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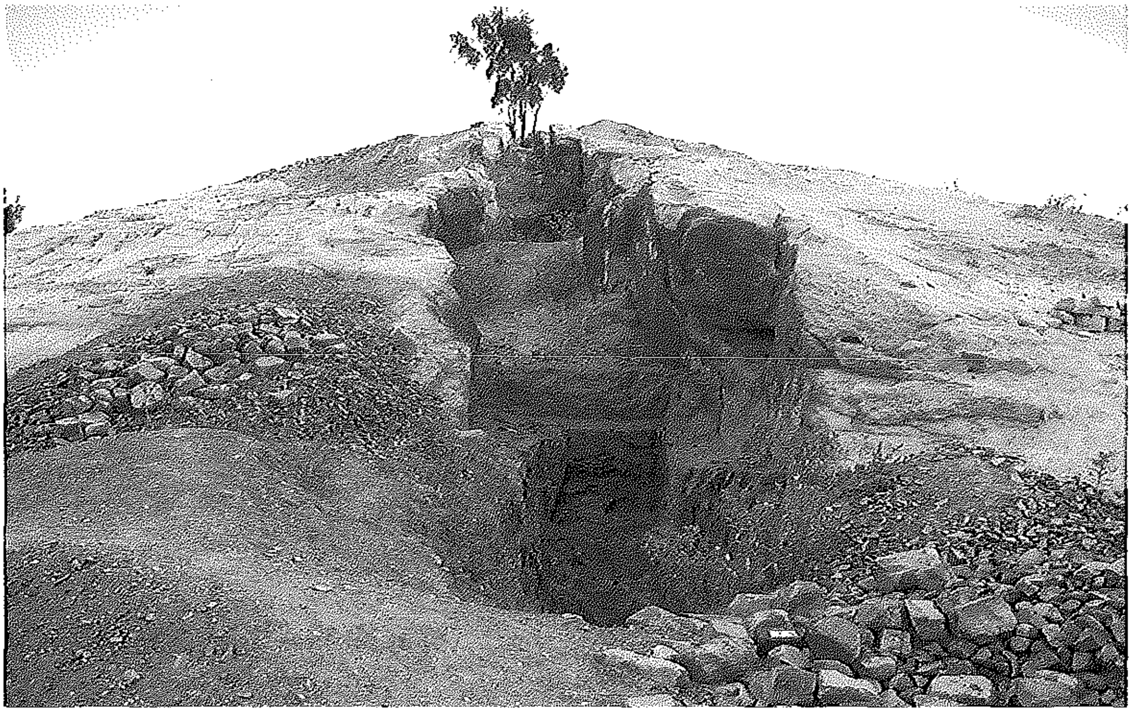
DEPARTMENT OF EARTH SCINCES

GROUNDWATER POTENTIAL EVALUATION OF UPPER SULUH VALLEY EASTERN TIGRAY, NORTHERN ETHIOPIA

BY

FETHANGEST W/MARIYAM



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ABSTRACT

Water resources potential evaluation of Upper suluh river basin which is located north of Addis Ababa and south of the town of Adigrate town. The evaluation is done based on the analysis of hydromorphometric meteorological, hydrogeological and river flow data. The has a total area of 443 km^2 with a big difference of altitude ranging from 2100 m to 3100 m above mean sea level and is the sub basin of River Tekeze. It has both low land with flat to gentle slope and rugged topography along its peripheral area with dominant sedimentary terrain. The low land area of the basin is covered with alluvial and Enticho sand stone. NNW-SSE and NE-SW structures dominate in the basin especially in the north and northeastern part of the study area.

The analysis result of different hydrormphic parameters overlaps with the geology and hydrogeology which indicates that the North -Eastern ,East-Central and limited part of west central part of the is the potential zone for ground water exploitation.

From long term mean monthly rainfall data annual precipitation of the basin is calculated as 722.32 mm per annum. The actual and potential evapotranspiraation for the basin are 652.63 mm and 808.3 mm respectively. Of the total rainfall, 20.1 million cubic meter (MCM) water leave the basin in the form of surface runoff per annum and 11.1 million cubic meter (MCM) water infiltrate within the basin, which is the annual recharge of the basin. The ground water potential estimation of the considering 25%of the total area for areas having slope of >20% is 336.54 MCM.

Based on the permeability of the rocks the is divided in to three hydrogeology groups higher permeability (1.76m/d), moderate to lower permeability (1.76-0.09m/d) and very low permeability group (<0.09m/d). For ground water exploitation, the alluvial deposit and the Enticho sand stone area are the best potential sites.

The hydrochemistry of the basin is also analyzed and categorized in to fresh water. Boreholes, hand dug wells and common springs are Ca-Mg-HCO_3 water type but two borehole samples show Na-HCO_3 water type assumed to have localized dolerite influence. Concerning water quality, the basin has no any water sources having values of parameters above the permissible limit for water supply, irrigation and industries. With respect to irrigation the quality of ground water in the is excellent to good. Presently, there is no ground water pollution indicated from agriculture, industry and towns.

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CHAPTER ONE
INTRODUCTION

1.1. BACKGROUND TO THE PROBLEM

Ethiopia in general and Tigray region in particular is suffering from chronic famine, rapid population growth and land degradation. The famine is mainly associated with uneven rainfall distribution.

Since groundwater supplies are less correlated with rainfall than surface supplies, one of groundwater's key functions can be its ability to mitigate the effect of erratic rainfall or drought on agricultural production and domestic water supplies. However, due to the nature of the terrain, the hydrogeological environment and distribution of rainfall, there is a considerable variation in the groundwater potential available for development.

Therefore, the purpose of this research is to study the groundwater potential of the study area with respect to various parameters such as geology and structure, geomorphology, hydrogeology and geochemistry.

1.2. PREVIOUS STUDIES

Due to various reasons the hydrogeology of the region has not been well studied except certain studies limited in number and localized in the main towns. There have been only some regional hydrogeological studies, which included the upper Suluh at a scale of 1:250,000.

Some such hydrogeological studies in the Suluh include the work of Tesfaye Chernet (1973), NEDCO (1997) and WAPCOS (2002). The work of Tesfaye Chernet (1973) was a preliminary report on the hydrogeology of the Suluh cachtement. The purpose of the study was for agricultural development.

The Tekeze river basin integrated development master plan project (1997) conducted by Netherlands Engineering consultants reported that the tectonic and stratigrphic history of Tekeze basin has produced a complicated geophysical environment and a complex groundwater region.

Another significant work was the Suluh Integrated Rural, Agricultural and Water Resources Development Study by WAPCOS (2002). The main purpose of the study was to assess the water resource of the area for irrigation, hydropower and other uses. This work concluded that the major aquifer formations with higher fracture hydraulic conductivity are Enticho Sandstone, Adigrat sandstone, and fractured metamorphic rocks and intrusive.

Despite their objectives, both investigations are conducted at preliminary level and serve only as bases for further detailed investigations. In addition, the estimation of the groundwater recharge made by Tesfaye Chernet (1973) is assumed. At the same time the later work has adopted the recharge estimation from the Ethiopian hydrogeological map by (1988). However, the estimation method used by the Tesfaye Chernet (1988) was applied to get an insight about the amount of recharge in the regional context, which is less worth to apply in such a small basin. Moreover the estimation method did not consider the variation of recharge within the same catchments from one locality to another depending on the topography, soil cover, vegetation cover, the rock type and intensity of rainfall at each location. Therefore, the recharge value which is estimated by the above method needs to be verified and updated taking into account all variations in the study area to find a reliable recharge estimate and exploitable potential of the area.

1.3 OBJECTIVE AND SCOPE OF THE STUDY

The main objective of the present work is directed to understand the aquifer system, to evaluate the hydraulic parameters, to quantify the amount of recharge, to assess the amount of the groundwater reserve, carry out the hydrochemicals evaluation and zone the groundwater prospective zones.

Specific Objectives

- To produce hydrogeological map and other supporting maps of the project area at a scale of 1:50,000;
- To understand the infiltration and groundwater recharge condition of the area using morphmetric parameters and correlate the result with hydraulic property of the rocks to delineate the groundwater potential zone.
- To determine the source and amount of the recharge to the aquifer;
- To determine the amount and location of the discharge from the aquifer;
- To evaluate the hydraulic parameters of the aquifer system and characterize the rock units of the project area;
- Determine the groundwater flow direction;
- To determine the quality of the water in the aquifer systems.

1.4 METHEDOLOGY

To achieve the general and specific objectives, the following office and field methods were implemented.

Office Work

- Collection of hydrometerological data from respective institutions and determine the different input parameters of the water balance.
- To understand the morphometry the basin was sub-divide in to sub basins and the order, stream length, area and perimeter of each sub basin was measured. The morph metric parameters of each sub basin were calculated. Based on the calculated parameters maps are developed using index numbers to indicate different hydrological property.
- The existing pump test data together with relevant empirical formulas were used to evaluate the hydraulic conductivity of the different rock units and classify into hydrogeological groups.
- Determine the groundwater flow direction and the recharge - discharge localities of the basin using groundwater level measurements.

CHAPTER TWO
GENERAL OVER VIEW OF THE STUDY AREA

2.1. LOCATION AND ACCESSIBILITY

The upper Suluh is located in Tigray region in the northern part of the country, about 998 km north of Addis Ababa. It is bounded by the grid 1539836mN to 1572495mN and 535912mE to 565675mE UTM zone of 37N. It covers a total area of 443km^2 (Figure2.1). The area is accessible by the partially asphalt Addis Ababa-Adigrat main road. Toward village towns it is accessible by all weather road but towards specific locations the area is more or less accessible by dry weather road.

2.2. CLIMATE

The climate of the area is semiarid with main annual rainfall ranging from 500mm around Wukro to 800 mm around Sinkata. The long term mean annual rainfall (1960 – 1998) is about 551mm. Exceptional high rainfall of 1110 mm occurred in 1996 with lowest 290 mm in 1984. Rainfall occurs in the months of June through September with about 70% falling in July and August. Monthly mean temperature ranges from about 8.4^{0}C in December to 27.2^{0}C in June. The relative humidity varies from about 52% in May to 83% in August.

2.3. TOPOGRAPHY AND DRAINAGE

The area comprises severely eroded, high altitude mountain ranges (2200 – 3300m) with dissected high plateaus (2000 – 2600m) and eroded medium to high altitude foot slopes and piedmont plains (1800 – 2400m). The dissected high plateaus are developed on sandstone, shale and volcanic rocks traversed by faults, fractures and lineaments.

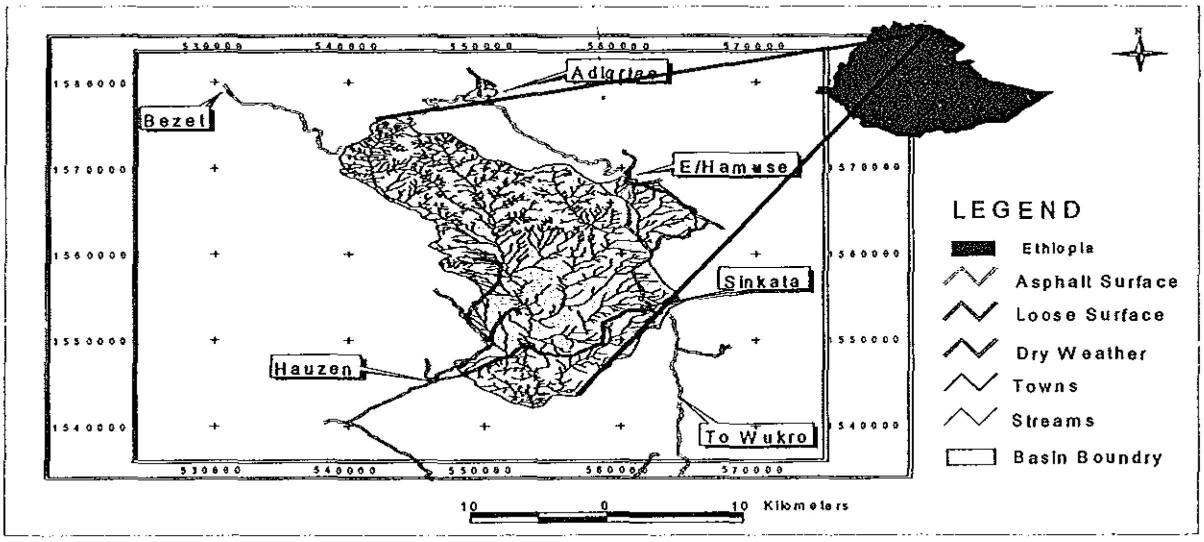
2.4. SOIL COVER

As per the field observation more than 85% of the upper Suluh area is covered by sand y soil having the parent material the Sandstone. The thickness varies from 0.15 to 0.5m. It is thick at the riverside and mountain foot. Soils are thick at lower elevation especially near streams where they are estimated up to 8m and are richer in inorganic material. There are small patches of black soil with limited aerial extent but mostly thicker than the dominant sandy soil.

2.5. LAND COVER

In the area people depend for their livelihood on farming. Therefore, the main activity in the area is farming using traditional methods. Due to this the main land use of the area like many underdeveloped regions and countries is extensive farming. That is according to the WAPCOS (2002) report except for the very steep slopes most of the area is under cultivation of cereal crops. Major crops growing in the are, Teff, Maize, Potato, Barley, Wheat, millet and others. Thorn bushes and cactus grow in drier areas, while big trees with broader leaves such as eucalyptus and fig, grow around water points or where the water points is close to the surface. Savanna grass is quite abundant, and is especially associated with black soils.

Figure 2.1. Location map of Upper Suluh .



CHAPTER THREE

GEOLOGY

3.1 REGIONAL GEOLOGY

The regional strtigraphic sequence from the oldest to the youngest is represented by the Basement Complex, Paleozoic-Mesozoic Sedimentary rocks, Cenozoic Volcanics and Recent Sediments (Levitte, 1970).

Rock assemblages covering a wide geologic time span characterize the Tigrai region. Upper Proterozoic, low-grade, extensively folded, non-homogeneous metavolcanics and metasediments dominate the eastern and western extremities of this region (Garland, 1980; Asefawosen Asrat et al., 2001). In a few locations, these crystalline basement rocks are covered by the Edaga Arbi Glacials of Permo-Carboniferous age (Garland, 1980). The northern and north central part is represented by the Enticho sandstone (Permo-carboniferous) and Adigrat (Triassic–Middle Jurassic) sandstones. There is also an overlying thick succession of Tertiary Trap basalts. The southern and south-central parts are represented by the Antalo Succession (Upper Jurassic) and an upper sandstone unit, the Ambaradam Formation (probably Early Cretaceous). Which has been preserved under the Tertiary basalts (Bosellini et al., 1997). The stratigraphy of central and eastern Tigray is summarized in, and the major sedimentary units that are of interest are described in some detail below.

3.1.1 The Basement Complex

The Basement Complex is represented by the juvenile Arabian Nubian Shield materials represented by thick sequences of low-grade (generally green schist facies) metavolcanics (the Tsaliet Group) and metasediments (the Tambien Group) (Asfawosen Asrat et al., 2001). This terrain is dominantly characterized by steeply dipping and extensively folded, low-grade metamorphic rocks intruded by various granitic and mafic intrusions. The metamorphic sequence in the Mekele–Adigrat area is composed dominantly of heterogeneous metavolcanics (breccias, agglomerates, bedded tuffs and lavas) all inter-bedded with subordinate marine clastics, rare limestones, tuffaceous slates, redeposit ash, and greywacke composed partly of volcanic fragments, exhibiting considerable lateral variations. The sequence, with a thickness reaching up to 2500 m in some sections, is metamorphosed to green schist facies except in contact aureoles of plutons. There is regional foliations oriented N–S to NNE–SSW direction. Felsic plutonism of variable age and lithology is a characteristic feature of this metamorphic terrain where syn-tectonic, late- and post-tectonic granitoids have been identified.

3.1.2. The Sedimentary Sequence

Asfawosen Asrat (2001) has described the general stratigraphy of the region with particular interest to the Rock hewn of the region this method of description of the stratigrahpic sequence is adopted for this work.

3.1.2.1. The Enticho Sandstone

The Enticho Sandstone takes its name from the town of Enticho in northern Ethiopia. It is a yellow to white, fine- to coarse-grained, massive to well bedded, and finely to coarsely cross-bedded calcareous sandstone with silty beds and some ferruginous layers. It is also friable and kaolinitic and contains polymict conglomerates with granite boulders (Garland, 1980) cited in Asrat, (2001). In the Tigrai region, the thickness of the Enticho Sandstone ranges from 150 m in the south to 300 m in the north (Beyth,1971). Enticho Sandstone either lies unconformably over a crystalline basement or inter fingers with the Edaga Arbi Glacials. It forms low hills dissected by deep canyons and, in some cases, buttes.

3.1.2.2 The Adigrat Sandstone

The Adigrat Sandstone was named for the town of Adigrat in northern Ethiopia by Blandford (1870). The sandstone is gray or red, fine to coarse-grained, well sorted, friable, cross-bedded, and very mature (quartz arenite). Bioturbation is common in the upper part of the section where several red, ferruginous laterite beds occur. Adigrat Sandstone has a maximum thickness of about 700 m in the Abi Adi area (Bosellini et al., 1997), but it is 300–650 m thick in other localities (Beyth, 1971; Garland, 1980). It lies unconformably over Enticho Sandstone or a crystalline basement and forms steep cliffs. Adigrat Sandstone was deposited over peneplained crystalline basement partly as a product of several erosional cycles and partly by the reworking of underlying Upper Palaeozoic glacio-fluvial rocks. Abundant laterite beds, point bar sequences, and fossil woods in the Adigrat Sandstone indicate a clear fluviatile origin, and the great thickness and abrupt changes over short distances suggest deposition in a piedmont area or in some intermountain basin.

3.1.2.3 The Antalo Succession

The Antalo Succession comprises the Agula Shale and Antalo Limestone. The Agula Shale (type section at Agula village) consists of variegated shale, marl, and clay interlaminated with finely crystalline black limestone and some thin beds of gypsum and dolomite. It has a maximum thickness of 250m (Beyth, 1971; Garland, 1980; Bosellini et al., 1997), conformably overlies Antalo Limestone, and forms wide terraced slopes.The Antalo Limestone (type section at Antalo Village, southern Tigray) consists of white (and rarely black) limestone, finely crystalline to lithographic, well-bedded, fossiliferrous, typically well-indurated, and interbedded with yellow marl and sandy limestone. It has a maximum thickness of 700 m (Beyth, 1971). Antalo Limestone conformably overlies Adigrat Sandstone and forms steep cliffs and gradual terraced slopes

3.1.2.4. The Ambaradam Formation

The Ambaradam Formation (named for a mountain in southern Tigray), or the "Upper Sandstone," is the youngest sedimentary unit in the Mekele Outlier. It consists of white to pink, medium to coarse-grained, immature, clastic sandstone interbedded with silt, shale, mudstone, laterite beds and quartz conglomerate lenses (Beyth, 1971; Bosellini et al., 1997).

3.1.3 Trap Volcanics

The trap volcanics form some ridges in the Mekele outlier, with up to 200m thickness, while it reaches a thickness of 600m on the Adigrat ridge. It reaches a maximum thickness of 2800 meters in the Simien Mountains further South (Mont, 1962 cited in Beyth, 1972).

According to Beyth (1972) the hypabyssal intrusion dykes and the Mekele Dolerite sills, which are common in the area, are of the same magmatic phase with the Trap basalt. The Mekele dolerites are black andesitic dolerites with ophatic texture, characterized on weathering by rounded exfoliated boulders. The trap basalts, on the other hand, are black olivine basalts, subophatic to intergranular in texture, occurring in numerous flows with well developed columnar jointing, which in many places have concentrations of white zeolite.

3.2. REGIONAL STRUCTURE

The dominant structure in the region is the fault of different age and system (Beyth, 1970). Fault of the basement complexes are the oldest and were active in the Precambrian. They are steeply dipping and strike north- north -East, parallel to the strike of the meta sediment and met.volcanic rocks of the area. Most of them are reveres faults.

The other next prominent structure in the region is the parallel faults that displace the mesozic sediments. They are oriented West-North-West direction this includes the Wukro, Mekele, Chelokot and Fusia Mariam located from north to south of Mekele and they are parallel to each other. They are characterized by normal faults, dip at moderate to steep slope angle and the presence of dolerite dykes along the fault zone.

The third, and by far the largest fault system, belongs to the African rift, a system of predominantly normal step faults. It forms the escarpment and the Danakil depression. The faults of this system have been active from the Tertiary to recent and strike North-South to

Northeast. These normal faults generally dip to the east with a total throw of more than 3000m over a horizontal distance of less than 50 km. The system in general is formed of numerous normal faults with steep planes, forming grabens and tilted blocks.

3.3. LOCAL GEOLOGY

Lithology units exposed within the study area (upper Suluh) from bottom to top are: Tsaliet Metavolcanics, Enticho Sandstone, Edaga Arbi Glacials, Adigrat Formation, Lower Basaltic Unit, Upper Basaltic Unit, and Alluviall Sediments. Several dolerite dykes and sills cut across many of the lithologies (see Figure 3.1 Geological Map). Table 3.1 summarizes the percentage area coverage of the various mappable lithologic units.

Table 3.1 Aerial distribution of mappable units in the study area.

Lithologic unit	Aerial coverage of each lithology in Km^2	Percentage of coverage of each unit
Alluvial Sediments	4.42	1.0
Upper Basaltic Unit	4.86	1.1
Lower Basaltic Unit	56.13	12.7
Adigrat Formation	54.81	12.4
Edaga Arbi Glacials	35.80	8.1
Enticho Sandstone	243.10	55.0
Tsaliet Metavolcanics	42.43	9.6

3.2.1 TSALIET METAVOLCANIC

This unit of rock is found exposed on the south and south central part of the study area along the Suluh main stream. The acid metavolcanics and greenshist rocks are mainly found exposed unconformable below the Enticho sandstone.

The acid metevolcanic found exposed around Kertse at UTM (0553396,1558546) and along the Suluh main stream where the rain gauge station is located is mostly show greenish and /or

pale red shading. In most cases the rock appear massive with out recognizable bedding or very faint bedding. It completely grades into silica composed rock which has in the field the appearance of red to green flint due to the silica and alkali feldspar composition.
At the Suluh main stream near the bridge slight vertical jointed and fractured oriented 40^0NE and 35^0 NW observed.

As observed in the field it is fine to medium grained, slightly jointed and fractured, less weathered and compact, showing augean like structure and follow structure; they are also dissected by quartz stringers with different orientation. At the south tip part of the study area a greenish schist rock of slate which shows slight lineation and jointing are observed but it has no significant aerial coverage.

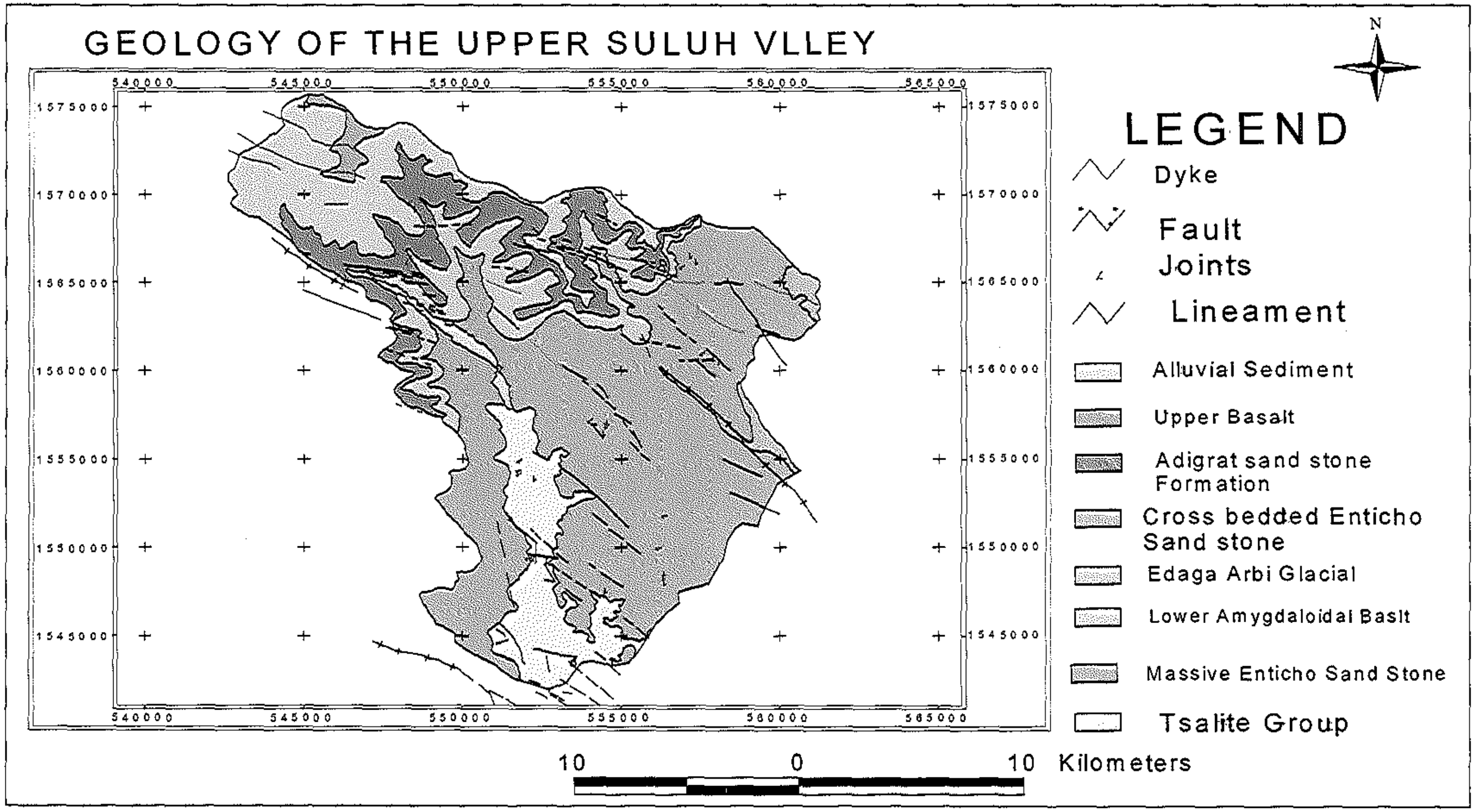
3.2.2 ENTICHO SANDSTONE FORMATION

This unit is found exposed in the flat laying central and eastern part of the study area including east and south -east part around the towns of Edagahamus and Sinkata. In general it is yellow to white in color, medium to coarse, that contains lenses of polymict conglomerate with well- rounded boulders of metamorphic and granite rock. It is horizontally bedded except near the fault zones that dip. It decreases its thickness towards the town of Hauzen down streams where the contact between the basements is exposed. In general thickness of this rock unit ranges from 50 to 100m with in the study area. This unit varies in grain size, type of cementing material and degree of cementation, bed thickness, nature of X-bedding as a result it is divide into two mapable units. These are called massive and Cross-bedded Enticho Sandstone. The massive Enticho sandstone is dominantly yellowish in color, coarsely cross-bedded, less cemented with calcareous and kaolinite type of cementing material, relatively coarse grained.

This unit is characterized by angular poorly sorted grains of quartz and lenses of conglomerate, pebbles and large granites boulders common around Edagahamuse that shows feature of glacio-fluvial deposit according to Garland, (1980). It is the dominant lithology of the area covering more than half.

The cross- bedded Enticho sandstone found exposed on the East and South- East part of the study area. It shows good exposure; with steeply bedding beds particularly in the fault affected areas and contains big fissures. It is fine to medium grained, dominantly dark brown color, finely cross bedded, with increased proportion of Fe-containing cementing material and relatively well cemented and bedded, mostly cliff forming, found mostly exposed N-E of the town of Edagahamuse and East of Sinkata town. It varies in thickness from 20-80 m and has aerial coverage of 1.5%of the study area .

Figure 3.1 Geological Map of the Upper Suluh



3.2.3 EDAGA ARBI GLACIALS

As described in Leveti,(1970) the Edaga Arbi Glacials inter fingurs with Enticho Sandstone. However, in the study area the two units are clearly exposed and the Enticho Sandstone falls below the Glacial Tillit due to this reason they are described as separate units. This unit is found in the study area immediately below the Adigrate sandstone cliff forming gently slopping morphology with dens drainage pattern. In general the unit is composed of silt and shale material that vary in color, lamination and contents of eratics such as pebble and boulders.

The upper part of the unit immediately below the Adigrate sandstone of this unit is observed as finely laminated thick layer of red and greenish shale and greenish gray shale inter bedded with thin beds of silty limestone that varies in thickness between few meters to 100m thick. The lowest part of the unit is of massive dark greenish -gray shale and dark gray tillite at the base, Which consist of pebbles and boulders of metamorphic and granite respectively. They are found exposed at the hillside and river gullies.

3.2.4. ADIGRAT FORMATION

It is found exposed in the northern part of the study area, it can be easily identified from distance by its steep cliff nature immediately below the volcanic series separating the sedimentary sequence. In the study area it is generally characterized by its horizontal bedding nature and the presence of tight and open vertical joints in it, and reaches maximum thickness of about 120m. It is frequently cross- bedded, with lenses of red silt, conglomerate and beds of latterite beds up to ten meter thick.

In general it is characterized by yellowish to pink in color fine to medium grained, non-calcareous quartz sandstone with well sorted, rounded grains with reddish weathering surface color. The common fractures and joints found in this formation generally strike in three direction. These are N-S striking joints having 60^0 dips towards East, E-W striking fractures having vertical joints, with 20-50 frequent aperture (fracture openings) with fair length and estimated 1-2cm spacing (see plate-4). The third common set of fractures and joints found in the formation strikes in the NW-SE direction, dips 80^0 towards NW; fracture spacing 50-80cm, with fracture openings up to 10mm having fair continuity.

3.2.4 LOWER BASLTIC UNIT

It forms a distinctive terraced topographic, composed of a series of basaltic flows, and break down in to a very dark rich soils. It is found in the higher relief part of the study area. The lower basalts, which have much interbeded pyroclastic material, and are intruded and overlapped by amygdaloidal columnar basalts, the amygdaloidal being in filled with chlorite and zeolites (Levitte, 1970).

It is also observed that this unit is relatively highly weathered and fractured forming basaltic core stone lithified by clay weathering product (see plate-4). Like the upper unit latter coming parallel dykes dissect it, which strike nearly in E-W direction and run long distances even out of the study area.

3.2.6 UPPER BASALTIC UNIT

This unit covers the northern tip of the study area forming the ridges of Akad, Dibehe, Bahira and Debre Me'ar. It forms steep cliffs capping the underlying rock units. The unit is represented by intercalations of trachytes, trachy-basalts and basalts, where the basalts are dominant in proportion. At places, the various beds are separated by fine-grained, reddish soil (paleosol). The aphyric, dark gray basalts are vertically jointed along the general columnar jointing direction. When moderately weathered, they form colluvial (fan) deposits at the foot of the ridges.

3.2.7 ALLUVIAL SEDIMENTS

In the study area recent sediment deposits including alluvial deposit, talus, colluvial material, residual soil and few land-slid masses are observed in different parts. Alluvial deposits, commonly found along River Suluh and its main tributaries, are composed of silty sand, silty clay and gravelly sand beds of up to about 3.8m thickness. They are mapped at the bottom of the Adigrat formation and the Tertary Basalts (e.g. at the foot of Debre Abay and Mugulat ridges; see plates 3 and 4). Although totally cover 1% of the study area, the alluvial sediments are found distributed in small pockets all over the study area.

3.2.8 DOLERITE DYKES AND SILLS

Although not map able it is described as separate due to its significance in the hydrogeology of the study area.Dyke formation as an effect of compressional stress and like sub axial splitting or tension (or pressure relief perpendicular to the maximum stress direction, show open up fractures in the crust, deep enough to reach regions with molten rock. It is evident that dike formation means tension acting perpendicular to the direction in the crust.

As explained in the regional structure regional tensional forces affect the area. Therefore, the dykes of the study area are the results of the regional structural effects. The dykes are mostly dolerite type found exposed in different parts of the study area particularly in the north part of the study area forming swarms of dikes around Edagahmuse. The dykes are found cross cutting the whole sequence of the lithologic succession of the study area. They run long distances greater than 10km with varying thickness from less than a meter to 3-4m thick in the E-W and NW-SE direction. As interpreted from aerial photo and field observation most of the dykes run across the direction of streams.

In general they are dark greenish to gray to grayish green in color, jointed and break into conical fragments along the joint the joint pattern. They are also less weathered and in general vary in width from less than 2m to about 6m. They extend along strike for a distance of less than kilometer to greater than tens of kilometers.

3.3 STRUCTURES

The prominent structures and lineaments observed in the area include faults, joints and bedding foliation.

3.3.1 JOINTS AND FRUCTURES

Joints and fractures are the most abundant structural features in the area. The density, orientation, spacing aperture and continuity in the different rocks lithologies available is considered. The result of the different measurements taken from WAPCOS, 2002) , Tesfaye Chernet, (1973) checked by field measurement is tabulated below.

Table 3.2 Structural Features in Enticho Sandstone

Joint set	Strike	Dip	Spacing	Aperture	Continuity
1	N-S	Vertical	50cm to 1m	10-20 mm	Long
2	E-W	Vertical	2-4 m	20 mm	Long
3	NE-SW	60° to SE	50cm – 80cm	Filled open up to 10mm	Long
4	NW-SE	Vertical	1m in general	10 mm	Long

Source: Table taken from WAPCOS,(2002) but checked by field measurements and observations

Table 3.3 Structural Features in Adigrat Sandstone

Joint set	Strike	Dip	Spacing	Aperture	Continuity
1	N-S	60° to East	30-60cm	15mm	Long
2	E-W	Vertical	1-2cm	20-50 mm	Fair
3	NW-SE	80° to NW	50-80cm	10mm	Fair

Source: Table taken from WAPCOS, (2002) but checked by some field measurements and observations

Table 3.4 Structural Features in Tsaliet Metavolcanics

Joint set	Strike	Dip	Spacing	Aperture	Continuity
1	E-W	50° to S or N vertical	30-50cm	10 mm or tight	Long
2	NW-SE	45° to NE	50-80cm	20 mm	-
3	N-S	Vertical	10-20cm	20-30 mm	Long
4	NE-SW	50° to SE	30-50cm	5-10 mm	-

Source: Table taken from WAPCOS, (2002) but checked by some field measurements and observations.

As observed from the table the different rock is affected by more than three sets of joints. Most of the joints in the Paleozoic and Mesozoic sediments are open that penetrates deep into the subsurface. Joints that strike E-W and NW-SE are dominantly open but some times they may filled filled up with dykes. The open joints with out dyke fill are stained due to water action or filled with ferruginous hard crusty material.

3.3.2 FAULT

Two prominent faults are recognized in the area. These area the fault line of Sinkata and Debre aby area at the water shad boundary Northwest part of the of the study. The Sinkata area fault is easily recognizable fault both from the aerial photo and field observation i.e. it is easily recognized by the presence of spring lines and the exposure of the slate below the Enticho sandstone on the up thrown side of the normal fault. This is typically observed at the bridge near to Maymegelta Village at UTM (0559026, 1560253). The fault is trending NW-SE direction with the rocks dipping 30^0 toward SW and forms discontinuity on the Enticho Sandstone.

According to Garland, (1980) this fault belongs to the Mesozoic age characterized with small vertical displacement with open fracture and some times feed with basaltic dykes. So, the joints and the normal faults of the study area belong to the same age formed by the tensional forces. The second largest fault recognized in the area is the fault around Debre abay near the water shade boundary having similar trend and nature of faulting, forming vertical steep cliff.

3.3.3 BEDDING AND FOLIATION

The metvolcanic rocks, which are found, exposed in the study area show some foliation which strike NNE-SSW to NE-SW with steep to moderate dips towards NW direction. The foliation forms the main structural controls for the course of the river Suluh for the south part of its stretch. The Paleozoic-Mesozoic rock to bedding is generally horizontal. But near the major fault features the bedding are strongly dipping tilted. The other important bedding feature is the inter flow bedding and paloeosoil observed on the upper and lower basaltic units.

CHAPTER FOUR
HYDROGEOMORPHOLOGY

Water shades are some of the classics in the field of topography. A water shade, defined as the area receiving water from a particular set of channels, is the most convenient unit for the study of geomorphology and hydrology. It has long been realized that catchment geomorphology relation ships can be used as predictors of cachtement flood properties. Stream flow depends upon those factors that determine the amount of rainfall excess and those which influence length of time for rainfall to travel through the basin. Rainfall excess is determined primiarily by climate, vegetation, infiltration capacity, and surface storage. Geomorphic factors such as stream lengths, basin shape and ground slope as well as geologic characteristics such as rock type and structures influence runoff intensity and discharge. Drainage density and bifurcation ratio affect discharge, as closely spaced, numerous tributaries would result in rapid runoff and probably a large volume of flow. Longer stream length would mean a longer lag from time of onset of the rainfall excess to flood peak. However, as all these factors are hard to isolate and relate to any particular parameter in a qualitative way, quantitative analysis must be carried out.

In this chapter, various morphmetric parameters of the upper Suluh water shade are analyzed and their hydrological significance is discussed. For a better understanding of the quantitative features of the drainage basin and its channel network have been subdivided into linear aspect of the channel system, and the aerial aspect of the drainage basin will be treated separately.

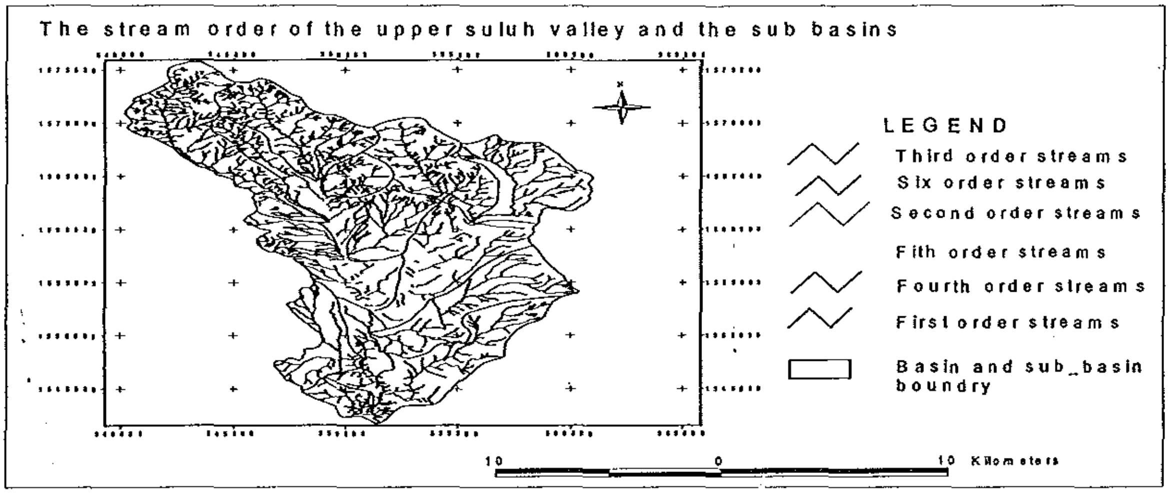
4.1 SUB BASINS OF THE UPPER SULUH WATERSHADE

As division of a water shade into sub basins allows morphmetric study to be carried out at a micro level scale, the water shade of the upper Suluh is divided into 14 sub basins. All the morphmetric parameters have been calculated for each of the sub basins. The area coverage of the sub basins ranges from 8 to 58 km^2 (Table 4.1 and Figure. 4.1). The advantage of dividing the basins into subbasins allows to see the spatial variation of the morphometric parameters within the basin, comparing and contrasting the parameters among the sub basins and zonation of sub basins having similar parameters using index values. Finally describe the hydrological contribution of each parameter in relation to the infiltration role to the groundwater of the basin. The classification of the subbasin is based on same stream order of the subbasins in order to make comparison among parameters easier. Therefore, the base for the classification of the sub basins is the fourth order stream and interbasin area.

Table 4.1 Area coverage and perimeter of Sub basins of the upper Suluh .

Sub basins	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Perimeter (Km)	44.48	27.88	27.88	14.12	29.2	12.23	33.86	17.69	34.85	27.88	11.92	58.72	21.67	55.89
Area Km²	53	34	38	9	37	12	45	13	42	23	8	47	23	58

Figure 4.1 Drainage map and the boundary of the sub basins



4.2 LINEAR ASPECTS OF THE CHANNEL SYSTEM

The definitions and symbols of morph metric variables used in the characterization of the sub basins of the upper Suluh are summarized in Table 4.2.

Table 4.2 Variables of the morphometry and the symbols used.

Morph metric Parameters	Symbol and formula
Drainage Network	

Order of streams	U
Number of streams	Nu
Total number of streams within a basin of order 'U'	∑Nu
Mean length of stream segment of order 'U'	Lu/Nu
Total stream length within a basin of order 'u'	∑Lu
Stream length ratio	Ri=Lu/Lu-1
Basin Circularity	
Area of the basin	Au (sq. km)
Length of the basin	Lb (km)
Basin perimeter	P (km)
Basin circularity	Rc
Basin elongation	Re
Form Factor	$F=Au/Lb^2$
Measurement of Intensity of Dissection	
Drainage density	Dd=Lu/Au
Constant of channel maintenance	Cch=1/Dd
Stream frequency	Fu= Nu/Au
Texture	T=Fu/Dd
Texture ratio	Tu=Nu/P
Measures Involving Height	
Minimum elevation	z
Maximum elevation	Z
Total basin relief	R=Z-z
Relief ratio	Rh=R/Lb
Ruggedness number	Rn=DdxR/1000

4.2.3 BIFURCATION RATIO AND STREAM LENGTH RATIO (Rb)

The bifurcation ratio is the ratio of the number of streams of a given order Nu to the number of streams of the next highest order N_{u+1}. The bifurcation ratio gives an important genetic clue about the evolution of stream segment indicating the property of streams to develop tributaries. It also indicates the frequency with which streams of a given order enter stream of next order. Basins with higher bifurcation ratio have well developed joints and fissures. According to strahler (1964), the values of bifurcation ratio characteristically range between 3.0 and 5.0 for a water shade in which the geological structures do not disturb the drainage pattern. In addition, Ventachew (1946) explained that abnormally higher bifurcation ratio shows steeply slopping rock strata where narrow strike s are confined between hog back ridges.

The computed bifurcation ratios of individual sub basins in the upper Suluh are shown in Table 3.5. The highest bifurcation ratio is observed in sub basin 1 with a value of 5.44 and the lowest in sub basin 14 with a value of 2.31 while most of the basins have bifurcation ratio between 2 and 4. The sub basins-2, 3, 4, 5,6, 9, 12 and 13 have Rb that lie between 3 and 5, which implies that the geologic structures do not distort the drainage pattern in this sub basins. This is supported by the horizontal sedimentary succession of the rock of the area. This shows the other sub joints, fractures and well-developed fissures, affect basins. On the other hand the higher Rb ratio with elongated basin shape of sub basin-1can be explained by lower yield but extended flow peak, which promotes infiltration with time if the rock is favorable. The sub basins with the Rb<3 are areas attributed to flash flooding (patrick, 1978). The small variation of the Rb value between the sub basins is attributed to the homogeneity of the geologic materials in the area see Figure 4.2.

Table 4.3. Bifurcation ratio obtained using Strahelr (1957) for the sub basins of the upper Suluh .

Sub basins	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rb	5.4	4.7	4.7	3.0	3.5	3.3	2.3	2.9	3.3	2.9	2.7	3.2	3.3	2.3

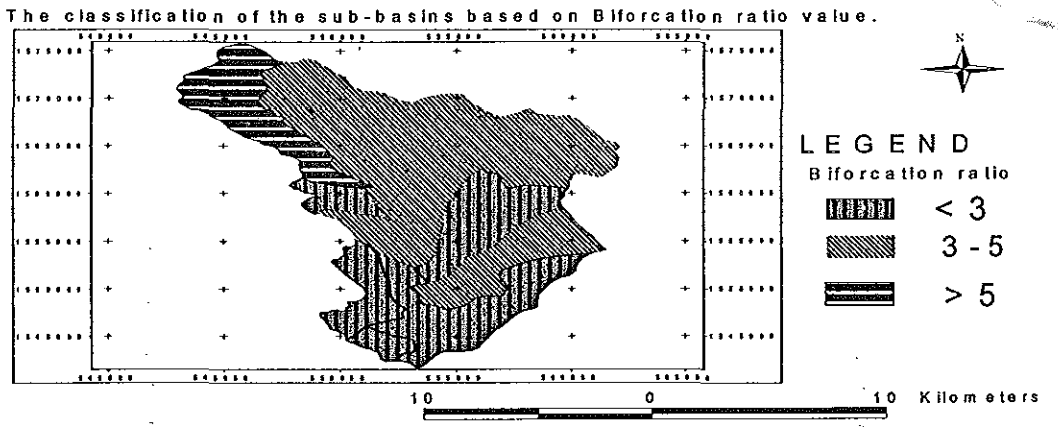
Calculation on average value of Rb for a given channel network is made by determining the slope of the fitting regression of logarithm of numbers (ordinate) on order abscissa. The regression coefficient b is identical with the logarithm of Rb. where b is the absolute value of the slope of the graph.

4.3 AREAL ASPECTS OF THE DRAINAGE BASIN

4.3.1 AREA

The area Ac of a basin of order 'u' is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of the given order and including all tributaries of lower order. The horizontal expansion of the drainage basin is the expression of intensity of different causative factors such as relief condition, drainage texture, climate and geology. The area of the sub basins of the upper Suluh ranges between 8 and 58 km^2.

Figure 4.2 the classification of the sub basins based on the bifurcation ratio.



4.3.2 PERIMETER

Perimeter is length of the boundary of the basin, which is drawn from topographic maps. The measured perimeter for all the sub basins in the upper Suluh is reported in Table 4.1.

4.4 DIMENSIONLESS RATIOS

Many of the .form elements have simple dimensions of length,. perimeter and relief. Dimensionless ratio is a geometrical property that describes pure shape or form of a basin irrespective of absolute size.

4.4.1 FORM FACTOR

The form factor Ff is a quantitative expression of drainage basin outline form (Horton, 1945), which is a dimensionless ratio of basin area (Au) to the square of the basin length (L_u).

$$F_f = Au/L_u^2 \text{ ------------------------------- Equation 4.1}$$

The form factor that indicates the shape or outline form of a drainage basin may conceivably affect stream discharge characteristics. It has been used in unit hydrograph applications as a measurement of basin shape, S=Lb2/Au (Corps of Engineers, 1954). Length of the basin is the longest dimension from the mouth to the farthest point on the perimeter of the basin, and width is measured normal to the length. Since the length of a basin increases with decreasing the peak discharge, the form factor shows an inverse relationship with the square of the length and a direct relationship with the peak discharge.

The form factor calculated for the sub basins of the upper Suluh water shade are shown in table 4.4. The values of the form factor range from 0.182 for sub basin 1, which is highly elongated, to 0.532 for sub basin 6,and sub basin 5 with a value of 0.519, which is relatively circular in shape.

Table 4.4. The form factor of the sub basins of upper Suluh .

Sub-basin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Ff	0.182	0.311	0.326	0.248	0.519	0.532	0.298	0.290	0.272	0.312	0.437	0.114	0.371	0.221
Re	0.48	0.63	0.56	0.56	0.81	0.82	0.60	0.65	0.59	0.63	0.75	0.38	0.69	0.53
Rc	0.331	0.549	0.614	0.567	0.545	0.861	0.493	0.522	0.434	0.372	0.705	0.171	0.615	0.233
Dd	2.68	2.55	2.11	2.33	1.72	2.54	1.53	2.39	1.54	1.7	2.11	2.34	2.07	1.86
Fu	3.7	4.4	3.5	4	1.7	4.4	1.1	2.7	1.3	1.5	3.8	2.4	2.2	1.9
Channel maintenance	0.4	0.4	0.5	0.4	0.6	0.4	0.7	0.4	0.7	0.6	0.5	0.4	0.5	0.5

4.4.2 ELONGATION RATIO (Re)

The shape of any basin is expressed by the elongation ratio Re which is defined as the ratio of diameter of a circle of the area as basin to the maximum length of the basin (Schumm, 1956. Normally this ratio varies between 0.6 and 1.0 over a wide variety of climatic and geologic types. Values near to 1 are typical of regions of low relief or the shape of the drainage basin approaches a circle. The elongation ratio of the sub basins of the upper Suluh are shown in Table 4.4.The values in the ranges between 0.6 and 0.8 are generally associated with strong relief and steep ground slopes. The elongation ratio in the upper suluh varies between 0.38-0.82. The elongation ratio signifies discharge characteristics. As the relief increases, discharge and surface run off increase implying lower infiltration to ground water: The infiltration increases with decreasing elongation ratio.

4.4.3 CIRCULARITY RATIO

Basin circularity Rc is the shape measure, which is related to the stream flow. Circularity within a basin is independent of the order. However, nearness of circularity tends to be more in lower order basins than in a higher order basin. Miller (1953) defined dimensionless circularity ratio Rc as the ratio of the basin area A to the area of a circle Ac having the same perimeter as the basin.

Rc =Au/Ac--- Equation 4.2

The circularity ratio ranges between 0 and 1. Values above 0.5 indicate maturity of the water shade in its evolutionary cycle, while circularity ratio lower than 0.5 indicates a youthful stage. The circularity ratio for the sub basins of the upper Suluh ranges between 0.032 and 0.861 (Table 4.4). All sub basins except sub basins 1, 7, 9, 10, and 14 have circularity ratios more than 0.5 indicating the maturity of the basin. Miller (1953) found that circularity ratio between 0.6 and 0.7 shows that the stream is flowing on homogeneous geologic materials. Sub basins 3, 6, 11, and 13 of the upper Suluh show this property.

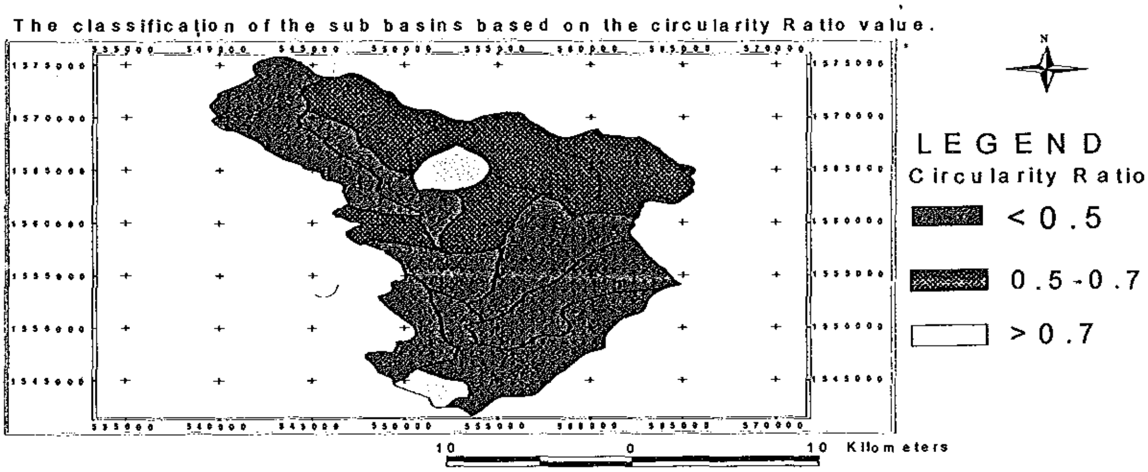


Figure 4.3 The classification of the sub basins based on the Circularity value.

4.5 MEASURE OF INTENSITY AND FORM

4.5.1 DRAINAGE DENSITY

The drainage density Dd represents the length of stream channel per unit area in the water shade. It is an important indicator of linear scale of landform elements in stream eroded topography and does not change regularly with orders of streams within the basins. The drainage density of the total basins tends to the approximate the mean drainage density of the first order basins in the water shade. The drainage density Dd is the ratio of the total length of all the streams in the basin ($\sum Lu$) to that of the basin area Au in km^2 (Deju, 1971).

$$Dd = \sum Lu / Au \text{ -- Eqaution 4.3}$$

Deju (1971) classify drainage conditions as poor, medium and excellent on the basis of their drainage densities (Table 4.4). Drainage density is used in measuring the fineness of basin topography. High drainage density is related to steep slopes and higher average relief. Thus drainage density is higher in mountainous areas. The higher the drainage density, the higher will be the run off volume following rainfall. Thus flooding in an area is more likely where the drainage density is high. The type of rock also affects the drainage density. In general, low drainage density is favored in regions of highly fractured or highly permeable sub soil materials, under dense vegetative cover, and where relief is low. As per the Deju (1971) classification scheme, all the sub basins of the upper Suluh are classified as excellent.

Table 4.5 Category of drainage density range (after Deju, 1971).

Drainage Density	Poor (P)	Medium (M)	Excellent
Range in Km^{-2}	<0.5	0.5-1.5	>1.5

Higher drainage density is favored in regions of hard or impermeable subsurface materials, sparse vegetation and mountainous relief. The drainage density in the study area ranges between 1.54 in sub basin 9 to 2.68 in sub basin 1. Smith (1950) graded the drainage density and expressed the same as drainage texture. Accordingly he has classified in to four.

Table 4.6 Drainage classification based on the drainage density.

Dd	<2	2-4	4-6	6-8	>8
Texture	V.coarse	course	Moderate	Fine	V. Fine

4.5.2 STREAM FREQUENCY

Stream frequency is defined as the number of streams of a given order per unit area (Horton, 1945).

$$Fu = \sum Nu/Au \text{ -- Equation 4.4}$$

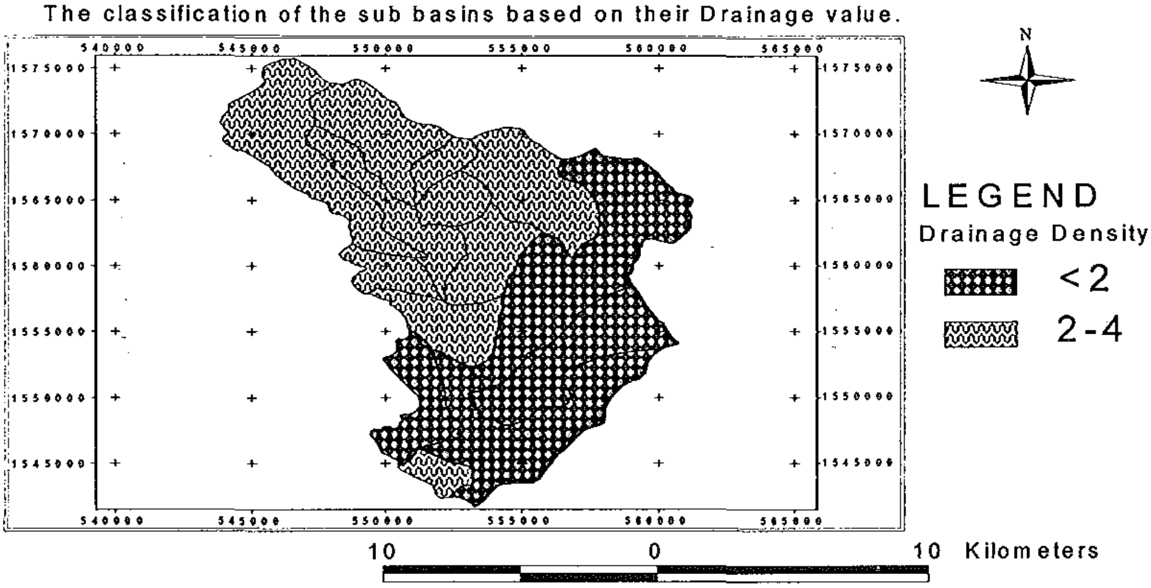
Stream frequency is used as a supplementary measure of the finesse of texture of the topography. According to Melton (1958), two hypothetical basins having equal areas and equal number of channel segments will have identical stream frequency. The stream frequency analysis for all the sub basins of the upper Suluh (Table 4.8) shows the highest value of 53.85 for sub basin 1 and a lowest value of 9.62 for sub basin 9. High stream frequency is found in sub basins 2, 4, 6, 11, and 12 as these basins are comprised of non-porous bedrock, and thin vegetation cover.

Table 4.7. Stream frequencies for the sub basins of the upper Suluh .

		Number of streams in each order						Stream frequency (km^{-2})						
Sub basin number	Area	N1	N2	N3	N4	N5	N6	F1	F2	F3	F4	F5	F6	ΣFu
1	53	153	44	7	1	0	0	2.89	0.698	0.132	0.019	0	0	3.736
2	34	112	29	7	1	0	0	3.29	0.853	0.206	0.029	0	0	4.382
3	38	102	26	5	1	0	0	2.68	0.684	0.132	0.026	0	0	3.526
4	9	26	7	2	1	0	0	2.89	0.778	0.222	0.111	0	0	4
5	37	44	15	4	1	0	0	1.19	0.405	0.108	0.027	0	0	1.73
6	12	38	11	3	1	0	0	3.17	0.917	0.25	0.083	0	0	4.417
7	45	44	6	0	0	1	0	0.98	0.133	0	0	0.022	0	1.133
8	13	26	6	2	1	0	0	2	0.462	0.154	0.077	0	0	2.692
9	42	39	11	4	1	0	0	0.93	0.262	0.095	0.024	0	0	1.31
10	23	26	6	2	1	0	0	1.13	0.261	0.087	0.043	0	0	1.522
11	8	20	7	2	1	0	0	2.5	0.875	0.25	0.125	0	0	3.75
12	47	93	20	1	0	1	0	1.98	0.426	0.021	0	0.021	0	2.447

13	23	38	9	3	1	0	0	1.65	0.391	0.13	0.043	0	0	2.217
14	58	95	14	1	0	0	1	1.64	0.241	0.017	0	0	0.017	1.914

Figure 4.4 The classification of the sub basins based on the Drainage density value.



4.5.3 DRAINAGE TEXTURE (T) AND TEXTURE RATIO (Tu)

Texture of topography is defined as the average size of the units composing a given topography (Johnson, 1933). There are three kinds of drainage texture, namely fine, medium and coarse. Hydrologically, the term texture exclusively refers to inter-stream area and hence is the manifestation of smallest streams that may be temporary or perennial. Thus, texture of topography is synonymous with stream frequency. It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief, and stage of development (Smith, 1950). Sparse vegetation of arid climates cause finer textures than those developed on similar rocks in humid climate. The drainage texture can be expressed by the following equation (Smith, 1950):

T = Fu*Dd--Equation 4.5

The texture and texture ratio (Table 4.9) are calculated for all the sub basins using the equation given above. The value of the texture ratio varies from 11.59 for sub basin 9 to 63.65 for sub basin 1. The texture of ratio of less than 3 indicates coarse texture of topography, 3 - 5 indicates medium texture and more than 5 indicates fine texture. Accordingly, the sub basins of the study area are classified as fine or medium textured (Table 3.10)

Table 4.8. Texture and Texture ratio for the sub basins of the upper Suluh .

Sub-basin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Texture	10.02	11.16	7.44	9.302	2.98	11.21	1.729	6.43	2.014	2.592	7.913	5.737	4.582	3.554
Texture Ratio	12	14	12	6	7.6	11	4.2	5.2	4.4	4.1	7	5.7	6.5	6.8

The sub basins of the study area have been classified accordingly in table 4.12 below.

Table 4.9. Classification of sub basins of the upper Suluh according to their texture ratio.

Type of topography	Texture ratio	Sub basin number
Coarse	<3	No sub basin belong to this classification
Medium	3-5	7, 9, 10
Fine	>5	1, 2, 3, 4, 5, 6, 8, 11, 12, 13, 14

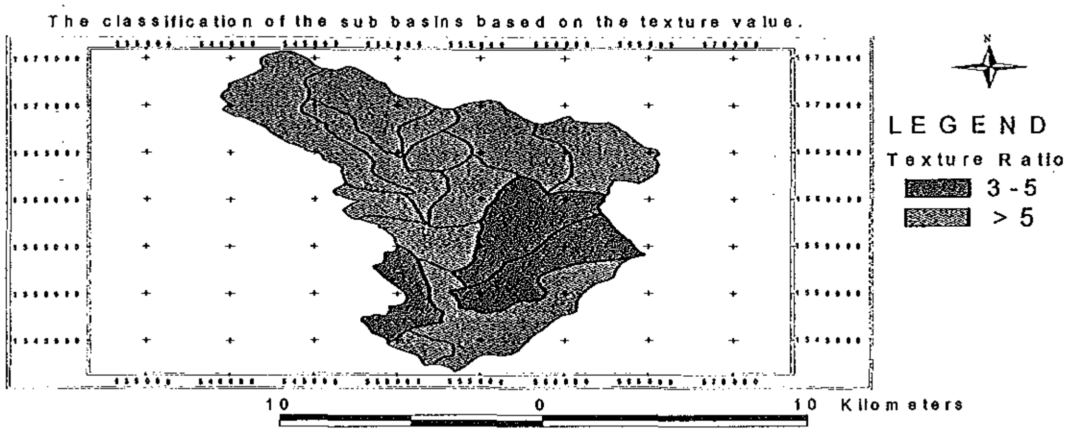
The weighted mean texture ratio is computed by taking into consideration the size of individual sub basins because the same weighted mean texture ratio cannot be attributed to texture ratio of small and large drainage basins. The weighted mean texture ratio Tm is the ratio of the sum of the product of texture ratio and area ($\sum TuAu$) of all sub basins to the sum of the area of all the sub basins $\sum Au$. This is expressed as:

$$Tm = \sum TuAu / \sum Au \text{ -- Equation 4.6}$$

Where Tm is the weighted mean texture ratio and Au area of all the sub basin and $\sum Au$ is the sum of the area of all the sub basins in the water shade.

The value of Tm for the upper Suluh is 7.79. According to Smith (1950), texture is graded on the basis of Tm as coarse textured if Tm is below 4.0, medium textured for Tm values between 4.0 and 10.0 and fine textured for values of Tm above 10.0. Thus, the weighted mean topography texture of upper Suluh can be defined as medium texture. The values of mean texture ratio (7.6) and weighted mean texture ratio (7.79) are close to each other and both values indicate medium textured topography. The greater the texture ratios, the greater are the number of first order streams leading to higher discharge.

Figure 4.5 The classification of the sub basins based on the Texture ratio value



4.6 MEASURES INVOVLVING HEIGHT

4.6.1 RELIEF

Total Basin relief R is the elevation difference between references points defined by any one of the several ways. Schumm (1954) measured basin relief along the longest dimension of the basin parallel to the principal drainage line. Maxwell (1960) measured relief along the basin diameter, an axial line found by the use of rigorously defined criteria. According to Strahler (1958), the maximum relief within a basin is the elevation difference between the highest and the lowest points. The relief of the upper Suluh has been measured according to Strahler (1958). Relief measures are indicative of the potential energy of the drainage system present by virtue of elevation above a given datum. Relief measures for the upper Suluh are given in Table 4.12.

Table 4.10. Total basin relief, relief ratio, and ruggedness number for the sub basins of the upper Suluh.

Sub basin number	1	2	3	4	5	6	7	8	9	10	11	12	13	14

R	940	880	720	600	440	540	340	380	440	80	180	800	560	200
Rh	0.06	0.08	0.07	0.1	0.05	0.11	0.03	0.06	0.04	0.01	0.04	0.04	0.07	0.01
Rn	2.52	2.24	1.52	1.4	0.76	1.37	0.52	0.91	0.68	0.14	0.38	1.88	1.16	0.37

The maximum relief of 940m is observed in sub basin 1, which also has a high drainage density and stream frequency. Sub basins 2, 3, 4, and 12 also exhibit comparatively higher relief along with high drainage density and stream frequency. The sub basins 6, 8, and 13 with lower relief also have high drainage density and stream frequency due to the fact that these sub basins occupy lesser areas. All these factors indicate high runoff and maximum discharge in the sub basins. The remaining sub basins show lower relief together with the lower drainage density and stream frequency.

4.6.2 RELIEF RATIO

Relief ratio Rh is defined as the ratio of the total basin to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schum, 1956). The highest relief ratio of 0.11 and 0.1 are observed in sub basin 6 and sub basin 4. The remaining sub basins are with relatively lower relief ratio that range between 0.01 and 0.08. The relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes on the slopes of the basin. It is also important in predicting the discharge and rainfall ratio.

4.6.3 RUGGDNESS NUMBER (Rn)

Ruggedness number (Rn) is a dimensionless quantity defined to combine the qualities of slope steepness and length. This quantity is a product of relief R and drainage density, where both terms are in the same units. Extremely high values of ruggedness number occur when slopes are not only steep but long as well. The sub basin 1, 2, 3, 4, 6, 12, and 13 have high ruggedness number which is greater than 1.16 while the remaining sub basins posses less than one.

4.7 GEOMORPHIC PARAMETERS AND IFILTRATION CONDITION

Groundwater a availability in a region depends primarily on infiltration conditions following precipitation. The infiltration is affected by several topographic conditions in addition to rainfall distribution. The most important of these is hydro geomorphology and slope characteristics. To understand the impact of geomorphology different hydromorphic parameter were considered. These include the linear aspect, aerial, intensity and slope of the drainage basin was considered to characterize the infiltration condition. These chapter deals with these parameters and their impact on groundwater. The slope characteristics control the amount of runoff along with other factors. In general the region with steep slope produces more runoff than regions with moderate slope. The plains or regions with gentle slope allow more time for the water to percolate there by contributing to the groundwater. Based on the hydromorphic parameter, the north & south tip of the study area is characterized by higher order number, shorter stream length, higher bifurcation ratio, drainage density, steep slope and fine topography and more of circular in shape. This area is then characterized by higher surface runoff but lower infiltration to the ground water. The area is then identified as lower infiltration zone see Figure 8.1.However areas with lower number stream order, longer length, lower drainage density, bifurcation ratio, gentle slope and lower relief together with permeable formation is zoned as higher infiltration area. It is located in the eastern, central and west-central part of the study area.

As a result the study area is classified in to three prospective zones that have different potential with respect to different hydromorphic parameters. These are zone-1, zone-2 and zone-3.

CHAPTER FIVE

HYDROMETEOROLOGY

The objective of the study is to understand the groundwater potential and the main controlling factors for the Upper Suluh . One component of this study is to analyze and study the meteorological conditions of the area. To achieve this objective the climatologically analysis of the available data in and around the Suluh is presented in this part of the study.

5.1 RAINFALL

The entire Ethiopia consists of undulated landmasses. There are considerable variations in altitudes over the country from about 120m below the sea level in Danakil depression to peaks in excess of 4000m. Much of the country is above the 1000m levels. The altitude plays an important role in controlling the weather and climate of the country. The rainfall in Ethiopia vary from less than 25 cm over some parts of northeast Ethiopia to more than 200 cm in parts of southwest Ethiopia. The rainfall increases from northeast to southwest. Besides broad synoptic situations discussed above orography plays a very important role in the variation of rainfall in the country. According to Griffiths, the wettest station, Gore Airport's annual average rainfall is more than 2200 mm with high annual total of 2786 mm reported in 1960 (World Survey of Climatology). The study area in the northeast part of the country falls approximately in the rainfall zone of 50 to 80 cm. In most parts of the country 70, 60, 80% of its annual rainfall occurs in the months of (June to August) during kremt (Long rain period). Annual rainfall shows very pronounced fluctuations from year to year.

Lemma Gonfa, (1996) made detailed climate classification of Ethiopia and divided the country in eleven principal climate types. According to this classification the climate of Upper Suluh could be classified as "Bsh" (hot semi-arid climate).

5.1.1 DATA AND STATION NET WORK

The National Meteorological Services Agency (NMSA) is the nodal Government agency trusted with the responsibility of meteorological data collection, archive and analysis in

Ethiopia. Inside the Upper Suluh area there are only two meteorological meteorological station which measure only rainfall. However, a few stations fall in the periphery of the under study. The meteorological stations from where the data was made available, for analysis are shown in figure 5.2. In many of the stations there are many gaps in the monthly data supplied. Data was missing in-between for many years in some of the stations. Besides rainfall data other meteorological data like temperature, humidity, evaporation, wind etc are available for analysis only for few stations and for limited number of years.

As has been mentioned that there are large gaps in observations almost in each station. Except for Mekelle, the data is not of enough length for climatologically analysis. Filling of rainfall data using simple usual methods is on the other hand difficult because of significant spatial and temporal variability as compared to some other atmospheric element. At the same time longer series of monthly rainfall data are required for various purposes like finding out climatic variations of the place, trends, and rainfall run-off relationships.

However, a filled up data taken from the work of WAPCOS, (2002) of the different stations using cross correlation technique will be used in the present study. Due to the similarity between the filled (generated) and observed and the advantage of continuity for analysis of the filled up data for 39 years will be used in this study see appendix 1 for filled up (generated). Finally, compute the annual average of the upper Suluh . The average annual of the observed and filled up data of the five stations considered are presented in table 5.1 below.

Table 5.1 Showing the location, Elevation and average annual rainfall of the upper suluh .

S.No.	Name	Z. dex No.	Lat.	Long.	Height of Station	Annual Rainfall (Observed)	annual Rainfall(Filled up)
1	Adigrate	39140023	14.28	39.36	2457	538.7	617
2	E\Hamuse	39140064	14.19	39.56	2690	682	608
3	Wukro	39130204	13.79	39.60	1980	506.5	551
4	Hawzen	39140114	13.98	39.43	2280	519.8	531
5	Senkata	39130084	14.05	39.56	2400	856.6	847

For the sake of comparison the average annual rainfall for the observed and filled up data are presented in the form of bar diagram figure 5.1.

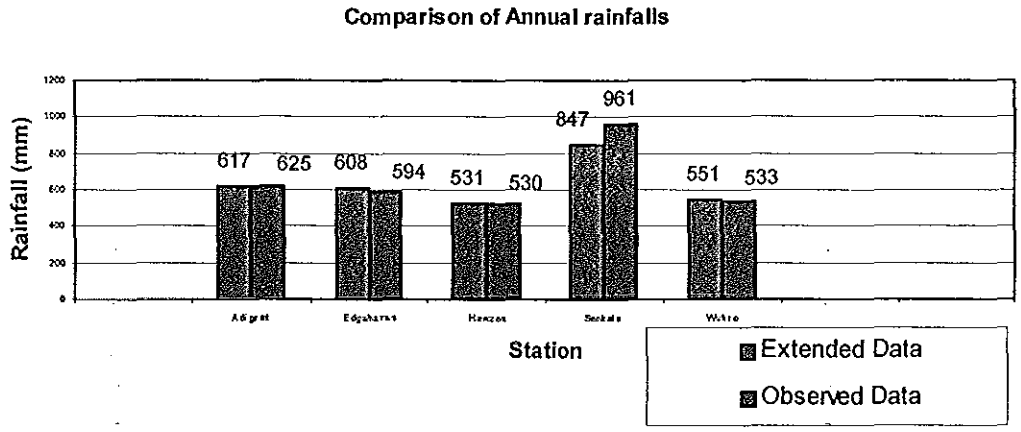


Figure 5.1 Comparison of the filled up and observed rainfall of the five stations.

5.1.2 MONTHLY DISTRIBUTION OF RAINFALL

As observed from figure 5.2 most of the rain, which is about 63.158% on average falls in the months of (June, July and August) i.e. the long rainy season of the area. But when we consider the individual station the amount of rainfall that falls in the described month of the year varies from 55% to 80%. According to the NMSA, (1989) the area is demarcated under region "A", which is characterized by three distinct seasons locally known as "Bega" (October to January), Bẹlg (February to May) and Kremt (June to September). Acc̣ording to the NMSA report region "A" shows two distinct peaks of rainfall during a year. Similarly the monthly rainfall distribution of the study area also shows with two distinct peaks i.e. from March to May and July to August except the eratics of the Sinkata station in June.

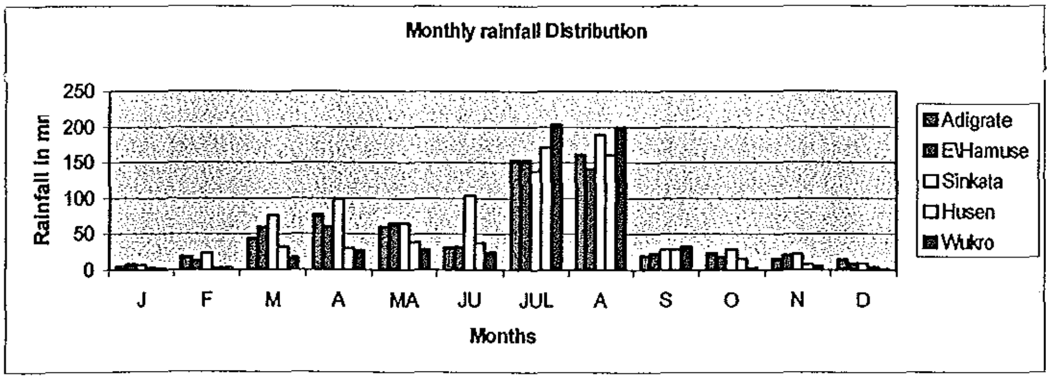


Figure 5.2 Monthly rainfall distributions of the stations

5.1.3 RAINFALL VARIABILITY

The annual average of the stations considered shows high inter annual variation. The highest rainfall observed is in 1981 with annual average amount of 557mm and the lowest is observed in1971 with rainfall 270mm amount of annul average of the stations.

The co-efficient of variation, which is defined as standard deviation divided by the mean, is a measure of rainfall variability in a place. Higher is the value more variable is the rainfall and dependency is less. The co-efficient of variation of rainfall for all the stations within and around the have been computed by considering synthetic data. It may be seen from the value that the co-efficient of variation is quite large around northeast sector of the study area. This means that though the average rainfall of that area is quite large but variability is also large, which also mean the year-to- year variability of rainfall is large. Normally rainfall is more variable in the less rainfall areas.

To see the trend of rainfall in the study area the five and ten years moving average is calculated using the average annual of the five stations filled up data. The result of the calculation is presented in fig 5.3 below.

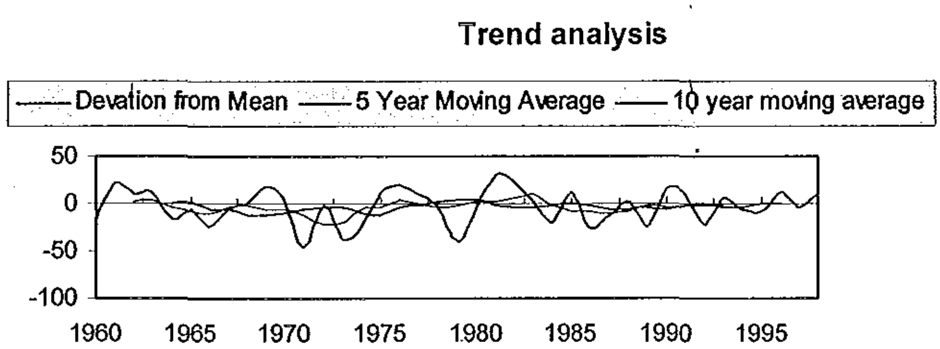


Figure5.3 The trend analysis result of the stations using five and ten years moving average and percentage devotion from the mean.

Monthly and yearly variations of rainfall for the upper Suluh area, considering synthetic data of all the five stations is made. The percentage departures of rainfall from the mean value of the five stations for 5 and 10 years moving averages are also shown in Fig 5.3. The percentage departure of rainfall starts with medium (1960 to1969) amplitude of departure and continues with larger amplitude of departure (1970 to 1984) ends with smaller amplitude of departure (1985 to 1998). The percentage of departure also shows that for twenty-three years of rainfall they are equal to and greater than the mean value. The remaining sixteen years of rainfall are below the mean value. The result shows that the rainfall varied in the past from 55.7 cm in 1981 to 27.0 cm in 1971. Where the lowest rain corresponds with the sever drought incidence of the region according to the NMAS, (1998). Year to year variations are large but the fluctuations are random. However, 5-year moving averages show a five-year period of decreasing and increasing rainfall though, the trend is not very significant.

5.1.4 AVERAGE AREAL DEPTH OF RAINFALL

There are several methods for obtaining the average depth of rainfall over an area depending upon the Physiographic features of the region and the network of rain gauges in the project area. The generally adopted methods are listed below: -

i) Arithmetic mean method

ii) Thiessen polygon method

iii) Isohyetal method

Arithmetic mean method is the simplest of the three methods and the result is obtained by dividing the sum of the rainfall amounts recorded at all the rain gauge stations which are located with in the area under consideration by the number of stations (Fetter, 2002).

That is : $$P = \frac{P1 + P2 + P3 + \ldots Pn}{n} \quad \text{-------------------------- Equation 5.1}$$

Where P is the average depth of rain fall and p1, P2,---,Pn are the rain falls recorded at stations 1, 2, etc and n is the number of rain gauge stations with in the area.

There fore: $$P = \frac{608 + 847}{2} = 727.5\text{mm}$$

This method is accurate as other methods if the area is flat and the Gauges are distributed uniformly over the area and the variation of individual gauge record from the mean is not too large (Shaw, 1988 and Jayerami, 1996). But these conditions are not full filled in the study area for the reason that the area is not flat (with altitudinal variation of 1100m.a.s) and the gauges are only two in addition to their non uniformly distribution.

The second method (Thiessen polygon method) attempts to make allowance for irregularities in gauge locations by weighing the record of each gauge in proportion to the area, which is closer to that gauge than to any other gauge (Figure 5.4).

The method is given by

$$P = \frac{A1P1 + A2P2 + --- AnPn}{\sum Ai} \quad \text{-----------------------Equation 5.2}$$

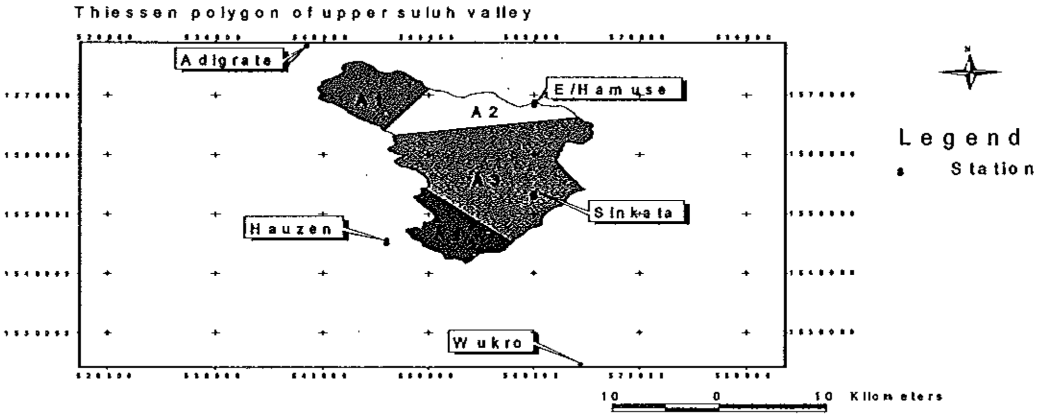
Where P=average areal depth rain fall.

P1, P2---Pn=mean annual rain falls recorded at each rain gauge stations.

A1, A2 ---An=Polygonal areas around each stations with in the basin .

Using this method, the result obtained is in (Table 5.3).

Figure 5.4 The thiessen polygon of upper suluh



The generally preferred method for averaging rainfall over an area is the Isohyetal method. This method has several advantages over the two methods described before. Because it does not only take into account the rainfall at the neighboring stations but also the results yielded by this method remain practically unaffected whether any new stations is added to or is missing from the network over the area under study. Further, this method also takes into account the physiographic features of the area. Results in this method is however dependent on the skill of the analyst drawing the isohytes.

To compute average rainfall for the Upper Suluh area therefore the isohyetal technique has been used. The formula used is

$$P = \frac{\sum_{r=1}^{n} P_r A_r}{\sum_{r=1}^{n} A_r} \quad \text{.......................Equation 5.3}$$

Where

P = Average rainfall and A_1, A_2, A_3.A_n are the areas between successive isohyets and P_1, P_2, P_3, ...P_n represents the average rainfall i.e. the mean of the two successive isohyets, over the areas A_1, A_2, ...A_n.

The source data for the construction of the isohytal map is the filled up data taken from WAPCOS, (2002) for thirty-nine years from 1960-1998.

The isohyetal map showing annual rainfall distribution of the is shown in Fig 5.5. The average rainfall considered here is based on uniform series of filled data (Generated data). The general rainfall pattern of the is that the rainfall increases towards northeast as well as southwest as one moves from the central part of the area. While most area of central parts of the annually receives less than 55cm of rainfall northeastern parts centering Senkata receives more than 80 cm of rain annually. Average rainfall of the as whole by this method works out to about 71.73cm. The result of aerial rainfall distribution using different method is similar as shown in the table above but the average result is considered.

Table 5.2 Areal ranfall distribution using different mothods and their averages.

Method	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Arthmetic	7.47	18.23	68.53	78.7	65.22	67.87	176.88	165.08	25.5	22.88	21.95	9.12	727.4
Theissen	6.26	17.9	62.36	78.2	60.22	70.52	178.18	171.35	25.51	23.64	19.11	9	722.27
Isohyetal	7.5	18.2	68.9	81.7	47.2	69.4	178	166.1	26.5	23.3	20.1	10.4	717.3
average	7.08	18.1	66.6	79.5	57.55	69.26	177.69	167.51	25.84	23.28	20.39	9.51	722.32

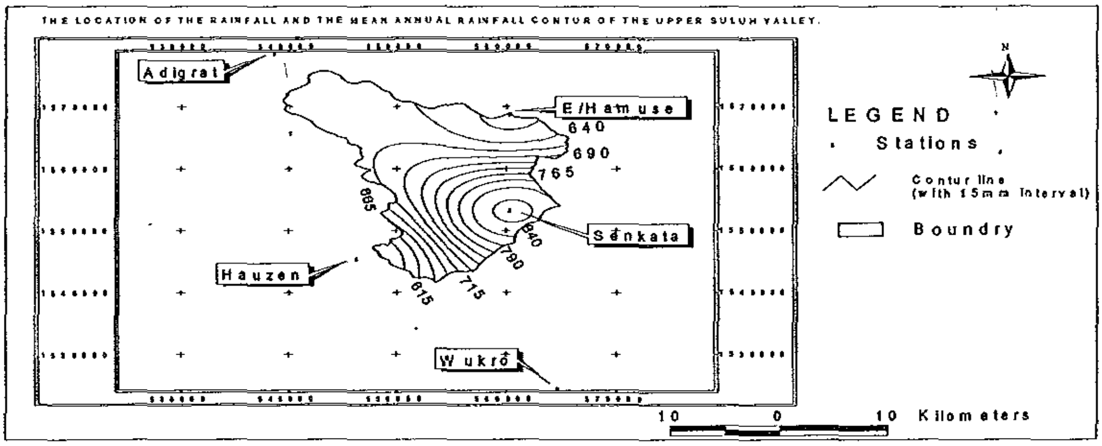


Figure5.5 The location of rain gauge station and isohytal map of the mean annual rainfall of the station

5.2 Analysis of Other Meteorological Elements

Other meteorological elements generally considered for analysis for study are the analysis of temperature, wind (direction and speed) duration of sunshine and relative humidity. In comparison to rainfall these elements, are less variable in space and time. Therefore data from fewer stations as also for shorter period could provide some general characteristics of these parameters over a small region like Upper Suluh . Temperature is however related to height of a place. Such data for all the stations is for very short period and the data other than temperature data, is available only for two stations. Characteristics of this parameters based on such limited information are summarized below.

5.2.1 Temperature

Average maximum monthly temperatures of the four stations (Adigrate, Huzen, Wukro, Mekele) are used to find the total average temperature of the raw data used for evaluation are in appendex-3. The highest monthly maximum is in the month of May or June. Range varies between 2 to 3^0c. The lowest monthly maximum is 22.26^0c in Adigrate in December and the highest was in Wukro in May with average value of 28.80^0c. Thus, the monthly maximum temperature in the area varies roughly from 20 to 30^0c.

The average monthly minimum temperatures of various stations are presented in Table 5.4. The monthly minimum temperature was the least in December for all the station except that of Adigrate the minimum temperature variation Ranges from 24.59^0c in December in Adigrat to 8.6^0c in Mekelle in December. The highest minimum temperature records are in the months of April, May and June, which ranges form 7.57^0c at Adigrat in April to 13.9^0c in April in Illala.

5.2.2 Wind speed

Wind speed data was available for few years for Mekelle and Illala. The Tabulated data is shown in. Data reveals that wind speed is the least in August (1.7m/s, average) and the highest in April ($4.2ms^{-1}$) the average wind speeds in March, April and May are of the same order ($1ms^{-1}$=3.6 kmph) in Mekelle. Picture is similar in Illala.

5.2.3 Relative Humidity (RH)

The monthly relative humidity for Mekelle for morning and afternoon as well as that of Illala. Data reveals that the average humidity in the month of August is the highest (83%) and least in February (58%). The humidity is the highest during morning (0600 local time) and the least in the afternoon (1500LT). Towards the morning in July and August the RH at times reaches to 97% in August. The picture of relative humidity in Illala is almost similar.

5.2.4 Sunshine

The sunshine data for Mekelle and Illala is used in the analysis. The sunshine hours are the least around (5.5 hours/day) in July and August and around 10 hours a day in the month of December. Obviously the decrease in sunshine hours in July and August is due to persistent cloudiness during rainy months. During December and January days are by and large clear (average 9 to 10 hours of sunshine in a day). The sunshine characteristic of Illala is broadly similar to that of Mekelle.

Table 5.3 the summery of the different meteorological data.

Summery of the average value of the different meteorological parameters

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Average Maximum(c^0)	25.0	26.2	26.9	27.0	27.5	27.6	24.3	23.8	25.3	25.2	24.4	24.3
Average Minimum (c^0)	7.2	8.2	10.4	12.0	12.3	11.9	11.9	11.7	9.9	10.0	8.2	7.2
Total Ave.Tem. (c0)	16.1	17.2	18.7	19.5	19.9	19.8	18.1	17.8	17.6	17.6	16.3	15.8
Relative humidity (%)	58.36	53.91	54.91	51.67	45.54	47.4	74.59	78.79	60.95	54.04	54.9	56.3
Sunshine hour(hours)	9.57	9.51	8.79	9.14	9.38	7.08	5.2	5.13	7.67	9.31	9.48	9.83
Average annual rainfall (mm)	5	12	46	58	47	45	176	170	27	18	14	7
Wind speed (m/s)	3.5	4.1	4.1	3.5	3.2	2.2	2.1	1.7	1.8	3.1	3.4	3.7

5.3 ESTMATION OF POTENTIAL EVAPORATION

Out of the rainfall that fall on the earth surface 62% is evapotranspired of this largest portion being from the land surface Dingmen (1994). This shows that evaporation is an important parameter to deal with, during the evaluation of water resource. Based on the data availability in this study two methods and approaches are considered to estimate the amount of water lose from the study area due to evaporation. The Thornthwait and the Penman methods. Therefore, potential evapotrnspiration (PET) and actual evapotransiration (AET) of the study area based on the above methods will be treated. Since there is no significant surface water body in the area evaporation from open water will not be consider.

5.3.1 Thornthwaite method (1948)

The Thornthwait method requires only temperature data and the equation is given as:

$$PET = \frac{16*(10t)^{a}}{I} \quad \text{.......... Equation 5.4}$$

PET= Potential evapotranspiration in mm/month

T= Mean monthly temperature in ^{o}c

I= Monthly heat index

i=Annual heat index obtained by summing the 12 monthly heat in indices.

$$i = \frac{(t)^{1.514}}{5} \quad \text{.......... Equation 5.5}$$

$$a = 675\times10^{-9}I^{3} - 771\times10^{-7}I^{2} + 1792\times10^{-5}I + 0.49239 \quad \text{.......... Equation 5.6}$$

Where equation 5.7 is not adjusted for day light factor, when the day light factor due to latitude is applied it becomes

$$PET = \frac{16Nm*(10t)^{a}}{I} \quad \text{.......... Equation 5.7}$$

Where Nm is the day light factor obtained by dividing the possible sunshine hour for the appropriate latitude.

5.3.2 PENMAN (COMBINATION) METHOD

Penman (1948) developed a formula to calculate open water evaporating based on fundamental physical principles with some empirical concepts incorporated, to enable standard meteorological observations to be used. The physical principle combines the mass transfer or (aero dynamic) method and the energy budget method. The formula used for open water is used for evapotranspiration with some modification, the penman formula used to calculate ET, is given as cited in Shaw (1994).

$$PET = \frac{(\Delta/\gamma)H_T + Eqt}{(\Delta/\gamma + 1)} \quad \text{.......... Equation 5.8}$$

Where PET = Potential Evaporatranspiration

Δ = is the slope of the curve of saturated vapor pressure plotted against temprature.

γ= hygrometric constant

$Eat=0.35\ (1+U_2/100)\ (e_a-e_d)$ ....Equation 5.9

Where Eat the energy for evapotranspiration in mm/day.

$H_T= R_I(1-r)-Ro$..Equation 5.10

Where: H_I is the incoming solar radiation in mm/day and Ro is the outgoing solar radiation.

r=the reflective coefficient for incident radiations the Albedo, from the basin depending on the nature of the surface.

$R_I\ (1-r)= (1-r)\ Ra.fa\ (n/N)$..................................... Equation 5.11

Ra =solar radiation which depends on latitude and season (mm of water /day)

n =daily mean bright sunshine hour (hr/day)

N =maximum possible sunshine hours determined by latitude and season (14° N latitude is for the study)from standard tables.

$fa(n/N)=(0.16+0.62n/N)$..Equation 5.12

For latitudes south of 54 .5 ^{0}N, the empirical equation for the out going radiation in the calculation takes the form:

$Ro= \sigma\ Ta^4\ (0.47-0.075\sqrt{e_d})\ (0.17+0.83n/N)$................Equation 5.13

$\sigma\ T^4$ =theoretical black body radiation (mm/day)

e_d = actual vapor pressure (mmHg)

σ =Stephan-Boltzman constant ($5.67 \times 10^{-8} \times Wm^{-2}\ T^{-4}$)

Albedo (short wave-reflection coefficient) of any basin can vary widely with time of day, season, latitude and cloud cover. In the absence of knowledge on crop the value of r (reflection coefficient), is recommended to be 0.23 (Maidment, 1993). In the study area, the average and dominant crops, forests, soil and grass are cereals, plantations, clay soil, sand soil, Eucalyptus tree, Grass and pasture and Bare soil with their Albedo, 0.25, 0.13, 0.3, 0.2, 0.25 and 0.22 respectively (Dunn and Leopold (1978) and Maidment (1993)). Therefore by averaging the above albedo the value of r is taken as 0.22.

Using this albedo, the value of R_I (1-r) will be

$R_I\ (1-r)=0.78\ Ra\ fa(n/N)$..Equation 5.1

H_T=is the available heat

Eat=is the energy for evapotranspiration

To find the values mean temperature, wind speed, clarity of the sky and other radiation data from available standard meteorology tables are used. The result of the PET of the different methods used is tabulated in (table 5.7). The result shows that the annual PET varies with 808.3mm using Thornthwaite to 1584.78 mm by penman. The great difference between the two methods is attributed to the data source used in Penman method other than temprature.

Table 5.4 Summery of the evapotrnspiration result using the different methods

Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Thornthwite	53.52	56.21	73.95	80.36	90.43	85.63	75.29	70.82	66.08	64.91	45.98	45.06	808.3
Combined (Penman)	118.4	147	158.8	166.45	172.5	137.2	93.8	86.32	114.3	138	125	123	1584.78

All values are in mm.

5.4 ESTIMATION OF ACTUAL EVAPOTRANSPIRATION

As explained earlier PET is the evaporation that exists when there is unlimited amount of moisture in soil. But AET is the amount of evaporation that occurs under field condition (Fetter,2003).

According to Lemma (1996) the area belongs to hot arid climate, which implies that there is high evaporation. In such area the impact of evaporation on the hydrology is significant. To see the impact of evaporation the AET is calculated using the Thornthwite and Matter (1955) method.

Inputs of this model consist of monthly rainfall (p) and potential evapotranpiration (PET) (Dingman, 1994). The soil-water storage capacity of the region is represented by a single value S_{max} and an initial value of soil moisture by S_o.

Following Alley (1984), if for a given month $P_m > PET_m$, the value of the soil moisture at the end of that month, S_m, is found as

$$S_m = \min\left[((P_m - PET_m) + S_{m-1}), S_{max}\right] \quad \text{.......Equation 5.9}$$

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

$$S_m = S_{m-1} \exp\left[-\frac{PETm - Pm}{S\max}\right] \quad \text{.......Equation 5.10}$$

The monthly actual evapotranspiration (AET) is then found as

$$AET = PET \qquad \text{if } P_m > PET_m \quad \text{.......Equation 5.11}$$

$$AET = P_m + S_{m-1} - S_m \quad \text{otherwise} \quad \text{.......Equation 5.12}$$

The basic assumptions of these methods is that when monthly rainfall is greater than or equal to the corresponding monthly potential evapotranspiration, actual evapotranspiration equals potential evapotranspiration if the moisture storage in the soil zone is at maximum capacity. When the rainfall plus the depletion from soil moisture storage. Any water surplus in the soil zone reaching the groundwater table can be consider as recharge.

The method uses monthly values of rainfall and potential evapotranspiration to estimate monthly actual evapotranspiration. In addition to the monthly rainfall (Pm) and monthly (PE Tm) it requires soil moisture content. To find the monthly soil moisture of the area land use land cover and soil type classification of WAPCOS (2002) with some modification was used.

According to the above classification the area is dominantly covered by sandy loam with a maximum moisture capacity of 150mm. Then the Actual evapotrnspiration (AET) is calculated using Thornthwait and Pennman methods. The result of the AET is tabulated in table 4.5. The result using Penmann shows that the area has a surplus of 14.21mm and the whole year except the month of august is under moisture deficit. That is the average surplus accounts 2%of the total rainfall. The AET is found to be 703.09mm. On the other hand the result of the soil water balance approach using the potential evapotranspiration of Thornthwait method shows that the surplus is 69.63mm, which accounts 9.64% of the total rainfall and AET of 652.34 mm.

The result shows that there is significant difference between the two methods used this difference might be attributed to the use of the climatic data except temperature from other station which is far away from the study area. Moreover, the data used are very few years observation, which is not greater than three and are not complete. For this reason the AET by Thornthwaite is used for the water balance calculation.

Table 5.5 Actual evapotrnspiration and Surplus result based on the Thornthwaite and Mather model using PET of different methods.

Method	AET(mm)	Surplus(mm)
Thornthwait	652.34	69.63
Pennman	703.09	14.21

5.5 RUNOFF

Rainfall is the source of Water for run off generation. But the amount of the run off to be generated is dependent on many factor. This includes climate conditions, type of rainfall, rainfall intensity and duration, rainfall distribution, physiographic factors etc. Due to this the computation of run off is a complex task. However, computation will be easier from measurement data station.

5.5.1 Data availability

Like other meteorological data the run off data was collected from the data achieves of the ministry of water recourse of Ethiopia. The collected data was observed at the Suluh River near Huzen. The data collected was for 24 years 1973-1996 with many gaps incompletes with in it. However, this observed data was scrutinized, gap filled and filled up data was generated and verified by WAPCOS (2002). Therefore, generated (filled up data) by WAPCOS (2002) was used in this work to fined total run off of the study area. For comparison the result of data analysis of the monthly generated and observed data is presented in table 5.5.

Table 5.6 the generated and the observed run off data at Suluh .

Months	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
Generated (MCM)	0.45	0.36	2	1.53	1.31	0.75	8.67	9.47	1.45	1.37	0.36	0.18	27.9
Observed (MCM)	0.52	0.95	1.31	2.31	1.31	2.79	7.7	9.29	1.84	1.46	0.85	0.57	30.9

Source: WAPCOS (2002)

5.5.2 Run off estimation

To estimate the run off of study area using the generated data a comparison was made between the observed data. The monthly distribution of the generated flow of Suluh River in

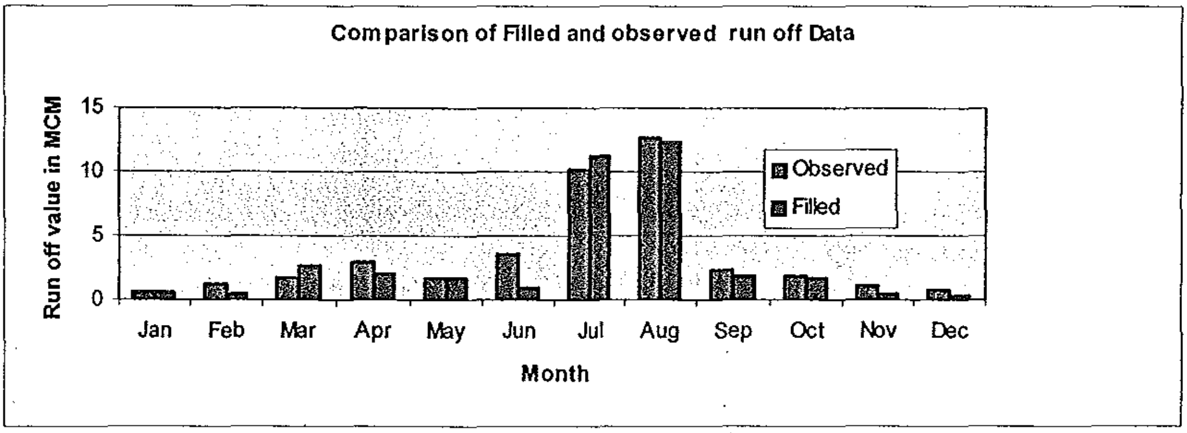


Fig 5.6 Comparison of the observed and generated monthly runs off data

Since the generated data is comparable and continuous the runoff coefficient was calculated for the catchments using the annual generated rainfall and runoff of the study area.
With this fact the gauge station represents only 79% of study area (upper Suluh). However, the remaining 21% of the study area is characterized by similar physiographical, soil, rainfall distribution and intensity and land use. As a result the runoff coefficient calculated for the observation site can be used to calculate the runoff of the catchments.

Therefore, the runoff coefficient of the study area is calculated using

$RC = Ro/(A \times P)$ ....Equation 5.13

Where:

Ro= Annual runoff

P=annual rainfall of the catchments

RC=runoff coefficient.

A= Area of the total catchment

The result shows that the study area has runoff coefficient of 0.144 and an estimated annual runoff 81mm· It also shows that the maximum runoff takes place in the months of July and August, which is parallel with rainy months of the study area. That is about 50%of the runoff is in the months of rainy seasons of the study area.

5.6 BASE FLOW SEPARATION

The total runoff from the catchments area consists of surface runoff, inter flow and base flow. The interflow is added to the base flow component. Surface runoff comprises the water, which travels over the surface sheet or channel flow. It is the main component of stream flow during flood and rainstorms. Base flow on the other hand represents the major long term component of the total run off and is important during long dry periods. The daily run off and base flow of Suluh River is given in figure 5.7 below. It is based on five years daily flow data calculated.

There are different methods to separate surface runoff from base flow. This includes chemical method, the time plot using Excl. and the graphic method etc. The TIMEPLOT program developed using the Excel. was used. It uses the daily discharge to separate the base flow from the total runoff measured in a gauge.

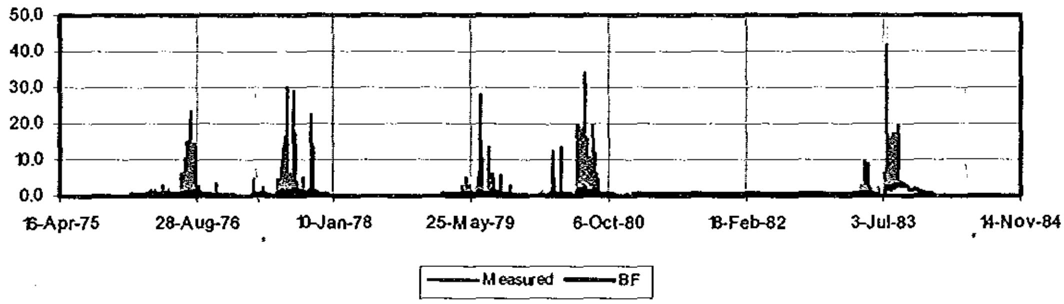


Figure 5.7 The monthly flow base flow and measured flow of the Suluh River at Hauzen station.

The result of base flow separation using the TIMEPLOT shows that the ratio of base flows to surface run off is 1:1.27. That is about 56% of the total run off is surface run off and the remaining 44% is the base flow. That means the 45.36mm is surface run off and 35.64mm of the total run off is base flow.

5.7 WATER BALANCE

5.7 WATER BALANCE

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specific period (Tenalem Ayenew and Tamiru Alemayehu, 2001). For natural catchments, measurement of the rainfall and river discharge may be made satisfactorily with some degree of precision. But the measurement of groundwater movements into or out of the drainage area cannot be made easily.

In this study of water balance, the catchment (basin) is assumed as a close basin. The presences of geological structures which extend out of the study area and the presences of springs along with them shows that the basin is not completely closed. However the low yield of the springs shows that the amount of water inflowing and out flow can be negligible. This condition made the evaluation relatively simple in avoiding the subsurface and surface movement of water across the defined watershed boundary. In previous section we have treated hydrologic processes separately. By now we are in a position to bring together the different parameters of the hydrologic budget to find the balance through water balance. It is the widely used method, for the reason that it uses the meteorological data, which are relatively available.

The water balance is always defined by equation that considers a balance between the incoming and out coming amount of water for a given basin in a given time. In general the equation of water balance can be defined as:

Input-Output = Change in storage

Where input includes :

P =PRECIPETATION

Sin = Surface water inflow

Gin =Groundwaterinflow

Iw = Imported water

Out put includes:

Et = Evapotranspiration

Gou = Groundwaterout flow

Ew = Exported water

Change in storage includes:

ΔGs = Change in groundwaterstorage

Ss = Change in surface water storage

The estimation of different input perimeter for the WB is done in the previous section. The different imputes parameters are presented below:

Rainfall (P)--722.32mm

Actual Evapotpanspiration (AET)-------------------------652.32mm

Surface runoff (SRO)-------------------------------------45.36mm

However, the equation of water balance varies based on the assumptions, input and output parameters. Freeze & Cherry (1976) gives the water balance equation assuming basin (watershed) having a surface water divide and groundwater divide coincides and no external in flow or out flows of groundwater storage changes are assumed zero and all quantities are long-term average values. The equation is given as:

P = Q+E---------------------Equation 5.14

Where P=Rainfall

Q=Stream flow leaving the basin

E=evapotranspairation

To draw the general equation of the water balance in to the considered the following facts and assumptions are considered.

- no surface and groundwater is imported and exported from the considered .
- It is assumed that the amount of inflow and outflow is negligible.
- Change in storage in annual case is almost negligible and is assumed to be zero.

Then finally, the study area will have a water balance equation of:

P = AET + SRO + R----------------------------Equation 5.15

There fore, the amount of recharge in Upper Suluh is calculated as 25mm (11.1MCM) annually. The above result shows that recharge, AET and SRO are 3.5%, 90% and 6.5% respectively which indicates that there is higher amount of evaporation as compare with recharge and surface runoff.

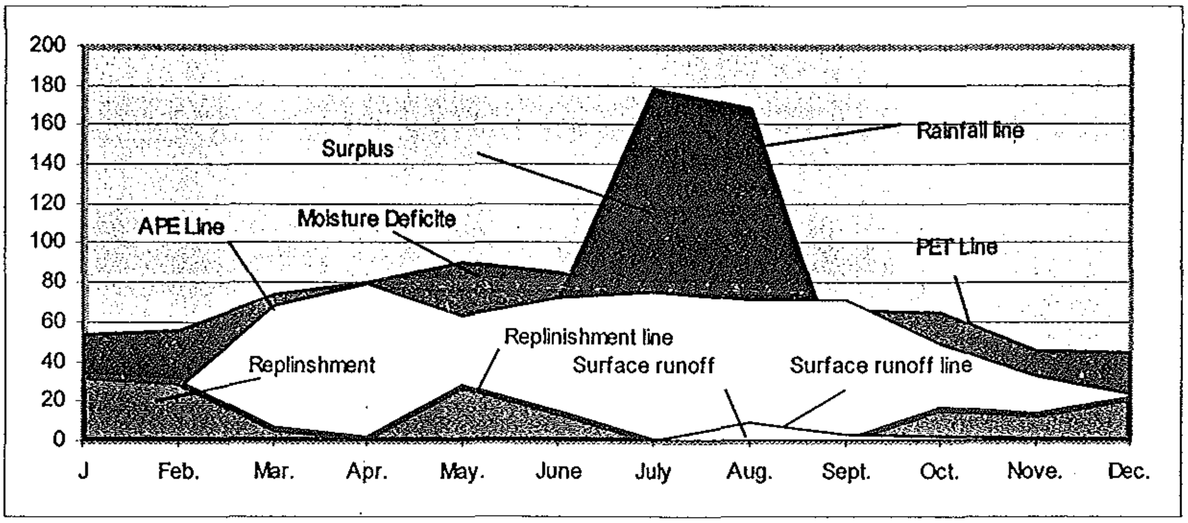


Figure 5.8 Showing the monthly water balance calculation result using Thornthwaite and Matter model.

CHAPTER SIX

HYDROGEOLOGY

Hydrogeology can be defined as the study of groundwater with particular emphasis given to its chemical chemistry, mode of migration and relation to the geologic environment (Devies & Dewiest, 1966). This chapter deals with the hydrogeological description of the area, aquifer characterization based on the hydraulic properties particularly hydraulic conductivity, recharge and discharge zone determination, groundwater flow direction determination and reserve estimation. The data used are field observation, well inventory, pump test, specific yield, slope map and the geology as base map.

6.1 AQUIFER CHARACTERIZATION

Field observation provides the basic understanding for the hydrogeological property of the rocks. Based on this principle the following geological and hydrogelogical field observation data were collected. Hydrogeological field observation such as the distribution and magnitude of spring discharge, well distribution with respect to the geologic units and structures, the degree of fracturing of the rock units, the thickness of the formation, the grain size rounding and sorting together with their distribution, clay proportion, the type and degree of cementation, and the extent of weathering are some of the significant field observation which provide evidence as to weather a rock unit is likely to be an aquifer of low, moderate or higher productivity and hydraulic conductivity.

These field observation data were supported by pump test data of ten wells, which are fairly distributed in space but poorly distributed within the different lithologies. The characterization and classification is based on the field observation of the different lithology units and the hydraulic properties of the different lithologic units from pump test data of the study area and reference of some standard books and empirical methods. The pump test data analysis result using A QUATEST program is tabulated below.

Table-6.1 Hydraulic parameters of the upper suluh

SNO	X	Y	DEPTH	FORMATION	YIELD	Transmissivity	Hydraulic Conductivity
1	561275.0	1562738.0	91	Enticho Sandstone	8	11	0.418
2	560350.0	1568090.0	90	Enticho Sandstone	8	93	1.403
3	559495.0	1557010.0	31	Enticho Sandstone	3		2.159
5	555034.0	1548407.0	0	Enticho Sandstone	3	1.4	0.026
6	555317.0	1552640.0	26	Enticho Sandstone	1	9.89	0.453
7	550780.0	1544400.0	70	Metavolcanics	2	0.3	0.005
8	547609.0	1544877.0	21	Metavolcanics	3		0.296
9	551014.0	1548403.0	50	Enticho Sandstone	3	11	0.235
10	549835.0	1558726.0	33	Alluvium +Enticho sandstone	6	52	1.756
12	562607.0	1534213.0	40	Metavolcanic	4	25.3	0.665

Taking the above parameters into consideration particularly the hydraulic conductivity of the rocks in the study area. The rocks are classified into three hydrogeological groups see Figure 6.3. In general the aquifers of the study area are unconfined aquifers this is confirmed by the similarity of the mean depth of water stricke and mean depth of water level, which is 0-52m below ground surface in both cases. This is derived by simple statistical manipulation of the water point inventory data by (WAPCOS,2002).

Table 6.2 The permeability range used for classification

Hydrogeologic formation	Average Hydraulic conductivity (m/d)
High Permeability	>1.76
Moderate to low Permeability	1.76-0.09
Very low Permeability	<0.09

6.1.1 HIGH PERMEABILITY FORMATION

This hydrogeological formation includes alluvial sediments, Enticho Sandstone and Adigrate Sandstone. According to field observation they are characterized by good fractures with variety of orientation, lower to moderate cementation and sorting, densely distributed wells and springs of higher discharge. According to pump test data this formation has relatively higher hydraulic conductivity greater than 1.76m/d on average.

6.1.1.1 ALLUVIAL SEDIMENTS

The alluvial sediments are located on the flat plain near the mainstream channel and intermountain depression with limited lateral and vertical extent. It has thickness that varies between 6-10m, which is confirmed by the hand dug well depth and streamside exposure. It is composed of clay, sand and gravel and characterized by inter granular primary porosity underlain by different rock units. The well sunk in this unit show good yield about 5l/s in Degamba area N-W part of the study area where this unit is found as mapable unit. It shows relatively higher hydraulic conductivity about 1.76m/d as calculated from pump test data considering the saturated aquifer column. It is shallow with limited aerial extent and can be considered as perched aquifer.

6.1.1.2 ENTICHO SANDSTONE

The Enticho Sandstone has both primary and Secondary porosity. The main permeability depends on the secondary porosity. Which are vertical joints and fractures and deep rooted. The secondary porosity is the result of joints and fractures with different orientation, aperture and spacing as discussed in section 3.3.1. These differently oriented and dominantly open fractures help in the direct in filtration of rainwater and surface water in areas, where the stream is loosing (see Figure6.2 &6.3). This unit is also dissected by long distance running dykes with dominant orientation of NW-SE direction, which acts as a natural dam and increase the groundwater potential of the aquifer. This is evidenced by the existence of springs up streamside of the dykes in the Sedewa and Edaga hamuse area see (Figure 6.1). In higher topography area this rock unit acts as a recharging zone particularly in the North -East part of the study area but mainly in the flat plain area it is the main potential unit for extraction of groundwater as observed from most boreholes in the inventory data (Figure 6.3).

In addition to the boreholes the presence of the number of spring along the Sinkata fault line is another evidence for the potentiality of the Enticho Sandstone. It can also be assumed the regional groundwater as the regional confining aquiclude layer the basement complex underlies it (Tesfay Chernet, 1993). When compare the massive and cross-bedded Enticho Sandstone the later unit is highly recharging, as it shows good exposure, steeply dipping beds and big open fissures but sometimes filled by dolerite dykes. It has relatively the highest hydraulic conductivity, which is estimated to be about 2.15m/d.

6.1.1.3 ADIGRTE SANDSTONE

It is a cliff forming sandstone, coarse to medium grained and cupped by about 10m thick laterit. In general it is massive but show minor cross bedding and is affected by vertical joints having different orientation refer to table 3.2. According to Tesfaye chernet, (1973) and supported from field observation the spacing of fissures and joints is about 15cm to 1/2m opening in every 5m spacing. It has a secondary porosity that depends on weathering and fracture.

As discussed from the geology in section 3.2.4. this unit is characterized by three joints that strike in N-S, E-W, and NW-SE direction with dip angle that vary from 60^0 to Vertical with dominant frequency of vertical once. The N-S striking joints have 15mm aperture with spacing variation of 30-60cm and long continuity. The E-W and NW-SE striking joints have with dip vertical and 80^0,spacing of 1-2cm and 50-80cm, and aperture of 20-50mm and10mm with fair continuity respectively.

However, this unit is highly affected by topography and stratigraphy for its recharge and storage potential. As per the field observation and borehole inventory data the Adigrat sandstone is recharging unit if the basalt layer and the lateritic cap do not underlie it. This is because the sandstone below the basalt is baked and is cupped by totally impermeable lateritic material. This is confirmed by the number of springs and seepages at the contact between the sandstone and weathered basaltic core above it. Similarly there is no observed spring between the sandstone and underlying Edagaarbi glacial, which is impermeable unit when the sandstone is below the basaltic unit. But this unit is a reaching zone when the overlying unit is removed by erosion and the upper few centimeter of the unit is weathered. This is observed in the NW part of the study area where the basalt is totally eroded and the Adigrat Sandstone found exposed to the surface then, through the above joints rainwater percolates and recharges the groundwater aquifer. As discussed in the geology this sandstone is found at higher topography forming cliff as a result this unit is not potential for groundwater storage. This is evidenced in the absence of productive well in this unit from the well inventory data. But as reported from water well drilling Agency Well completion report (1993) around Wukro a nearby basin, the Adigrat Sandstone is the main aquifer unit with hydraulic conductivity variation of 8.81-11.87m/d.

As there is no borehole in the Adigrat sandstone there is no any pump test data to see the hydraulic conductivity of this unit. However, the hydraulic conductivity of fractured system vary considerably and are dependent on aperture, frequency or spacing (density), length, orientation (random or preferred) wall roughness (asperities, including skin factor), presence of filling material, fractured connectivity, channeling (preferred paths)and the porosity and hydraulic conductivity of the rock. According to Gerit vanTonder and Yongxin Xu (1999), the hydraulic conductivity of fracture rock with smooth parallel walls is proportional to the square of the aperture as demonstrated by the following equation:

$$K_f = \frac{\rho g b2}{12\mu} \quad \text{------------------------------------Equation 6.1}$$

Where K_f : hydraulic conductivity

b: aperture

μ: dynamic viscosity

g: gravitational acceleration

ρ: Fluid density

However, the above formula doesn't consider spacing of the fractures due to this the empirical formula of Serfim (1968) is used to calculate the hydraulic conductivity of the formation. The formula is expressed as:

$$K = \frac{e^3 \gamma_m}{12d\mu} \quad \text{-- Equation 6.2}$$

Where e: Joint opening (aperture)

d: Joint spacing

μ: Viscosity of water at (20^0) from field measurement.

γ_m : Unit weight of water

*Source Bell (1990) Engineering geology, South Africa.

The hydraulic conductivity result using the above equation taking an average value of opening 0.5m and 5m of spacing results in an average value of 2.08m/d hydraulic conductivity of the formation. This shows that the Adigrat sandstone formation is a good aquifer when it is found in favorable topography and exposed to the surface. The hydraulic conductivity from the empirical formula is used in the classification because the pump test data seems a bit exaggerated, as the source data for the pump test are limited boreholes in number.

6.1.2 MODERATE TO LOW PERMEABILITY FORMATION

The rock units included in this formation are trap volcanic and the metavolcanics. Both of which are characterized by secondary porosity dependent on weathering and fractures.

6.1.2.1 TRAP VOLCANICS

They occupy higher lands in the northern parts of the project area. It comprises amygdaloidal and columnar basalts. The presence of amygdales in the vesicular basalts has reduced the primary porosity but the columnar joints facilitate infiltration, which increases the secondary porosity, and hydraulic conductivity. The trap basalt is moderately weathered with clay soil as by product. It is characterized by moderate productive aquifer and has fracture and weathering hydraulic conductivity. Due to the absence of the boreholes in this rock unit there is no pup test data but the hydraulic conductivity of the unit is considered from standard book of hydrogeology as 8.64x10-2m/d Freez and Cherry, (1979).

This rock as discussed above is vertically jointed and at places deeply weathered, due to this it has good potential of storage. However due to its topographic position and the presence of paleosols between the inter flow is forced to release its storage at the foot of the hills which is expressed by the moderate yielding spring at the locality of Mywoyni (0543802E, 1571660) and other low yielding springs at the topographic breaks.

The density of faults in the highland is quite low. Much of the water bearing zones in the highlands is within the upper few tens of meters in the weathered volcanic sequence.

6.1.2.2 METAVOLCANIC ROCK

As discussed in geologic part this rock unit is represented by geosynclinal formations that accumulate in the subsiding marine basins. It has undergone weak metamorphism (green schist farcies) and the rock formations contain fracture hydraulic conductivity and weathered zones. In general the Precambrian rocks are almost with low hydraulic conductivity and are classified as aquifuge.

As per the field observation however, locally there are some joints and fracture zones and weathered top layer that provide productive zones. The weathered top part is about 10-50m thick as per the depth of the number of boreholes in this unit. According to WAPCOS (2002), the north-South trending joints associated with the regional structure, cross cutting quartz veins and schistosity and foliation plane are the principal conduits for vertical infiltration and where they crossed by streams they have good storage. In addition to the above condition their topographic location has increased the potential for groundwater storage this supported by the presence of a number of bore holes located in this unit as per the inventory data of the study area. This rock unit is located in the discharge zone as evidenced from the grid deviation map and the water level map.

According to the pump test result the metavolcanic rock unit has 0.09m/d hydraulic conductivity. Taking the field observation and pump test data result this rock unit is classified under moderate to low hydraulic conductivity formation which is also confirmed by the presence of wells and springs in the formation with relatively moderate to low yields.

6.1.2 VERY LOW PERMEABILTY FORMATION

This formation includes the rock unit, which we discussed as Edaga Arbi glacials. As per the discussion in the geologic section this is dominantly shale and clay containing unit with high porosity and very low hydraulic conductivity. Stratigraphically it is found overlying the Enticho Sandstone and underlies the Adigrat sandstone and occurred forming gentle slopes with common deep gull eying to bedrock. It is characterized by high drainage density. It has variable thickness usually about 10m. It acts as aquiclude. There is no productive well inventoried in this rock, which indicates that this unit is not potential aquifer both from its topographic position and the hydraulic conductivity nature. The higher drainage density from the geomorphologic study of the study area confirms this. Therefore, they are classified as very low permeability formation having less than 0.09m/d.

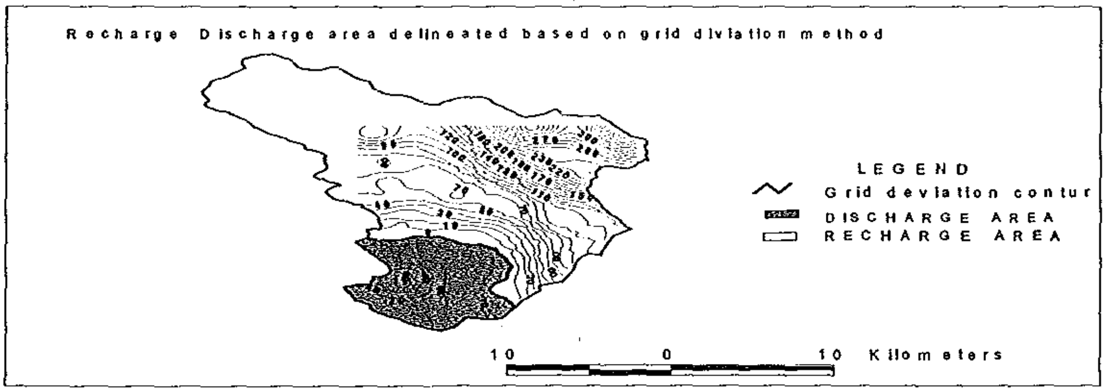
6.2 GROUNDWATER MOVEMENT RECHARGE AND DISCHARGE

6.2.1 GROUNDWATER MOVEMENT

Groundwater in unconfined aquifer moves from topographically high area (recharge) to low area (discharge). In a recharge area, the potential energy decrease with depth, which results in downward movement of water. Between the recharge and discharge areas, groundwater flow is horizontal. In a discharge area, the potential energy increase with depth, which results in upward movement of ground water.

To identify the recharge and discharge zone of the study area the water level measurement of about 57 bore wells was used. The method used to determine the recharge and discharge zone is the grid deviation. That is the difference between the water level of the well below ground level and the elevation of the surface and the result is deduced by the mean groundwater level elevation from mean sea level. The result of the grid deviation is positive, zero, and negative. Using the result a contour of the study area is made which shows positive contour are in the recharge zone and negative contour shows the discharge zone. The area between them is identified by the zero contours. The results are displayed in figure-6.2 below. According to this result in general most of the upper part of the study area is classified as recharge zone and the down stream part as discharge zone. The area classification using bore hole shows general similarity, which confirms the hypothesis of the grid deviation.

Figure 6.1 Recharge and Discharge zone delineated using Grid deviation method from Borehole data.



Geologic conditions (type and sequence of rocks) and structure in the subsurface can have major control on the direction and rate of groundwater flow. The first systematic study to define the movement of water through porous materials was performed in 1856 by Henry Darcy, a French engineer. Based on his observation he formulated as:

$$Q=KAh/l \text{ ------------------------------------ Equation 6.2}$$

Where

Q: volumetric rate of water flow

A: Crossectional Area

h: The difference in pressure head

l: Length of the flow path

K: Hydraulic conductivety

In the study area, groundwater flow follows the topography of the basin. Local groundwater flow is different from regional groundwater flow in that the local flow direction varies with in small areas according to the topographic & structural effect at shallow depth and the regional groundwater flow has general direction of flow at depth. The local groundwater flow in this area supports the regional flow as evidenced by the groundwater flow hand dug wells and the presence of many springs following the topography (Figure 6.3). Accordingly, local flows have general directions of flow towards the Suluh River. The main (regional) flow is from North to South direction i.e. from high land of the basin to the low land of the basin along the central (Figure 6.3).

The two principal functions of aquifer are to store and transmit water. Groundwater is transmitted through aquifers along the hydraulic gradient from areas of high head to areas of low head due to the driving force of gravity, generally (for unconfined aquifers) confirming to the slope of the land surface. Moore, 2002.as noted above, groundwater flows in response to an energy gradient i.e. it moves or flows from high energy or head to low energy.

The flow direction of the groundwater system of the study area was also treated from chemical point. That is based on the principle that as groundwater moves along its flow paths in the saturated zone, increase total dissolved solids and most of the major ions normally occur. According to Freez & Cherry (1979), it has been observed in groundwater investigations in many parts of the world that shallow groundwater in recharge areas is lower in dissolved solids than the water deeper in the same system and lower in dissolved solids than water in shallow zones in the discharge areas.

Based on the above principle analysis on the Total Dissolve Solid (TDS) of the collected Samples was done for both the hand dug wells and bore wells of the study area. Contour was constructed using the TDS of the collected samples of both hand dug and bore well. However the result shows no definite trend in the direction of flow. This is because of the existence of different lithologic units through which the groundwater moves so that it will dissolve different chemicals at different rates.

However, the grid deviation and the water level contour show a general down stream flow following the topography except some mounds and depressions, which might be due to local recharge of the groundwater by an upward seepage and due to pumping from wells or down ward seepage respectively.

6.2.2 GROUNDWATER DISCHARGE

The longest segment of the hydrologic cycle is completed when groundwater is discharged at the surface or into bodies of surface water. The discharge may take place in a variety of ways of which spring, artificial (Hand dug wells, Boreholes) and evapotranspiration from soils vegetations from seepage (Davies& Dewiest, 1966).

6.2.2.1 SPRING

Springs are natural groundwater discharge at the land surface and are important sources of hydrogeological information. Springs can be classified in many ways. They can be classified based on the quantity of discharge, temperature, gravity and /or artesian, morphology and structure.

Based on the Mainzer's classification of spring discharge most of the springs in the study area belongs to the discharge magnitude of Sixth order with discharge amount of between 0.0631l/s-0.613l/s. According to the structural classification most of the springs are bedding/contact and joint springs, and most belongs to the hillside spring according to the geomorphologic classification. Based on the temperature they are all cold-water springs. As per the inventory data by WAPCOS (2002) forty (40) cold water data was collected see Figure 6.4. All the springs collected are perennial with average discharge of 0.44l/s. From the average discharge of the forty springs there is annual discharge of $0.56x10^6$ m^3.

6.2.2.2 WELLS

The geographic location of the water points in the upper Suluh is most uneven mainly determined by the distribution of hydrogeological units, geomorphology, water use, location of population settlements accessibility and current pressure of water demand for water supply. When we see the distribution with respect to the geological formations the major distribution of existing water points is in the Enticho sandstone, followed by weathered alluvial deposits, and Precambrian metavolcanics.

6.2.2.2.1 HAND DUG WELLS

Hand dug wells are constructed in shallow depth by excavation in 2-6m diameter in a depth of range of 3-20m. These are mostly located in the shallow weathered overburden or alluvial deposits intervening rock formations. As per the inventory data by WAPCOS (2002) no yield is measured for the hand dug wells.

6.2.2.2.2 BOREHOLES

The depth of boreholes varies up to 91m with general depth range 30-40m. Table 6.2 below provides the hydrological characteristics of boreholes indicating the drilling depth 21-91m, the water strike depth 0-0.52m, the thickness of aquifer screened 6-30m, and the well yields in the range of 2-10l/s with mean yield about2.9l/s.

Table-6.3 Hydrologeological Characteristics of the boreholes in the upper suluh

S No	Name of Locality	Borholes	Depth drilled (m)	Water Stricke (m)	Aquifer screened	Well yield (l/s)

					(m)	Range	Mean
1	Ganta afeshum	10	30-80	0-31	6-12	0.5-9	3.5
2	Hawzen	22	21-82	3-18	6-22	0.5-10	2.4
3	Sinkata	33	25-91	6-52	6-30	0.5-8	2.7
Total		65	21-91	0.52	6-30	0.5-10	2-9

Most of the wells are located in the sandstone and metavolcanic rocks of the study area. From the given above number of boreholes and given average pumping capacity of the boreholes the amount of extraction of water from the through pumping of boreholes is estimated to be about 5.94×10^6 m^3.

6.3 GROUNDWATER RESERVE ESTIMATION

The area of the , which is likely to be contributing to the groundwater recharge occurrence, has also been assessed. The groundwater levels vary from area to area as per local geomorphology, geology, structural conditions, hydrogeology and availability of the rainfall infiltration capacity. The fracture hydraulic conductivity varies from one hydrogeological unit to another as per the local and regional conditions, and accordingly the specific capacity also varies with the nature of hydrogeological units. Therefore, keeping in view of the various aforesaid factors, the estimation of groundwater resource is made tentatively for the likely saturated column of 30 m below water table (variable) in different hydrogeological units of the upper Suluh as follows. The 30 m saturated column is considered at present because mostly the depth of existing boreholes is around 30 m.

According to the inventory data analysis two aquifers that is shallow and deep aquifers are identified. The shallow aquifer is commonly found in the alluvial deposit and weathered top part of the formations. The depth of the wells varies between 3-22m with average depth of 10m and average static water level of 3.5m below groundwater level. The second aquifer is deep aquifer mostly confined to the Enticho sandstone, and Metvolcanic the depth of the wells varies between 25-91m with average depth 50m and average static Water Level of 10m. Therefore, by taking the average saturated water column of each lithology a unit from the inventory of wells made by WAPCOS (2002), the estimation of the groundwater potential of the catchments is made.

The recommended specific yield of the groundwater estimation methodology of India (1997) for different hydrogeological unit is considered because of the availability of data. The groundwater estimation is made by considering the contribution of slope and with out consideration. This is because of the influence of slope in infiltration and storage of an aquifer. In the consideration of the slope of the slope map developed by the WAPCOS, (2002) was used. The area with a slope of 0-20% was considered flat and with more than 20% as hilly. For the hilly area only 25% was considered in the calculation of the groundwater potential estimation see table 6.3. As a result 336.54MCM amount of water is calculated by taking into consideration of slope. On the other hand the result of calculation without slope consideration is 381.06MCM. Comparing the two there is no significant difference between them but to minimize the exaggeration, due to the assumptions of continues and inter connected aquifer. But actually the aquifer is discontinues due to structure, geomorphology, stratigraphic relation between layers and other factors, which are not considered. Therefore, the result from slope consideration is taken as the groundwater potential of the upper suluh .

To calculate the reserve the aerial coverage of each lithlogic unit is calculated then find the average water column of each lithology and their specific yield. By multiplying these three parameters we fined the estimated reserve of each lithology. Finally by adding the reserve of each lithology we fined the estimated reserve of the area under consideration. Since all the land surface particularly areas with higher slope do not contribute for reserve and infiltration only 25% of the hilly area (slope>20%) is considered see table 6.3.

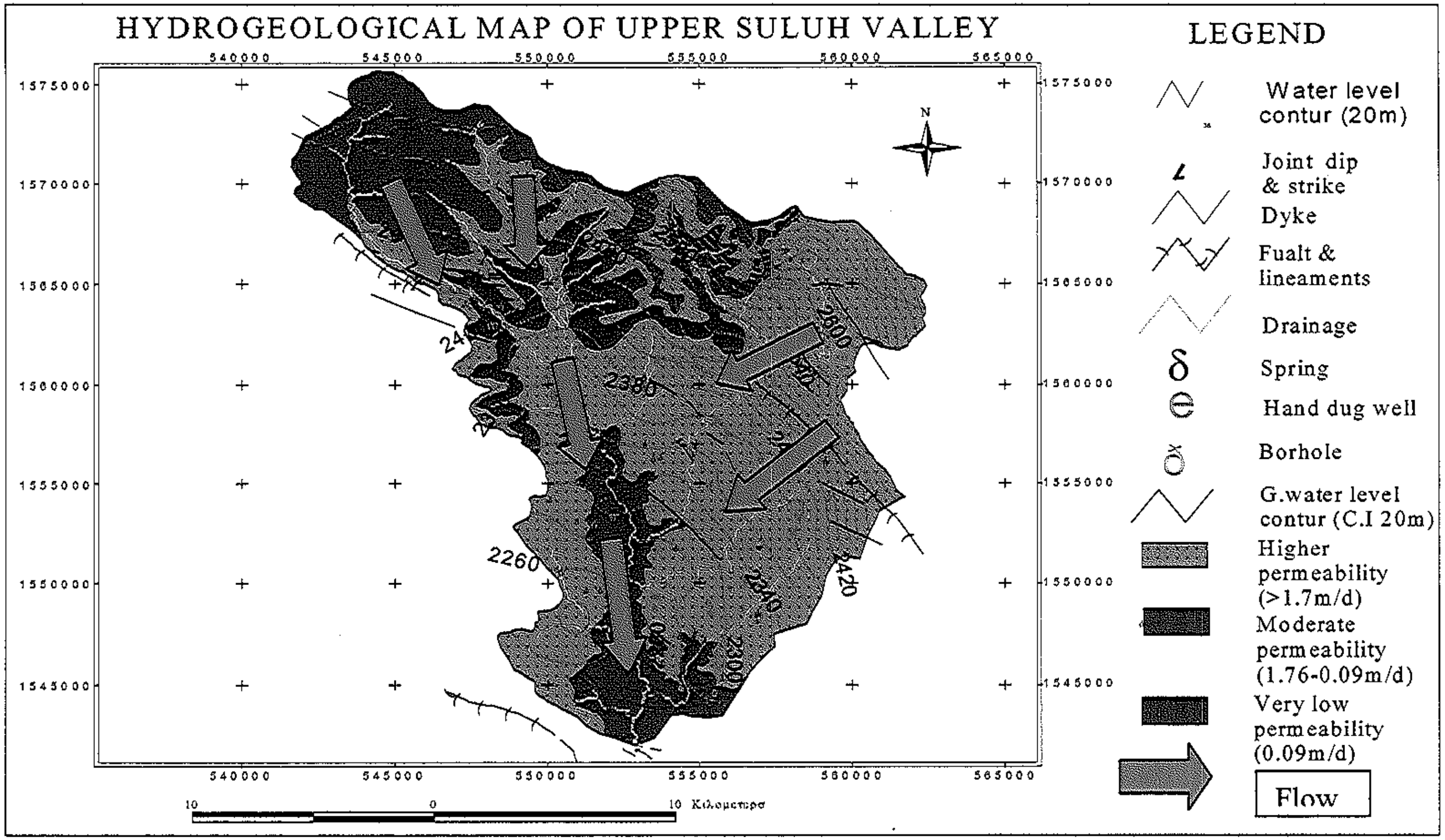
Table-6.4 The groundwater reserve estimation with and with out the consideration of the slope of the land surface.

Hydrogeological unit	Aerial coverage of each Lithology in Km^2	Arial coverage of each lithology considering slope25%	Average saturated water column (m)	Standard specific yield of each lithology (%)	Estimated GW Potential Without Slope (Mm3)	Estimated GW potential Considering Slope (Mm3)
Alluvial Sediments	>4.42*	4.42	6.5	7	2.01	2.01
Trap Basalt	60.99	26.67	6.5	2	7.93	3.47
Adigrate formation	54.81	30.77	40	3	65.77	36.92
Enticho Sandstone	243.1	235.84	40	3	291.72	283.01
Tsaliet Metavolcanics	42.43	35.46	20	1.5	12.73	10.64
Edaga Arbi glacials	35.80	19.42	5**	0.5	0.9	0.49
Total					381.06	336.54

*Although small aerial extent as map able unit they are distributed as small patches in the stream sides intermountain depression and hill foot area they are important to consider them.

**Since most of the thickness of this unit is10m it is assumed that one half is saturated.

Figure6.2 Hydrogeological Map of Upper Suluh



CHEPTER SEVEN

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 rainfall reactions occurring below the land surface, and cultural effects resulting from human activities (Hem,1989).

Because of the above facts, in any basin the chemistry of water varies from place to place and this variation has an impact on different water utilization programs such as water supply, irrigation, industry, etc. Therefore, to see the general chemistry variation (spatial variation), the possible sources for the variation, and the suitability of the groundwater for different uses with particular emphasis to irrigation water samples have been taken for chemical analysis and field parameters were measured at field in the basin.

7.1 MAJOR PROPERTIES OF WATER SAMPLE

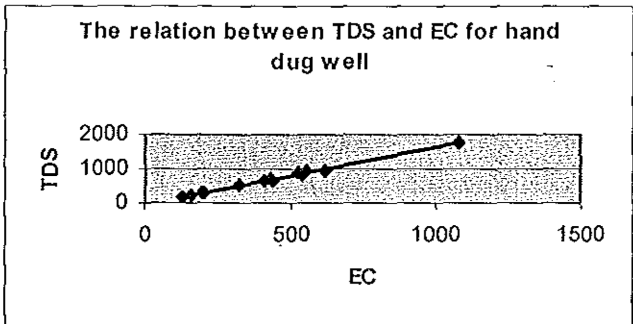
Before the field work the available chemical data of the study area was collected and checked for their reaction error. The collected data includes WAPCOS (2002), Tenalem (2003) and Engida (2004). The result shows that most of the samples are with an error of more than 20%. More over, the samples with an error within the permissible limit lacks some of the chemical parameters, absence of location and those accepted ones are totally out of the study area. Due to this reason only the primary data are used for analysis and conclusion of this study.

Measurement of some important parameters such as PH, Temperature, TDS and EC were conducted in the field using standard instruments for field measurement. This is to understand the difference and similarity between field and laboratory result and check the accuracy of the laboratory result in addition to the electro chemical neutrality method. The chemical analysis has been carried out at Water Works Design and Supervision Enterprise

Water laboratory. Representative water samples were collected from existing water bodies, which have been surveyed to study water quality condition to classify water types. Water quality, pollution and their use for certain purposes have been determined based on chemical analysis.

7.1.1 ELECTRICAL CONDUCTIVITY

Electrical conductance or conductivity is the ability of the water to conduct an electric current. The unit is microsiemens per centimeter (μs/cm).



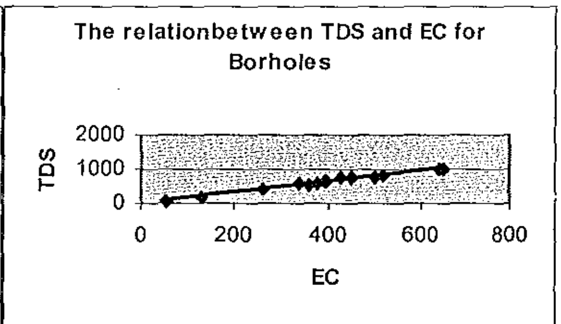


Figure7.1 Field to Laboratory relationship of the Electrical Conductivity from Boreholes and hand dug well Data

Table-7.1 Results of chemical analysis of major ions, TDS, EC and PH

No.1	Code	TDS	EC	PH lab.	Na	K	Ca	Mg	Cl	HCO3	SO4	No3	TH	SAR	%Na	RSC	pHc
1	SUDW1	440	673	7.4	35	15.9	96.1	17.8	24	354	38.8	17.5	313	0.86	23.48	5.32	18.4
2	SUDW2	1078	1768	7.23	48	1.2	178	102.6	186	798.8	680.8	10.5	865.8	0.71	10.82	8.74	41.5
3	SUDW3	615	928	7.15	18	0.8	173.6	14.6	56	401.6	66	11.5	492.8	0.35	7.51	3.27	25.9
4	SUDW4	524	854	7.22	54	3.5	133.5	8.6	104	285.9	47.5	17.5	368.5	1.22	24.80	1.98	21.1
5	SUDW6	126	175	6.67	4.3	0.9	26.7	5.4	4	79.42	7.4	18	88.8	0.20	10.53	0.82	4.6
6	SUDW8	540	842	7.19	50	3.3	124.6	16.2	75	333.6	71.3	21.5	377.4	1.12	22.96	3.36	21.5
7	SUDW10	160	262	6.84	9.2	0.8	41.8	7.02	7	158.8	2.6	12.5	133.2	0.35	13.58	2.53	7.8
8	SUDW11	324	510	6.89	30	1.4	81	4.9	23	240.3	21	12.5	222	0.87	23.11	3.42	13.8
9	SUDW12	412	647	6.99	29	1.7	106.8	9.7	66	248.6	37	10.75	306.4	0.72	17.50	2.00	16.8
10	SUDW14	434	700	7.42	62	2.7	93.5	8.6	50	285.9	63	17.7	268.6	1.64	33.90	3.98	17.4
11	SUDW15	200	290	6.48	9.9	2.5	47.2	4.9	24	84.5	20.3	33	137.6	0.37	15.16	0.00	6.9
12	SUDW16	550	912	7.28	42	2	120.2	35.1	55	449.3	60.7	12.5	444	0.86	17.36	5.80	24.1
13	SUDW17	192	291	7.6	12.4	1	49	6.5	10	165.6	15	12.5	148.7	0.44	15.88	2.44	8.7
14	SUDW18	160	211	6.52	8.9	1.7	31.2	6.5	12	81.7	16.6	20	104	0.38	17.00	0.58	5.4
15	SUBH-1	54	83	6.43	3	0.9	13.4	2.7	5	43.1	3.2	4	44.4	0.19	14.64	0.52	2.4
16	SUBH-2	430	787	8.1	192	4.5	8	3.2	32	426.6	34.3	10.7	33.3	14.46	92.70	13.32	16.4
17	SUBH-3	520	842	7.09	46	9.1	120.2	18.9	71	344.9	66	18	277.4	1.03	22.75	3.72	21.2
18	SUBH-5	450	740	7.7	100.6	6.3	34.7	21.1	43	351.7	59.7	7	173.2	3.31	56.49	8.04	15.4

19	SUBH-6	394	643	7.17	29	1.3	97.9	21.6	23	381.2	24	5	333	0.69	16.20	5.80	19.1
20	SUBH-8	650	1015	7.22	40	4.7	129.1	47.5	78	472	89.7	17.5	517.3	0.76	15.15	5.06	26.3
21	SUBH-10	380	613	7.22	24	1	93.4	24.3	20	383.5	11.4	5	333	0.57	13.77	5.88	18.7
22	SUBH-11	130	172	6.15	7.2	0.7	22.3	5.9	17	45.4	13.2	21.5	79.9	0.35	17.08	-0.12	3.8
23	SUBH-12	500	770	7.14	16.5	70	83.7	24.8	29	397.1	68.6	12.5	310.8	0.41	28.67	6.77	17.7
24	SUBH-13	360	558	7.17	19	1.5	94.3	14.04	15	351.7	19.3	7.5	245.5	0.48	12.81	5.65	17.2
25	SUBH-14	340	561	7.36	24	2.5	81.9	16.2	21	313.1	25.6	7	270.8	0.63	16.90	4.82	15.7
26	SUBH-15	450	757	7.28	34	1.6	111.3	13.5	67	295	63.3	14.2	333	0.81	18.51	2.98	18.6
27	SUBH-16	260	405	7.34	9.1	1	75.6	5.4	10	204.2	14.8	22	210.9	0.27	9.06	2.47	11.8
28	SUBH-17	640	980	7.09	68	1.6	129.1	22.7	91	358.5	134.6	12.5	415.1	1.45	26.42	3.41	23.6
29	SUSP -1	184	301	7.39	9.6	2.9	40.1	13.5	18	127.1	18.5	20	155	0.33	13.58	1.04	7.6
30	SUSP -2	221	330	7.91	14	1.9	51.6	5.94	10	145.2	13.7	27.8	153.2	0.49	17.61	1.69	8.6

TDS in mg/l and EC in µs/cm Major anions and cations are in meq/l

7.1.2 TOTAL DISSOLVED SOLID (TDS)

As water flows through rock media or on the earth's surface it may dissolve many salts and some types of organic matter. The amount of dissolved materials in natural water is one of the basic measures of the water quality. Dissolved material can also be added to groundwater by human activity. The total dissolved solids (TDS) thus include all the solid material in solution. Therefore, it is determined from the weight of dry residue remaining after a sample of water has evaporated at a temperature of $105C^{o}$. The values of TDS have direct correlation to the EC showing zonal variation corresponding to the EC values. The variation shows that the higher TDS are concentrated in shallow aquifer areas, where there is higher clay content derived from the glacial material.

Groundwater can be classified based on the total dissolved solid. Freez & Cherry (1979) has classified the groundwater in to four based on the TDS (table 7.2) below.

Table 7.2 Groundwater classification based on total dissolved solids.

Category	Total Dissolved Solid (mg/l)
Fresh water	0-1000
Brackish Water	1000-10,000
Saline Water	10,000-100,000
Brine Water	>100,000

Source: Freez & Cherry (1979)

According to the above classification the water samples of the study area have a TDS of less than 1000 mg/l, which shows that the groundwater in the study area is fresh water.

7.1.3 HYDROGEN ION ACTIVITY (pH)

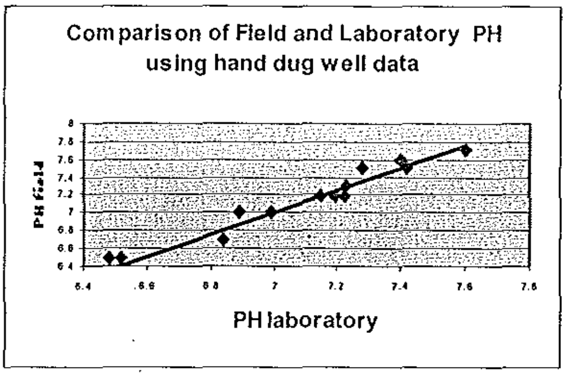
The total hydrogen concentration is not normally determined for a solution; instead the activity of the free, uncombined hydrogen ion is measured. Because of the reactivity of hydrogen ion, its activity (or effective concentration) in groundwater is an especially important parameter. The activity of hydrogen is measured as the pH of the water, which is defined as follows:

$$pH = -Log\,[H^{+}] \text{--Equation 7.1}$$

Where: H^{+} is the hydrogen ion concentration

Log is the logarithm to base ten

A value for pH should be determined in the field and in the laboratory immediately the water sample is received. For most natural waters, pH is in the range about 6 to 8.5 Davis & Dewist (1966). In this range the commonest reaction to result in a pH change is loss of carbon dioxide. This occurs rapidly and results in an increase in pH. Although an increase in pH is to be viewed with concern, there is no specific difference between field and a laboratory determined pH values beyond which the geologist should question the entire analysis. Comparison of the field and laboratory pH values relay acts as a check to warn of possible detrimental changes that may take place in the water sample between the field and the laboratory. The graph of the field and laboratory pH of the study area shows a good linear relation ship which implies that there is no detrimental changes that have been taken place in the water sample between the field and the laboratory (see Figure 7.2).



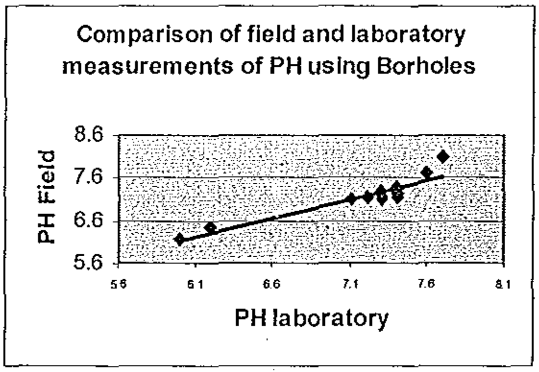


Figure 7.2 Showing the comparison between field and laboratory pH of Upper Suluh

According to Davis & Dewist (1966) the pH values indicate the presence of the type of carbonate species carbonic acid, bicarbonate and carbonate. Those at higher pH greater than 8.2 the carbonate ion exists, between 4.5 to 8.2 is a measure of bicarbonate ions and below pH of 4.5 indicates most of the bicarbonate ions are converted to carbonic acid molecule. This concept is confirmed in the study area. That is most of the water samples are with pH value that range 6.48 to 7.6 in the hand dug wells and 6.15 to 8.1 values in the boreholes. Which shows that the carbonate exists in the form of bicarbonate. It is observed that water samples from the clay containing sediments have higher pH value than water samples from the other formations. This is attributed to the increased rate of reaction with increased surface area, which increses the dissolution of minerals.

7.2 MAJOR CATIONS AND ANIONS

According to Freeze & Cherry (1979) the major constituent of the groundwater occurs mainly in ionic form and is commonly referred to as the major ions. These are Na^+, Mg^{2+}, Ca^{2+}, Cl^-, $HCO3^-$ and $SO4^{2-}$. The total concentration of the six major ions normally comprises more than 90% of the total dissolved solids in the water, regardless of weather the water is dilute or has salinity greater than seawater.

The laboratory result of the major ions of 30 samples with 2 springs, 18 hand dug wells and 10 borehole water samples was used to describe the chemistry of the study area. No river or pond water sample was taken, as all of them have no water at the time of sampling. The precision and accuracy of all analysis was verified by ionic balance and all were within +10% except four samples, which range between +15percent.

Table 7.3 The mean value of the major ions in the water sample analysis in mg/l.

Source Type	Na	K	Ca	Mg	Cl	HCO_3	SO_4	NO_3
Han dug well		2.81	93.09	17.74	49.71	283.43	82	16.28
Bore hole		7.62	78.21	17.27	37.29	312	44.84	11.74
Spring		2.4	45.85	9.72	14.00	136.2	16.1	23.9

7.2.1 CATION

In the analyzed water sample most of the dominant constituents are Na and Ca cations. The water sample with the highest sodium concentration is SUBH - 2 with sodium concentration value of 192mg/l followed by SUBH -5 with 100.6mg/l. Boreholes, springs and Hand dug wells have an over all average value of 78.21mg/l, 45.85mg/l and 93.09mg/l of calcium concentration respectively.

The concentration of calcium ion varies between the ranges of 8mg/l to129.1mg/l with an average value of 78.21mg/l in boreholes. The variation of the cation depends on the spatial variation of the clay and shale material overlying the aquifer.

The higher amount of calcium in the groundwater is related with the presence of the clay and shale material of the sedimentary rock. Which release calcium from the dissolution of the calcium containing minerals such as calcite and other carbonate containing rocks. This is confirmed by Davis & Dewist (1966) that states sub surface waters in contact with sedimentary rocks of marine origin derive most of their calcium from the solution of calcium containing minerals. Since the dykes are composed of sodium containing minerals such as plagioclase when weathered they release sodium cation which increase locally the amount of the sodium ion in the ground water. From table 7.3 it is observed that there is higher amount of calcium in boreholes and springs than hand dug wells. On the opposite there is lower concentration of sodium in boreholes and springs than hand dug wells. This down ward decrease of calcium with parallel increase of sodium concentration is attributed to the exchange of Na+ from the clay materials.

7.2.2 ANIONS

The major anions of water samples of the study area in their decreasing order are: bicarbonate, chloride, sulfate and nitrate.

The water samples are characterized by higher bicarbonate and lower anions of sulfate and chloride. Since glacial deposits cover most of the study area it can be explained according to the following. As discussed in the geology part the area is covered by glacial deposits, which are composed of clay, thin layers of carbonates and boulders granite and pebbles of metamorphic carbonate origin. In addition the Enticho sandstone is at places cemented with calcite minerals. This has attributed to the higher amount of carbonate ion in the ground water in addition to the atmospheric and soil source of CO_2.

The chemistry of groundwater in glacial deposits is quite variable, because these deposits are composed of mixtures mineralogical assemblages derived by glacial erosion of bedrock strata and of preexisting glacial sediments. That is, Freeze & Cherry (1979) has stated that the glacial materials are composed of carbonate minerals derived by glacial erosion of Paleozoic bedrock near the shield and erosion of local zones of marble or other metamorphic rocks that contain carbonate minerals. Freez & Cherry has classified the ground waters of the glacial deposits into three based on some generalization. That is Type I waters, Type II waters and Type III waters. The waters of the study area are characterized by slightly alkaline, fresh waters (<1000 mg/l of TDS), where $Ca^{2+}$and $Mg^{2+}$are the dominant cations and HCO_3^- is the dominant anion. These waters are hard or very hard. According to the above classification the water of the study area belongs to Type II waters.

From the above table it is also observed that the sulfate ion is very small in all the sources but there is a small increment in boreholes and springs as compared with the hand-dug wells. The lower concentration of sulfate is attributed to the absence of SO4 bearing rocks such as gypsum and anhydrite except at specific locality where SUHD-2 is located.

The other dominant anion found is nitrate, which varies from 4 to 28 mg/l. It is observed that there is higher amount of nitrate in hand-dug wells and springs as compared with the boreholes except SUBH-3 and SUBH-8 with 18mg/l. According to Edmunds (1973) as cited in Freez & Cherry (1979) the decrease in nitrate concentration is attributed to the process of denitrification, which requires denitrifying bacteria and a moderate redox potential. In addition, the source for the relative increase can be due to pollution from anthropogenic sources.

7.3 WATER TYPE CLASSIFICATION

An important task in hydrogeochemical investigation is the compilation and presentation of the chemical data in a convenient manner for visual interpretation. There exists different methods for water classification; it is believed that methods based on the major ions are the best for practical purposes. This type of classification uses a percentage of mill equivalents per litter of the anions and cations. It combines two chemical families of main constituents of anions (Ca2+, Mg2+, Na+ K+) and cations ($HCO3^{+}$, CO3 $^{2-}$, $SO4^{2-}$, Cl^{-}) to classify water type. For this the trilinier diagram developed by Hill (1940) and Piper (1944) as cited in Freez & Cherry (1979) is used with the help of AQUACHEM program.

This method is in common use because in addition to the capacity of showing many more samples at once it shows mixing effects between different water samples, when two projected line cross each other. In addition the degree of mixing can also be directly read from the crossing point or it may tell the water of the same origin.

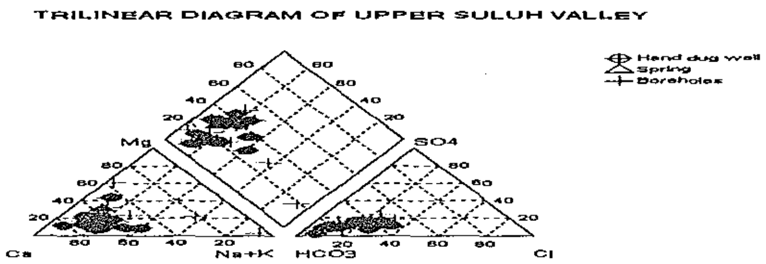


Figure7.3 Showing the type of water in the upper Suluh .

It is observed from figure 7.3 that at least there are two types of waters. These are the Ca-Mg-HCO_3, and Na-K-HCO_3. The higher amount of the sodium cation at place can be explained by the presence of plagioclase feldspar from the dykes in the study area, which is composed of quartz and plagioclase feldspar. When the plagioclase mineral containing rock is in contact with the flowing ground water it gets dissociated and releases the sodium cation. It is also noted in Freeze & Cherry (1979) that Cl and SO_4 are not significant constituents in silicate rocks and there is no tendency towards development of SO_4 or Cl as groundwater moves along flow paths in these rocks.

7.4 WATER QUALITY

An immediate purpose of the usual quality of water study is to determine if the water is satisfactory for a purposed use. Accordingly, the subject of water analysis interpretation must often include some consideration of standards and tolerance that have been established for water that is to be used for various purposes. According to Driscoll (1986) the three main class of use are domestic (household), agricultural and industrial. In this study the water of the upper suluh will be treated with respect to the above uses with particular emphasis to irrigation.

7.4.1 HARDNESS

According to Freeze & Cherry (1979) hardness of water is defined as its content of metallic ions which react with sodium soaps to produce solid or scummy residue and which react with negative ions, when the water is evaporated in boilers to produce solid boiler scale (Camp, 1963). Hardness is normally expressed as the concentration of Ca^{2+} and Mg^{2+} expressed in milligram per litter equivalent $CaCO_3$. It can be determined by substituting the concentration of Ca^{2+} and Mg^{2+}, expressed in milligram per liter, in the expression

Total Hardness $=2.5(Ca^{2+})+4.1(Mg^{2+})$ ....Equation 7.2

The classification of Durfor and Becker (1962) as cited in Hem (1992) has been used to classify the water based on hardness to see the variation and similarity between samples with respect to water use particularly household use.

Table 7.4 Hardness range in mg/l of $CaCO_3$

Hardness range		Hardness of samples		
		Hand dug wells	Springs	Boroles
0-60	Soft			1,2
61-120	Moderately hard	6		11
121-180	Hard	10,15,17,18	1,2	5
More than 180	Very hard	1,2,3,4,8,11,12,14,14,16		3,6,10,12,13,14,15,16,17

The numbers are sample codes

The total hardness of the study area varies 88.8 to 865.8 mg/l of $CaCO_3$ in hand dug wells, 33.3 to 517.3 mg/l of $CaCO_3$ in boreholes and about 155mg/l of $CaCO_3$.The highest hardness values are recorded for hand dug wells with the highest average value of 305.06 mg/l and 255.54 mg/l for boreholes and 154.1mg/l for springs. In the study area only three water samples have total hardness less than 100mg/l. According to the above range of classification waters from hand dug wells and boreholes are very hard and from springs are hard.

Though there is no specified range of limit for hardness in drinking water Freez & Cherry (1979) stated that water used for boiler feed will cause excessive scale formation (carbonate mineral rainfall) if the hardness is above about 60- 80 mg/l. He also stated that water softening is common practice in many communities where the water supply has hardness greater than about 80 to 100mg/l. This shows that water with 100mg/l of hardness has a problem for household use. This shows that the water of the study area needs treatment before use with respect to household.

Ramakrishnan (1998), for irrigation uses hard water is superior to soft water. It is often said that hard water makes soft soil and soft water makes the soil hard. This is because calcium and magnesium present in the hard water flocculates the soil, colloids structure and hydraulic conductivity. There fore, the groundwater of the study area can be considered good for irrigation with respect to hardness.

7.4.2 SODIUM ADSORPTION RATIO (SAR)

Water quality problems in irrigation include salinity and toxicity. Excessive salinity occurs when there is an accumulation of salts in topsoil. Sodium has far-reaching effects on soils. Most sodium in natural water originates with the release of soluble products during the weathering of plagioclase feldspars.

The particular consequence is the ratio of sodium to calcium and magnesium. When sodium-rich water is applied to soil, some of the sodium is taken up by clay; the clay gives up calcium and magnesium in exchange. This reaction, called Base Exchange alters the physical characteristics of soils and can even lead to growth retardation. Clays that takes up sodium becomes sticky and slick when wet and has low hydraulic conductivity. When dry, the clay shrinks into hard clods and that are difficult to cultivate.

The United States Salinity Laboratory (1954) as cited in Hem (1989) proposed that the Sodium Adsorption Ratio (SAR) using the following relation could calculate the sodium effect.

$$SAR=\frac{Na}{\sqrt{(Ca+Mg)/2}} \quad \text{.........Eqation 6.3}$$

The three ions are expressed in mill equivalent per litter. Development of excessive sodium in soils will result from irrigation water that has high SAR values (18 or above). Values below 10 indicate little danger of sodium hazard.The United States Department of Agriculture has developed a classification with reference to the sodium adsorption ratio as an index for sodium hazard and specific electrical conductance (EC) as an index of salinity hazard.

Table7.5 Qualitative classification of water based on the EC and Alkali hazard for irrigation.

Water class	EC in μS/cm	Alkali hazard (SAR)
Excellent	Less than 250	Up to 10
Good	250 – 750	10 –18
Medium	250 – 2250	18 –26
Bad	2210 – 4000	Greater than 26
Very bad	Greater than 4000	-

Source: US Regional laboratory published in 1954

Using the above formula the SAR value of the water samples of the study area is calculated the result shows that the samples from hand dug , boreholes and spring except one are with SAR value of less than ten. But SUBH -2 has SAR value of 11.43. In addition the water samples of the study area showes an EC varation from 83 to 1768 μS/cm. That is an average value of EC 647.4μS/cm, 627.21 μS/cm and 315.5μS/cm is observed from hand-dug wells, boreholes and springs respectively.

So, the result shows that all of the groundwater is excellent for irrigation with respect to SAR vales and good for irrigation with respect to salinity. Considering the sodium hazard it is also possible to classify water for irrigation according to the following formula and EC values of water.

%Na = (Na+K)/(Ca+Mg+Na+K)*100------------------------Equation 7.4

Table 7.6 Qualitative classification of water based on the EC and Alkali hazard for irrigation.

Water class	EC in μS/cm	%Na
Excellent	Less than 250	<20
Good	250 – 750	20-40
Permissible	250 – 2250	40-60
Doubtful	2210 – 4000	60-80
Unsuitable	Greater than 4000	>80

Source: US Regional laboratory published in 1954

The calculated result of the %Na also shows that groundwater in the area belongs excellent to good except SUBH 5 with56.5%Na and SUBH -2 92.7% Na values which belong to permissible and unsuitable respectively.

The dominant soil in the study area is Sandy loam WAPCOS (2002) it can accommodate much salinity and sodium hazard the presences of patches of black cotton soil and unsuitable water quality at places needs careful management and handling with respect to sodium and salinity hazard.

7.4.5 RESIDUAL SODIUM CARBONATE

It is defined, as twice the amount of carbonate or bicarbonate water would contain after subtracting an amount equivalent to the calcium plus the magnesium. It is there for expressed by the formula

RSC =2*(CO3+HCO3) -(Ca+Mg)-------------------------------Equation 7.5

Eaton (1950) as cited in the Ramakrishinan (1998) contended that carbonate and bicarbonate ions might have an indirect effect on water quality through the decrease of calcium and magnesium there by increasing the percentage of sodium. This is particularly more when the carbonate and bicarbonate ions are in excess of calcium and magnesium. This excess of carbonate and bicarbonate combines with sodium to form sodium bicarbonate, which affects the soil structure.

According to US salinity laboratory hazards do exist when waters high in bicarbonate and low in calcium are used for irrigation. It was proposed therefore that waters containing more than 2.5meq/l of residual sodium carbonate are not suited for irrigation that those containing 1.25-2.5meq/l are marginal, and that those containing less than1.25meq/l are probably safe.

The value of the residual Sodium ratio of the samples shows variation among the different sources. That is in hand dug well, and boreholes have RSC value of 0.0022-8.7402, -0.11814-13.32 respectively.

According to the analysis result three of the hand dug samples are classified as safe (<1.25meq/l) other three samples of hand dug wells are marginal with the remaining samples being unsuitable for irrigation according to the above classification. The borehole result also shows that two samples are safe, one sample belongs to marginal and the rest eleven ones are unsuitable for irrigation. But the result of the two spring samples shows that they are safe for irrigation. The result implies that most of the samples have bicarbonate in excess of Calcium and Magnesium.

7.4.6 SATURATION INDEX (Langlier Index)

The tendency of water to cause calcium rainfall can be predicted although there is no proven practical method to evaluate how serious the problem will be since it depends upon many factors. A first approximation of the calcium rainfall can be made using the saturation index of Langelier which simply says that upon reaching the calcium saturation point in the presence of bicarbonate, lime ($CaCO_3$) will precipitate from the solution. The saturation index is defined as the actual pH of the water (pHa) minus the theoretical pH (pHc) that the water could have if in equilibrium with $CaCO_3$ Nakayama (1982).

Saturation Index = pHa-pHc----------------------Equation 7.6

Where pHc =(pK_2 - pKc) + pCa + p(Alk)------------------Equation 7.7

Where: (pK_2 - pKc) = (Ca+Mg+Na)

pCa = Ca in meq/l

p(Alk) = (CO3+HCO3)

Positive values of the index (pHa > pHc) indicate a tendency for $CaCO_3$ to precipitate from the water whereas negative values indicate that the water will dissolve $CaCO_3$. The value of pHa is obtained from laboratory data, while pHc is estimated using the procedures described above.

The saturation index for each of the samples from the study area is calculated. As result with the exception of two samples from hand dug well (SUDW -6 and SUDW-18) and two samples from boreholes (SUBH -1 and SUBH -11) with positive saturation index most of the samples are with negative saturation index. This implies that the groundwater in the study area has a tendency to dissolve than to precipitate. This can be explained by the problem of corrosion than encrustation. There for the materials that will be used in the construction of the irrigation system and well completion should be with this understanding.

All water having positive values should be considered as potential problem water for use through drip systems and the need for preventative measures should be considered in design. The most effective method of preventing problems caused by rainfall of calcium carbonate is to control the pH or to clean the system periodically with an acid in order to prevent deposits building up to levels where clogging might occur. A common practice among those with problems is to inject hydrochloric (muriatic) or sulphuric acid into the system periodically. The system may need to be flushed as often as once a week.

7.5 GROUNDWATER QUALITY INDIX

In practice there are different chemical parameters used to show ground water quality. This includes the presences of higher amount of NO3, an extreme increase of chloride and others are used to indicate ground water quality. But these individual chemical parameters cannot give an overall picture of its quality and suitability of the water for its intended purpose. Therefore, Subba Rao, (1998) has recommended using groundwater quality index (GQI) method to study the degree of qaulity of water. In this method to calculate the GQI, the chemical parameters determined are multiplied by appropriate weights (W) based on their importance in the overall water quality (Table 7.8), following the guidelines of Tiwari and Mishra (1985). A weight of 4 has been assigned to the parameters like pH, TDS, NO_3, and F, 3 to Na, SO_4 and Cl and 2 to TH, Ca and Mg. In terms of unit weight (Wi), the weightings of 4, 3, 2 are equated to 0.16, 0.12 and 0.08, respectively. The GQI is finally calculated, using the following formula.

$$GQI = \sum q_i w_i \text{-------------------------------Equation 7.8}$$

Where qi is the degree of groundwater quality rating, assigned one of the values of 100, 80, 50 or 0 based on the values of the parameters measured as explained in table 7.7 and Wi is the unit weight. For the parameters, which do not use mean but range use this formula to find the total rating of the samples of a given source.

$$q_T = q_1 * N_1/N_T + q_2 * N_2/N_T + q_3 * N_3/N_T + \ldots qn * Nn/N_T \ldots\ldots\ldots\ldots\text{Equation 7.9}$$

Where: q1,q2,q3... qn are scale ratings and N1,N2, N3...Nn are number of sample . NT the total number of samples considered in the evaluation.

Table 7.7: Chemical composition of ground waters for hand dug wells and its weight (W) and unit weight (wi).

Parameters	Min.	Max.	Mean & range	ISI Standards	Weights (W)	Unit weight (wi)
pH*	6.48	7.42	6.48-7.42	6.5-8.5	4	0 16
TDS	126	1078	411	500-1500	4	0.16
TH	88.8	865.8	305.06	300-600	2	0.08
Ca	26.7	178	93.09	75-200	2	0.08
Mg	4.9	102.6	17.74	30-100	2	0.08
Na*	8.9	62	4.3-62	200	3	0.12
K	0.9	15.9	2.81			
HCO3	79.42	798.8	283.43			
Cl	4	186	49.71	250-1000	3	0.12
SO4	26	680.8	82	150-400	3	0.12
NO3	10.5	33	16.28	45	4	0.16
F				0.6-1.2	4	0.16

* use only the range

Table 7.8 Scale rating for groundwater quality parameter.

Parmeters	Degree of groundwater quality (pollution) rating (qi)

	Permissible	Slight	Moderate	Sever
	100	80	50	0
pH*	7-8.5	8.6-8.8	8.9-9.2	>9.2
	>7	6.8-7	6.5-6.7	<6.5
TDS	500	501-1000	1001-1500	>1500
TH	300	301-450	451-600	>600
Ca	75	76-137	138-200	>200
Mg	30	31-65	66-100	>100
Na	200	201-400	401-600	>600
Cl	250	251-625	626-1000	>1000
SO4	150	151-275	276-400	>400
NO3	<14	15-29	30-44	>45
F	0.6	0.7-0.9	1-1.2	>1.2

Table 7.9 Calculation of GQI based on the mean values of hand dug wells, as showing table 7.7.

Parameter	pH*	TDS	TH	Ca*	Mg	Na	Cl	SO4	NO3	F	Total GQI
qi	80.8	100	80	80	100	100	100	100	80		
wi	0.16	0.16	0.08	0.08	0.08	0.12	0.12	0.12	0.16		
GQI (qiwi)	12.93	16	6.4	6.4	8	12	12	12	12.8		98.53

Table 7.10: Chemical composition of ground waters for boreholes and its weight (W) and unit weight (wi).

Parameters	Min.	Max.	Mean	ISI Standards	Weights (W)	Unit weight (wi)
pH*	6	8.1	6-8.1	6.5-8.5	4	0.16
TDS	54	650	397	500-1500	4	0.16
TH	33	517	255.54	300-600	2	0.08
Ca	8	129	78.21	75-200	2	0.08
Mg	3	47.5	17.3	30-100	2	0.08

Na	3	192	30-192	200	3	0.12
Cl	5	78	37.3	250-1000	3	0.12
SO4	3	135	44.84	150-400	3	0.12
NO3	4	22	11.74	45	4	0.16
F				0.6-1.2	4	0.16

*use the range

Table 7.11 Calculation of GQI based on the mean values of boreholes, as showing table 7.7.

Parameter	pH	TDS	TH	Ca	Mg	Na	Cl	SO4	NO3	F	Total GQI
qi	86	100	80	80	100	100	100	100	80		
wi	0.16	0.16	0.08	0.08	0.08	0.12	0.12	0.12	0.16		
GQI (qiwi)	13.76	16	6.4	6.4	8	12	12	12	12.8		97.76

Table 7.12: Chemical composition of ground waters for springs and its weight (W) and unit weight (wi).

Parameter	pH	TDS	TH	Ca	Mg	Na	Cl	SO4	NO3	F
Min.	7.39	184	153.2	40.1	5.94	9.6	10	13.7	20	
Min.	7.91	221	155	51.6	13.5	14	18	18.5	27.8	
Mean	7.39-7.91	202.5	154.1	45.9	9.72	11.8	14	16.1	23.9	0.14
ISI standard	6.5-8.5	500-1500	300-600	75-200	30-100	200	250-1000	150-400	45	0.6-1.2
Weights(W)	4	4	2	2	2	3	3	3	4	4
Unit weight (wi)	0.16	0.16	0.08	0.08	0.08	0.12	0.12	0.12	0.16	0.16

Table 7.13 Calculation of GQI based on the mean values of spring, as showing table 7.7

Parameters	pH	TDS	TH	Ca	Mg	Na	Cl	SO4	NO3	TotalGQI
qi	100	100	100	100	100	100	100	100	80	
wi	0.16	0.16	0.08	0.08	0.08	0.12	0.12	0.12	0.16	
GQI (qiwi)	16	16	8	8	8	12	12	12	12.8	104.8

The computed values of GQI is worked out to be 100, 100.and 104.8 for hand dug wells, boreholes and springs which in general show that the groundwater in the area is good quality water and is not t subject to any chemical pollution. This is also confirmed by the presence of lower values of NO3 i.e. all the samples have less than 50mg/l which is below the recommended limit for nitrate in drinking water by WHO European standard as cited in Freeze & Cherry (1979).

CHAPTER EIGHT

SYNTHESIS AND GROUNDWATERPOTENTIAL ZONATION MAP

This study attempts to analyze and recommend appropriate recommendations concerning water resource potentials in Upper Suluh based onhydromorphological, meteorological, hydrogeological, and hydrochemical data. Primary field data measurements are the supplementary data for the evaluation of different parameters. In this chapter, results of the study will be explained more briefly in order to show how the result is obtained using different evidences from the existing data and newly measured data.

8.1.1 The results of the hydro geomorphology

The results of the hydro morphology can be generalized in to three these includes the linear aspect, dimensionless ratio and measure of intensity and form of the channel system of the . The linear aspect of the channel system, which includes the stream order, stream length and bifurcation ratio. There is a general decrease of stream order down stream and lower order of the whole basin is a six-order stream. There stream order also shows that there is lower number of order in areas where there is lower elevation and the sandstone is found exposed. The result of the bifurcation ratio ranges between 2.31-5.44 with the dominant lower value is located on the eastern side of the upper Suluh . The result shows that there is a variation of 2.31more order than the next order to 5.44 more order than the next. In general all this linear aspect of the stream system of the upper Suluh show lower value in the lower topography and eastern part of the basin.

The dimensionless aspects include form factor, elongation ratio and circularity ratio. The result of this aspects show that the form factor varies from circular to intermediate in shape that varies in value between 0.114 to 0.532.The higher the value of the form factor the higher will be the surface run off which indirectly implies lowered groundwater infiltration. The other non-dimensional ratio is the elongation ratio, which varies in value from 0.38-0.82.

That is eight of the sub basins show an elongation ratio value between 0.6-0.8 and the remaining six are below 0.6 elongation ratio value.

The third non-dimensional aspect is the circularity ratio the value of the basin ranges 0.171-0.861. According to the map based on the Rc most of the flat land of the basin is mapped to be <5 Rc value and most of the higher topography of the study area are mapped to as a Rc value 0.5-0.7 and only two sub basins are with a Rc of >0.7. In general the analysis result of the non dimensional aspect of the basin show that sub basin -5,7,9,12and 14 show lower value of form factor and elongation ratio and higher value of circularity ratio.

Measure of intensity and form aspect of a basin includes drainage density, channel maintenance, stream frequency, drainage texture and texture ratio. The result of the analysis of the sub basins shows that the Dd value varies between 1.53-2.68.This implies that the basin is classed in to coarse and very coarse. The eastern part of the study area belongs to the lower drainage density, which shows a permeable rock exposure.
This implies that there is According to the value of the form factor the Except the two sub basins that show higher circularity ratio the remaining sub basins show intermediate to lower value which implies that there is higher to intermediate potential of infiltration where the rock is impermeable. Most of the sub basins in the eastern and the central part of basin show intermediate circularity ratio value.

8.1.2 Results from the anaiysis of hydrometeorology components

Rainfall in the basin shows great difference between low land areas and high land areas. This is because high land areas get more rainfall than low land areas. According to the data records, perception in the basin is bimodal with first is from March to May which is with small peak and the second is from July to August with higher peak. The area gets most of its rain in the months of July and August. The whole temporal variation of 6-month rainy season and six month dry season. Maximum and minimum annual rainfall from spatial point of view is 531mm and 847 mm respectively.

The areal distribution of rainfall was computed using arithmetic, thiessen, and isohyets the computed result is 727.4mm, 722.27, and 717.3 respectively. The average result of all the methods, which is 722.32mm, is used for further water balance calculation.

To determine actual evapotranspiration, determination of potential evapotranspiraton primarily is necessary. For the sack of comparison the potential evapotranspiration was calculated using temperature Thornthwaite methods and penman (combined method). Using the above methods annual evapotrannspiration that vary from 808 mm to 1584mm.
One major soil category and vegetation cover was identified for computing actual evapotransiration. Sandy loam soil type with h water holding capacity of 150mm was used. According to the model result, actual evaptranspiration values are 652.34mm, and 703.09mm per year based on the Thornthwaite and Pennman potential evapotranspiration respectively. But the annual actual evapotranspiration for the basin considered is 652.34mm.

River discharge long term-measured values of Suluh river discharge are the main data in providing information about the catchments characteristics and nature of river. The remaining part of the was calculated based on run off coefficient. The value of the run off coefficient is 0.144.The annual run off the basin at the observation station is 34.25 MCM. To separate the amount of surface run off and base flow from the total run off a five years daily flow was used. The result shows that 1:2.7 ratio of base flow to surface flow. That means the 20.1 MCM is surface runoff and 15.79MCM of the total run off is base flow.

8.1.3 Results from the analysis of water balance

The evaluation of water resource is done based on the meteorological and hydrogeological data analysis. The amount of water entered in to the basin is break down into other components as surface runoff, Recharge, evapotranspiration and change in storage. Due to the closed nature of the basin, the only inflow to wards the basin is rainfall. The inflow and out flow of groundwater can be or not equal, but for the time of this evaluation they are assumed to be equal. The change in storage annually is assumed to be negligible since there is no abstraction of significant water. From base flow separation, surface runoff is calculated as 55.78mm with an actual evapotransporation of 476.78 mm. Finally from water balance equation, and the amount of recharge is calculated as

$$R = P + Gi - (SRO + AET + Go \pm \Delta s)$$

$$R = P - (SRO + AET)$$

Where R = Recharge P = Rainfall (722.32 mm) Δs = Change in water storage

SRO = Surface runoff (45.36mm) AET = Actual evapotranspiration (652.32 mm)

Gi =Groundwaterinflow Go = Groundwateroutflow

Their fore, the amount of recharge in the basin is 25mm and total volume is 11.1 mcm annually, which is about 3.5% of the total rainfall. Generally, the basin has the following summary of water balance (Table 8.1).

Table 8.1 Summary of water balance for upper Suluh

Area (km^2)	Computation of water balance for the basin			
443	P (mm)	AET (mm)	SRO (mm)	Recharge (mm)
	722.32	652.34	45.36	25

8.2 Results from the analysis of hydrochemistry

Water chemistry: - Laboratory analysis supplemented by field measurements provides the information necessary to characterize water sources according to their chemistry. Due to shallow groundwatercirculation, most of the water sources are fresh water according to their TDS classification most of the samples have less than 1000mg/l.

Chemistry of all other water sources (hand dug wells, springs, rivers, and boreholes) reflects the local geology of the basin.

The analysis result shows that the pH value of the ranges between 6-8.5, which is common for ground water. In addition, the analysis shows that the dominant cations and anions are calcium and bicarbonate. The classification of the groundwaterof the based on the piper diagram is Ca-Mg-HCO3 and Na-K-HCO3 types.

The water quality analysis of the water samples with respect to hardness shows that water samples from wells (hand dug wells and boreholes) are very hard and from springs are hard. Parallel the result of the analysis of water samples with respect to SAR, EC and %Na and RSC show excellent, good, excellent and dominantly not suitable respectively.

The groundwater quality using Groundwater quality Index (GQI) shows that there is no groundwater quality problem with different uses of the ground water.

8.3 GROUNDWATER PROSPECTIVE ZONES

Based on results of previous discussions of the hydro morphological, hydrometer logical, hydrogeological and hydrochemistry the following groundwater prospective zone map is developed. These prospective zones are grouped into priority area for development, purpose of water and further detailed study. The study area is divided in to three groundwater prospective zones.

Zone-1

This is the area showing good hydromorphic parameter, good hydraulic conductivity, which allows the infiltration and storage. This is the first priority area for future development for different purposes.

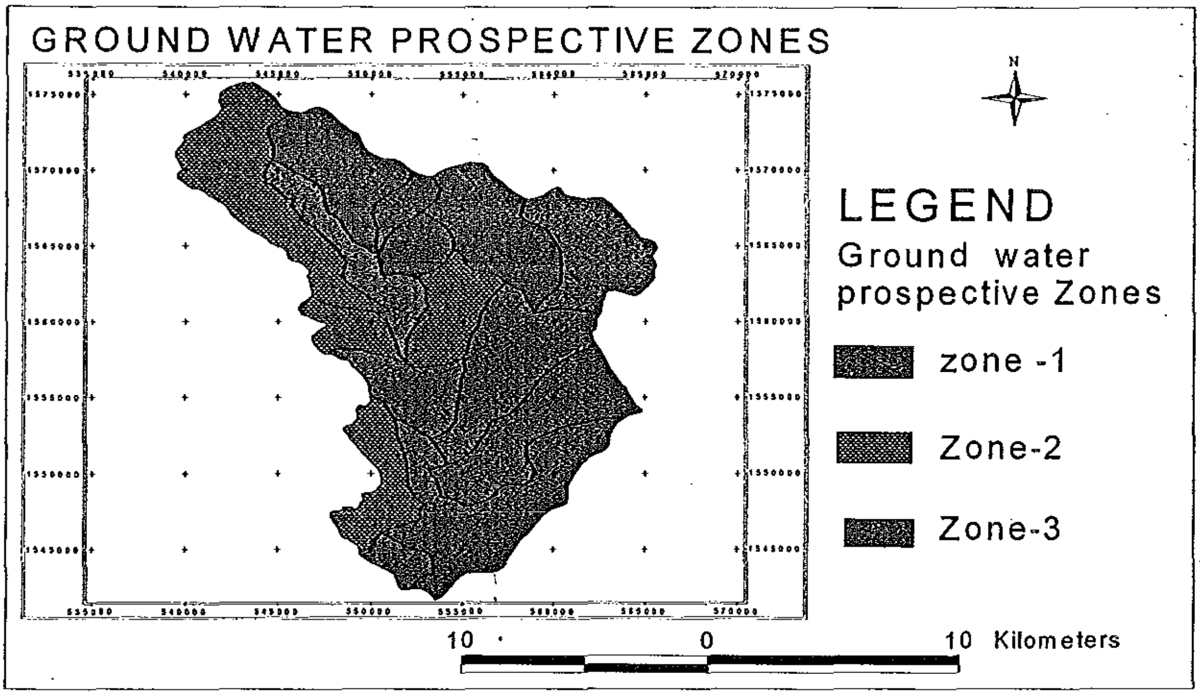
Zone-2

This is the area with moderate hydromorphic parameters and hydraulic conductivity, which shows limited aerial extent relatively lower groundwaterpotential zone and is the second priority area for future development.

Zone-3

This is the area with list priority for future development. It is the area located with higher topography and lower hydraulic conductivity rocks and poor hydromorphic parameters. In this zone no development of groundwater for shallow and deep boreholes except hand dug wells and limited springs.

Figure 8.1 Ground water prospective



CHAPTER NINE

CONCLUSION AND RECCOMMENDATION

10.1 CONCLUSION

Upper Suluh river basin situated south of Adigrat has a total area of 443 km^2 and is characterized by moderately flat to highly rugged topography that results in dense drainage patterns dominated by first and second order streams with sixth order of main stream it generally flows following the topography. From geological map of newly produced with a scale of 1:50,000, seven lithologic units have been identified. alluvial sediments Upper basaltic unit, Lower basaltic unit, Adigrat sandstone, Edagarbi Glacials, Enticho sandstone and Tsalite metavolcanics. The dominant rock unit is the Enticho sandstone with55% of the study area. In terms of structure the area is affected by lineaments, fractures and dolerite dykes dominantly oriented towards NW-SE direction.

From long term mean monthly rainfall the basin gets 722.32mm annual rainfalls. The actual and potential evapotranspiration computed using different empirical methods varies between 652.34-703.09 mm and 808.8-1584mm per annum respectively. The Potential evaporation and actual evapotranspiration result using Thornthwait & Matter model was used for the water balance of the area. The actual evapotranspiration was 652.34m. The annual recharge assuming closed system and negligible change of water storage is found 25mmper annum, which is about 3.5% of the rainfall.

In general lower geomorphic parameters such as bifurcation ratio, drainage density, form factor, elongation ratio, drainage density, stream frequency, texture ratio and ruggedness number are found in areas of flat plain and in association with the rocks having higher hydraulic conductivity. These imply that the hydrogeology of the area is controlled by the geomorphology and geology.

Based on the hydraulic conductivity of the rocks, three hydrostratigraphic units are mapped. Higher hydraulic conductivity formation, moderate to low hydraulic conductivity formation and very low hydraulic conductivity formation. The higher hydraulic conductivity units are alluvial deposit and the Enticho sandstone, which is the potential zone for groundwater exploitation. Based on the zero grid deviation most of the upper elevated part of the measured about 82.2% is a recharge zone and the remaining lower part measured about 17.8% is the discharge area. Water balance results show that the basin receives 184.74mm in the form of recharge and losses 55.78mm and 476.78mm in the form of surface runoff and actual evapotranspiration respectively.

Analysis of the hydrochemistry of different water sources show that two types of water are identified based on their TDS value. All water sources have almost similar range in the classification and are fresh water. But there are two springs, which are not the derivative of the local geology and are brackish water type. The water type in the study area is Ca-Mg-HCO_3 except one sample, which is Na- HCO3 type show, localized geology.

Concerning water quality, except those Na-HCO_3 water type the rest type of water samples are with in the limit of acceptable value of WHO water quality standards for water supply, irrigation, and industries excluding trace elements which are not analyzed in this study. Since the basin is free of industry, and extensive irrigation, there is no detected pollutant for ground water. In particular the different irrigation parameters result shows that the groundwater of the upper Suluh is good with respect to irrigation.

10.2 RECOMMENDATION

Based on the realities encountered during the evaluation of water resources potential, the following recommendations are forwarded.

- Surface runoff in the basin is not only pure water but also eroded soils from elevated and rugged areas move together with the flood. This condition reduces water infiltration to the ground. Hence soil and water conservation program should be promoted especially in the high topographic areas.
- As observe from the waterbalnce result there is higher amount of evaporation (66.47%) from the basin as compare to the surface run off and recharge. Besides the has large recharge zone and permeable rock formation, which promotes infiltration. As a result artificial method of increasing the resource is more preferable than constructing dams and pond.

- In order to evaluate the basin fully, distribution of bore holes are not uniform and even the drilled ones have no proper drilling and pump test data. Therefore additional test boreholes, which can also be used as a productive well for the required purpose, are recommended in the Enticho sandstone.
- To evaluate the basin as flexible as possible the constraint of data availability for different parameters must be avoided, through data management for different hydrological and hydrogeological parameters.
- In the area there is high topographic difference in the basin and there is no meteorological station except at the periphery. Therefore, the installation of new station at the center of the in addition to the existing ones is important to have even distribution and reliable data.
- Irrigation practice using hand-dug wells is already started though it is not extensive from Upper suluh using dewatering pumps. But as number of beneficiaries increase the river may not satisfy all users. To bring sustainable agriculture, utilization of groundwaterfor irrigation. The spatial distribution and the number of wells in the sub basins should be understood to minimize interference and over exploitation.
- In the study area the main aquifer is dissected by open fractures and dolerite dykes, taking the dependency of the hydraulic conductivity of the rocks dominantly on the secondary porosity the role and contribution of the structures and the dykes should be studied in detail using magnetics supported by VES.

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