Addis Ababa University

School of Earth Sciences

Comparative study between South-Jema and Kesum Catchment

A Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the requirements for Degree of Master of Science in Hydrogeology

By:

Zekarias Ashine Bekele

Advisor: Tilahun Azagegn (Ph.D.)

June, 2020

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This is to certify that the Thesis Prepared by Zekarias Ashine, entitled: Comparative study between South-Jema and Kesum Catchment submitted in the partial fulfillment for the requirements for the Degree of Master of Science in Hydrogeology complies with the regulations of the University and meets the accepted standard with respect to originality and quality.

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Zekarias Ashine Signature:

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Abstract

The study comprises of South-Jema and Kesum catchment, is located in the central highland. It is geographically confined within 38°50´00´´E to 39°00´00´´ E longitude and 8°45´00´´N to 10°00´00´´N latitude covering a total area of 5,683 km^2. The study has been conducted with objective to make a comparative analysis of recharge and hydrochemistry.

From the hydro chemical data analysis, concentrations of Na and Ca were found to be higher and being the dominant species in both catchment whereby concentration of Na shows an increment towards the downstream part of both catchments whereas concentration of calcium doesn't shows any decrement towards the downstream part of south-Jema catchment but a decrement in concentration of Ca has been observed in the downstream part of Kesum catchment with rise in TDS. The anion species are dominated by bicarbonates, showing an increment towards the downstream part of both catchments.

As evidenced from hydro-chemical Data, there exists a clear evolutionary trend in increment of TDS towards the downstream part of both catchments.

Four types of groundwater facies exist in the region ranging from Ca-HCO3 water types mainly concentrated in representing shallow groundwater circulation with relatively short sub-surface residence time to a Ca-NaHCO3/Na-Ca-HCO3 water type representing evolutionary tend of groundwater along its flow path towards the downstream of Kesum catchment.

The spatially distributed groundwater balance model, Wetspass has been used in seasonal and annual estimation of groundwater resources, actual evapotranspiration and surface runoff of both catchments. By coupling of physical and hydro-metrological characteristics of the watershed, the wetspass have simulated the average annual long-term groundwater recharge, actual evapotranspiration and surface runoff in South-Jema catchment is found to be 122.02 mm/ year, 380.64mm/ year and 534 mm/year respectively. In the case of kesum catchment, the average long-term groundwater recharge, evapotranspiration and surface runoff is found to be 114.91 mm/year, 455.61mm/year and 410.08 mm /year.

The long-term annual precipitation in South-Jema catchment (1023 mm) is distributed as 11.92% recharge, 37.14% evapotranspiration and 52.19% runoff, indicating almost half of the precipitation feeding the watershed is lost due to surface runoff. In the case of Kesum catchment the long-term annual precipitation (973.81 mm) is distributed as 11.8% recharge, 46.7 % evapotranspiration and 42. 11% surface runoff.

Key Words: Sodium, Calcium, Bicarbonate, Water types, Groundwater, Recharge, Actual Evapotranspiration, Surface Runoff, Wetspass

Acronyms

EC	Electrical conductivity
EIGS	Ethiopian Institute of Geological Survey
GWL	Ground water Level
ITCZ	Inter-Tropical Convergence Zone
MA	Meteorological Agency
m.a.s.l	Meter above Sea Level
MCM	Million Cubic Meter per Month
MER	Main Ethiopian Rift
MoA	Ministry of Agriculture
MoWIE	Ministry of Water, Irrigation and Energy
m/s	meter per second
mg/l	milligram per litre
m^2/day	meter square per day
Mm^3	Million-meter cube
NE	North-East
NW	North -West
NWP	North Western Plateau
NSE	Nash –Sutcliffe Model Efficiency
PET	Potential Evapotranspiration
SE	South-East
SEP	South Eastern Plateau
SW	South-West
SWL	Static Water Level
TDS	Total Dissolved Solute
YTVL	Yere Tullu Wele Volcanic Lineament

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Chapter One: Introduction

1.1 Background to the problem

Volcanic aquifers are major sources of groundwater supply in central Ethiopian highland. Owing to their proximity to the regional tectonic systems i.e. Yere-Tullu Welle Volcano-Tectonic Lineament (YTVL) and within the main Ethiopian rift system, these rocks are known for their lateral heterogeneity, discontinuity and are being dissected in to small pockets of aquifer (Kebede et al.,2007).These rocks has been a center of investigation for which numerous researches has been carried out and still being engaged in recent times related to geology, geomorphology, volcano-tectonics, hydrology and hydrogeology(Di paola,1972; Kazmin,1979; Zanettin et al.,1974; Visentin et al.,1974;Tesfaye Korme et al.,2004; Tenalem Ayenew, 2003,2008; Bekele Abebe et al.,2007, 2009;Seifu Kebede et al.,2007,2010;Tesgaye Abebe,2014; Tilahun Azagegn,2015; Xue et al.,2019). According to Ethiopian institute of geological survey (EIGS) an explanatory note on hydrogeological and hydrochemical map of Debre Birhan map sub-sheet, based on qualitative and quantitative characterizations of the aquifer systems, volcanic aquifers of the central highlands are marked by largest and moderately productive aquifers making them to serve as a good potential source of groundwater supply.

Variability in compositional texture and the role of tectonic structures make the volcanic aquifer systems of these region very complex (Seifu Kebede et al, 2007; Tenalem Ayenew, 2008; Andarge Yitbark, 2011; Tilahun Azagegn, 2015).The study area is a part of Blue Nile and Awash basin, located in the central highland mainly lies on the northern segment of the main Ethiopian rift margin and can be broadly classified in to two main physiographic regions i.e. rift and escarpment.

Several studies have been carried out regarding to the volcanic aquifer systems and their interconnection between the Blue Nile and Awash Basin (Seifu Kebede et al, 2007; WWDSE, 2008, Wakgari Furi, 2011; Tilahun Azagegn, 2015). The study has been extended mainly with further investigation with defining of recharge boundary, contribution of recharge from adjacent sub-basins and the possible source factors that control flux of groundwater across their transboundary on selected transect (Tilahun Azagegn, 2015). As an example, a study conducted across different transect in Muger and Holeta catchments shows similar hydrodynamic relationship between these two sub-basins has been observed (Kidist Hailu, 2016).

Understanding of the hydrogeological, hydro chemical characteristics of aquifer systems of a given watershed suited adjacent to each other and their resources is vital important that could pave the way for further study in relation to hydrodynamic condition, contribution of amount of fluxes from the corresponding catchments. Therefore, the present study tries to make comparative study of recharge and hydrochemistry of South-Jema and Kesum catchment.

1.2 Previous studies

Numerous geological (Kazmin;1972; Gethaneh Assefa,1991; Mengesha Tefera et al.,1996; Gani et al.,2006; Genene Mulugeta et al.,2007) and hydrogeological studies (Tenalem Ayenew,2003;2008; Seifu Kebede,2005,2007,2010,2013; Molla Demile, 2008) has been conducted in the study area. Related geological and structural data has been documented by geological survey of Ethiopia at a scale of 1:250,000 scale in revising the previous 1:2,000,000 geological map of Ethiopia. This has given a good opportunity in modifying and refinement of previous hydrogeological knowledge that has been conducted using small-scale geological maps.

A number of hydrogeological studies has been carried out by National, regional bureaus, NGOs and institutions. Their study mainly concerns on the development of suitable groundwater potential zones that can meet for the demand of water supply for the current alarmingly increasing population. Most M.Sc. and Ph.D. researches has been conducted at catchment and sub-catchment level in characterizing the aquifer systems. A more comprehensive work has been done by different researchers to understand the hydrogeological framework of such complex volcanic aquifer systems within plateau and the rift valley aquifers. Understanding of the groundwater system has been a crucial point in understanding of the hydrodynamic relationship between the adjacent basins and draw a regional picture of groundwater flow hydrodynamics. In such a complex system variability in groundwater dynamics has been pointed out which is due to the disruption of litho-stratigraphic unit by prominent regional tectonic zones (Tenalem Ayenew, 2003; Seifu Kebede et al., 2007). In addition to these prominent structures, architecture of the mountains of humid highland bounding the rift valley aquifers has been identified as a major controlling factor that controls flow of groundwater pattern (Seifu Kebde et al.,2007).

As most of the target area mainly lies on following prominent structures and distinctly known hydrogeological systems, still knowledge on the aquifer systems of adjacent basins away from such prominent zones are not studied at large scale. Therefore, the present study attempt to make a comparative study of recharge and hydro chemical characteristics of the corresponding catchment that could lead for further study in relations to the hydrodynamic conditions of the region in the future.

1.3 Objectives of the research

1.3.1 General objective

- The main objective of this work is to make a comparative study of recharge and hydrochemistry in South-Jema and Kesum Catchment.

1.3.2 Specific Objectives

- Determination of recharge for the corresponding catchment within the proposed area.
- Determination of hydro chemical parameter for the corresponding catchment
- Determination of the evolutionary trend of water quality data along the flow path.

1.4 Description of the study area

1.4.1 Location and Accessibility

The study area is located in central highland, on the western shoulder of the northern segment of the main Ethiopian rift margin. It is geographically confined within 38°50´00´´E to 39°00´00´´ E longitude and 8°45´00´´N to 10°00´00´´N latitude covering a total area of 5,683 km^2, which include the north western plateau and the rift escarpment. The altitude ranges from 3667meter above sea level (m.a.s.l) in the highland to 1231 meter above sea level (m.a.s.l) in the rift escarpment.

The study area can be accessed through main asphaltic roads running from the city of Addis Ababa to Debre Birhan. Sheno, Chacha, Debre Birhan are towns which lies on the main asphaltic road. Gravel roads which emanate from the main asphaltic road towards western direction give an access to Mndida, Deneba, Inewari and Jihur. Asphaltic road which branch out to the eastern direction give an access to Kotu, Hagere Mariam (Shola Gebeya) and Arerti. Foot trails which emanate from the main asphaltic road and branch out in two different village can be used to access most part of the study area (Daniel Meshesha et al., 2010).

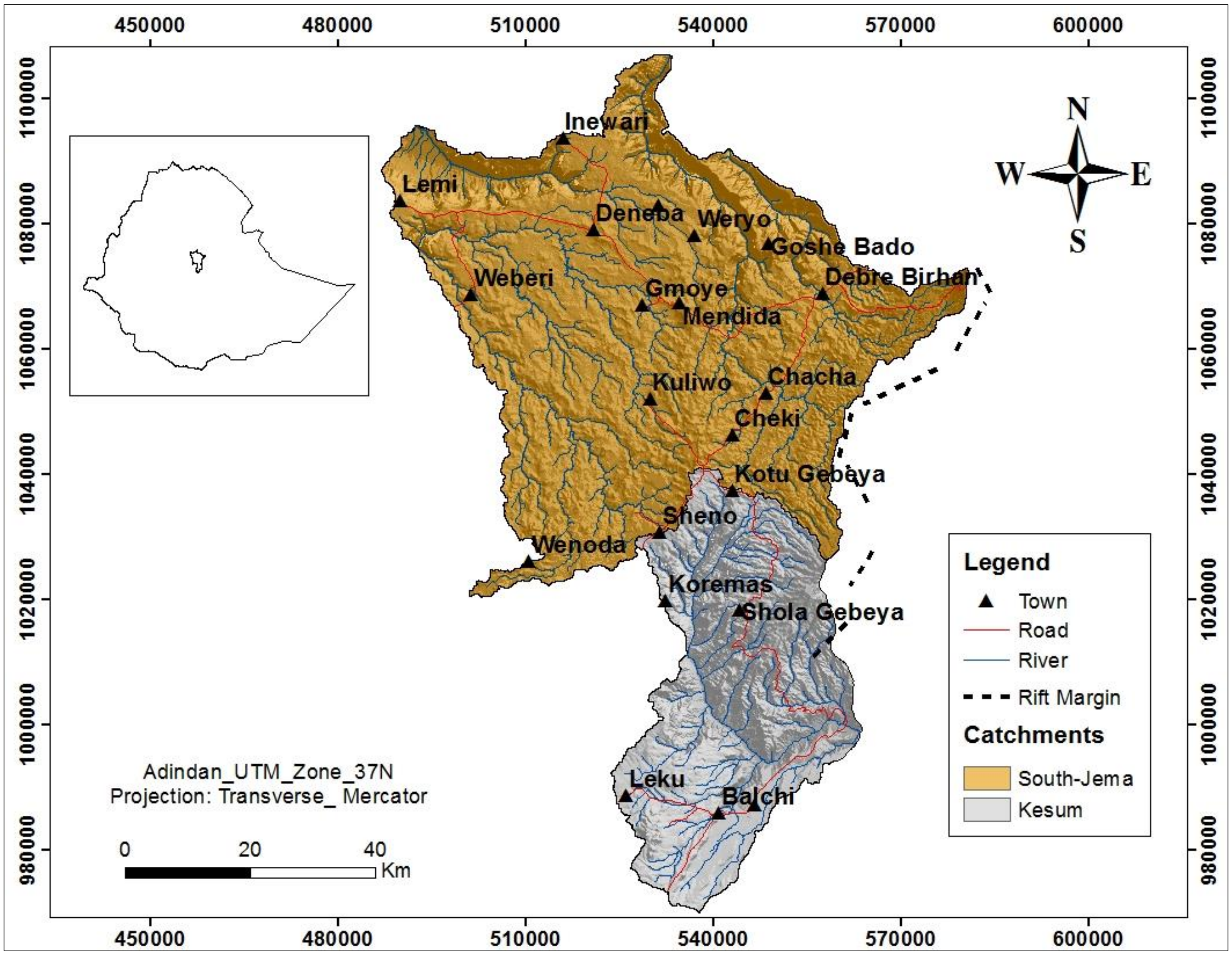

Figure 1: Location Map

1.5 Physiography and drainage

1.5.1 Physiography

The study area is mainly characterized by diversified geomorphology which can be categorized in to two physiographic regions i.e. plateau and escarpment. The plateau part of the study area consists of variable topography with an elevation greater than 2600 meter above the main sea level (m.a.s.l). It mainly consists of long undulating chains of mountains forming the Tarmaber –Megeze basalt, flat laying topographic features covered with tertiary volcanoes, deep dissected valleys oriented nearly northwestern direction exposing the Mesozoic sedimentary succession. The escarpment mainly comprises of steep morphology forming a step like faults oriented in N-S and E-W directions. With a ranging between 2600 m.a.s.l-1231 m.a.s.l (meter above sea level) (Daniel Meshesha et al., 2010).

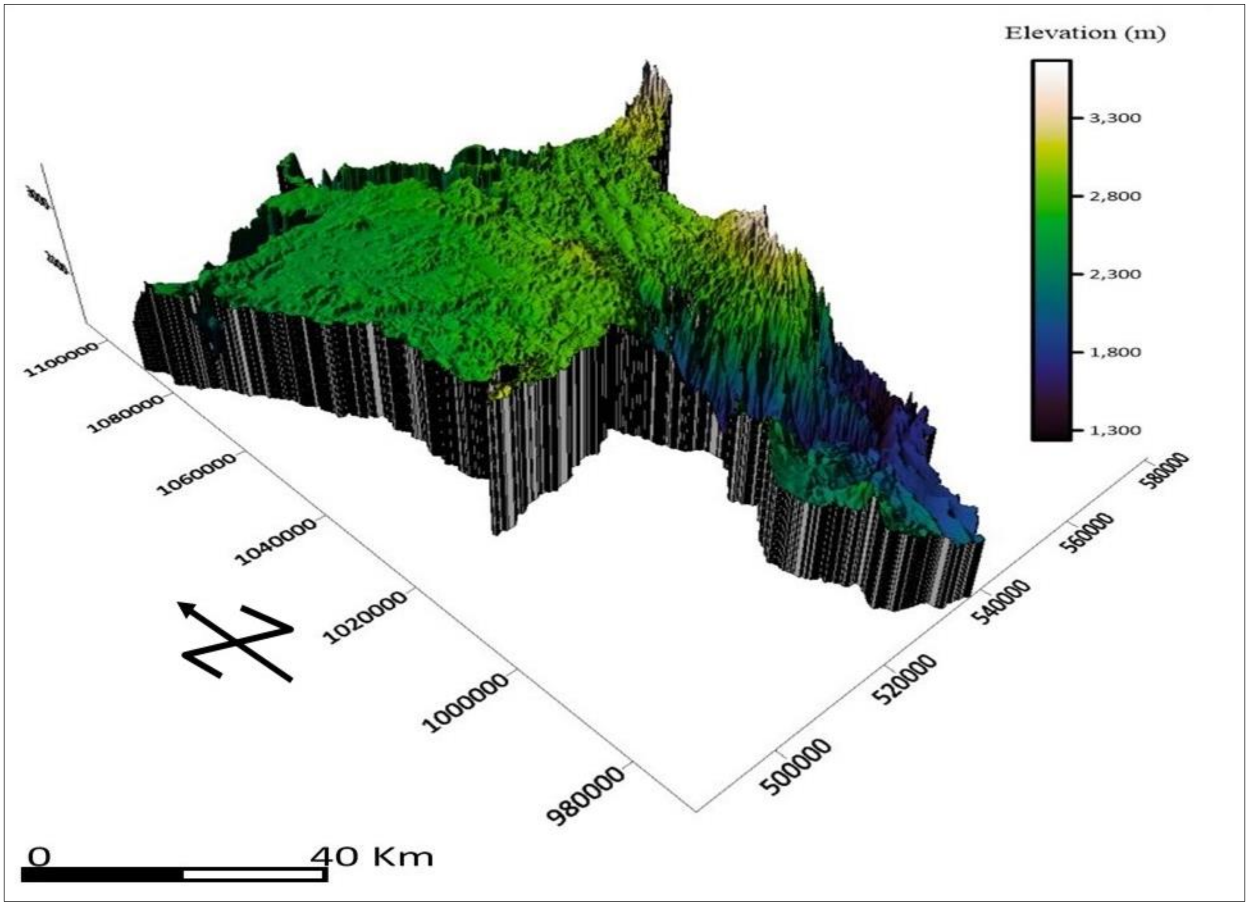

Figure 2: Physiography

1.5.2 Drainage pattern

The study area consists of different drainage pattern developed due to dissection and formation of river gorges. Two catchments namely South-Jema and kesum are separated from each other by Chancho-Berek ridge marking a water divide between the two. On South-Jema catchment, rivers and streams (Berresa, Chacha, Bersina, Robi-Gemero, Robi-Jida) emanate from the south-eastern part of the plateau and drains nearly north western direction in parallel fashion and join the Jema River. The streams and the rivers within the plateau shows sub-parallel to dendritic pattern. In the case of Kesum catchment, rivers and streams emanate from the north and drains to south and finally joins Kesum River. Rivers and streams in Kesum drainage pattern shows sub-paralle to dendritic pattern (Daniel Meshesha et al., 2010).

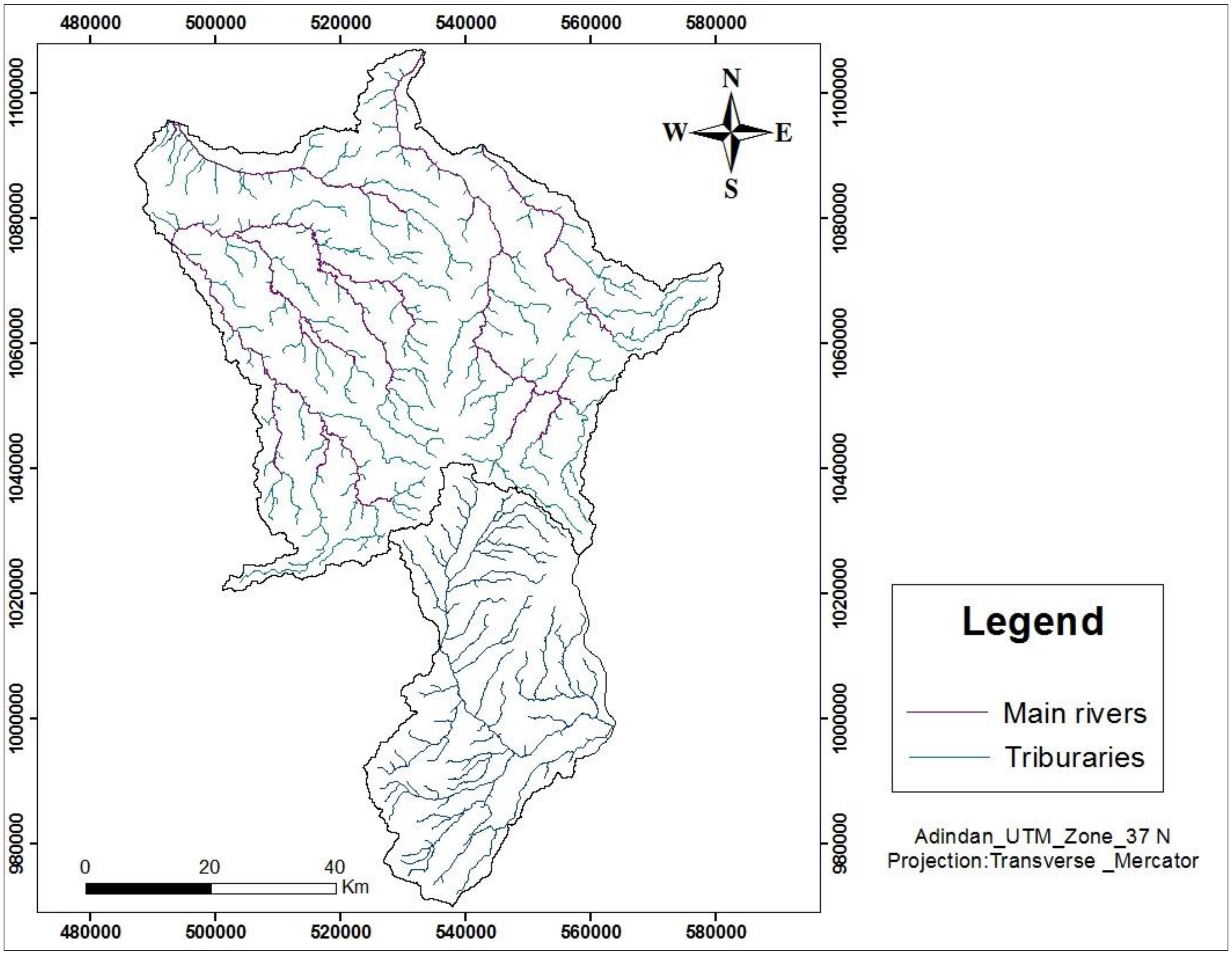

Figure 3: Drainage Map

1.6 Climate

The distribution and the amount of rainfall received in Ethiopia depends on the position of the Inter-Tropical Convergence Zone (ITCZ). Once it reaches to the continent it is modified by topographic effect (Gemchu, 1977 as citied in Seifu kebede, 2004). During the summer (June,July and August) the ITCZ just lies north of Ethiopia. southwesterly and southerly monsoonal winds from the Atlantic Ocean, which is a major source and certain portions from the Indian ocean and with minor from Congo vegetation basin and some tropical lakes bring summer rainfall to Ethiopia where by about 75% of country receive rainfall during this season. The NWP including the study area and the MER region gets rainfall during this time. During autumn and winter, the ITCZ lies south of Ethiopian. Off shore and cold monsoonal winds from Arabian landmass marked Ethiopia to exhibit dry season. Some southward onshore monsoonal winds from northern Indian Ocean and Arabian Sea invade eastern lowlands bordering the south eastern plateau bring rainfall to the region. During the spring (March, April, May) The ITCZ make its position from the south to northern crossing the country. Northwesterly and easterly onshore monsoonal winds fed by northern Indian Ocean bring rainfall to SEP and south eastern part of the northwestern plateau where by about 25% of the country's rainfall occur during this season. Geomorphological setup of the country plays a great contribution for the Ethiopia to exhibit variability of rainfall and temperature where by the mean rainfall and temperature within the study area and its surrounding ranges from 500mm to 1600mm and 20°c to 25°c and within the rift region 800mm to 1000mm and 37°c to 40° (Daniel Meshesha et al., 2010).

1.7 Methodology and Materials

To meet the desired objectives all relevant existing papers i.e. published journals, MSc. and PhD thesis, geological, hydrological and hydrogeological reports have been reviewed. Collection of hydro metrological, river gauge, existing borehole data from different responsible organizations and bureaus have been collected prior to field work. A geological map of 250,000 have been bought and important water sample site has been selected for data collection during field work.

During field activity a total of 19 water samples has been collected on systematically selected site in bore holes' hand dug wells and springs. In situ measurement of EC, temperature and pH has been made during the field activity

During post field activity 30m resolution of soil and land use/land cover map of the study area has been prepared from dataset obtained from the ministry of agriculture. The spatially distributed water balance model Wetspass-M 1.3 (2016, released date) has been used in estimation of the amount of recharge for the corresponding catchments. As the model requires data as a map prepared by the required format, all the required physical and hydro metrological data sets have been prepared to the appropriate format. Secondary sources of water quality data have been used in assessing the hydro chemical parameters of the watershed. All the required analysis has been manipulated using the appropriate software's and the results are presented in maps and tables.

1.8 Significance of the research

The study can greatly contribute to in determination of the annual resources of groundwater obtained from the corresponding catchments and hydro chemical variability between the aquifer systems of south-Jema and Kesum catchment.

Chapter Two: Geology, Hydrology and Hydrogeology

2.1 Regional Geology

Geological phenomenon that occurred during the Mesozoic era is responsible for the accumulation and deposition of multi-layer sedimentary strata (kazmin,1972).Two cyclic events namely transgression and regression of sea leads to the accumulation of successive sedimentary layers with variable thickness from the oldest to the youngest: Adigrat Sandstone , Gohatsion formation ,Antallo limestone ,Muger Mudstone and Debrelibanos Sandstone units exposed along the gorge of river basin within the country (Kazmin,1972;1980;Gethaneh Assefa 1981,1991;Ahemed Wolela,2008, 2009). Following this event, volcano tectonic processes that occurred during the Cenozoic era is marked by the outpouring of voluminous flood basalts represents the present-day geomorphological configuration of Ethiopian highlands. (Beccaluva et al., 2009). Flood basalt forming the Ethiopian plateau has been erupted within episodic manner forming various successive layers of rock layers with the oldest and earliest fissural type flood basalt i.e. Ashenge basalts (Zanettin et al., 1974; Mengesha Tefera et al., 1996). According to Ethiopian institute geological survey (EIGS) a report on geological map of Debre Birhan map-sheet, the rock of these age has been pointed to be 49-46 Ma. These basalt forms several km thick basalt and has been subjected to tectonic processes prior to the eruption of another episodes of volcanism known as Aiba basalt (Zanettin et al., 1980). These rocks are thick layers of basaltic rocks with intercalated of pyroclastic and rhyolites (Zanettin and Justine-Visentine, 1973). The Alaje series, other episodes of fissural type volcanism was followed on the north western plateau and consists of an interbedded layer of basalt and ignimbrite (Znettin et al., 1980). A central type of volcanism known as Tarmaber Megezez basalt has been erupted following the rift shoulders (Kazmin et al., 1980). These volcanic episodes have been indicated to separate two ignimbritic unites namely Alaje and Balchi formulations (Visentine et al., 1974).

The formation of the main Ethiopian rift is believed to have been developed during upper Eocene age and its initiation has been related to the South African super plume (Kieffer et al., 2004; Furma mann, 2007; Dainiel Meshesha; shinjo, 2008). These enormous continental tectonic zones have been classified in to three mainly structural segment showing different evolution in terms of space and time (Marco et al., 2005). Rifting process of the segment has been started in the southern most end following Kenyan rifting propagation during 20-21Ma and has been undergoing until it has been resumed11 Ma. Following its termination, rifting process mainly focus on the northern most end that leads to the formation of the afar rifting. Rifting process begin in central segment with eruption of voluminous lava flows during Pliocene of ignimbrite composition which are exposed both in the rift and rift shoulder (Macro et al.2005).

2.2 local Geology

Within the study area the litho-stratigraphic units can be broadly classified in to two subdivisions which consists of Mesozoic sedimentary rock succession representing certain portion of the study area and with majority of being covered with tertiary volcanism and minor quaternary volcanism and superficial deposits.

2.2.1 Mesozoic sedimentary rocks

Sedimentary succession of these age is exposed within the study area following the gorges of rivers. According to Daneil Meshesha,Dejene Hailemariam and Abrham Mamo (2010), a report on the geological map of Debre Birhan and Addis Ababa map sub-sheet has indicated three litho-stratigraphic units: Upper Sandstone, Mudstone units and Antalo Limestone are exposed within the study area.

Antalo limestone

This unit are exposed in the north western tip of the study area following gorge of Berssina River. According to Bereket Fentaw, Leta Alemayehu (2011), a report on hydrogeological, hydro chemical, engineering geological report of Addis Ababa, these rocks shows a gradational contact with the underlying mudstone formation where the formation progressively changes from siltstone layer followed by calcareous siltstone, silty limestone and gradually to limestone unit. Alternation of marl and intercalation of shale are the characteristics of these rocks which have been frequently observed within the bottom of these unit. Light gray to yellow fresh surface color and dark, white, and deep yellow weather surface color have been observed in this litho-unit (Bereket Fentaw et al., 2011).

Muger mudstone

Exposure of these rock unit are found on the north western tip of the study area following the gorge of Berssina River. Rocks of these unit are conformably overlaying both the upper sandstone and the underlying Antalo limestone unit with a gradational contact. According to Daneil Meshesha, Dejene Hailemariam and Abrham Mamo (2010), a report on the geological map of Debre Dirhan map sub - sheet, these rock unit shows fine to medium grained, with fresh surface color of light gray and light sometimes dark brown weathered surface color have been observed. Alternation of gypsum lenses has been also observed within these rock unit. Petrographic thin section of Gypsum units shows equigranularity grains of gypsum cemented with calcite (Daniel Meshesha et al., 2010).

Sandstone Unit

Rocks of these unit are exposed on the north western tip of the study area following the gorge of Berssena,Chacha and Brerssa River. The rock shows unconformable sharp contact with the overlaying basaltic rocks and conformable gradational contact with the underlying mudstone unit. They form a steep cliff following river cuts. This unit forms steep cliff along the stream cuts. A maximum of 30m thickness has been observed in the downstream part of Chacha River (Daniel Meshesha et al., 2010).

Sandstone units are medium grained with sub-rounded grains, exhibiting light red to reddish fresh surface color and yellowish, pinkish, brownish weathered surface color (Daniel Meshesha et al., 2010).

Petrographic thin-section of these rocks shows an average composition of quartz cemented with clay minerals, plagioclase feldspars and trace amount of calcite (Daniel Meshesha et al., 2010).

2.2.2 Cenozoic Volcanic rocks

Tertiary volcanic rocks

Volcanic rocks and their associated sediment of tertiary and quaternary age are exposed with great portion of the study area. Based on their stratigraphic sequence, rocks of these age can broadly classify into Paleogene and Neogene sequence

Paleogene rocks

A. Ashangi basalt

According to Fedlu Hassen,Baweke Birhan and Tigist Regassa (2017) a report on hydrogeological and hydrochemical map of Were-Ilu map-sub-sheet, Ashangi rock units are exposed in the northern tip of the study area. The rocks are unconformable overlain by Alajae basalts. These rocks are dominantly composed of basalt with minors of pyroclastic interlayerings exposed at the upper part of this unit. Strongly weathered, intensely fractured joints, friability and presence of vesicles are the characteristics of these rock units. Usually the vesicles are filed with secondary minerals of calcite, silica and zeolites. These lithologic units in a place where they are exposed with deep dissected valleys within the plateau, they are marked by three flow units which are separated from each other by intra-layered sediments or paleo sols. The lower end mainly consists of randomly distributed weathered aphanitic basalt. Middle flow exhibits medium grained porphyritic basalt with phenocrysts of pyroxene, plagioclase and olivine. The upper is composed of basalt and with certain portion of interlayers of phenocrysts (Hassen et al., 2017).

B. Kesum basalt

According to (Daniel Meshesha et al.,2010) this litho-units are exposed in the northern, north eastern and southern tip of the study area following dissected valleys of Jema and its tributaries Bersina, Derek wenz, Chaira, Chacha, Beressa, kesem. Compositionally kesum basalts are dominated by aphanitic which consists of plagioclase pyric basalts and thin beds of ignimbrites. Characteristically they are strongly fractured, having irregular to columnar joint sets exhibiting fine grained texture with fresh surface color dark gray to black and weathered surface color of bluish gray. Along the Jema river basin the rocks exhibit a sharp contact with the underlying upper sandstone units marked by 0.6 m Palo sols. At some localities near to the north of Inewari town these rocks contain petrified wood near the George of Wintaf River (Daniel Meshesha et al., 2010).

Petrographic thin sections of these units show the aphanitic basalt consists of dominantly of groundmass of 70% with the groundmass being dominated by plagioclase and microlith exhibiting trachytic to seriated texture, plagioclase of 10%, olivine of 6%, and pyroxene of 5% and an opaque mineral of 4% with secondary chlorite (Daniel Meshesha et al., 2010).

The intercalated plagioclase phyric basalt within the Kesum unit are exposed at the top part of the rock unit. They are coarse grained, dark gray and phyric in texture. Petrographic thin section of these units shows these basalts have a composition of 38% plagioclase, groundmass 39%, olivine 6%, pyroxene 8% and opaque minerals of 3%. In addition, secondary minerals such as chlorite4%, iddingsite are also incorporated within these unit (Daniel Meshesha et al., 2010).

The thin beds of ignimbritic units are very limited compared to aphanitic basalt. Texturally, they are fine to medium grained, bluish gray, friable and composed of small rock fragments. Petrographic thin section of this rocks is composed of glass 59%, sanidine 30%, rock fragments 5%, and quartz 3% with sericite 2% and chlorite 1% of alteration minerals (Daniel Meshesha et al., 2010).

C. Sela Dengay-Debre Birhan-Gorogo-ignimbrite

According to (Daniel Meshesha et al., 2010) Exposure of these rocks are found at Debre Birhan, Ankober localities within the study area. Rock of this unit has a sharp contact with overlaying Tarmaber-Megezez and the underlying Kesum basalt. These rocks are mainly composed of ignimbrite being the dominant, rhyolite, tertiary sediment, tuffaceous sediment, aphanitic basalt, agglomerate and ash (Daniel Meshesha et al., 2010).

The Ignimbritic unit forms a gentle to steep cliffs with elongated ridges and randomly distributed isolated hills (e.g Kotu Gebeya and Cheki) compositionally these rocks show medium to coarse grained, light, bluish, brownish gray to gray fresh surface color to dark gray weathered surface color. Highly consolidated to weathered tuff and bedded with columnar joint, vertical joints, and fractures characterize these rocks. Petrographic thin section of ignimbritic unit has an average composition of glass 60%, plagioclase 25%, rock fragment 8%, quartz 5%, sphene 1%, and iron-oxide 1 %(Daniel Meshesha et al., 2010).

Rhyolitic litho-unit within the ignimbrite are found within the study area close to Deneba, north east of Debre Birhan, Shola gebya and Gina Ager. These rocks are fine to medium grained, bluish, light, greenish gray fresh surface color to dull gray, light dark brown weathered surface color. Highly fractured and vertically jointed at the northeastern of Debre Birhan. Petrographic thin section the rhyolite units consist of glass 50%, plagioclase 30%, quartz 15% and pyroxene1%, and plagioclase is altered to sericite (Daniel Meshesha et al., 2010).

Tertiary sedimentare mainly exposed along the dissected gorges of Jema and its tributies and Kesum River. They are mainly consisting of alterations of tuffaceous sediment and sandstones. Two different layers i.e. upper and lower layers are found within these litho-units. The upper part of these layer is exposed in chacha and Berssena River gorges within the study area (Daniel Meshesha et al., 2010).

Tuffaceous sedimentary units shows light gray to pinkish gray, coarse grained with basaltic fragments and lamination. Petrographic thin section of these rock unit shows clay matrix of 50%, rock fragments of 40%, and plagioclase 10% with trace amount opaque minerals. The aphanitic basalt is a fine grained which is characterized by irregular fracture, slightly, columnar joint sets. Agglomerate of ignimbrite within these unit consists of Varity of dark gray porphyritic to aphanitic basalt cemented by ash. Ash unit are represented by slope and flat topography consists of fragments of basalts (Daniel Meshesha et al., 2010).

d.Tarmaber Megezez basalt

According to (Daniel Meshesha et al., 2010) these rock units are exposed dominantly within the study area forming linear ridges. Texturally these rocks consist of fine, medium to coarse grained basalt. These rock forms a sharp contact with the underlying Sela Dengay-Debre Birhan Gorgo Ignimbrite units. These rock units are characterized by different phases of lava flows separated by reddish paleo sols and scoraceous basalts. The rock unit is dominantly marked by plagioclase verities i.e. plagioclase phyric and olivine-plagioclase phyric basalts together with minor olivine phyric, pyroxene phyric, plagioclase–pyroxine-olivine phyric and aphanitic basalt (Daniel Meshesha et al., 2010).

The plageoclase phyric basalt are the dominant rocks types which covers most of the highlands characterized by columnar joints. It is medium to coarse grained with dark gray fresh surface color mainly consists of phenocrysts of plagioclase. Petrographic thin-section of this basalt shows 35% groundmass, plagioclase 30%, pyroxene (augite) 10%, olivine 10% and opaque 10%. Olivine phyric basalt is exposed within the study area near the towns of Shola Gebeya exhibiting coarse grained texture with fresh surface color greenish gray to weathered surface color of gray(Daniel Meshesha et al.,2010).

Neogene rocks

Nazret Group

Exposures of these rocks are mainly found in the southern part of the study within the escarpment within the study area, mainly consists of unwedded tuff, ignimbrite, ash flows, rhyolite and trachyte (Kazmine and Seifemechael, 1975). Petrographic thin sections of ignimbritic units exhibits eutaxitic texture with oblate glassy fragment where alkali feldspar, quartz, arginine and amphiboles are the most common crystals (Tilahun Azagegn, 2008).

2.2.3 Quaternary volcanic rocks and superficial deposits

Rhyolite domes

Exposure of these rocks are mainly found on the southern part of the study area forming a dome near close to Ejere town. They consist of older alkaline and per alkaline rhyolite domes and flows (Kazmine and Seifemechael, 1975).

Pliestocene recent to sub recent basalt.

These rock types are related to a volcanism related to an extensional fault known as Wonji fault belts are part of the wonji group volcanics. These rocks are mainly exposed in the southern part of the study area within the rift escarpment. The original lava has been preserved in some area with some of the most recent basalt forming the aa lava. The older Pleistocene basalts exhibits pantellertic with fisural type basalt where the recent one being a central type (Kazmine and Seifemechael, 1975).

Eluvium soil

Eluvium soils are mainly found in the plateau and escarpment of the study area. They are weathering products of basalt rhyolite and ignimbrites units. Texturally these soils exhibit silty to clay size, light gray to brownish fertile soil (Daniel Meshesha et al., 2010; Kazmine and Seifemechael, 1975).

Alluvium Soil

Exposures of these rocks have been found on the north eastern, central and south eastern part of the study area. Texturally, these rocks are characterized by fine to medium sand and gravel deposits. These rocks are part of weathering products which are derived from the plateau. The fine to medium sand is the most abundant covering majority of the area where the gravel has been locally exposed following the gorges of Kesum River (Daniel Meshesha et al., 2010; Kazmine and Seifemechael, 1975).

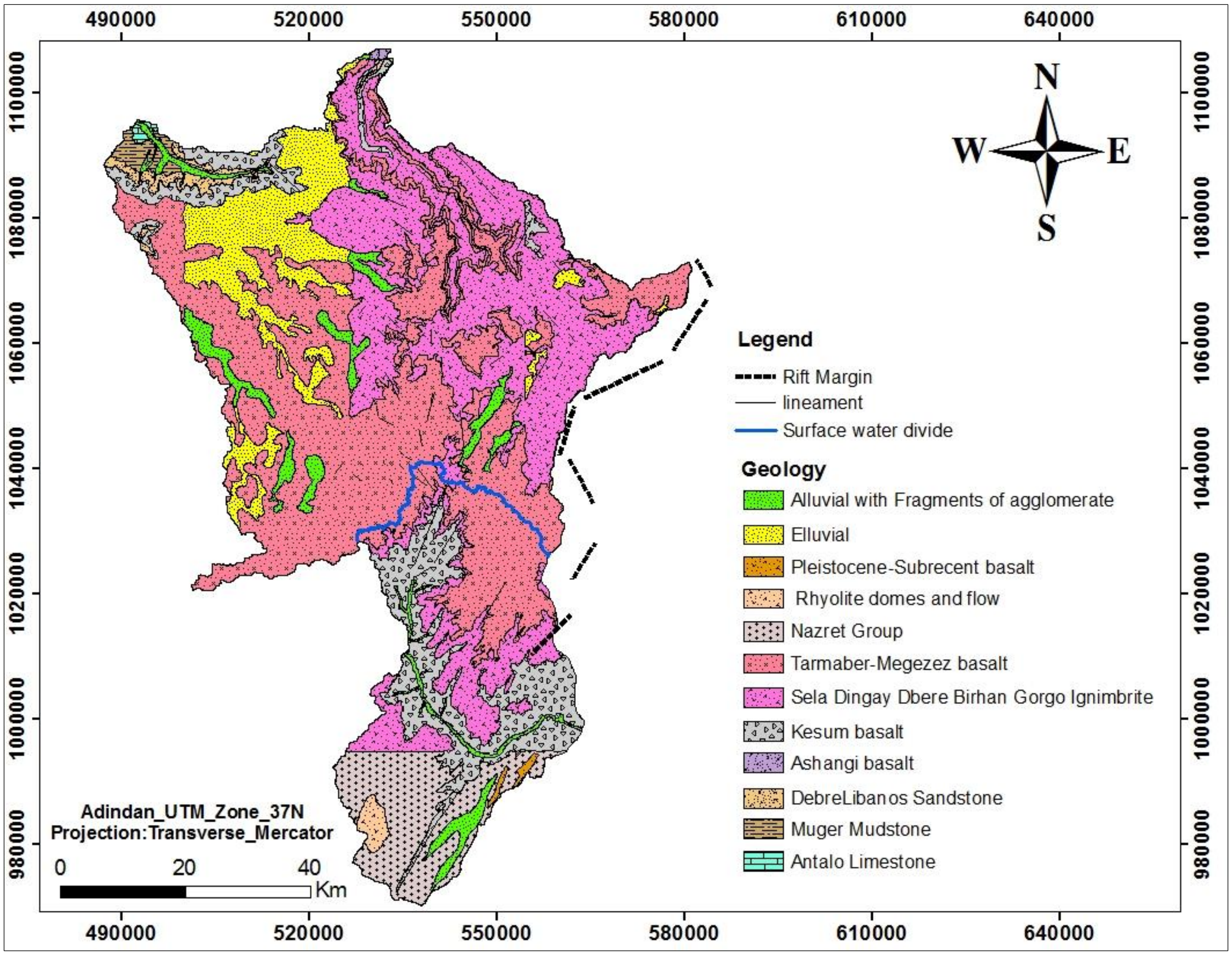

Figure 4 : Geological Map (Modified from EIGS, 2010)

2.3 Geological Structures

According to (Daniel Meshesha et al., 2010) Geological structures within the study area are mainly confined along the rift margin. NE-SW trending normal faults, liniments, joints and fractures are the tectonic structures which are mainly found within the proposed study area. Normal step like faults are found along the rift margins mainly dipping towards the rift axis and shows variable strike length. Lineament structures with variable strike length having NW-SW, E-W, NE-SW trend have been recognized. Joints sets and fracture are mainly localized in ignimbrite and basaltic units. Two sets of horizontal and vertical joints have been found. In addition to these, irregular columnar joints set of hexagonal face has been observed on the basaltic and ignimbrite units (Daniel Meshesha et al., 2010). Lineament density map has been prepared using structural data obtained EIGS. As indicated in the figure below (Figure 5) lineament are mainly concentrated in the south-eastern part of South-Jema and at the surface water divide of both catchments.

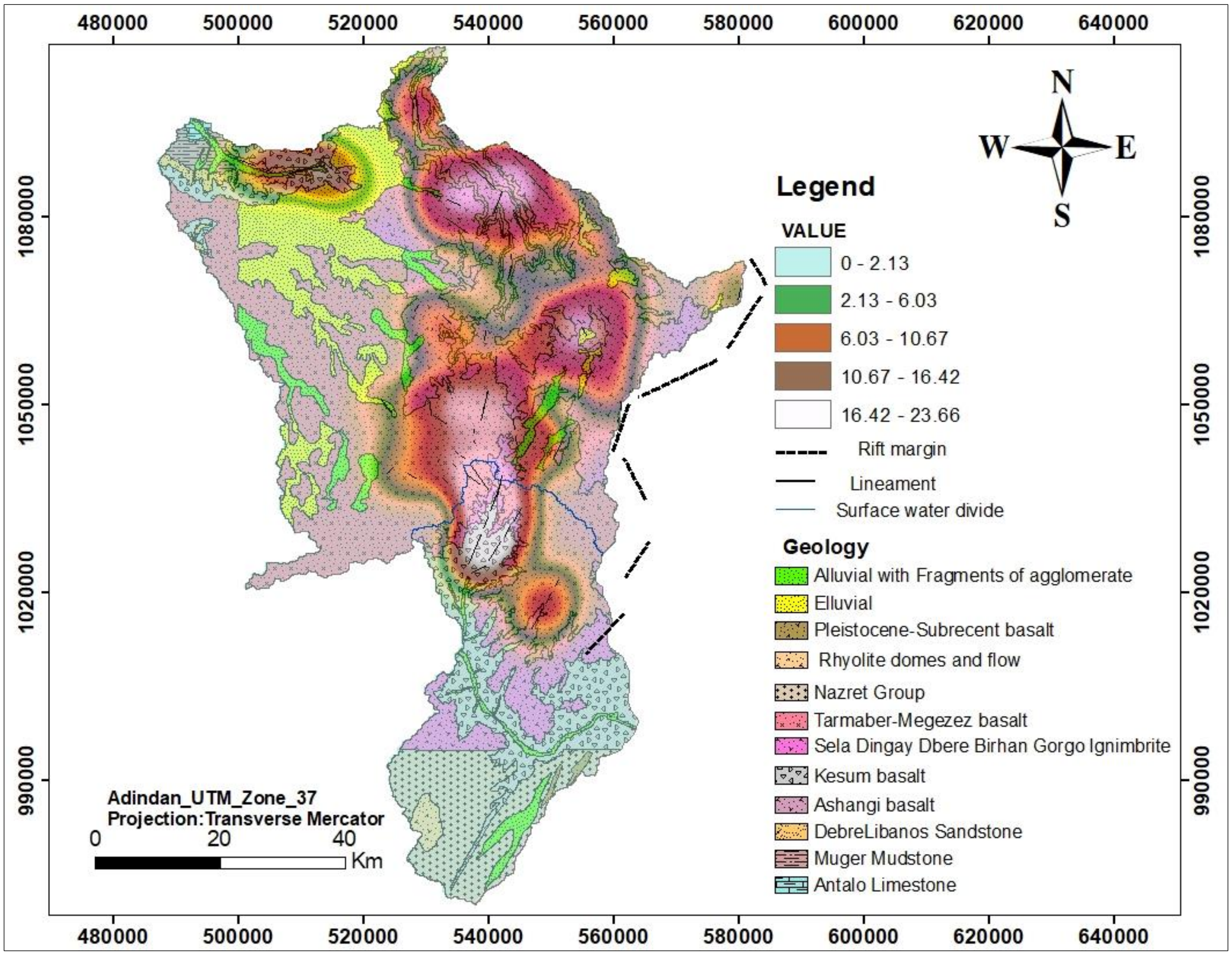

Figure 5: Lineament Density Map (Modified from EIGS, 2010)

2.4 Hydrology and Hydrogeology

2.4.1 Hydrology

Hydrological investigation has been carried out within the study area and its surrounding at a map sub-sheet level. According to the geological survey an explanatory report on hydrogeological and hydro chemical map of Debre Birhan map sub-sheet has been pointed out that from the analysis made for river discharge shows, the mean flow of rivers varies from 3.38m^3/s to 60m^3/s and the specific runoff varies from 2.0 to 16.0 l/skm^2 around Debre Birhan area. Base flow analysis for different gauge station within the study area has been implemented to understand the variation of base flow and runoff within the study area. According to the report an increment in runoff has been observed during the rainy season and gradually decreases during the dry seasons. Compared to the Kesum at Awara Melka and Awash at Melka Werer, rivers namely Beressa, Chacha, Robi and Robe shows less measured value of base flow and runoff. The reason for this is attributed to the undulating topography and thick covers of eluvial deposit which likely enhance infiltration rate. In addition to this the placement of gauge stations at the upper course in the plateau compared to the escarpment gauge station provides less measurement values of river discharge (Thomas Agzaw et al 2018).

2.4.2 Hydrogeology

According to the report on hydrogeological and hydro chemical map of Debre Birhan map sub-sheet, the hydrogeological systems of the study area have been classified based on qualitative and quantitative methods. Classification and characterization of the aquifers based on qualitative approaches was based on dominant primary porosity, secondary fissured permeability and impermeable rock unit. The quantitative classification of was based on field water point inventory data, pumping test data either measured in the bore hole or obtained from regional offices (Thomas Agezew et al., 2018).

Qualitative classification of aquifer systems within the study area

1. Aquifers with porous permeability

Hydrogeological units with dominant porous medium are represented by Alluvial and Eluvial of quaternary sediments are exposed in the study area. The groundwater occurrence within these units is the function of their size, sorting, pore throat connectivity, cementing material. From the hydrogeological map it has been observed both in the Awash and Blue Nile part of the study area. Texturally the Alluvium consists of sand silt and gravel with variable of grain size. High sorting and transmissivity make the alluvium as good source of groundwater water resource for shallow aquifer (Thomas Agezew et al., 2018).

2. Aquifers with fissured permeability

Hydrogeological units of these rocks are mainly represented by tertiary volcanic rocks and sedimentary rocks unit subjected to secondary deformation. Occurrence of groundwater in these rocks is mainly governed by the fracture that can give an access for transfer and storage of water. As most of volcanic rocks found within the study area are subjected to high degree of weathering, fractures and joint sets, they have the capacity to store and transmit appreciable quantity of groundwater and are considered to have high to medium permeability (Thomas Agezew et al., 2018).

3. Aquifers with mixed (porous and fissured) permeability

Hydrostatigraphic units exhibiting both primary and secondary permeability are mainly exposed on the plateau part of the study area. These types of permeability area mainly developed in porous basalts and tertiary sedimentary rocks intercalating volcanic rocks in the plateau (Thomas Agezew et al., 2018).

4. Aquitard and Aquicludes

Less permeable hydrogeological units are presented within the study area marked with limited Eluvium aquitard to groundwater barrier mudstone unit representing an aquiclude within the study area (Thomas Agezew et al., 2018).

Quantitative classification of aquifer system within the study area

According to Ethiopian institute of geological survey a report on hydrogeological and hydro chemical map of the study area has classified hydro stratigraphic units based on field-based water point inventory data, and borehole pumping test in to the following classes (Thomas Agezew et al., 2018).

1. Extensive and moderately productive porous aquifers

Aquifers of these units have a transmissivity ranging between 1.1-10m^2/day, discharge between 0.011-1l/sm and yield of 0.5-5l/s for wells and /or springs. As indicated in the map above Aquifers of these rocks are mainly represented by Alluvium with fragments of Agglomerates which are mainly exposed both in the Plateau part as well as in the escarpment of the study area (Thomas Agezew et al., 2018).

2. Extensive and highly productive fissured aquifers

Aquifers of these hydro-stratigraphic units have transmissivity value ranging between 10.1-100m^2/day, a discharge of 1.1-10l/sm, and a yield of 5-25l/s for wells and/or springs. These units include pliestocene-sub recent basalts exposed in the awash part of the study area and are indicated on the map with pink color (Thomas Agezew et al., 2018).

3. Minor and highly productive Karst aquifers

Aquifers of these hydro-stratigraphic units are found in small portion within the study area are located in the north western tip of the study area. Having similar hydrogeological character similar to the above aquifer systems (Bereket Fentawet al., 2011).

4. Extensive and moderately productive aquifers with mixed and porous and fissured permeability

Aquifer systems of these units are mainly consisting of Sela Dingaye-Debre Birhan Gorog Ignimbrite and Nazret Group formations exposed both on the plateau part of the study area. They are characterized by transmissivity value ranging 1.1-10m^2/s, a discharge of 0.011-1l/sm, and yield of 0.5-251/s for wells and springs (Thomas Agezewet al.,2018).

5. Extensive and moderately productive fissured aquifers

Aquifer systems of these rocks cover majority part of the study area. They consist of the Mesozoic Debrelibanos sandstone, Tertiary volcanic rocks of Kesem basalt and Tarmaber-Megezez basalt and the rhyolite domes and flows. They are characterized by a transmissivity ranging between 1.1 -10 m^2/d, a discharge of 0.011-1l/sm, and a yield 0.5 to 5l/s (Thomas Agezew al., 2018).

6. Limited Aquifer

Aquifer systems of these unit consists Eluvial sediments of unconsolidated materials of shallow depth with variable aquifer thickness suited within the plateau. They are marked on the map with yellow color (Thomas Agezew et al., 2018).

7. Aquitards

These minors less water bearing formations are exposed within the study area having local and limited amount of groundwater. The rhyolite domes and flows exposed on the south waster tip of the study area can be considered as local aquitard (Thomas Agezew et al 2018).

8. Aquiclude

These litho-stratigraphic formations are very less permeable rocks that serves as a groundwater barrier. The Mesozoic mudstone formation exposed in the northern tip of the study area is an aquiclude which is an extension of the mudstone caped horst extended from mugger sub-basin (Tilahun Azagegn, 2015).

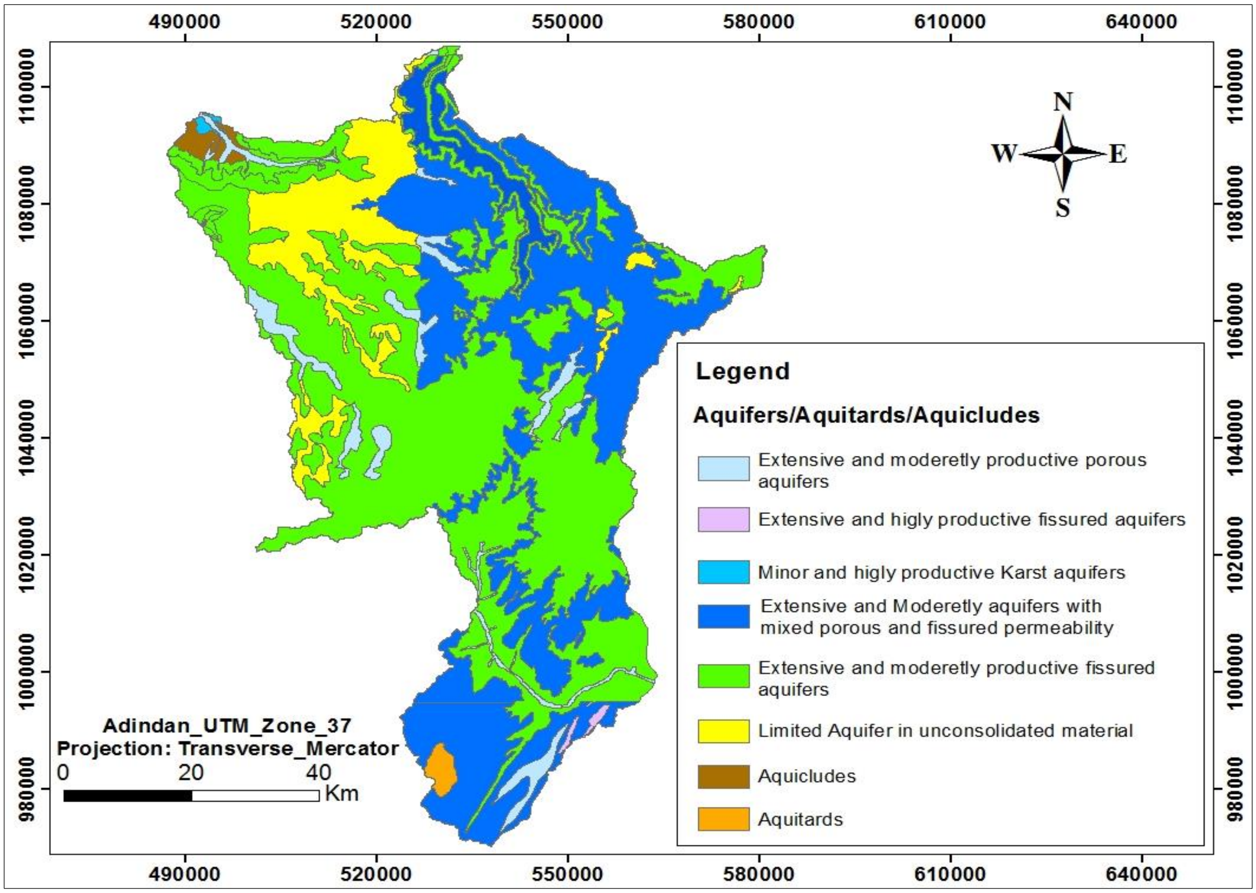

Figure 6: Hydrogeological Map (Modified from EIGS, 2018)

Chapter Three: Recharge

3.1 Groundwater Recharge

Estimation of the amount of recharge to the sub-surface is key role for efficient and sustainable management of groundwater resources. Different methods have been employed to quantify the amount of water that is contributed to the saturated zones. Among them Soil moisture water balance, Chloride mass balance and base flow separation method have been widely used since the past, but due to invent of computer-based hydrological models now a days, the water balance components with respect to the residual component in the case of these study the recharge, Surface runoff and Actual Evapotranspiration can be easily computed and analysis can be made through over the outputs. In this study the spatially distributed water balance model, Wetspass 1.3 version has been employed to estimate the amount of recharge, surface runoff and actual evapotranspiration.

Estimation of amount of recharge to the sub-surface has been made independently for south-eastern part of Jema sub-basin (South-Jema) and Kesum catchment.

For this study all relevant hydro-metrological data of 30 years from MA, river discharge data 15 years from MoWIE and land use/land cover and soil map of 30 m resolution has been employed from Ministry of Agriculture. Before preparation of hydro-metrological data's as an input, missing data have been filtered out and they have been filled with the appropriate missing data methods.

3.2 Data availability

In the analysis of hydrology of a give watershed, the most problematic difficulties that has been faced through the past is the absence of full and accurate data records within the stations. Within the study area, only certain stations were full of all the required hydro-metrological variables. Stations within and around the study area where considered for data preparation. The availability of data for the corresponding stations is given in the table below:

Table 1: Availability of Metrological Data

	Stations	Year		Coordinate		PP	T	RH	S_{HR}	W
		from	to	UTME	UTMN					
1	Arerti	2012	2017	546850	986890	*	*			
2	Bologiorgis	1987	2017	539071	976730	*				
3	Chacha	1987	2015	549231	1055629	*				
4	Debre Birhan	1987	2018	554629	1064995	*	*	*	*	*
5	Deneba	1987	2018	521926	1079600	*				
6	Ejere	1987	2018	528276	969428	*	*			
7	Eneware	2000	2018	516370	1086903	*	*	*	*	*
8	Ginager	2007	2018	562090	1030864	*	*			
9	Jihur	1987	2015	527483	1108810	*	*			
10	Koremash	1987	2015	532404	1019275	*				
11	Kotu	1988	2018	547961	1044834	*				
12	Lemi	1987	2018	488906	1085157	*	*			
13	Mendida	1987	2018	522085	1039436	*	*			
14	Sheno	1987	2018	531293	1030864	*	*			
15	Shola Gebeya	2006	2018	560503	1019275	*	*	*	*	*
16	Siadebr	2008	2017	507480	1081823	*				
17	Debele	2002	1018	569869	1059598	*				
18	Aleltu	2011	1018	516846	1017846	*	*			
19	Melka Jilo	2007	2018	568123	982763	*	*			
20	Meteh Bila	2006	2018	577330	1018481	*	*			
21	Debre Tsige	1987	2018	480492	1065630	*	*			
22	Sendafa	1987	1208	502082	1011814	*				
23	Muke Turi	1987	2018	485731	1054835	*				

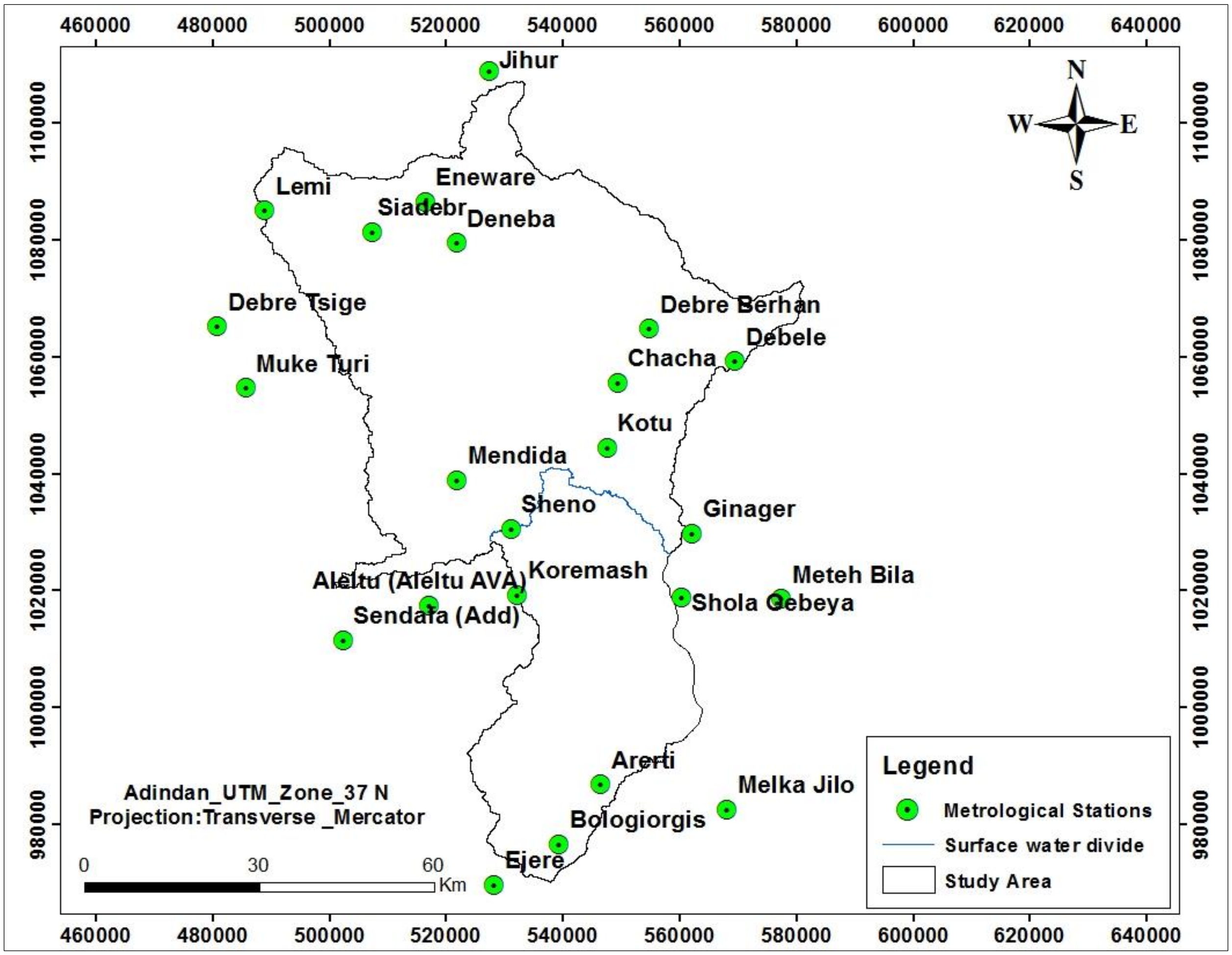

Figure 7: Metrological Stations within the Study Area

3.3 Wetspass model and its application

The wetspass model is spatially distributed quasi-steady state water balance model which is designed to predict the hydrogeological processes at annual and seasonal time steps (Batelann&De Smedth, 2001, 2007). This model is designed to work with GIS environment for data preparation. Especially the new version (wetspass 1.3) has the ability to simulate interception from vegetated surfaces, runoff from land escape, evapotranspiration, soil water balance, and recharge at monthly time step using long term mean monthly values.

The model is designed by conceptualizing the hydrogeological system of a basin based on Physical and empirical relationships which mainly consists of plant canopy, soil zone, root zone, atmosphere and saturated groundwater zones partitioned in to grids/cells to take in to account of heterogeneity (Gebremedhin Gebremeskel, 2015). Grid maps of the same cell size of the long-term mean monthly values of precipitation, temperature, potential evapotranspiration, winds speed prepared on Arc GIS environment and parameter tables of land uses types with respect to their root depth and leaf area index and soil parameter tables with respect to their field capacity, wilting point permeability and runoff of the appropriate format are required to run the model.

3.3.1 Model concept

The model is a type of distributed one in which the area to be studied is discretized in to raster grid cells where by the water balance computations are performed at each individual cells/element. Discretization of the area under consideration is performed within the GIS environment by defining the size of the cell. Calculations of individual water balance is performed by summing up independent water balance for the vegetated, bare soil, open-water, and impervious fraction of a raster cell. Therefore, the total water balance for a given watershed can be computed by summation of the water balance for each raster cell.

3.3.2 Water balance calculation per raster cell

In calculations of the total water balance of a raster cell, the water balance components of vegetated, bare-soil, open water, and impervious surfaces are required. Are given according to the following equitation's

$ET_{raster} = a_v ET_{v} + a_s E_{s} + a_o E_{o} + a_i E_i$………………………………........... (1)

$S_{raster} = a_v S_{v} + a_s S_{s} + a_o S_{o} + a_i S_i$…………………………………........... (2)

$R_{raster} = a_v R_{v} + a_s R_{s} + a_o R_{o} + a_i R_i$……………………………………. (3)

Where: ET_{raster} is the total evapotranspiration of a raster cell [LT^{-1}]

S_{raster} is surface runoff of a raster cell [LT^{-1}]

R_{raster} is groundwater recharge of a raster cell [LT^{-1}]

a_v is vegetated component for each the corresponding water balance component

a_s is bare-soil component for each corresponding water balance components

a_o is open water component for each corresponding water balance components

a_i is impervious component for each corresponding water balance components

During computations, precipitation is the starting point of calculation for the water balance each components of a raster cells mentioned above the rest of the process (interceptions, runoff, evapotranspiration and recharge) follow in ordinary manner. The order is prerequisite for quantifications of processes at seasonal time scale.

Water balance components performed by the model are described hereunder:

Vegetated Area:

The water balance computations performed for vegetated area is mainly depends up on the seasonal precipitation(P), interception fraction (I), surface runoff (S_s), actual evapotranspiration (T_v) and groundwater recharge (R_v) where all the magnitude is expressed [LT^{-1}] units and is given by:

$$P = I + S_v + T_v + R_v \quad (1)$$

Interception*:*

Interception fractions is represented by percentage of annual precipitation value which mainly depends up the type of vegetation cover. Since the vegetation cover is taken as constant throughout the simulation period. The interception by a constant vegetation cover represents a constant percentage of annual precipitation value

Surface runoff

Surface runoff calculations are performed in considerations of precipitation amount, its intensity, interception and soil infiltration capacity. Initially the potential surface runoff (S_{v-pot}) is performed using the equation:

$$S_{v\text{-}pot} = C_{sv}(P\text{-}I) \quad (2)$$

Where = C_{sv} is surface runoff coefficient for the vegetated area, is a function of vegetation soil type and slope. In groundwater discharge zones saturated surface runoff is likely to be observed which in turn dramatically increase the surface runoff coefficient but due to the less dependency of soil and vegetation type in the surrounding area of a river, the runoff coefficient is assumed to be constant. The second step is calculation of the actual surface runoff from the potential surface runoff will be performed according to the following equation:

$$S_v = C_{Hor} S_{v\text{-}pot} \quad (3)$$

Where: C_{Hor} is the coefficient for parameterization that part of seasonal precipitation contributing to Horton overland flow.

But for groundwater discharge area the value of C_{Hor} is equal to 1.0 since intensity of the precipitation contribute to the surface runoff. Only storms can generate surface runoff in infiltration areas.

Evapotranspiration

Before calculation of evapotranspiration the wetspass model calculates a reference value of transpiration from open water bodies and vegetation coefficient according to the following equation:

$T_{rv} = cE_o$………………………………………………………….. (4)

Where: T_{rv} is the reference transpiration of vegetated surface $[LT^{-1}]$

E_o is potential evaporation of open water $[LT^{-1}]$

C is vegetation coefficient [-]

The vegetation coefficient can be determined from the ratio of the reference vegetation transpiration expressed by the Penman-Monteith equation to the potential open water evaporation is calculated by the following equation:

$$C = \frac{1+\Upsilon/\Delta}{1+\frac{\Upsilon}{\Delta}(1+\frac{r_c}{r_a})} \quad \text{……………………………………………… (5)}$$

Where: γ = psychrometric constant $[ML^{-1}T^{-2}C^{-1}]$

Δ = Slope of the first derivative of the saturated vapor pressure curve (slope of saturation vapor pressure at the prevailing air temperature) $[ML^{-1}T^{-2}C^{-1}]$

r_c = Canopy resistance $[TL^{-1}]$

r_a = aerodynamic resistance $[TL^{-1}]$

The value of the aerodynamic resistance is calculated by:

$$r_a = \frac{1}{k^2 u_a}\left(ln(\frac{Z_a - d}{Z_o})\right)^2 \quad \text{…………………………………… (6)}$$

Where: k is von karman constant (0.4) [-].

Ua is the wind speed $[LT^{-1}]$ at measurement level Za =2m.

d is the zero-plane displacement length [L].

Zo is the roughness length for vegetation or soil [L].

The penman coefficient (γ/Δ) varies with temperature and can be obtained from the following table:

Table 2: Variation of penmann coeffient (γ/Δ) with temperature

T(ºC)	-20	-10	0	5	10	15	20	25	30	35	40
γ/Δ	5.86	2.83	1.46	1.07	0.76	0.59	0.45	0.35	0.27	0.25	0.17

In the case where there is vegetated groundwater discharge area, the actual transpiration will be equal to the reference transpiration. This is due to there will be no water or soil availability limitation. This can be expressed mathematically as:

$Tv = Trv$ if $(Gd - ht) \leq Rd$………………………………………….…. (7)

Where Gd is the groundwater depth [L]

h_t is the tension saturated height [L]

Rd is the root depth [L]

In the case for vegetated area where the groundwater level is below the root zone, the actual transpiration is calculated as:

$Tv = f(\theta)Tv$ if $(Gd-ht) > Rd$………………………………………. …..… (8)

Where $f(\theta)$ is a function of the water content and for a time variant situation and it is defined as:

$f(\theta) = 1 - a_1^{w/Trv}$……………………………………………………..… (9)

where W is given as: $w = P + (\theta_{fc} - \theta_{pwp})$ Rd…………………………………. (10)

a_1 is the calibrated parameter related to the sand content of a soil type [-].

W is the available water content [LT^{-1}] and

$\theta_{fc} - \theta_{pwp}$ is the plant available water content [T^{-1}] per time step, and is described as the difference in water content at field capacity and at permanent wilting point.

Recharge

The final component to be calculated as a residual component during the simulation is the recharge and is calculated as:

$$R_v = P-S_v-ET_v-I \ldots\ldots (11)$$

Where: ET_V is the actual evapotranspiration [LT^{-1}] is given as the summation of T_v and $E_{s.}$

Therefore, the spatially distributed from the vegetated type, soil type, slope, groundwater depth, climatic variables of precipitation, potential evapotranspiration temperature and windspeed is computed.

A similar procedure as that of the vegetated surface is followed for the calculation of the water balance for bare-soil, open water and impervious surfaces. The only difference in here is there is no interception and transpiration term as there is no vegetation in this case. Therefore, the ET_v in this case becomes Es.

3.4 Hydro-metrological analysis

3.4.1 Precipitation

Precipitation is one of the major hydrological components that has a great effect on the spatial and temporal pattern of recharge. The amount of precipitation over given area is mainly influenced by the physiographic and geomorphological characteristics of the watershed. According to (Gemechu, 1977) the orographic mechanism of rainfall is the main controlling factor that determines the distributions rainfall over the Ethiopian highlands. As indicated in the table above (Table 1) Rainfall records ware available from 1987 to 2018. Rainfall data of 23 stations ware available within and around the study area. 16 and 12 stations as indicated in the table below (Table 3 and Table 4) within and around South-Jemma and kesum catchment have been used for preparation of input data. Daily long-term rainfall records have been converted to mean monthly values. Only data with missing not more than three months has been considered during the conversion process and missing values of the data has been filled by taking the long-term average values of each month of twenty years record. Examples of the distributions of rainfall with different localities has been indicated in the figure below (Figure 8) from the analysis of the figures (Figure 8 a and b) it is clearly observed that Precipitation is strongly influenced by elevation in both catchments. (Figure 7 c and d) shows the long term mean monthly precipitation values for the corresponding catchments. From the analysis of the figure it is clearly observed each catchment shows bimodal pattern of rainfall whereby small rain fall occur during March, April and May and highest rainfall is attained during June, July August and September. Average long-term annual rainfall within the South-Jema and Kesum catchment is estimated to be 1023mm and 973.81mm respectively (Figure 10). Preparation of data has been made at monthly time step and the result has been divided in to two seasons which consists of four months of summer (JJAS) and eight months of winter. Average annual precipitation for South- Jemma during the winter and summer season is found to be 227.49

mm and 795.51mm(Figure 9and Figure 10) where as for the corresponding Kesum catchment, the average long-term precipitation for the winter and summer season is found to be 237.69mm and 736.12 mm respectively(Figure 9 and Figure 10).

Table 3: Long term mean monthly rainfall for the 12-time step used for Kesum catchment

Catchment	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kesum	Arerti	1.55	13.55	28.55	51.3	61.30	62.50	209.8	273.9	139.8	38.69	17.88	0
	Bologiorgis	15.40	36.63	50.74	69.82	48.86	68.57	218.9	236.9	103.7	31.7	10.68	7.33
	Ejere	12.6	26.26	46.9	65.57	48.75	74.93	231.6	204.8	111.4	20.98	10.97	7.55
	Aleltu	5.05	6.92	21.65	47.05	62.05	78.28	346.1	326.0	127.8	15.22	5.25	0.70
	Metha Bila	15.52	19.40	87.34	54.84	43.92	26.41	133.8	173.1	72.62	41.70	26.45	9.05
	Melka Jilo	11.58	2.72	16.99	38.79	27.06	19.34	114.6	156.7	49.56	12.9	9.61	0.49
	Ginager	20.25	60.74	110.2	138.9	156.0	113.26	394.6	448.2	156.1	75.12	59.69	17.42
	Sendafa	15.18	22.74	39.51	70.11	51.09	108.69	320.5	331.2	106.2	17.40	4.35	3.19
	Shola-Gebeya	3.89	13.05	27.27	57.78	48.61	86.06	285.9	257.2	102.5	24.39	6.73	3.33
	Kormesh	5.50	14.40	33.86	55.79	31.86	88.70	289.2	333.1	167.1	34.54	7.92	4.09
	Sheno	6.25	15.96	36.2	65.43	36.31	87.64	311.8	290.1	93.18	15.58	6.34	6.97
	Kotu	7.79	23.73	44.74	58.52	39.50	61.61	270.6	250.6	88.74	13.95	12.7	7.63

Table 4: long term mean monthly rainfall for the 12 time step used for South-Jema catchment

Catchment	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South-Jema	Debre-Birhan	9.71	16.88	40.99	54.65	42.43	53.26	311.8	208.43	82.73	18.71	6.06	4.45
	Deneba	16.37	25.65	62.27	56.26	38.20	72.95	303.14	274.27	88.11	11.0	6.26	4.32
	Debele	5.07	9.51	36.58	67.68	68.69	37.89	236.59	267.55	109.94	24.89	9.91	11.50
	Eneware	5.62	17.72	52.61	76.73	63.74	97.33	344.55	361.48	101.04	11.07	6.93	5.86
	Ginager	20.25	60.74	110.2	138.9	156.0	113.26	394.6	448.2	156.1	75.12	59.69	17.42
	Kotu	7.79	23.73	44.74	58.52	39.50	61.61	276.09	250..61	88.74	13.95	12.76	7.63
	Sheno	6.25	15.96	36.2	65.43	36.31	87.64	311.8	290.1	93.18	15.58	6.34	6.97
	Jihur	8.98	27.36	46.71	48.21	27.59	55.57	276.66	269.36	79.42	12.19	7.48	4.95
	Siadebre	3.70	19.24	36.59	62.74	93.42	78.40	414.56	366.95	110.90	10.69	5.82	2.09
	Debre-Tsige	16.64	22.23	57.61	55.18	41.86	77.38	270.88	224.79	85.48	16.39	7.75	8.08
	Muke-Turi	19.96	23.25	62.90	48.69	55.18	87.60	261.02	277.04	106.50	21.36	8.81	8.39
	Sendafa	15.18	22.74	39.51	70.11	51.09	108.69	320.56	331.88	106.20	17.40	4.35	3.19

	Aleltu	5.05	6.92	21.65	47.05	62.05	78.28	346.10	326.03	127.98	15.22	5.25	0.70
	Lemi	8.30	31.32	76.01	74.65	73.52	75.45	395.94	407.85	105.98	19.04	8.78	7.89
	Chacha	3.85	9.08	12.81	34.68	50.75	30.24	64.56	282.71	299.03	97.71	19.97	5.40
	Mendida	13.45	13.52	15.00	14.87	15.58	15.07	14.24	13.94	13.67	13.61	12.72	12.61

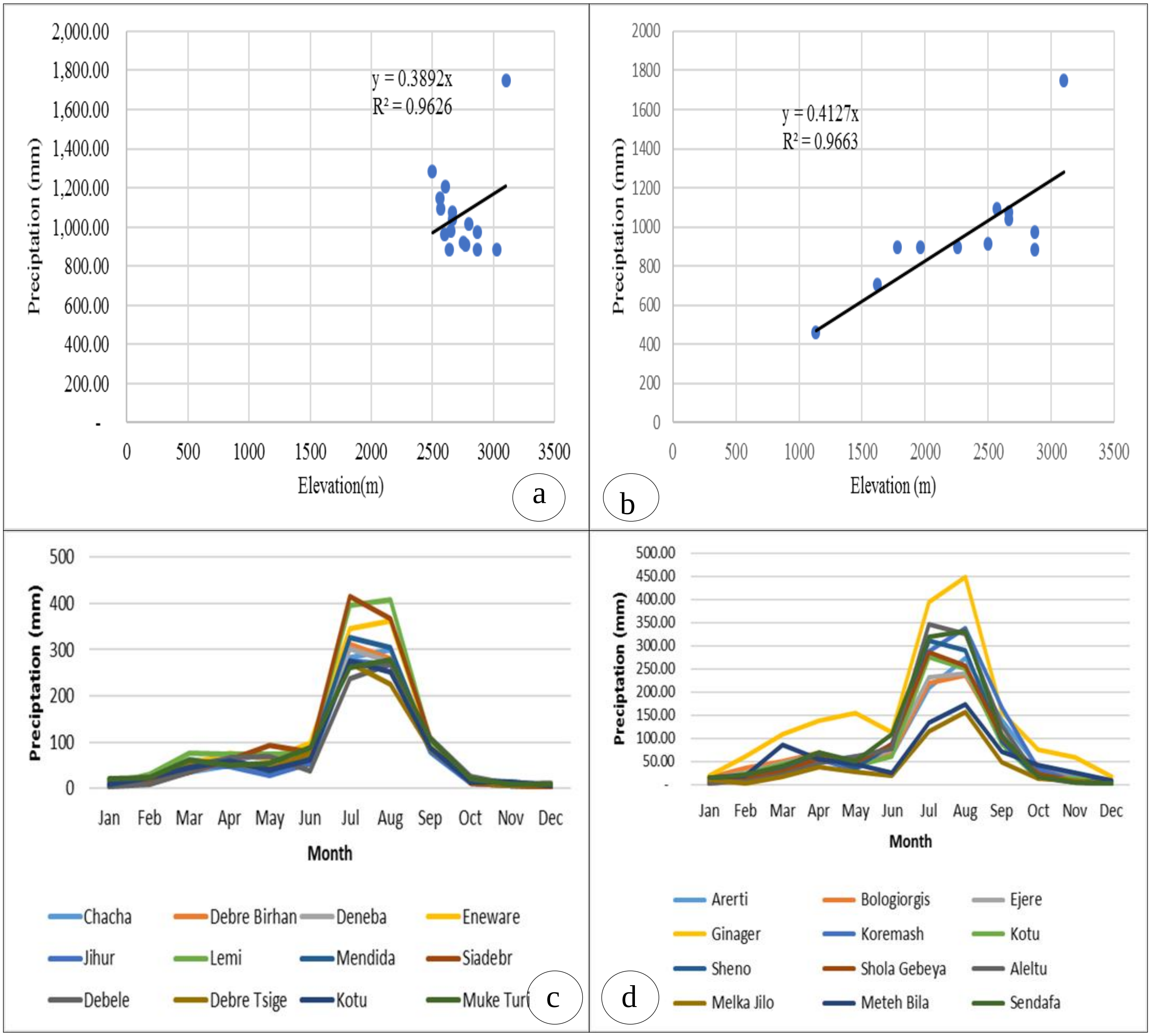

Figure 8: a)Precipitation Versus Elevation in South-Jema catchment b)Precipitation Versus Elevation in Kesum catchment c) long term mean monthely rainfall of each station in South Jema catchment d) Longterm mean monthely rainfall of each station in Kesum catchment

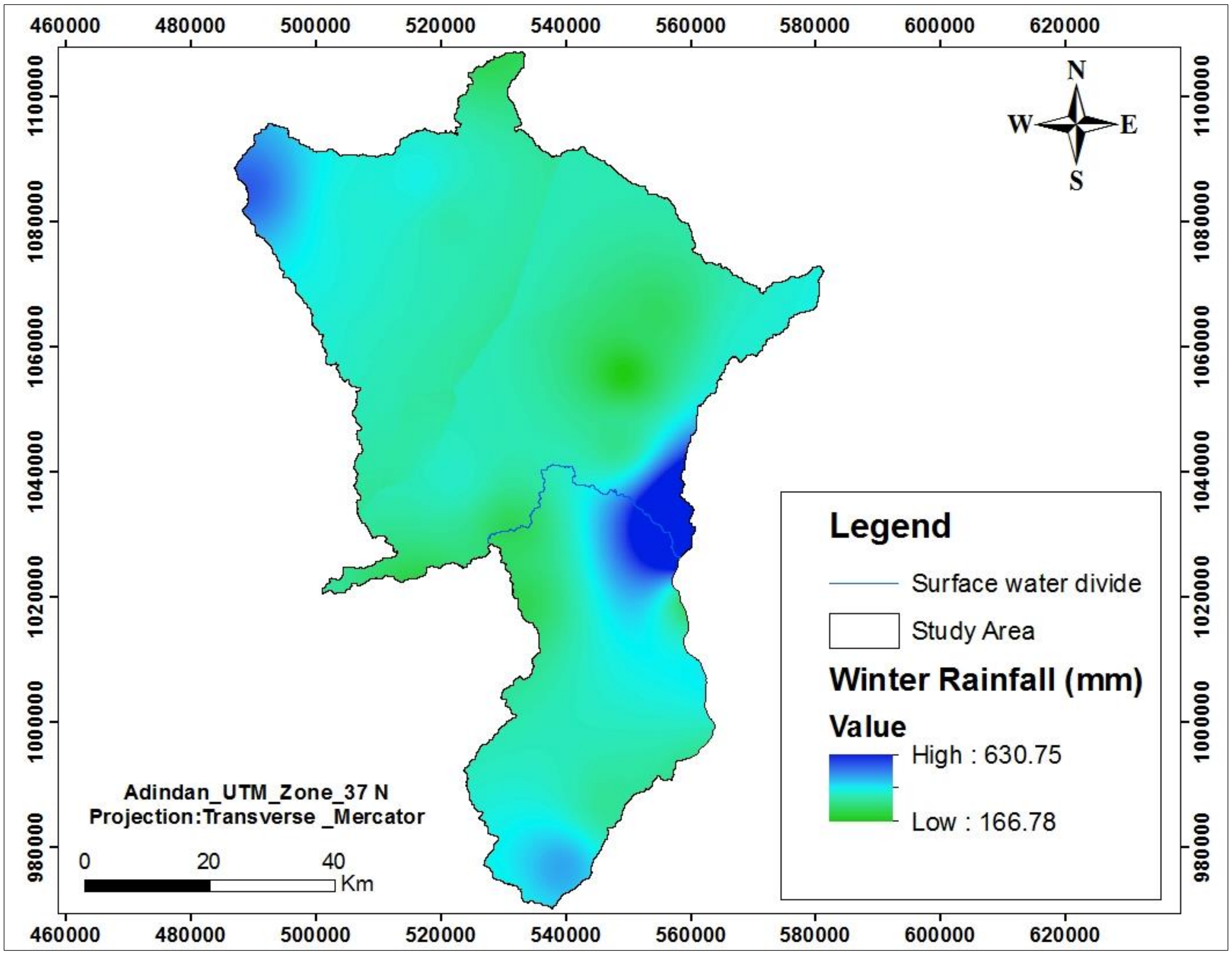

Figure 9: Winter Rainfall

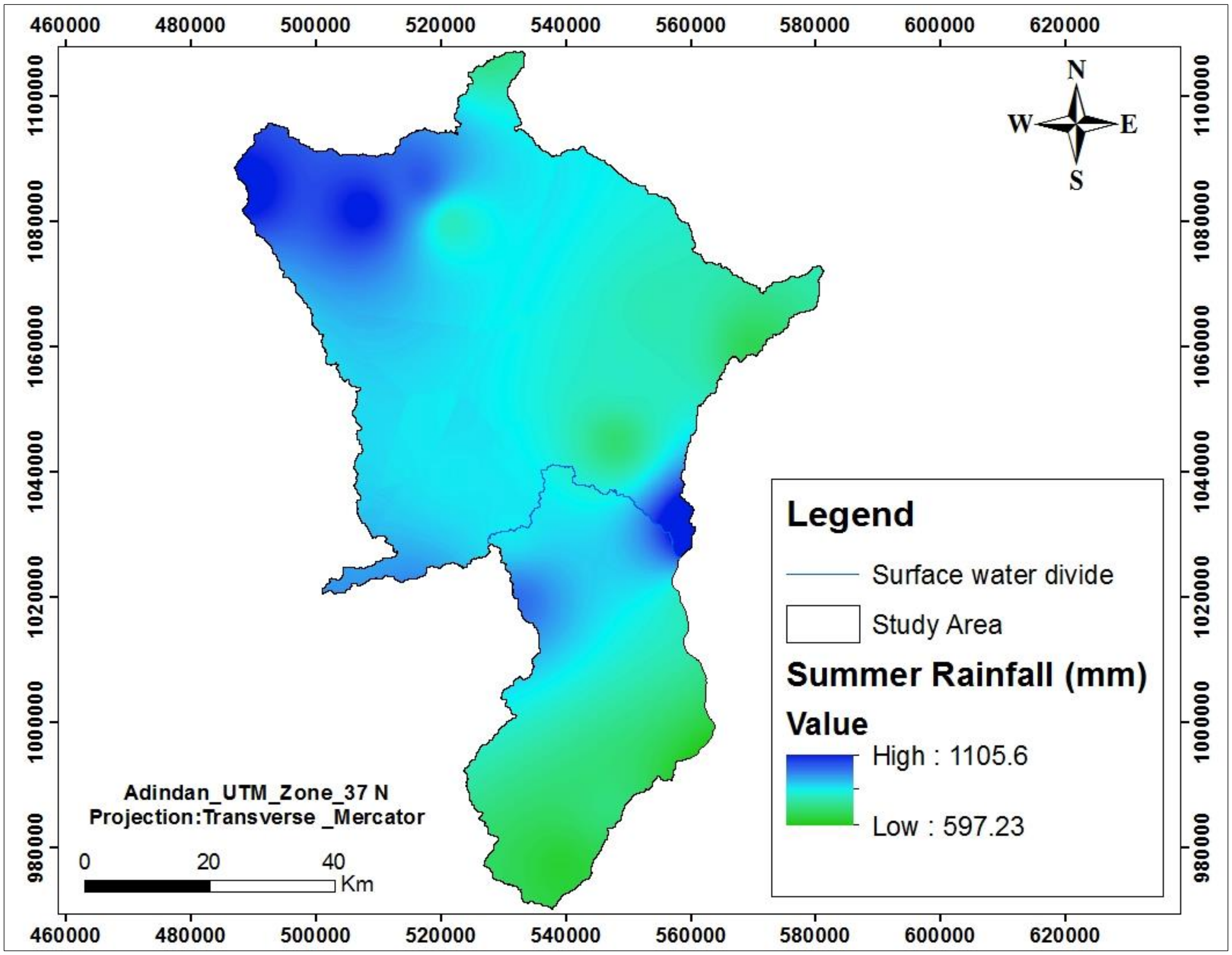

Figure 10 :Summer Rainfall

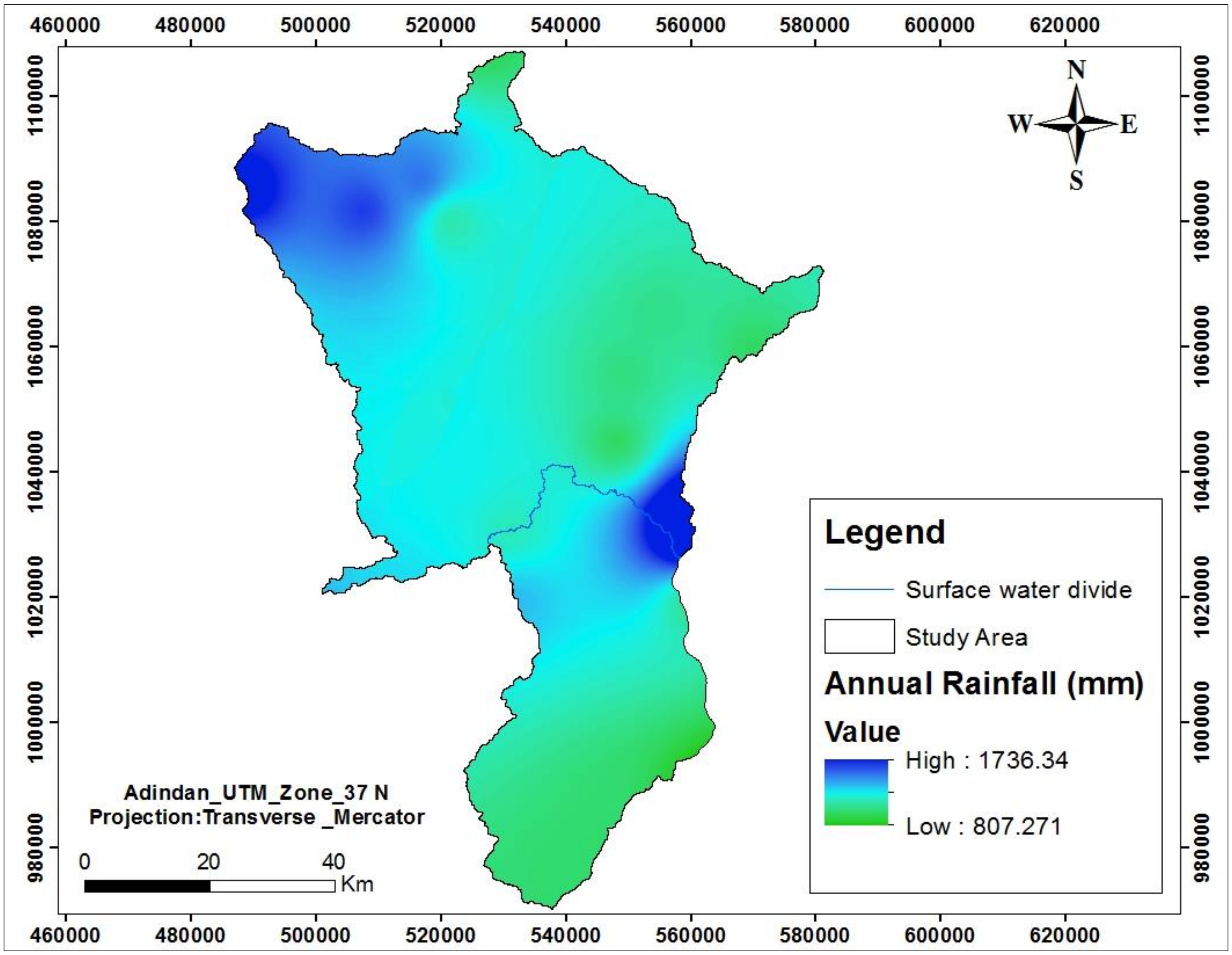

Figure 11: Annual Rainfall

3.4.2 Temperature

Temperature is the other hydro-metrological variable that has an ability to influence evaporation either from surface water body, intercepted from bare soil or leaves. The temperature of a given environment is much more dependent on the geomorphological setup, Altitude and geographic location. The long term annual and seasonal values of Temperature have been indicated in the figure below (Figure 12, figure 13 and figure 14). the average annual long-term values of temperature Within the South –Jema catchment ranges from 11.25ºC-15.25ºC with a mean value of 13.25°C. In the case of Kesum catchment the value ranges from 12.68ºC-20.10ºC with a mean value of 16.39 °C respectively (Figure14).14 temperature records were available within the study area. A good correlation coefficient has been observed from the plot of altitude versus temperature record for each month of all available records (Table 5). Therefore, simple linear regression method has been employed to estimate the monthly temperature record of missing stations. From the plot of altitude and temperature it can be clearly observed that the temperature of a given area is mainly dependent up on the elevation and it gradually decreases with increase in altitude. The relationship between altitude and temperature of the 12 months for the corresponding 14 stations is given in the table below (Table 5).

The long term mean monthly temperature records of the available stations along with the estimated missing records from the linear regression method (Table 6 and Table 7) has been employed in data preparation.14 and 12 stations within South-Jema and Kesum catchment has been used in the preparation of seasonal and annual temperature map of the study area.

Table 5: Regression equation of Altitude Versus Temperature

Month	Correlation coefficient	Regression equation
January	$R^2 = 0.9168$	$y = -0.0058x + 29.112$
February	$R^2 = 0.9358$	$y = -0.0054x + 28.097$
March	$R^2 = 0.9722$	$y = -0.0071x + 34.166$
April	$R^2 = 0.9703$	$y = -0.0073x + 34.577$
May	$R^2 = 0.9668$	$y = -0.0077x + 36.365$
June	$R^2 = 0.9645$	$y = -0.008x + 36.665$
July	$R^2 = 0.9605$	$y = -0.0075x + 34.49$
August	$R^2 = 0.9585$	$y = -0.007x + 32.784$
September	$R^2 = 0.9631$	$y = -0.0071x + 32.84$
October	$R^2 = 0.9322$	$y = -0.0069x + 32.237$
November	$R^2 = 0.9462$	$y = -0.0066x + 30.539$
December	$R^2 = 0.8795$	$y = -0.0058x + 28.272$

Table 6: Long term mean monthly Temperature used for the 12-time step for Kesum catchment.

Catchment	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kesum	Arerti	17.47	18.36	21.50	21.68	22.46	22.35	22.20	20.88	20.27	18.32	18.51	15.22
	Bologiorgis	17.73	17.50	20.23	20.25	21.25	20.96	19.77	19.10	18.90	18.69	17.58	16.89
	Ejere	17.05	15.93	18.28	17.71	19.02	18.08	16.94	16.69	16.63	17.20	16.54	16.41
	Aleltu	13.30	13.05	15.26	15.15	16.01	15.61	15.10	15.10	15.12	14.89	13.39	12.74
	Metha Bila	20.83	20.14	23.02	23.49	24.70	25.25	23.50	22.22	22.32	22.80	20.97	20.32
	Melka Jilo	21.95	21.38	25.62	25.87	26.93	27.06	25.27	24.49	24.71	24.06	22.58	21.86
	Ginager	10.72	10.92	11.27	11.60	11.85	11.86	11.53	11.44	11.37	11.00	10.45	10.28
	Sendafa	14.21	14.22	15.93	15.82	16.58	16.11	15.22	14.86	14.60	14.51	13.58	13.37
	Shola-Gebeya	13.35	13.39	15.84	15.41	16.47	15.73	14.66	14.29	14.01	13.72	12.72	12.63
	Kormesh	13.66	13.71	15.24	15.12	15.84	15.35	14.50	14.19	13.92	13.85	12.95	12.8
	Sheno	12.80	12.40	14.38	14.16	14.98	13.80	13.28	13.10	12.71	12.8	11.91	12.47
	Kotu	12.47	12.60	13.79	13.63	14.27	13.71	12.97	12.75	12.46	12.43	11.60	11.63

Table 7: Long term mean monthly Temperature used for the 12-time Step within South -Jema catchment

Catchment	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South-Jema	Debre-Birhan	12.27	13.21	14.44	14.26	14.48	14.68	13.75	13.51	12.94	11.32	10.70	11.16
	Deneba	14.03	14.06	15.71	15.60	16.35	15.87	14.99	14.64	14.38	14.30	13.38	13.19
	Debele	10.40	11.17	11.82	11.66	11.77	12.11	11.73	11.00	11.09	10.96	10.69	9.83
	Eneware	15.19	15.43	16.98	16.63	17.36	16.53	14.17	13.83	14.39	14.27	13.67	13.89
	Ginager	10.72	10.92	11.27	11.60	11.85	11.86	11.53	11.53	11.37	11.00	10.45	10.28
	Kotu	12.47	12.60	13.79	13.63	14.27	13.71	12.97	12.75	12.46	12.43	11.60	11.63
	Mendida	14.35	14.74	15.80	15.93	16.53	16.44	14.88	14.69	14.77	13.90	13.49	13.17
	Jihur	13.45	13.52	15.00	14.87	15.58	15.07	14.24	13.94	13.67	13.61	12.72	12.61
	Siadebr	13.78	13.75	15.57	15.76	16.01	15.12	14.67	13.69	13.69	13.50	12.75	12.18
	Debre-Tsige	13.80	13.84	15.42	15.31	16.04	15.55	14.69	14.36	14.10	14.02	13.12	12.96
	Muke-Turi	13.75	13.79	15.36	15.24	15.97	15.47	14.62	14.30	14.03	13.96	13.06	12.91
	Sendafa	14.21	14.22	15.93	15.82	16.58	16.11	15.22	14.86	14.60	14.51	13.58	13.37
	Aleltu	13.30	13.05	15.26	15.15	16.01	15.61	15.10	15.10	15.12	14.89	13.39	12.74
	Sheno	12.80	12.40	14.38	14.16	14.98	13.80	13.28	13.10	12.71	12.82	11.91	12.47
	Chacha	13.05	13.14	14.50	14.36	15.04	14.51	13.72	13.45	13.17	13.12	12.26	12.21
	Lemi	15.09	16.55	16.32	16.72	16.11	14.61	14.23	4.51	15.29	15.29	14.68	14.94

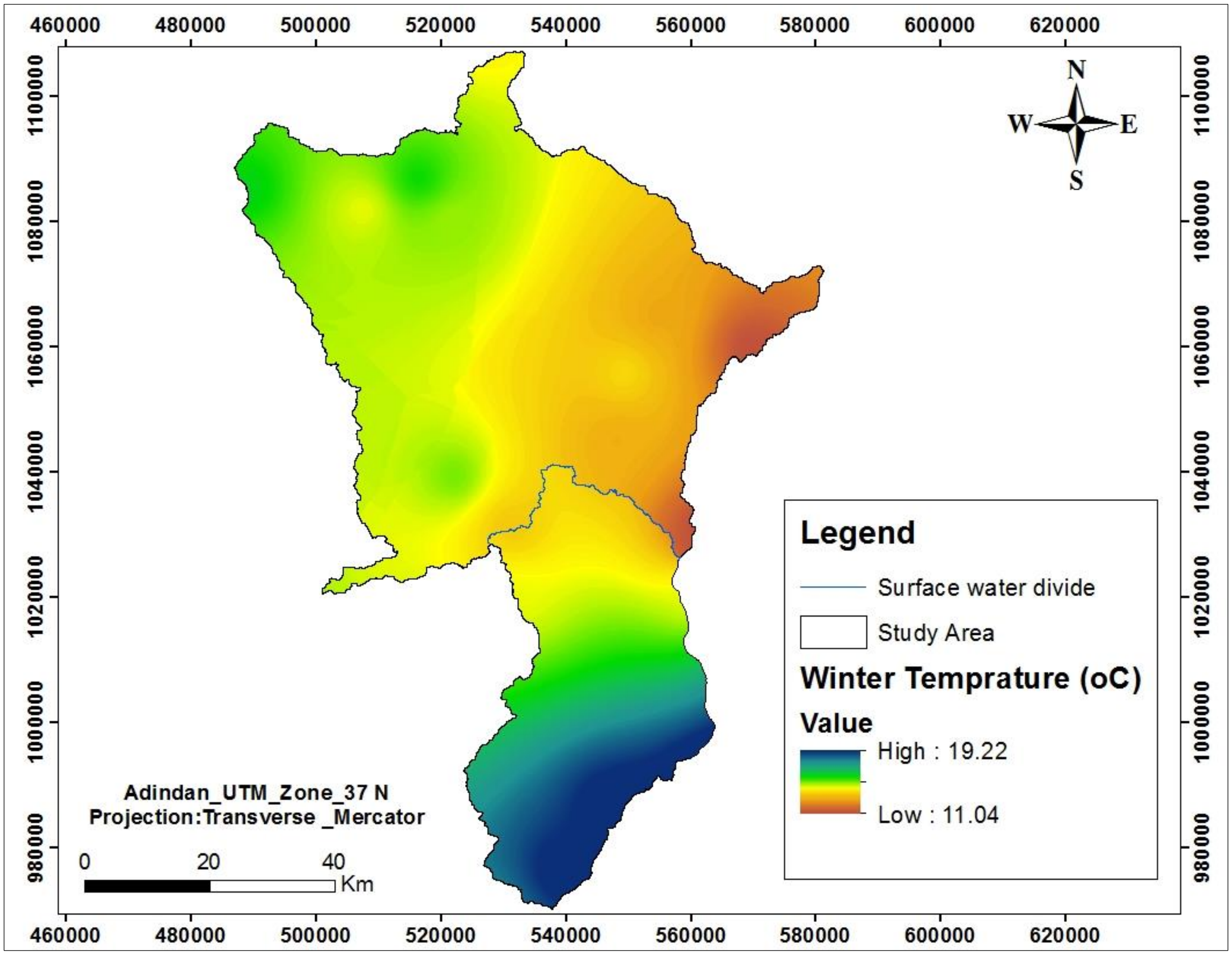

Figure 12: Winter Temperature

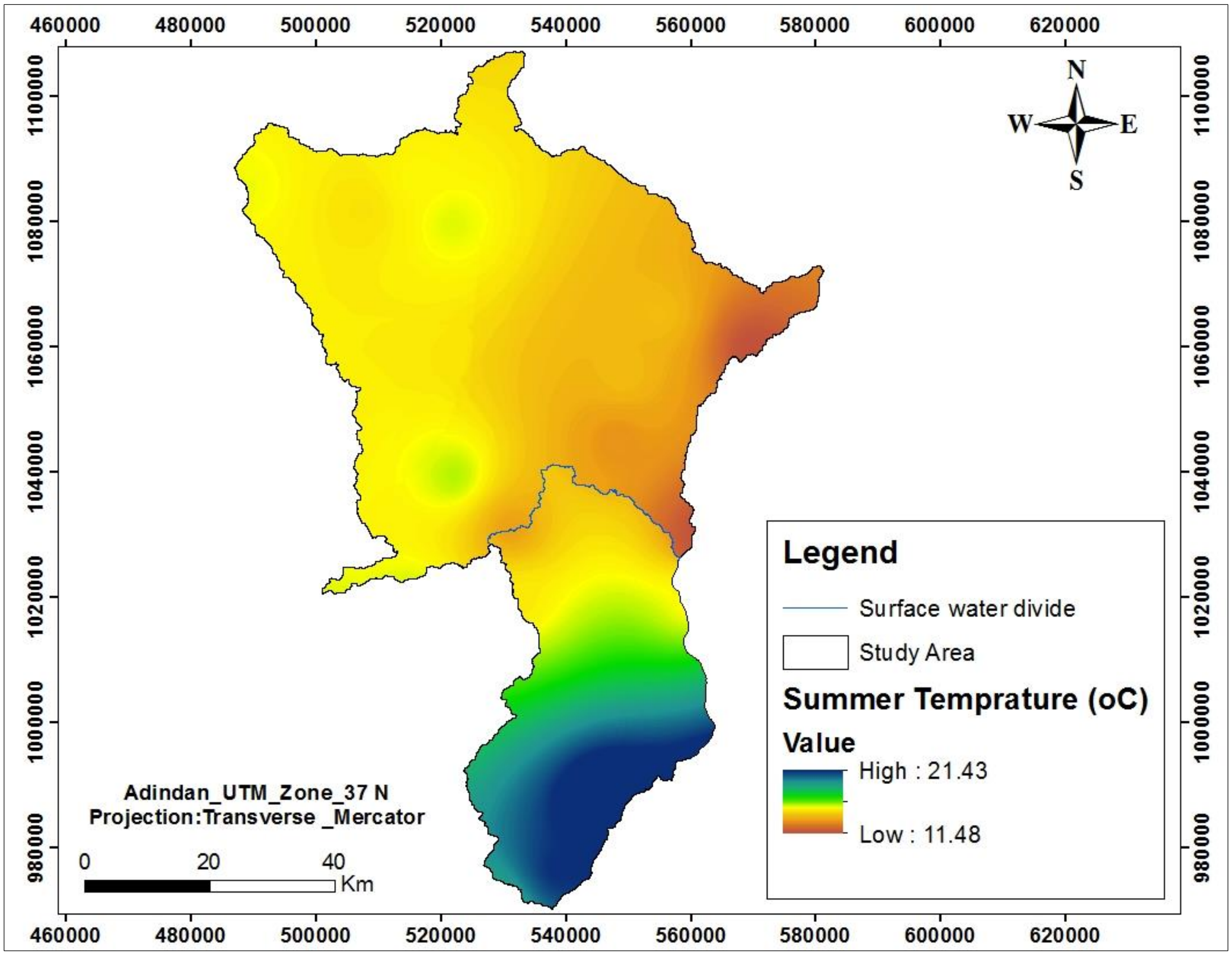

Figure 13: Summer Temperature

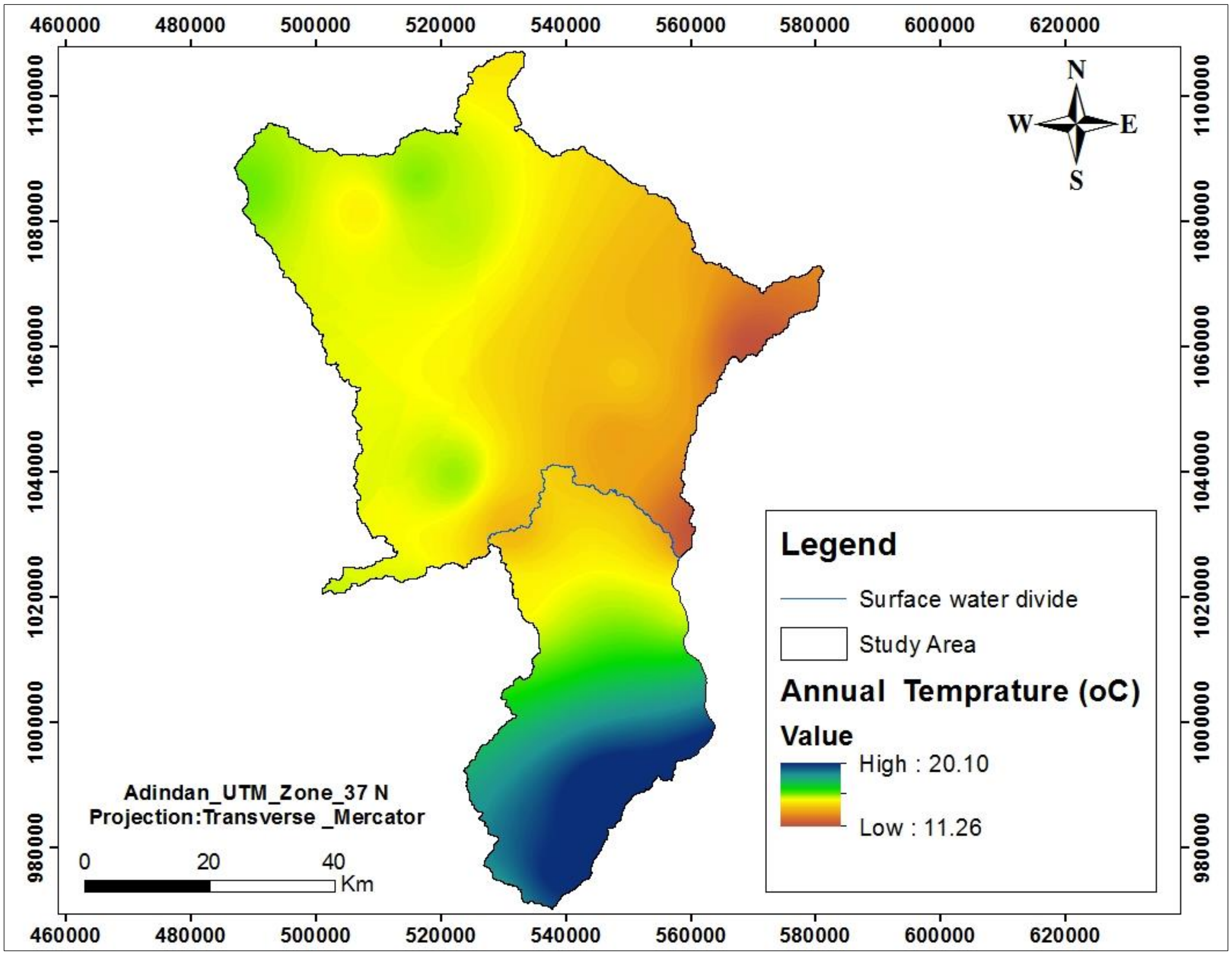

Figure 14: Annual Temperature

3.4.3 Potential evapotranspiration

Is the evaporation from vegetation cover if sufficient water is supplied to obtain optimum growth or it is the maximum amount of water which might be transferred under the existing metrological condition (Tenalem Ayenew and Tamiru Alemayhu, 2001). There are few stations having only sunshine hours, relative humidity and wind speed records, because of this Penman combination method can't be employed. The Thornthwaite method requires temperature data as to calculations of potential evapotranspiration. By making some adjustment of latitude correction, this approach has been used to calculate the potential evapotranspiration of the two catchments. 14 temperature records along with 9 stations of temperature record which has been estimated from the regression equation pointed above has been used to calculate the long-term mean monthly potential evapotranspiration values of each stations. From calculated PET, 14 station for the south –Jema (Table 8) and 12 station for kesum catchment (Table 9) has been used in preparation of seasonal and annual map of the study area. Figure 15 Figure 16 and Figure 17 gives seasonal and annual PET values of the corresponding catchment. From the figure mentioned the average annual long-term PET values in south-Jema and Kesum catchment is found to be 665.35mm and 820.4mm respectively. The potential evapotranspiration can be calculated using the following equation:

$Et = 1.6b[10T_a/I]^a$ ……………………………………….(1)

Where: Et is the potential evapotranspiration in cm/month

T_a is mean monthly air temperature in (ºC)

I is the annual heat index

b is latitude correction

The value if heat index (I) can be calculated as:

$$I = \sum i_m = \sum \left(\frac{\bar{T}_m}{5}\right)^{1.5}$$

$$a = 6.7x10^{-7} I^3 - 7.7x10^{-5} I^2 + 1.8x10^{-2} I + 0.49$$

Table 8:PET used for the 12-time step within Kesum Catchment as calculated by Thornthwaite method

Catchment	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kesum	Arerti	48.43	47.42	59.87	60.15	65.71	63.68	60.43	60.14	59.67	57.5	48.90	45.31
	Bologiorgis	50.16	50.68	65.07	63.50	70.53	66.34	59.70	57.28	55.16	52.73	46.82	46.12
	Ejere	61.40	54.84	70.38	67.60	77.29	71.16	63.21	61.28	60.32	63.03	58.25	57.20
	Aleltu	48.43	47.42	59.87	60.15	65.71	63.68	60.43	60.14	59.67	57.52	48.90	45.31
	Metha Bila	53.63	56.07	62.76	64.48	68.80	68.55	58.84	57.47	57.39	51.65	48.93	46.98
	Melka Jilo	58.93	56.28	65.46	65.06	68.21	64.73	55.44	53.04	54.11	57.72	53.69	54.85
	Ginager	57.13	58.7	68.63	67.50	72.71	67.87	53.51	51.31	53.94	52.50	48.68	49.62
	Sendafa	53.56	53.77	65.84	66.59	71.91	70.22	62.97	59.69	58.78	55.97	50.82	48.73
	Shola-Gebeya	51.13	49.26	60.55	60.22	65.51	59.06	55.87	54.62	51.97	51.77	46.48	49.13
	Kormesh	52.30	52.82	62.81	63.28	67.83	65.88	59.65	57.03	56.08	53.52	49.04	47.54
	Sheno	52.66	52.75	63.49	65.58	67.69	62.79	59.86	54.03	54.59	51.70	47.22	44.05
	Kotu	49.59	50.79	56.33	56.23	59.12	56.59	52.56	51.35	50.32	48.30	45.23	45.00

Table 9:PET used for the 12-time step within the South Jema Catchment as Calculated by Thornthwaite method

Catchment	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South-Jema	Debre-Birhan	48.64	53.85	61.04	60.97	62.78	64.24	58.71	57.10	53.44	44.28	40.70	42.77
	Deneba	53.16	53.46	64.86	65.52	70.59	68.82	61.90	58.83	57.91	55.18	50.25	48.35
	Debele	52.30	58.22	81.56	84.28	91.50	91.05	89.34	78.31	72.96	58.29	58.95	39.09
	Eneware	61.40	54.84	70.38	67.60	77.29	71.16	63.21	61.28	60.32	63.03	58.25	57.20
	Ginager	57.13	58.76	68.63	67.50	72.71	67.87	53.51	51.31	53.94	52.50	48.68	49.62
	Kotu	49.59	50.79	56.33	56.23	59.12	56.59	52.56	51.35	50.32	48.30	45.23	45.00
	Mendida	53.63	56.07	62.76	64.48	68.80	68.55	58.84	57.47	57.39	51.65	48.93	46.98
	Jihur	51.84	52.47	61.70	62.08	66.34	64.29	58.44	56.06	55.10	52.63	48.39	47.1
	Siadebre	52.66	52.75	63.49	65.58	67.69	62.79	59.86	54.03	54.59	51.70	47.22	44.05
	Debre-Tsige	52.63	53.07	63.60	64.14	68.89	67.01	60.52	57.72	56.79	54.16	49.50	47.85
	Muke-Turi	52.51	52.98	63.31	63.83	68.51	66.60	60.20	57.47	56.53	53.93	49.34	47.74
	Sendafa	53.56	53.77	65.84	66.59	71.91	70.22	62.97	59.69	58.78	55.97	50.82	48.73
	Aleltu	48.43	47.42	59.87	60.15	65.71	63.68	60.43	60.14	59.67	57.52	48.90	45.31
	Sheno	52.66	52.75	63.49	65.58	67.6	62.79	59.86	54.03	54.59	51.7	47.2	44.0
	Chacha	50.91	51.78	59.49	59.67	63.37	61.12	56.02	54.12	53.13	50.85	47.09	46.24
	Lemi	47.58	48.83	51.17	53.65	55.5	55.84	53.78	53.06	52.17	49.4	46.2	45.1

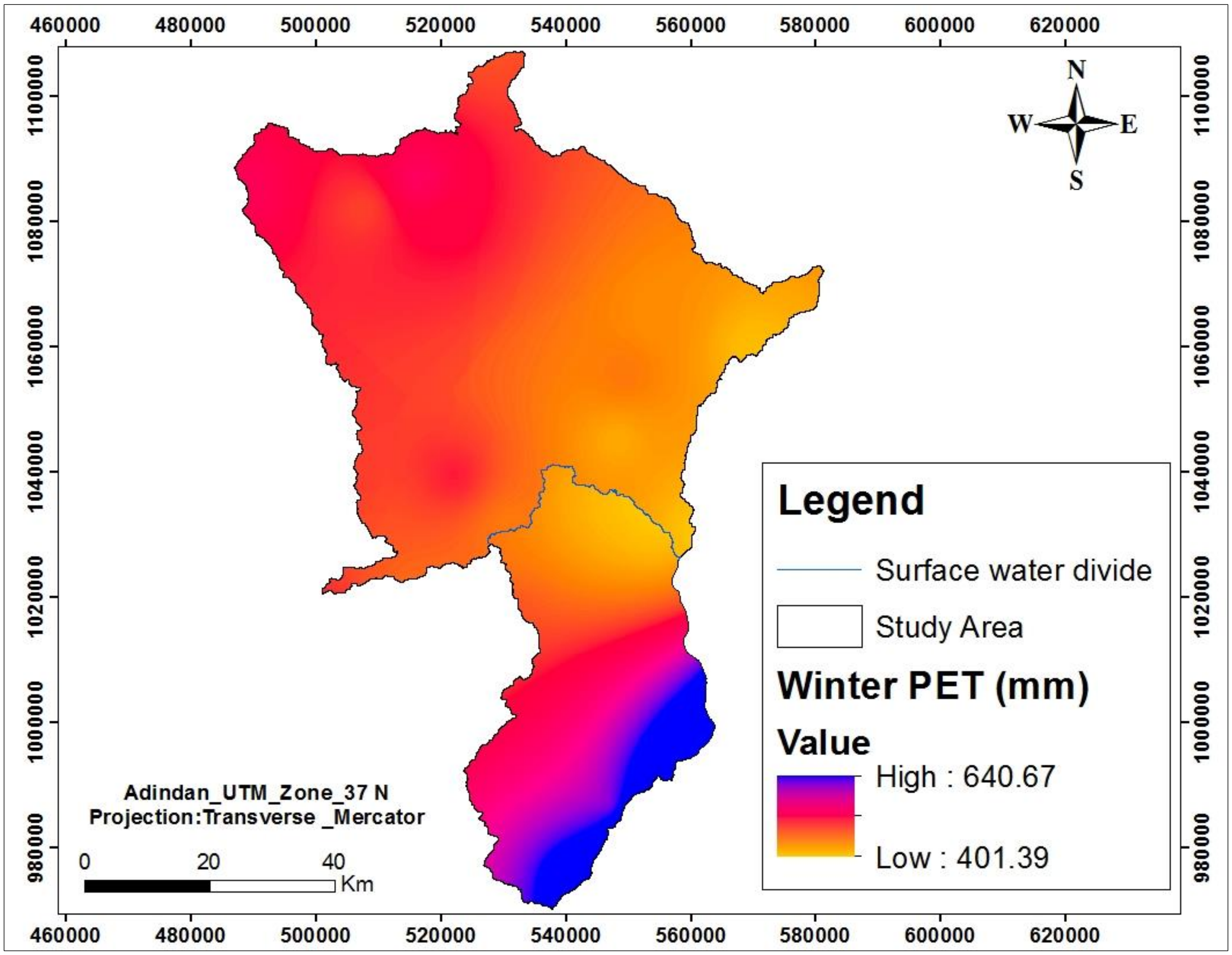

Figure 15: Winter Potential evapotranspiration

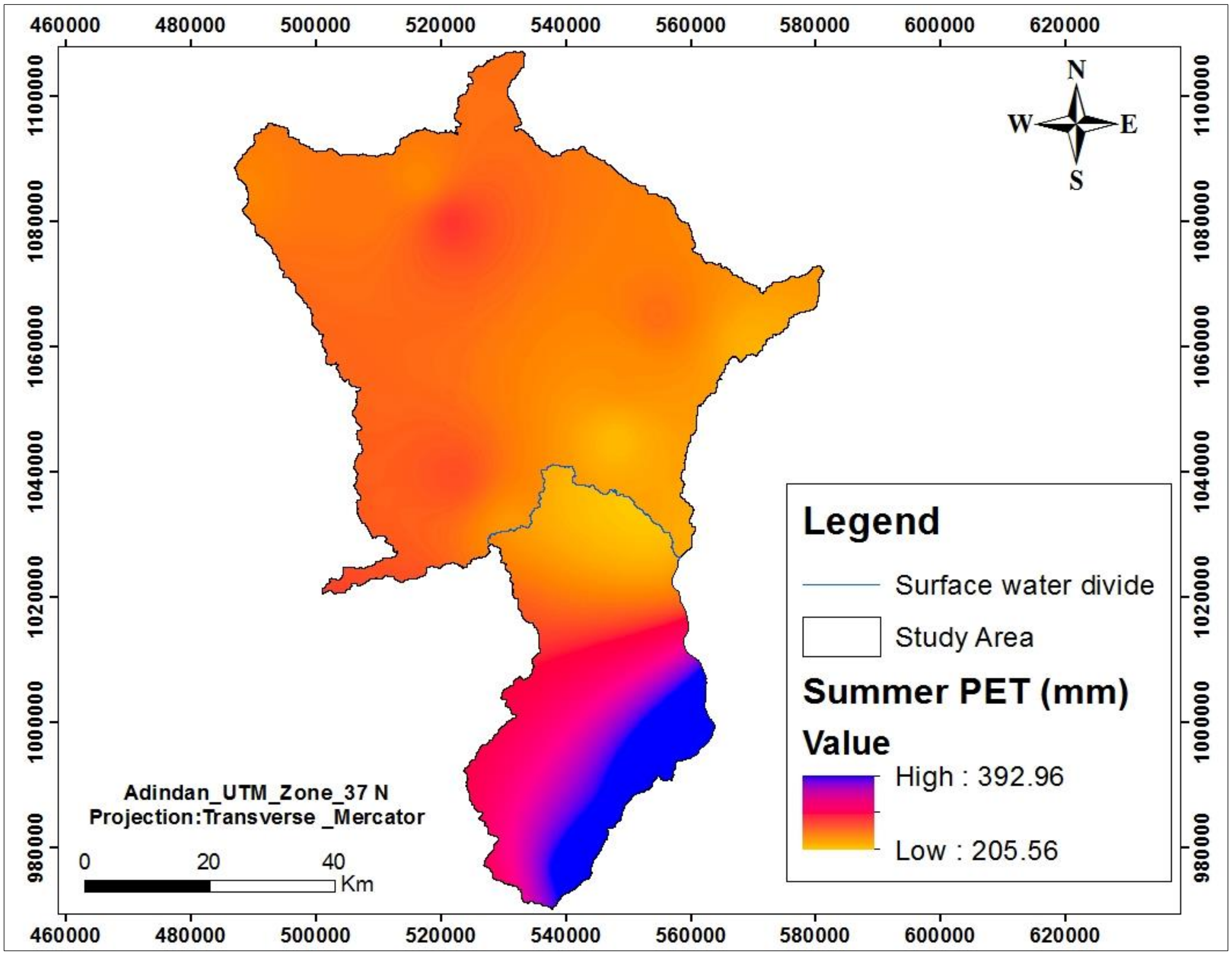

Figure 16: Summer Potential evapotranspiration

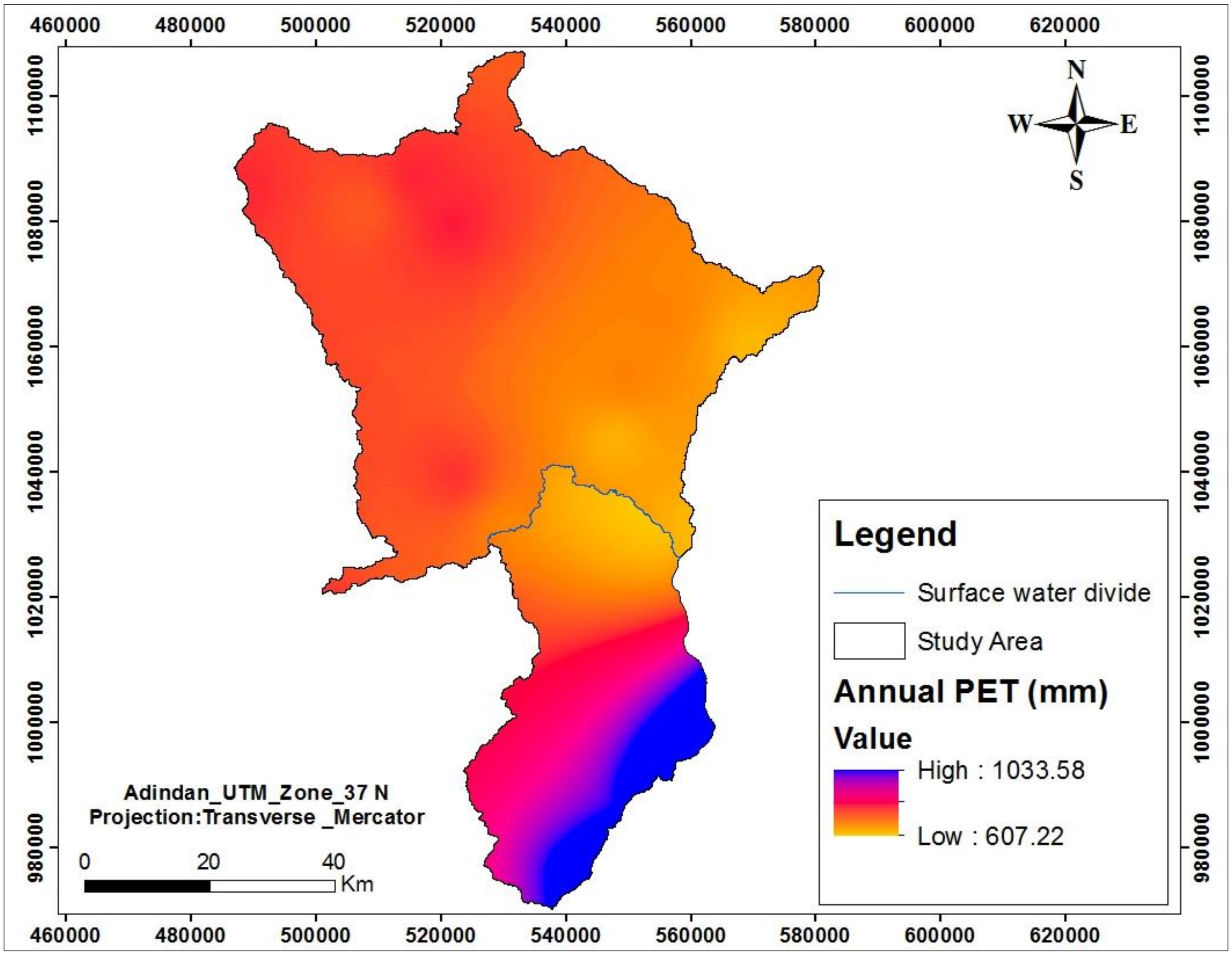

Figure 17: Annual Potential evapotranspiration

3.4.4 Wind speed

Wind speed were available only for few stations.16 station has been used in preparation of seasonal and annual wind map of South Jema catchment (Figure 18, Figure 19 and Figure 20). 2 stations namely Debre Birhan and Enware stations (Figure 6) have only wind speed records in this catchment. Mean monthly values of this stations has been averaged and the average value has been filled for the missing 14 stations. In the case of kesum catchment, only one station Shola Gebeya (Figure 6) station has only wind data record. In this case stations in the southern and eastern part outside and those stations within the catchment, has been filled with values of the wind speed data similar to Shola Gebya station. And the rest stations found in the west and Northern part outside the catchment has been filled with the average values of the (Debre Birhan and Eneware) stations that has been used for South-Jema catchment.12 station were used in the preparation of wind map of this catchment (Figure 18 Figure 19 and Figure 20). Form the figure the average annual long-term wind speed within South-Jema and Kesum catchment is found to be 2.26 m/s and 2.01 m/s respectively.

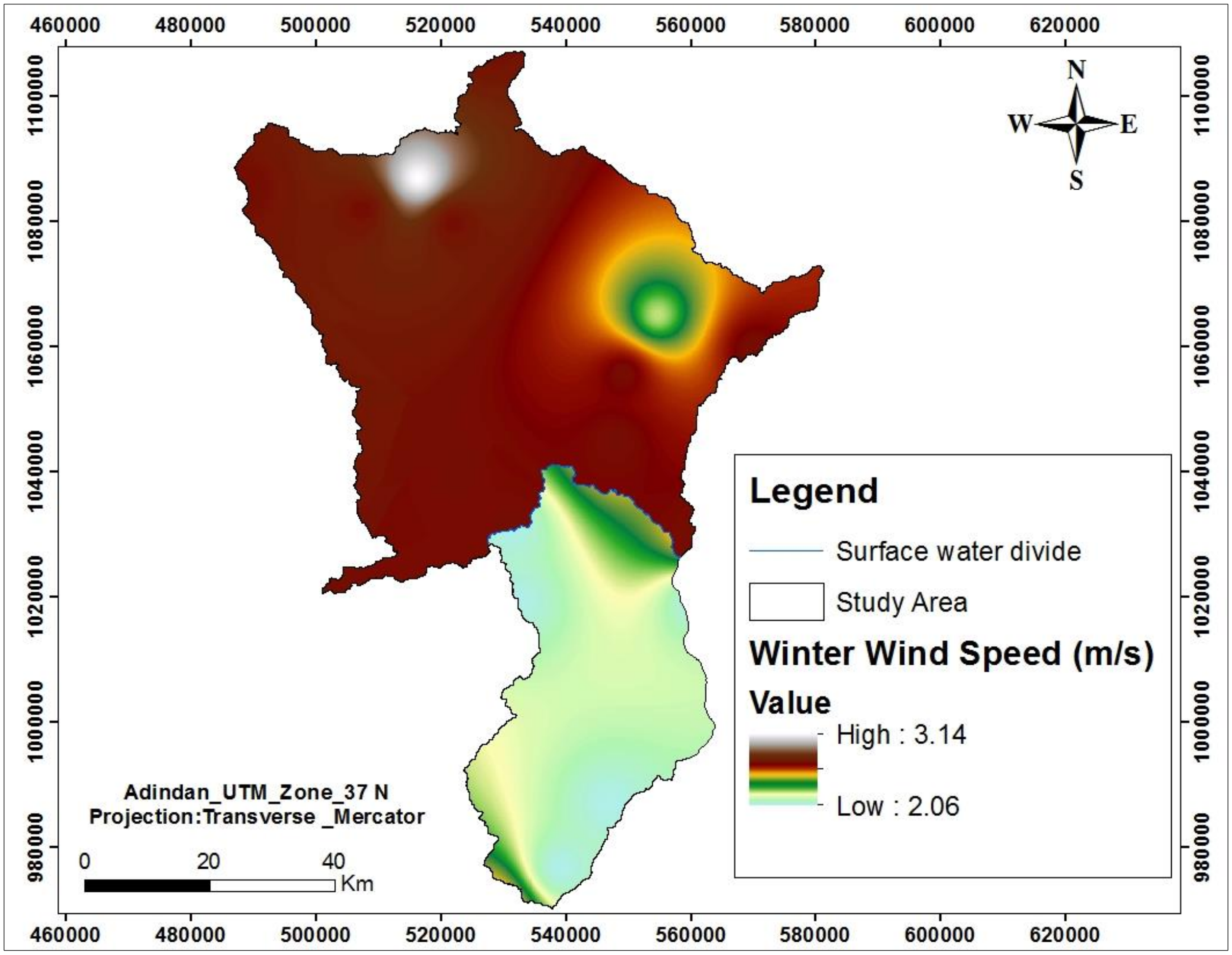

Figure 18: Winter Wind Speed

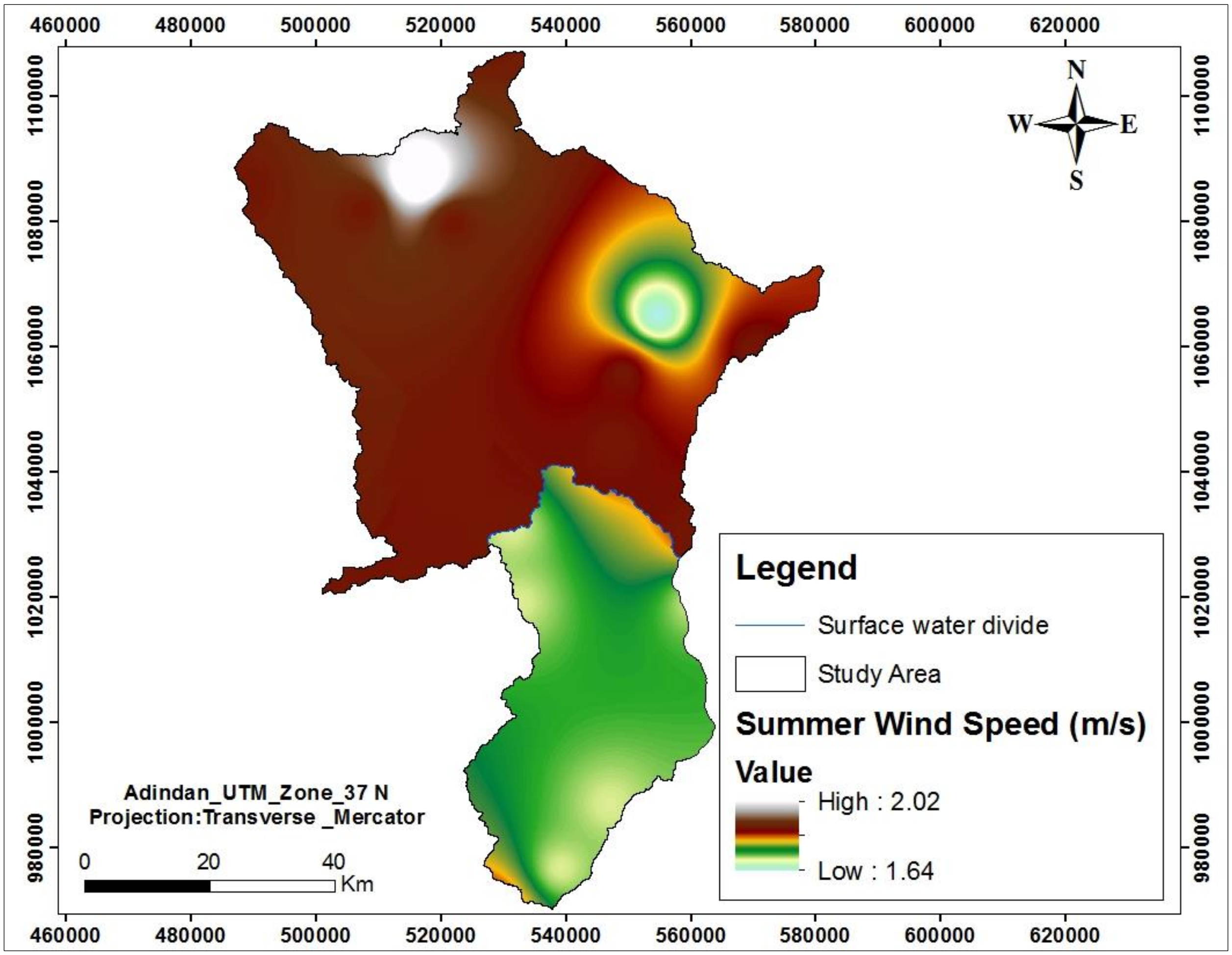

Figure 19: Summer Wind Speed

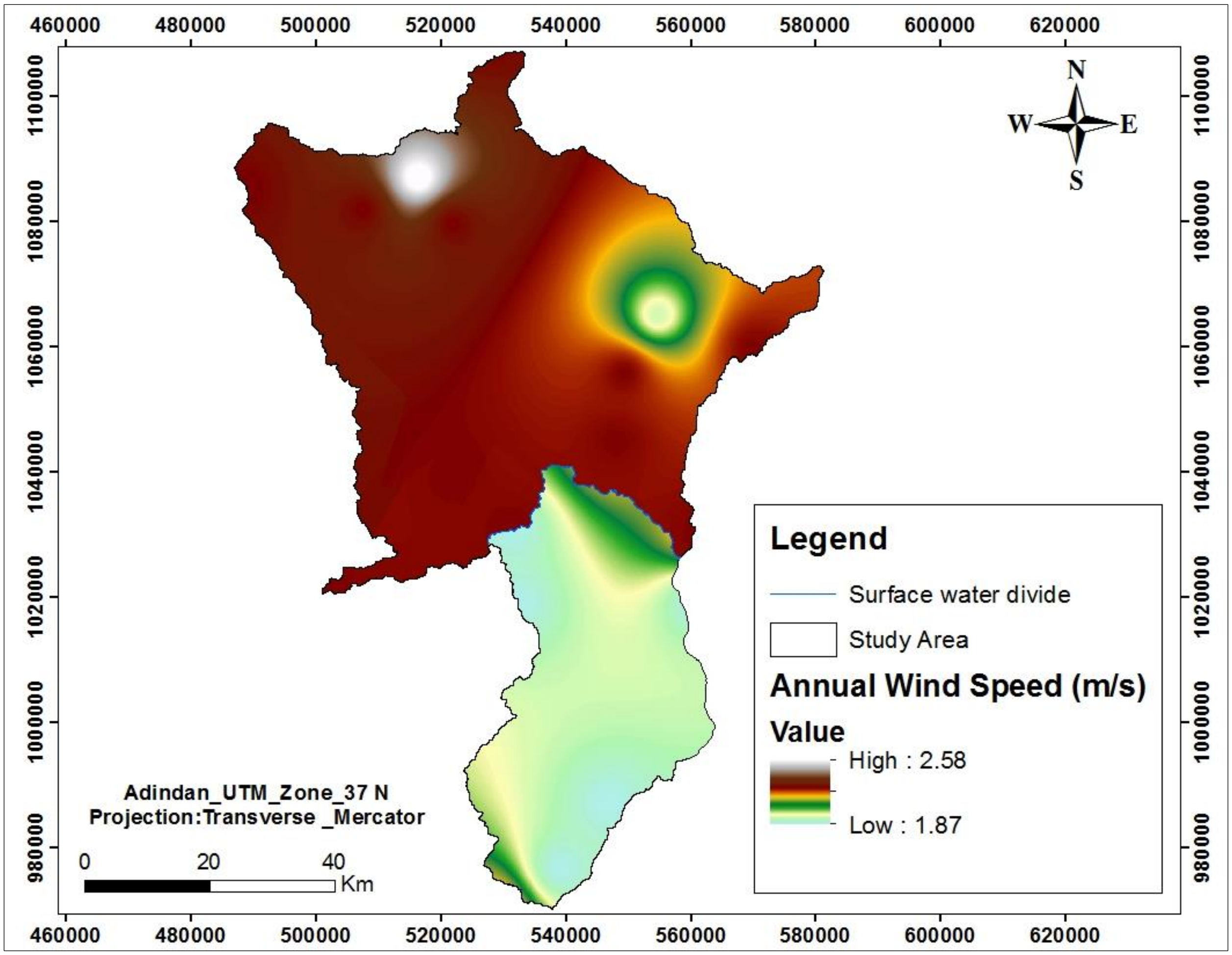

Figure 20:Annual Wind Speed

3.4.5 Land use and land cover

Land use and land cover are the major controlling factors in analysis of the hydrology of a given watershed. The most noticeable influence of land use on the water balance of a given watershed is on the process of evaporation. The evaporation is mainly dependent up on the type of vegetation cover, leaf area index, and root depth (Belelann and DeScmedth, 2001).

A land use/cover map of 30m resolution which has been employed form ministry of agriculture has been used during preparation of land use /land cover map. Land use/land cover map of the study area has been prepared for the two catchments. Land use and land cover map of the South-Jemma catchment consists of settlement, bare land, agriculture, grassland, wetland, forest, shrub land and waterbody. Agriculture is the most dominant land use type that mainly accounts of 71.31% of the total watershed followed by grassland, forest and shrubland which accounts for 11.45%, 9.53% and 6.39% of the catchment. Only small percentage i.e. settlement, bare land, wetland and waterbody constitutes 0.35%, 0.94%, 0.000089% and 0.013% respectively. In the case of kesum catchment, the most dominant type of land cover constitutes shrubland which accounts for 45.20% of the total catchment which is followed by agriculture and forest which accounts for 37.29% and 14.80% respectively. Small percentage of the area constitutes bare land, wetland, settlement and grassland, water body which accounts of 2.55%, 0.10%, 0.02% and0.0008% of the total area of catchment.

Table 10: Land use/Landcover South Jema catchment

Catchment	Land use Type	Area $(km)^2$	Area (%)
South-Jema	Settlement	14.07	0.35
	Bare land	37.68	0.94
	Agriculture	2870.89	71.31
	Grassland	461.14	11.45
	Wetland	0.0036	0.000089
	Forest	383.85	9.53
	Shrub land	257.25	6.39
	Waterbody	0.53	0.013

Table 11: Landuse/Land cover types in Kesum catchment

Catchment	Land use type	Area $(Km)^2$	Area (%)
Kesum	Settlement	0.48	0.02
	Bare land	42.30	2.55
	Agriculture	617.90	37.29
	Grassland	0.13	0.008
	Wetland	1.69	0.10
	Forest	245.22	14.80
	Shrub land	748.84	45.20

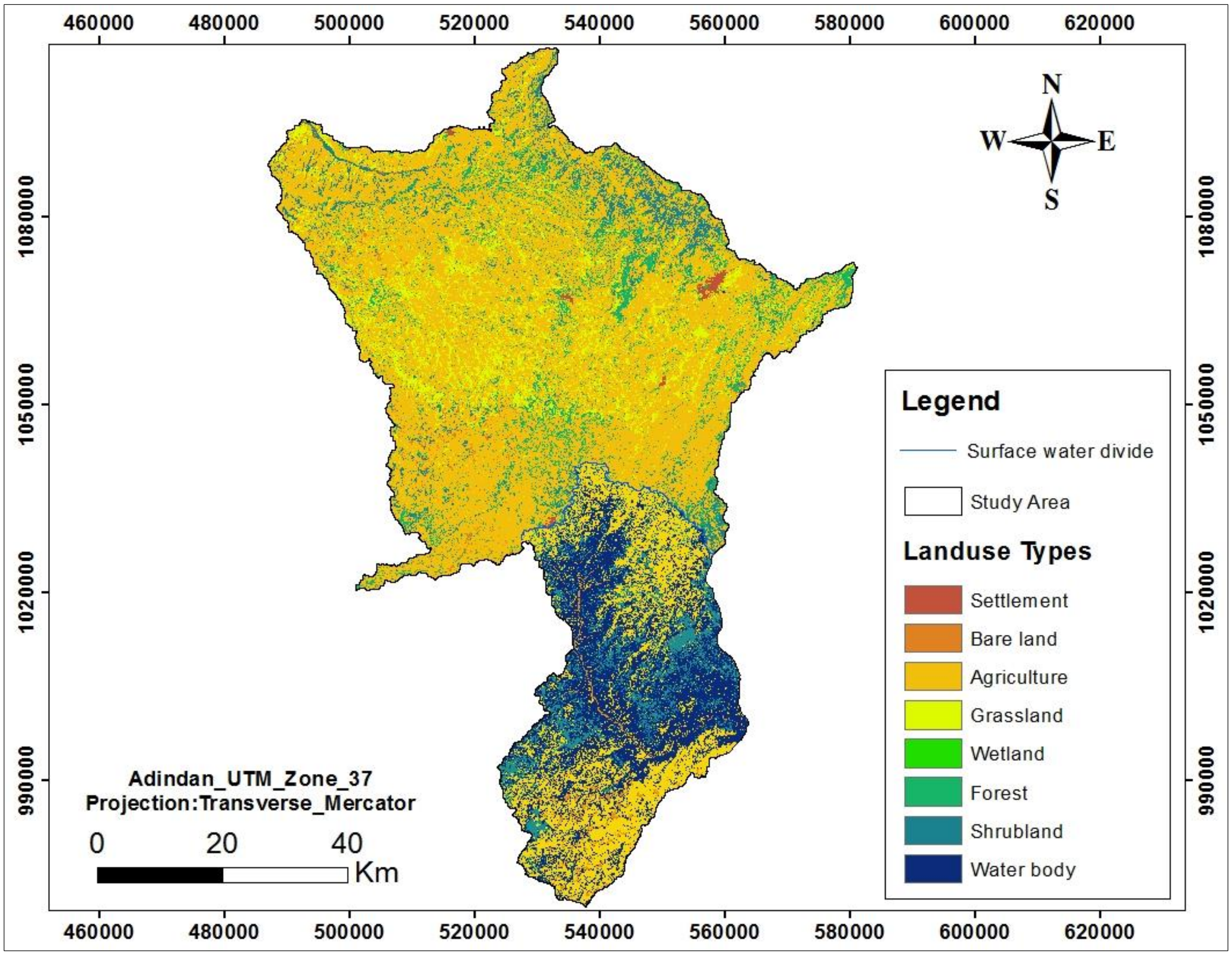

Figure 21 Landuse/ Land cover map (Modified from MoA, 2016)

3.4.6 Soil texture

A raster map of 30 m resolution which was obtained from the ministry of agriculture has been used in preparation of soil map of the two catchments. As the wetspass model uses soil texture of the area under consideration during simulation, the United State Department of Agriculture (USDA) classification system has been employed for classification of soil texture for the corresponding catchments. In South- Jemma catchment clay is the dominant soil type which accounts of 74.82% of the total catchment followed by Sandy loam and loam accounting 24.67% and 0.50% respectively. Within the kesum sub -basin, Sandy loam is the principal soil type which consists of 53.68% of the watershed followed by clay and loam accounting 43.67% and 2.92% of the sub-basin.

Table 12: Soil texture of South Jema catchment

Catchment	Soil Type	Area (Km^2)	Area (%)
South -Jemma	Clay	3012.21	74.82%
	Sandy loam	993.24	24.67%
	loam	20.43	0.50%

Table 13: Soil Texture of Kesum catchment

Catchment	Soil type	Area (Km^2)	Area (%)
Kessem	Sandy loam	889.46	53.68%
	Clay	718.94	43.39%
	Loam	48.40	2.92%

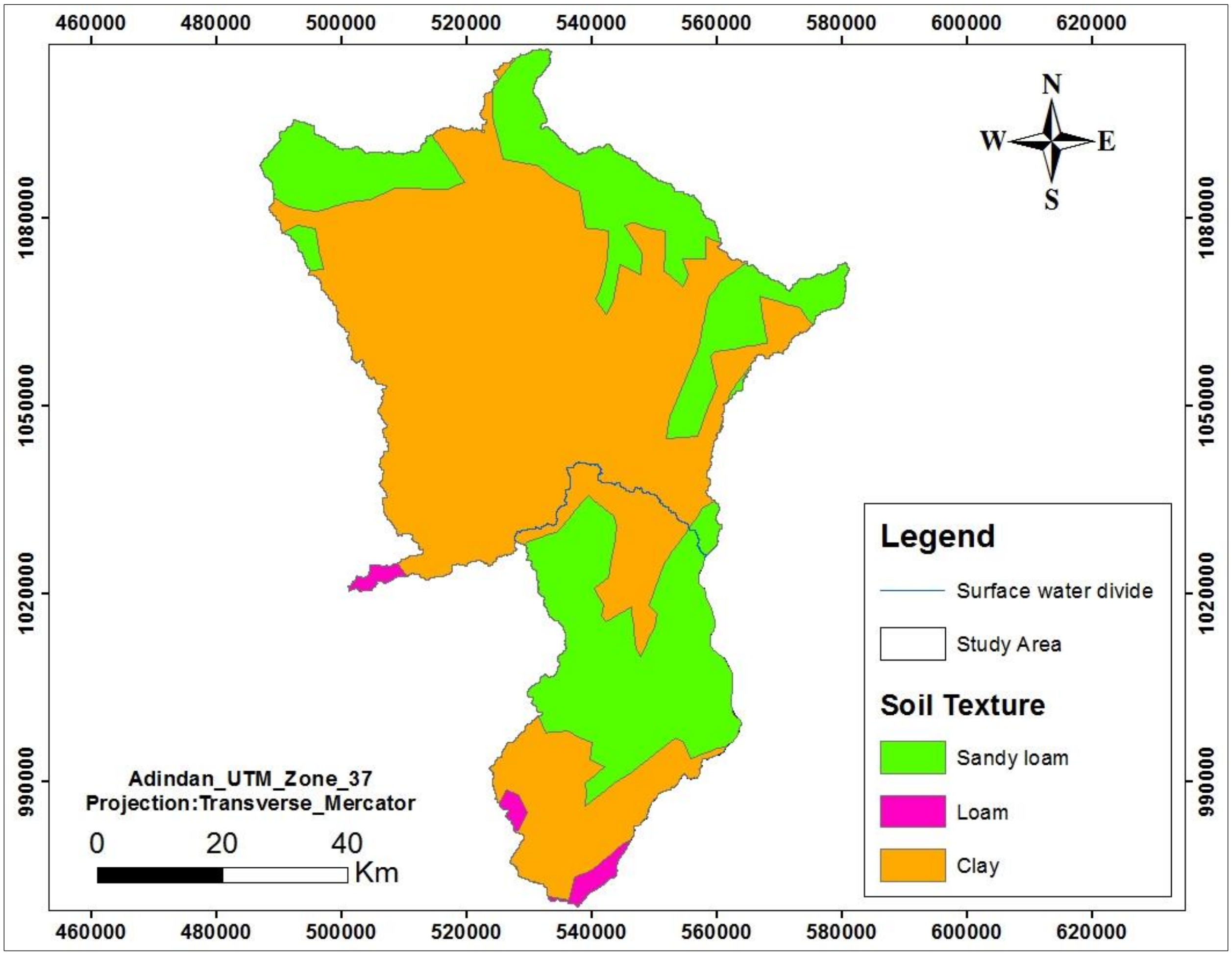

Figure 22:Soil Textural map (Modified from MoA,2016)

3.4.6 Elevation and Slope

The topography of the corresponding catchment has been prepared from the Shuttle Rader Topography Mission (SRTM) of 30m resolution dataset downloaded from the United State Geological Survey (USGS). Within the South-Jemma sub-basin, the maximum elevation is found to be 3637m and the elevation gradually decreases in the area where catchment is dissected by the rivers, with the lowest elevation record is found to be 1293m. The mean elevation of the catchment is 2638.07m. The slope of the catchment is extracted using the slope tool box using 3D spatial analyst extension in Arc Map. The slope of the area ranges from 0º to 59º where steep slopes are observed following the river gorges whereas flat laying slope is observed within the plateau. The mean of slope of the catchment is found to be 5.69º. In the case of Kesum catchment, the highest elevation point record is found to be 3,533 m at the upstream part of the catchment. The elevation gradually decreases in the place where the area dissected by kesum river. And the elevation of the lowest record is found to be 1,231 m. the mean value of elevation record within this catchment is 2,209 m. the slope of the catchment is extracted as the same method used for its adjacent catchment. The slope ranges from 0º to 55º. Steep slope has been observed along the river gorge of Kesum River. The mean slope of the catchment is found to be 10º.

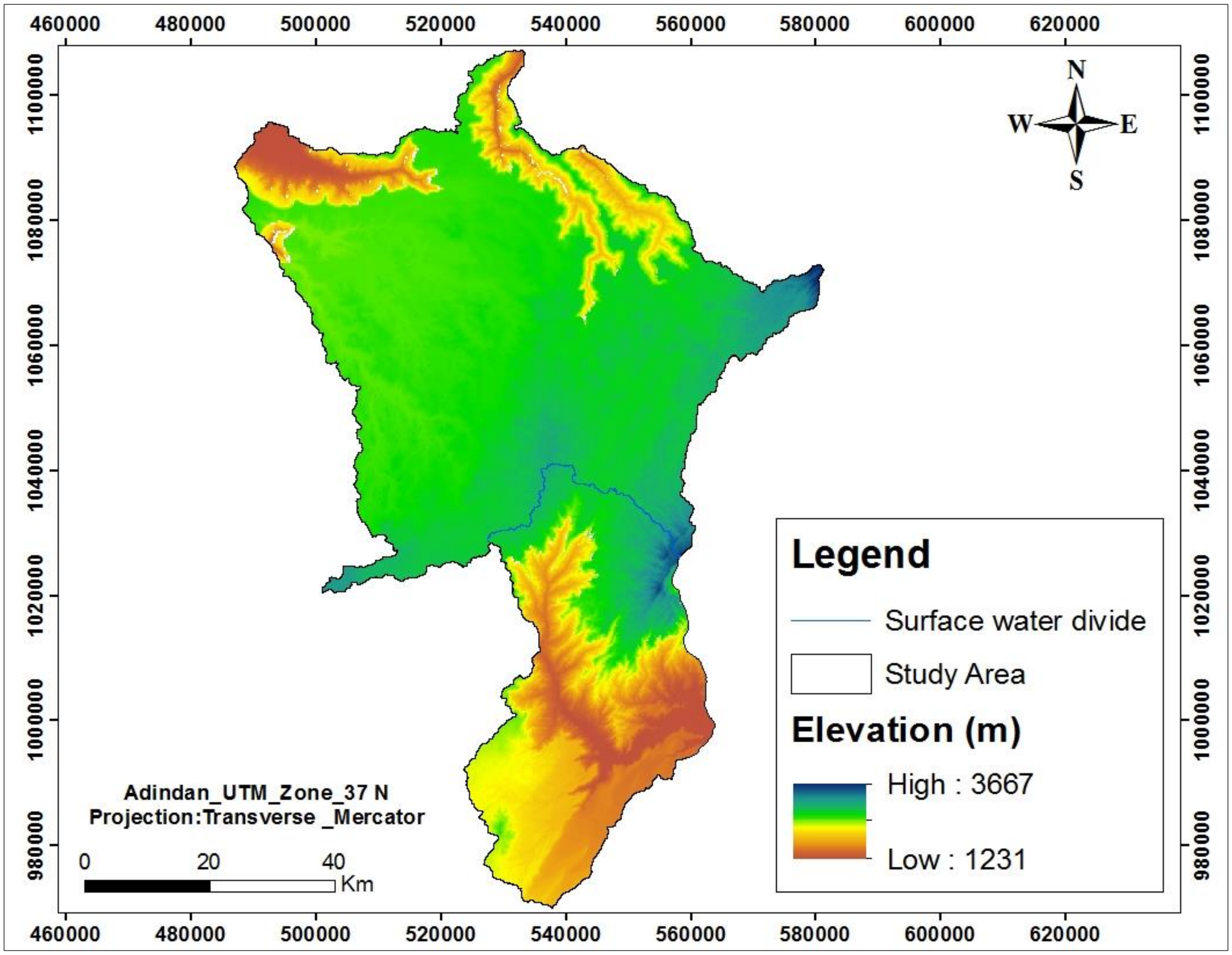

Figure 23: Elevation Map

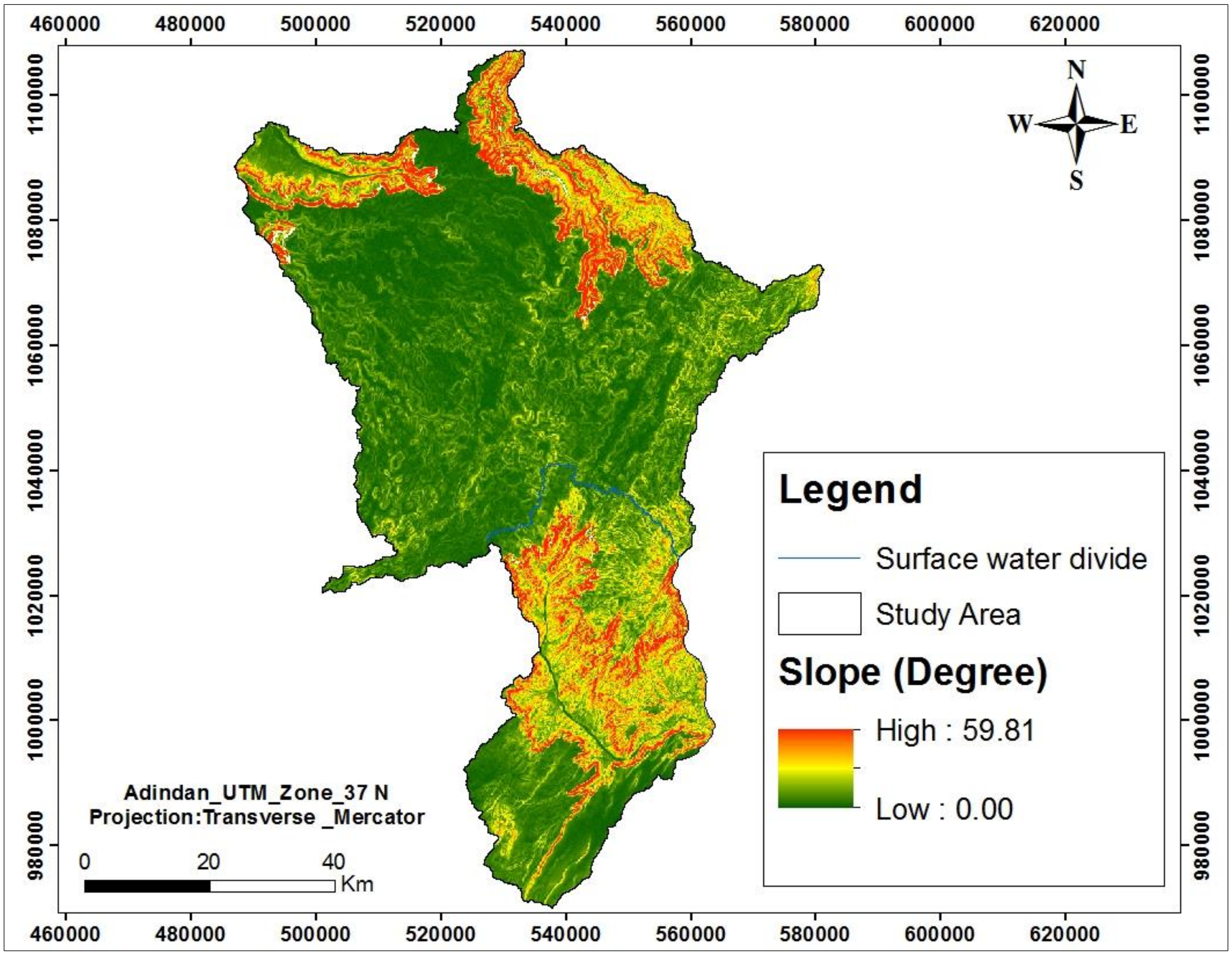

Figure 24: Slope Map

3.5 Physical and Hydro metrological grid maps

Two types of data input are required for the model to run. The first one are the physical characteristics of the watershed such as land use/landcover, soil, slope and elevation map and the metrological data which corresponds to precipitation, temperature, potential evapotranspiration and windspeed. The second one is parameter tables prepared for the corresponding land use/landcover and soil maps each catchment.

Preparation of the Hydro- metrological raster map has been done using the Kriging interpolation within the spatial Analyst extension tool box in the Arc Map. A 30 m resolution obtained from Ministry of Agriculture has been used in the preparation of land use/landcover and soil map of the two catchments.30m grid cell size has been used in the preparation of the raster map. The elevation has been obtained from the shuttle Rader Topography Mission data set and the corresponding slope map has been derived from the digital elevation model using the 3D spatial Analyst extension. The groundwater depth map of each catchment has been prepared from existing bore hole data which consists full record of the static water level and they have been used uniformly throughout the month. The corresponding raster map of 30m grid size has been converted to ascii grid format using the conversion too box in Arc map environment. Within the southern Jema catchment, the input ascii format consists of 3141columns and 2889 rows. While within the case of kesum catchment 1343 columns and 2370 rows.

3.5.1Parameter tables

Parameter table have been prepared for the land use/landcover and soil map of the two catchments and they have been saved with the appropriate TBL format. The same type of land use/landcover and soil parameters have been used throughout the month during simulation. The parameter tables are used as lookup table which serves as a linkage for the corresponding grid map of land use/landcover and soil map for the computation to be performed.

3.6.4 Model calibration

The Nash-Sutcliffe model efficiency Coefficient (NES) has been used for evaluation of simulated result. This statistical measure is used to assess the predictive power of a Hydrological model which can be given as:

$$NSE = 1 - \frac{\sum_{i=1}^{N}(Qs_i - Qo_i)^2}{\sum_{i=1}^{N}(Qo_i - \overline{Qo})^2}$$

Where: NSE= Nash –Sutcliffe Model Efficiency [-]

N= Number of time step

Qo = Observed discharge [MCM]

Qoi= Simulated Discharge [MCM]

$\overline{Qo}$ = Mean of Observed Discharge [MCM]

Kesum catchment has been calibrated using a river gauge near to its outlet (Kesum at Awra Melka). A Nine years of full data of this gauge stations has been used for calibration process. The new version of Wets pass (Wetspass 1.3) has global and local calibration parameters that allows to be adjusted until the desired result is obtained. Several multiple trials of simulation have been made by adjusting the calibration parameters and the result and the model evaluation is given below:

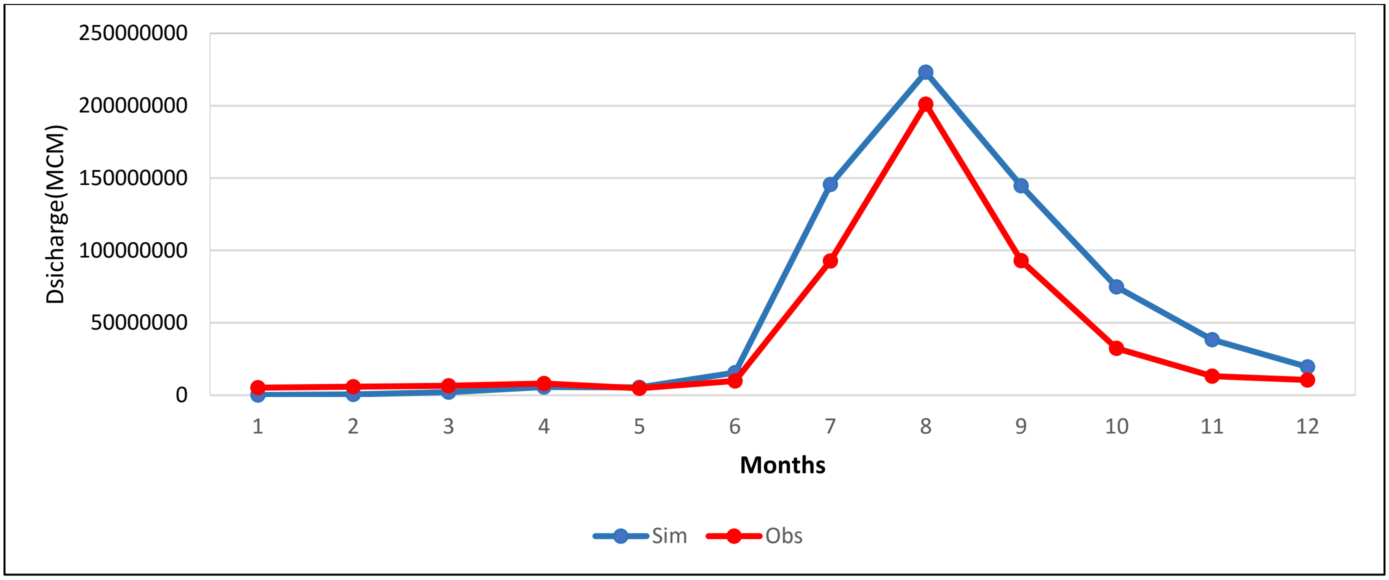

Figure 25:Graph of long-term average Simulated and Observed Discharge

The predictive power of the model has been evaluated using the above statistical measurement (NSE) and the value is found to be 0.78.

The absence full river gauge data that can represent the whole watershed and placement of river gauge station in the upper course of river in the plateau part of the study area for existing River gauge stations, which leads less measurement of discharge within the catchment make it difficult in calibration of simulated result in South- Jema catchment. Instead, the simulated result has been compared to base flow result gained by previous researchers.

Table 14: Recharge Estimated by Previous Researchers

	Previous workers	Catchment	Base flow
1	Tilahun Azagegn,2014	Jema-Sub Basin	82mm/ year
2	Yonas Mulugeta,2009	Cacaha Catchment	150 mm/year
3	Melkamu Ademnew,2019	Beressa Catchment	211.84 mm/year

Compared to the above mentioned selected base flow within the catchment, the amount of recharge as calculated using wetspass shows within the range of the work done by previous researchers as mentioned in the above table (Figure 14). Therefore, the simulated result can be considered as acceptable for the catchment.

3.6 Outputs of Wetspass model

As explained earlier in the above, model inputs of precipitation, temperature, potential evapotranspiration have been prepared at monthly time-time step. The same value of groundwater depth for each month has been used for each the months. The output of the corresponding month has been converted to two seasons through map Algebra tool box in the spatial analyst extension in Arc Map. The output results are presented as raster map. The discussion of the output results is explained hereunder:

3.6.1 Actual Evapotranspiration

When rain falls to the surface, fractions of its constituents can be intercepted by vegetation which mainly depends up on windspeed, duration of rainfall, interception capacity, type and morphology of the vegetation cover, growing stage of the vegetation and form and frequency of the vegetation (Tenalem Ayenew and Tamiru Alemayhu, 2001). The residual fraction that has passed from being intercepted by vegetation and other infrastructure can eventually joins in to soil. During the day light hours evaporation can takes place from vegetation canopy, water bodies and soil surfaces (Dragoni &Sukhija, 2013).

The wets pass simulates the long-term annual interception, transpiration and bare soil evaporation of the two catchments (Figure 26, Figure 27 and Figure 28). The average annual interception for South-Jema catchment ranges from 0 mm to 244.59 mm with a mean and standard deviation value of 110.43 mm and 33.70 respectively. The transpiration with this catchment ranges from 0 mm to 365.87mm with mean and standard deviation value of 207.91 mm and 45.27 respectively. The bare soil evapotranspiration has a value range from 0 mm to 555.01 mm with a mean and standard deviation 61.60 mm and 49.73 respectively.

Within the adjacent kesum catchment, the interception value within the catchment ranges from 0 mm to 245.74 mm with a mean and standard deviation value of 171.59 mm and 63.96 respectively. The transpiration value ranges from 0 mm to 365.02 mm with a mean and standard deviation value 234.69 mm and 51.25 respectively. The bare soil evaporation to this corresponding catchment ranges from 0 mm to 563.88 mm with a mean and standard value of 49.27mm and 84.19 respectively.

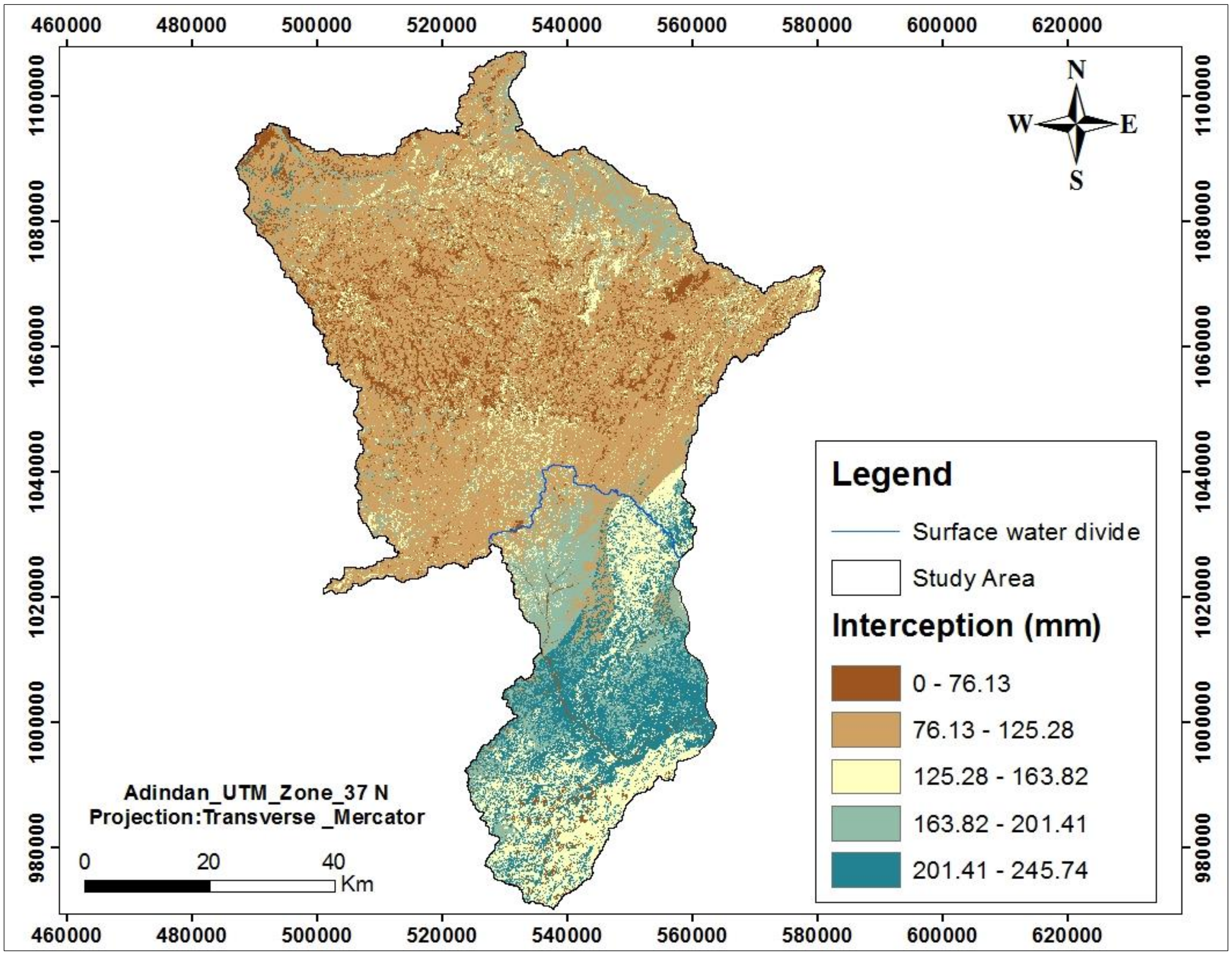

Figure 26: Interception Map

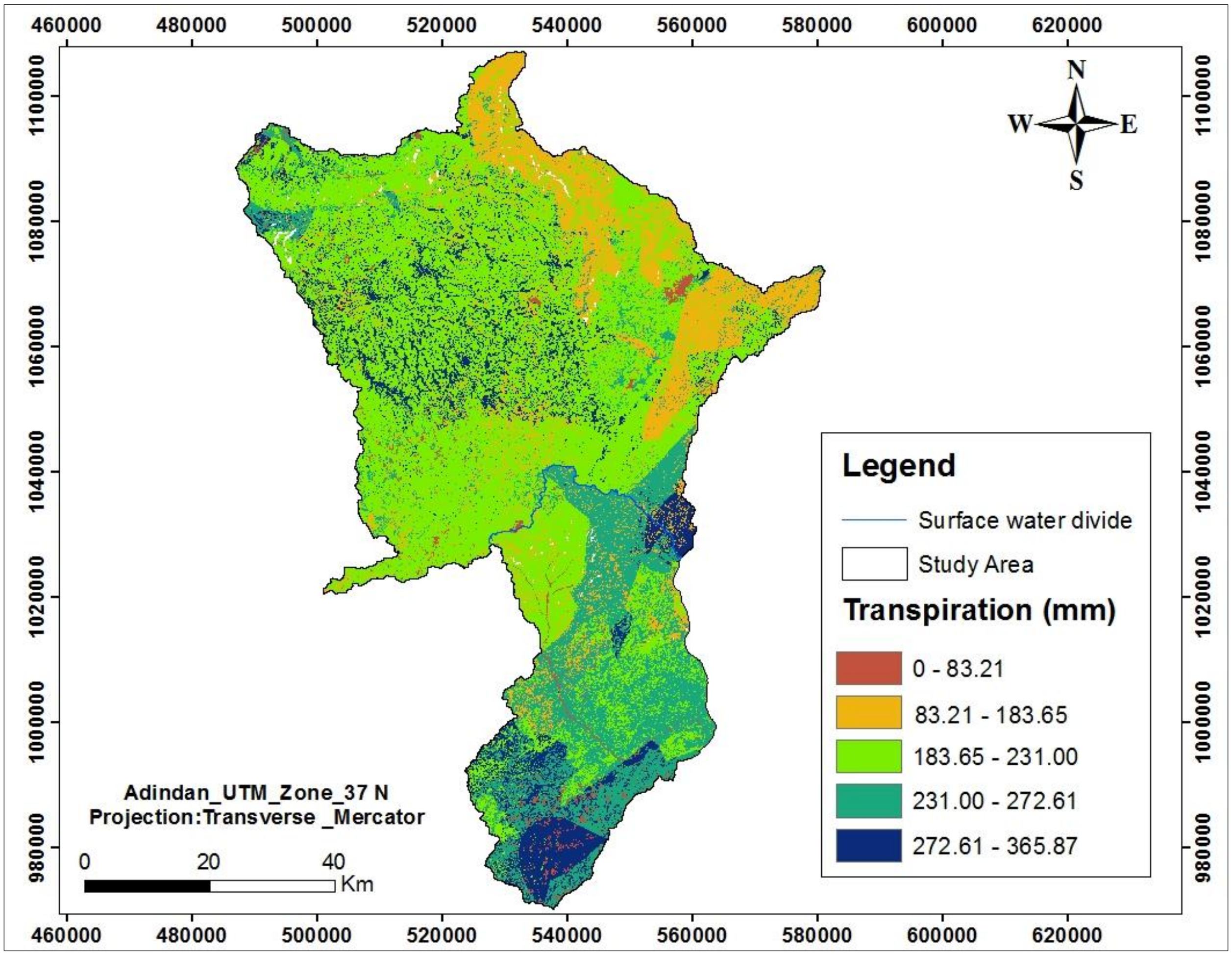

Figure 27:Transpiration Map

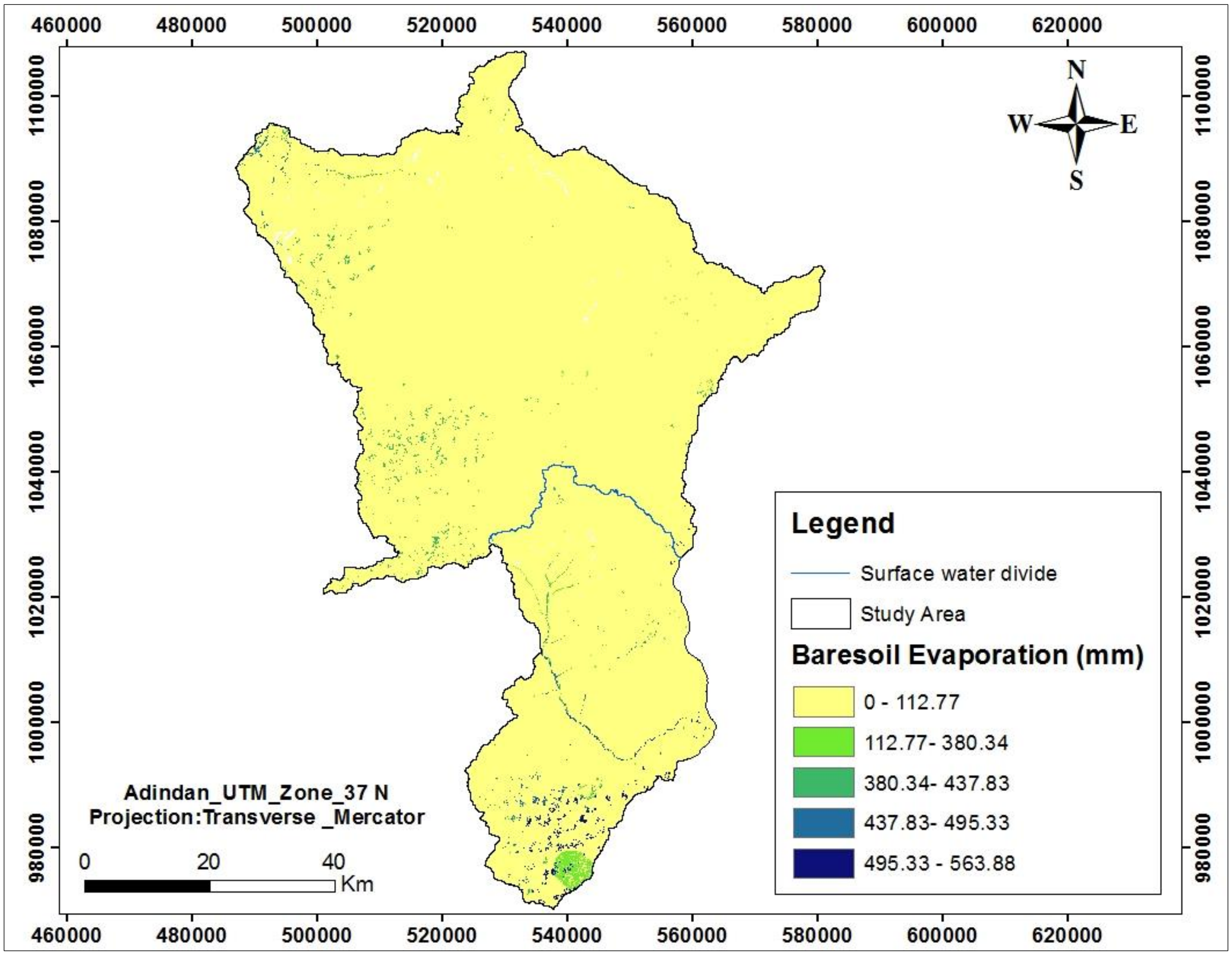

Figure 28: Bare soil evaporation Map

Results of the long-term actual evapotranspiration has been simulated for each months of the year and the result has been prepared in two seasons for catchments (Figure 29, Figure 30 and Figure 31).

For Jemma catchment the mean long term annual actual evapotranspiration is found to be 380. 64mm.Out of these about 41.46% of the total the actual evapotranspiration which consists of 157.84 mm occurs during winter, whereas the rest 58.53% which consists of 222.80 mm occurs during the summer season. The long term mean annual actual evapotranspiration accounts for 37.14% of the total mean annual precipitation.

In the case of kesum catchment, the long-term annual actual evapotranspiration is found to be 455.61 mm. Out of these about 43.98 % of the total actual evapotranspiration, which is 200.11 mm occurs during the dry season. Whereas about 56.15 % which is 255.50 mm occurs during the summer season. The mean annual actual evapotranspiration within this catchment accounts of 46.82% of the total mean annual precipitation.

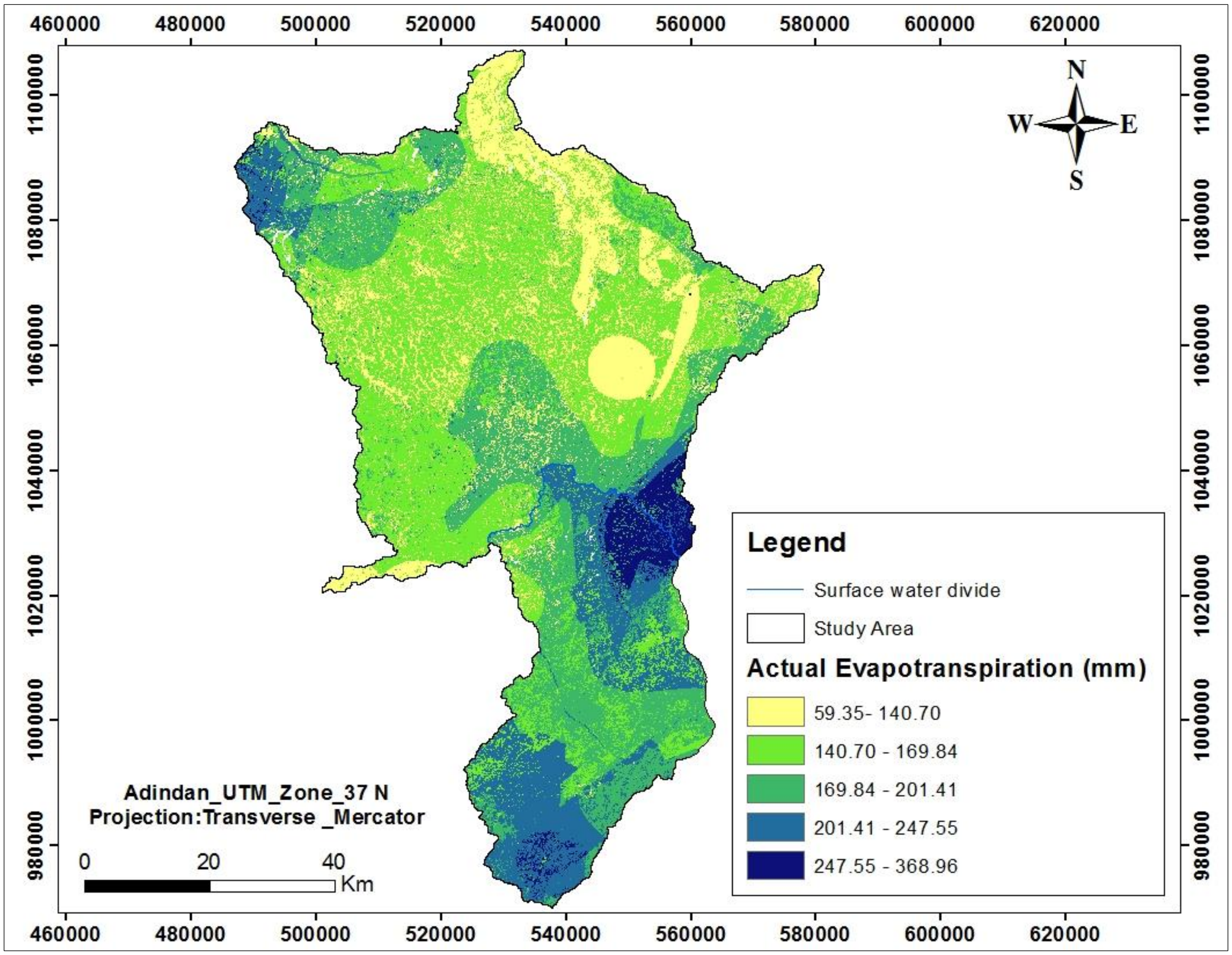

Figure 29 :Winter Actual Evapotranspiration

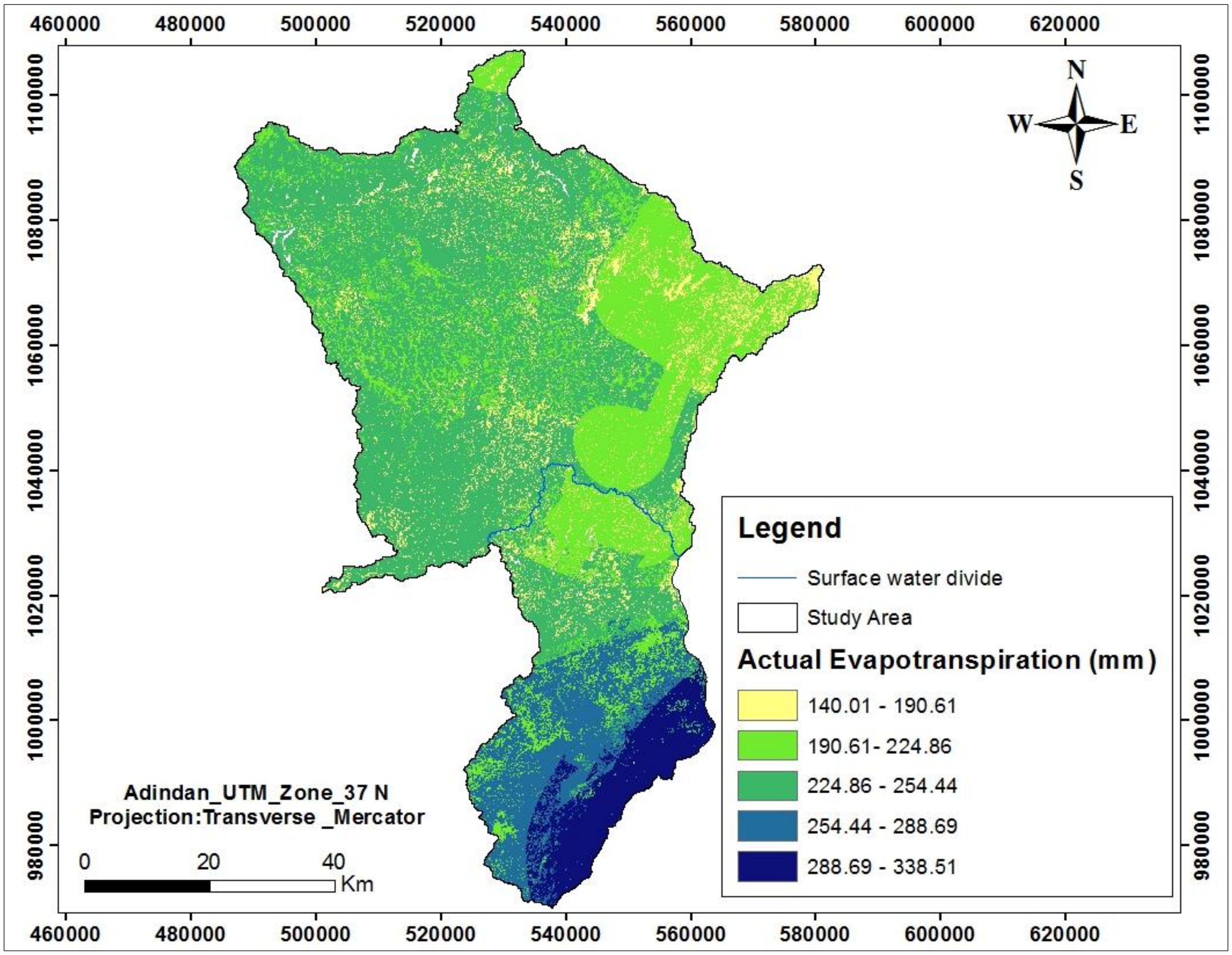

Figure 30:Summer Actual Evapotranspiration

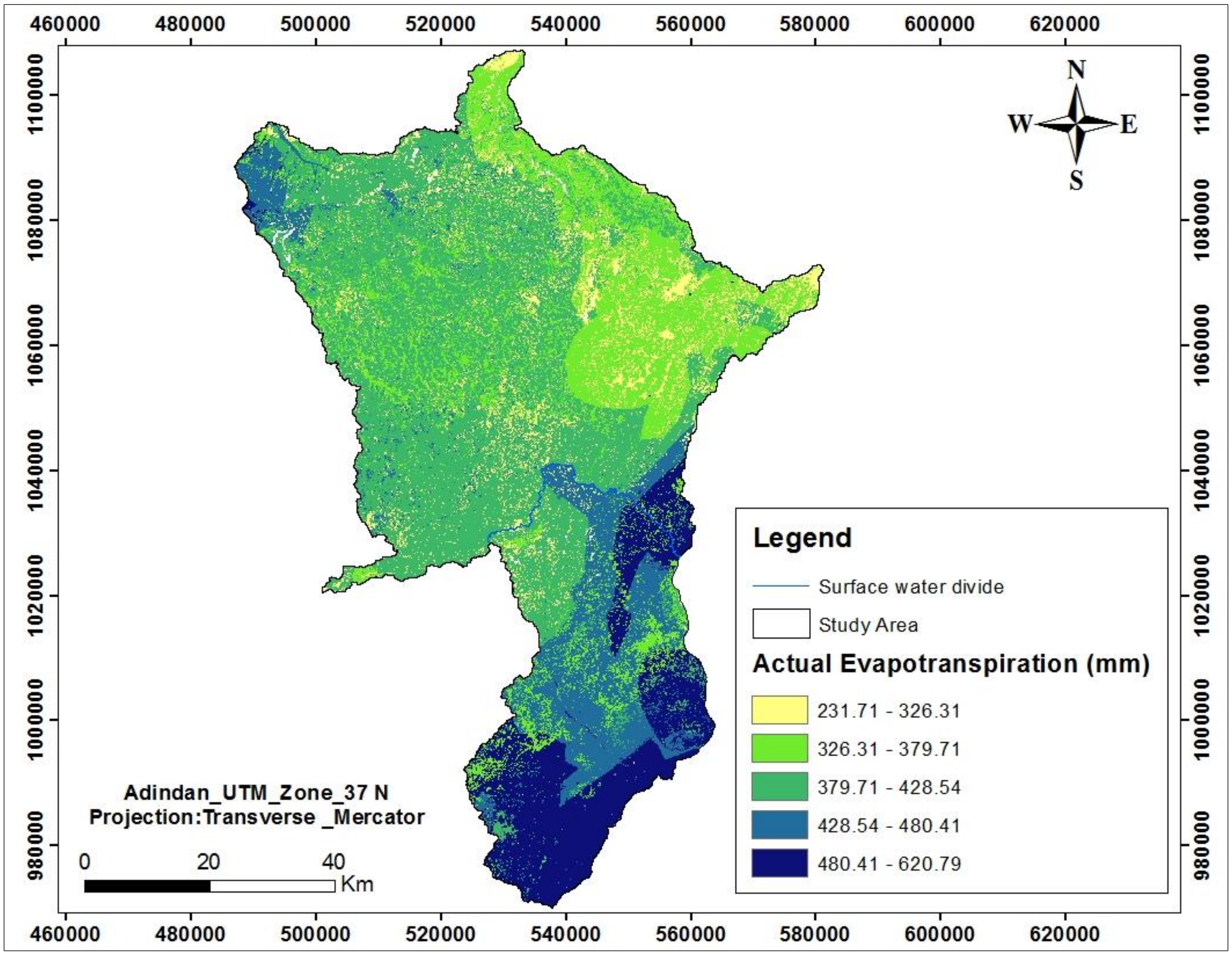

Figure 31: Annual Actual Evapotranspiration

Table 15: Relationship of AET to different combination of Land use/Land cover and Soil Textural Types in South- Jema cathment

	Actual Evapotranspiration (mm)	Clay	Loam	Sandy Loam
South-Jema Catchment	Settlement	Min: 256.97 Max: 351.02 Mean:277.87	-	Min:238.89 Max:244.40 Mean:242.20
	Bare land	Min:349.10 Max :532.01 Mean:397.41	Min:394.23 Max:407.41 Mean:401.90	Min:356.24 Max:555.01 Mean:442.80
	Agriculture	Min:350.73 Max:566.61 Mean:401.31	Min:369.73 Max:405.00 Mean:380.32	Min:322.02 Max:546.91 Mean:374.20
	Grassland	Min:306.00 Max:426.10 Mean:347.513	-	Min:260.43 Max:364.20 Mean:306.44
	Wetland	-	Min:322.20 Max:337.13 Mean:333.50	-
	Forest	Min:206.92 Max:381.04 Mean:296.28	Min:231.60 Max:315.72 Mean:302.06	Min:261.00 Max:385.40 Mean:290.42
	Shrubland	Min:375.70 Max:557.08 Mean:438.00	Min:396.20 Max:429.42 Mean:405.60	Min:346.01 Max:551.51 Mean:407.50
	Waterbody	Min:554.16 Max:620.80 Mean:579.24	-	Min:506.24 Max:526.86 Mean:515.60

Table 16: Relationship between AET to different combination of Land use/Land cover and Soil textural types in Kesum catchment

		Clay	Loam	Sandy Loam
Kesum Catchment	settlement	Min:231.71 Max:325.03 Mean:282.06	-	-
	Bare land	Min:286.13 Max:563.90 Mean:485.00	Min:411.60 Max:561.60 Mean:486.60	Min:278.50 Max:546.23 Mean:433.21
	Agriculture	Min:405.29 Max:556.61 Mean:480.90	Min:650.70 Max:515.24 Mean:482.94	Min:374.661 Max:528.40 Mean:437.20
	Grassland	Min:368.50 Max:415.87 Mean:388.85	-	-
	Wetland	Min:419.40 Max:442.80 Mean:427.20	Min:378.20 Max:381.60 Mean:379.61	Min:338.83 Max:375.31 Mean:354.04
	Forest	Min:303.73 Max:442.83 Mean:373.30	Min:367.60 Max:430.35 Mean:399.00	Min:300.40 Max:407.63 Mean:357.85
	Shrubland	Min:403.13 Max:570.20 Mean:486.70	Min:477.40 Max:539.00 Mean:508.20	Min:385.03 Max:531.80 Mean:456.10

Different combination of land use and soil texture given in the above table (Table 15 and Table 16) clearly shows the highest evapotranspiration has been observed in in the area covered with Clay and water body within South-Jema catchment. In the case of Kesum catchment, highest evaporation rate has been observed in an area covered with Loam and Shrubland.

3.6.2 Surface Runoff

Surface runoff over a given watershed is mainly dependent up on the intensity of rainfall, the type of land use/landcover and the soil texture. As observed from the output (Figure 32, Figure 33 and Figure 34) within the South-Jema catchment, the long-term annual surface runoff corresponds 534.05 mm. during dry season the surface runoff is found to be 23.75 mm which is about 4.45% of the total annual runoff. While about 95.56% which is 534.30 mm of the total surface runoff is obtained during the rainy season. The surface runoff accounts about 52.02 % of the annual precipitation. Therefore, we can conclude that the amount of precipitation that is lost within the South-Jema is attributed to the surface runoff. In the case of Kesum catchment, the mean long-term annual surface runoff is found to be 410.08mm respectively. Out of this about 3.072%, which consists of 12.60mm is distributed during the winter season. Whereas about 397.48 mm which accounts for 96.92% of the annual surface runoff occurs during the summer season. The mean annual surface runoff accounts about 42.14% of the total annual precipitation that is received by this catchment.

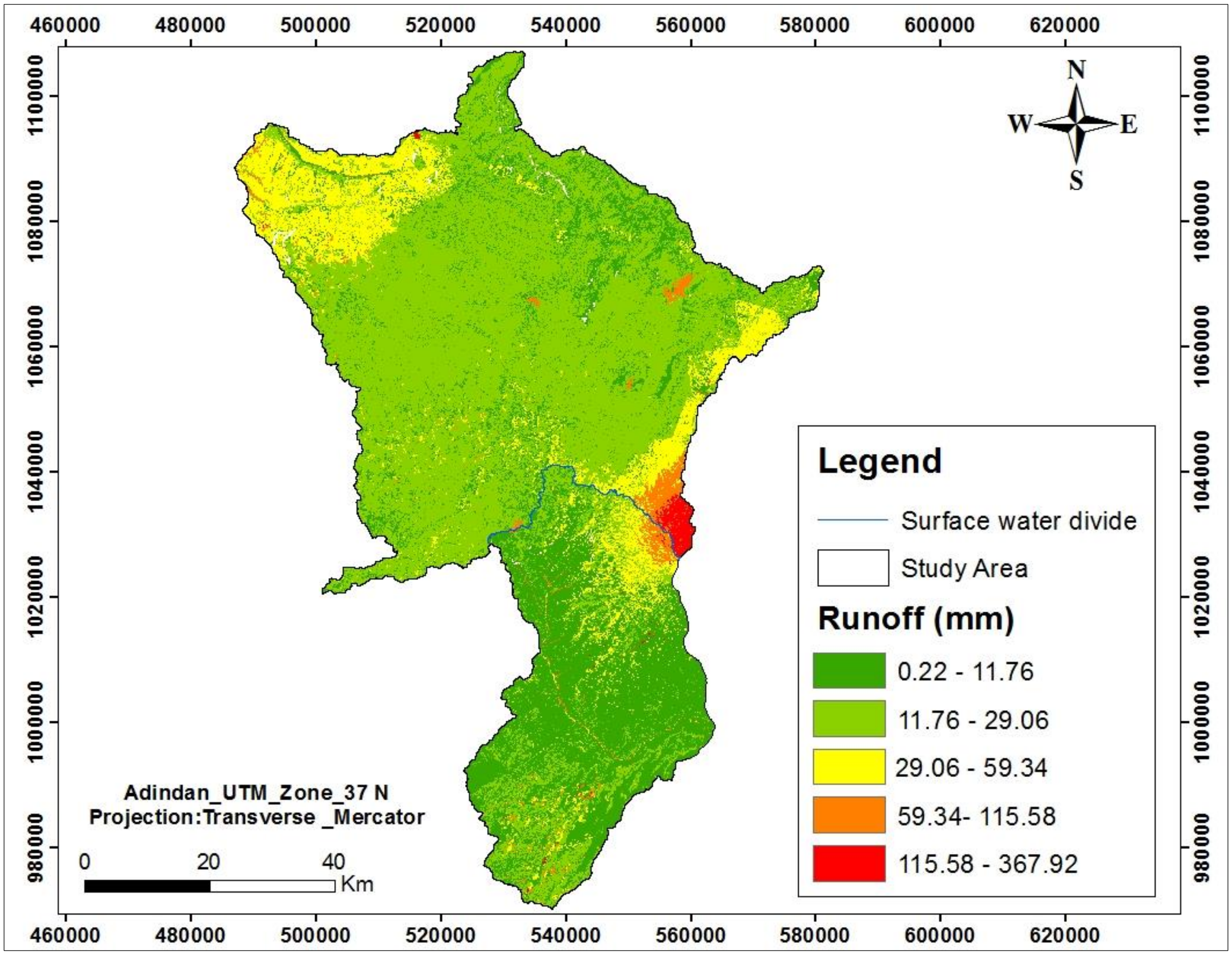

Figure 32 Winter Runoff

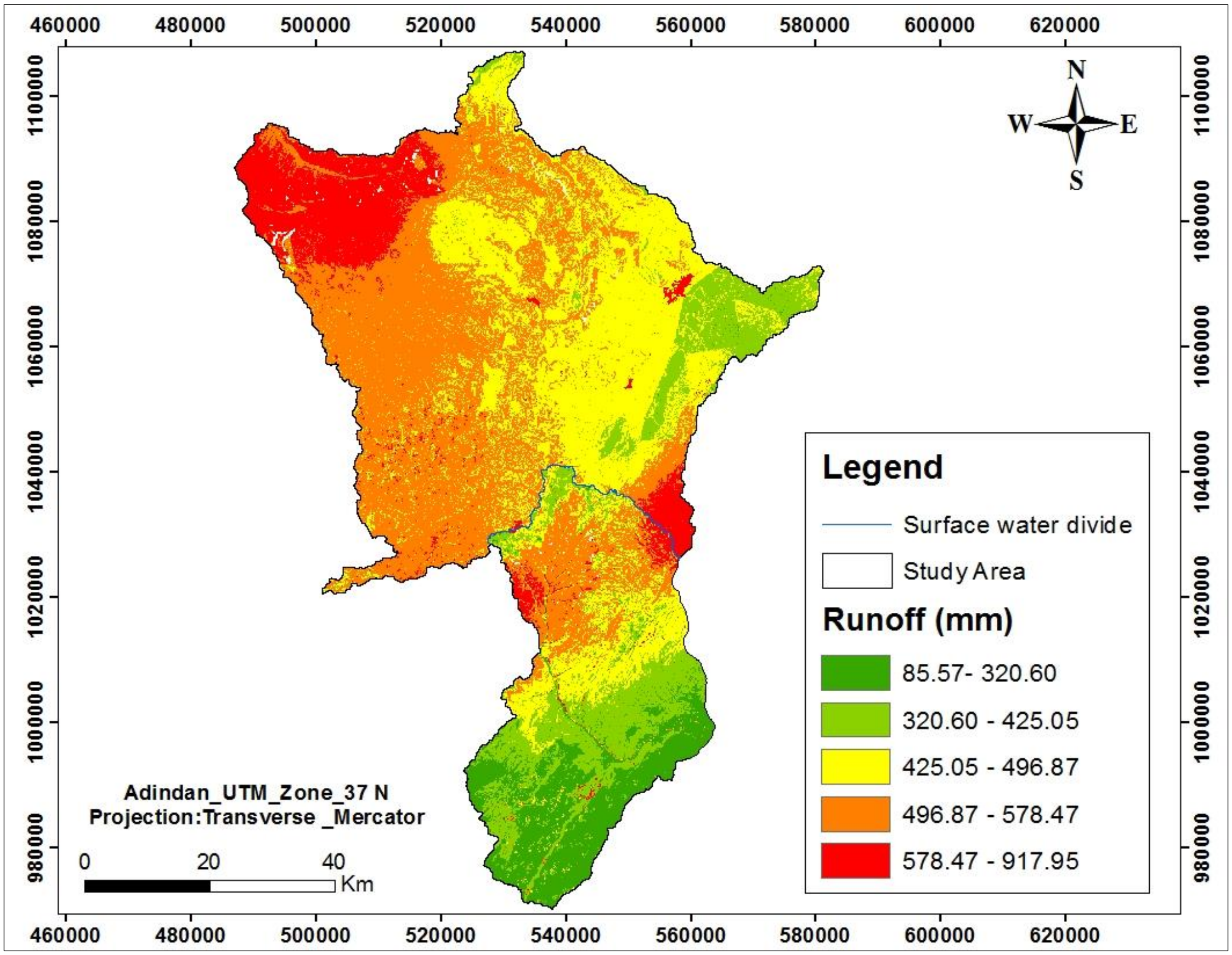

Figure 33: Summer Runoff

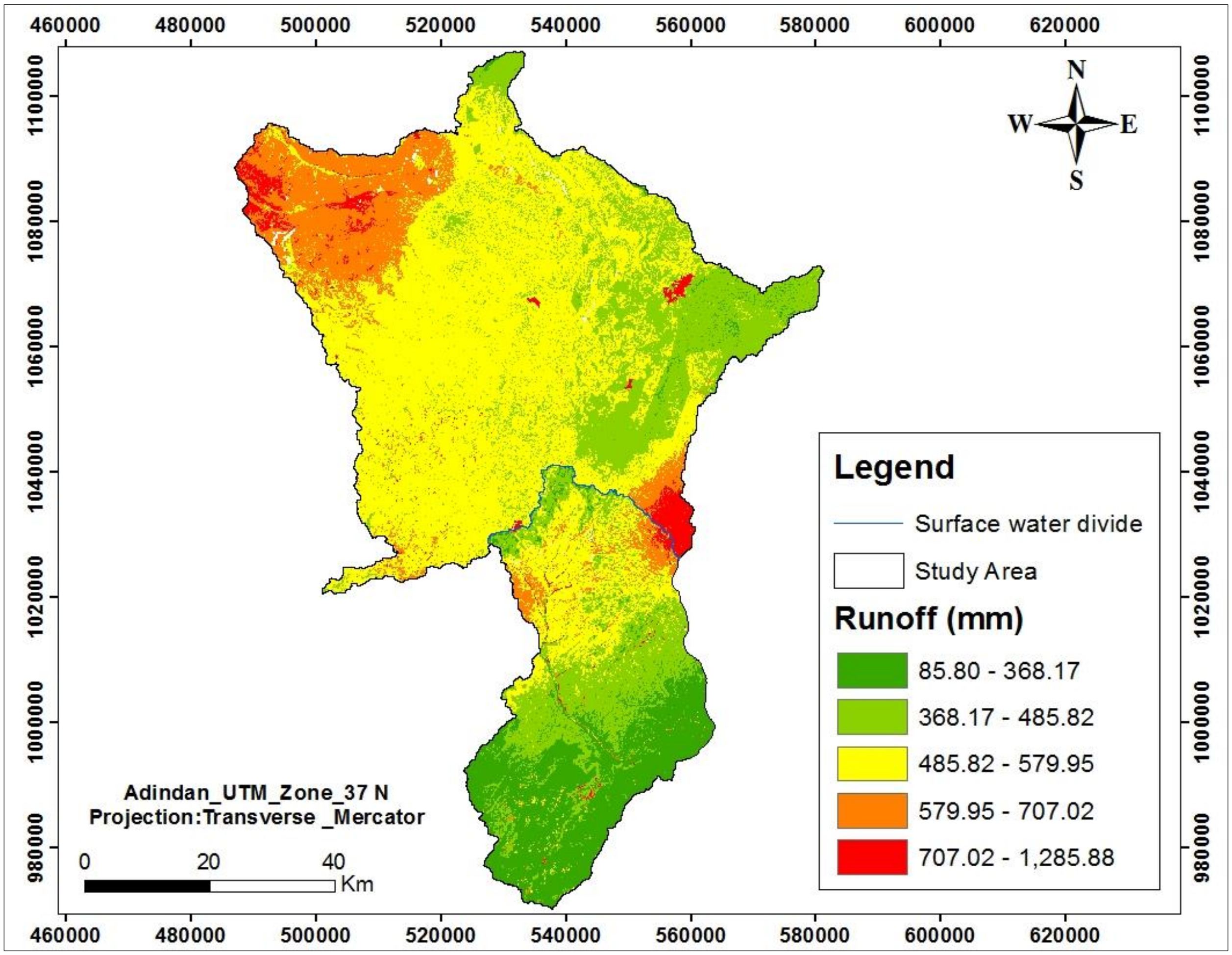

Figure 34: Annual Runoff

Table 17: Relationship between Runoff and Different combination of Land use/ Land cover and Soil textural type in South-Jema catchment

		Clay	Loam	Sandy Loam
South - Jema Catchment	Settlement	Min:708.51 Max:903.25 Mean:744.60	-	Min:703.60 Max:708.04 Mean:706.20
	Bare land	Min:558.80 Max:1285.90 Mean:714.70	Min:530.44 Max:742.40 Mean:638.74	Min:420.70 Max:1274.90 Mean:739.73
	Agriculture	Min:407.20 Max:977.60 Mean:539.60	Min:554.36 Max:558.51 Mean:555.60	Min: 337.60 Max: 1023.00 Mean: 539.04
	Grassland	Min:399.00 Max:785.20 Mean:529.21	-	Min: 301.33 Max: 792.40 Mean:519.60
	Wetland	-	Min:471.80 Max:581.00 Mean:534.20	-
	Forest	Min:351.73 Max:896.60 Mean:491.61	Min:372.40 Max:522.80 Mean:447.03	Min:253.62 Max:921.50 Mean:455.03
	Shrubland	Min:386.80 Max:911.60 Mean:532.20	Min:430.90 Max:537.30 Mean:495.70	Min:310.01 Max:958.00 Mean:519.00
	Water body	Min:519.30 Max:720.71 Mean:575.62	-	Min:473.30 Max:537.51 Mean:503.51

Table 18: Relationship between Runoff and Different combination of Land use /Land cover and Soil Textural Types in Kesum catchment.

		Clay	Loam	Sandy Loam
Kesum Catchment	Settlement	Min:682.30 Max:730.90 Mean:201.32	-	-
	Bare land	Min:222.60 Max:952.04 Mean:587.31	Min:234.82 Max:701.31 Mean:468.10	Min:167.80 Max:1192.90 Mean:637.00
	Agriculture	Min:133.22 Max:780.00 Mean:466.60	Min:123.34 Max:429.9 Mean:276.62	Min:103.40 Max:814.72 Mean:468.32
	Grassland	Min:268.44 Max:550.30 Mean:383.90	-	-
	Wetland	Min:192.24 Max:473.30 Mean:304.60	Min:154.51 Max:340.50 Mean:247.50	Min:189.60 Max:600.83 Mean:429.84
	Forest	Min:128.80 Max:765.10 Mean:446.94	Min:118.10 Max:386.90 Mean:252.50	Min:85.80 Max:792.40 Mean:96.90
	Shrub land	Min:128.30 Max:770.30 Mean:449.30	Min:105.30 Max:386.40 Mean:245.82	Min:85.80 Max:792.40 Mean:430.30

From the table above (Table 17 and Table 18), it is clearly observed that, highest runoff within the South-Jema catchment is in an area covered with clay and settlement whereas highest value of surface runoff is attained in an area covered with Sandy loam and Bare land.

3.6.3 Recharge

The amount of water that is percolated to the sub-surface mainly depends up on the physical characteristics of the watershed. Different types of land use/landcover soil texture have variable capacity to transmit water through them. The model has calculated the amount of recharge that is percolated to the saturated zone by subtracting the average annual and seasonal value of surface runoff and evapotranspiration from annual and season precipitation.

Within the Southern Jemma catchment, the long term mean annual recharge is found to be122.02 mm which accounts for 11.9 % of the annual precipitation respectively. During the dry season the recharge is found to be 47.85mm. Whereas in the rainy season the amount of recharge increase and is found to be 74.17mm (Figure 35, Figure 36 and Figure 37).

In the case of Kesum catchment, the long term mean annual recharge to the sub-surface is found to be 114.91mm which is 11.80% of the total annual precipitation. During the winter season the amount of recharge constitutes 27.57 mm whereas during the rainy season the amount shows increment and is found to be 87.34 mm respectively (Figure 35, Figure 36 and Figure 37).

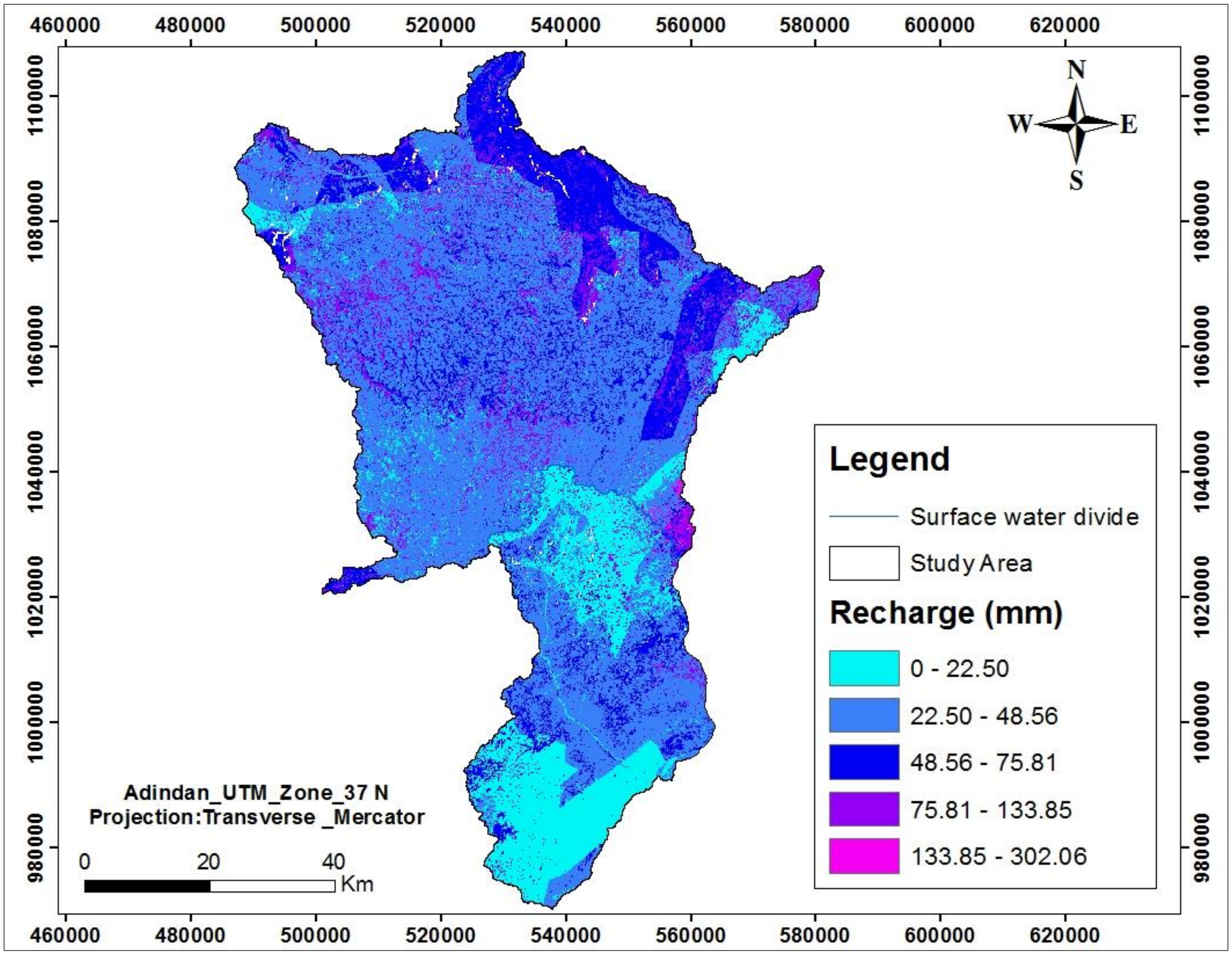

Figure 35: Winter Recharge

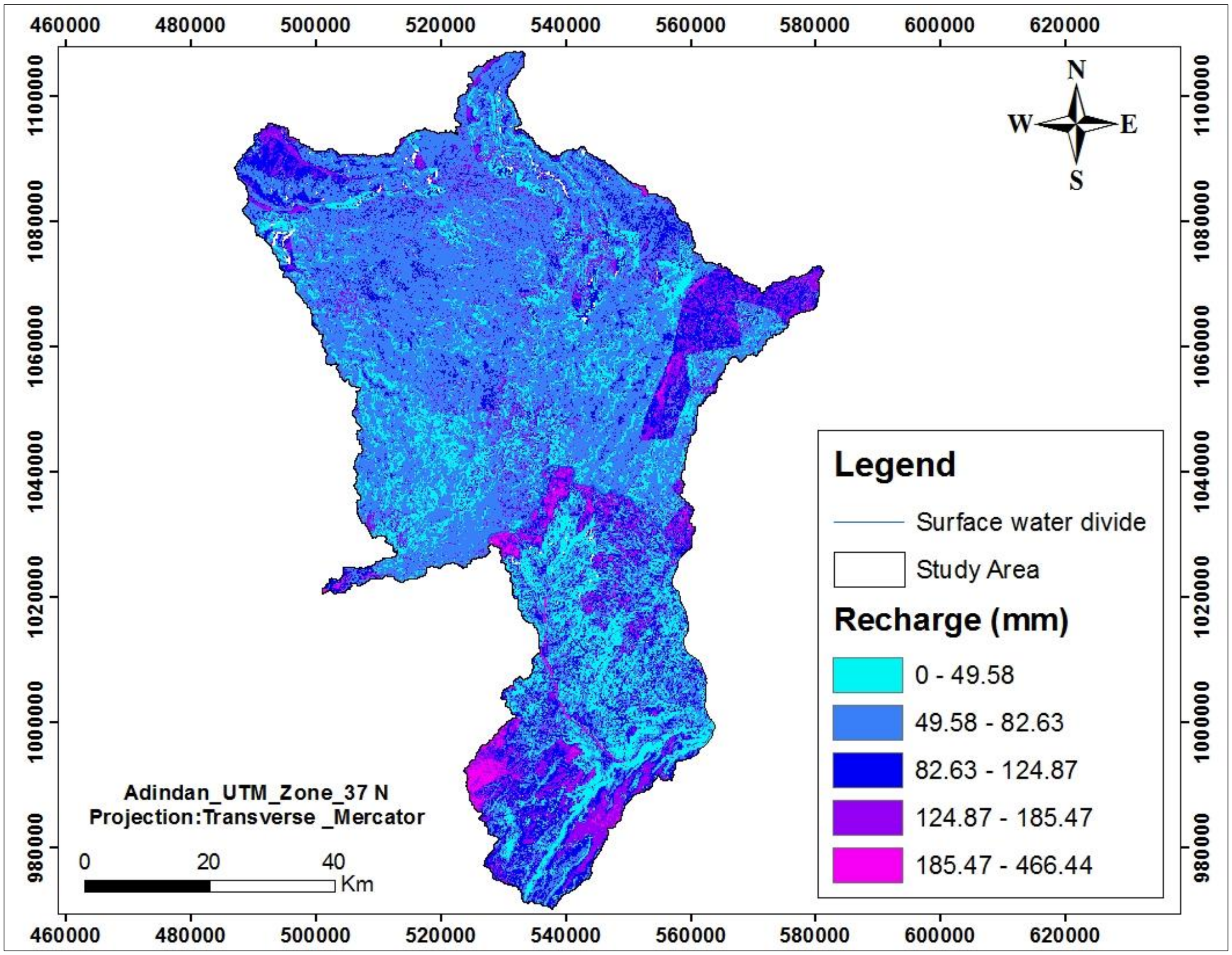

Figure 36 : Summer Recharge

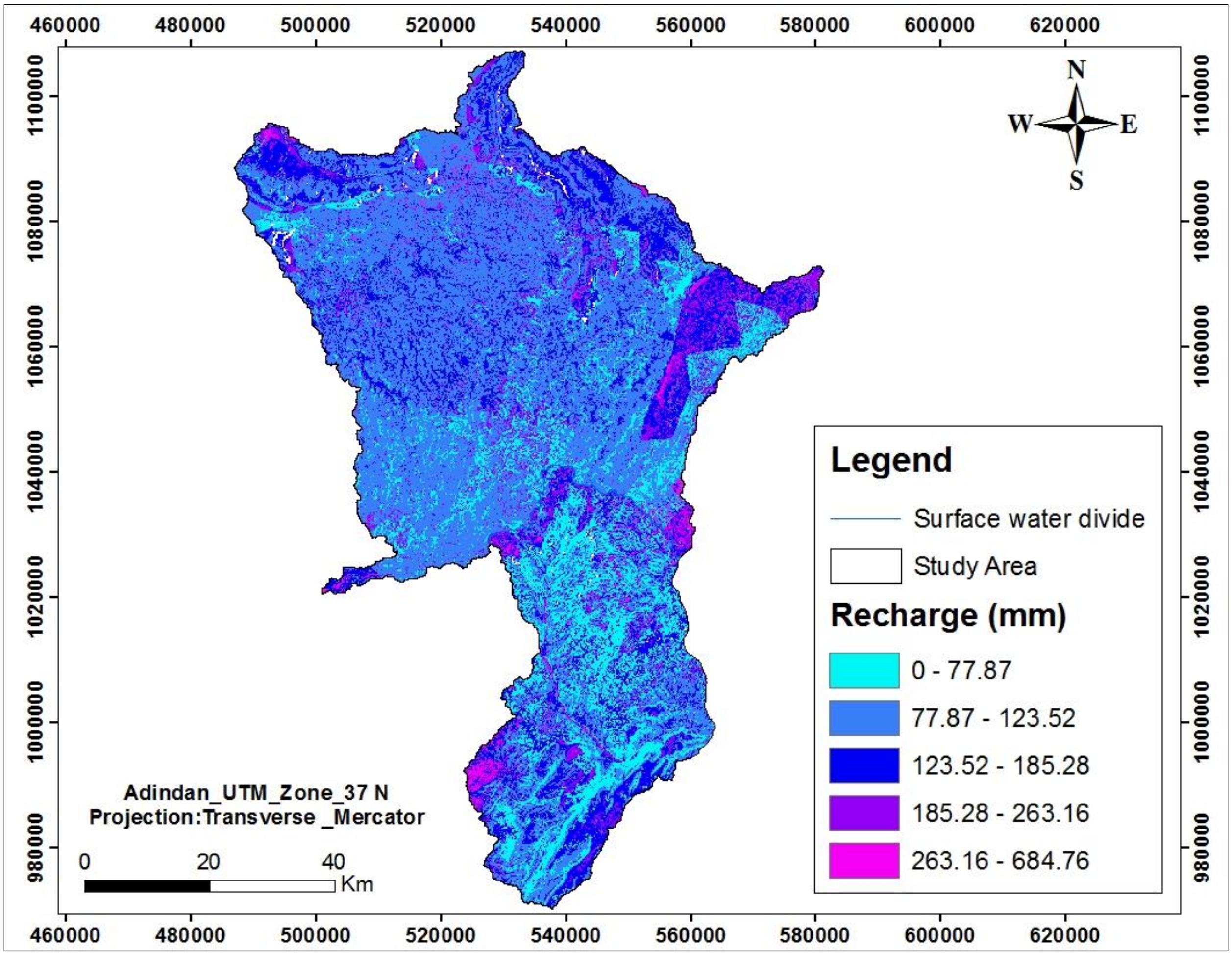

Figure 37:Annual Recharge

Table 19: Relationship between Recharge and different combination of Land use /Land cover and Soil Textural Types in South-Jema catchment

		Clay	Loam	Sandy Loam
South-Jema Catchment	Settlement	Min:14.70 Max:33.50 Mean:26.23	-	Min:43.51 Max:48.41 Mean:45.30
	Bare land	Min: 0 Max:27.00 Mean:4.80	Min:1.52 Max:144.12 Mean:52.00	Min: 0 Max:231.80 Mean:54.94
	Agriculture	Min:28.70 Max:151.10 Mean:92.93	Min:106.32 Max:206.10 Mean:148.50	Min:69.52 Max:342.30 Mean:135.20
	Grassland	Min:45.71 Max:183.90 Mean:141.10	-	Min:129.21 Max:355.20 Mean:218.10
	Wetland	-	Min:175.54 Max:193.00 Mean:181.80	-
	Forest	Min:163.15 Max:387.82 Mean:229.90	Min:229.83 Max:386.54 Mean:308.70	Min:206.30 Max:684.80 Mean:269.50
	Shrubland	Min:41.80 Max:184.60 Mean:92.30	Min:115.91 Max:220.30 Mean:153.50	Min:87.24 Max:396.54 Mean:144.12
	Waterbody	Min:6.81 Max:36.24 Mean:21.21	-	Min:42.81 Max:92.30 Mean: 68.50

Table 20: Relationship between Recharge and different combination of land use and Soil Textural Types in Kesum catchment.

		Clay	Loam	Sandy Loam
Kesum Catchment	Settlement	Min:15.30 Max:62.00 Mean:32.00	-	-
	Bare land	Min:0 Max:230.00 Mean:115	Min:0 Max:198.19 Mean:99.10	Min:0 Max:294.70 Mean:35.10
	Agriculture	Min:2.94 Max:344.40 Mean:173.70	Min:37.10 Max:314.44 Mean:175.80	Min:17.90 Max:475.61 Mean:100.30
	Grassland	Min:94.60 Max:344.34 Mean:229.80	-	-
	Wetland	Min:56.20 Max:327.90 Mean:211.94	Min:202.81 Max:399.00 Mean:279.23	Min:91.70 Max:437.20 Mean:182.32
	Forest	Min:133.62 Max:551.73 Mean:232.70	Min:148.07 Max:443.50 Mean:295.80	Min:125.10 Max:588.54 Mean:183.54
	Shrub land	Min:7.80 Max:365.20 Mean:98.33	Min:50.35 Max:318.34 Mean:184.34	Min:33.33 Max:595.11 Mean:94.10

As listed in the table (Table19 and Table 20) above, highest value of Recharge to South-Jema Basin and Kesum has been attained in an area covered with Loam and forest.

The annual groundwater resource of the two catchment is given in the table below

Table 21: Annual Resource of Groundwater recharge per year

	Catchments	Area (Km^2)	Recharge (mm)	Recharge (Mm^3/Year
1	South -Jema	4026	122.02 mm/ year	491.172 Mm^3/year
2	Kesum	1657	114.91mm/Year	190.505 Mm^3/year

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Chapter Four: Hydrochemistry

4.1 Hydro geochemistry

Water is the most effective compound that have the capability to dissolve many environmental substances. Its chemical constituents can be modified as its pass through the atmosphere and reacts with chemical constitutes found within the atmosphere and as it infiltrates to the subsurface and react to geologic martials of variable mineral composition.

Within the sub-surface environment, the chemical constituent of groundwater can originate either from direct input of precipitation which can have marine or continental sources or chemicals and minerals which either precipitate or dissolved as the water moves along the geologic materials (Yitbarek Andarge ,2009).

As composition of groundwater is highly variable with respect to space and time, assessment of variable signature of its chemical constituents will allows to draw what factors are responsible for the genetic evolution of groundwater. (Todd 1980). Therefore, hydrochemistry is an important tool to interpret and understand processes that are responsible for the chemical makeup of groundwater as it passes through the aquifer materials.

4.2.1 Data Availability

Within the study area, water quality data has been collected from published explanatory reports and PhD thesis work. 19 InSitu measurement of pH, EC and temperature has been taken during field activity. Figure 37 show data availability within the study area. Before for further usage of data for analysis and interpretation, the electro neutrality test has been conducted for each data and those with percentage error less than 5% has been used. The figure below shows error distribution graph of data's which has been used during analysis.

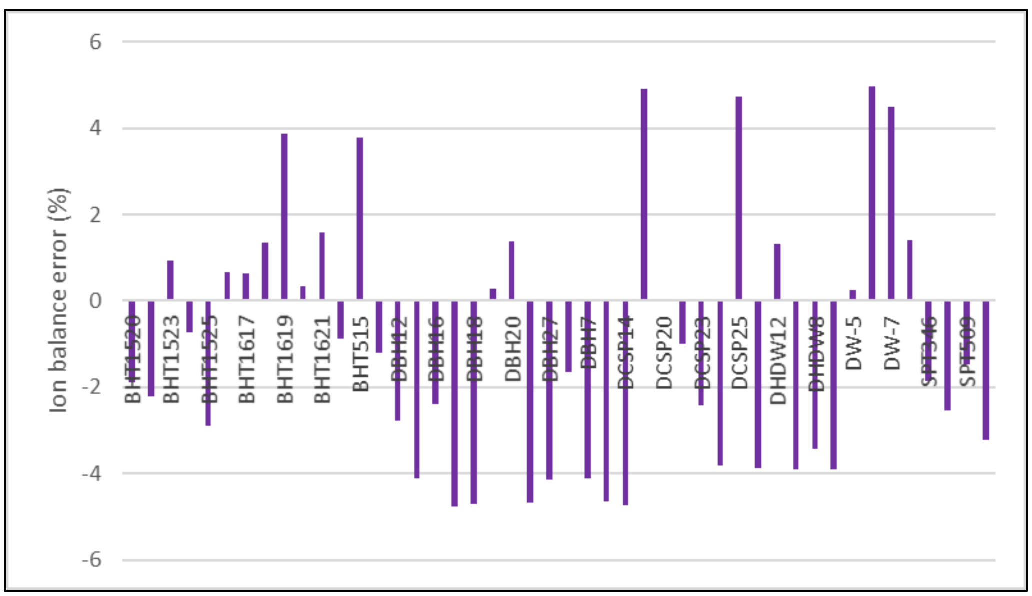


Figure 38: Error distribution Graph

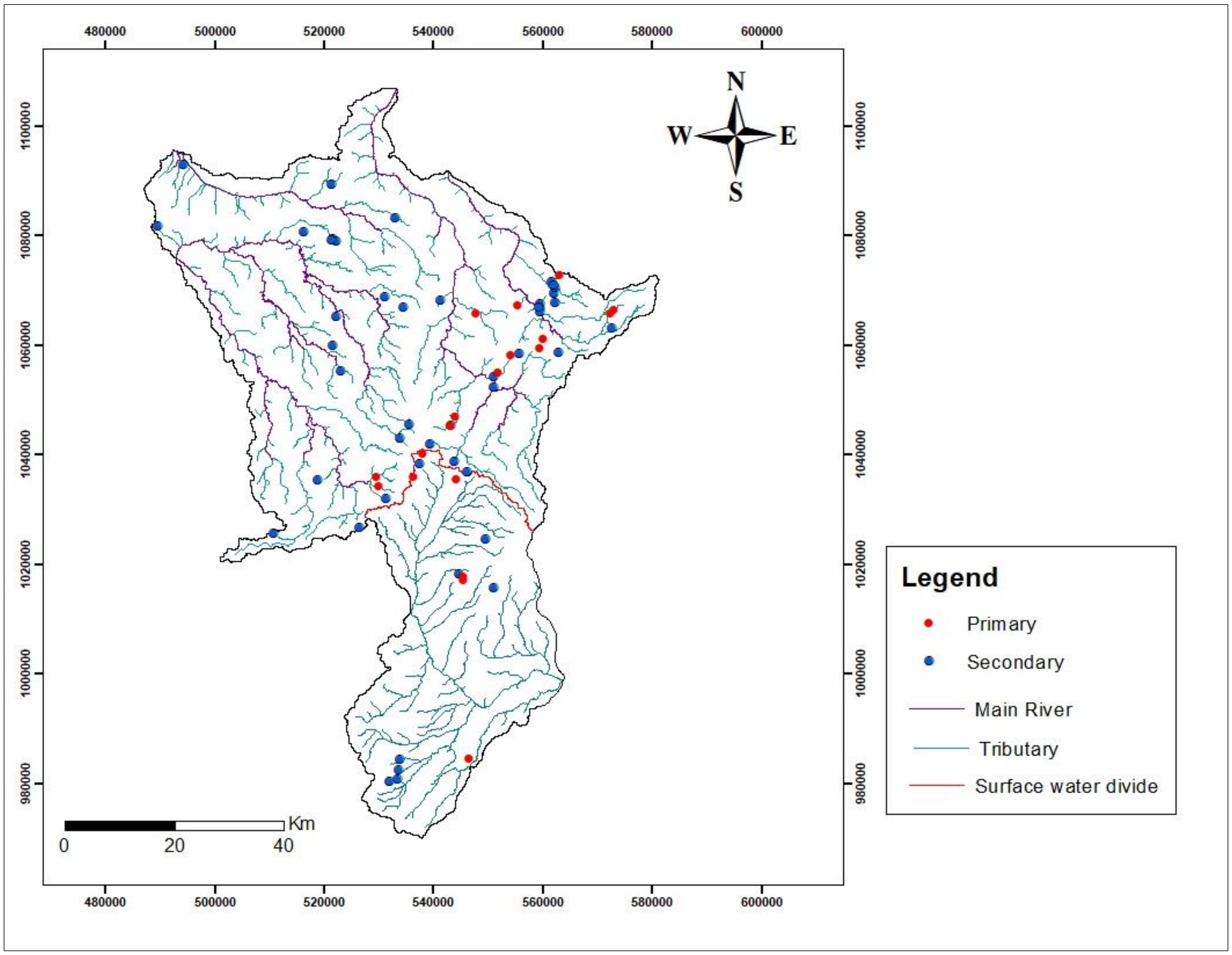


Figure 39: Hydro chemical data Availability

Table 22: Primary Data

BH	E	N	Elevation	EC	PH	T	Type
Z1	547670	1065955	2768	176.3	6.05	17.5	shallow
Z2	562907	1072827	2808	141.3	6.37	20	shallow
Z3	554008	1058383	2788	171.1	6.67	17.1	shallow
Z4	559390	1059664	2862	117.5	6.62	19.6	spring
Z5	560029	1061185	2864	104.5	6.84	19.2	spring
Z6	543167	1045463	2837	372	7.19	18.9	Shallow
Z7	543976	1047041	2812	391	6.9	20.7	Shallow
Z8	551711	1055171	2778	277.8	6.74	19.3	Shallow
Z9	572958	1066589	3115	84.8	6.57	15.7	Hand dug well
Z10	572398	1065845	3106	337	6.59	14.9	shallow well
Z11	555477	1067455	2768	245	6.73	19.5	Shallow
Z12	538017	1040391	2957	269	6.38	19.1	shallow well
Z13	536255	1036077	2926	143.7	6.86	18.4	shallow well
Z14	529506	1035996	2817	290	6.73	21.8	shallow well
Z15	529892	1034365	2816	362	6.73	17.6	shallow well
Z16	544068	1035539	2794	129.1	6.49	18.2	spring
Z17	546461	984693	1780	538	6.67	31.1	Shallow well
Z18	545506	1017771	2723	217	6.88	21.9	spring
Z19	545356	1017171	2715	318	6.75	20.6	spring

4.2 Hadrochemical analysis

The study area consists of different aquifer systems that ranges from highly productive porous aquifer systems to double porous aquifer systems distributed both in the plateau and the escarpment. From the explanatory borehole lithologic logs, majority of borehole have a depth of penetration less than 150m are considered to be shallow groundwater system which lies mainly on the basalt and ignimbrite rock units in the plateau part of the study area to an acidic volcanic rock towards the escarpment. insitu measurement of EC along with secondary data shows a good correlation coefficient. And the relationship has been used to fill missing value of TDS secondary hydro-chemical analysis results. In analysis of spatial distribution of chemical data, units of mg/l of major is used in the text, the electrical conductivity values are given µs/cm, ratios of $Ca^{+2.}$ + Mg^{+2} /Na^{+} +K^{+} is indicated as Ca/Na in the text.

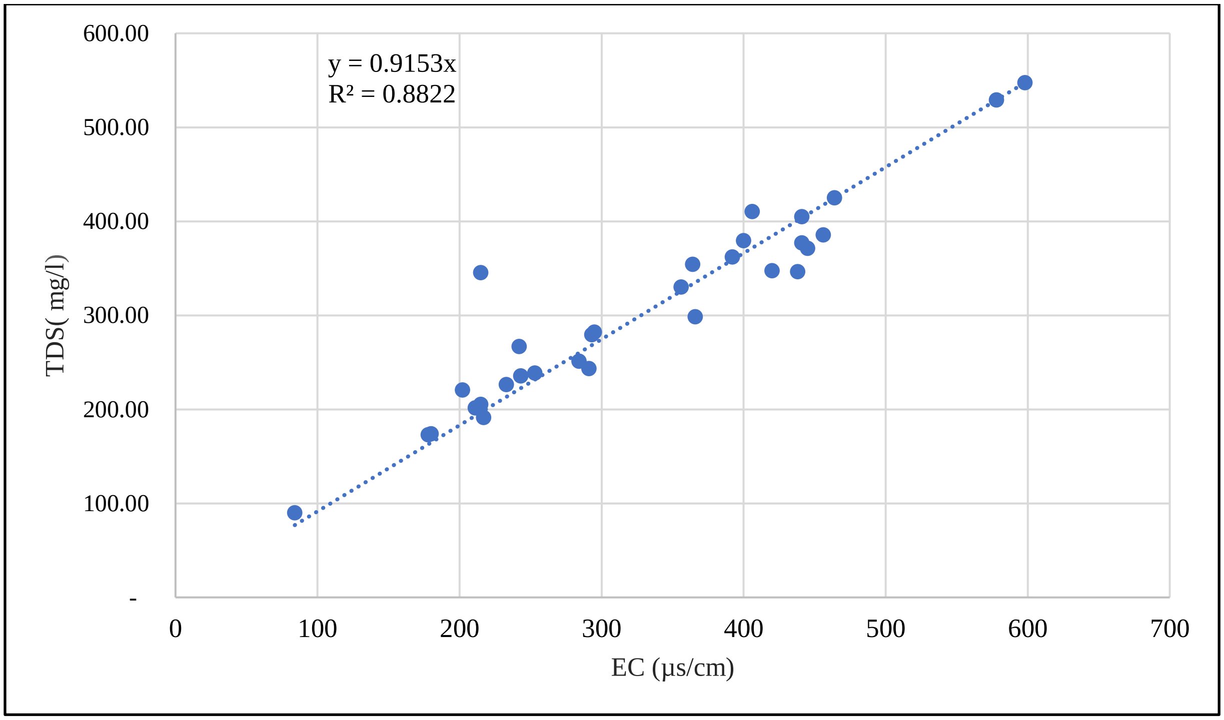


Figure 40: Relationship between E.C and TDS

4.2.1Total dissolved solids (TDS)

The solubility of a substance can be divided into electrolyte and non-electrolytes solutions. Electrolytes are those substances that dissociate into ionic forms (Positive and negative ions) and conduct electric current (Kresic, 2007). Therefore, the amount of dissolved ion constituents determines the capacity of the water to conduct electric current. Spatial distribution map of TDS has been prepared on Arc Map environment. From the analysis of the map, the amount of TDS within the study area ranges from 90.06 mg/l to 507.50 mg/l.

Comparatively the minimum and maximum value of TDS recorded within the South-Jema catchment ranges from 90 mg/l to 391 mg/l where by the lowest value is recorded at the upstream part of the plateau and the maximum value is recorded at the downstream part of the catchment whereas within the Kesum catchment, concentration of TDS ranges from 171 mg/l to 507.50mg/l where by the lowest value of record is attained at the upstream part of the catchment and highest value is recorded in the downstream part of the catchment.

From the analysis of TDS map, it has been observed a clear evolutionary trend of TDS following the Groundwater flow path in both catchments has been observed. But certain anomalies of high TDS compared to the downstream part of South–Jema catchment has been observed across the surface water divide of the catchments.

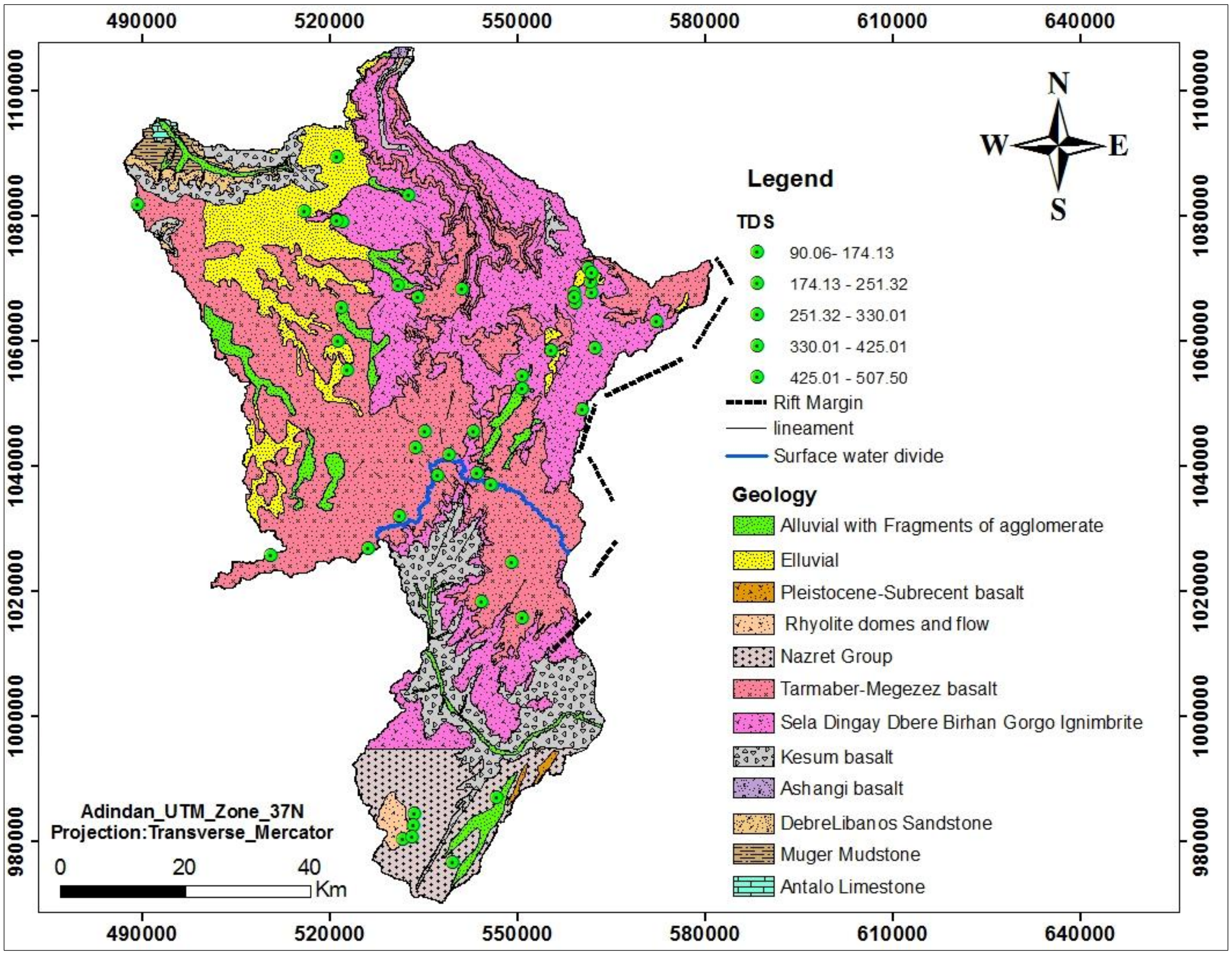


Figure 41: TDS distribution Map

4.2.2 Cations and Anions

The figure below shows distribution of cation and anion species within the study area. From the graph it is clearly observed that Na and Ca are the dominant Cation species. Compared to South Jema catchment a relative higher concentration of Na has been observed in the downstream part of Kesum catchment. Concentration of Ca increases toward downstream part of South- Jema catchment but in the case of Kesum catchment, a high value of Ca has been observed in the upstream part and Hund dug wells found in the downstream part of the catchment. Low concentration of Ca has been observed in boreholes found in the downstream part of the catchment. The bicarbonate is the dominant anion in the study area. Its concentration increases towards the downstream part of both catchments.

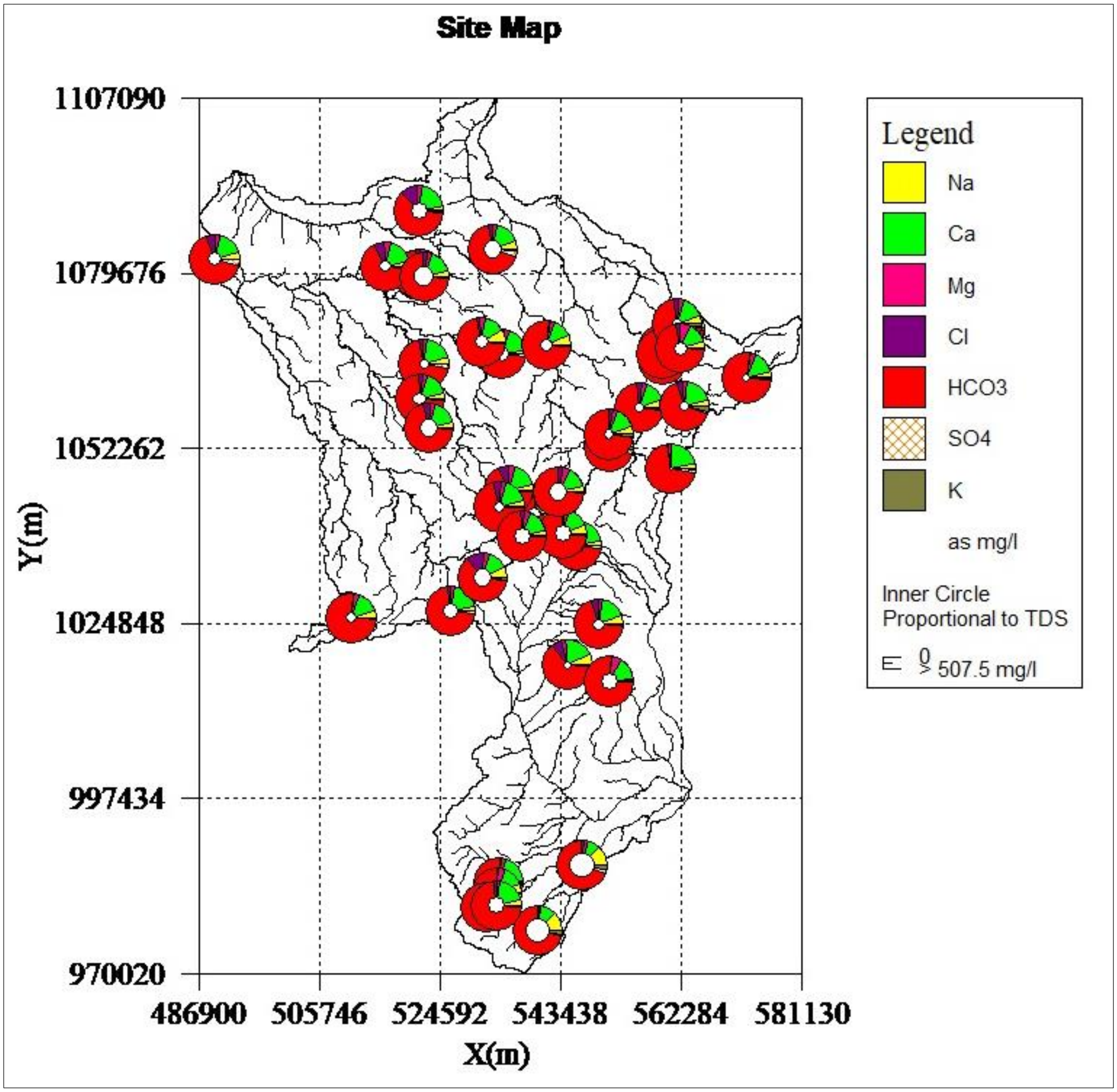


Figure 42: Distribution of Major Cation and Anion

4.2.3 Ionic Ratios

Cation ionic species and their relationship to TDS has been used to elucidate the processes that are responsible for the final make of observed composition. The graph of Na^{+}+ K^{+} Versus TDS seems to show poor correlation coefficient but, as observed from the graph below the concentration Na^{+} and K^{+} generally increase with TDS following the groundwater flow path. Whereas concentrations of Ca+ and Mg + Ratio increases during early stage of geochemical evolution due to dissolution of silicate minerals in volcanic rocks, which gradually decline when the water is saturated with respect to calcite.

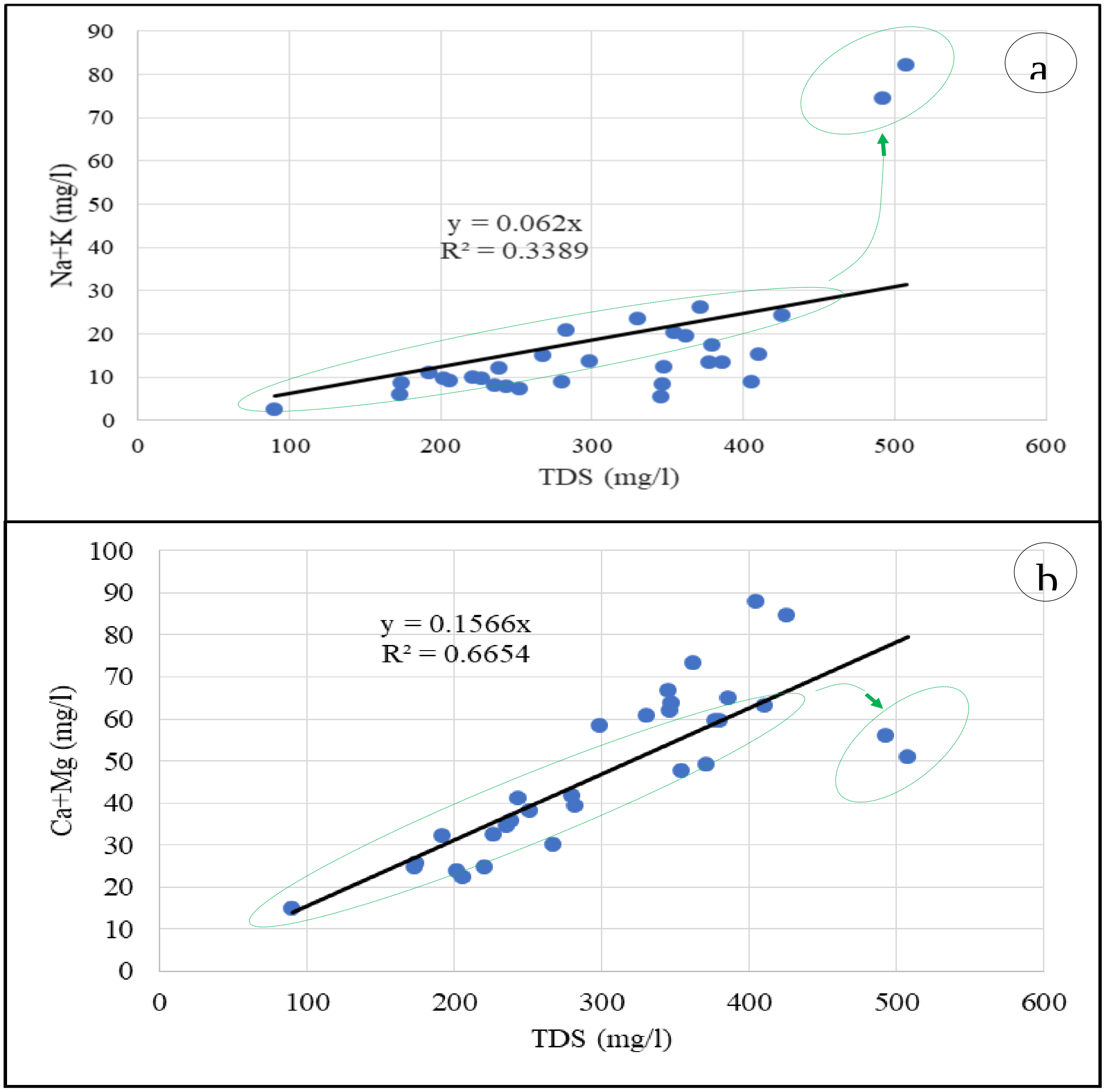


Figure 43 a) TDS Vs Na +K b) TDS Vs Ca+Mg

4.3 Water Types

The piper plot was used to classify major cations and anions in to different hydro chemical facies. From the piper plot diagram four major different Water types have been recognized where Na and Ca, dominate the cation species while bicarbonate (HCO_3) dominate the negatively charged species and the explanation is given hereunder:

4.3.1 CaCO3 Water type

This type of hydro chemical facies is distributed both in the Souh-Jema and Kesum catchments of the study area in boreholes, springs and Hund dug wells (e.g. BHT1520, DW-8, and DCSP21). In the South-Jema part of the study area they are associated with Boreholes and springs. In the case of Kesum catchment they are associated with Hund dug wells. Water types of this group represent early stage of geochemical evolution associated with shallow groundwater circulation with relatively short residence time in the sub-surface (Seifu Kebede et al., 2005, 2007).

4.3.2 Ca-Mg-HCO3 water Types

The hydro chemical facies are concentrated mostly in South-Jema catchment part of the study area. These water groups are associated with shallow system which mainly circulates in shallow basaltic aquifer systems.

4.3.3 Ca-NaHCO3 and Na-CaHCO3 water types

Water types of this group are found both in the South- Jema and Kesum within the study area.as evidenced from borehole lithologic logs the presence intercalations of clay in basaltic aquifers can give rise to anomalous concentration of dissolved ions.

According to Hem, 1992 high cation exchange minerals like clays have that capability to retain sodium to their surface, as the result cation exchange process in the groundwater systems tends to extract divalent ions Ca^{2+} from a solution and replace them with monovalent ions Na^{+}. Therefore, the presence of this water types observed especially in the plateau part of the study are cation exchange reaction of Ca by Na. In the escarpment of the study area, these types of water facies could be the result of groundwater evolutionary trend along its flow path. Along the flow path as the residence time increases sodium and potassium could be derived by dissolution of silicate minerals are responsible for such type of water facies. The geology of the study area mainly changes from basaltic rocks in the plateau to an acidic volcanic towards the escarpment and the rift. The presence of this water type to a borehole drilled to acidic volcanic rock in in the (Areti Town) confirms this idea.

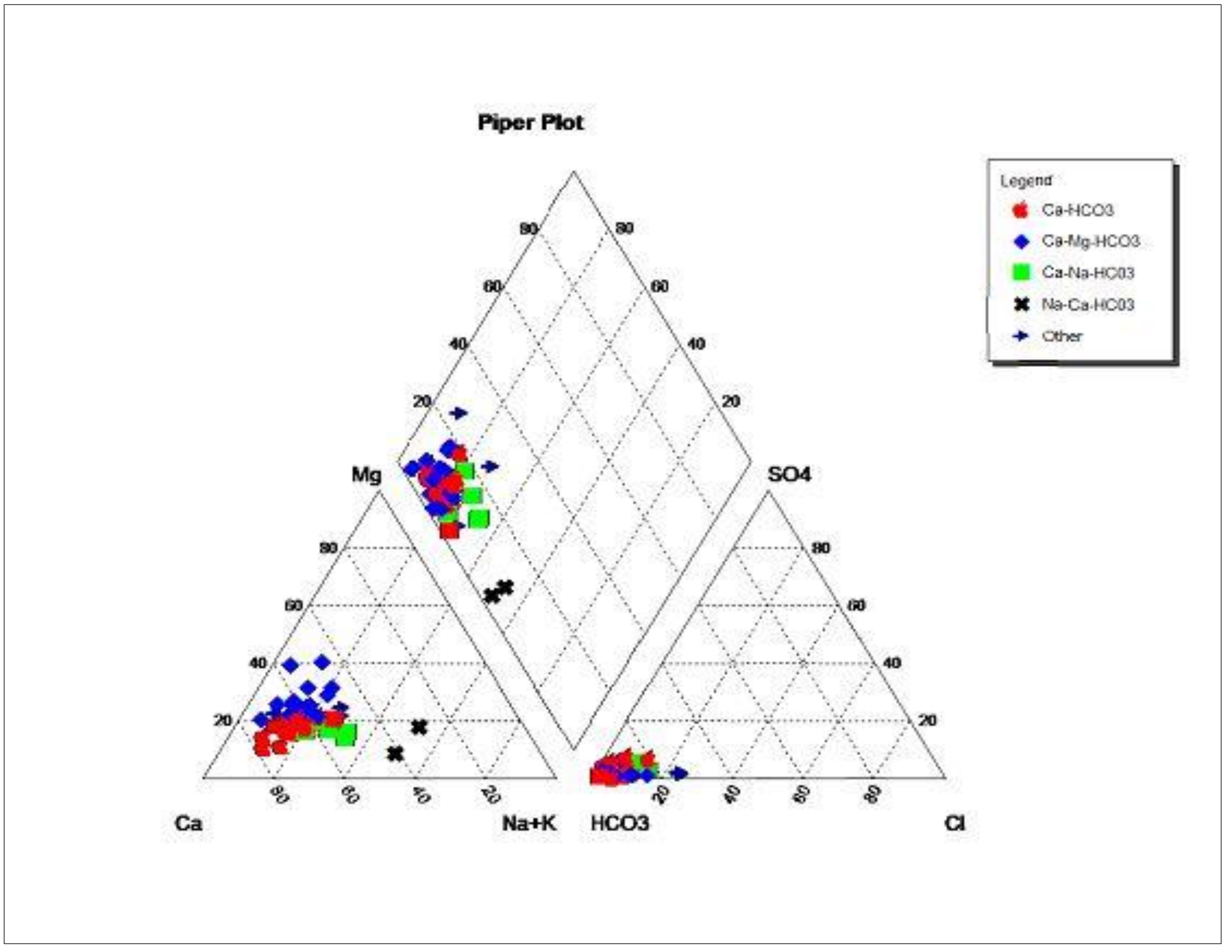


Figure 44 :Piper Plot

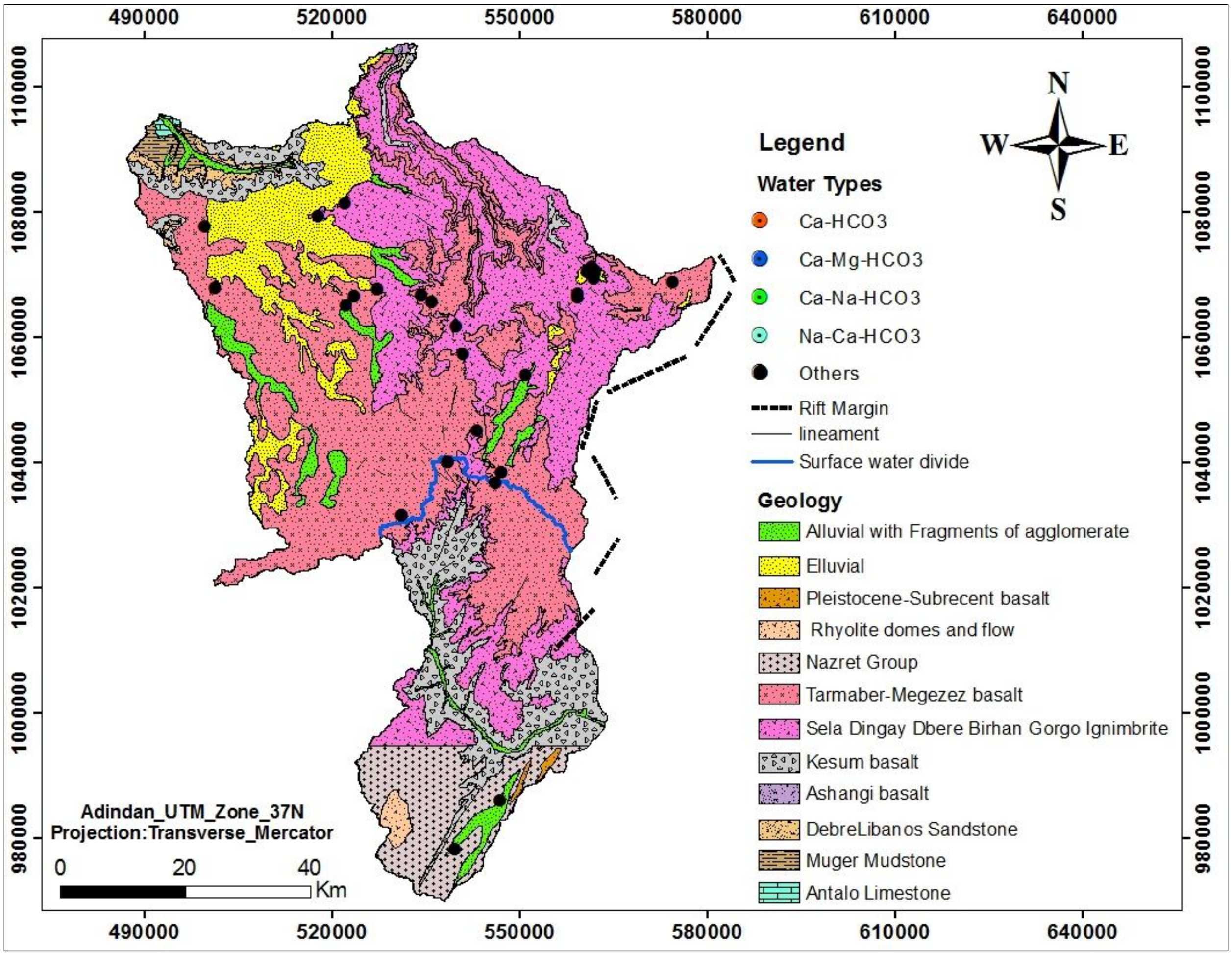


Figure 45: Groundwater facies

4.4 Groundwater flow

According to (Singhal and Gupta, 1999) Litho-Structural frame work and the presence of geological structures control the groundwater flow pattern of aquifer systems.40 borehole data ware used to reconstruct the groundwater contour map. As evidenced from groundwater elevation map aided with hydro chemical data shows the groundwater flow direction follows the topographic setup where by the groundwater moves towards the north in South -Jema catchment whereas it moves towards the south in Kesum catchment.

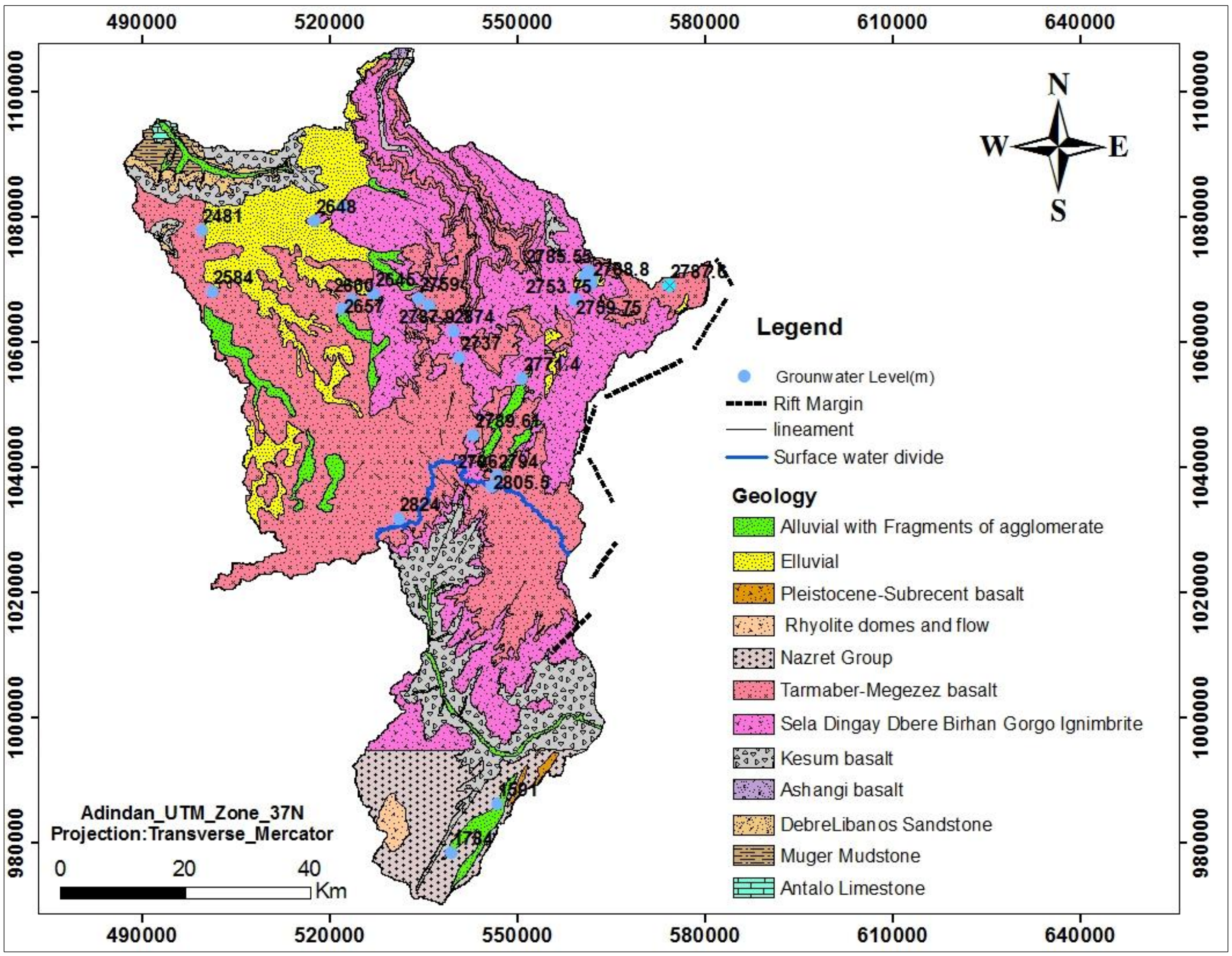


Figure 46: Groundwater level Map

Chapter Five: Conclusion and Recommendation

5.1 Conclusion and Recommendation

5.1.1Conclusion

The overall objective of this work to make a comparative study between South-Jema and Kesum catchment. Hydro chemical data has been used in order to understand the hydro chemical variability of the region. The amount of groundwater resource has been evaluated using a spatially distributed groundwater balance model, Wet pass 3.1. By coupling of this method, the following conclusion has been made.

- Na and Ca are found to be the dominant cation species whereby concentration of Na increases towards the downstream part of both catchments. Concentration of calcium shows an increment in south-Jema catchment but in the case of Kesum, its concentration begins to decline towards the downstream part when the ground waters are saturated with respect to calcite. The bicarbonate dominates the anion species where by an increment has been observed in both catchments.
- There is a clear evolutionary trend of cation ratio species where by the concentration Alkaline metals increases toward the downstream part of both catchment with increase in TDS while concentration of Alkaline Earth meals increases during early stage of geochemical evolution and gradually decline during the late stage of geochemical evolution when the water becomes saturated with respect to calcite in the Kesum catchment.
- Four types of water facies existed dominantly within the study area where by Ca-HCO3 and Ca-Mg HCO3 water types majority of water sample having this signature cluster in the plateau part of the study area, recharge zone, indicating early stage of geochemical evolution with short sub surface flow path, circulating in the shallow basaltic unit formations. A more evolved groundwater with a water facies Ca-Na HCO3 and Na-Ca HCO3 water type, where by the Ca dominating is found at the part of in south Jema sub-basin and Na dominance exhibiting in Kesum catchment.

- From the spatially distributed groundwater balance model the average long-term Recharge, Actual Evapotranspiration and Surface runoff for south-Jema catchment is found to be 122.02 mm, 380 mm, and 534 mm respectively. In the case of Kesum catchment the amount is found to be 114.91mm, 455.61mm and, 410 .08 mm respectively. Where by about 491.172 Mm^3/year and 190 Mm^3 /year of ground water is recharged to the aquifer systems of the two catchments.

5.1. 2 Recommendation

- Field based assessment of lithologic units and geological structures are required for better understanding of the chemical make up the ground water and the possible cause of anomalous signatures of hydro chemical data.
- The absence of full hydro chemical data especially on concentration of Fluoride, Nitrate has been observed in this study. Data Collection of as much Primary Water samples are required in each catchment is required for better understanding of different sources of chemical constituent of groundwater.

References

Ahimed Wolela, 2008. Sedimentation of the Triassic-Jurassic Sandstone Formation, Blue Nile Basin, Ethiopia. Journal of African Earth Sciences, 52: 30-42.

Ahimed Wolela, 2009. Sedimentation and Deposition Environments of the Barremian-Cenmanian Debre Libanose Sandstone, Blue Nile Basin, Ethiopia. Createaceous Research, 30: 1133-1145.

Andarge Yitbarek, 2009. Hydrogeological and hydrochemical framework of complex volcanic system in the Upper Awash River Basin, Central Ethiopia. University of Poitiers, France, unpublished, Ph.D. Thesis.

Andarge Yitbarek, Moumtaz R., Tenalem Ayenew, Engida Zemedagegnehu, Tilahun Azagegn, 2012. Hydrogeological and hydrochemical framework of Upper Awash River basin, Ethiopia: With special emphasis on interbasin groundwater transfer between Blue Nile and Awash Rivers. Journal of African Earth Sciences, 65:46-60.

Batelaan, O., & De Smedt, F. (2001). WetSpass: A flexible, GIS-based, distributed recharge methodology for regional groundwater modeling. In H. Gehrels, J. Peters, E. Hoehn, K., Jensen, C., Leibundgut, J., Griffioen, B., Webb, & Zaadnoordijk, W. (Eds.), Impact of human activity on groundwater dynamics (pp. 11 –17). International Association of Hydrological Sciences, IAHS Publ. no. 269.

Bonini, M., Corti, G., Innocenti, F., Manetti, P., Mazzarini, F., Abebe, T. and Pecskay, Z. (2005) Evolution of the Main Ethiopian Rift in the frame of Afar and Kenya rifts propagation. Tectonics, 24**,** TC1007, doi: 10.1029/2004TC001680.

Beccaluva L., Bianchini G., Natali C., Siena F., 2009. Continental flood basalts and mantle Plumes a case study from Northern Ethiopia Plateau. Journal of Petrology. 1: 1–27.

Bekele Abebe, Acocella, V., Tesfaye Korme, 2007. Quaternary faulting and Volcanism in the Main Ethiopian Rift. Journal of Arfican Earth Science, 48:115-124.

Bekele Abebe, Dramis,F., Fubelii,G., Mohammed Umer,Asfawossen Asrat,2010.Landslids in the Ethiopian Highlands and the Rift Margins. Journal of African Earth Science, 56:131-138.

Daneil Gemachu. (1977). Aspects of climate and Water Budget in Ethiopia. Addis Ababa University Press.

Daneil Meshesha and Shinjo, R. (2008) Rethinking geochemical feature of Afar and Kenya plumes and geodynamic implications. Journal of Geophysical Research, doi: 10.1029/2007JB005549.

Di Paola, G.M. (1972): The Ethiopian Rift Valley (between 7.00' and 8.40' lat. North). Bull. Volcanol. , 36, 317-560.

Dragoni, W., & Sukhija, B., S. (2013). Climate change and groundwater: A short review. *GeologicalSociety, London, Special Publications.* ***288***:1–12.

EIGS (Ethiopian Institute of Geological Survey) (2010). A report on Geology of Addis Ababa city. Published Report, Addis Ababa,Ethiopia.

EIGS (Ethiopian Institute of Geological Survey) (2007). A report on Geology of Debre Birhan Area. Published Report, Addis Ababa, Ethiopia.

EIGS (Ethiopian Institute of Geological Survey) (1978). A Report on Geology and Development of Nazret Area, Northern Ethiopian Rift. Published Report, Addis Ababa, Ethiopia.

EIGS (Ethiopian Institute of Geological Survey) (2011). An explanatory Note on Hydrogeological, Hydrochemical, Engineering geological map of Addis Ababa Map (NC 37-10) sub-sheet. Published Report, Addis Ababa, Ethiopia.

EIGS (Ethiopian Institute of Geological Survey) (2018). An explanatory Note on Hydrogeological, Hydrochemical map of Debre Birhan Map (NC 37-11) sub- sheet. Published Report, Addis Ababa, Ethiopia.

EIGS (Ethiopian Institute of Geological Survey) (2018). An explanatory Note on Hydrogeological, Hydrochemical map of Nazret Map (NC 37-15) sub- sheet. Published Report, Addis Ababa, Ethiopia.

EIGS (Ethiopian Institute of Geological Survey) (2018). An explanatory Note on Hydrogeological, Hydrochemical map of Were- Ilu Map (NC 37-7) sub- sheet. Published Report, Addis Ababa, Ethiopia.

EIGS (Ethiopian Institute of Geological Survey) (2019). Water Resources Management and Environmental Protection studies of Jemma River Basin for improved food security.

Freeze,R.A., and Cherry,J.A. (1979).Groundwater. Prentice-Hall,New Jersy,616 pp.

Furman, T. (2007) Geochemistry of East African Rift basalts: An overview. Journal of African Earth Sciences, 48**,** 147-160.

Gani, N. DS., Abdusalam, M.G., 2006. Remote Sensing Analysis of the Gorge of the Blue Nile, Ethiopia, with Emphasis on Dejen-Gohatsion Region. Journal of African Earth Sciences, 44: 135-150.

Gebremedhen Gebremeskel,2015. Estimation of Groundwater Recharge and Potentials under changing climate in Werii Watershed,Tekez River Basin. M.Sc thesis,Haramaya University, Haramaya, Ethiopia.

Getaneh Assefa, 1981. Gohatsion Formation: A New Lithostratigraphic Unit from the Blue Nile River Basin, Ethiopia. Geosciences Journal, 1: 63-88.

Getaneh Assefa, 1991. Lithostratigraphy and Environment of Deposition of the Late Jurassic-Early Cretaceous Sequences of the Central Part of Northern Plateau, Ethiopia. N.Jb. Geol, 182: 255-284.

Hem, J. D., 1985. Research and Interpretation of the Chemical Characteristics of Natural Water (3rd edition), U.S Geological Survey Water Supply Paper 2254: 1 - 263.

Kazmin, V. (1972) Geological map of Ethiopia, scale 1:2,000,000. Ethiopian Institute of Geological Survey, Addis Ababa, Ethiopia.

Kazmin, V. (1979): Stratigraphy and correlation of volcanic rocks of Ethiopia. Ethiopian Institute of Geological Surveys. Note number 106: 1- 26.

Kididst Hailu, 2016. Groundwater Dynamics in the Tributary streams of Muger and Holota River catchment. Unpublished M.Sc. thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Keiffer, B., Ardnt, A.,and Claudin Meugnet, 2004. Flood and Shield basalts from Ethiopia: Magma from the African Super swell. Journal of Petrology, 45: 793-834.

Mengesha Tefera, Tesfaye Cherinet, Workneh Haro, 1996. Explanation of the Geological Map of Ethiopia, 2nd edition, 1:2000000 scale.

Molla Demlie, Stefan, W., Tenalem Ayenew, 2008. Major ion hydrochemistry and environmental isotope signatures as a tool in assessing groundwater occurrence and its dynamics in a fractured volcanic aquifer system located within a heavily urbanized catchment, central Ethiopia. Journal of Hydrology, 353: 175–188.

Seifu Kebede, 2004. Environmental isotope and geochemistry in groundwater and hydrology lake cases from Blue Nile basin, main Ethiopian rift and Afar, Ethiopia, PhD.Thesis,University of Avignon.

Seifu Kebede, Yves Travi, Tamiru Alemayehu, Tenalem Ayenew, 2005. Groundwater recharge, circulation and geochemical evolution in the source region of the Blue Nile River, Ethiopia. Applied Geochemistry, 20: 1658–1676.

Seifu Kebede, Yves Travi, Asfawosen Asrat, Tamiru Alemayehu, Tenalem Ayenew, Zenaw Tesema, 2007. Groundwater Origin and Flow Along Selected Transects in Ethiopia Rift Volcanic Aquifers. Hydrogeology Journal, 10:1007-1040.

Seifu kebede, Yves Travi and Susanne Stadler, 2010. Ground waters of the central Ethiopian rift: diagnostic trends in trace elements, $\delta 18O$ and trace elements. Hydrogeology Journal.

Seifu Kebede. (2013). Groundwater in Ethiopia. Springer Hydrogeology.

Singal, B.B.S. and Gupta, R.P., 1999. Applied Hydrogeology of Fractured Rocks. Springer, London, pp 429.

Tenalem Ayenew and Tamiru Alemyahu, 2001. Principle of Hydrogeology, AAU press.

Tenalem Ayenew (2003). Environmental isotope-based integrated hydrogeological study of some Ethiopian rift lakes. Journal of Radio-analytical and Nuclear Chemistry 257(1):11 – 16.

Tenalem Ayenew, Molla Demlie, Wohnillich, S., 2008. Hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers. Journal of African Earth Sciences, 52: 97-113.

Tesfaye Korme, Acocella, V., Bekele Abebe, 2004. The Role of Pre-existing Structures in the Origin, Propagation and Architecture of Faults in the Main Ethiopian Rift Gondwana Research, 2: 467-479.

Tsegaye Abebe (2014). The Occurrence of complete continental rift type of volcanic rocks suite along the Yerer-Tullu-wellel volcano Tectonic Lineament, central Ethiopia. Journal of African Earth Sciences, 99:374-385.

Tilahun Azagegn, 2008 Hydrogeochemical characterization of aquifer systems in upper awash and adjacent abay plateau using geochemical modeling and isotope hydrology. Unpublished M.Sc. thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Tilahun Azagegn, 2015. Groundwater Dynamics in the Left Bank Catchments of the Middle Blue Nile and the Upper Awash River Basins, Central Ethiopia. Unpublished Ph.D Thesis. University of Addis Ababa, Addis Ababa Ethiopia.

Tilahun Azagegn, Asfawossen Asrat,Tenalem Ayenew ,Seifu Kebede ,2015. Litho-stuctural control on inter basin groundwater Transfer in central Ethiopia. Journal of African Earth Sciences,101:383-395.

Todd, D.K., 1976. Groundwater Hydrology (2nd edition), John Willey and Sons, New York, pp 535.

Visentin, E.J., Micoletti, L. Tolomeo and Zanettin, B., 1974. Miocene and Pliocene Rocks of the Addis Ababa – Debra Berhan Area (Ethiopia) Geo-Petrographic and Radiometric Studies, Geological Surveys of Ethiopia, unpublished report, Addis Ababa, Ethiopia.

Wakgari Furi, 2011. Hydrogeological System Analysis of the Middle Awash Basin, Ethiopia. University of Poitiers, France unpublished Ph.d. Thesis.

WWDSE, 2008. Adaa-Becho Groundwater Resource Evaluation for Irrigation. Unpublished report, Addis Ababa, Ethiopia.

Zanettin, B. and Justin Visentin, E. (1973) the volcanic Succession in central Ethiopia. Bull. Soc. Geol.Ital., 90, 313-327.

Zanettin, B., Justin, E., Viesntin, E. Piccirillo, M., 1974. Geological and Petrological Researches on the Volcanics of Central Ethiopia. Geological Surveys of Ethiopia, Addis Ababa, and unpublished report.

Zanettin, B., Justin-Visentin, E., Niccoletti, M. and Piccirllo, E.M. (1980): Correlation among Ethiopian volcanic formations with special references to the chronological and stratigraphic problems of the Trap series. Rome, Italy, Accademia Nazionale dei Lincei, 47: 231-2.

Appendices

Groundwater Types

Sample ID	Station ID	X coordinate	Y coordinate	Water Type
BHS1	47	546842	986989	Na-Ca-HCO3
BHS2	46	539897	976670	Na-Ca-HCO3
BHT1520	30	546007	1036961	Ca-HCO3
BHT1521	31	539356	1041891	Ca-Mg-HCO3
BHT1523	32	522137	1065293	Ca-HCO3
BHT1524	33	526300	1026800	Ca-HCO3
BHT1525	34	534308	1066945	Ca-Mg-HCO3
BHT1616	35	559369	1067725	Ca-HCO3
BHT1617	36	559318	1066823	Ca-Na-HCO3
BHT1619	37	561897	1069503	Ca-HCO3
BHT1619	38	551014	1052479	Ca-Na-HCO3
BHT1620	39	562106	1070685	Ca-Na-HCO3
BHT1621	40	562015	1071000	Ca-Mg-HCO3
BHT38	41	521310	1079208	Ca-Mg-HCO3
BHT515	42	559432	1066077	Ca-HCO3
BHT579	43	559277	1067055	Ca-HCO3
DBH12	1	531241	1032007	Ca-Mg-Na-HCO3-Cl
DBH14	2	555694	1058493	Ca-Mg-HCO3
DBH16	3	543775	1038871	Ca-Na-HCO3
DBH17	4	543155	1045456	Ca-Mg-HCO3
DBH18	5	550965	1054370	Ca-HCO3
DBH19	6	521406	1079418	Ca-Mg-HCO3
DBH20	7	531119	1068827	Ca-Na-Mg-HCO3
DBH22	8	541284	1068348	Ca-Na-HCO3
DBH27	9	510749	1025652	Ca-Mg-HCO3
DBH28	10	561597	1071647	Ca-Mg-HCO3
DBH7	11	516160	1080692	Ca-Mg-HCO3
DBH9	12	522173	1079088	Ca-HCO3
DCSP14	13	521471	1059909	Ca-HCO3
DCSP16	14	562711	1058789	Ca-HCO3
DCSP18	15	560655	1049119	Ca-HCO3
DCSP20	16	544561	1018246	Ca-Na-HCO3
DCSP21	17	549400	1024627	Ca-HCO3
DCSP23	18	535420	1045613	Ca-Mg-HCO3
DCSP24	19	533862	1043003	Ca-Mg-HCO3
DCSP25	20	562152	1067829	Ca-Mg-HCO3

DCSP6	21	572478	1063198	Ca-Mg-HCO3
DHDW12	22	551017	1015722	Ca-Mg-HCO3
DHDW7	23	521384	1089373	Ca-Mg-HCO3-Cl
DHDW8	24	522924	1055406	Ca-Mg-HCO3
DHDW9	25	537428	1038453	Ca-Mg-HCO3
DW-5	26	533698	984286	Ca-Mg-HCO3
DW-6	27	533476	982572	Ca-Mg-HCO3
DW-7	28	531841	980318	Ca-Mg-HCO3
DW-8	29	533429	980683	Ca-HCO3
SPT509	44	532826	1083279	Ca-HCO3
SPT510	45	489497	1081850	Ca-HCO3

Groundwater Level

FID	UTM_N	UTM_E	GWL	SWL	Elevation
BH1	483172	1061127	2602.85	28.15	2631
BH2	559277	1067055	2759.75	6.25	2766
BH3	560716	1070578	2782.08	7.92	2790
BH4	546007	1036961	2805.5	11.5	2817
BH5	543073	1045257	2789.61	51.39	2841
BH6	550872	1054157	2771.4	6.6	2778
BH7	562016	1070480	2788.21	12.79	2801
BH8	561928	1070820	2787.32	11.68	2799
BH9	561901	1069500	2788.8	9.2	2798
BH10	574362	1069000	2787.6	7.4	2795
BH11	561507	1071446	2785.55	11.45	2797
BH12	559242	1066637	2753.75	6.25	2760
BH13	501322	1068067	2584	70	2654
BH14	522021	1081587	2645.3	6.7	2652
BH 15	517671	1079518	2648	3	2651
BH16	535934	1065864	2787.9	22.1	2810
BH17	522137	1065293	2657	3	2660
BH18	523522	1066826	2660	1	2661
BH19	540847	1057529	2737	18	2755
BH20	539856	1061843	2874	6	2880
BH21	527123	1067773	2645	1	2646
BH22	546910	1038657	2796	2	2798
BH23	534285	1066959	2759	7	2766
BH24	499617	1077915	2481	80	2561
BH25	531153	1031801	2824	5	2829

BH26	546826	986191	1591	129	1720
BH27	554349	988809	1561	188.9	1750
BH28	539540	978445	1784	115.8	1900
BH29	546984	981524	1684	115.8	1800
BH30	580079	989682	977	22.6	1000
BH31	501564	974968	1874	25.59	1900
BH32	501564	974968	1871	28.58	1900
BH33	501564	974968	1875	24.87	1900
BH34	501564	974968	1876	24.1	1900
BH35	501564	974968	1877	22.64	1900
BH36	560042	968804	1014	177.15	1191
BH37	546910	1038657	2794	2	2796
BH38	538520	1040269	3006	3	3009
BH39	502600	1011700	2443	82	2525
BH40	531153	1031801	2852	5	2857

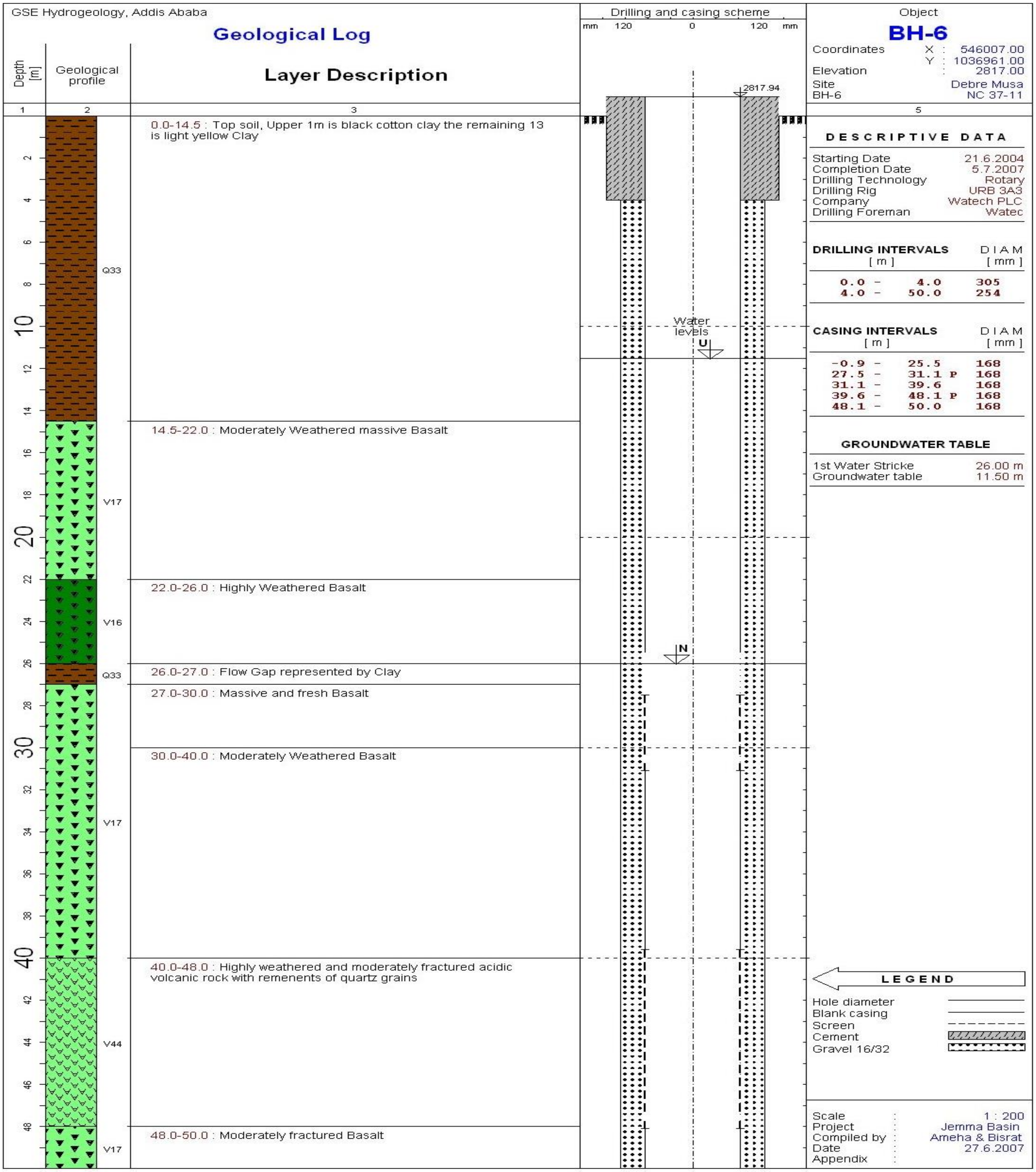
Water quality Data

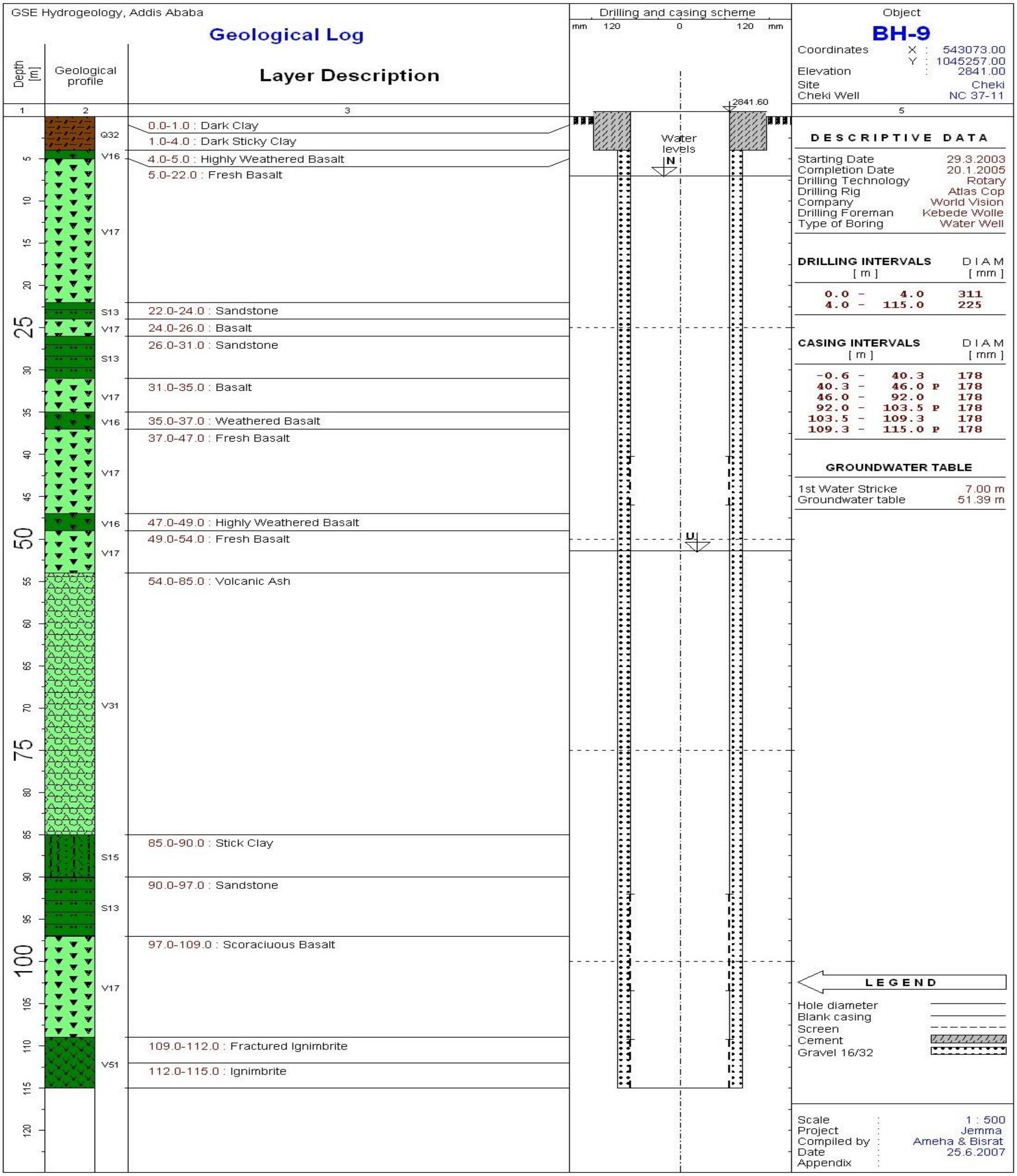
ID	Location	E	N	Elevation	Na	K	Ca	Mg	HCO_3	Cl	F	SO_4	NO_3	pH	EC	TDS
DBH12	Sheno	531241	1032007	2823	21.3	5.07	37.7	11.5	179.34	34.03	0.62	2.14	10.19	7.33	445	371.23
DBH14	Arikeso	555694	1058493	2791	7.2	2.08	18.2	4.2	90.28	4.54	0.43	0.75	8.86	7.18	215	205.44
DBH16	Kotu	543775	1038871	2807	16.9	3.53	39.55	8.15	202.52	6.45	0.82	0.73	6.2	7.48	364	354.19
DBH17	Cheki	543155	1045456	2831	12.2	1.4	44.3	15.3	237.9	11.13	0.34	1.1	14.62	7.53	441	377.24
DBH18	Chacha	550965	1054370	2768	7.75	2.35	20.3	4.55	106.14	4.04	0.43	0.82	5.32	7.62	202	220.6
DBH19	Deneba	521406	1079418	2648	15.5	2.09	47.2	12.6	223.26	9.07	0.56	0.73	10.63	7.73	400	379.42
DBH20	Moya Gadula	531119	1068827	2672	18.95	1.97	31.25	8.2	161.04	4.82	0.29	0.85	16.83	7.73	295	282.29
DBH22	Muti Cherkos	541284	1068348	2750	13.2	2	24.3	5.8	146.4	1.77	0.62	0.75	3.54	7.44	242	266.86
DBH27	Wondo Bida	510749	1025652	2918	9.2	0.53	26.5	6.2	137.86	1.13	0.28	0.72	9.3	7.52	233	226.39
DBH28	Debre Birhan	561597	1071647	2789	7.2	2.49	19.65	4.43	92.72	5.03	0.38	0.64	6.65	7.18	211	201.68
DBH7	Gasha amiba	516160	1080692	2610	6.7	0.73	30.75	7.65	115.9	12.69	0.2	2.11	29.22	7.25	284	251.32

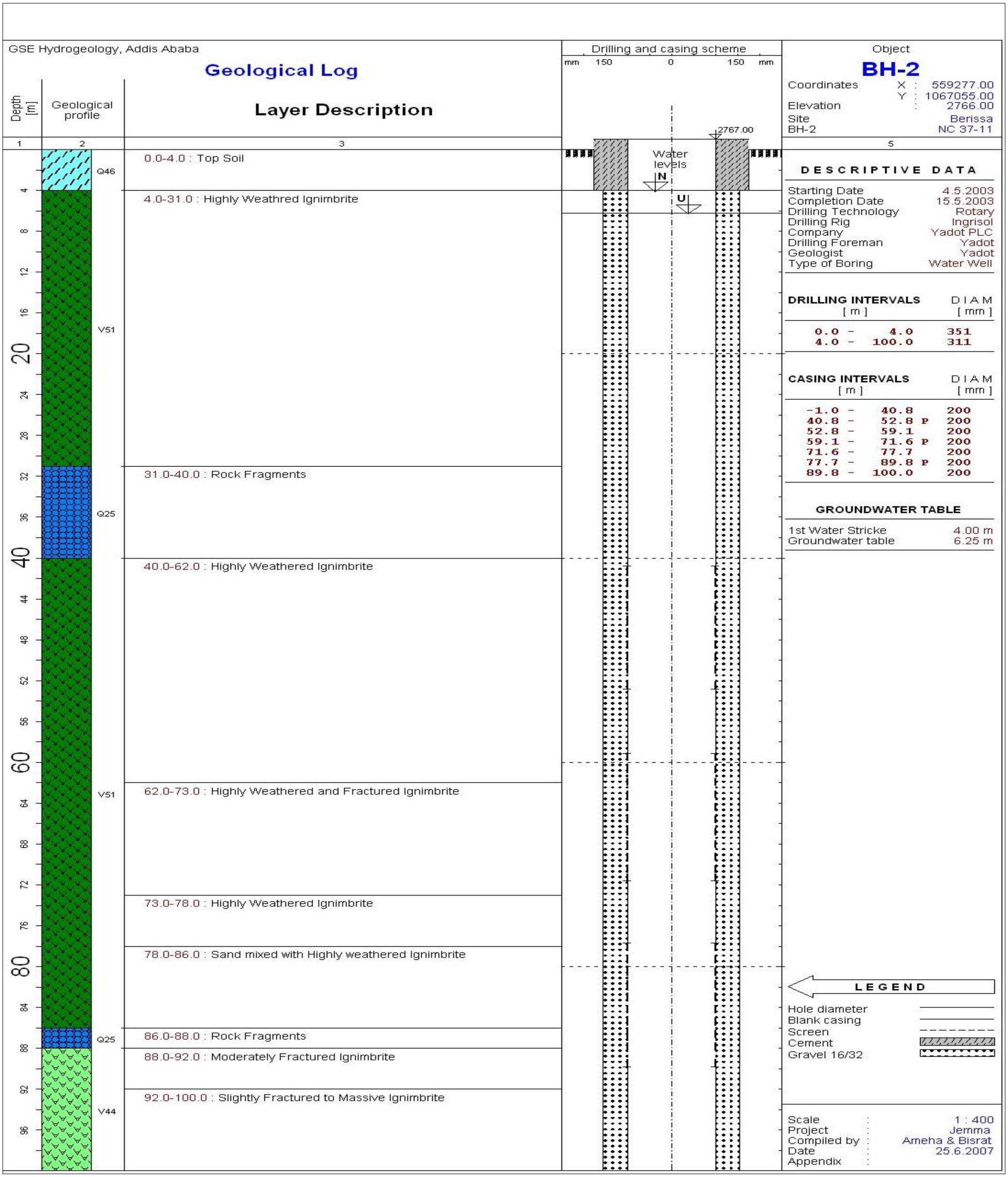
DBH9	Deneba	522173	1079088	2667	13.9	1.54	53.2	10.2	245.22	11.41	0.62	1.56	10.63	7.23	406	410.34
DCSP14	Mutie	521471	1059909	2656	8.3	0.63	35.1	6.75	159.82	6.1	0.28	1.53	8.86	7.11	293	279.63
DCSP16	Tsigereda	562711	1058789	2895	5.8	5.39	28	4.3	93.94	5.81	0.28	2.21	13.73	7.03	217	191.56
DCSP18	Tera Atir	560655	1049119	2864	2.2	0.45	13.8	1.1	45.14	0.43	0.12	1.56	0.44	6.68	84	90.06
DCSP20	Hagere Mariam	544561	1018246	2712	8.5	0.11	22.4	3.4	74.42	7.78	0.2	1.79	22.15	7.88	180	174.13
DCSP21	Nefas Amiba	549400	1024627	2886	10.8	1.42	30.85	5.05	126.88	8.86	0.28	1.46	10.63	7.86	253	238.6
DCSP23	Ade Deleti	535420	1045613	2898	7.2	0.81	32.6	8.6	130.54	13.75	0.45	1.06	17.72	7.49	291	243.55
DCSP24	Masit	533862	1043003	2837	7.5	0.69	28.9	5.75	124.44	9.08	0.18	0.94	8.86	6.98	243	235.56
DCSP25	Debre Birha no.7	562152	1067829	2789	12	1.84	38.4	20.1	201.3	8.22	0.3	1.2	15.06	7.42	366	298.42
DCSP6	Dibat	572478	1063198	3051	5.1	0.87	20.1	4.7	101.26	0.92	0.5	1.52	1.77	7.22	178	173.12
DHDW12	Gorfu	551017	1015722	2909	4.9	0.51	47	19.9	242.38	2.48	0.13	1.55	1.33	6.92	215	345.43
DHDW7	Mangudo	521384	1089373	2655	7.7	0.66	51.7	10.3	159.82	29.57	0.2	3.67	42.53	7.13	438	346.38
DHDW8	Abdela	522924	1055406	2660	12.3	1.28	54	11.1	226.92	15.1	0.23	1.79	21.71	7.19	456	385.52
DHDW9	Wonitu	537428	1038453	2920	12.4	0.01	50.8	13	246.44	9.1	0.49	0.84	11.1	7.64	420	347.56
DW-5	Bokan Tseiti	533698	984286	0	5	4	75.35	12.65	299.75	2.49		5.35		7.4	441	405.01
DW-6	Bokan Tebela	533476	982572	0	19	4.5	45.49	15.56	237.9	2.26		5		7.84	356	330.01
DW-7	Bokan Arba Chorga No.1	531841	980318	0	20	4.5	67.33	17.56	303.54	7.56		5		7.6	464	425.01
DW-8	Bokan Arba Chorga No.2	533429	980683	0	15	4.5	67.33	6.23	259.98	8.88		0		7.6	392	362.01
BHT1520	A	546007	1036961	0	8	0.8	45	7	184	3	1	5	4.4	7.6		312
BHT1521	B	539356	1041891	0	13	1.1	35	8	167	5	0.4	8	5.3	8		269

BHT1523	C	522137	1065293	0	7	0.8	28	4	105	4	0.2	4	6.7	7.6		197
BHT1524	D	526300	1026800	0	8	0.4	53	6	194	7	0.3	5	4	7.8		318
BHT1525	E	534308	1066945	0	6	0.8	43	10	183	7	0.2	4	12	7.9		296
BHT1616	F	559369	1067725	0	9.7	3.2	25.2	5.1	108.3	6	0.5	0.6	13.2	7.3		146
BHT1617	G	559318	1066823	0	20	4.5	30.4	5.8	150	7.9	0.5	6.6	7.5	7.8		164
BHT1619	H	561897	1069503	0	10	2.2	28	5.4	127	3	0.5	0.8	4.8	7.7		132
BHT1619	I	551014	1052479	0	21	4.7	42	7.6	173.1	11.8	0.7	8.7	6.8	7.3		200
BHT1620	J	562106	1070685	0	20	4.5	31.2	4.9	148	7.9	0.5	7.7	7	7.7		162
BHT1621	K	562015	1071000	0	7.7	2.6	25.2	5.1	110	2.9	0.5	0.3	7.5	7.3		116
BHT38	L	521310	1079208	0	18	2	38	15	212	9	0.5	8	8.9	7.7		364
BHT515	M	559432	1066077	0	6.7	2.4	26.1	3.7	94.6	5.8	0.2	1.1	5.4	6.9		110
BHT579	N	559277	1067055	0	9	2.7	26	4	116	2	0.6	5	3.5	7.4		229
SPT509	Q	532826	1083279	0	17	3	50	9	203	9	0.6	13	22.6	7.5		391
SPT510	R	489497	1081850	0	18	0.8	60	12	240	22	1.1	15	14	7.8		313.3
BHS2	Bologiorgis	539897	976670	1963	61	13.7	49.8	6.2	343	4		4.2	3.35	8.09	578	
BHS1	Arerti	546842	986989	1741	66	16.2	37.6	13.5	339	8.7		12.7	10.5	7.12	598	

Lithologic Logs




GSE Hydrogeology, Addis Ababa
Geological Log
Depth [m]
Geological profile
Layer Description
Drilling and casing scheme
Object
BH-9
Coordinates X : 543073.00
Y : 1045257.00
Elevation : 2841.00
Site Cheki
Cheki Well NC 37-11
2841.60
Water levels
0.0-1.0 : Dark Clay
1.0-4.0 : Dark Sticky Clay
4.0-5.0 : Highly Weathered Basalt
5.0-22.0 : Fresh Basalt
22.0-24.0 : Sandstone
24.0-26.0 : Basalt
26.0-31.0 : Sandstone
31.0-35.0 : Basalt
35.0-37.0 : Weathered Basalt
37.0-47.0 : Fresh Basalt
47.0-49.0 : Highly Weathered Basalt
49.0-54.0 : Fresh Basalt
54.0-85.0 : Volcanic Ash
85.0-90.0 : Stick Clay
90.0-97.0 : Sandstone
97.0-109.0 : Scoraciuous Basalt
109.0-112.0 : Fractured Ignimbrite
112.0-115.0 : Ignimbrite
Q32
V16
V17
S13
V17
S13
V17
V16
V17
V16
V17
V31
S15
S13
V17
V51
DESCRIPTIVE DATA
Starting Date 29.3.2003
Completion Date 20.1.2005
Drilling Technology Rotary
Drilling Rig Atlas Cop
Company World Vision
Drilling Foreman Kebede Wolle
Type of Boring Water Well
DRILLING INTERVALS [m] DIAM [mm]
0.0 - 4.0 311
4.0 - 115.0 225
CASING INTERVALS [m] DIAM [mm]
-0.6 - 40.3 178
40.3 - 46.0 P 178
46.0 - 92.0 178
92.0 - 103.5 P 178
103.5 - 109.3 178
109.3 - 115.0 P 178
GROUNDWATER TABLE
1st Water Stricke 7.00 m
Groundwater table 51.39 m
LEGEND
Hole diameter
Blank casing
Screen
Cement
Gravel 16/32
Scale : 1 : 500
Project : Jemma
Compiled by : Ameha & Bisrat
Date : 25.6.2007
Appendix :


GSE Hydrogeology, Addis Ababa
Geological Log
Depth [m]
Geological profile
Layer Description
Drilling and casing scheme
mm 150 0 150 mm
2767.00
Water levels
N
U
Object
BH-2
Coordinates X : 559277.00
Y : 1067055.00
Elevation : 2766.00
Site Berissa
BH-2 NC 37-11
1 2 3 5
Q46
V51
Q25
V51
Q25
V44
0.0-4.0 : Top Soil
4.0-31.0 : Highly Weathred Ignimbrite
31.0-40.0 : Rock Fragments
40.0-62.0 : Highly Weathered Ignimbrite
62.0-73.0 : Highly Weathered and Fractured Ignimbrite
73.0-78.0 : Highly Weathered Ignimbrite
78.0-86.0 : Sand mixed with Highly weathered Ignimbrite
86.0-88.0 : Rock Fragments
88.0-92.0 : Moderately Fractured Ignimbrite
92.0-100.0 : Slightly Fractured to Massive Ignimbrite
DESCRIPTIVE DATA
Starting Date 4.5.2003
Completion Date 15.5.2003
Drilling Technology Rotary
Drilling Rig Ingrisol
Company Yadot PLC
Drilling Foreman Yadot
Geologist Yadot
Type of Boring Water Well
DRILLING INTERVALS [m] DIAM [mm]
0.0 - 4.0 351
4.0 - 100.0 311
CASING INTERVALS [m] DIAM [mm]
-1.0 - 40.8 200
40.8 - 52.8 P 200
52.8 - 59.1 200
59.1 - 71.6 P 200
71.6 - 77.7 200
77.7 - 89.8 P 200
89.8 - 100.0 200
GROUNDWATER TABLE
1st Water Stricke 4.00 m
Groundwater table 6.25 m
LEGEND
Hole diameter
Blank casing
Screen
Cement
Gravel 16/32
Scale : 1 : 400
Project : Jemma
Compiled by : Ameha & Bisrat
Date : 25.6.2007
Appendix :

Dug Well	Loction	E	N	Elelevation	EC µS/cm)	T (ºC)	Depth	Aquifer
DHDW12	Gorfu	551017	1015722	2909	217	15.8	9	Tarmaber Basalt

Land use/Land Cover Parameter Table

Code	LUSE_TYPE	RUNOFF_VEG	VEG_AREA	BARE_AREA	IMP_AREA	OPENW_AREA	ROOT_DEPTH	LAI	MIN_STOM	VEG_HEIGHT	n Manning	Land Factor	Aerodynamic Resistance
1	city - buildig	grass	0.2	0	0.8	0	0.3	2	100	0.12	0.03	0.667	212.0135
7	excavation	bare soil	0	1	0	0	0.05	0	110	0.001	0.09	0.222	692.1602
21	agriculture	crop	0.8	0.2	0	0	0.4	4	180	0.6	0.037	0.541	115.0131
23	meadow	grass	1	0	0	0	0.3	2	100	0.2	0.07	0.286	177.4676
28	wet dow	grass	1	0	0	0	0.3	2	100	0.3	0.055	0.364	152.4954
33	mixed st	forest	1	0	0	0	2	5	375	16	0.1	0.2	28.09757
36	shrub	grass	1	0	0	0	0.6	6	110	2	0.05	0.4	66.32867
44	mud salt marsh	open er	0.4	0.2	0	0.4	0.3	2	110	0.5	0.035	0.571	124.2209

Soil Parameter Table

Code	SOIL	FIELDCAPAC	WILTINGPNT	PAW	RESIDUALWC	A1	EVAPODEPTH	TENSIONHT	P_FRAC_SUM	P_FRAC_WIN	Teta
3	sand oam	0.21	0.09	0.1	0.041	0.4	0.05	0.15	0.09	0.01	0.26
5	loam	0.25	0.12	0.1	0.027	0.3	0.05	0.11	0.15	0.02	0.33
12	clay	0.46	0.33	0.1	0.09	0.2	0.05	0.37	0.95	0.85	0.85