. Although some small-scale irrigation systems serve an individual farm household, most serve a group of farmers, typically comprising between 5 and 50 households.

WATER REQUIREMENTS AND IRRIGABLE AREA: Crops require a large amount of water for irrigation, and it is important to calculate water requirements accurately, both to design the supply canal and the pump (if any), and to check that enough water is available from the source. The amount of water required by a crop depends on the local environment, the climate, the crop and its stage of growth, and the degree to which the crop may be stressed. This requirement may be expressed as a uniform depth of water over the area in millimeters per day (mm/d). In the study area, Sibilu and its tributaries at the middle have minimum flow of 400l/sec. the topography of the catchment is suitable for dam construction at relatively narrow stream course to utilize the runoff at different season.

IRRIGATION REQUIREMENTS: Reference evapotranspiration (ET) is the water use of grass (in mm/d) under standard conditions. Local estimates may be available from water calculation which is about given in the hydrometeorological section. For most crops, the reference evapotranspiration at mid-season can be taken as a reasonable estimate of the peak water requirement. This data is therefore available for agronomist or irrigation Engineer to design and calculate the water requirement for the type of crop.

DESIGN COMMAND AREA: The required canal discharge depends on the field area to be irrigated (known as the 'command area'), and the water losses from the canal. For a design command area A (m 2), the design discharge required Q (l/s) for irrigation hours (H) every day, is given by the field-irrigation requirement multiplied by the area, divided by the time (in seconds): The area under consideration is very plain to get any required commend area for the available discharge of stream or river in the catchment.

IRRIGATION-CANAL LOSSES: Water is lost from canals by seepage through the bed and banks of the canal, leakage through holes, cracks and poor structures, and overflowing low sections of bank. The canal losses depend on the type of canal, materials, standard of construction and other factors, but are typically about 3 to 8 litres per second (l/s) per 100 metres for an unlined earthen canal carrying 20 to 60 l/s. Losses often account for a large proportion of water requirements in small-scale irrigation, and may be estimated by 'ponding' water in a trial length of canal, and then measuring the drop-of-water level.

7.7 WATER QUALITY AND POLLUTION SOURCES

This activity, among others, aims to generate information on the quality of the spring and groundwater resources within the coverage area and to address the present condition of water quality and pollution and contamination potential. Pollution assessment includes a measure of human activity above an aquifer in addition to the hydrogeologic factors.

The first step requires the user to determine if an aquifer with a useable supply of water exists. We recognize that because there is linkage between all forms of groundwater, protection of all groundwater is desirable.

In the Sululta catchment, aquifers located in fractured and alluvial top cover derived materials are of greatest value due to their generally good water quality, high yields, and shallow depths. The water must be of such quality that it is useable for human needs. Useable water quality is considered to be low in total dissolved solids and free of pollutants like nitrate, fluoride, bacteria, etc. The term shallow has been used to describe vulnerable aquifers with less than 50m of material overlaying them. Many fractured and alluvial aquifers in the central and upper recharge area fulfill this explanation; however, some are deeper than 50. All alluvial aquifers will be considered as worthy of protection, particularly those shallower than 20 m. The bacteriological water quality test shows that shallow hand dug well and streams are total coliforms MPN/100ml greater than 16 and 1,300,000 respectively.

7.7.1 FERTILIZER, PESTICIDE USE AND SEPTIC TANK, AND ANIMAL FEED LOTS

Distribution of land use has been recognized as an important factor in protecting groundwater from agricultural chemicals (Thomas, 1992a). Different types of land use will require different levels of agricultural inputs. Land use is a general indicator of the amount and type of fertilizers, pesticide and chemicals applied above an aquifer.

The common fertilizer used in the catchment is urea $CO(NH_2)_2$ and Ammonium sulphate $(NH_2)SO_4$. The commonly used fertilizer is Urea. In the soil it hydrolysis rapidly, and the reaction is catalyzed by an enzyme called urease, which is released in to soil by many micro-organisms. The decomposition of urea is as follows:

In the catchment according to data from the Wereda Agriculture office, 50 kg of urea or Ammonium sulphate is used for one hectare of farmland. The totally around 80 to 100 quintal of fertilizers are used annually in the catchment for different crops.

Septic system is other nitrate-producing source that could soak in to the groundwater. The number of septic tanks is very dense in the Chancho, Sululta, and Weserbi area and placed in the recharge zone with respect to the well supplying the respective towns.

7.7.2 FILTRATION POTENTIAL

After the location of aquifers and surface water sources fertilizer and pesticide usage over them is assessed, the site properties that affect these chemicals movement must be determined. In simple terms, the soil and geologic materials act as a filter to protect aquifers from contamination. In this case, the amount of the chemicals is lessened as it is filtered-out on soil and geologic materials. An estimate of the potential for materials to attenuate or filter-out pollutants will be presented as the "filtration potential".

In reality, filtration is a complex process that depends not only on the physical and chemical characteristics of the overlaying materials, but also on the physical and chemical characteristics of the fertilizers, pesticides and any pollutant sources.

Depth to the aquifer and vadose zone texture has been recognized as important factors in several groundwater assessment systems. Determined soil organic matter to be the most important soil characteristic influencing these pollutants movement through soils. Depth to the saturated aquifer combined with predominant water flow direction, Soil and geologic strata permeability, Soil organic matter content, and Fertilizers or Pesticide half-life and organic carbon adsorption coefficient. The samples analyzed in the catchment have nitrate which shows the intense use of fertilizer and animal waste product in the field. In future all the factors mentioned above to be the serious factors in affecting quality of water.

7.7.3 AQUIFER DEPTH & WATER FLOW DIRECTION.

Depth to the saturated aquifer can be determined from the catchment groundwater level. Depths less than 50 m are considered to be shallow. Soils are an excellent indicator of long term water flow direction (Bigler and Richardson, 1984).

Central part of the catchment is covered by thick black cotton soil that overlay sandy size alluvial deposits and some tenth meter of weathered parent rock. The presence and depth of the weathered and fractured rock and the alluvial deposits governs the hydraulic properties of the media. As the depth of these materials increase, so does the groundwater recharge potential.

A groundwater recharge area overlaying a shallow aquifer constitutes low potential for filtration of contaminants from percolating water. All other combinations of groundwater flow and aquifer depth have high filtration potential.

7.7.4 SOIL AND GEOLOGIC MATERIAL PERMEABILITY

Soil permeability is closely related to soil texture. Soils in the sandy and sandy skeletal textural families that overlie sand and gravel geologic materials have low potential for filtration. All other textures or combination of textures will have intermediate potential for filtration.

7.7.5 ORGANIC MATTER CONTENT

Soil organic matter content has the largest influence on pesticide attenuation compared to the other soil factors. Organic matter content of < 2% in the A horizon (very low to moderately low) will have low potential to filter pollutant from percolating water. As organic matter content increases, filtration potential also increases.

7.7.6 CHEMISTRY OF POLLUTANTS: The tendency for pollutant to move with water through soils is also influenced by its chemistry. This is referred to as leaching potential. It is just the opposite of filtration potential or fertilizer or pesticide tendency to be removed from the water and trapped or filtered by the soil.

Regardless of the form of nitrogen added--chemical fertilizer, an organic mix, manure, or sewage sludge--soil organisms convert it to nitrate before plants take it up. Nitrate leaches through soil very easily. If too much nitrogen fertilizer is applied, the extra nitrate ends up in groundwater.

Some fertilizers contain additives or industrial waste products that might contaminate groundwater. Not much is known about the potential risk of these compounds. Until these chemicals are proven to pose little risk to groundwater, they must be considered a potential contaminant.

Causes of groundwater contamination are more fertilizer applied than plants can use, over-watering after fertilizer is applied, timing of fertilizer application that does not match plants needs, and additives in fertilizers

Individual septic systems treat wastewater from homes and businesses in areas where there is no public sewer. Solids are removed from the wastewater in the septic tank, and then the remaining wastewater flows to the drain field where it percolates into the soil. Natural biological and chemical actions in the soil remove most of the hazardous substances from the wastewater, but there are exceptions.

Nitrate is not removed by the soil as the wastewater percolates downward. Ideally, septic systems should be spaced far enough apart that the nitrate simply is diluted by the large volume of groundwater under the acres of land surrounding the septic system. When there are many septic systems close together, however, there often isn't enough groundwater for dilution.

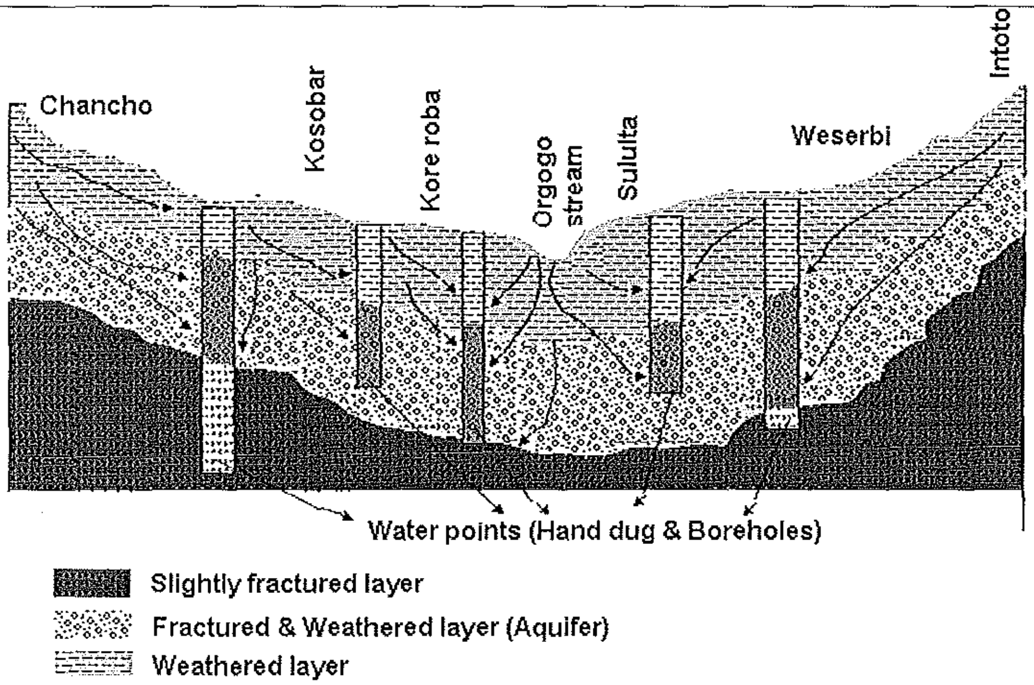


Figure 7.2 Schematic model showing major movement of pollutants in groundwater

CHAPTER EIGHT

8. SYNTHESIS

8.1 RESULTS FROM THE ANALYSIS OF HYDROMETEOROLOGY

METEOROLOGICAL PARAMETERS: A fifteen to twenty one years rainfall record from NMSA (National Meteorological Service Agency) for Sululta catchment is analyzed using different methods of the precipitation analysis. The effective annual depth of precipitation in the study area is calculated by using the above thee methods and the result is given by the intermediate value which is obtained by Theissen polygon. Therefore, the annual precipitation in the basin is 1201.31 mm (The average the three methods close to this value). The mean annual minimum and maximum temperature are 5.35 & 15.8 ^{o}c respectively. The estimated annual average relative humidity is 68.14 %. The wind speed at 2m heights is about 1.77 m/sec. The annual mean sunshine hours is estimated to be 7.9 hours a day. The average climatic values, the altitude of the catchment above sea level, and the geographic location of the catchment suggest that the area has humid tropical climatic condition.

EVAPOTRANSPIRATION: Based on the available data in the basin and around, the following results were obtained. The penman equation yields low value of potential evapotranspiration during the month of August and higher value in March which is respectively 79.3 and 126.47mm/month. The potential evapotranspiration of the basin is estimated to be 1328.91 mm/year. The potential evapotranspiration calculated by Thornthwaite method is 590.6 mm/years which very small with respect that calculated based on the Penman method. Almost the evapotranspiration obtained by Thornthwaite method is the reflection of the variation of the mean monthly temperature. The estimated average value of the two methods which is 959.81 mm/year taken for the Sululta catchment.

Based on the evapotranspiration values obtained by Thronthwaite method, the calculated actual evapotranspiration is 585.63 mm/year and the amount of water that the basin gains from surplus is 614.81mm/year. The value obtained by Turc method is 642 mm per year.

When the result obtained by these two methods compared, the potential as well as the actual evapotranspiration calculated by Thronthwaite method is smaller than that analyzed penman. Actual the values are close to each other and the average value is best represent the catchment.

RIVER DISCHARGE & RUNOFF DEPTH: In the study area both perennial and intermittent rivers and streams exist. Sibilu is the main river that discharges all the runoff from the catchment. The other streams are tributaries for this river and gauged at one point at the mouse of Sibilu River near Chancho town. During dry period their flows are very small when compared to the wet period of the year.

The data indicate that high mean discharge occurrence in the months of June, July, and August. It corresponds with the high concentration of rainfall occurring in that period as it is confirmed by the immediate correlation of rainfall and discharge.

The mean annual runoff depth throughout the Sululta catchment has been calculated by taking into account the mean annual discharge of the river and surface area of the catchment.
Runoff depth in the basin is 388mm. The value indicates the annual runoff depth of the Sululta basin, includes surface runoff and groundwater base flow. Using the graphic separation (tangent method) of the surface runoff and base flow of the two components used for analysis and showed that 54% (210mm) of the flow is contributed by base flow. Therefore, the mean annual surface runoff is 178 mm. There are various factors that control runoff; among them are soil infiltration capacity, physiography, vegetation, land use, climate, and soil type. Therefore, the south and eastern part pf the catchment are prone to high runoff than the central and western part of the catchment.

WATER BALANCE: The basic assumption that considered is the surface water divide coincides with the surface drainage basin. Therefore, other than the water that is percolated within the limit of the surface water divide, there is no inter-flow (inflow or out flow) of groundwater.
The basic equation of water balance is:

$$\text{Inflow} = \text{outflow} \pm \Delta S$$

The average value of the three methods considered fair to represent the AET of the catchment, and it is 684.82mm/year. The area has a total annual precipitation of 1200.13 mm, and an estimated overland flow of 178mm/year. Hence, the area's annual recharge value is 342 mm/year. When the value of annual base flow is subtracted 132mm/year depth of water is being added to the reservoir. This value is very important to categorize the groundwater development of the catchment exactly knowing the entire groundwater withdrawal per year.

8.2 Results from analysis of Hydrogeology

DISTRIBUTION OF LITHOLOGIES AND STRUCTURES: Based on the well log of different wells found in the catchment and the geology of the area, the major hydrostratigraphic units are slightly to highly fractured and weathered rhyolite and trachyte, slightly to highly fractured and weathered basalt, pyroclastic deposits (welded & unwelded tuff) and quaternary deposits (Alluvial material). In the central part of the catchment following the streamline thick weathered and fractured formation is identified as potential water bearing layer. It is obvious that the groundwater storage of the volcanic rocks is attributed to its primary and secondary hydro-structures. The structures include vesicles, joints (due to weathering, tectonic or cooling processes), lava tubes, and voids between successive flows.

ELECTRICAL RESISTIVITY SURVEY: To evaluate the stratigraphy to the required depth of about 120m at three fields namely Sululta town, Chancho and some specific points in western part of the catcment along Denba stream trace, it was decided to conduct electrical resistivity tests.

For groundwater investigation purposes, resistivity testing can provide information regarding lithology and can be correlated with borehole information. The result yield that the low resistive layers are more relate to fracture and weathered formation. Low resistive layer goes greater depth around Sululta and Chancho towns following the main fracture lines. In the west and eastern part the layer becomes thinner with increase in elevation.

PUMPING TEST AND WATER LEVEL: The boreholes drilled in central part of catchment have a discharge in the ranges of 2 to 4 l/sec. As the resistivity survey in the catchment indicates; most wells with partial penetration of the aquifer. The ranges of the transmissivity of wells in this zone are from 27.4 to 34 m^2/day (Chancho & Sululta wells) & mapped as high permeable zone. Upper recharge zone (around Intoto ridge) is classified as low permeability zone. The aquifer has moderate yield in the ranges of 0.5 to 1 l/sec. The pumping test result evaluation gave the transmissivity values about 1.12 to 4.49 m^2/day. The remaining areas in between these zones are moderate permeable zones. It has higher elevation than the lower central part of the catchment. The transmissivity estimated from Kajima well (17.6 m^2/day) and extrapolated for the rest zone based on the lithologic logs and qualitative interpretation. Water level decreases from 0.5m to 17m at the mouse of the catchment (Chancho-1 & 2) to Intoto (Weserbi –2).

GROUNDWATER FLOW: Groundwater flows underground until it reaches a discharge zone, an area where the water is above the land surface. Springs are clearly visible discharge zones. Groundwater flow in the study area follows the topography. Most flows are similar to the regional groundwater flow direction that almost parallel to the major fracture traces of the main streams. However, local flow directions at shallow depth are found in small sub-basin catchment due to local structure and local trend of the slope. The regional groundwater flow is north direction. While the local shallow groundwater flows are vary between NW & NE directions (similar to drainage direction).

8.3 RESULTS FROM THE ANALYSIS OF HYDROCHEMISTRY

The chemical composition of natural water is derived from many different sources of solutes, including gases and aerosols from the atmospheres, weathering and erosion of rocks and soils, solution and precipitation reactions occurring below the surface, and cultural effects resulting from the human activities.

The turbidity, the maximum value is for river/stream and unprotected springs (min 257 to Maximum 900NTU). Some hand-dug wells and sprigs also show objectionable values of turbidity in the range of 6 to 46 and 7 to 55 NTU respectively. Relative to other sources drilled wells have low value of turbidity expressed in NTU and ranges from nil to 5 to 21. The pH value of the samples ranges from 5.7 to 8.19. The lower value is measured for the spring water along the Intoto ridge, and the higher value is for Gometa hand dug well near Chancho town

THE WATER TEMPERATURE: To some extent the water samples collected near the Intoto ridges are less than 20 ^{0}c and the surface water and those found at relatively low elevation exhibit a bit higher temperature.

TOTAL DISSOLVED SOLID (TDS) & ELECTRICICAL CONDUCTIVITY (EC): The TDS obtained for the catchment is generally below 256mg/l and maximum EC is 540 microsiemens (μS). The value is below recommend and maximum recommend standards. For spring the TDS is below 100 mg/l and higher is for wells.

WATER TYPES: - The water is mainly Ca- Mg-HCO_3-CO3 and Ca- Na-HCO_3-CO3 water type. In most samples percentage of Ca^{2+}+Mg^{2+} is greater than Na^{+}+K^{+}.

HARDNESS: Most samples have more Ca^{++} + Mg^{++} so that also hardness of water is one factor of water quality. In general, it is relatively high for borehole and small for spring water. 68 % of the samples indicate hard & very hard water

REDOX POTENTIAL (EH): is generally positive nearby the recharge area and gradually decrease downstream part of the catchment.

IRRIGATION WATER QUALITY, SODIUM HAZARD & SODIUM ABSORPTION RATIO (SAR): SAR is computed for the rivers, springs, shallow and deep wells and the results show low SAR values well below 10. Na% calculation indicates the water is good for irrigation. These indicate low sodium hazard in which reduction in soil permeability and hardening of soil is not serious. Hence, the surface and ground water of the Sululta catchment can generally be considered as suitable for irrigation purpose with respect to sodium hazard.

NITRATE, FLUORIDE CONCENTRATION & BACTERIAL POLLUTION: - The average value of nitrate in the boreholes, springs, and hand dug wells, and rivers/streams is 14.59, 20.98, 6.49 & 7.13 mg/l respectively. Potential sources of nitrate include septic systems, animal waste, commercial fertilizer, and decaying organic matter. Fluoride is low and the minimum and maximum values are 0 to 0.8 mg/l. The source of bacteria is both related to the human and cattle population in the area. Hand dug well shows the bacterial pollution because of its shallow water table.

8.4 RESULTS FROM ANALYSIS OF WATER RESOURCE EVALUATION

The study catchment is in Abay basin separated by main divide line of Intoto ridge from Awash basin. Interflow of groundwater from adjacent basins to the study basin very insignificant. Most of the streams in the upper recharge zone have no flow during the months of January to May. In middle and lower most catchment even though the amount is small the groundwater feed the streams and sustain the river flow of the catchment.

The permeability of the soil condition is qualitatively identified and in hill slope areas the rocks are well-fractured and permitting infiltration than the plain areas covered with clay soil. Actually the slope is the main factor controlling infiltration than permeability because the boundary in southern and eastern part is highly slope.

The vertical electrical survey (VES) interpreted results, borehole log, pumping test and qualitative interpretation have indicated that the upper 3-20 meters in most part of the central plain area is potential for hand dug well and shallow groundwater. This same area is potential for borehole of maximum depth 120 following the main fracture zones. The boreholes well data confirms that the aquifer systems are thin alluvial deposits and thick weathered & fractured basaltic & welded tuff, hydraulically interconnected and moderate to high yielding. To the south of this area all along the Intoto foot hills, occur the fracture lineaments that favor recharge, and springs with discharge between 0.5 to 4 l/sec are out flowing condition.

The other streams are simply flowing by passing the plain of Sululta. Excess water from cattle demand is therefore has to be used for small-scale irrigation to increase the self-food sufficiency of the households in the vicinity.

At present condition the pollution from natural condition is low, example fluoride. However the test for nitrate even though below the maximum level addition to water sources show an increasing trend. Therefore, control of the different developmental process that could add this nutrient to the water sources need some improve.

CHAPTER NINE

9.CONCLUSION AND RECOMMENDATION

9.1 CONCLUSION

Sululta catchment (tributary of Abay basin) situated north of Intoto ridge has a total area of 480.80 km^2 and is characterized by flat plain in the central part to highly rugged topography in the southern and eastern part. Dense drainage density in upper part and low around the mouth with third order stream characterizes the catchment.

The Sululta basin comprises of volcanic rocks belonging to the Ashangi group of the trap series (southern and central part). The rocks of Shield group and Magdala groups are exposed to the west and east and extreme south boundary of the catchment respectively. Basaltic lava flows outcrops on most of the hills and the riverbeds and occurs as thick lava flow or as thin band intercalating with pyroclastic deposits. Trachytic lava flow is found exposed in the northern part of the area covered by rhyolitic rock unit. Rhyolitic lava flow is exposed at the top and foot of Intoto ridge. The outcrop is very visible at the road cut and highly eroded stream cut places. Pyroclastic deposits is found exposed intercalated the basaltic rock at Ochi & Asere ridge. This rock unit is highly friable. It composed of tuff, agglomerate and locally scoria. Qutaternary deposits includes residual soils, alluvial and colluvial deposits. The residual (elluvial) deposits ranging in size from silt to clay are observed in the western and southern part of the catchment. They are formed from the weathering of trachyte and basalt.

The effective annual depth of precipitation in the study area is calculated by using thee methods (arithmetic, theiessen polygon, and isohyetal) and the result is given by the intermediate value which is obtained by Theissen polygon. Thus, the annual precipitation in the basin is 1201.31 mm. The mean annual minimum and maximum temperature are 5.35 & 15.8 ^{o}c respectively. The estimated annual average relative humidity is 68.14 %. The wind speed at 2m heights is about 1.77 m/sec. The annual mean sunshine hours is estimated to be 7.9 hours a day. With this precipitation the annual actual evapotranspiration (AET) is estimated 684.82mm. The annual groundwater recharge is 132mm which is about 11 % of the total annual rainfall.

The predominant aquifer is weathered and/or fractured basaltic lava flow. Central part has alluvial deposit on the top of these formations. Thin intercalation of pyroclastic aquifer layer found intercalated the main aquifer of the catchment. In upper most part of the catchment, however, acidic lava flow (Ryholite and tuff) is the main aquifer. Groundwater potential of the catchment is more localized along fractured and weathered part of the rocks.

Based on the aquifer characteristics comparison from hydrogeological point of view, three hydrostatic units are mapped. Highly permeable, moderately and low permeable with some impermeable layer is the zones mapped in the catchment. Highly permeable layer (transmisivity greater than 27.4 m^2/day and 2 to 4 l/sec) cover the central part along the stream fracture lines. The low permeable aquifer (transmissivity values about 1.12 to 4.49 m^2/day & aquifer has yield in the ranges of 0.5 to 1 l/sec) is the one covered by acidic lava flow around Intoto ridge. The transmissivity value in between these is mapped as moderate permeable zone & covers areas surrounding the highly permeable zone.

The resistivity survey carried in the catchment show the depth of ground goes to a depth of 120 meters. Indicate partial penetration of aquifer which can affect the yield of wells.

Recharge areas for the basin are those elevated areas starting from Intoto and found at different locations within in the central, eastern and western part of the catchment. Although infiltration is not high in the thickly clay covered areas, the plain area are both recharge and discharge zone. Based on the successive location of springs, borehole yields and aquifer type (unconfined condition) groundwater flow is generally following the topography to the north (mouse of the catchment).

Analysis of the hydrochemistry of different water sources show that the total dissolved solid is generally less than 256 mg/l and most water is mainly Ca- Mg-HCO_3-CO3 and Ca- Na-HCO_3-CO3 water type. In most samples percentage of Ca^{2+}+Mg^{2+} is greater than Na^{+}+K^{+}.

Concerning water quality, except for turbidity, color and bacteria the rest parameters are within the limit of acceptable value of WHO (World Health Organization) water quality standards for water supply, irrigation and industries excluding trace elements which is not fully analyzed for all of them in this study. Since the catchment is now free of industry and irrigation, there is no detected pollutant for surface and groundwater.

9.2 RECOMMENDATIONS

- Surface runoff in the catchment erodes soils from elevated and rugged areas move together with the flood. This condition reduces water infiltration into the ground. The soil profile is deceases. Therefore, soil and water conservation program should be promoted in the high topographic areas.
- Fast land cover change is occurring in converting most of the grass and cultivated land to industrial. This activity reduces the groundwater infiltration. Therefore, attention has to given to the water resources protection of the area.
- Groundwater evaluation of the catchment requires fear distribution of wells and fully penetration of aquifer.
- Better aquifer location should be done by integrating different methods which include, structures, qualitative interpretation of lithology and well log data, resistivity survey, and hydrometrological data.
- Most potential groundwater is found along the major fracture lines following the streams. Site location in the catchment needs better understanding of fractured area.
- In order to reduce groundwater interference as well as depletion, control on the exploitation of groundwater. This is going on near Sululta town by different private company.
- Reduce planting of such deep-rooted trees that creates the groundwater depletion. Especial attention near spring eyes where water table is very shallow (Intoto ridge).
- Small scale and/or traditional irrigation practice has to get attention in order to bring food sufficiency particularly in the catchment and generally in the wereda.
- Reduce and control fertilizer use and different agricultural inputs to minimize the nitrate in water sources. Now the limit of nitrate is below maximum permissible value but increases with time.

- Reduce septic tanks number, avoid leaky tanks or connect with sewer lines to minimize the stress on the water sources (shallow groundwater and surface water). The awareness at community level and the sectoral attention is required.
- Surface water and shallow water tables are not potable due high coliform bacteria. Therefore,
- Disinfection of hand-dug wells
- Well head protections
- Avoid the flash and damp of waste to the surface water and well head of the wells
- Control on the different waste producing industries in the catchment
- Giving awareness developing training for communities and individual users on the water pollution and water quality.

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