Groundwater Recharge Estimation for Mullu Catchment in Somale Region, Eastern Ethiopia

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This is to certify that the thesis prepared by Naol Gurmu, entitled: Quantifying Groundwater Recharge for Mullu Catchment in Somale Region, Eastern Ethiopia submitted in partial fulfillment of the requirements for the Degree of Master of Science in Hydrogeology compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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By my signature below, I declare and confirm that this thesis is my own work. I have followed all ethical and technical principles of research in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly article that is included in the thesis has been given acknowledgment through reference.

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Abstract

Groundwater Recharge Estimation for Mullu Catchment in Somale Region, Eastern Ethiopia

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Addis Ababa University, 2019

The increasing demand placed on groundwater has encouraged distinguishing of water resource, which would be the foundation of exploration, management, and conservation. In this study, quantitative estimation of groundwater resources of Mullu catchment has been made. Therefore, the main objective of the study is to estimating the amount of ground water recharge for Mullu Catchment using Water Balance Method. And also, the specific objectives are identifying the recharge area and groundwater flow characterization using water level information.

The methodology used to estimating the groundwater recharge for Mullu catchment passes through three different stages; desk study, field work, and post field work. The desk study includes literature search and review and/or collection of available data. The sources of data used in this stage comprise published and unpublished reports, both local and international. The field work includes observing the topography and drainage system, Soil type, Land use/cover, geology and hydrogeology of the study area. After field work, data interpretations coupled with thesis writing have been done.

Mullu Catchment is situated at narrow valley that surrounded by quaternary volcanic rocks ridges in which the surface drainage out flows towards Afdem area. The area is drain by seasonal streams originating from south, south east and south west high land areas. The flood from high land area is transporting alluvial sediments comprise silt, sand and gravel to vast central plains. The main aquifer of the area is volcanic rocks under laid the alluvial deposits. Particularly volcanic rocks underlying alluvial deposits are considered to be the most potential aquifers of the area. The Groundwater Recharge for Mullu Catchment has been estimating using Water balance method is 73.41mm/year.

Key words: Rainfall, Groundwater, Runoff, Recharge, Mullu Catchment, Water Balance, Soil Moisture

Acknowledgment

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Table of Contents

List of Figures

List of Tables

Appendix

List of Acronyms

DEM	Digital Elevation Model
EIGS	Ethiopian Institute of Geological Survey
ETo	Reference Evapotranspiration
FAO	Food and Agricultural Organization (of UN)
GIS	Geographic Information system
km	Kilometers
km^2	Kilometers square
LocClim	Local Climate Estimator
m	meter
m.a.s.l.	Meters above sea level
m^3	meter cube
mm	millimeter
mm^3	Million meter cube
MoARD	Ministry of Agricultural and Rural Development
MoWR	Ministry of Water Resources
N	North
NMSA	National Meteorological Service Agency
NNE	North North East
OWWDSE	Oromia Water Works Design and Supervision Enterprise
UTM	Universal Transverses Marcater
WMO	World Meteorological Organization
WWDSE	Water Works Design and Supervision Enterprise

1. INTRODUCTION

1.1. Background

In every human society, water is alleged to be life as all aspects of life depend on it. It is an essential input for abundant sectors of the global economy. Besides freshwater comprises less than 3% of the world's entire water, it is one of the world's most imperative natural resources and an indispensable part of all terrestrial ecosystems. Availability and access to freshwater largely determines the pattern of economic growth and social development (Odada, 2006). Freshwater resources are pivotal to key economic and social activities such as water supply and sanitation, agriculture, industry, urban development, hydropower generation, inland fisheries, transportation and recreation. These activities provide employment and generate revenue that sustains economies. Besides its economic value, freshwater plays an important role in addressing issues of health, poverty and hunger.

Water resources, in the world remain constant while the demand for it continues to increase due to ever increasing population, prospect for more water resource, increased skill of human being to utilize, enhancement of life standard, extended service due to expansion of urbanization, land use shift to more intensive crop production and economic development. A magnificent pressure was added to global water resource as a whole and groundwater resource in particularly since the beginning of industrial revolution (Bedient et al., 2002).

Research on water resource, in the past mainly focused on surface water and very little is on groundwater. Different studies made revealed that groundwater potential of Ethiopia lay in a range of 2.6-6.5 billion meter cube. Nevertheless the country's groundwater potential is not known with any certainty. Sustainable and efficient exploitation of the groundwater resource to keep sustain the human race and other living things accurately quantification of this vital resource is the agenda of the day.

Surface water is an important source uses for irrigation domestic and city water supply. Ground water constitutes an important source for multiple uses such as domestic water supply for urban and rural communities. Ground water is a good alternative in areas which have scarcity of surface water particularly lower reach of the Mullu Catchment. This thesis presents the findings of the hydrological investigations for the ground water recharge estimation in Mullu Catchment which located in Somale Region, Eastern Ethiopia.

1.2. Previous works

Master Plan for the development of surface water resources in the Awash Basin (1989). The major recharge source for Shinile Zone is precipitation. Rainfall situation of the area is variable with topography. Highest points receive far better regular precipitations as compared to the lower plain area that experiences sporadic rainfall. Recharge condition of the area is crucially controlled by topographic settings. Prominent intensive fracturing has also taken place which largely allows circulation of groundwater. Besides, the porous superficial deposit greatly serves as recharge inducing element.

OWWDSE (2011). Shinile Groundwater Potential Assessment Study Project. On monthly time scale groundwater recharge estimation; most of the Eastern Awash sub basin receives a satisfactory recharge in the rainy seasons. From the analysis it has been observed that the sub basin of Eastern Awash (Shinile Zone) receives low mean annual rainfall of about 368mm. The surface water yield is estimated to be about 5.2mm for Eastern Awash sub-basins while the Groundwater Recharge is 4.8mm/year.

Tenalem Ayenew and Tamiru Alemayehu (2001). Principles of hydrogeology. The general coverage of the recharge mechanism based on the geological cover of the country as: i) Basement cover = 18%; ii) Paleozoic and Mesozoic cover = 25%; iii). Tertiary volcanic = 40%; iv).Quaternary sediments and volcanic = 17%. On the basis of these proportions, the main source of recharge for the groundwater system is generally the abundant rainfall over the highlands. The annual recharge of Southern Afar and the extreme northern end of the western lowlands is less than 50mm/year.

Tesfaye Cherinet (1993). Hydrogeology of Ethiopia and Water Resources Development, EIGS. The general recharge to groundwater from rainfall was estimated for different parts of the country. On the basis of the estimated recharge values, the country has been divided into four recharge regions. The annual recharge values (recharge amounts) for most of Eastern Ethiopia are less than 50mm/year, were estimated by distributing or dividing the base flows of the streams over the catchment areas.

The National Water Resources Master Plan (1995). In recharge areas, gentle slopes seem to offer more favorable conditions. Moderate rainfall over an extended period of time accelerates infiltration. During heavy rains for short periods, the recharge is minimal. Usually indirect methods are used due to the scarcity of data in almost all the potential areas of development. The recharge areas of most of Eastern Ethiopia are less than 50mm/year.

WWDSE (2004). Dire Dawa Administration Council Integrated Resource Development Master Plan Study Project, Volume III-Water Resource, Part 2, Hydrogeology. The distribution of rainfall in the DDAC groundwater study area is mainly determined by altitude. Based on the Hydro-meteorological data analysis, the high land of the study area like Karamile, Kobo, Chalenko, Haramaya, Kora and Asebot receive the highest mean annual precipitation in the range of 800-1300mm. The central part of the Shinile zone, relatively receive higher mean annual precipitation than the eastern part in the range of 150-800mm

WWDSE (2009). Allaidege Plain Groundwater Resources Assessment Project, Hydrogeology Report. The annual flow of the Awash Arba River at Awash Arba is $33Mm^3$/year. Considering the rate of recharge to be 7% of the runoff of the river, the recharge worked out to be $2.31mm^3$/year. The recharge from the eastern escarpment (Asebot volcanic ridge) is calculated by taking only 5% of the total annual rainfall of 710mm for an area of 1500sq.km, which is computed out to be $53mm^3$/year.

1.3. Statement of the Problems

Groundwater constitutes an important source for multiple uses such as domestic water supply for urban and rural communities, agriculture and industry as well. It is a good alternative in areas with scarce surface water resources. Surface water availability in the study area is inadequate necessitating conjunctive use of surface and groundwater resources. Any future sustainable utilization of the groundwater resources and proper mitigation measure of the scarcity of domestic water supply problem in the area, demands the establishment of proper conceptual hydrologic and hydro geological model of the basin.

Most of the previous studies considered the large scale area and more general information were considered. Consequently, there is no independent ground water recharge study in the Mullu catchment. And also there is no detailed study made on the groundwater recharge for the Mullu catchment. Some of the studies are indirectly address on different aspects of the groundwater of the Awash basin. So estimating the groundwater recharge of Mullu Catchment is highly crucial for proper management of groundwater resources.

1.4. Objectives of the study

1.4.1. General Objectives

The main objective of the study is to quantifying the amount of ground water recharge for Mullu Catchment using Water Balance Method.

1.4.2. Specific Objective

The specific objectives include:

- Identifying the recharge area and estimate the groundwater recharge of Mullu Catchment using Water Balance Method.
- Groundwater flow characterization using water level information

1.5. Methodology

The methodology used to quantifying the groundwater recharge for Mullu catchment passes through three different stages; desk study, field work, and post field work. The desk study includes literature search and review and/or collection of available data. The sources of data used in this stage comprise published and unpublished reports, both local and international.

The field work includes observing the topography and drainage system, Soil type, Land use land cover, geology and hydrogeology of the study area. The soil map, land use land cover map, and geological map are modified based on field observed. After field work, data interpretations coupled with thesis writing are done.

1.6. Thesis Structure

This thesis is arranged by chapters starting with the introduction, methodologies and describe the source of data and discussion on methods followed in order to estimating the groundwater recharge for Mullu catchment in chapter one. The general overview of the study area is discussed in chapter two which presents location, climate, topography and drainage system, soil, and land use land cover of the study area. Chapter three covers regional geology which concerns more on geology of the Mullu catchment. Chapter four presents hydrology y of the study area which interprets the hydrological data in detail. Chapter five presents the hydrogeology of the study area. Chapter six presents the result discussion. Chapter seven presents the conclusion and recommendation for local community water used direction and future research in this study.

2. STUDY AREA

2.1. Location

The Mullu Catchment is located in the Shinile Zone found in Somale Regional State of Eastern Ethiopia. It is bounded by latitudes 5°51’35"N to 6°04’25"N and longitudes 43°55’15"E to 44°11’6" E. The Mullu Catchment has a total area of 415.85km$^{2.}$ The location of the Mullu Catchment is indicated in Figure 2.1.

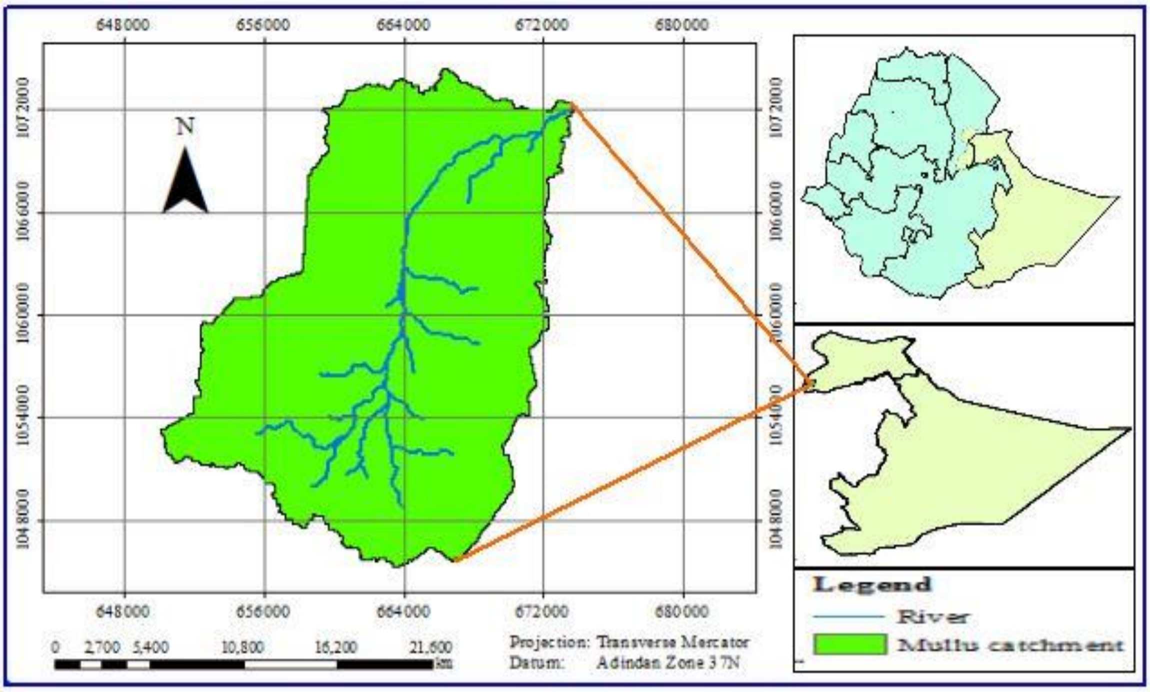

Figure 2.1: The location map of the Mullu Catchment (modified from EIGS, 1996)

2.2. Climate

The climate characteristics in the study area was determined by analyzing the nearby meteorological stations, namely Mieso, Melka Werer, Afdem, Asebot, and Gewane. Some of the stations are class one meteorological stations that should have all climate data while the others stations are class four meteorological stations having only rainfall recorded data.

The study area is characterized by arid and semi-arid climate. The moisture for precipitation in the study area originates from south-east equatorial air stream, which moves northwards within tropical convergence zone (ITCZ), (NMSA, 1996). The climate is typical of equatorial region and modified by altitude.

The study area is the part of South and Southeastern of Ethiopian moisture region that have two distinct dry periods (December to February and July to August) and two rainy seasons (March to May and September to November). The main rainy season is referred to as the Belg rain because it occurs from March to June (NMSA, 1996).

2.3. Drainage

The study area has a total catchment area of about 415.85km^2 as obtained by digitizing from the hard copy of 1:250,000 scale map of the study area and compared with the watershed delineated from the DEM data by application of Global Mapper, Arc View GIS 10.3 and Av.SWAT2012 software's. Watershed is a natural topographical and hydrological entity which collects all the rainwater falling on it to a common outlet and hence forms an ideal unit for management and sustainable development of its natural resources like water, soil, land and vegetation (Goswami, 2004). Generally, watershed is the boundary of the drainage basin.

The drainage systems of the catchment generally originate from the highlands of the escarpment area and recharge the alluvial sediments of the plains. Shinile Zone gently slopes to the north and to the northwest, and as a result, the seasonal streams and flood plains flow to the north and to the north-northwest. The seasonal streams from the Somalia and Oromia highlands drain to the southwest and northeast (Mullu catchment) and tribute to the Kullen Valley.

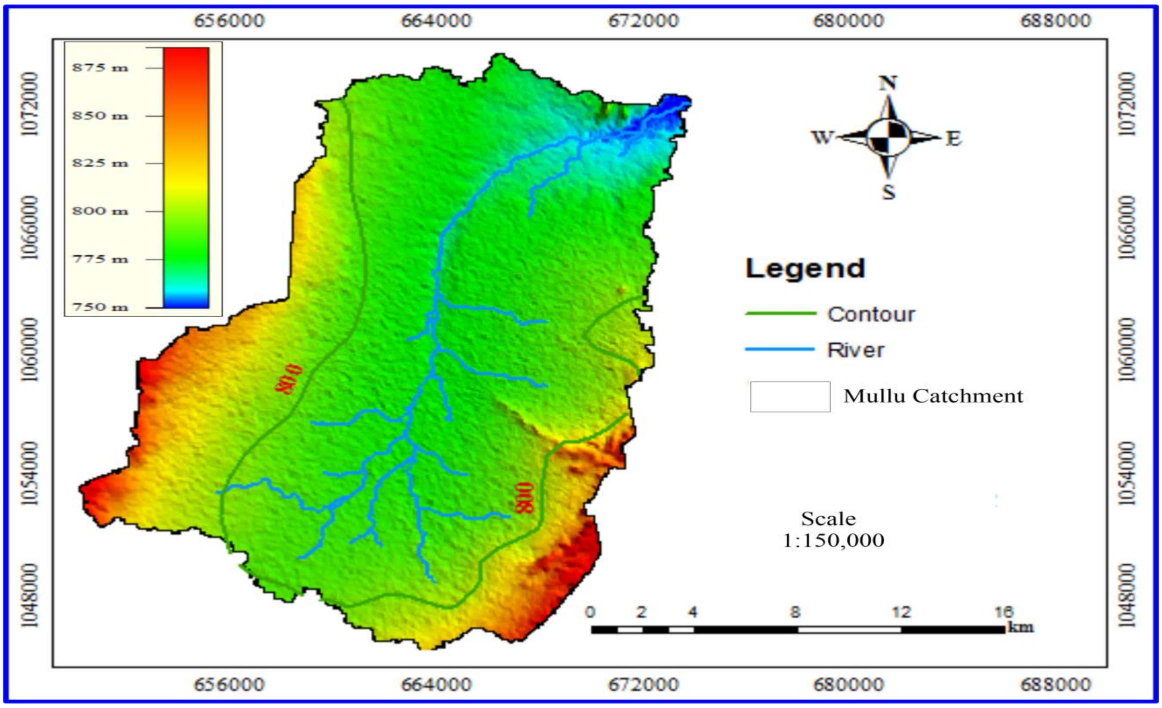

Figure 2.2: Drainage system of Mullu catchment

2.4. Soil

Soil map of the study area was obtained from Ministry of Agricultural and Rural Development in a soft copy; subsequently modified using observed and collected sample data during field work. According to the FAO (1977) soil classification, the soil mapping units have been identified in the study area at a scale of 1:250,000. From these soil classifications map units, broad divisions of soil types into different families were grouped as silt clay, clay loam, and sandy loam.

Table 2.1: The major soil groups in the Mullu Catchment

Major soil groups	**Soil texture**	**Drainage**
Eutricfluvisols, Eutric regosols, cambisols	SiL-SL	Well, moderately, very poorly, imperfectly drained
Vertic Cambisols	SiL-SL	Well, moderately, excessively drained
Orthic Solonchaks	SiL-CL, SiL-SCL, CL-SCL	Well, moderately drained

Remark: - S-Sandy, SCL-Sandy Clay Loam, L-Loam, Si-Silt, C-Clay

The soil map of the study area was determined based on the above classification of soil texture. This map is used to compute actual evapotranspiration for the Mullu catchment.

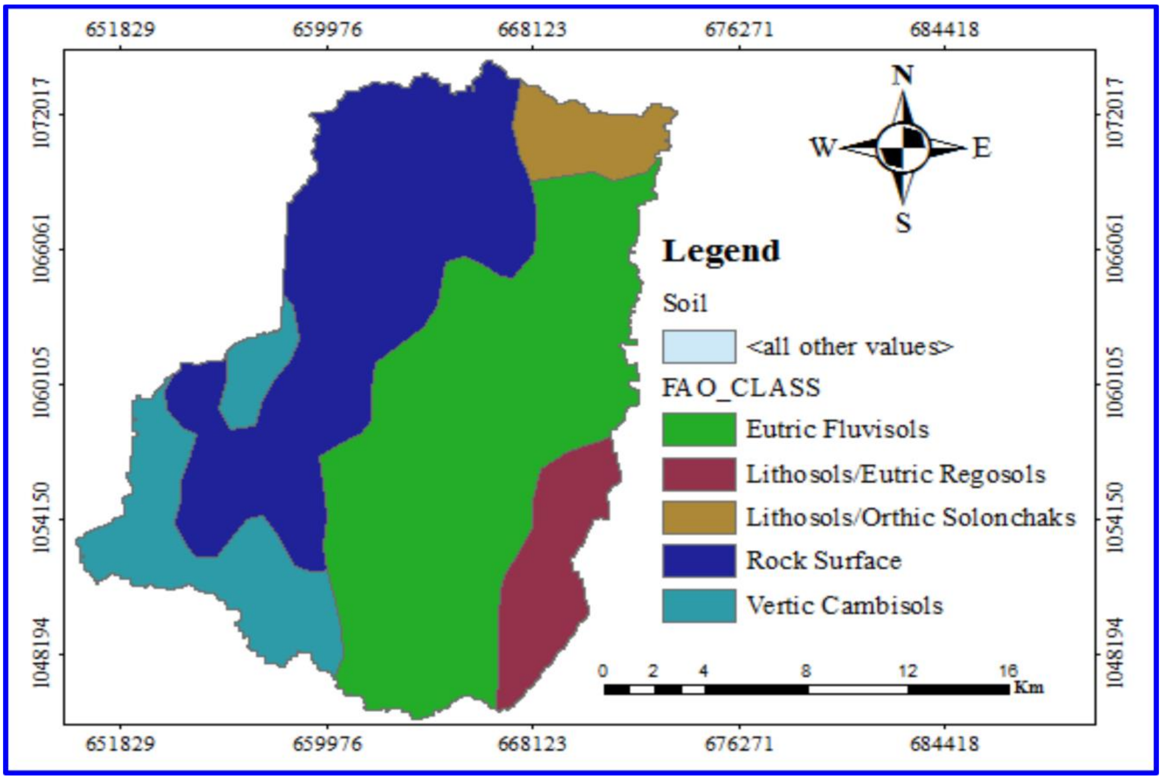

Figure 2.3: Soil map for Mullu Catchment (modified from MoARD, 2009)

2.5. Land use Land cover

Land use land cover map of the study area was obtained from Ministry of Agricultural and Rural Development in a soft copy; subsequently modified using observed and collected sample data during fieldwork. On the extreme where the climate is arid, exposed rock or sand surface is predominant land cover. The wide occurrence of shrubs and grass land is perhaps associated with the less population pressure and cultural orientation of the people, which is of pastoral farming system. The reclassified land use land cover map is used for the calculation of actual evapotranspiration.

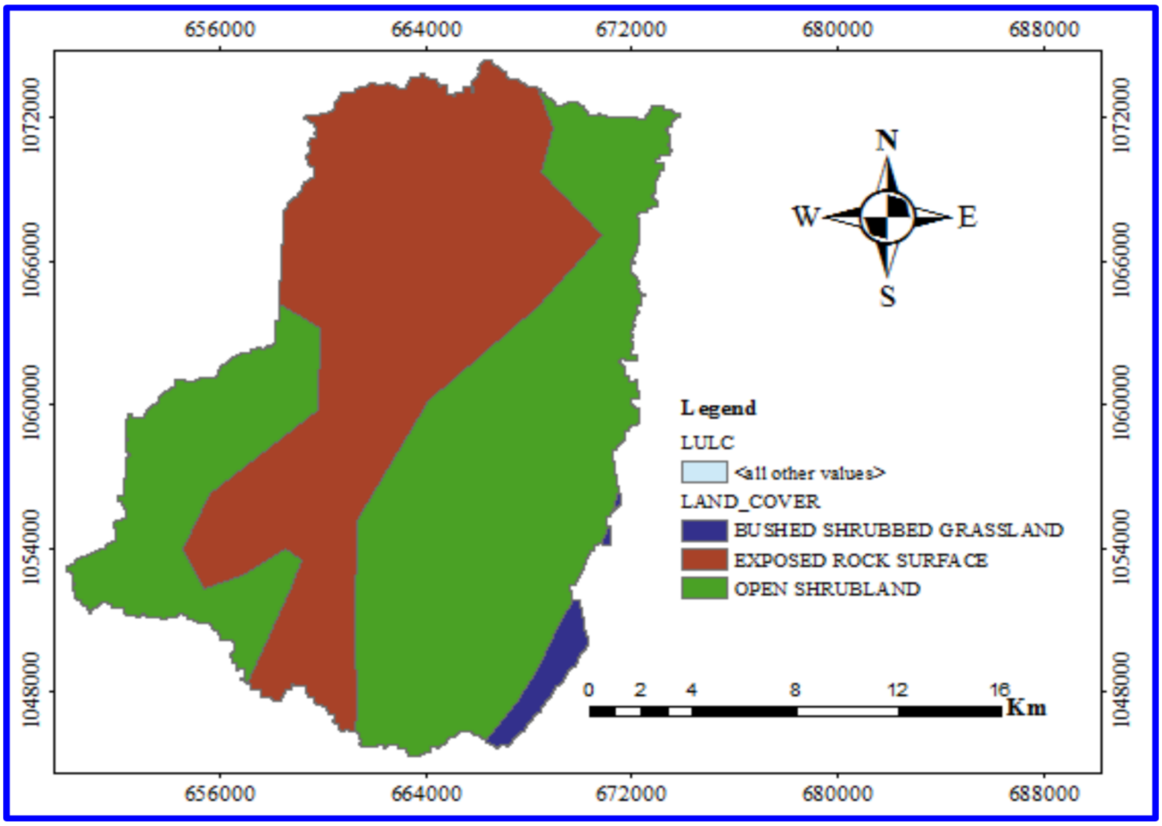

Figure 2.4: Land use land cover map for Mullu Catchment (modified from MoARD, 2009)

3. GEOLOGY

3.1. Geomorphology

The geomorphology of Mullu catchment is mainly controlled by prolonged tectonic processes, which gave rise to the formation the plateaus and the rift valley. The geomorphologic future of the catchment is produced as the results of geologic processes are the deposition of thick successions of quaternary alluvial sediments and volcanic rocks. And also, the geologic process tended to level down the rugged topographic features of the area and produced smooth terrain of the plateau and the escarpment.

Mullu Catchment is situated at narrow valley that surrounded by the silicic volcanic rocks ridges in which the surface drainage out flows towards Afdem area. The area is drain by seasonal streams originating from south, south east and south west high land areas. The altitude of the study area ranges from 750 to 850m a.m.s.l. with few mountains having greater elevations.

3.2. Regional Geology

The geology of eastern Ethiopia is comprised of Precambrian metamorphic rocks, Mesozoic sedimentary rocks, Tertiary and Quaternary volcanic rocks and unconsolidated sediments. The Paleozoic era of Ethiopia is an era of erosion and denudation. Minor occurrences of continental sedimentary rocks which are deposited during Late Paleozoic to Early Mesozoic times occur in the northern, southern and eastern parts of Ethiopia underlying thick Mesozoic sedimentary succession.

The Quaternary Period of Ethiopia has been principally an era of basic and felsic volcanism and deposition of lacustrine, marine and alluvial sediments. Extensive outcrops of Quaternary and Recent volcanic rocks occur within the rift floor of the Main Ethiopian Rift. In addition, in situ weathering of all of the rock types have given rise to the development of eluvial soils. Erosion along the escarpment and the plateaus produced thick unconsolidated sediments of mainly fluvio-alluvial origin. Carbonate precipitates occur in the form of travertine materials or beds within or at the margins of the rift valley.

3.3. Geology of the Study Area

3.3.1. Unconsolidated Sediments

Unconsolidated sediments of Quaternary age occur in several areas of Mullu catchment and the Awash River Valley. Thick succession of alluvial deposits cover most parts of the plains of Mullu catchment. Coarse alluvial deposits with rounded to sub rounded fragments of volcanic rocks cover a wide area at the foot of the escarpment. The alluvium becomes finer in grain size (Silty to clayey) in the northern part of the plains. The general decrease in grain size of the alluvial sediments could be explained in terms of distance of transportation from the escarpment. The longer the distance of travel, the finer the grain size. A recent water-well drilling operation (OWWCE, 2011) which is outside the Mullu catchment indicate the thicknesses of the alluvial deposits to vary from 174 meters in the Biyo Bahi area of eastern Shinile Zone to more than 250 meters in the Aydora area of central Shinile Zone.

Thin interbeds of volcanic rocks are reported from the alluvial sediments the Allay Dege plains of southwestern Shinile Zone (K. Tadesse and H. Ferdinand, 1983). Both felsic and basic lava flows are encountered in the drill logs of water well drilling operations. Interbeds of sandy and clayey layers characterize the alluvial section in most localities. The clay usually occurs as thin discontinuous layers within the Silty materials. The alluvial sediments have been described as good storage places of fresh groundwater (K. Tadesse 1982, T. Keleta, 1974 and WWDSE, 2009). The actual thickness of the alluvial deposits remains for further investigation. Electrical, gravity, and magnetic geophysical surveys conducted in the area (Shimelis Ashenafi1986) remained inconclusive in regards to the thickness of the alluvial sediments due to the absence of geological and drilling data. In this regard, other effective methods such as seismic refraction and airborne magnetic surveys would produce better results in regards to the determination of the depth of the alluvial deposits and to map out the zones of fractures underlying the thick alluvial cover, both of which are very important factors in the evaluation of the groundwater resources of the area.

3.3.2. Quaternary Volcanic Rocks

These rocks are extruded after the opening of the Main Ethiopian Rift and the Afar Depression, and mainly occur along the floor and margins of the rift. The Quaternary volcanic rocks occur as intercalations within ancient and modern alluvial sediments indicating the existence of concomitant processes of sedimentation and volcanism in the Rift Valley during the Quaternary period. The volcanic rocks of the Afar Series, like the Trap Series, are stratoid volcanic rocks which are dominated by fissural-type basaltic flows. At the southern margin of the Afar Depression, Quaternary shield volcanoes which are comprised of both basaltic and felsic rocks occur in the form of domes. The Asebot and Afdem mountains which occur at the southern margin of the Afar Depression are included under this category and grouped with the Chilalo Formation (Mengesha T. et al. 1996). These rocks are comprised of basaltic and trachytic to rhyolitic flows and pyroclastic falls. The basaltic rocks occur at the lower and upper parts of the succession, whereas the trachytic rocks occur sandwiched between the basaltic flows. Similar shield volcanoes of Quaternary age occur in the Mullu catchment.

The recent (Holocene) volcanic rocks occur in association with trachytic to rhyolitic rocks and scoracious cones and flows. In the Mullu catchment, the recent volcanic rocks extruded at the intersections of the NNE faults. These rocks are basaltic in composition and appear as fresh lava flows which are devoid of any soil or vegetation.

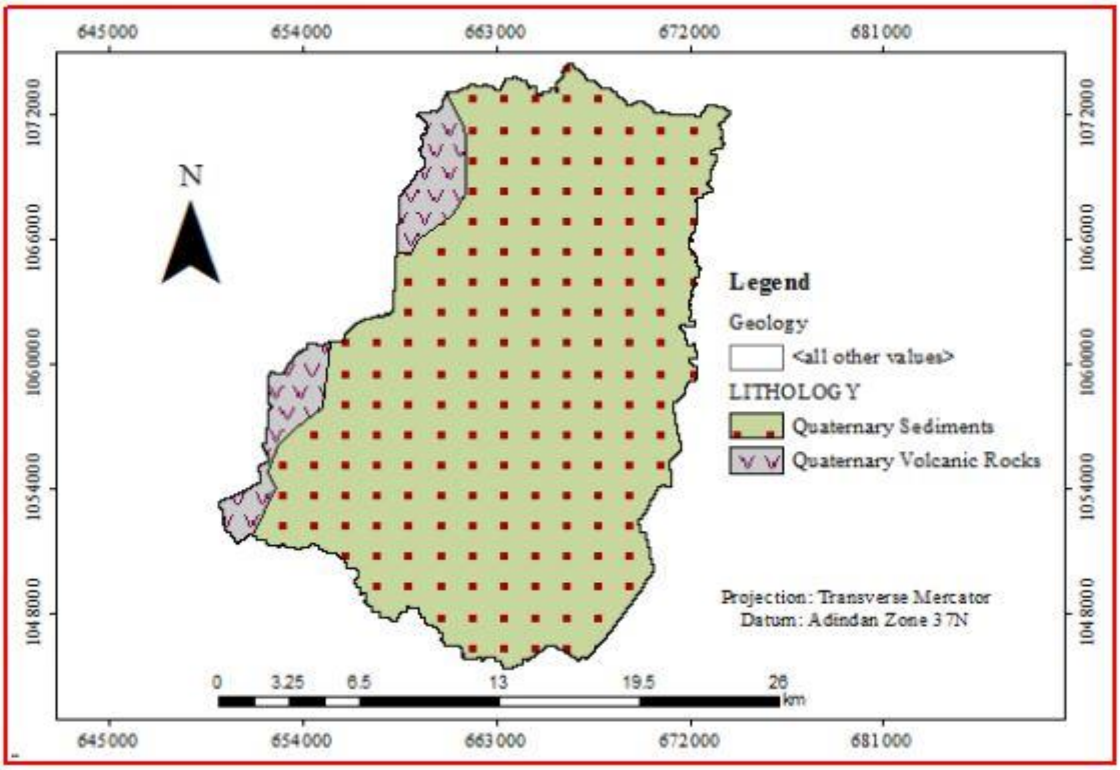

Figure 3.1: Geology of Mullu catchment (modified from EIGS 1996)

3.4. Stratigraphy

The Quaternary volcanism appears to occur concomitantly with the opening up of the rift valley which followed the down faulting of the domed areas which resulted from the regional uplift. The uplifted terrain was eroded and it produced thick succession of alluvial and fluvial sediments. Both volcanism and deposition of alluvio-fluvial sediments took place at the same time. It leads to the existence of intercalations of volcanic rocks and alluvial sediments in several places of the Mullu catchment.

The felsic volcanic rocks of the Quaternary Period, is mainly took place along the margins of escarpment of Mullu catchment. The intermittent volcanic eruptions of the catchment gave rise to the intercalations of unconsolidated sediments and volcanic flows. Based on boreholes drilled data found outside Mullu catchment data, the stratigraphy for Mullu catchment is described.

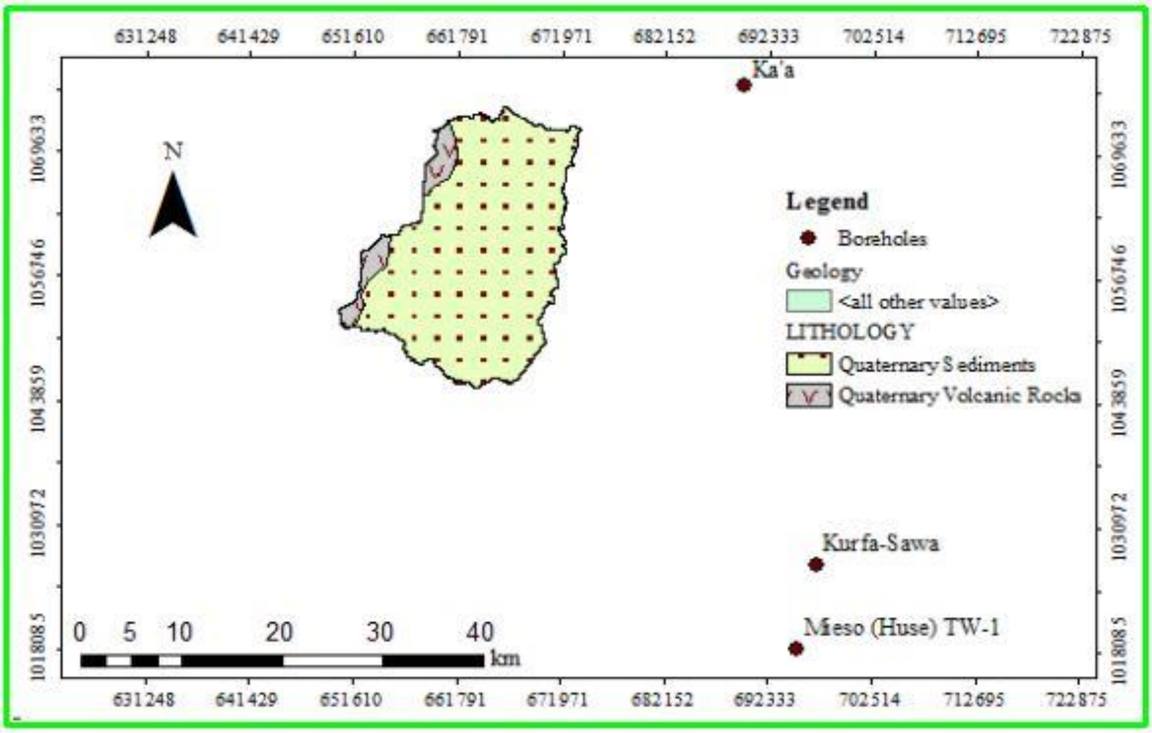

Figure 3.2: Borehole locations found outside Mullu catchment

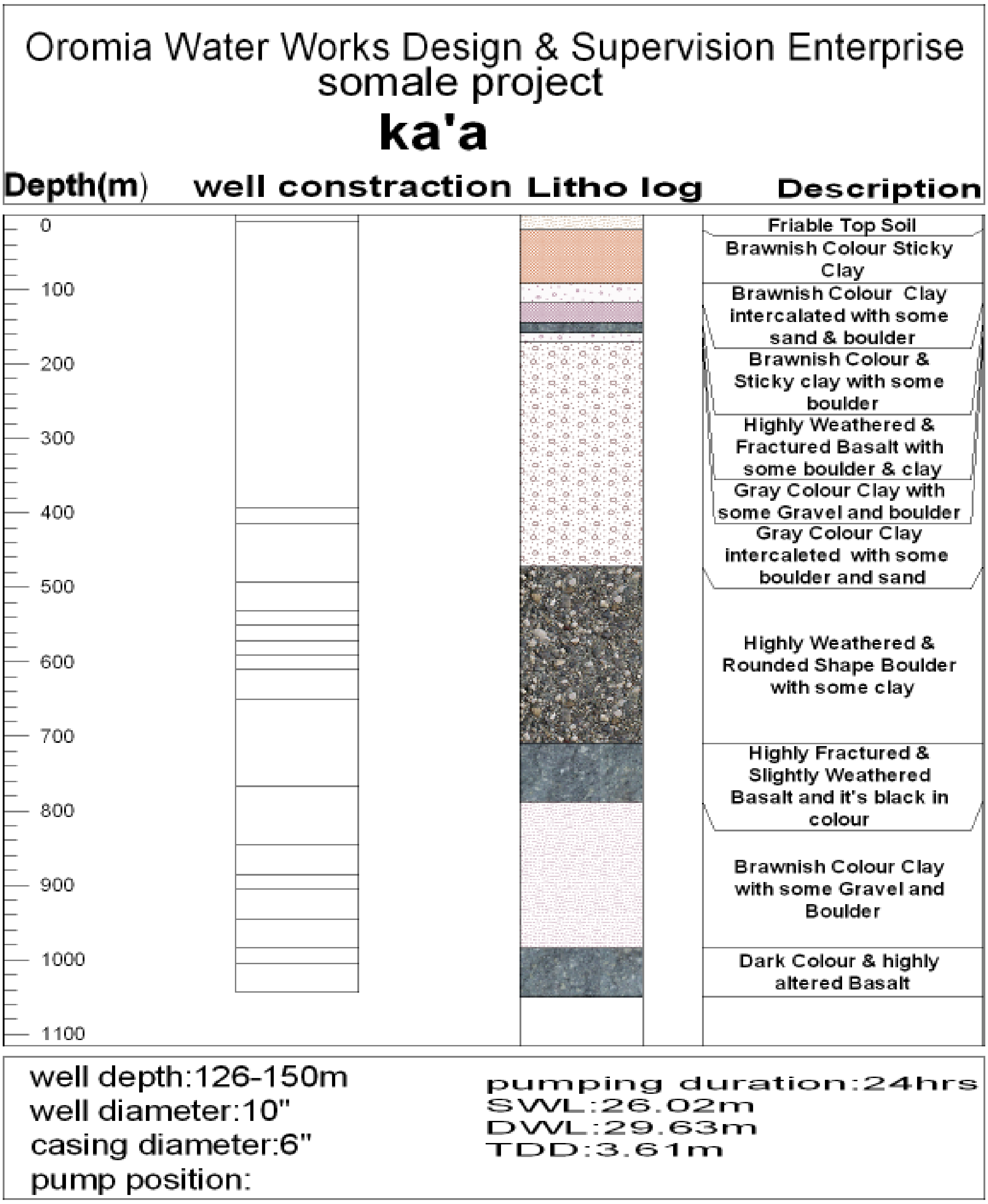

Figure 3.3: Lithological logging for Ka'a borehole (OWWDSE, 2011)

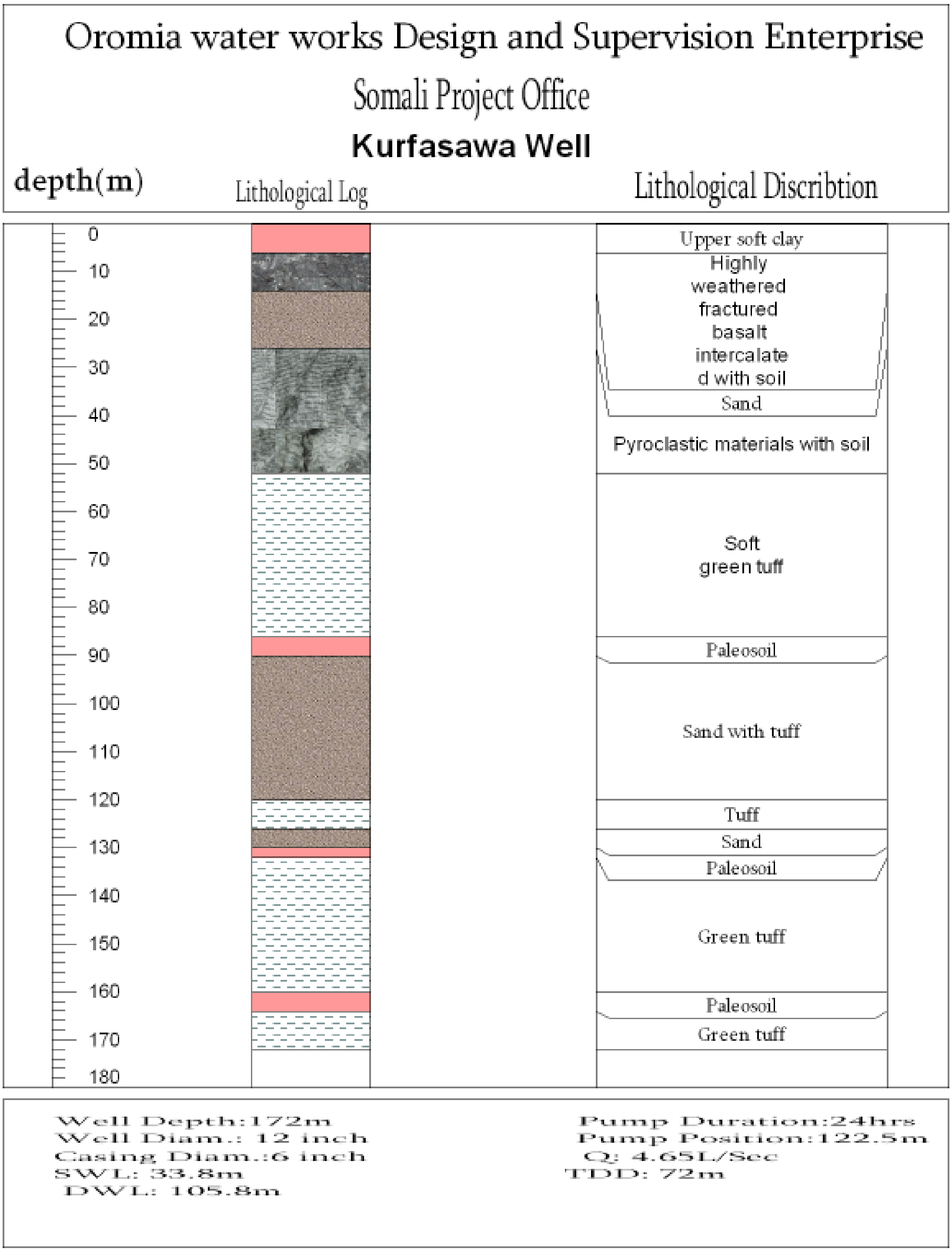

Figure 3.4: Lithological logging for Kurfa Sawa borehole (OWWDSE, 2011)

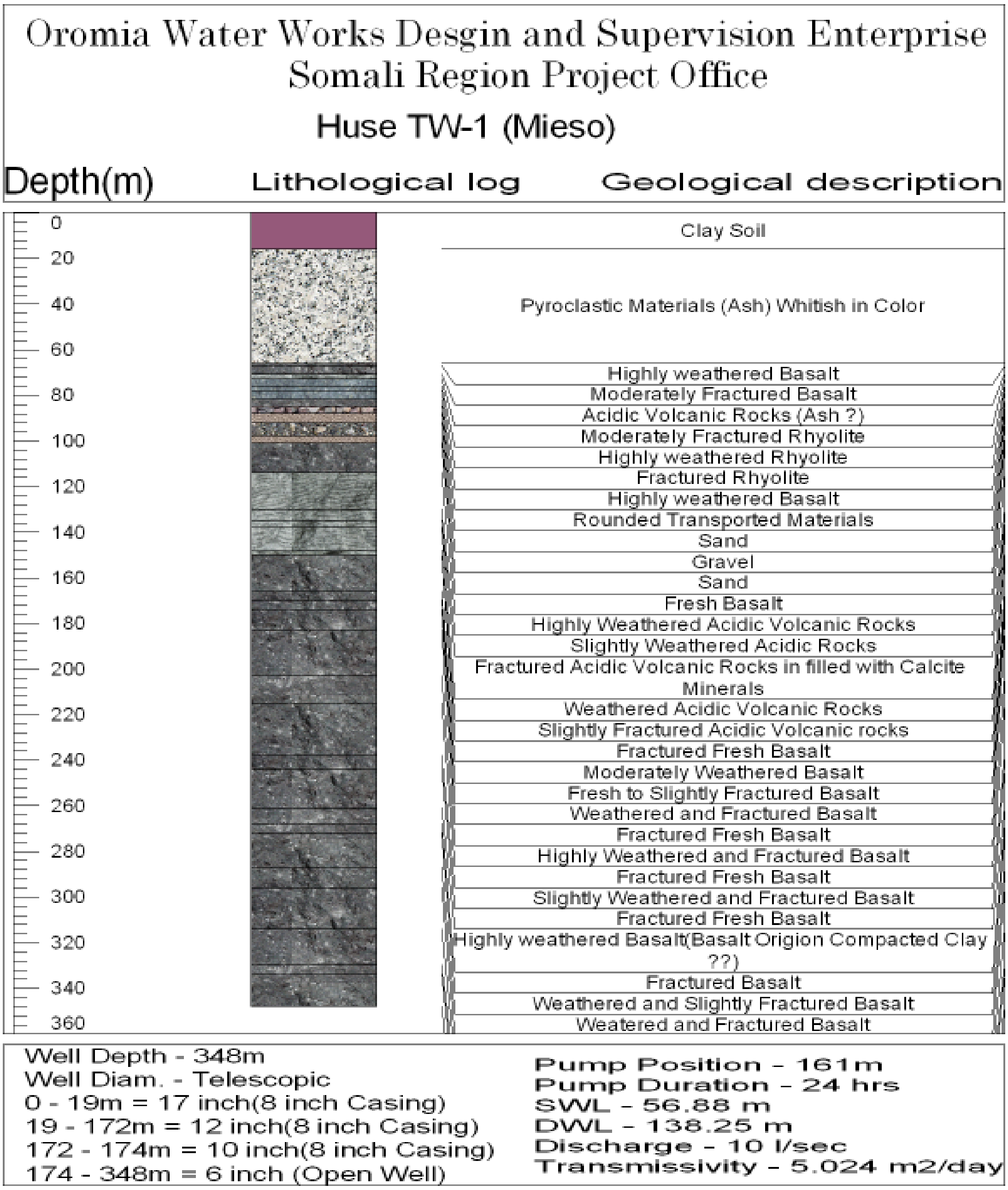

Figure 3.5: Lithological logging for Huse TW-1 (Mieso) borehole (OWWDSE, 2011)

3.5. Geologic Structure

One of the most conspicuous structural features of the area is the triangular depression which marks the northeastern part of the Main Ethiopian Rift (MER) that is referred in the literature as the Afar Triangle. The Afar Triangle attains its present shape as a result of interactions of three major sets of normal faults which down throw the rocks of the northwestern and southeastern plateaus to give rise to the spectacular depression. The three major faults which impart a triangular shape to the depression have EW (Aden), NNW (Red Sea), and NE (Nazret) trends. Other major structural features of the rift structure include a younger NNE- fault is developed at the central part (axial zone) of the Main Ethiopian Rift and the Afar Triangle. This fault belt is situated in the Mullu catchment. The NNE-oriented Wonji Fault Belt structure is truncated by a parallel set of NW oriented transverse faults in the southwestern part of the Shinile zone. The transverse faults appear to control the emplacement of the youngest Holocene volcanic rocks.

3.5.1. Lineaments

The most prominent lineaments in the area are those related to NNE faults. These lineaments played major roles in the formation of the rift valley and the subsequent deposition of the different types of rocks and sediments of the Mullu catchment. The NNE oriented lineaments of Mullu catchment is related to the Wonji Fault Belt. Groundwater movement in Mullu catchment is largely controlled by the system of the lineaments which is related to the NNE oriented faults.

3.5.2. Faults

One set of fault is mapped in Mullu catchment and is correspond to the major lineament sets of the catchment. The major geomorphologic feature of the area and the deposition and emplacement of the Quaternary volcanic rock is controlled by the fault systems. The most prominent faults in the Mullu catchment is those related to NNE faults which play major roles in the formation of the Rift Valley.

This fault system appears to be the northern continuation of the Wonji Fault Belt which occurs in the Nazret area south of the Mullu catchment. This fault has a length of 38.9 kilometers. The emplacement of recent volcanic rocks and minor discontinuous lacustrine deposits appears to be controlled by the existence of this important structure which lies at the central part (axial zone) of the rift valley.

4. HYDROLOGY

4.1. Rainfall

There are five meteorological stations most closely located to the study area, which were installed by National Meteorological Agency (NMA) of Ethiopia. They are located at Afdem, Asebot, Gewane, Mieso, and Melka Werer area. In spite of the fact that sufficient numbers of meteorological stations have not been established throughout the study area, or even the existing ones are not properly functioning and data are so scanty, information regarding the detail climatic conditions of the study area is very limited or more general.

Different approaches for estimating missing rainfall data varying with and based on the effect of topography on rainfall distance between the rainfall stations and the variation of rainfall amount recorded on the stations. Normal-ratio method is one which is recommended to estimate missing rainfall data in the Mullu Catchment.

The arithmetic mean method is usually applied for preliminary evaluation of precipitation depth and in flat areas with even distribution of stations in the catchment but in practice; this method is used very rarely. The Thiessen polygon method of calculating the average precipitation over an area is superior to the arithmetic average method as some weight is given to the various stations on a rational basis. Further, the rain gauge stations outside the catchment are also used effectively. Therefore, Thiessen polygon method is more applicable to determine areal rainfall for the study area.

Table 4.1: Areal Rainfall interpolated using Thiessen Polygon Method for Mullu Catchment

Station	**Pi**	**Ai**	**Ai/At**	**Pi(Ai/At)**
Afdem	451.6416	8	0.019231	8.685519094
Asebot	940.8573	37	0.088942	83.68172704
Gewane	485.1462	19	0.045673	22.15808118
Melka Werer	450.3912	289	0.694712	312.8921389
Mieso	830.853	63	0.151442	125.8260373
Total	3158.889	416	1	**553.2435035**

4.2. Runoff

Runoff is water that is not percolated by soil or that does not soak into the soil but flows into surface waters. The Geology, slope, and topography of the area are the most influencing circumstances of runoff, and in addition the area, actual evapotranspiration, rainfall and vegetation cover least to influence runoff. In general, less than average rainfall, high evapotranspiration, gentle slope, very permeable volcanic falls and disappearing drainage pattern can assure the lowest runoff. Direct runoff is that component of the precipitation, snow melt, or irrigation water that come in existence in uncontrolled surface streams, rivers, drains and sewers. It is composed of precipitation that neither evaporates, transpires nor goes into the surface to become groundwater. It happens whenever the rate of rainfall on a surface go beyond the rate at which water can percolate the ground and any depression storage has already been become full. This is more frequently takes place in arid and semi-arid area, to which rainfall intensities are far above and the soil infiltration ability is become smaller by reason of surface impervious, or in pavement region. Runoff for Mullu catchment is calculated using Excel Sheet empirical formula (MoWR, 2002).

Table 4.2: Long term mean monthly surface runoff (mm) of Mullu catchment

Year	**Afdem**	**Asebot**	**Gewane**	**Melka Werer**	**Mieso**	**Mean**
Jan	0.001629	2.0301415	1.37766758	0.1515786	0.9999691	0.91219721
Feb	0.284913	16.396475	6.79484934	4.7196126	2.7654924	6.19226839
Mar	1.136902	15.753716	13.6520098	5.2290066	12.049542	9.56423533
Apr	0.866401	18.18907	6.82978848	3.6384678	19.361376	9.77702064
May	0.328425	9.123805	3.1312288	0.6395851	5.660736	9.77702064
Jun	0.129307	2.9831917	0.09204774	0.3011982	0.7452316	3.77675607
Jul	1.273474	30.096644	13.1854445	4.4909976	19.871269	13.7835657
Aug	1.065572	29.908126	17.4090791	6.3496791	19.691519	14.8847949
Sep	0.518474	9.9740504	1.6817735	1.8729593	6.1693751	4.04332639
Oct	0.294182	7.077772	3.28234928	0.8611018	8.3050716	3.96409539
Nov	0.132674	2.2513125	1.40219148	0.1975175	1.0075702	0.99825322
Dec	0.026638	3.5074892	1.12700925	0.2909608	0.7127144	1.13296242

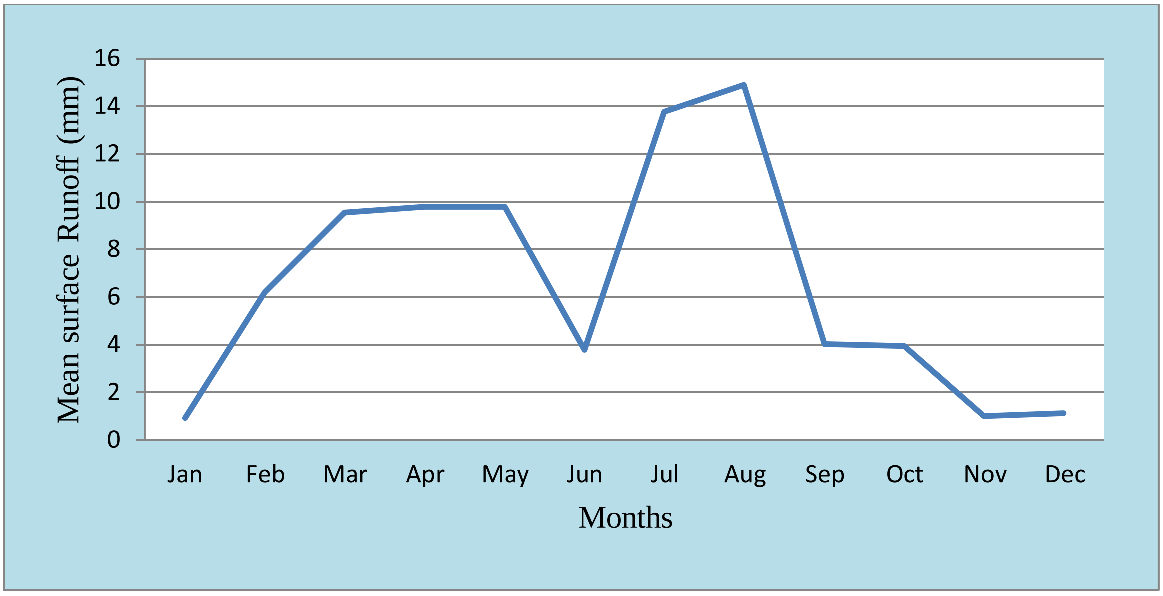

Figure 4.1: Long term mean monthly surface runoff of Mullu catchment

The discharge records evidence of the same fashion, the peak flow agrees almost exactly with the rain months of July and August. The existing real sequence of flow throughout the course of the year is controlled by precipitation, evapotranspiration, soil and geological feature of the Mullu catchment. The higher the percolation in the storage amount of a stated catchment, the high flows is validated through the dry period of the year, and the highest flows after time of highest precipitation.

4.3. Potential Evapo-Transpiration (PET)

Potential Evapotranspiration is the combination of evaporation from the soil surface and transpiration from vegetation. The Penman- Monteith method is used for estimating Potential evapotranspiration. Monthly potential evaporation for different stations has been computed by using Local Climate estimator (New_LocClim) software/ Penman-Monteith equation / produced by FAO. New_LocClim v.1.10 does not only calculate different climate variables at given locations; but also provides quite a variety of tools to improve the estimates. This software gives potential evapotranspiration for the given average data.

The ETc can be estimated as:

ETc = Kc*PET, Where: ETc-Crop/Vegetation évapotranspirations.

Kc is the crop/ vegetation coefficient.

The Kc value relates to evapotranspiration of a disease free crop grown in large fields under optimum soil cover and fertility conditions and achieving full production potential under the given growing environment for a crop depend on the stage of crop.

Table 4.3: Potential Evapotranspiration of Mullu Catchment estimated using by FAO New_LocClim Estimator v.1.10.

PET (mm)	**Afdem**	**Asebot**	**Gewane**	**Melka Werer**	**Mieso**	**Mean**
January	161.2	161.6	148.8	161.6	161.6	158.96
February	152	159	140	159	159	153.8
March	174.1	179.4	164.3	179.4	179.4	175.32
April	154.7	149.3	153	149.3	149.3	151.12
May	146.6	146.7	148.8	146.7	146.7	147.1
June	161.7	157.5	144	157.5	157.5	155.64
July	162.4	166.7	142.6	166.7	166.7	161.02
August	176	173.5	151.8	173.5	173.5	169.66
September	168.5	177.5	147	177.5	177.5	169.6
October	137.6	144	139.5	144	144	141.82
November	135.7	135.6	144	135.6	135.6	137.3
December	151.7	145.3	130.1	145.3	145.3	143.54

As it is shown from the above table maximum mean monthly PET is recorded in March, while minimum mean monthly PET in recorded in November.

4.4. Actual Evapotranspiration (AET)

During the months in which the rainfall exceeds the potential evapotranspiration the actual evapotranspiration will be set equal to the potential evapotranspiration. During the dry months the actual evapotranspiration exist of the sum of the rainfall of the current month and the amount of water extracted from the soil (the soil moisture utilization). The soil moisture during the dry month is obtained using the following formula (Thornthwaite, 1997).

$S_M = W.\exp(-L_{aM}/W)$,

Where: S_M= Soil Moisture During month, M (mm)

L_{aM} =Accumulated potential water loss at month, M (mm)

W= Available water capacity of the root zone (mm)

Source: Water balance calculation of the Thornthwaite, user manual, June 1997.

For deep rooted crops/pasture grass and shrub lands/, Clay & Clay loam Soil, W=250
For moderately Deep rooted crops, Silt loam, Sandy loam, Clay loam Soil available water capacity of root zone (W) =150. For mature Forest, Silt loam, Sandy loam, Clay loam Soil available water capacity of root zone (W) =350. For this study area we have considered the land use/covers and soil textures depending on land use/cover of the areas. The Actual evapotranspiration computed using Thornthwaite and Mather soil water balance model for Mullu Catchment is illustrated in the following table.

Table 4.4: Monthly Actual Evapotranspiration interpreted using Thornthwaite method for Mullu Catchment

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
Rainf	11.26	32.96	72.1	77.25	40.32	28.06	117.06	131.95	67.37	30.69	11.89	10.86	631.77
Effective Rainf	11.26	32.96	72.1	77.25	40.32	28.06	117.06	131.95	67.37	30.69	11.89	10.86	631.77
Reference Poten Evapo	158.96	153.8	175.32	151.12	147.1	155.64	161.02	169.66	169.6	141.82	137.3	143.54	1864.88
Kc values	0.4	0.4	0.4	0.4	0.6	0.4	0.4	0.4	0.4	0.6	0.6	0.4	
Crop. Poten.Evapo	63.6	61.5	70.1	60.4	88.3	62.3	64.4	67.9	67.8	85.1	82.4	57.4	831.2
Rainf - Crop.Pot Evapot	-52.3	-28.6	2.0	16.8	-47.9	-34.2	52.7	64.1	-0.5	-54.4	-70.5	-46.6	-199.4
Accumu.Poten Water Loss	-223.8	-252.3	-250.4	0.0	-47.9	-82.1	-29.5	34.6	34.1	-54.4	-124.9	-171.4	
Soil Moisture	33.7	27.9	28.3	150.0	109.0	86.8	123.2	188.9	188.3	104.4	65.2	47.8	
Difference in Soil Moisture	-14.1	-5.9	0.4	121.7	-41.0	-22.2	36.5	65.7	-0.6	-84.0	-39.1	-17.4	
Actual Evapo Tran (AET)	25.3	38.8	71.7	151.1	81.4	50.3	80.6	66.3	68.0	141.8	51.0	28.3	854.6

4.5. Water Balance Method

Catchment water balance allows to study the hydrologic process-taking place in a catchment area and to determine the inflow to the catchment or out flow from the catchment. By assuming the boundary of the surface water catchment coincides with that of the ground water, the net ground water flow was taken to be zero. The water inflows in to the catchment area are therefore considered to be only from rainfall while the water leaving the catchment area includes runoff (R) and actual evapotranspiration (ETA).

The difference between them constitutes the change both in groundwater storage and soil moisture (ΔS).

ΔS=RF-(ETA+DRO) Where;

ΔS: is change in groundwater and soil moisture storage i.e. Recharge;

RF: is precipitation (mm);

ETA: is actual evapotranspiration from the catchments (mm);

DRO: is direct runoff from the catchments (mm)

The drainage system decreases downstream into the valley and plains indicates infiltration to the ground water and Potential evapotranspiration increases. The negative values obtained during the spreadsheet water balance are considered to be zero, implying no recharge takes place during those months.

Table 4.5: Catchment water balance of Mullu Catchment Water Balance Method

Month	**RF (mm)**	**PET (mm)**	**K_c**	**ETC (mm)**	**AET (mm)**	**RO (mm)**	**AET+RO**	**ΔS (Recharge)**
Jan	11.26	159	0.4	63.6	25.3	0.91	26.21	0
Feb	32.96	153.8	0.4	61.5	38.8	6.19	44.99	0
Mar	72.1	175.3	0.4	70.1	71.7	9.56	81.26	0
Apr	77.25	151.1	0.4	60.4	151.1	9.78	160.88	0
May	40.32	147.1	0.6	88.3	81.4	9.78	91.18	0
Jun	28.06	155.6	0.4	62.3	50.3	3.78	54.08	0
Jul	117.06	161	0.4	64.4	80.6	13.8	94.4	22.66
Aug	131.95	169.7	0.4	67.9	66.3	14.9	81.2	50.75
Sep	67.37	169.6	0.4	67.8	68	4.04	72.04	0
Oct	30.69	141.8	0.6	85.1	141.8	3.96	145.76	0
Nov	11.89	137.3	0.6	82.4	51	1	52	0
Dec	10.86	143.5	0.4	57.4	28.3	1.13	29.43	0
Total	631.77	1865			854.6	78.8	933.4	73.41

Where:

PET=potential evapotranspiration (mm);

Kc =crop coefficient of the vegetation which given for perennial crops having similarity with shrubs and grass,

ETC = crop or vegetation evapotranspiration (mm)

ETA=actual evapotranspiration (mm) which is obtained by Thornthwaite Method;

PPT*=rainfall minus actual evapotranspiration (mm)

DRO=direct runoff (mm)

ΔS=change in storage (mm), which is ΔS=RF-ETA-DRO.

5. HYDROGEOLOGY

5.1. Generals

Groundwater potential assessment Mullu catchment is intended to address communities' critical water shortage and associated food insecurity problems. The raging recurrent drought over a long period of time has put the livelihood of the society and their livestock under stress. The alarming expansion of desertification is also distinct feature of the study area which may take significant part in posing such overwhelming poverty that has gripped the society's lives.

The groundwater is one of the feasible resources to counteract life crippling situation in Mullu catchment. To undertake the study designed methodologies are Geological and hydrogeological mappings, analysis of GIS, hydrometorological analysis, review of pervious works, etc. greatly help the understanding of groundwater quantity of the catchment. Hydrogeologically, the alluvial deposit is preferred to the other lithology. Likewise, the primary and secondary porosities are important hydraulic characteristics in the volcanic rocks unless they are sealed by secondary fillings such as detritus of calcite and quartzes material.

The main recharge is from precipitation which is more regular and dominant on the southern boundary (EW Oromia high land). The low land experiences sporadic rainfall that would also have part in recharging contribution. Many streams are generated from the EW highlands, however almost all of them disappear into the thick alluvial deposit.

5.2. Water Bearing Characteristics

Thick alluvial deposit and quaternary volcanic rocks characterize the Mullu catchment. The alluvial deposit occupies most of the area particularly central lowland plain of the catchment. This unit is jammed in between the bounding rift quaternary volcanic formations and is occurred as a pocket in the catchment. The water bearing characteristics of the rocks of the Mullu catchment is briefly summarized as follows:

5.2.1. Massive Volcanic Rocks

The massive volcanic rocks of Quaternary periods, which commonly occur in the form of stratoid basalts can be considered as major Aquicludes in the Mullu catchment, if not fractured and shattered. Similarly, the massive alkaline trachytic and rhyolitic domes and the weakly deformed to massive basaltic and trachytic flows act as natural barriers to groundwater flows.

5.2.2. Clay Beds of the Alluvial Sediments

Thin discontinuous layers of clay in Mullu catchment, usually on the order of a few meters are commonly exposed along stream sections in the alluvial plains. These clay layers could act as Aquicludes within the porous alluvial aquifers. In most cases, the clay beds are usually very thin (1 to 2 meters) and discontinuous, and, may not have significant regional impact in hampering the movement of groundwater within the alluvial sediments which are usually comprised of much thicker coarse alluvial sediments.

5.2.3. Alluvial Aquifers

The unconsolidated alluvial sediments of the Mullu catchment fall into the highly productive aquifer system which is characterized by inter-granular permeability. The unconsolidated sediments cover most parts of the catchment. Drilling data conducted outside Mullu catchment indicates the unconsolidated sediments become thicker in the southwestern parts of Shinile Zone. Both surface and drilling data indicate that the unconsolidated sediments are comprised of gravel, sand, silt and clay interbeds.

Volcanic cuttings are commonly encountered within the drill logs of boreholes outside Mullu catchment, which are located within the unconsolidated sediments of south western parts of Shinile Zone. The basaltic materials are described as thin intercalations within the alluvial succession.

5.2.4. Volcanic Aquifers

The volcanic aquifer of the Mullu catchment is classified as medium-to high-yield aquifers. The fractured and weathered volcanic rocks of the escarpment area act as passageways of moving water from the southern highlands to the alluvial plains of the lowlands of Mullu catchment. Similarly, the volcanic rocks of the catchment is strongly fractured and weathered where these rocks are transected by regional faults. The fractured volcanic rocks act as groundwater aquifers where water is stored. Fault scarps of fractured and weathered volcanic rocks generally increase the permeability of the fractured volcanic rocks along the escarpment, which makes up the major area of recharge for the lowland areas of the catchment.

5.3. Groundwater System

5.3.1. Recharge and Groundwater Availability

The major recharge inducing to groundwater of Mullu catchment comes from precipitation regularly experienced on south boundary marking highland. It is dissected; structural controlled and has distinct elevated topography that receives prolonged annual rainfall of significant amount. The pretty heavily modified geomorphologic configuration of the intermountain system presumably enhances rate of infiltration as the same time the deep seated structures imprints over these mountains serve as regional to local groundwater flow controlling conduits. Ever present tectonic dynamicity of the catchment triggered the onset of networked geological structures that would function as groundwater path flow to the low land of Mullu catchment. Recently drilled and existing several water yielding wells outside Mullu catchment and within the Shinile plains evidence availability of groundwater whereby strongly referring to the source of aquifers replenishment comes from precipitation on the high lands to some extent from directly received erratic rainfall.

Unlike the south bounding Oromia high land the lowland plain of Mullu catchment only receives unusual torrential rainfall where rate of evaporation and infiltration prevalence is spatially variable in relation to geological geometric configuration and associated tectonic impression. The enhance rate of infiltrations are deep seated tectonic structures and porous thick extensive superficial deposits with high infiltration capacity Ketema Tadesse, 1983.

The major recharge source for the Mullu catchment is precipitation. Rainfall situation of the catchment is variable with topography; highest points receive far better regular precipitations as compared to the lower plain area that experiences sporadic rainfall. Obviously, more recharge takes places along the NNE oriented ridge which is the direct impression of NNE regional fault system. Recharge condition of the catchment is crucially controlled by topographic settings, prominent intensive fracturing has also taken place which largely allows circulation of groundwater. Besides, the porous superficial deposit greatly serves as recharge inducing element. Local, intermediate and regional recharges preferentially take place along the dissected ridges which makes this inevitable are considerable topographic gradient variations, tectonic controlled morphology and geological settings.

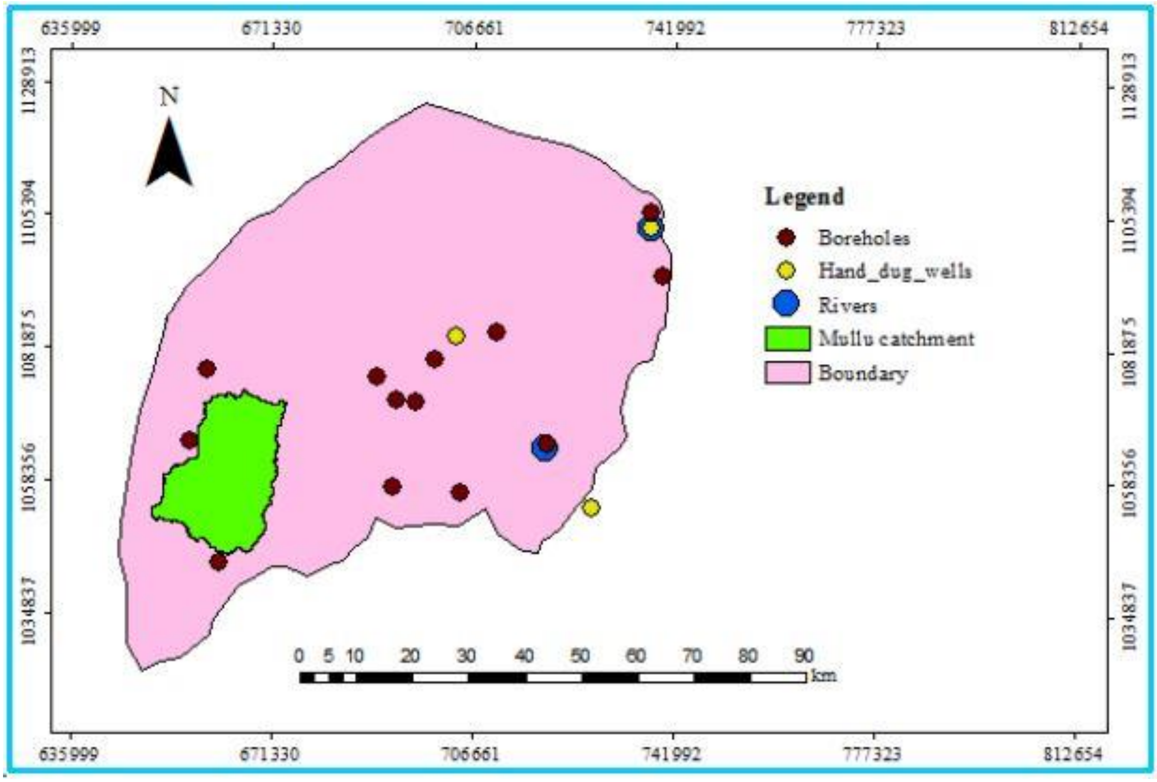

Figure 5.1: Water points found outside Mullu catchment catchment

Work of Ketema Tadesse and Ferdinand, 1983 and WWDSE, 2009 in Allaidege plain elaborates the possible hydraulic linkage between groundwater and surface water. As a rule of thumb this functions in light of the simple general principle that water flows from high to lower energy level similarly it is presumed that groundwater may assume that of surface topography gradient head difference. Work of Seifu Kebede, et.al, 2010 argue that rift escarpment characterizing networks of fault systems serve as a regional path flow for groundwater to rift floor whereby regional recharge is possibly induced. `Moreover, productive deep and shallow groundwater occurrence in arid environment of various Shinile part is strong implication of fair recharge occurrence and coinciding northward groundwater flow direction; productive wells with appreciable discharge are also suggestive parameters of hydraulic linkage in between the Mullu catchment plain and the southern high land boundary (identified as recharging zone).

Water supply boreholes of Afdem, Bike, Mullu towns and others located in the intermountain system land escape which are suggestive of local recharge where networks of large scale deep seated geological structures crucially facilitate groundwater flow to mullu catchment as a regional recharge.

5.3.2. Discharge

Major discharge components in Shinile plain includes groundwater withdrawal for domestic purpose (human and livestock consumption), evapotranspiration from wet land areas mainly typical at the end of streams. Wells drilled outside Mullu catchment for testing and other purpose mainly turned to be productive; wells with diameter of 12 inch give rise to discharges greater than 20l/s. For instance Mete artesian well discharge is about 28l/s even the well yield could be more than this had not been the capacity of pump and well diameter that limits rate of water to be pumped out. Evapotranspiration is prominent water withdrawing factor besides groundwater abstraction for community water supply, irrigation of household and few state farm (e.g. Erer Gota) are also notable means by which water is reduced from the system.

Most wells tend to have surpulus water for any sort of use even though quality delimit exists along certain corners. Understanding of recharge and discharge relationship necessitate mechanism how to employ groundwater to any sort of utilization under safe exploitation. The pocket structural controlled wet lands are specific location where groundwater discharge takes place. Ostensibly in this place evapotranspiration prevalence is more significant and practical on account of available potential shallow groundwater that can be lost to evaporation.

5.4. Groundwater Movement

Groundwater movement of the Mullu catchment is clearly related to prevailing tectonic features and associated geomorphological modification that tend to maintain hydraulic gradient to define groundwater flow direction. Flow of groundwater in Mullu catchment can make sense when treated in the light of southern highlands which controls major groundwater recharges to the catchment plain. Apparently all geological, hydrological and hydrogeological works strongly suggest the general converges of groundwater flow direction is toward the NNE.

In hydrogeological environment overlaping eposodes Fault system, rocks hydraulic chractersatiscs, faulted rocks spatial distribution, dispalcement and nature of the faulted rocks curcially determine fate of groundwater (Apaydin A, 2010). Boreholes drilled outside the Mullu catchment with aprreciable yields in Shinile plain and adjoining area heavily depicts significant hydraulic linkage presence between the high land (high rainfall recieving and recharge area) and the extensive flat plain.

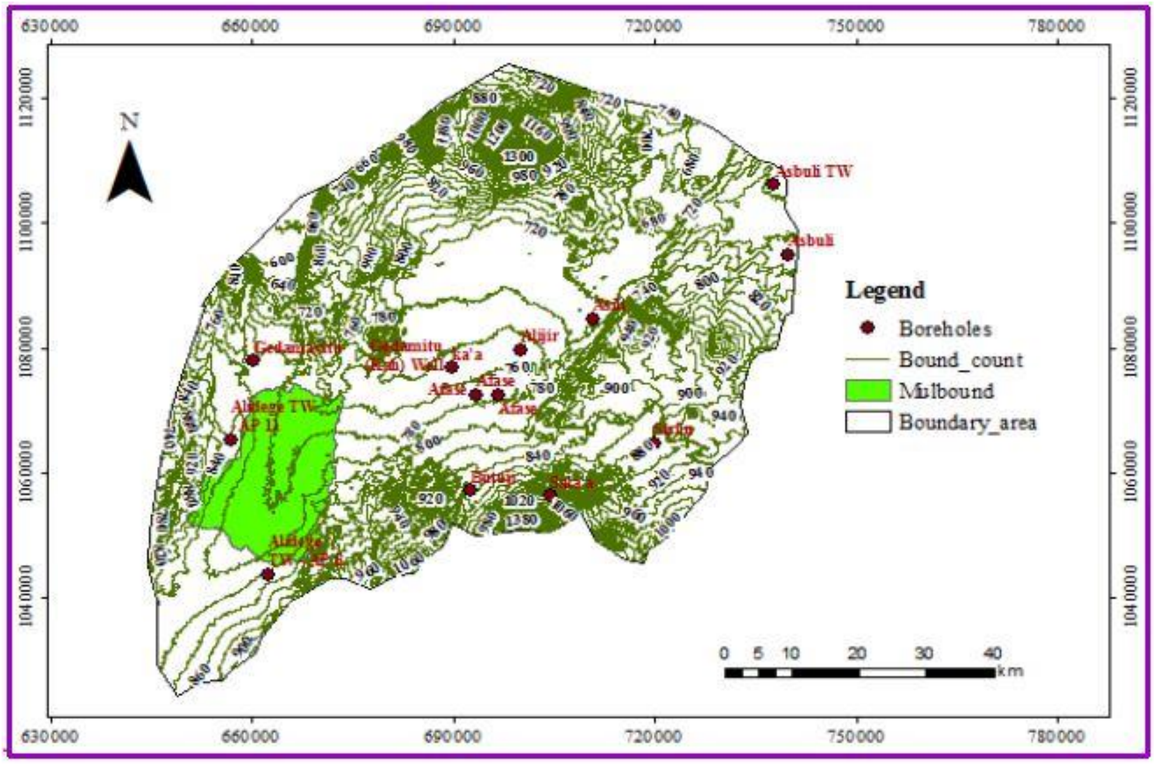

Figure 5.2: Groundwater Contour map of boundary area

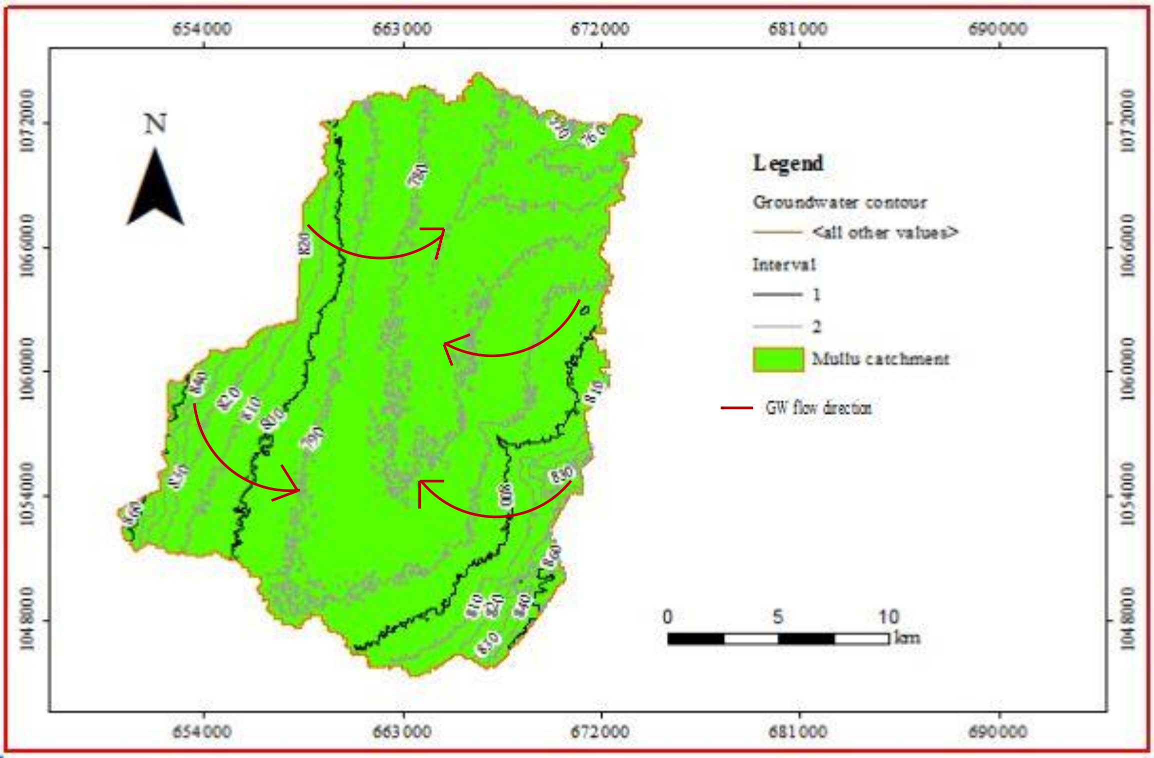

Figure 5.3: Groundwater Contour map of Mullu catchment shows groundwater flow direction

6. RESULT AND DISCUSSION

6.1. Geology

Mullu Catchment is situated at narrow valley that surrounded by the silicic volcanic rocks ridges in which the surface drainage out flows towards Afdem area. The area is drain by seasonal streams originating from south, south east and south west high land areas. The altitude of the study area ranges from 750 to 850m a.m.s.l. with few mountains having greater elevations.

Unconsolidated sediments of Quaternary age occur in several areas of Mullu catchment and the Awash River Valley. Thick succession of alluvial deposits cover most parts of the plains of Mullu catchment. Coarse alluvial deposits with rounded to sub rounded fragments of volcanic rocks cover a wide area at the foot of the escarpment. The alluvium becomes finer in grain size (Silty to clayey) in the northern part of the plains. The general decrease in grain size of the alluvial sediments could be explained in terms of distance of transportation from the escarpment.

The felsic volcanic rocks of the Quaternary Period, is mainly took place along the margins of escarpment of Mullu catchment. The Quaternary volcanism appears to occur concomitantly with the opening up of the rift valley which followed the down faulting of the domed areas which resulted from the regional uplift. The uplifted terrain was eroded and it produced thick succession of alluvial and fluvial sediments. Both volcanism and deposition of alluvio-fluvial sediments took place at the same time. It leads to the existence of intercalations of volcanic rocks and alluvial sediments in several places of the Mullu catchment.

One set of fault is mapped in Mullu catchment and is correspond to the major lineament sets of the catchment. The major geomorphologic feature of the area and the deposition and emplacement of the Quaternary volcanic rock is controlled by the fault systems. The most prominent faults in the Mullu catchment is those related to NNE faults which play major roles in the formation of the Rift Valley.

6.2. Hydrology

There are five meteorological stations most closely located to the study area, which were installed by National Meteorological Agency (NMA) of Ethiopia. They are located at Afdem, Asebot, Gewane, Mieso, and Melka Werer area. In spite of the fact that sufficient numbers of meteorological stations have not been established throughout the study area, or even the existing ones are not properly functioning and data are so scanty, information regarding the detail climatic conditions of the study area is very limited or more general. Different approaches for estimating missing rainfall data varying with and based on the effect of topography on rainfall distance between the rainfall stations and the variation of rainfall amount recorded on the stations. Normal-ratio method is one which is recommended to estimate missing rainfall data in the Mullu Catchment.

Runoff for Mullu catchment is calculated using Excel Sheet empirical formula (MoWR, 2002). The peak runoff agrees almost exactly with the rain months of July and August. The existing real sequence of flow throughout the course of the year is controlled by precipitation, evapotranspiration, soil and geological feature of the Mullu catchment. The higher the percolation in the storage amount of a stated catchment, the high flows is validated through the dry period of the year, and the highest flows after time of highest precipitation.

Potential Evapotranspiration is the combination of evaporation from the soil surface and transpiration from vegetation. The Penman- Monteith method is used for estimating Potential evapotranspiration. Monthly potential evaporation for different stations has been computed by using Local Climate estimator (New_LocClim) software/ Penman-Monteith equation / produced by FAO. New_LocClim v.1.10. The maximum mean monthly PET is recorded in March, while minimum mean monthly PET in recorded in November.

During the months in which the rainfall exceeds the potential evapotranspiration the actual evapotranspiration will be set equal to the potential evapotranspiration. During the dry months the actual evapotranspiration exist of the sum of the rainfall of the current month and the amount of water extracted from the soil (the soil moisture utilization). The soil moisture during the dry month is obtained using formula of Thornthwaite, 1997. And also, the Actual evapotranspiration computed using Thornthwaite and Mather soil water balance model for Mullu Catchment.

Catchment water balance allows to study the hydrologic process-taking place in a catchment area and to determine the inflow to the catchment or out flow from the catchment. By assuming the boundary of the surface water catchment coincides with that of the ground water, the net ground water flow was taken to be zero. The water inflows in to the catchment area are therefore considered to be only from rainfall while the water leaving the catchment area includes runoff (R) and actual evapotranspiration (ETA).

The drainage system decreases downstream into the valley and plains indicates infiltration to the ground water and potential evapotranspiration increases. The negative values obtained during the spreadsheet water balance are considered to be zero, implying no recharge takes place during those months.

Table 6.1: Quantified Groundwater Recharge for Mullu Catchment using Water Balance method

Month	**RF (mm)**	**PET (mm)**	**K_c**	**ETC (mm)**	**AET (mm)**	**RO (mm)**	**AET+RO**	**ΔS (Recharge)**
Jan	11.26	159	0.4	63.6	25.3	0.91	26.21	0
Feb	32.96	153.8	0.4	61.5	38.8	6.19	44.99	0
Mar	72.1	175.3	0.4	70.1	71.7	9.56	81.26	0
Apr	77.25	151.1	0.4	60.4	151.1	9.78	160.88	0
May	40.32	147.1	0.6	88.3	81.4	9.78	91.18	0
Jun	28.06	155.6	0.4	62.3	50.3	3.78	54.08	0
Jul	117.06	161	0.4	64.4	80.6	13.8	94.4	22.66
Aug	131.95	169.7	0.4	67.9	66.3	14.9	81.2	50.75
Sep	67.37	169.6	0.4	67.8	68	4.04	72.04	0
Oct	30.69	141.8	0.6	85.1	141.8	3.96	145.76	0
Nov	11.89	137.3	0.6	82.4	51	1	52	0
Dec	10.86	143.5	0.4	57.4	28.3	1.13	29.43	0
Total	631.77	1865			854.6	78.8	933.4	73.41

Where:

PET=potential evapotranspiration (mm);

Kc =crop coefficient of the vegetation which given for perennial crops having similarity with shrubs and grass,

ETC = crop or vegetation evapotranspiration (mm)

ETA=actual evapotranspiration (mm) which is obtained by Thornthwaite Method;

PPT*=rainfall minus actual evapotranspiration (mm)

DRO=direct runoff (mm), data obtained from generated flow;

ΔS=change in storage (mm), which is ΔS=RF-ETA-DRO.

6.3. Hydrogeology

The massive volcanic rocks of Quaternary periods, which commonly occur in the form of stratoid basalts can be considered as major Aquicludes in the Mullu catchment, if not fractured and shattered. Similarly, the massive alkaline trachytic and rhyolitic domes and the weakly deformed to massive basaltic and trachytic flows act as natural barriers to groundwater flows.

Thin discontinuous layers of clay in Mullu catchment, usually on the order of a few meters are commonly exposed along stream sections in the alluvial plains. These clay layers could act as Aquicludes within the porous alluvial aquifers. In most cases, the clay beds are usually very thin (1 to 2 meters) and discontinuous, and, may not have significant regional impact in hampering the movement of groundwater within the alluvial sediments which are usually comprised of much thicker coarse alluvial sediments.

The unconsolidated alluvial sediments of the Mullu catchment fall into the highly productive aquifer system which is characterized by inter-granular permeability. The unconsolidated sediments cover most parts of the catchment. Drilling data conducted outside Mullu catchment indicates the unconsolidated sediments become thicker in the southwestern parts of Shinile Zone. Both surface and drilling data indicate that the unconsolidated sediments are comprised of gravel, sand, silt and clay interbeds.

The volcanic aquifer of the Mullu catchment is classified as medium-to high-yield aquifers. The fractured and weathered volcanic rocks of the escarpment area act as passageways of moving water from the southern highlands to the alluvial plains of the lowlands of Mullu catchment. Similarly, the volcanic rocks of the catchment is strongly fractured and weathered where these rocks are transected by regional faults. The fractured volcanic rocks act as groundwater aquifers where water is stored. Fault scarps of fractured and weathered volcanic rocks generally increase the permeability of the fractured volcanic rocks along the escarpment, which makes up the major area of recharge for the lowland areas of the catchment.

Groundwater movement of the Mullu catchment is clearly related to prevailing tectonic features and associated geomorphological modification that tend to maintain hydraulic gradient to define groundwater flow direction. Flow of groundwater in Mullu catchment can make sense when treated in the light of southern highlands which controls major groundwater recharges to the catchment plain.

7. CONCLUSION AND RECOMMENDATION

7.1. Conclusion

The increasing demand placed on groundwater has encouraged distinguishing of water resource, which would be the foundation of exploration, management, and conservation. In this study, quantitative analysis of groundwater resources of Mullu catchment has been made. Therefore, the main objective of the study is to estimating the amount of ground water recharge for Mullu Catchment using Water Balance Method. And also, the specific objectives are identifying the recharge area and groundwater flow characterization using water level information.

The methodology used to estimating the groundwater recharge for Mullu catchment passes through three different stages; desk study, field work, and post field work. The desk study includes literature search and review and/or collection of available data. The sources of data used in this stage comprise published and unpublished reports, both local and international. The field work includes observing the topography and drainage system, Soil type, Land use/cover, geology and hydrogeology of the study area. After field work, data interpretations coupled with thesis writing have been done.

Unconsolidated sediments of Quaternary age occur in several areas of Mullu catchment and the Awash River Valley. Thick succession of alluvial deposits cover most parts of the plains of Mullu catchment. Coarse alluvial deposits with rounded to sub rounded fragments of volcanic rocks cover a wide area at the foot of the escarpment. The alluvium becomes finer in grain size (Silty to clayey) in the northern part of the plains. The general decrease in grain size of the alluvial sediments could be explained in terms of distance of transportation from the escarpment.

The volcanic rocks of the Quaternary Period, is mainly took place along the margins of escarpment of Mullu catchment. The Quaternary volcanism appears to occur concomitantly with the opening up of the rift valley which followed the down faulting of the domed areas which resulted from the regional uplift. The uplifted terrain was eroded and it produced thick succession of alluvial and fluvial sediments. Both volcanism and deposition of alluvio-fluvial sediments took place at the same time. It leads to the existence of intercalations of volcanic rocks and alluvial sediments in several places of the Mullu catchment.

Mullu Catchment is situated at narrow valley that surrounded by quaternary volcanic rocks ridges in which the surface drainage out flows towards Afdem area. The area is drain by seasonal streams originating from south, south east and south west high land areas. The flood from high land area is transporting alluvial sediments comprise silt, sand and gravel to vast central plains. The main aquifer of the area is volcanic rocks under laid the alluvial deposits. Particularly volcanic rocks underlying alluvial deposits are considered to be the most potential aquifers of the area. The Groundwater Recharge for Mullu Catchment has been estimating using Water balance method is 73.41mm/year.

The massive volcanic rocks of Quaternary periods, which commonly occur in the form of stratoid basalts can be considered as major Aquicludes in the Mullu catchment, if not fractured and shattered. Thin discontinuous layers of clay in Mullu catchment, usually on the order of a few meters are commonly exposed along stream sections in the alluvial plains. These clay layers could act as Aquicludes within the porous alluvial aquifers

The unconsolidated alluvial sediments of the Mullu catchment fall into the highly productive aquifer system which is characterized by inter-granular permeability. The unconsolidated sediments cover most parts of the catchment. The volcanic aquifer of the Mullu catchment is classified as medium-to high-yield aquifers. The fractured and weathered volcanic rocks of the escarpment area act as passageways of moving water from the southern highlands to the alluvial plains of the lowlands of Mullu catchment.

7.2. Recommendations

- ✓ The severity of the dry season increases during the sequence of months with excessive potential evapotranspiration, which is the accumulation of negative values of (P – PET) for the dry season. So the Groundwater should be managed by either from the demand side, that is by limiting the amount of abstraction by reducing wastage, changing agricultural practice, etc. or by managing the supply side that is enhancing the resource by different form of artificial recharge, watershed management, etc.

- ✓ The groundwater potential zones needs to be assessed in detail with relevant scale of both hydrogeological and geological mapping.

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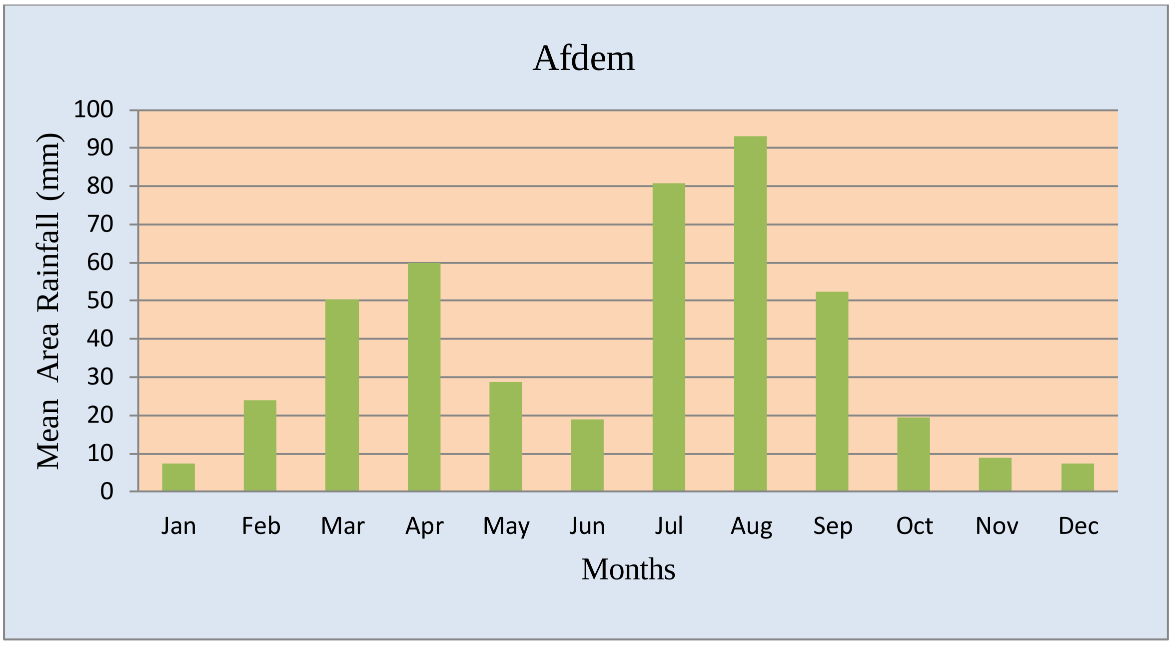
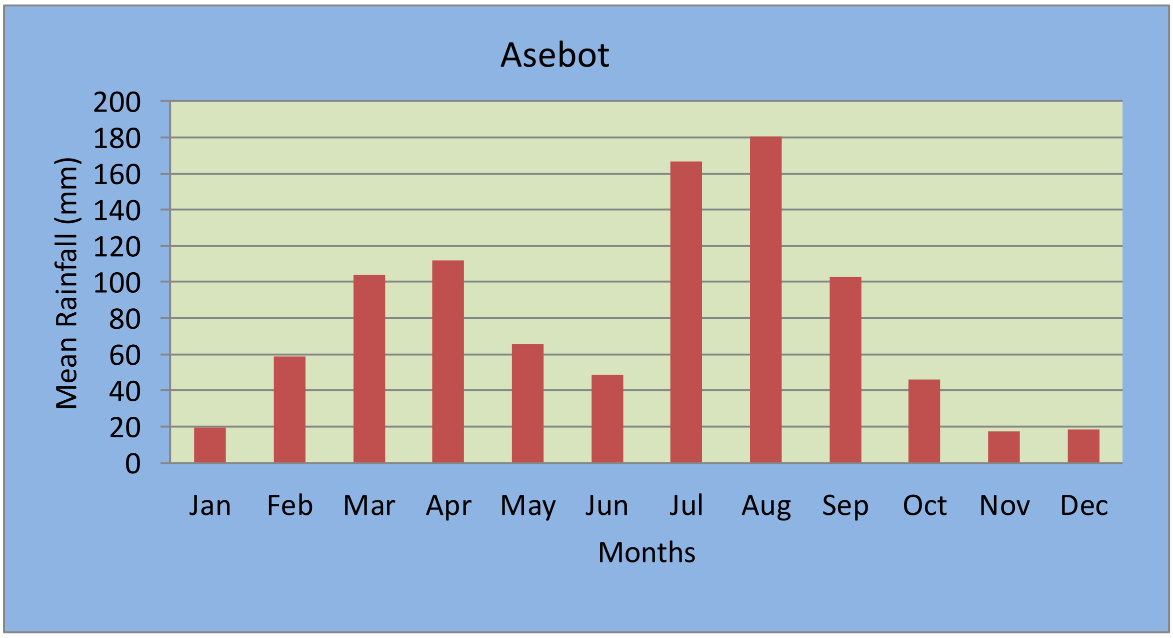
Appendices

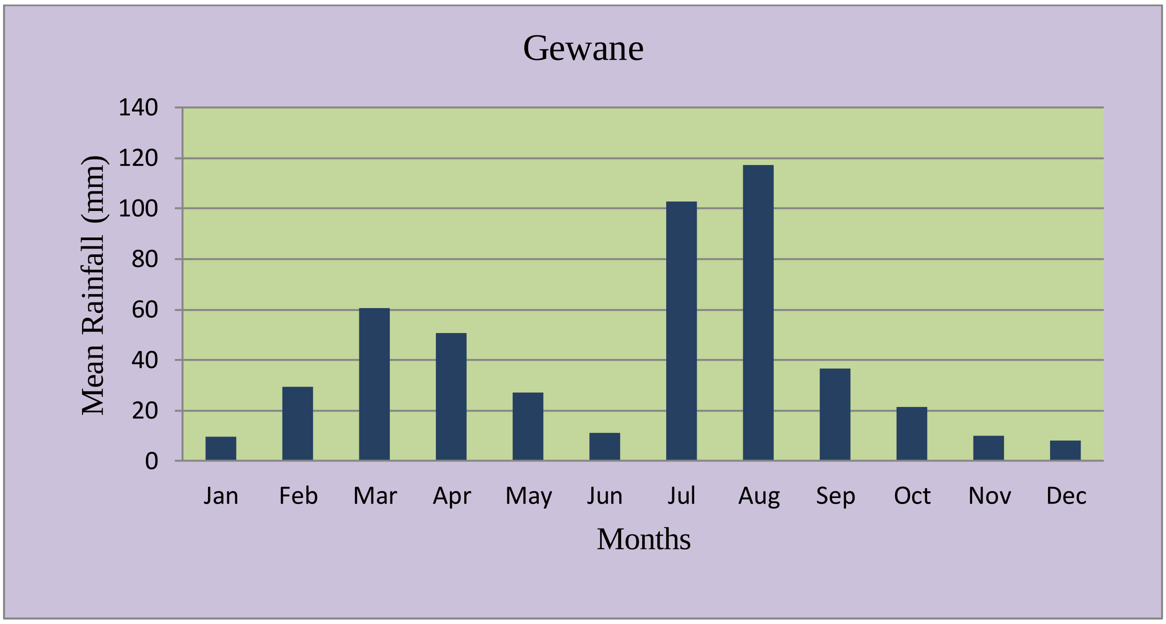
Appendix 1: Monthly Rainfall (mm) for Afdem meteorological station



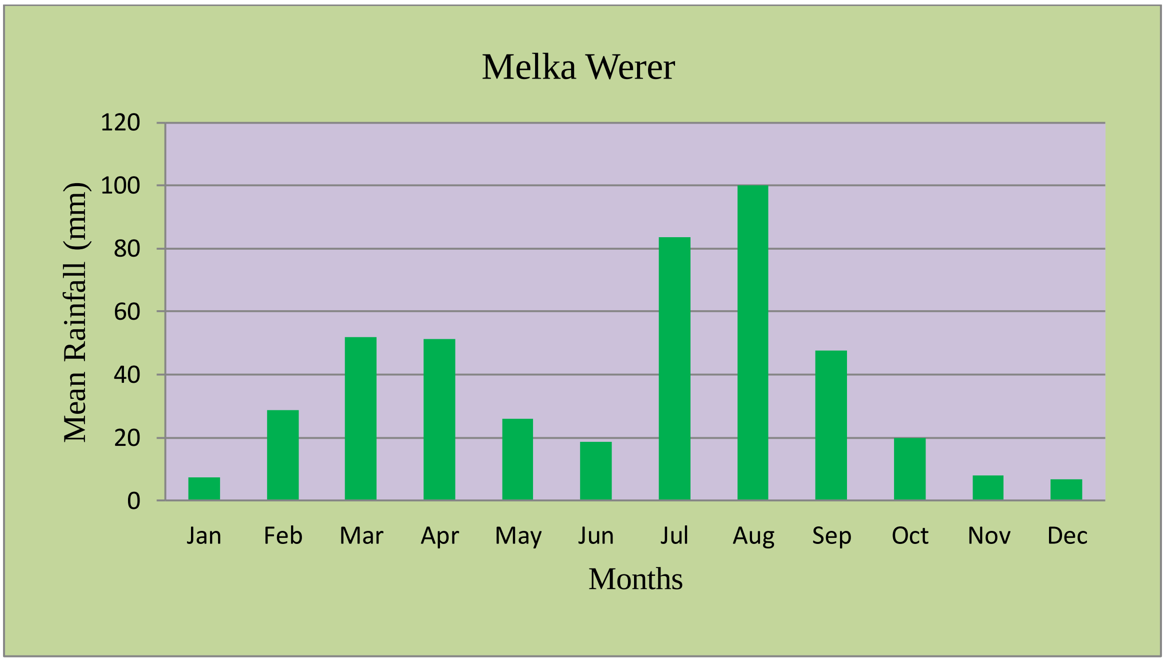
Appendix 2: Monthly Rainfall (mm) for Asebot meteorological station



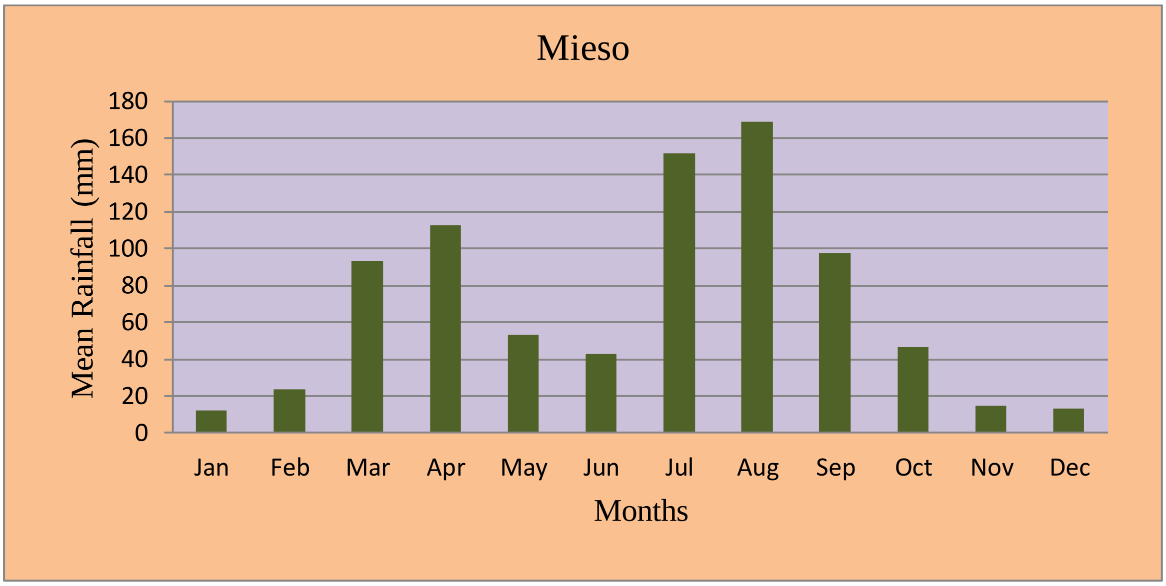
Appendix 3: Monthly Rainfall (mm) for Gewane meteorological station



Appendix 4: Monthly Rainfall (mm) for Melka Werer meteorological station



Appendix 5: Monthly Rainfall (mm) for Mieso meteorological station



Appendix 6: Annual Rainfall (mm) for Afdem meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	42	57	26	29	51	77	54	54	5.8	0	0.9
1987	0	26	117	95	87	1.8	16	88	13	2.5	0	0
1988	12.7	32	8.2	72	1.9	12	85	143	47	7.2	0	1.6
1989	0	21	57	40	63	7.8	49	52	34	6.9	0	34
1990	6.76	185	43	79	12	3.1	64	88	61	3.7	0.1	0.3
1991	1.74	26	78	24	33	13	74	91	22	27	0	5.2
1992	19.3	17	2.7	54	16	8.3	36	82	50	21	5.6	3.8
1993	32.3	74	73	93	32	3	95	46	37	18	0	0
1994	0	0	29	30	14	12	96	95	58	0.6	22	0
1995	0	65	58	53	14	6.8	65	72	27	1.1	0	14
1996	19.8	8.1	70	29	79	25	104	65	27	1.1	4	0
1997	6.98	0	57	44	7.8	19	80	68	12	128	31	0
1998	37.3	32	53	22	12	23	70	97	59	36	1.6	0
1999	0.1	0.3	53	13	4.5	16	116	90	40	61	3.4	0.7
2000	0	0	14	35	30	20	71	128	41	50	33	16
2001	0.17	8.3	65	12	33	14	90	109	31	0.4	0.1	13
2002	18.3	0	70	28	2.4	5.5	70	45	38	4.3	0	41
2003	3.41	16	32	31	4.5	30	54	84	47	0	23	11
2004	16	0.7	46	78	1	9.3	57	98	50	27	4.9	5.3
2005	5.67	14	50	45	36	19	164	54	47	0.6	5.6	0
2006	1.87	14	29	70	7.5	19	61	101	22	4.6	2.9	42
2007	0	11	25	66	5.9	15	50	41	61	4.7	0	0
2008	11.7	0	0	29	23	28	49	62	18	11	40	0
2009	27.5	4.5	28	173	52	15	72	137	34	91	34	37
2010	0	126	161	163	52	84	222	192	91	0	0	0
2011	0	0	82	117	74	12	55	177	132	0	0	0
2012	0	0	24	47	12	66	147	155	81	9.7	0	0
2013	0	0	48	33	40	0	101	115	94	0	35	0
2014	0	0	57	196	51	2.7	90	102	185	62	18	0
2015	0	0	22	0	37	29	39	64	55	0	3.8	0

Appendix 7: Annual Rainfall (mm) for Asebot meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	115	158	70	78	141	211	147	149	16	0	
1987	0	70	322	261	240	5	44	243	36	7	0	0
1988	35	87	23	199	5.2	32	234	394	128	20	0	4.3
1989	0	57	158	111	174	22	135	143	94	19	0	93
1990	19	509	119	216	32	8.4	177	242	169	10	0.4	0.9
1991	4.8	73	214	67	90	35	204	251	62	75	0	14
1992	53	46	7.4	147	43	23	100	225	137	58	15	10
1993	89	202	201	256	89	8.3	261	127	103	50	0	0
1994	0	0	81	83	38	32	264	260	160	1.7	60	0
1995	0	180	158	210	25	36	108	115	52	5.5	0	36
1996	84	42	144	175	129	87	165	107	107	0.7	20	0
1997	30	0	85	104	56	60	159	129	58	304	110	0
1998	0	76	115	31	43	94	111	143	164	60	7.7	0
1999	1.1	0	64	21	27	37	205	181	129	188	5.4	0
2000	0	0	32	80	40	59	121	150	84	81	22	43
2001	0.7	36	114	75	111	43	141	305	104	0.1	1	50
2002	81	0	59	84	5.5	15	0	125	103	12	0	111
2003	21	30	98	89	12	83	148	232	130	0	62	29
2004	44	1.8	35	164	5.2	24	119	113	134	67	10	2.8
2005	14	0	121	84	98	70	451	85	94	1.7	13	0
2006	6.2	19	181	105	24	50	191	276	62	13	7.9	115
2007	0	41	85	129	19	41	118	122	168	6.1	0	0
2008	63	0	0	80	61	120	143	122	45	26	82	0
2009	36	0	56	45	12	58	45	104	46	91	5.2	45
2010	0	153	183	38	88	27	160	43	28	0	46	0
2011	0	0	97	18	115	37	119	297	87	0	0	0
2012	0	0	22	75	6.8	26	192	201	85	0	16	0
2013	0	24	69	184	109	96	319	101	56	72	27	0
2014	0	9.3	124	146	104	7.4	248	214	163	189	0	0
2015	0	0	4.6	12	101	80	107	220	152	7.8	10	0

Appendix 8: Annual Rainfall (mm) for Melka Werer meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	99	83	43	54	79	107	67.1	115	5.8	0	0
1987	0	37	168	96	44	0	36	136	35	7.6	0	0
1988	5.7	57	24	111	5.7	28	107	262	70	8.8	0	0
1989	0	21	57	40	63	7.8	49	51.9	34	11	0	34
1990	13	258	18	79	12	3.1	64	109	91	5	0	0.2
1991	0	37	126	25	42	22	86	122	25	32	0	5.2
1992	19	17	2.7	54	16	8.3	36	81.9	50	21	5.6	3.8
1993	32	74	73	93	32	3	95	46.2	37	18	0	0
1994	0	0	29	30	14	12	96	94.8	58	0.6	22	0
1995	0	65	58	53	14	6.8	65	71.9	27	1.1	0	14
1996	20	8.1	65	29	79	25	104	65.3	27	1.1	4	0
1997	7	0	57	44	7.8	19	80	67.5	12	128	31	0
1998	37	32	53	22	12	23	70	165	58	54	0	0
1999	0	0	78	30	0.4	30	187	90.1	35	61	7.8	2.6
2000	0	0	10	31	60	24	97	185	65	46	34	13
2001	0	17	69	12	33	14	90	109	31	0.4	0.1	13
2002	18	0	70	28	2.4	5.5	70	45.4	38	3.2	0	41
2003	3.4	16	29	31	4.5	30	54	84.4	47	0	23	11
2004	16	0.7	46	78	1	9.3	57	97.9	50	27	4.9	5.3
2005	5.7	14	50	45	36	19	164	53.6	47	0.6	5.6	0
2006	1.9	14	29	70	7.5	19	61	101	22	4.6	2.9	42
2007	0	11	25	66	5.9	15	50	40.8	61	4.7	0	0
2008	12	0	0	29	23	28	49	61.7	18	11	40	0
2009	27	4.5	28	58	15	16	44	80	26	54	9	13
2010	0	62	107	66	24	36	124	142	37	0.6	7.8	7.6
2011	0	0	42	48	45	8.5	43	154	66	0	10	0
2012	0	0	16	39	17	29	172	151	42	3.8	2	0
2013	0	2.9	68	63	32	14	120	104	50	12	16	0
2014	0	17	69	124	44	2.7	90	89.3	95	78	9.2	0
2015	0	0	9.3	1.4	37	29	39	71.9	55	1.4	3.8	0

Appendix 9: Annual Rainfall (mm) for Mieso meteorological station

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1986	0	27.5	0	0	5.7	66	111	79.3	101	32	0	0
1987	0	2	185	371	213	15	27	90	0	0	0	0
1988	72	0	1.7	9.4	0	20	156	188	76	16	0	8.6
1989	0	57.2	158	173	4.44	20	102	127	55	11	0	101
1990	6.7	87.2	119	136	13.9	7.7	122	234	122	17	1.1	2.2
1991	14	93.6	48	58	48.3	19	199	191	66	23	0	25
1992	7.1	19.4	15	97	68.2	36	43	163	71	18	30.6	3.9
1993	89	128	397	137	44.1	5.3	77	93	71	23	0	0
1994	0	0	56	50	48.9	9.5	241	89.9	113	3.4	38.7	0
1995	0	11.3	98	114	26.2	19	93	102	60	3.9	0	23
1996	45	24.6	161	42	230	80	269	170	70	8.5	0	0
1997	3.7	0	89	154	7.6	41	105	109	0	391	74.2	0
1998	14	32.9	62	26	34.7	27	114	96.4	162	86	10.2	0
1999	0	3.2	131	11	17.7	34	158	129	73	126	10.9	0
2000	0	0	7.1	83	19.9	57	129	151	120	138	78.5	0
2001	1.2	5.4	113	24	86.3	61	184	279	123	0.9	0	24
2002	27	0	53	83	4.6	28	73	80.8	53	12	0	54
2003	5.5	3.6	37	139	25.4	110	108	180	130	0	9.1	26
2004	18	0	75	142	3.4	38	119	131	112	63	13.1	1.2
2005	3.7	18.9	93	71	97.6	76	176	96.7	108	3.4	18.1	0
2006	9.2	26.1	58	168	37.5	53	147	276	62	13	7.9	50
2007	0	19.3	52	231	13.4	43	158	102	168	20	0	0
2008	29	0	0	48	37.8	59	104	111	33	61	33.2	0
2009	27	2.9	30	116	4.8	41	64	103	74	65	0	0
2010	0	91.1	201	133	32.5	97	192	120	57	6.4	10.4	81
2011	0	0	116	131	123	23	119	422	183	0	27.9	0
2012	0	0	43	107	45.5	79	473	416	114	10	5.47	0
2013	0	8	188	174	87.3	38	330	286	137	32	44	0
2014	0	47.7	190	342	121	7.4	248	245	262	214	25.3	0
2015	0	0	26	3.9	101	80	107	198	152	3.9	10.3	0

Appendix 10: Annual Rainfall (mm) for Gewane meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	16	86.90	32.50	28.41	49.97	80	62.90	10.90	0.00	0	2.5
1987	0	37.6	113.8	53.1	137.2	0	1.5	93.5	5	0	0	0
1988	6	37	0	100.3	0	0	89.2	96.6	40.6	7.03	0	1.53
1989	0	20.25	55.75	17.4	121.7	8.1	59.9	55.8	47.4	5.7	0	30.2
1990	4.7	258.3	66.6	104.5	17.6	3.2	82.1	68.1	48.2	0.1	0	0
1991	0	7.7	87.8	26.8	37.6	9.9	62.8	80.2	17.8	40.9	0	1.2
1992	35	25.5	0	69.9	6.2	3.5	55.5	101.5	71.8	34.5	0	6
1993	31.3	97.8	1.8	133	47.2	4	157.2	56.9	47.6	27.5	0	0
1994	0	0	37.5	41.4	9.6	19.4	101.1	152.5	73.1	0	29	0
1995	0	123.2	77.3	40.4	23.6	0	119.7	132.9	40.1	0	0	18.5
1996	11.8	0	77	9.2	104.6	13.2	150.6	92.3	17.3	0	4.6	0
1997	8.5	0	105.2	37.8	0.4	19.1	141.6	112.7	1	126.4	26.5	0
1998	87.9	54.2	91.2	42.6	7.79	23.85	125.8	134.6	59.1	35.3	0	0
1999	0	0	61.8	9.3	1.4	7.6	140.8	153.1	25.4	65.9	0	0
2000	0	0	31.3	47.2	38.3	13	95.1	211.6	24.8	73.9	58.1	33.5
2001	0	1.2	103.8	0	27	5.4	147.9	111	9.9	0.8	0	12
2002	15	0	164.7	24.3	3.3	1	110.6	59.7	54.6	0	0	59.9
2003	0.6	35.4	35.1	11.1	0	19.5	66.5	100.47	46.09	0	41	0
2004	24.7	1.3	94.8	119.5	0	5.3	83.3	199.4	57.8	32.4	6.1	13.9
2005	10.2	35.5	69.1	74.8	34.55	3.3	257.2	92.1	65.6	0	5.43	0
2006	0	25.4	0.5	107.7	0	18.07	59.75	97.77	21.84	4.506	2.80	63.5
2007	0	10.58	24.16	63.70	5.72	14.73	48.87	39.63	59.54	4.60	0	0
2008	1.5	0	0	39.9	30.9	18.7	56.4	97.6	24.2	0.4	76.6	0
2009	57.9	12	50	1.4	2.4	12.7	61.6	104.9	28.1	67.7	0	0
2010	0	33	125.5	39.5	0	14.6	141.4	308.6	25.5	0	10.4	0.8
2011	0	0	9.1	19	18.5	0	30.4	170.5	34.8	0	29.6	0
2012	0	0	14	41.5	34.4	11.4	291.5	219.5	12.9	1.7	0	0
2013	0	0	128.8	87.5	0	6.2	139	156.4	34.2	8.7	3.2	0
2014	0	47.4	102.8	120.10	42.98	2.62	87.72	86.2	40.5	99.8	8.95	0
2015	0	0	3.9	0	35.86	28.14	37.84	69.96	53.63	1.38	3.65	0

Appendix 11: Afdem Runoff in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	4.4	2.87	0	0.14	0.8	0	0	0.6	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0
1993	0.05	4.1	0	4.6	0	0	2	0.5	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0.55	0	2.84	0	2.6	0.3	0	0	0	0
1997	0	0	4.32	1.3	0	0	3.6	3	0	5.7	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0.17	0	0	0	6.8	2.3	0	0.4	0	0
2000	0	0	0	0	0.78	0	1.1	5.5	0	1.9	0.2	0
2001	0	0	0.3	0	0	0	4.2	1.4	0.2	0	0	0
2002	0	0	10.8	0	0	0	4.8	0	3.2	0	0	0.8
2003	0	0	0	0.1	0	0	0.1	4.9	0	0	3	0
2004	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	12.6	8.4	2.83	0	1.4	5.4	2.7	0	0	0
2012	0	0	0.43	3.7	0	3	5.7	4.4	0.9	0	0	0
2013	0	0	1.15	0.6	0.06	0	3.5	3.2	1.3	0	0.7	0
2014	0	0	0.65	7.2	0	0	2.4	0.9	3.3	0.8	0	0
2015	0	0	0.26	0	3.2	0	0	0.2	3.3	0	0	0
Mean	0	0.3	1.14	0.9	0.33	0.1	1.3	1.1	0.5	0.3	0.1	0

Appendix 12: Asebot Runoff in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	35	42.2	0.9	6.53	25	13	8.5	16	0	0	0
1987	0	9	93.3	82	64.7	0	0	55	0	0	0	0
1988	0	32	0.03	37	0	0	41	112	20	0.1	0	0
1989	0	12	40.6	7.5	37.9	0.1	11	5.9	13	0	0	20.1
1990	0.3	193	20.1	71	4.19	0	27	36	16	0	0	0
1991	0	9	49.1	1	15.5	0	34	40	0	18	0	0
1992	0.02	7.1	0	45	0.01	0	4.7	41	18	11	0	0
1993	13.3	51	0.08	55	4.92	0	44	11	2	2.1	0	0
1994	0	0	4.31	15	1.66	0.8	70	72	13	0	19	0
1995	0	97	26.4	38	0	0.3	3.3	0.9	0	0	0	6.98
1996	16.9	0	6.16	29	21.6	0	16	2.2	7.7	0	0	0
1997	0.62	0	6.28	11	0.51	1.6	33	21	0.1	86	12	0
1998	2.56	17	9.08	1.3	0.3	5.8	4.6	15	20	1.3	0	0
1999	0	0	7.75	0	0	0	38	30	7.6	19	0	0
2000	0	0	7.58	4.3	0.64	0.8	11	12	0.8	7.1	0	1.79
2001	0	1.4	13.8	6.9	12.3	0	20	81	8.8	0	0	11.7
2002	9.59	0	1.31	6.3	0	0	49	6.3	28	0	0	16.3
2003	0.86	1.2	15.7	11	0	0.5	12	54	4.5	0	26	0
2004	5.92	0	0	15	0	0	8.5	6.8	8.5	2.2	0	0
2005	0.16	0	12.9	15	16.9	2.4	172	4.8	16	0	0	0
2006	0	0	4.39	3.8	0.44	0.3	34	73	1.1	0	0	48.2
2007	0	3.6	17.3	14	0.18	0	14	8.4	30	0	0	0
2008	10.6	0	0	9.8	2.74	26	19	18	0.3	0	6.7	0
2009	0.11	0	5.71	1.6	0	0.6	0.4	7.8	0.2	9.2	0	0.03
2010	0	21	40.3	0.1	13.3	0	20	3.1	0	0	4.4	0
2011	0	0	14.7	0	26.9	0	9.8	34	1.4	0	0	0
2012	0	0	1.66	6.1	0	0	44	23	0.6	0	0.5	0
2013	0	2.4	1.87	27	29	24	90	3.1	0.3	22	0	0
2014	0	0	29.8	31	4.5	0	52	64	29	36	0	0
2015	0	0	0	0	26.8	1.1	7.6	49	36	0	0	0
Mean	2.03	16	15.8	18	9.12	3	30	30	10	7.1	2.3	3.51

Appendix 13: Gewane Runoff in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	0	13	0	0	0.4	3.2	6	0	0	0	0
1987	0	3.4	15	12	39.3	0	0	20	0	0	0	0
1988	0	8.2	0	15	0	0	5.5	12	3	0	0	0
1989	0	0.4	2.4	1.3	16.5	0	1.3	1.7	5.5	0	0	3.1
1990	0	84	11	21	1.34	0	10	0.6	0	0	0	0
1991	0	0	7	0.4	4.21	0	0.5	1.3	0.2	9.1	0	0
1992	0	2.6	0	12	0	0	0.8	8.7	5.8	4.3	0	0
1993	1.4	13	0	15	0.79	0	16	4.1	0.2	0.4	0	0
1994	0	0	0.3	3.7	0	0.3	11	33	3	0	6.1	0
1995	0	55	9.9	3.3	0.34	0	16	32	2.5	0	0	0
1996	0	0	12	0	13	0	18	6.4	0	0	0	0
1997	0	0	29	4.9	0	0	15	33	0	19	2.4	0
1998	30	8.9	23	1.8	0	1.9	10	19	1.2	6.1	0	0
1999	0	0	8.3	0	0	0	23	26	0	3.5	0	0
2000	0	0	2.8	4.1	7.95	0	3.8	44	0.4	11	3	2.5
2001	0	0	13	0	0.79	0	18	4.2	0	0	0	0
2002	0	0	65	0	0	0	19	1.5	11	0	0	3.9
2003	0	3.1	1.4	0	0	0	1.3	9.2	0	0	13	0
2004	1.7	0	23	23	0	0	6.2	51	0.6	2.6	0	0.5
2005	0	9.7	27	12	0	0	68	11	6.7	0	0	0
2006	0	4.3	0	18	0	0	0	5	0	0	0	24
2007	0	0	0	0.6	0	0	0.8	0	2.8	0	0	0
2008	0	0	0	1.2	1.04	0	0.4	9.9	0	0	15	0
2009	8	0	10	0	0	0	6.6	15	0	11	0	0
2010	0	3.3	37	0	0	0.2	22	88	0.9	0	0	0
2011	0	0	0	1.8	0	0	0	11	1.6	0	2.2	0
2012	0	0	0.5	1	5.4	0	93	41	0	0	0	0
2013	0	0	52	32	0.77	0	24	21	2.2	0	0	0
2014	0	7.2	47	22	0	0	1.4	5.5	0.4	32	0	0
2015	0	0	0	0	2.43	0	0	0.2	2.4	0	0	0
Mean	1.4	6.8	14	6.8	3.13	0.1	13	17	1.7	3.3	1.4	1.1

Appendix 14: Melka Werer Runoff in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	29.7	13	0	7.84	8.29	7	2.08	18	0	0	0
1987	0	7.34	46	35	0.71	0	0.3	16	0.5	0	0	0
1988	0	11.6	0.4	17	0	0	10	65	12	0	0	0
1989	0	0.46	2.7	0	1.79	0	0.1	0.01	0.6	0	0	1.33
1990	0.3	72.8	0	9.2	0	0	2.2	4.49	14	0	0	0
1991	0	0.02	30	0	0.57	0.09	8.2	6.6	0	2.1	0	0
1992	0	0.09	0	6.1	0	0	0	3.21	0.6	0.4	0	0
1993	0	3.26	0	3.7	0	0	1.4	0.29	0	0	0	0
1994	0	0	0	0.2	0	0	5.8	8.71	0.1	0	1.36	0
1995	0	14.7	1.4	0.4	0	0	1.3	2.36	0.1	0	0	0
1996	0	0	0.4	0	2.23	0	1.9	0.16	0	0	0	0
1997	0	0	3.5	1	0	0	3	2.35	0	4.5	0	0
1998	4.1	0.07	2	0	0	0	0.2	26.2	0.9	10	0	0
1999	0	0	17	6.4	0	0.66	34	1.64	0	0.2	0	0
2000	0	0	0	0	3.34	0	8.5	22.4	1.2	2.9	1.19	0
2001	0	1.17	2.3	0	0	0	3.3	0.99	0.1	0	0	0
2002	0	0	9.3	0	0	0	3.9	0	2.7	0	0	0.56
2003	0	0	0	0	0	0	0	3.94	0	0	2.5	0
2004	0	0	0.8	1.3	0	0	0	5.52	0	0	0	0
2005	0	0.37	2.7	0.3	0.06	0	19	0.44	0	0	0	0
2006	0	0	0	1.6	0	0	0	5.49	0	0	0	6.84
2007	0	0	0	0.7	0	0	0.9	0	3	0	0	0
2008	0	0	0	0	0	0	0	0.39	0	0	0.88	0
2009	0.2	0	0.3	0	0	0	0	0.11	0	0.4	0	0
2010	0	0	7.5	0	0	0	2.7	6.3	0	0	0	0
2011	0	0	0	0	0	0	0	0.46	0	0	0	0
2012	0	0	0	0	0	0	17	2.43	0	0	0	0
2013	0	0	7.9	2.9	0	0	2.2	1.82	0	0	0	0
2014	0	0.01	9.3	23	0	0	1.7	0.74	0	5.3	0	0
2015	0	0	0	0	2.65	0	0	0.23	2.7	0	0	0
Mean	0.2	4.72	5.2	3.6	0.64	0.3	4.5	6.35	1.9	0.9	0.2	0.29

Appendix 15: Mieso Runoff in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	0.13	0	0	0	6	6.7	5.11	2	0.05	0	0
1987	0	0	49.8	116	82.7	0.2	3.1	30	0	0	0	0
1988	5.8	0	0	0	0	0	20	9.54	4.1	0	0	0
1989	0	10.7	37.8	28.2	0	0	13	1.52	0.5	0	0	19
1990	0	5.88	8.34	27.1	0	0	4	66.8	3.1	0.36	0	0
1991	0	37.1	0.34	0	1.31	0	33	28	1	0	0	0
1992	0	0	0	19.7	3.71	0.4	0	13.7	4.6	0	0.24	0
1993	16	17.9	9.78	8.19	1.98	0	5.3	5.59	0.2	0	0	0
1994	0	0	8.75	0.17	4.22	0	60	7.76	3.6	0	0.33	0
1995	0	0	5.94	9.21	0.46	0	1.3	0.52	0.7	0	0	0
1996	6.2	0	17.5	0.9	29.7	0.9	58	20.8	4.3	0	0	0
1997	0	0	10.1	46.3	0	0	7.1	1.23	0.4	106	12	0
1998	0	3.09	0.32	0	0.18	0	1.1	9.64	16	10.9	0	0
1999	0	0	23.8	0	0	0.1	12	3.8	0.5	13.6	0	0
2000	0	0	0	3.83	0	3.1	15	8.31	3.7	36.9	15.1	0
2001	0	0	4.06	0	6.07	4.7	39	60.1	19	0	0	0.1
2002	0	0	7.94	1.26	0	0.2	0	4.56	0	0	0	1.7
2003	0	0	5.93	24.4	0.07	2.8	6.2	31.9	3.8	0	0	0
2004	0.1	0	3.85	6.81	0	0	6.3	12.7	9.9	15.4	0	0
2005	0	0	5.53	2.36	1.94	0.7	16	1.63	18	0	0.38	0
2006	0	0.58	0.05	26.2	2.23	0	11	68.2	0.8	0	0	0.5
2007	0	0	2.46	56	0	0	20	1.04	28	0.49	0	0
2008	1.6	0	0	4.95	0.11	0.5	7.5	5.54	0	3.41	0.97	0
2009	0.2	0	0.12	18.3	0	0	0.8	0	2.4	9.86	0	0
2010	0	1.73	33.6	14	0	0.4	8.7	2.91	2.6	0	0	0.1
2011	0	0	8.28	9.1	1.62	0	8.3	41.6	6.5	0	0.78	0
2012	0	0	0.03	6.78	2.79	0.7	133	63	0.2	0	0	0
2013	0	0	56.1	27.9	4	0.7	44	40.7	6	0.54	0.35	0
2014	0	5.79	60.9	123	1.45	0	47	26.2	8.7	52	0.04	0
2015	0	0	0	0	25.3	0.8	6.6	18.4	34	0	0	0
Mean	1	2.77	12	19.4	5.66	0.7	20	19.7	6.2	8.31	1.01	0.7

Appendix 16: Static water level of boreholes in Shinile Zones

Well_ID	**Easting__m**	**Northing_m**	**Altitiued_m**	**Zone**	**SWL_m_**	**Well__Dept**
Biyo Bahay Irr Well # 4	227840	1111091	959	38	46.42	180
Biyo Bahay WS Well # 3	228536	1110869	965	38	41.9	174
Biyo Bahay WS Well # 2	229915	1110283	979	38	37.43	185
Biyo Bahay WS Well # 1	229175	1110571	971	38	35.92	180
Degago - Laserat WS Well	228047	1165185	823	38	6.78	113
Jama Dere TW	214296	1131593	831	38	84.69	250
Mete Irr Well # 2	786149	1099151	731	37	0	195
Mete Irr Well # 1	786138	1098605	730	37	0.58	158
Aydora TW	759581	1091435	797	37	7.8	250
Harawa TW	826331	1097377	790	37	32.68	250
Asbuli TW	737767	1106062	711	37	119.24	227
Haseliso TW - 1	801859	1057371	1254	37	80	220
Haseliso NPW-1	802293	1057401	1255	37	74	220
Haseliso NPW-2	801838	1057385	1255	37	81	214
Haseliso NPW-3	801309	1057318	1267	37	90	252
Haseliso NPW-4	801632	1057297	1263	37	90	218
Gedamitu (Kah) Well	689741	1076778	750	37	26.02	320
Mieso (Huse) TW-1	695163	1018275	1370	37	56.88	348
Hulabora	748960	1050023	1226	37	67.6	147
Kurfa-Sawa	697094	1027068	1246	37	33.85	172
Jedene	807818	1068565	1061	37	19.88	158
Mete - Bisile WS Well	786294	1098124	731	37	1.67	150
Dire Dawa TW - 4 (Bore)	796050	1058100	1254	37	31	160
Dire Dawa TW - 5	806549	1064183	1100	37	33.4	124
Alidege TW - LA 3	627464	1015684	823	37	75.66	192
Alidege TW - LA 1	633633	995025	962	37	101.17	252
Alidege TW - AP 1	652507	996029	1118	37	62.27	350
Alidege TW - AP 2	641424	1007510	892	37	72.95	257
Alidege TW - LA 5	636415	1039961	733	37	3.6	262.5
Alidege TW - LA 4	626003	1025081	745	37	0.8	196
Alidege TW - LA 2	635543	1021775	817	37	68.42	236
Alidege TW - AP 6	645495	1034311	808	37	68.17	146
Alidege TW - AP 3	635543	1021775	835	37	86.4	288
Alidege TW - AP 5	645334	996709	996	37	149.86	310
Alidege TW - AP 8	662292	1043646	822	37	72.27	300
Alidege TW - AP 10 '	637170	1016759	830	37	79.4	267
Alidege TW - AP 11	656917	1065145	840	37	149.7	0
Alidege TW - AP 6 '	642503	1031094	813	37	68.17	250

Appendix 17: Hydrologic Soil groups & Run off Curve Numbers of the study area

Land use cover	**Area(Ha)**	**Hydrologic condition**	**Hydrologic soil group**	**“CN” values of average moisture condition**
Shrub grass land	706	Fair	B	65
Shrub land	22943	Fair	C	73
Rocky surface	17,936	-	B	84

Appendix 18: SCS Runoff Curve Numbers

Cover description	Curve numbers for Hydrologic soil group				
Cover type	Hydrologic Condition	A	B	C	D
Herbaceous mixture of grass, weeds, and poor Low-growing brush, with brush the main element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	83
Oak-aspen mountain brush mixture of oak poor Brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinion-juniper pinion, juniper, or both: grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	83
	Fair		51	63	70
	Good		35	47	55
Desert shrub major plants include saltbush, Greasewood, creosotebush, blackbrush, bursage, Paid verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

*poor:< 30% ground cover(litter, grass, and brush overstory).

Fair 30 to 70% ground cover.

Good:> 70% ground cover.

Appendix 19: Kc values assumed for different land cover types in the estimation of Evapotranspiration.

Land cover	**Crop coefficient (Kc)**	**Remark**
Dense shrub lands	0.65	Assumed
Open grass land (grass cover for gazing)	0.65	An average Kc for grazing pasture is assumed. Source (FAO,I&D paper 56)
Open bush land (scattered bushy area)	0.6	
Cultivated land (semi-seasonal crop)	0.4 or 0.3	An average Kc for major crops on the area (Maize and sorghum) source FAO I & D paper 56.Average value for the variable Kc of different growth stage.
Dense bushy woodland (mainly covered with bush and some grass in a closed area)	0.6	Assumed the value given for fully covered forest in FAO I & D paper 56.
Barren sparsely vegetated	0.4	Assumed
Bare land (rock exposure)	0	Assumed
Shrubby grass land (grass land with scattered shrubs)	0.65	Similar to value given for grass above
Open shrub land (mainly composed of shrub with little grass)	0.6	Assumed

Appendix 20:- Online site used for originality test

Student name	NAOL GURMU
ID: No	GSR/0438/08
Stream	HYDROGEOLOGY
Thesis title	Quantifying Groundwater Recharge for Mullu Catchment
Online site used for originality test	Wtth://www.paperrater.com/plagiarism_checker

Appendix 21: Plagiarism checked results

Particulars	Test 1		Test 2		Test 3		Test 4		Test 5		Average		Remark
	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	
Abstract	100	0	100	0	100	0	100	0	100	0	100	0	
Introductory chapter	100	0	100	0	100	0	100	0	100	0	100	2	
Literature review	100	0	100	0	100	0	100	0	100	0	100	0	
Methodology	100	0	100	0	100	0	100	0	100	0	100	0	
Result and discussion	100	0	100	0	100	0	100	0	100	0	100	0	
Conclusion	100	0	100	0	100	0	100	0	100	0	100	0	
Over all thesis	100	0	100	0	100	0	100	0	100	0	**100**	**0**	

	Name	Signature
Student	Naol Gurmu	
Advisor	Dr. Tilahun Azagegn	

Declaration

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

Naol Gurmu Bune

Signature___________________Date_________________

School of Earth Science

May, 2019

This thesis has been submitted for examination with my approval as university advisor.

Dr. Tilahun Azagegn

Signature___________________Date_________________