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ONE LAYER TRANSIENT GROUNDWATER FLOW MODELING AT BECHO PLAIN

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

SIMEGNEW TADEG MELKIE
ADDIS ABABA, ETHIOPIA
MAY, 2019

ONE LAYER TRANSIENT GROUNDWATER FLOW MODELING OF BECHO PLAIN

By
Simegnew Tadeg

Advisor
Dr. Tilahun Azagegn

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

ADDIS ABABA UNIVERSITY
Addis Ababa, Ethiopia
May, 2019

Statement of the Author

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

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Date: May, 2019

This thesis has been submitted for examination with my approval as University Advisor

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Signature:_____________

Date:_________________

Addis Ababa University
School of Graduate Studies

This is to certify that the thesis prepared by Simegnew Tadeg, entitled: One layer Transient Groundwater Flow Modeling at Becho Plain and submitted in partial fulfillment of the requirements for the Degree of Master of Science (Hydrogeology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Examiner Seifu Kebede (PhD) Signature ____________________ Date ________________

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Abstract

The study focused on assessment of groundwater level responses and its spatial and temporal variability of the Becho plain using transient state flow following from steady state Modeling. Nowadays most of the water for domestic, irrigation and industrial within the study area is from the groundwater. Despite of this, the effect of abstraction with respect to recharge is not well assessed.

The groundwater recharge of the study area is mainly from direct rainfall. WetSpass modeling and Base flow separation was employed to estimate the recharge of the study area. The groundwater recharge was estimated with WetSpass modeling and Base flow separation is 120 mm/year and 85.78 mm/year (10.65% &7.8% of the annual rainfall) respectively.

The finite difference schematization of the modeled area was discretized into a uniform squared grid size 400m by 400m, comprising 265 rows and 226 columns. The transient model was simulated with MODFLW pm8 for a period of one year for one layer aquifer of 500 meter thickness. The initial aquifer parameters (hydraulic conductivity and initial hydraulic heads) were used from the steady state model.

The model was calibrated with trial and error by adjusting hydraulic conductivity and groundwater recharge by comparing the observed and simulated values. In MODFLOW, average groundwater recharge was simulated 97.72 mm/year which is within the range of recharge estimated by WetSpass model and Base flow separation methods. The water budget of the transient model shows that the aquifer storage declines from 148mm/year to 59.8 mm/year. After abstraction of groundwater with 275376 m^3day^{-1} for ten years, the groundwater declines with an average 90.87m.

Key Words: Abstraction Rate, Becho Plain, Groundwater recharge, Groundwater Flow Modeling, Groundwater Monitoring, Model Calibration, Transient state flow modeling.

Acknowledgements

First and foremost I would like to thank Addis Ababa University. I wish also to extend my gratitude to my organization for help me for this study and giving me chance to on off from work place.

I am deeply indebted to my Advisor Dr.Tilahun Azagegn for his supervision, encouragement and guidance.. His critical comments and helpful guidance gives me a chance to explore further. My deepest gratitude goes to all my Instructors for their kind support and encouragements during my research work.

I gratefully acknowledge the Ethiopian Construction and Design and Supervision Corporation and all Hydrogeology processes staffs allow me data and give time for my study and for their help during my study. I would like to extend my gratitude to colleagues for their kind advice me. I wish also to thank to Tsegaye Amisew for his comment and his help.

I would like to extend my appreciation to my classmates for their support, socialization and help to each other. Last but not least, I would like to thank my lecturers for giving me all the basics of science and their courage to help everybody. My thanks also go to every staff in the program and the institute.

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CHAPTER ONE

1. Introduction

1.1. Background

Groundwater is a critical resource in steadily increasing demand of human. In history of water use in the country in general in Addis Ababa in particular, groundwater is one of the major resource supplies for domestic, industrial and agricultural consumption. In the suburban areas of Addis Ababa; Urbanization, major industries, horticulture-floriculture and animal husbandries are extensively established and demand a huge quantity of water. Due to this reason, most of the above mentioned industries and agricultures have their own boreholes.

The impact of groundwater extraction must be monitored in the plain for proper groundwater management for both quantity and quality. The influence of seasonal variation, and the amount of abstraction are among of the factors governing the groundwater level response. Unless, the groundwater is abstracted in optimum way the final results would be unbalanced supply, which may create unsustainable and unbalance demand and supply of water.

During the past few decades, groundwater flow models have become one of the most significant components in hydrogeological assessments and management. Numerical models using computer programs for analyzing flow in groundwater systems have played an increasingly important role in the evaluation of alternative approaches to groundwater development and management.

Because of extended drought condition, increase in population size and advancement in civilizations, the recharge and potential of groundwater is decreasing and water demand is increasing at an alarming rate. This generalization is true for the Becho plain catchment.

This research work is to model an aquifer system of Becho plain transient state following steady state by assuming one layer confined /unconfined aquifer system using one year monitoring water level data to calibrate the model based on observed head, to analysis model sensitivity to different model parameter and different scenario which may be happening due to increase groundwater abstraction rate and variable recharge due to different factors of the study area. The research is expected to give insight for understanding of the behavior ground water level response of the study area which is very essential for future water resources management of the study area.

1.2. Statement of Problem

In Addis Ababa and the suburban areas of Addis Ababa groundwater usage has increased at an alarming rate due to, increase in population size, fast growing of industrialization, large scale irrigation project by Ministry of water, irrigation and energy. Government organizations as well as several individual companies are occupied in the construction of deep boreholes in the country. However there is no well-organized system to monitor & mange groundwater resource.

There is not well organized system how to manage, monitor and plan to use as compared with groundwater investigation. In order to ensure as wise management of groundwater, based on prediction is required, its present status should be studied and prediction of the future status of the water resource and groundwater level responses related to abstraction rate should be properly addressed.

The effect of abstraction with respect to recharge and water level is not well known. To understand the sensitivity of the groundwater system with respect to well abstraction, recharge and aquifer storativity it is worthwhile to assess the hydrogeological properties of the groundwater flow system using a transient state model for present and future prediction and to generate greater public awareness of the issues.

Broadly, these research works will try to solve problem related to the future use of groundwater system especially related to the water level response of the study area.

1.3. Objective

1.3.1. General objective

The main objective of the study is to asses variability of groundwater resource and groundwater level response of Becho plain with one layer transient state groundwater flow modeling following from the steady-state model.

1.3.2. Specific objective

- To develop conceptual hydrogeological model of Becho plain,
- To conduct recharge estimate and other model input parameters for the plain
- To simulate one layer transient numerical groundwater flow model of Becho plain
- To make prediction under various abstraction scenarios to illustrate the effect of future stresses on the groundwater resource of Becho plain.

1.4. Research question

- How to establish a transient model of the study area?
- Which data are necessary to establish a transient model of the study area
- How to estimate the aquifer parameters for the transient model?
- Can a transient state flow model improve our understanding of the effect of future abstractions with respect to recharge?
- How long does it take before the aquifer is affected by the groundwater abstractions?

1.5. Literature review and previous work

1.5.1. Literature review

In the modern world of the science and technology, modeling has emerged as a major tool in all branches of science (Igboekwe et al., 2008). Groundwater models are simple representation of actual physical processes. According to Anderson and Woessner (1992) groundwater flow models can be either transient or steady state and can have one, two and three spatial dimension. Steady state simulation cannot capture certain critical aspects of the groundwater system. The assessment of possible groundwater development scenarios is now possible through transient simulations (Bentley, 2007). Lubczynski (2006) advocate that transient models are more reliable in aquifer management than steady-state models because they are more constrained by temporal (monitoring) data and involve calibration of the storage coefficient, which is critical in groundwater storage prediction scenarios.

According to Lubczynski and Gurwin (2005), there are two types of transient models:

partially transient and fully transient models. In partially transient model solutions the temporal head variability is only due to the change of aquifer storage driven by stresses, e.g. well abstraction, where as the fluxes R and ET_g are time invariant, similar to steady state solutions. Whereas fully transient models are temporally variable R and ETg but it is least explored due to demanding input data requirements. The use of time as a fourth dimension makes transient model calibration far more complicated than steady state model calibration, particularly when not only storage but also input fluxes are temporally variable. The time discretization into stress periods, which largely influences the transient model solution, is a critical Modeling step. The advantage of dividing into stress periods and time steps is to allow the option of changing some parameters or stresses while the simulation progresses. More stress periods add more temporal variability in the calibration process, allow for a better fit between calculated and measured heads, but also make the calibration task more complicated and more time consuming because more stress periods and time steps need more input data and require therefore more processing time (Lubczynski and Gurwin, 2005).

Regarding to model validation and verifications different authors take in different thoughts. In order to minimize the unreliability the model has to be tested against a second independent set of stress conditions. Alas, it is frequently impossible to validate a model because usually just one set of observed data is available which already is explored for calibrations. A calibrated but unverified model can even be applied to arrive at predictions as long as careful sensitivity analysis of calibrated model is performed (Anderson and Woessner, 1992).

The applications of MODFLOW to the description and prediction of the behavior of groundwater systems have increased significantly over the last few years. MODFLOW can simulate for groundwater flow for confined, unconfined, or a combination of both aquifers, flows from external stresses such as flow to wells, aerial recharge, evapotranspiration, flow to drains, and flow through riverbeds. MODFLOW is a finite difference model code, developed by United States Geological Survey (McDonald and Harbaugh, 1988), to simulate transient groundwater flow in three-dimensions in a continuous porous medium under a variety of hydrogeological boundaries and stresses (Chiang and Kinzelbach, 1998).

1.5.2. Previous work

There have been numerous hydrogeological and groundwater modeling studies conducted in the area for the purpose to quantify the groundwater resource, groundwater flow dynamics and determine its sustainability at a regional scale.
The Becho plain irrigation water is mainly to supply by the groundwater from Becho plain and AAWSA is plain to supply groundwater to Addis Ababa from the study area. This part of the Area outlier has been subject to geological, hydrogeological and geophysical investigations (WWDSE, 2008). The groundwater table lowering creates a great concern and shortage of drinking water is one of the critical issues in the subrubs of Addis Ababa. As a result different geological and hydrogeological studies have been conducted by different researchers and organizations.

Several researches and investigations have been undertaking in the study area.
Those are;
Alemu Mesele (2017). Groundwater dynamics and aquifer characterization of the shallow aquifers of Becho and Koka area.

Behailu Berehanu et al. (2017) focused on inter-basin groundwater transfer and multiple approach recharge estimation of the upper Awash aquifer system, Journal of Geoscience and Environment Protection. They were found that recharge estimated for the upper Awash river basin ranges from 51.5 mm/year to 157 mm/year, and estimated mean annual recharge from base flow separation over the upper Awash river basin is 91.25 mm.

Reys Asfaw (2016) worked on ground water potential evaluation and use trends in upper Awash basin, unpublished MSc Thesis, Addis Ababa University. According to his investigation the amount of land irrigated using shallow groundwater and the corresponding number of shallow groundwater wells used to irrigate is increasing with time.

Daniel Nuramo (2016) to evaluate the temporal changes of groundwater recharges which will be vital information for future sustainable use of the groundwater resource in the Upper Awash Basin with particular emphasis to Becho and Koka areas, Central Ethiopia MSc Thesis, Addis Ababa University. According to his investigation the mean annual recharge of the Becho area using the water balance method was found to be 319.5 mm and using base flow separation excel spread sheet program it was found to be 81.4 mm.

Andarge Yitbarek et al. (2013) conducted a study on the title of estimating transmissivity using empirical and geostatistical methods in the volcanic aquifers of upper Awash river basin, explained that transmissivity and specific capacity values are spread over several orders of magnitude, revealing the strong heterogeneity of the volcanic aquifer.

Andarge Yitbarek et al. (2012) conducted a study on the title of Hydrogeological and hydrochemical frame work of upper Awash river basin: with special emphasis on inter basins groundwater transfer between Blue Nile and Awash river. According to their study the different aquifers in the area at different places have different water levels. In the upper basaltic aquifer and lower aquifer, the static water level varies from place to place from artesian condition to 120 to150 m and 67.5 m below ground surface respectively.

Andarge Yitbarek (2009). Hydrogeological and hydrochemical framework of complex volcanic system in the Upper Awash River basin, Central Ethiopia: with special emphasis on inter-basins groundwater transfer between Blue Nile and Awash rivers. This work, from available data identified two aquifer systems (Upper basalt and Lower basalt aquifers).

Seifu Kebede et.al (2010). Groundwater of the Central Ethiopian Rift: diagnostic trends in trace elements, d18O and major elements.
From geochemical trend, it shows a continuity of groundwater flow from the western highlands to the rift valley floor following the regional groundwater flow path. And it summarized, regional flows are not evident in the volcanic aquifers of the region because of faulting, heterogeneity in permeability and dissection of aquifers, and groundwater levels and their development is largely unknown, in the studied region, Central Ethiopian Rift, there is a clear regional trend in groundwater flow and geochemistry. The fact that this region falls at the intersection between an E–W running fault zone and the NNE–SSW running fault zone may be responsible for the flow of groundwater’s from the highlands to the rift floor.

Seifu Kebede et.al (2007). Ground water origin and flow along selected transects in Ethiopian rift volcanic aquifer.
The most important factor that controls the groundwater flow continuity between the high rainfall region in the plateau and the rift floor aquifers is the geological architecture of the interface zone.

TilahunAzagegn (2015), Groundwater Dynamics in the Left Bank Catchments of the Middle Blue Nile and the Upper Awash River Basins, Central Ethiopia.
Characterize the barely known hydrogeological system of the area with emphasis given to amount of recharge, aquifer distribution, groundwater flow pattern, hydraulic connection and flux between aquifer systems of adjacent basins and the factors that control the groundwater dynamics.

TilahunAzagegn (2008), Hydrogeochemical characterization of aquifer systems in Upper Awash and adjacent Abay plateau using geochemical modeling and isotope hydrology. From geochemical data, stable isotope data and tritium data, the work addressed schematic conceptual models for spatial geochemical variations, evolution and recharge area zonation for shallow and deep aquifer systems. The regional groundwater flow system of the area is controlled by the structural and stratigraphic relationship of rock formations which constitute confining beds, traps and aquifer systems in the study area. Recharge area for the aquifer systems of a given river basin can either be within the same basin and/or as inter-basin groundwater flow from adjacent basins.

Ketema Wogari (2006). Water resource potential evaluation of Holota River Catchment, central Oromia, West Shewa. The research found that from direct and indirect investigation of the study area, the area revealed that it has enormous potential of surface water and subsurface water. The work estimated that the annual recharge to ground water from rainfall is about 24% of the mean annual rainfall of the catchment, in other words, the annual recharge to ground water is estimated to be about 160Mm3/year

Tenalem Ayenew.et.al (2007). Environmental isotopes and hydrochemical study applied to surface water and groundwater interaction in the Awash River basin
The dominant source of recharge to the rift aquifers comes from shallow groundwater inflow from the adjacent highlands. However, the presence of variable groundwater chemistry, depth and groundwater occurrence in the region suggests complex groundwater dynamics, often governed by the intensity and attitude of the rift faults and the volcanic stratigraphy and its relation with the various water bodies.

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

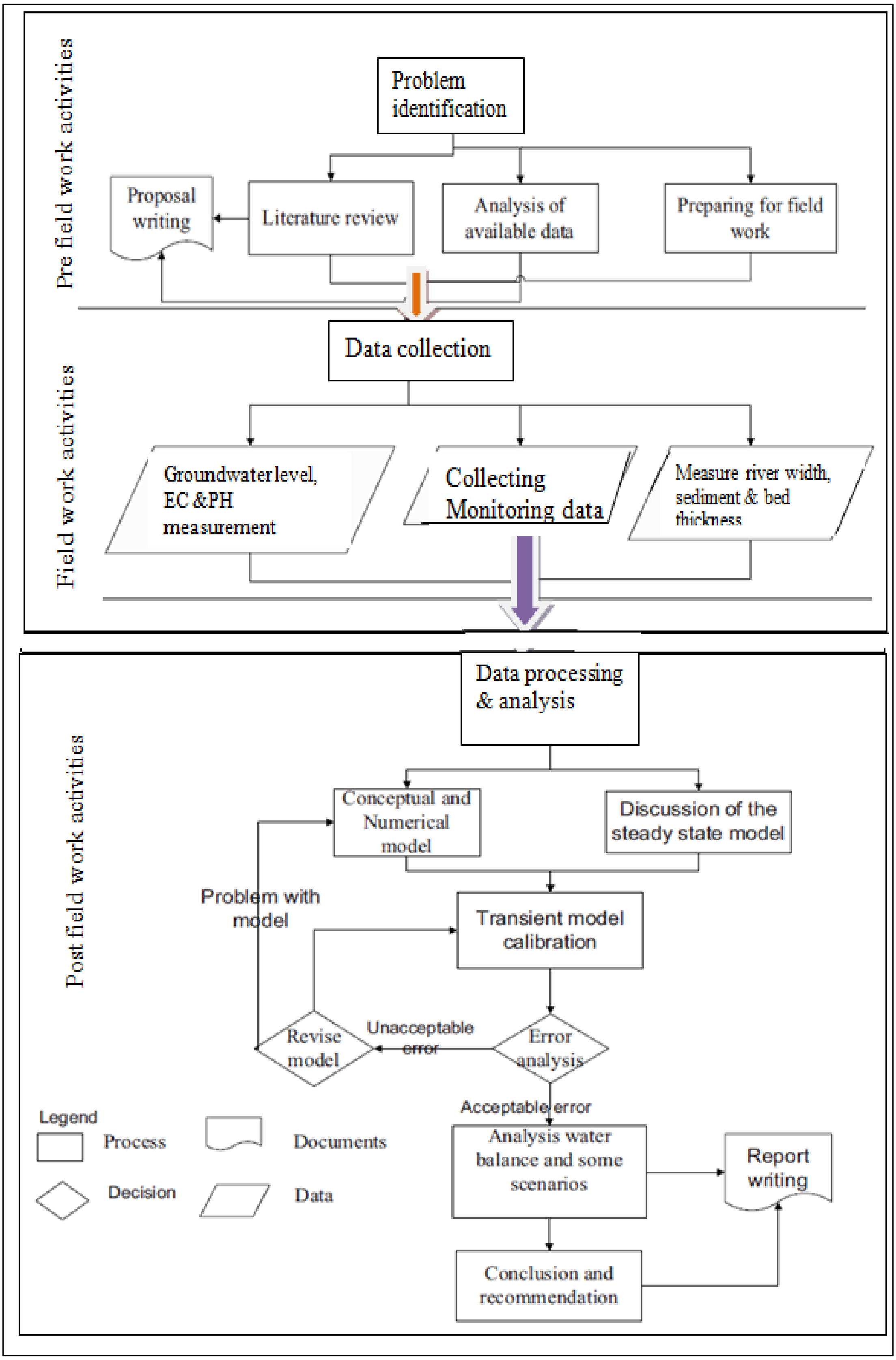


Figure 1.1Flow chart of methodological approach

CHAPTER TWO

2. Description of Study Area

2.1. Location

The study area is located in the upper Awash River Basin within Oromia Regional State north west to south west of Addis Ababa. Geographically the study area is located approximately between 37^0 56'E - $38^0$45'E and 8^0 23'N - 9^0 18'N. and elevation between 1800 and 3559 m a.s.l.

Becho Plain is far from 20km to 100 km from Addis Ababa along Addis Ababa-Jima and Addis Ababa to Ambo road. The study area is bordered in the north by the east-west trending rift escarpment (Ambo fault), in the east, Wechecha Mountain and Melka Kunture horst, while in the south, it is bordered by Guraghe highlands and in the west by Weliso highlands. The total area of Becho plain is about 4779km^2.

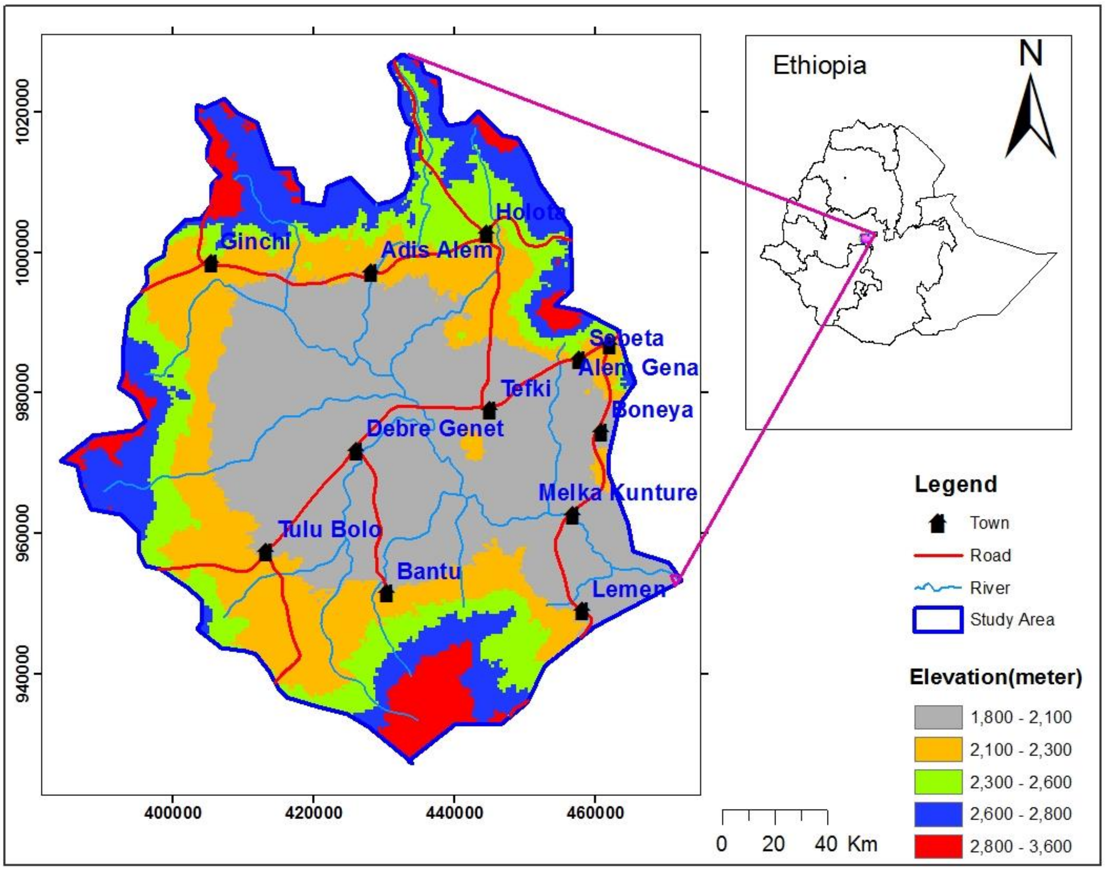


Figure 2:2 Location map of the study area.

2.2 Geological Characteristics of the study area

2.2.1. General Geological information

The outline of the regional geological setting as described by Pierre Gouin , (1979 as cited in WWDSE, 2008) summarized as: The Ethiopian plateau is underlain at depth by Precambrian rocks of the Afro Arabian Shield. The Precambrian basement is covered for the most part by glacial and marine sediments of Permian to Paleogene period and Tertiary volcanic rocks with related sediments. The Precambrian rocks of Ethiopia is consisting of high grade gneiss, metamorphosed volcano sedimentary rocks and associated ultramafic bodies and intrusive ranging from mafic to granitic composition. At the end of Precambrian era, 600 million years ago, the crystalline basement complex of the present Afro Arabian swell had been above sea level for a long time and remained for another 370 million until the end of Paleozoic era. Such a long period of erosion and denudation left the earth's surface almost completely peneplained. Crustal motion started in the beginning of Mesozoic era, about 225 million years ago. During the late Triassic and early Jurassic periods, a regional epirogenic sinking of the crust commenced causing a progressive transgression of the ocean from the south east that is, from the Indian Ocean coast of present day Somalia in the general direction of Lake Tana in the North-West Ethiopia. This downward crystal movement, connected with a sedimentation process, started a cycle of marine transgression and recession of Mesozoic sea. Within this large epicontinental sea, extensive layers of sediments were deposited to form hundreds of meters of rocks consisting of sandstone, shale, gypsum, limestone and other varieties of sedimentary rocks.

The crustal movement was reversed into the upward motion during the late Jurassic period, which brought the crust's surface up to sea level by marine regression in late Cretaceous period.

The youngest sediments are quaternary age. These include conglomerate, sand clay and reef limestone which accumulated in the Afar Depression and the northern end of the main rift Valley. Sediments which accumulated in the former Lakes occur in the south end of the Afar, in the Main Rift Valley, and in the Omo valley Kazmin, (1972 as cited in Andarge Yitbarek , 2009).

2.2.2. Site Specific geological characteristics

Site specific geology is simplified from previous, drilled well Lithological logging and geophysical logging data.

Alluvial deposits is consisting of regolith, reddish brown soils, talus and alluvium with maximum thickness of about 7 m.

Centeral volcanics of wechecha is porphyritic in texture with phenocrysts of feldspar up to 1cm across. Trachytes of Wecheca composed of alkaline pyroxene and rare olivine.

Addis Ababa Ignimbrite is grayish to white color and when welded it exhibits elongated rock fragments of various color. It is composed of welded tuff (ignimbrite) and non-welded pyroclastic fall (ash and tuff). In the Becho area it is covered by a thin 5 to 7m thick residual soil developed from the same rock.

Entoto Becho rhyolite, the rhyolites form isolated cones. Obsidian up to 10 cm across is common at the picks of the cones. From the cross cutting relationship, they can be younger than the adjacent ignimbrite. The Intoto ridge forms watershed divide of Abay and Awash river basins. The ridge forms steep slope towards the Abay basin, and steep to gentle slope towards the Awash basin. In fresh hand specimen, it is grayish pink and reddish brown to yellowish grey color when weathered.

Trachyte. The Central Volcanoes units are mainly trachytic lavas exposed at Wochecha, Southeastern part of the study area (in Holeta river catchment) forming an elevated ridges or mountain picks. It is grayish color fine to medium grained trachyte with subordinate ash falls and ignimbrite.

Tarmaber Basalt. The Tarmaber Basalt which is the dominant unit exposed in central part of the study area (in both Tributary streams of Muger River catchment and Holota River catchment). It is consisting of mainly scoraceous lava flows and at places it is columnar olivine bearing basalt as pockets within the scoraceous components. It is highly weathered, fractured and pinkish to grayish in color

Akaki Basalt (NakB) This unit is outcropped at Dukem area. It is coarse grained porphyritic olivine basalt. It is highly vesicular basalt and at places the vesicles were filled by carbonate minerals. It is consisting of scoria and spatter cones with associated lava flows. Both the basalt and scoria is quarried for construction around Dukem area.

2.3.Fault system

The groundwater in study area is mainly in fracture rock and hence, fractures, faults and joints play an important role. With respect to the hydrogeology of the area different studies were conducted.

According to WWDSE (2008), Tilahun Azagegn (2015) the area is highly affected by fracturing and faulting which are aligned NW-SE, E-W, N-S and play an important role in the movement and occurrence of groundwater in the study area.

Four principal fault systems have been identified in the area by previous.

North West Fault System

The NW fault system, the oldest fault system have extended history affects all the rock type in the western escarpment. They are crustal scale served as a conduit for the extensive volcanic formation in the area and their age may go up to early Paleozoic, but becomes reactivated latter with the main tectonic event in the region. The trend of the Bede Gebaba -Wecheca volcanic belt can be associated with this NW fault system.

East West Fault System

The EW fault system, which is the upper boundary of the Ethiopian rift margin, is running approximately E-W north of the Addis Ababa Ambo road. They are major fault on the western plateau part and densely affected the Tarmaber basalt in the area.

North South Fault System

The NS fault system is the recent fault system which serves as a conduit for young volcanic (Addis Ababa basalt).

North East South West Fault System

The NE-SW fault system is common along the MER margin and field relationships confirm that this system is younger than the NW-SE and E-W fault systems.

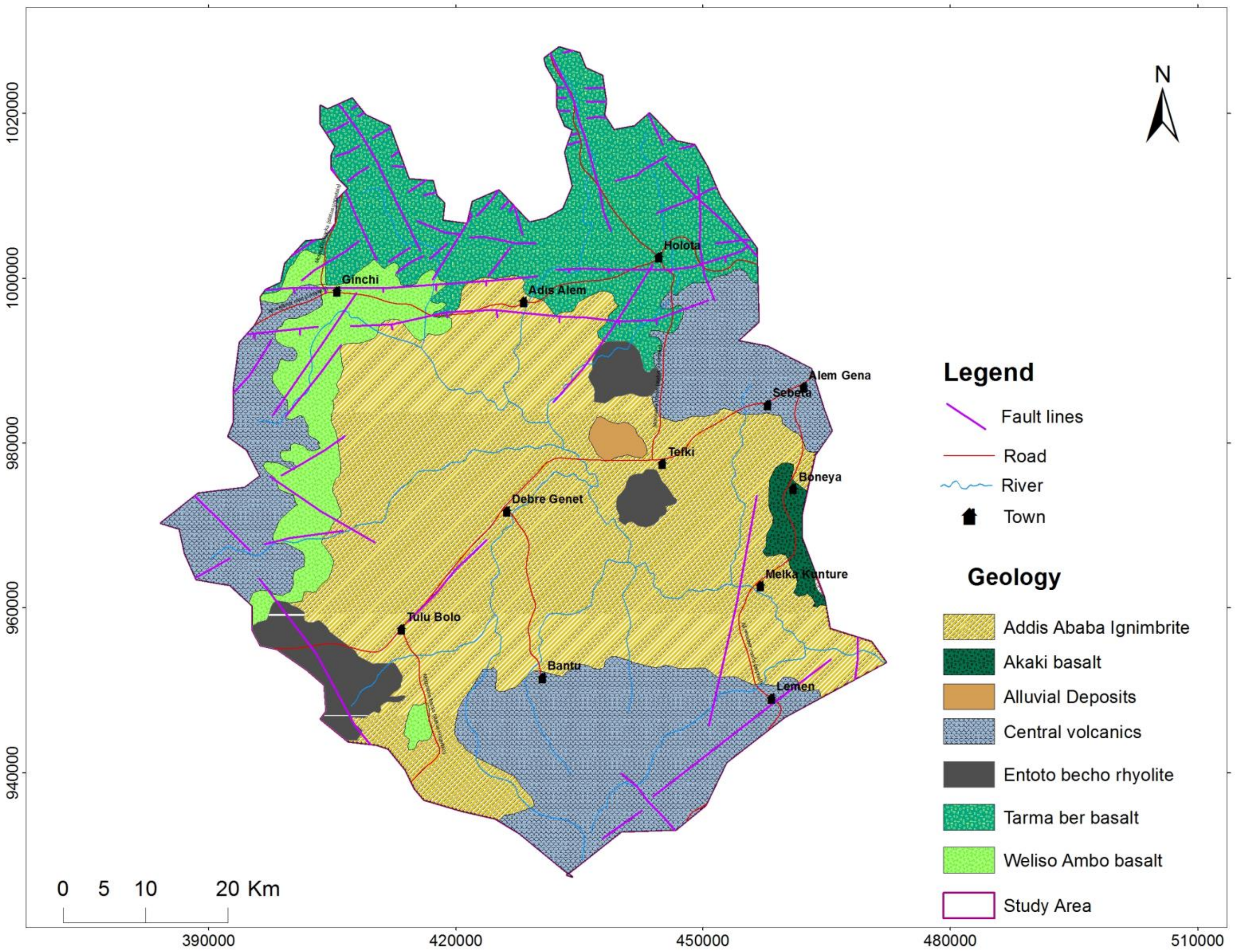


Figure 3:2 Simplified (WWDSE,2008) Geological map of the study area

2.4 Hydrogeological Characteristics and Aquifer System

The surficial geological mapping units (WWDSE, 2008) in the Becho groundwater system were differentiated at depth based on previously drilled bore holes, mapping wells, pilot production wells and geophysical investigation into aquifers and confining (aquiclude) units on the basis of areal extent and general water bearing characteristics. In Becho plain it was penetrated two aquifers by drilling of about 550 meters i.e. upper and lower basaltic aquifer, while the lower aquifer is confined and the upper is confined and unconfined. The aquifers and confining (aquiclude) identified are referred to as hydrogeologic units because the differentiation takes into account both the geologic and hydraulic characteristics of the units. Four principal hydrogeological units are recognized in Becho plains groundwater system (WWDSE,2008).

- Localized aquiclude
- Upper basalt aquifer (UBA)
- Ignimbrite
- Lower Basalt aquifer (LBA)

1. Localized aquiclude (barriers)

Quaternary Bede Gebaba volcanic unit: Rhyolitic to minor trachytic lavas and pumice and Ziqualatrachytes and TertiaryEntoto-Becho Rhyolites and Central Volcanic of Wechecha, Furi, Yerer: prophyritic trachytic lavas. They have very low permeability, except along weathered and fractured zones. They act as local barriers.

2. Upper Basalt aquifer

The upper basalt aquifer is composed of weathered, fractured and massive basalt, thickness less than 50 meters, recharged locally and in the larger part of the plain it is confined. The yield of bore holes in this aquifer highly depends on the intensity of fracturing and faulting. Along faults the yield is highly significant while the massive basalt has low yield. The transmissivity is highly variable and in most cases it is less than 50m^2/day the Electrical conductivity of the aquifer varies from 250 µS/cm to 900 µS/cm. The groundwater level depth increases from north-south direction. At the northern part the groundwater of the aquifer is shallow (less than 5 meters) and at the central part it varies from 5 to 20 meters deep and to the south depth increases progressively to more than 50 meters deep) for shallow well or upper aquifer. The groundwater potential of this aquifer is not significant as compared to the lower basalt aquifer, however this aquifer can be exploited for the water supply of the rural towns and rural settlements wells depth of up to 150 meters.

3. Ignimbrite and Trachyte

Chefe Donsa Pyroclastics, Nazaret unit (Welded ignimbrites) and Addis Ababa ignimbrites of low productive along the weathered and fractured zone. Acts as a regional aquiclude which separates the upper and lower volcanic aquifer in Becho plain

4. Scoracious Basalt aquifer

The drilling at Becho plain in the lower basalt aquifer showed that the aquifer is composed of scoracious basalt and scoria. The water level at the southern part is above the surface of the earth and in the central part less than 5 meters. The transmissivity of the aquifer from the drilled deep wells shows the transmissivity is greater than 1000 m2/day.

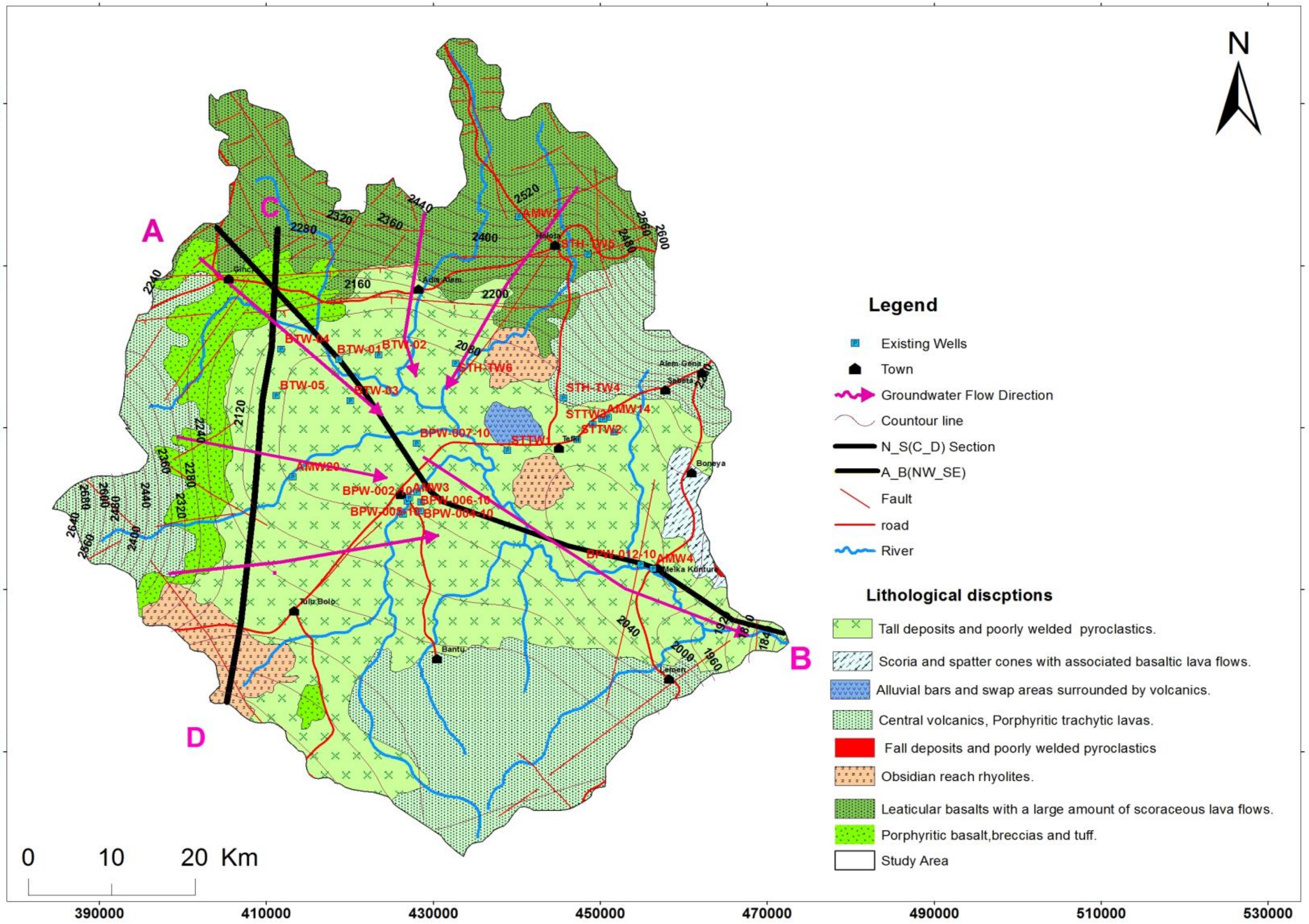


Figure 4:2 Simplified (WWDSE ,2008) Hydrogeological map of the study area

Chapter Three

3. Conceptual model development and model input data preparation

3.1 Groundwater Recharge Estimation

3.1.1 WetSpass Modeling

WetSpass model is a method for estimating spatially distributed, long-term average groundwater recharge developed by Batelaan, O. and De Smedt, F. ,(2001, 2007 as cited in Ashiber.G, 2016). It uses long-term average climatic data together with elevation, land use/land cover and soil map of an area to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area. This model is fully integrated or embedded in the Arc View (version 3.2) as raster model. Inputs for this model include grids of land-use, groundwater depth, precipitation, potential evapotranspiration, wind speed, temperature, soil and slope, where by parameters such as land-use and soil types are connected to the model as attribute tables of their respective grids, Batelaan, O and Woldeamlak, (2007 as cited in Ashiber.G, 2016).

Input data for WetSpass Model

Recharge is one of the components in the hydrologic cycle and an important issue for hydrogeological characterization of aquifer systems. Characterizing recharge is also one of the major objectives in hydro-meteorological studies Shaw, (1994).

Ten stations which can represent the study area were selected and analyzed for all metrological parameters.

In this study, data used for recharge estimation include mean monthly meteorological data up to 30 years from 1987 to 2017 and some data downloaded from New_LocClim_1.10. Only records with complete measurements were considered for analysis. Soil and land use/land cover maps were also used from modified FAO Land use/land cover and soil maps of Ethiopia (FAO, 2016).

The monthly meteorological data, land use land cover, soil, slop & groundwater depth map are converted to special grid(ASCII) with ArcGIS for WetSpass modeling.

Precipitation

In addition to inter basin transfer rainfall is the additional water source for the plain. The precipitation data is from National Meteorological Agency for 30 years starting from 1987 up to 2017 from stations have complete set of precipitation records. The total amount of the rainfall is very good, and the analyses show that most of the rainfall occur summer, from Jun to mid-September. To calculate aerial depth of precipitation of the study area, point measurements with complete data found in each stations were averaged by using arithmetic mean method (Annex II) the mean annual precipitation has (1127.11mm).

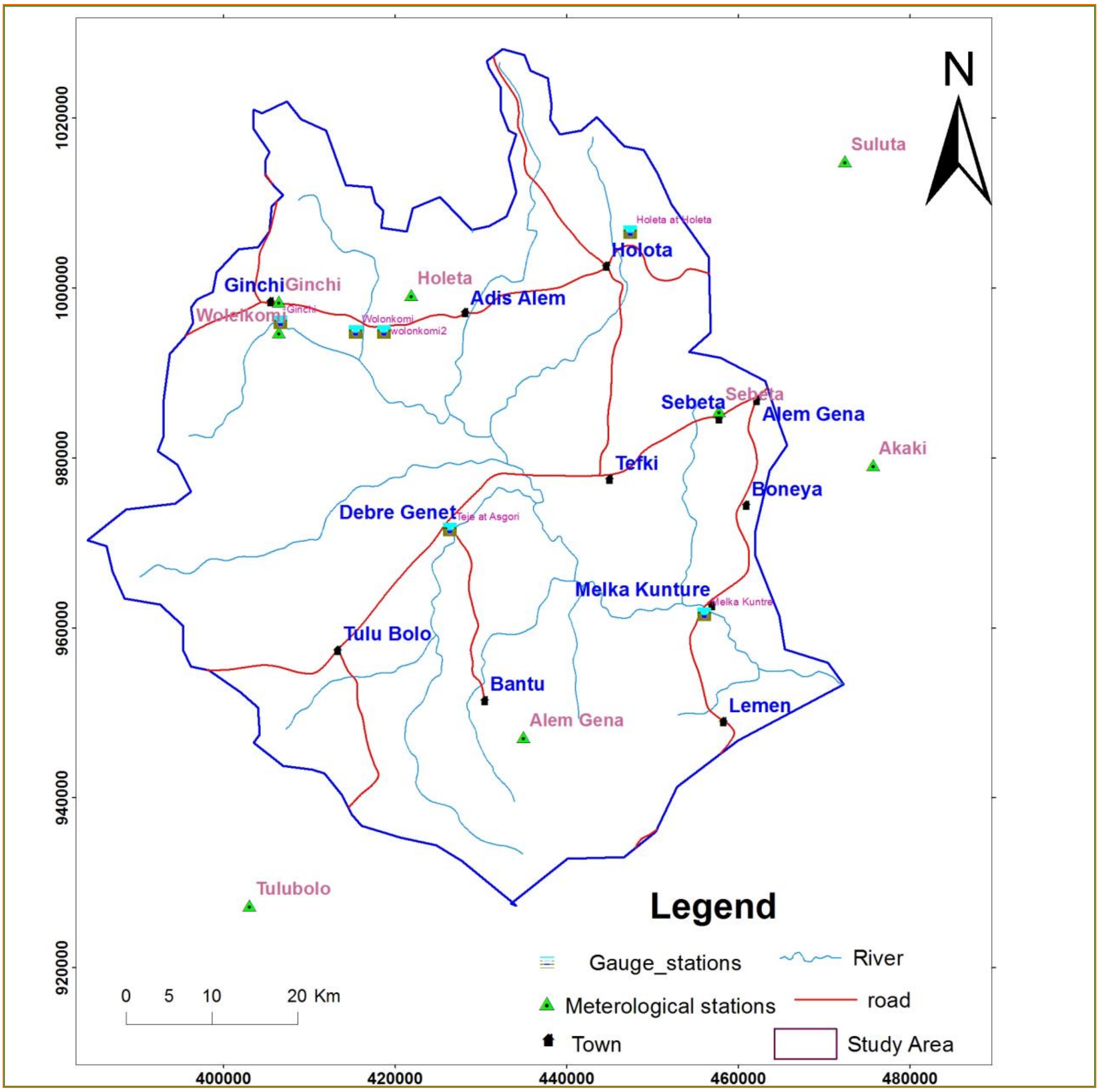


Figure 5:3 Meteorological and Gauge Stations of the study area

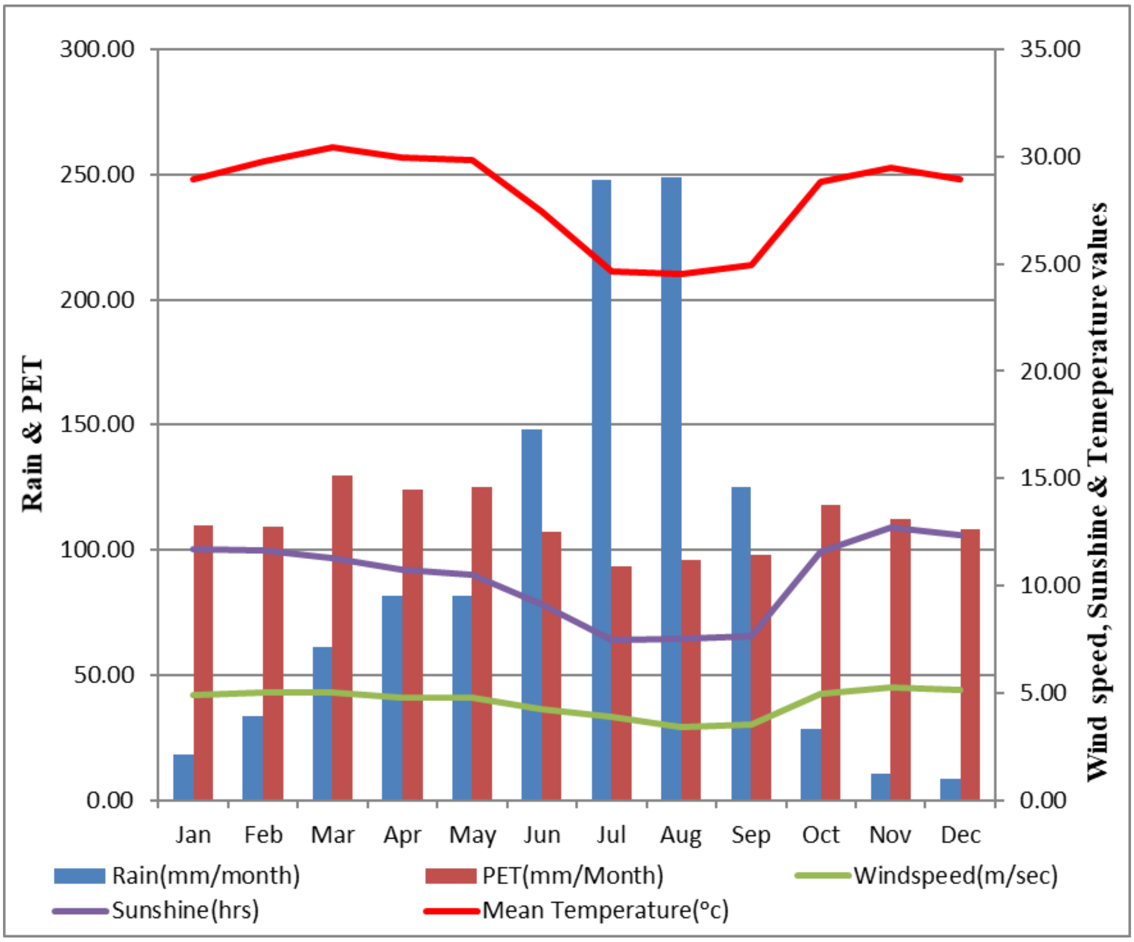


Figure 6:3 Meteorological data graph representation of the study area.

Mean Annual Temperature of the study area

The mean annual temperature of the study area is about 17.74°C and with a fluctuation of 4.2°C on December to 29.80°C recorded during the month of May. The mean monthly temperature variation at all station is shown in graph on the figure below.

Wind Speed

Rate of evaporation and evapotranspiration has a direct relation to and is strongly affected by wind speed. As water vaporizes into the atmosphere, the boundary layer between earth and air becomes increasingly more saturated so that the water vapor has to be removed and replaced with drier air continuously. This movement of the air and moisture transfer is directly proportional to wind speed and turbulence Shaw, (2005). Monthly and annual means of wind speed in the study area were taken from available point data (Annex II).

Sunshine hours

Although evaporation takes place almost without interruption during the day light and the night, the process is most active under direct radiation from the sun. Therefore variation in sunshine hour is important factor for evapotranspiration.

Potential evapotranspiration (PET)

Potential evapotranspiration describes the water losses that will occur under a given climatic condition with no deficiency of water for vegetation. Potential evapotranspiration (PET) is among the important input parameters of WetSpass model.

LocClim was developed to provide an estimate of climatic conditions at locations for which no observations are available. The programme provides estimates of Meteorological data with potential evapotranspiration. So PET data from New_Loc Clim_1.10 is 997.71mm/year .

Table 13 Potenitial Evapotranspiration(PET) from previous work of the study area

Author	Method	PET(mm/year)	Average
Daniel Nuramo,2016	Penman	1071.1	**927.45**
	Thornthwaite	783.8	
Abel Abebe,2017	Penman	1012.04	**957.2**
	Thornthwaite	902.33	

Land use parameter table

Land-use parameters table were prepared as; either crop, forest, grass, bare soil and open water. Since there is no monthly monitored land use land cove parameters, maps used from modified FAO Land use/land cover and soil maps of Ethiopia (FAO, 2016).

Impacts of LU/LC change on subsurface components of the hydrologic cycle are less well recognized, particularly groundwater recharge. In this study, LU/LC map were used to calculate distributed recharge map by using WetSpass Model. Land use is an important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration.

Soil attribute table

The soil attribute table contains soil type of the area, field capacity, permanent wilting point, plant available and residual water content of these soils (Annex IV).

Land use/land cover, soil texture and precipitation are the three controlling factors affecting the water balance of Watershed hydrology (Fetter, 2001). In this study, a soil Textural classification is used to estimate spatially distributed groundwater recharge. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration.

Rainy Days per month parameter table

The rainy days characteristics parameter table contains three month for each corresponding frequency of rain per day. Values in these tables are modified based on average stations Meteorological data. Parameters of these tables (Annex IV).

Grid maps

Topography, slope, land-use, soil, evapotranspiration, rain, wind, temperature and groundwater level maps were prepared. Hence, the topographic grid map, which is used to characterize the horizontal hydrological characteristics of the land surface and the slope data layer, describes the maximum change in elevations were derived from SRTM using Global Mapper 17.

Actual evapotranspiration

Actual evapotranspiration account the field condition, it depends on the availability of water. It is the sum total of evaporation of the water intercepted mainly by vegetation, direct evaporation from the soil surface, Lake, seas and all water body, transpiration of plants. The evapotranspiration is highly affected by sunshine, wind and humidity. The highest evapotranspiration is observed on March and May when there is high sunshine hours and wind speed, implying that those meteorological parameters are important factors to evapotranspiration.

The Turc method is used to estimate the evapotranspiration of the study area to compare with WetSpass model result and the result is attached on Table2:3.

$$ETA = \frac{P}{\left[\left(1.9 + \left(\frac{P}{J}\right)^2\right)\right]^{0.5}}$$

Where P = the annual precipitation in mm

ETA=Annual actual evapotranspiration.

$J = 300 + 25*T + 0.05 * T^3$

T = Annual average temperature (^{0}C)

Table 2:3 Actual evapotranspiration(AET) of the study area

Stations	Average Annual precipitation(mm)	Average Annual Temperature(°c)	AET(mm/year)
Ambo	977.50	17.66	585.3
Akaki	927.00	18.58	572.22
Asgori	1037.50	17.84	606.73
Alem Gena	1042.10	17.69	609.42
Holeta	1060.12	17.40	609.26
Ginchi	1125.55	17.44	635.90
Sebeta	1318.51	18.48	716.58
Tulubolo	1144.60	17.23	635.89
Wolelkomi	1097.90	17.44	623.81
Woliso	1203.60	17.80	668.67
Average AET using Turc method			**626.37**
Average AET of the study area from **WetSpass Model**			**655.61**

3.1.1.1 WetSpass model Results

The WetSpass model produces seasonal and annual hydrological parameters like grid maps of groundwater recharge, actual evapotranspiration, surface runoff, interception loss, evaporation, etc. Annual groundwater recharge, annual actual evapotranspiration and annual surface runoff are the main outputs of the WetSpass model. A brief description of this output is given below:-

Annual evapotranspiration

Evapotranspiration is the process which returns water to the atmosphere and therefore completes the hydrologic cycle and, it includes evaporation from open water, vegetation and ground surface. Also transpiration, which is the removal of water from the soil by plant roots, transport of the water through the plant into the leaf as well as evaporation of the water from the leaf's interior in to the atmosphere.

The annual evapotranspiration is calculated by WetSpass as a sum of evaporation from bare soil, transpiration of the vegetated cover, interception loss by vegetation and evaporations of open water body.

About 655.61mm of water is lost through evapotranspiration from the study area. This accounts for 58.17% of the study area annual precipitation.

According to the WetSpass simulated results of monthly evapotranspiration, its value ranges from 14.91 to 110.81 mm in the study area. The output of annual evapotranspiration grid map is displayed in (figure 8:3). precipitation and land-use/land-cover are the main controlling factors of evapotranspiration.

Surface runoff

The surface runoff of the study area shows variation with land-use, soil type, slope, topography, precipitation and the other meteorological parameters (figure 7:3).

The amount of Surface runoff in the study area is 359.33mm which ranges monthly from 1.17 to 99.61 mm. The value represents 31.88% of the total annual precipitations of the study area.

Groundwater Recharge

Groundwater recharge is a key component in any model of groundwater flow and its accurate quantification is crucial to proper management and protection of groundwater resources. In this study, spatially distributed groundwater recharge estimated by using WetSpass modeling is 120mm annually which is 10.65% of total annual precipitations.

Table 3:3 Water balance between WetSpass result with rainfall

TimeStep	AET	Runoff	Recharge	Stations	Rain fall(mm/year)
1	14.91	1.17	3.50	Akaki	1038.63
2	26.79	4.17	5.71	Alem Gena	1042.10
3	42.02	19.47	3.30	Holeta	1060.12
4	61.26	14.74	12.14	Ginchi	1125.55
5	56.32	26.94	3.61	Sebeta	1318.51
6	100.26	48.83	0.13	Wolelkomi	1158.80
7	102.89	99.61	41.11	Tulubolo	1149.74
8	108.12	98.76	41.20	Suluta	1123.46
9	90.04	40.82	0.56	**Input for the model**	**1127.11**
10	25.46	2.91	5.32	**AET%**	**58.17**
11	13.43	1.71	2.21	**Runoff%**	**31.88**
12	14.11	1.51	1.21	**Recharge%**	**10.65**
Total	**655.61**	**359.33**	**120.00**	**Error%**	**0.69**
WetSpass Model output			**1134.95**		

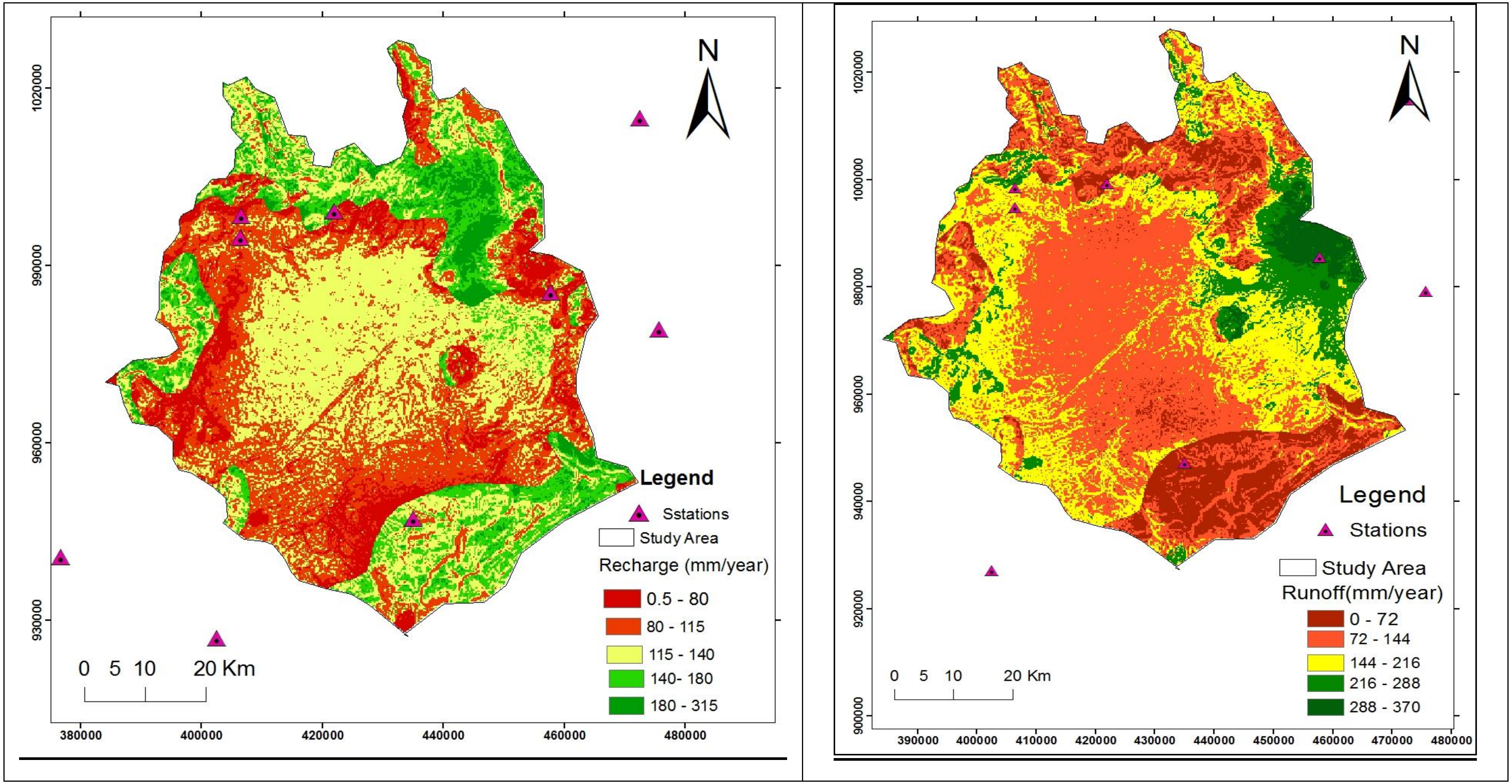


Figure 7:3 Annual Recharge and Runoff of the study area in mm WetSpass Model

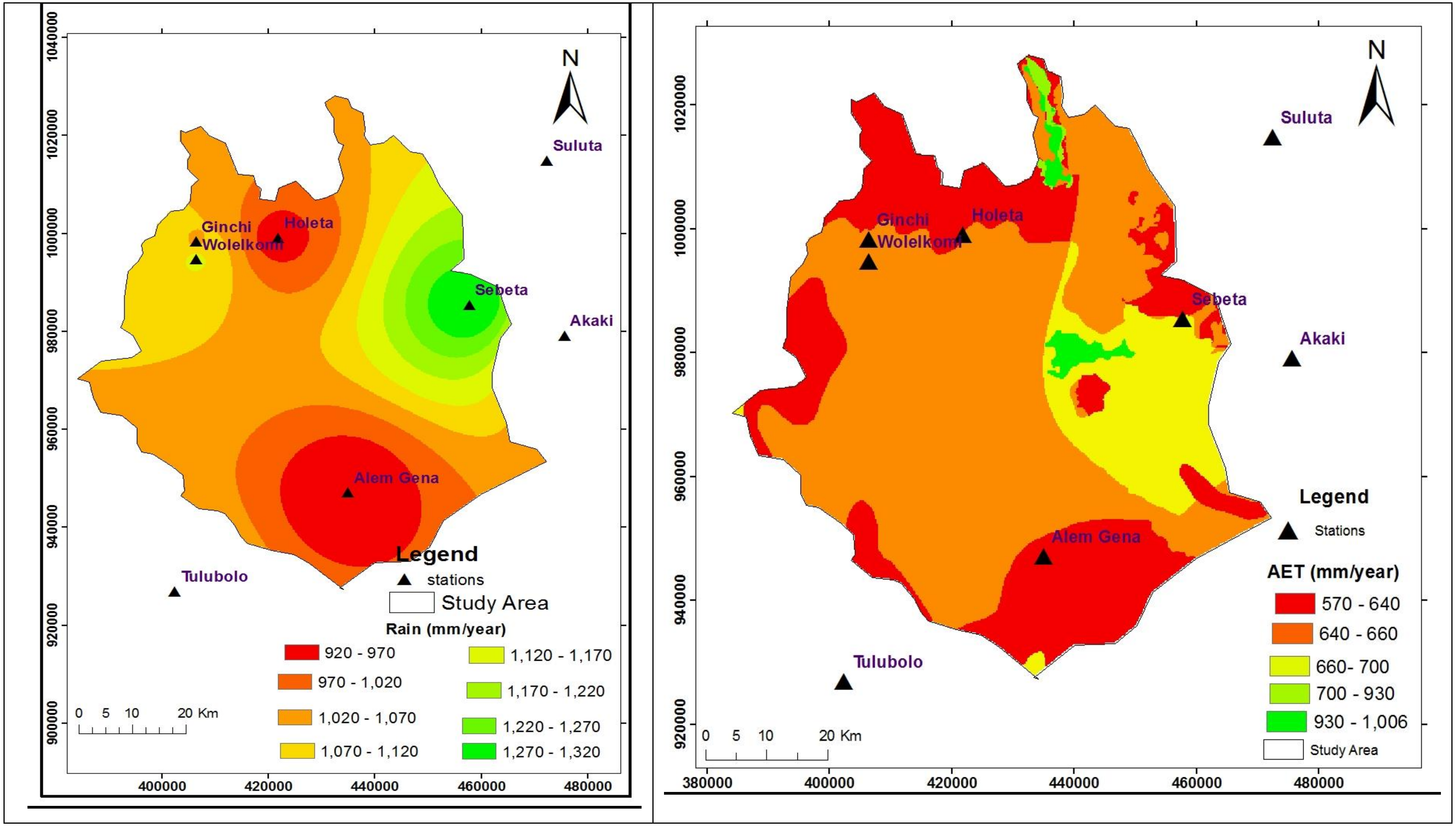


Figure 8:3 Annual Rain fall and Actual Evapotranspiration of the study area in mm

3.1.2 Base Flow separation

Base-flow separation methods were employed to place the base flow component of current flow at a number of currently operated and discontinued stream flow gauging- station locations. Stream gain-loss measurements were drawn and were used to identify and quantify gaining and losing stream reaches both spatially and temporally. These measurements provide further understanding of ground-water/surface-water interactions.

Base flow has been utilized as an approximation to recharge with the recognition that it is probably less than the amount recharging the groundwater system (Daniel, 1996). Daily river discharge records of over 30 to 7 years from 3 stations were used for the analysis.

The separation of surface runoff and base flow has been made using a computer code river analysis package(RAP) (version 3.0.3) time series analysis. Base flow results from the two computer codes become similar for the attenuation coefficient of 0.95 for RAP instead of default value 0.975.

The weighted mean base flows, representative of the study area, were obtained from the base flows of the gauged streams weighted with their respective catchment areas. Estimated mean annual recharge from base flow separation over the Awash melka kunture, Holeta, Tejie at Asgori are 82.83mm, 132mm and 39.65mm respectively. Sample base flow separation graphs using RAP for Awash River at Melka Kunture and Holeta at Holeta station is also given (Figure 9:3 and 10:3).

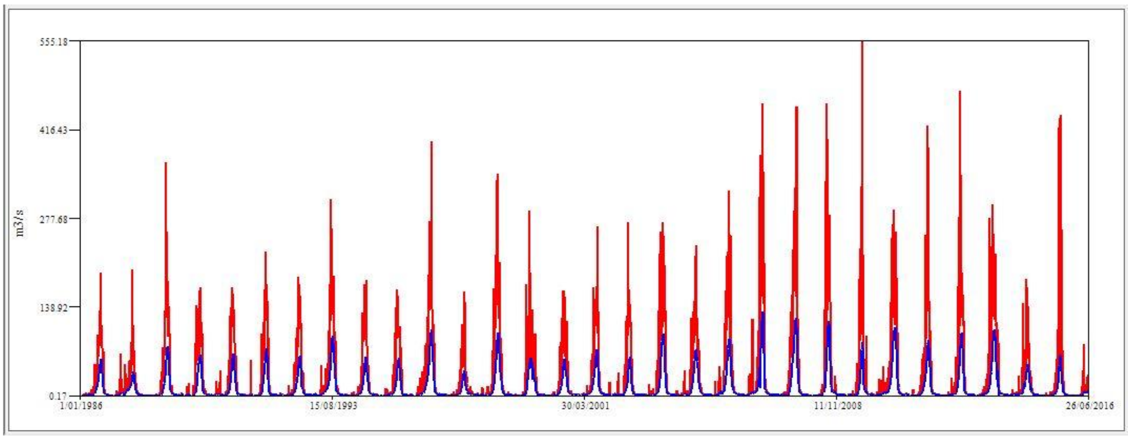


Figure 9:3 . Hydrograph analysis for Awash River at Melka Kunture using River Analysis Package.

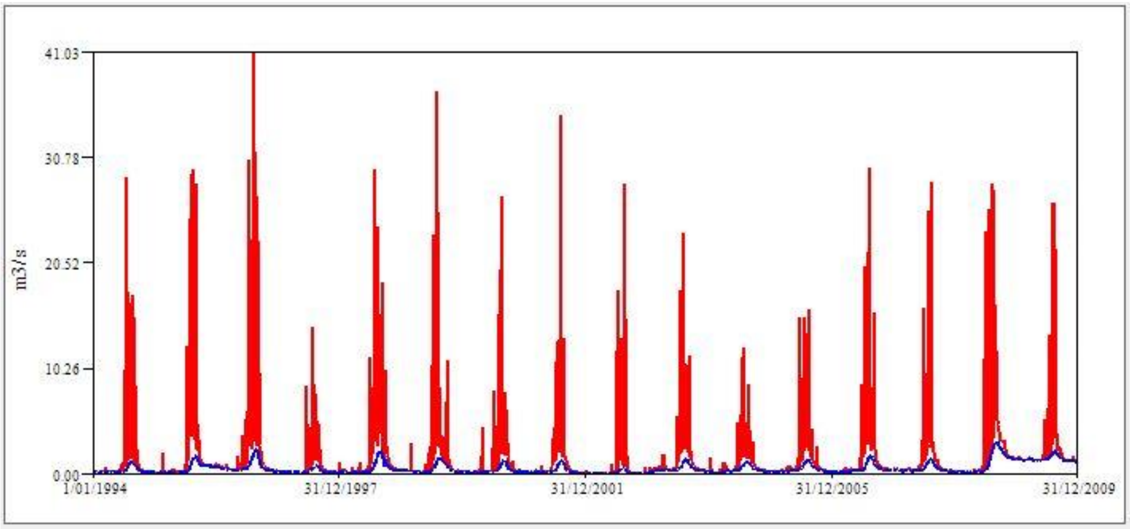


Figure 10:3 Hydrograph analysis for Awash River at Holeta using River Analysis.

Table 4:3 Summary groundwater recharge determined by different authors

Author	Recharge(mm/year)	Methods	Area
Daniel Nuramo(2016)	81.4	BFS	Becho
Daniel Nuramo(2016)	319.5	WBM	Becho
WWDSE(2008)	142	WBM	Melka Kuture
WWDSE 2007	32.4	WBM	Melka Kuture
Andarge Yitbarek (2009)	18.4	BFS	Melka Kuture
WWDSE(2016)	82.5	WBM	Melka Kuture
This Study	**120**	**WetSpass**	**Becho**
	85.78	**BFS**	

WetSpass Model consider more parameters and for this study the meteorological and land use land cover map input data are up to 2018 updated data, so the recharge value estimated by WestSpass method is used for the model input.

3.2. Pumping Test Analysis

The principle of pumping test is that if we pump water from a well and measure the discharge of the well and the drawdown in the well and in piezometers at known distance from the well, we can substitute these measurements into an appropriate well flow equation and are these able to evaluate the hydraulic characteristics of the aquifer, Kruseman and de Ridder, (1991 as cited Gebrehaweria Gebrekirstos Teferi ,2009) such as transmissivity and well performance characteristics. In the analysis of these parameters such as transmissivity and hydraulic conductivity the acquisition of accurate hydrogeological field data with carefully monitored pumping test data is crucial.

Pumping test data was collected for tests carried out during the drilling of wells. The pumping test data includes drawdown test, constant rate test and recovery of single well pumping test. The majority of the test was conducted to evaluate an aquifer through constant pumping test and results show that there is high range of transmissivity that varies from very low values (17.85 m^2day^{-1}) to high values (2080 m^2day^{-1}) Annex I..

The static water level data of the deep wells shows it is above the level at which the groundwater was struck during drilling of the deep wells. This can be evidence to consider the aquifer as confined, semi confined aquifer of deep wells and unconfined system of shallow wells. Previous works of geophysical and deep wells drilling indicates that the groundwater in the study area is mostly confined for deep wells because of the alternating layers of tuff, Ignimbrite, trachyte and due to tectonics and fractures. The work of WWDSE (2008) confirms that, the groundwater of most deep wells in study area is mainly confined to semi-confined aquifer.

In the study area pumping test data are obtained only for twenty six wells from water works design and supervision enterprise (WWDSE). Distance drawdown pumping test was not conducted on the study area hence, interpretations of specific capacity and aquifer storativity of these wells were not made.

The pumping test data can be used as initial values in the model and can be optimized in model calibration. The pumping test analysis here can represent most part of the study area.

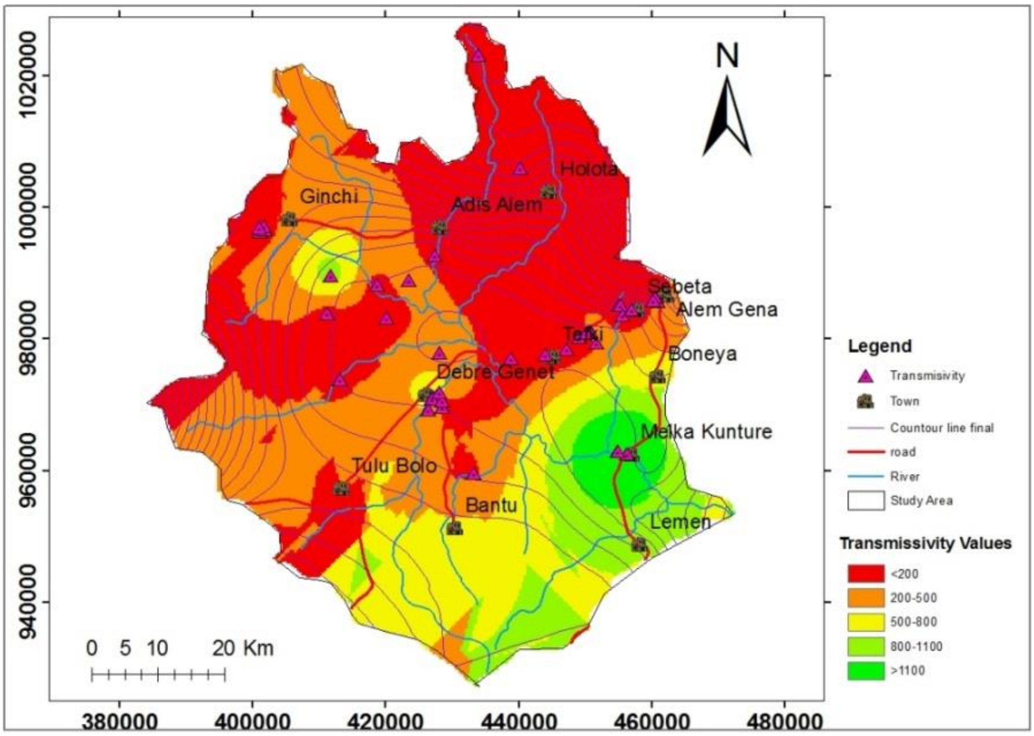


Figure 11:3 Transmissivity map of the study area

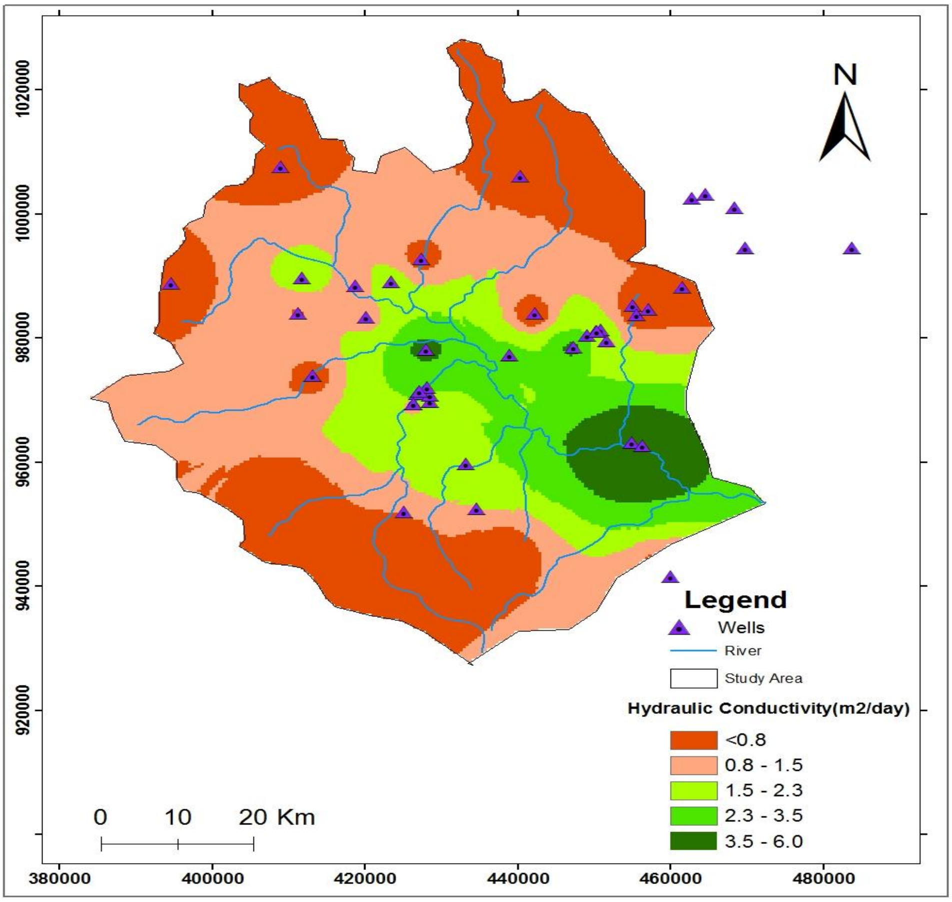


Figure 12:3 Hydraulic Conductivity map of the study area

3.3 Groundwater level records

The groundwater level in Ethiopia is not well monitored because of lack awareness about monitoring, observation pipe problem, accessibility to the wells and budget problem. Most wells were constructed without observation pipe, even wells constructed with observation pipe the measuring ceased during well development and wellhead construction. Groundwater level monitoring data used for this modeling were recorded with data logger for one year used during calibration for drawdown curve and during scenario development.

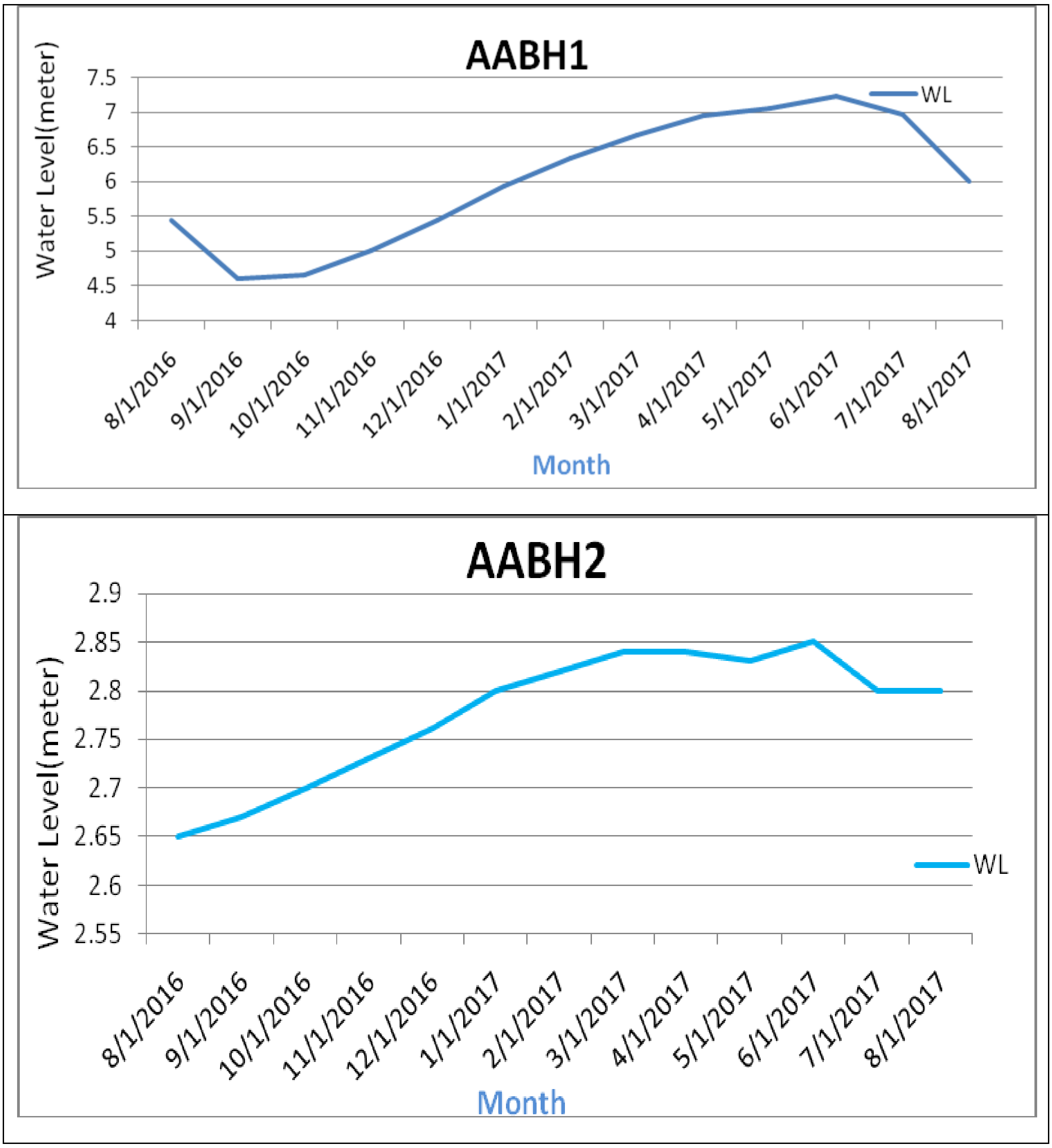


Figure 13:3 Monthly groundwater levels for monitored wells (data logger result)

3.4. Conceptual model development of the study area

3.4.1.Conceptual model boundaries

(Anderson and Woessner, 1992) states that a conceptual model is a pictorial representation of the groundwater flow system, frequently in the form of a block diagram or a cross section. It is a simplified but valid representation of field situation. the development of a conceptual model is "synonymous with site characterization" so that the conceptual model is an integration of relevant local and regional hydrogeologic information using simplifying assumptions and qualitative interpretations of site-specific.

To build a conceptual model the concept of hydrographic unit will be apply. This concept implies that units having similar hydro-geological properties may be combined into a single hydrostratigraphic unit or a geological formation may be subdivided in to aquifers and confining units depending on their hydrogeological characteristics (Anderson and Woessner, 1992). In general more valid data is needed for construction of a model. The extent of the aquifer location and boundaries, the flow of water into and out of the aquifer (recharge and discharge zones), hydrostratigraphic unit, area of interconnection for surface water and groundwater are the most important data for the conceptual model.

The conceptual model of the study area is developed by making use of existing well and geophysical log data, hydrostratigraphic, geological map and geological cross section and topo sheet and DEM extracted from ASTER images of previous reports.

The study area groundwater basin is found at the margin of the western part of the Ethiopian Rift valley. The recharge condition, groundwater flow and aquifer parameters in the study area is highly governed by volcanic unit, the tectonic condition and the hydraulic properties of the different volcanic units that outcrops in the Plain.

Review of previous studies, analysis of available hydrogeological data, geological mapping, isotope hydrological study, drilling of mapping, pilot & production wells and also water quality monitoring along the different part of the plain along the transects, mainly north west-south east direction, which is the major groundwater flow direction has revealed the general aquifers configurations of the plain and the recharge and discharge mechanism and aquifers properties.. Here the general hydrogeological map and the main groundwater flow paths are given in figure15:3.

The groundwater flow concentrates in the plain and the potential is significant. The drilled wells together with vertical electrical sounding and currently under drilling wells depth greater than 550 meters enabled to draw hydrogeological x-sections in different direction mainly along the groundwater flow direction and perpendicular to the flow direction to understand the three dimensional configuration of the groundwater system.

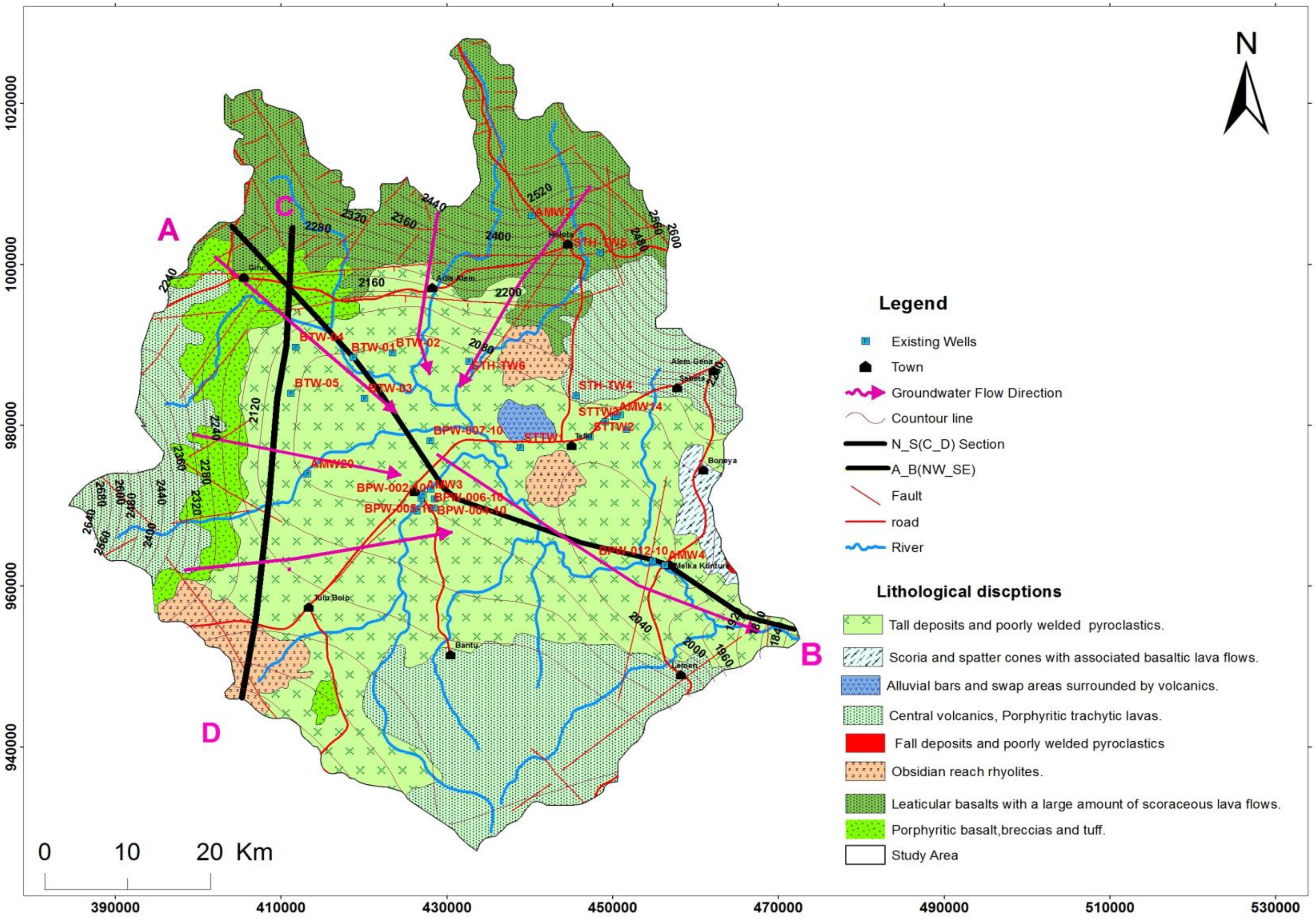


Figure 14:3 Simplified (WWDSE, 2008) Hydrogeological map of the study area

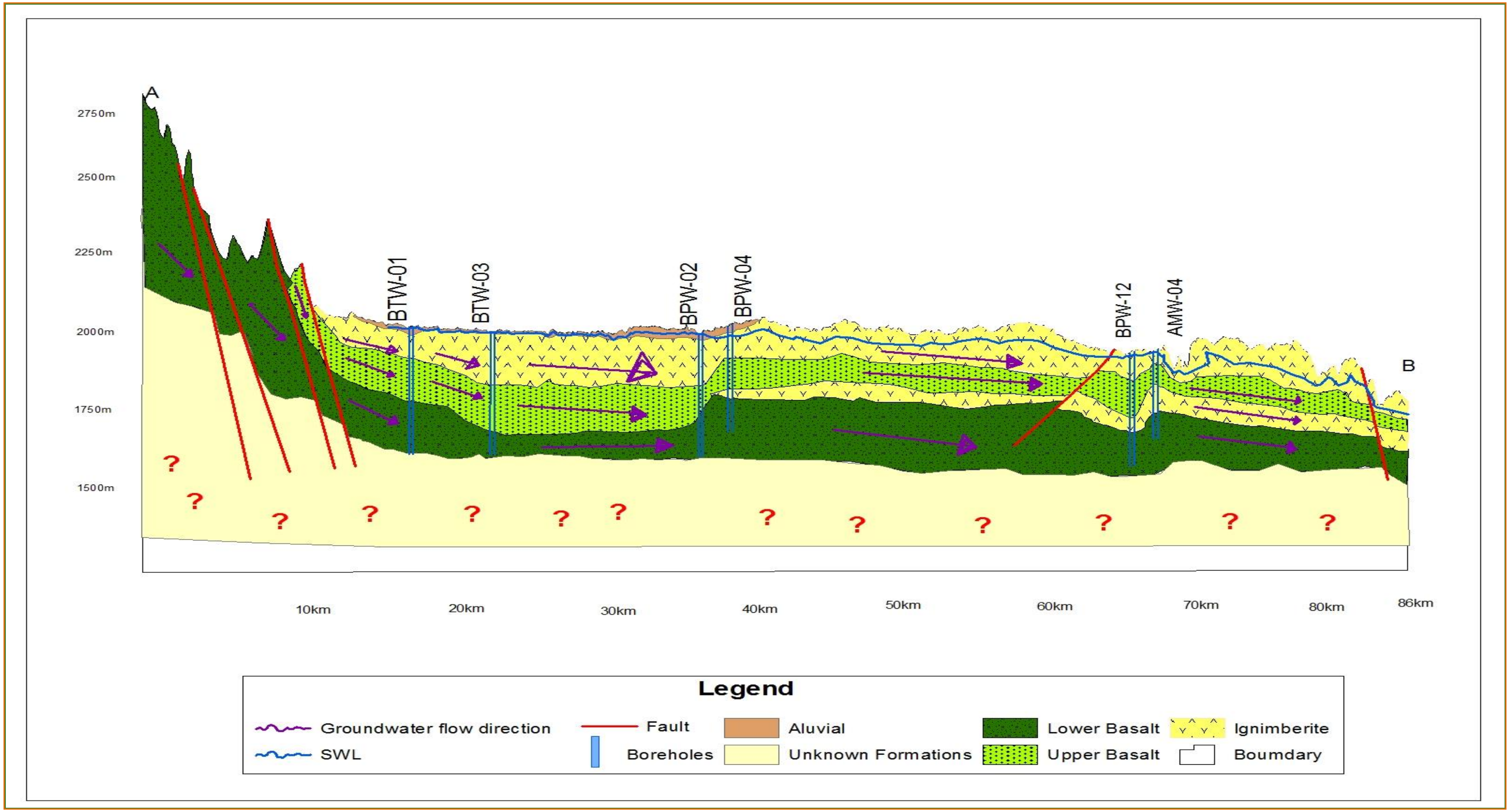


Figure 15:4 Hydrogeological Cross section along North West-South East (AB)

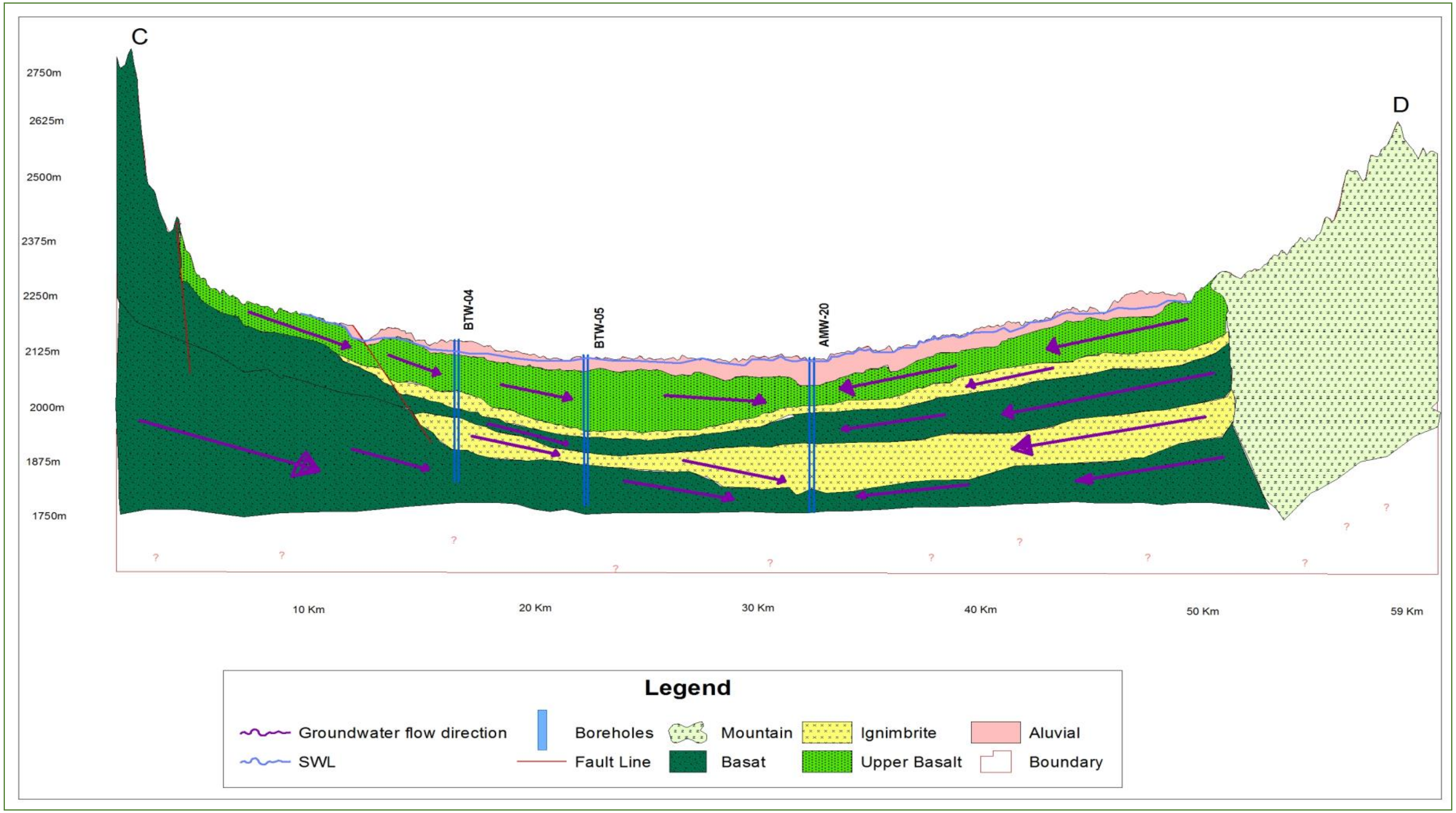


Figure 16:4 Hydrogeological Cross section along North-South(C-D)

3.4.2 Hydrogeological investigations (WWDSE, 2008)

Table 5:3 Lithologic and hydrogeologic characteristics units of study area groundwater system (WWDSE,2008).

Hydro-geologic Unit	Unit Label	Estimated average thickness in meters	Lithologic and hydrologic characteristics
Localized aquiclude (barriers)	LA	Most probably volcanic centers	Quaternary Bede Gebaba volcanic unit: Rhyolitic to minor trachytic lavas and pumice and Ziqualatrachytes and TertriaryEntoto-Becho Rhyolites and Central Volcanic of Wechecha, Furi, Yerer: prophyritic trachytic lavas. They have very low permeability, except along weathered and fractured zones. They act as local barriers.
Upper Basalt Aquifers	UBA	50 to 300 [100]	In most part of Becho groundwater system it is confined except at some part , where it is slightly confined. The geological formation is highly variable from place to place i.e. massive basalts, scoraceous basalt and scoria. The basalts when it is faulted and fractured the yield of bore holes increases. The static water level varies from place to place from 5 to 20 meters. The transmissivity of this aquifer is less than 50m2/day.
Upper Confining unit	UC	60 to 150 [120]	Chefe Donsa Pyroclastics, Nazaret unit (Welded ignimbrites) and Addis Ababa ignimbrites of low productive along the weathered and fractured zone. Acts as a regional aquiclude which separates the upper and lower volcanic aquifer in Becho plain
Lower basalt aquifer	LBA	Below 300 m	Lower Basalt aquifer (LBA) is composed of tertiary Tarmaber basalt composed of dominantly scoraceous basalt and Amba Aiba basalt. Static water level mostly artesian condition to a depth of above the water struck depth. Regional aquifer transmissivity 100 -1700 m2/day. Highly permeable.

- The drilling at Becho plain showed that the lower aquifer is confined. For example at Asgori water strike at 255 meters and the water level raised to 4.2m, at Melka Kunture water strike at 192 meters and the well became artesian and at Teji water strike at 300 meter and water level raised to 9.40 meters at STH-TW4 water strike at 152m and the water level raised to 5.4m, STH-TW6,STH-TW9 and STH-TW10 the water strike below 174m and the well is artesian. These results show the confinement of this aquifer varies from 190 meters to 260meters. The large part of the plain groundwater depth (Piezometric level) varies from artesian to 10 meters deep, especially the northern, central and southeastern part of the plain. In general the Piezometric level of the lower aquifer is shallow less than 30meters.

- The transmissivity determined from mapping, test and production wells clearly shows, the larger penetration of the lower aquifer have higher transmissivity (Annex I). As can be seen from the Annex the more depth penetration the higher the transmissivity and permeability and few depth penetration the lower the value. The transmissivity map of the study area showed that most of the area lower aquifer has an average transmissivity of about 407.94 m^2/day (WWDSE2008).

- According to attempts made to schematize regional groundwater dynamics by constructing regional cross sections along a line running along groundwater flow path (North West– South East) and North-South directions, two main aquifer, upper and lower basalt exists in Becho plain (figure 15:3 and 16:3). Water level of boreholes that penetrated the lower aquifer of Becho plain is less than 10 meter and in most case it is artesian. However, water level of boreholes that penetrated upper basalt is relatively deep.

- The groundwater flow directions are from all direction to the center of the plain and the main groundwater flow direction is from North, North West to South East direction (figure 14:3). Almost all part of Becho plain is potential for groundwater resources development.
- The current evaluation of Becho plain groundwater system showed that almost all part of the plain main aquifer has high transmissivity, and the electrical conductivity is within 260 -1943 µS/cm (WWDSE,2008) and the groundwater Piezometric level is generally shallow and less than 30 meters in most of the areas.

Chapter Four

4.Result ad Discussion

4.1 Numerical groundwater flow modeling of the study area

4.1.1. Introduction

The groundwater flow equations that comprise the groundwater flow model of this study were solved using the model code MODFLOW-2000 that is based on the finite-difference method. The groundwater flow model was set up as a one-layered, local and transient-state condition. The design of the example was to simulate groundwater flow of the aquifer, and thereby compute the dispersion of water table elevations and groundwater fluxes to manage the groundwater system in the sub basin.

4.1.1.1 Model geometry

As discussed in the conceptual model development section, the model domain is defined based on the surface topography and local physical boundaries.

Horizontal extent

The horizontal extent of the model domain is 64 by 74 km bounded by 382800 to 473200 m UTM East 926000 to 1032000 m UTM north. The irregular shape of the study area reduces the model domain to an area of about 4736 square kilometers.

Vertical extent

As depicted in the conceptual model, a simplified one layer model was employed to map the geologic materials in the work region. In groundwater modeling, the number of model layers, which are considered in the discretized domain, depends on the hydrogeological stratification of the system. In many model approaches hydrogeological layers of a real world system can be simulated by a single model layer. Established along the geologic and geophysical logs and well completion data a layer with a constant average thickness of 550 meters is considered to model for the study area aquifer system. The top and bottom elevations of the aquifer system are set based on the lithologic logs and the DEM extracted from the 30 by 30 ASTER image.

4.1.1.2 Model design

The most important activities of model design include the design of spatial domain, selection of initial conditions and setting the boundary conditions.

Discretization

In numerical models, the continuous natural phenomenon is replaced by a discretized domain, the so called grid. Grid size depends on hydraulic gradient, degree of aquifer heterogeneity, size of the model area, level of detail required and availability of data. Selecting the size of the nodal spacing is a critical step in grid design (Anderson & Woessner, 1992). A grid with a smaller number of nods is preferred in order to minimize data handling, computer storage and computation time. The finite-difference model grid must be regular spacing, in order to facilitate data input from DEM, ArcGIS in ASCII & SURFER files; certain cells may represent areas outside the modeled area (which can have any shape), Such cells are considered inactive cells.

The size of the nodal spacing in horizontal dimension is a function of the expected curvature in the water table or potentiometric surfaces. By making simplifications and assumptions about the actual field condition, the model area is discretized to one layer with a regular grid of 400m by 400m, 265 rows by 226 columns.

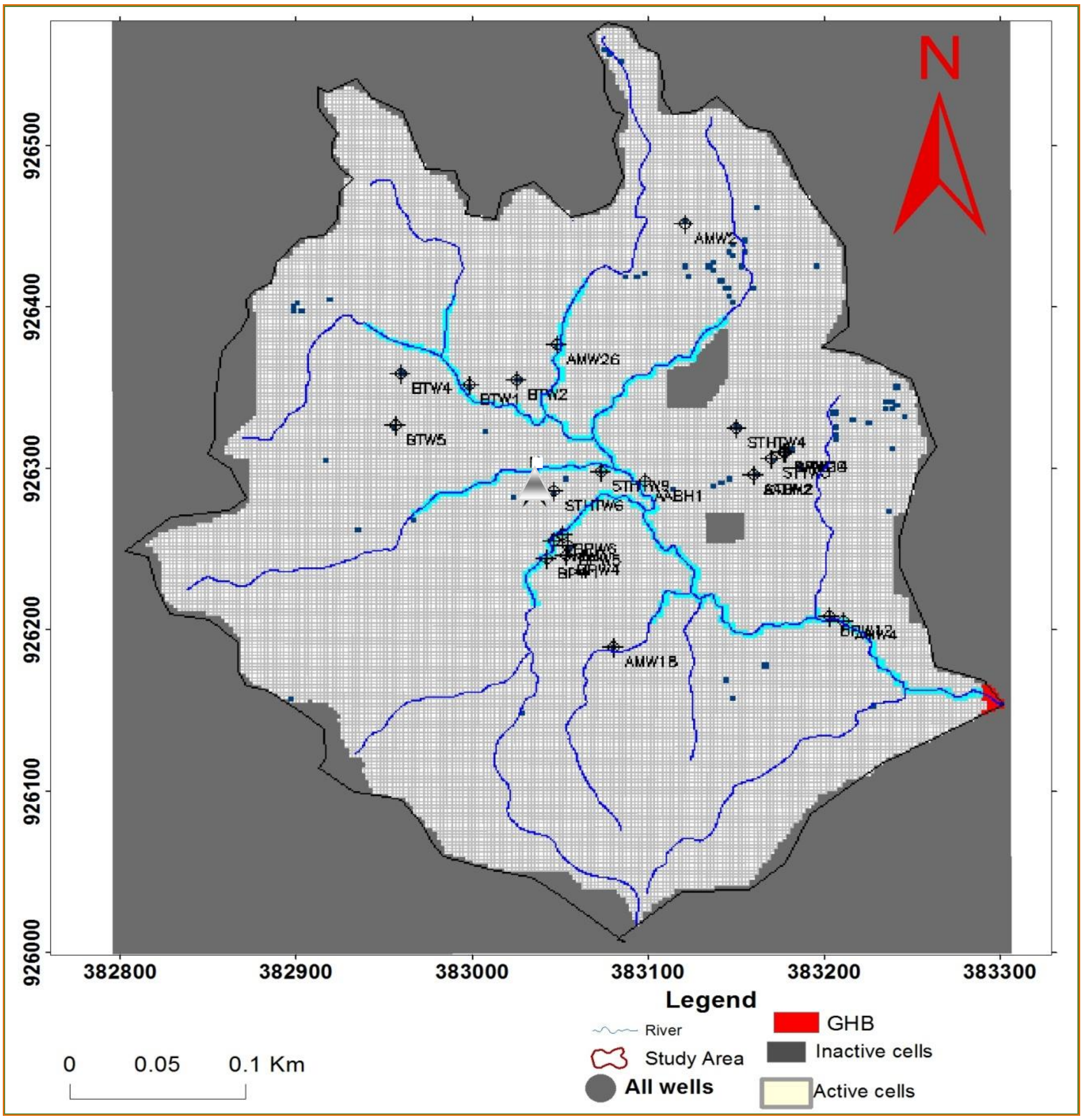


Figure 17:4 Model Area Discretization

4.1.1.3 Boundary Conditions

Boundary conditions are mathematical statement, specify the dependent variable (head) or the derivative of the dependent variable (flux) at the boundary of the problem domain (Anderson and Woessner, 1992). The boundary condition can be physical boundaries formed by an impermeable body of rock, faults, outcrops, large water bodies or result of hydrological condition of groundwater divides or stream lines.

The two types of boundary conditions, namely defined no-flow and Specified flux (Neumann) were considered for this model. Boundary conditions used in the model are discussed in the following subdivisions.

No-Flow Boundaries and Specified flux Boundaries

Model boundaries that overlap with watershed boundaries were defined as no flow boundaries. Geologic or hydrologic barriers to ground-water flow, the contact between permeable and nearly impermeable bedrock were simulated using no-flow boundaries. For example, the no-flow boundaries in the west of the model domain coincide with western boundaries of the Weliso highlands boundaries. Correspondingly, the no-flow boundary in the East Furi & Wechecha Mountain & Melka Kunture horst, in the south bordered by Guraghe highlands. The boundary in the North of the model area is E-W trending rift escarpment (Ambo fault).
Known or estimated hydrologic fluxes, such as recharge and well discharge, are represented using specified-flux boundaries.

General-Head Boundaries (GHB)

The General-Head Boundary (GHB) package is used to simulate head-dependent flow boundaries, where flow into or out of a GHB-cell from an external source is provided in proportion to the difference between the head in the cell and the head assigned to the external source.
Boundaries of the model that could neither are assigned as no-flow or constant head were defined as GHBs, which permitted groundwater flux interactions with neighboring aquifers. GHBs require the assignment of two parameters; a conductance value and head value representing a distant constant-head boundary.

The General-Head Boundary Package requires the following information for each General-Head grid cell:

The Conductance value (C) for the scenarios illustrated in the preceding figure may be calculated using the following formula:

$$C_b = K \times L$$

Whereas, where L is the length of the general-head boundary within a cell (LxW),K is the average hydraulic conductivity of the aquifer material separating the external source/sink from the model grid.

4.1.2 Model Input Parameters

Simulation of groundwater flow and fluxes requires specifying aquifer system properties and stresses. Aquifer system properties can vary considerably both horizontally and vertically and thus, cannot be precisely represented in a numerical model. The initial aquifer system properties of the study area were conceptually modeled from different groundwater literatures and deep water well drilling log and Geophysical data and analysis of pumping test

4.1.2.1 Top and Bottom of layer

Layer top or surface elevations were extracted from DEM of 30m spatial resolution. Layer bottom elevations were obtained by subtracting aquifer thickness from layer top elevations. Aquifer thickness of 500m is considered, except along the boundaries where ridges with high elevation are found. Elevated zones were simulated by giving relatively higher thicknesses at the cells in order to avoid drying of cells during simulations.

4.1.2.2 Initial and Prescribed Hydraulic Head

MODFLOW requires initial hydraulic heads at the beginning of a flow simulation. Initial hydraulic heads at constant head cells are used as specified head values of those cells and remain constant throughout the flow simulation. For transient flow simulations, the initial heads must be the actual values, since they are used to account for the storage terms. The real value of 45 wells water level elevation (groundwater level depth ASCII) map was given as an initial heads for active cells.

4.1.2.3 Hydraulic Conductivity

Groundwater flow within the model layer was assumed to be horizontal. Hydraulic conductivity is property that, in conjunction with the horizontal hydraulic gradient, control horizontal flow of groundwater. Hydraulic conductivity is a measure of the water transmitting properties of aquifer material. The hydraulic conductivity of the study area was estimated from pumping test data of 30 boreholes drilled in the study area. The horizontal hydraulic conductivity was applied to each active model cells from ASCII map produced by ArcGIS based on the hydraulic conductivity value of Annex I & Figure 12:3.

4.1.2.4 River Package

The River Package is used to simulate the flow of water between an aquifer and an overlying (or underlying) source reservoir which is usually a river or lake. It allows water to flow from the aquifer to the source reservoir, thereby removing water from the model by seepage to gaining stream reaches. Water can also flow out of the stream into the aquifer but the seepage out of the stream is independent of the stream discharge. Thus, a losing reach of stream could recharge the aquifer with more water than is being carried in the stream.

Based on at some place site measurement and estimation, river bed sediment thickness has been assumed to vary between 0.15 to 0.45m and river widths range from 2 to 30m. River length in a cell has been roughly considered to be equal to the side of the cell size (400m), since tracing and measuring the river length in a cell is difficult. Hydraulic conductivity of river bed sediments was not characterized and measured in the field, instead the hydraulic conductivity of the underlying formation has been considered. The hydraulic conductance of the river bed sediments has been calculated using the relation: $C_{RIV}=K_r *L*W/M$

The R_{IV} package uses the river bed conductance (C_{RIV}) to account for the length(L) and width(W) of the river channel in the cell, the thickness of the river bed sediments(M), and their hydraulic conductivity(Kr).

4.1.2.5 Groundwater recharge

The groundwater recharge process of the study area is highly controlled by topography, geology and structure which directly infiltrated water towards the discharge area. The groundwater recharge was estimated using WetSpass Model method which is 120 mm year^{-1} and with RAP 3.0.3 time series analysis which is 85.78 mm year^{-1}. The recharge map in ASCII form was applied to the top most active cell using the recharge package of MODFLOW shown on Figure 7:3.

4.1.2.6 Ground Water Abstraction

The estimated groundwater pumping rates were assigned to the model is about 194,693.19 m^3/day. Ground water pumping for the model was simulated using well package of the MODFLOW depending on the geographic coordinates of the wells in ASCII form prepared by ArcGIS.

4.1.3 Steady-State Model

Steady-state flow condition exists when inflow is equal to the out stream and aquifer storage does not survive. The steady state model of Becho plain is developed and calibrated and used as an input for Transient state flow model. The steady-state model was set up as one layer, two dimensional with confined/unconfined transmissivity =variable.

4.1.3.1 Steady State Model Calibration

Calibration verifies that the simulation is reproducing field measured heads and flows (Anderson and Woessner1992). It engages regulation and modification of parameter structure and values to provide the best match between measured and calculated hydraulic heads and flows. The steady- state model was calibrated without pumping and with pumping scenario. Static water level records during pumping test were used to calibrate the steady-state model.

Hydraulic heads for steady-state conditions are sensitive to the hydraulic conductivity of the aquifer system, aquifer thickness and recharge. The model was calibrated through trial and error by varying the recharge and hydraulic conductivity were made within sensible ranges based on field hydrogeological observations and comparing the calculated and observed heads.

Criteria used to evaluate the simulation result with measured data.

- Comparing measured water levels or drawdown in the well with scatter plot;
- Comparing simulated water level contours with observed water level contours;
- Comparing the simulated water budget and input data.

The calibration result is presented in graphical form and tables. The scatter plot simulated Vs. observed heads are indicated in Figure 18:4.

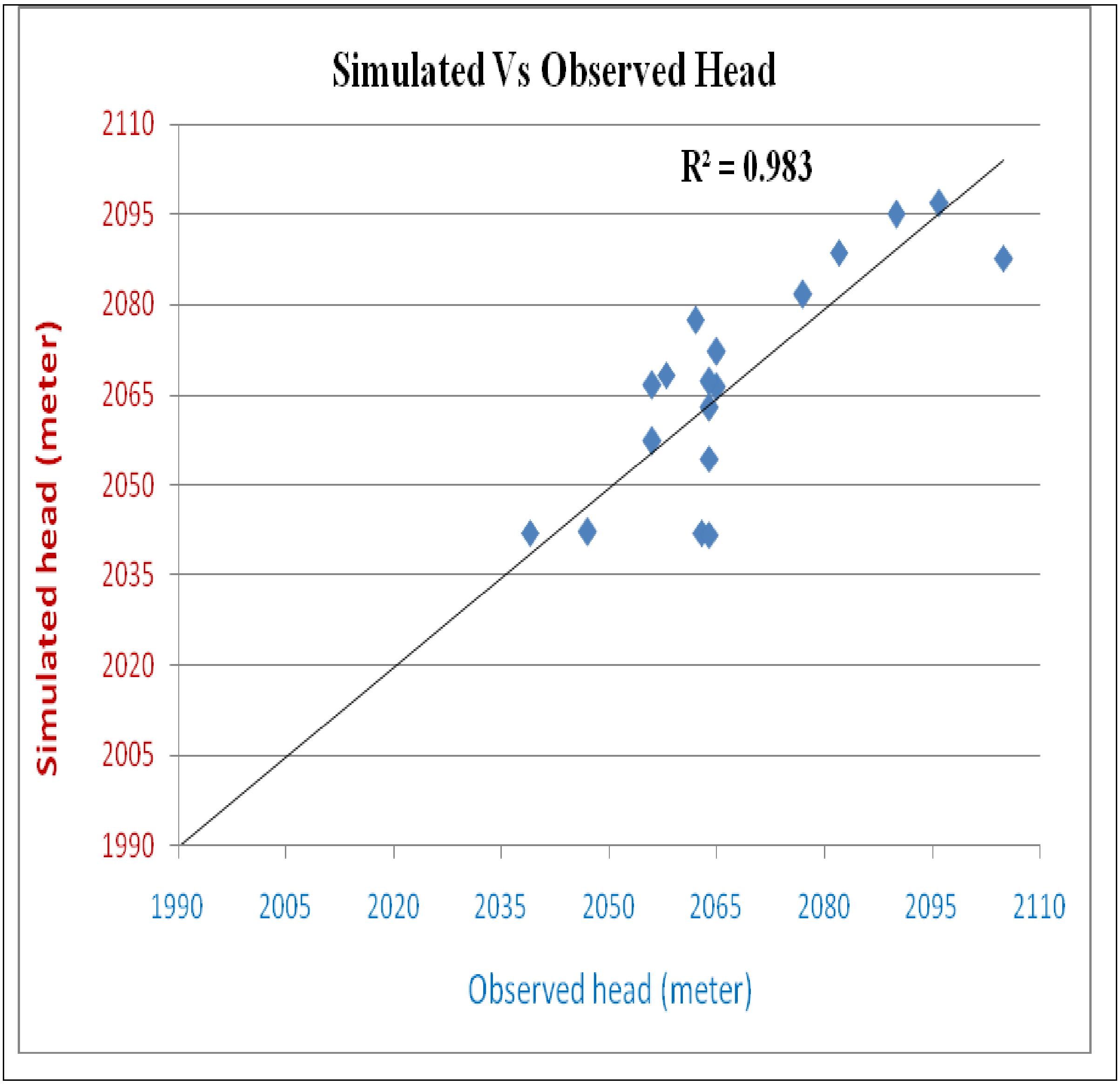
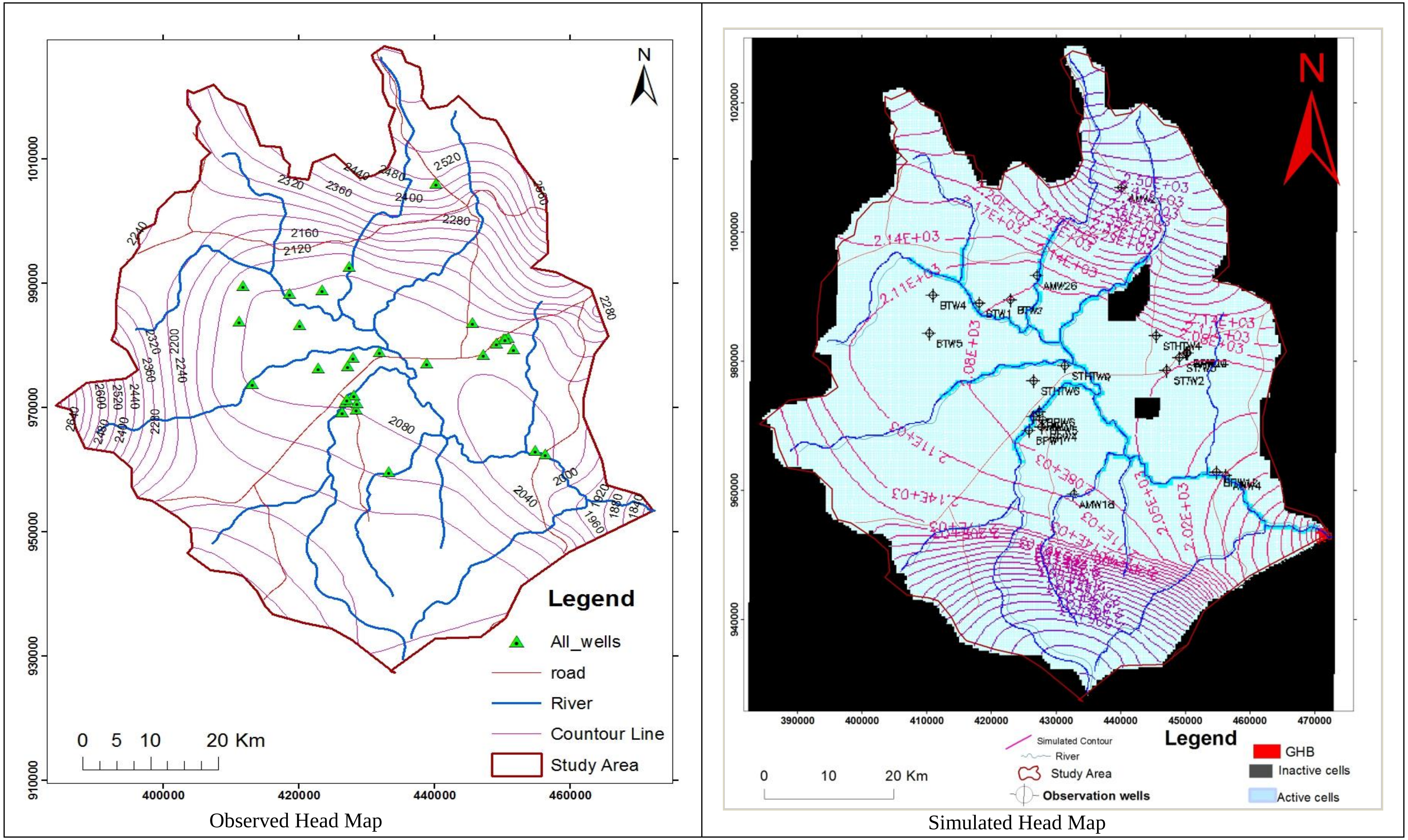


Figure 18:4 Observed Vs Calculated head scatter plot of steady state model



Observed Head Map

Simulated Head Map

Figure 19:4 Comparison Of Observed and Simulated Hydraulic Head map

Statistical comparison between the simulated and measured values of hydraulic heads (table 6:4) was done to quantitatively asses the calibration match. The mean error (ME), the mean absolute error (MAE) and root mean square error (RMSE) provide ways to determine the overall goodness-of-fit between the simulated and the measured hydraulic heads.

1. The mean error (ME) is the mean difference between measured/observed heads (hm) and simulated/calculated heads (hs). $\mathbf{ME=1/n\ \Sigma\ (hm-hs)}$

2.The mean absolute error is the mean of the absolute values of the differences between measured heads and simulated heads. $\mathbf{MAE=1/n\ \Sigma|\ (hm-hs)|}$

3.The root mean square error is the square root of the averages of the squared differences between measured heads and simulated heads.

$\mathbf{RMS=\{1/n\ \Sigma\ (hm-hs\ )2\ \}0.5}$

Table 6:4 Simulated Head (meter) with ObservedHeads (meter)

Wells Used for Calibration						
No.	Well ID	Simulated	observed	(hm-hs)	|(hm-hs)|	$(hm-hs)^2$
1	BPW1	2072.174	2065	-7.17	7.17	51.47
2	BPW4	2068.242	2058	-10.24	10.24	104.90
3	BPW5	2066.67	2056	-10.67	10.67	113.85
4	BPW6	2066.231	2065	-1.23	1.23	1.52
5	BPW12	1993.955	1989	-4.95	4.95	24.55
6	BPW20	2042.013	2063	20.99	20.99	440.45
7	BTW1	2081.629	2077	-4.63	4.63	21.43
8	BTW2	2077.332	2062	-15.33	15.33	235.07
9	BTW4	2095.037	2090	-5.04	5.04	25.37
10	STTW2	2042.063	2039	-3.06	3.06	9.38
11	STTW3	2042.262	2047	4.74	4.74	22.45
12	STHTW4	2054.333	2064	9.67	9.67	93.45
13	STHTW6	2062.961	2064	1.04	1.04	1.08
14	AMW2	2495.546	2493	-2.55	-2.55	6.48
15	AMW3	2067.289	2064	-3.29	3.29	10.82
16	AMW14	2041.716	2064	22.28	12.12	146.92
17	AMW26	2087.766	2105	17.23	17.23	297.01
18	BTW5	2088.703	2082	-6.70	6.70	44.93
19	STHTW9	2057.263	2056	-1.26	1.26	1.60
				ME=0.53	MAE=7.14	RMS=9.26

4.1.4 Transient state model

In the transient state model the groundwater heads are a mapping of time. This applies to problems such as influencing the change in head around a pumping well or growth of the groundwater mound beneath a recharge basin Fetter, (2001 as cited in Gebrehawria Gebrekirstos Teferie,2009). A transient simulation typically begins with steady state initial conditions. Transient simulations produce a set of heads for each time step. Transient model can be partially transient or fully transient.

The fully transient model is the most reliable but also the least explored probably due to demanding input data (Gebrehawria Gebrekirstos Teferie 2009). This survey has been conducted using two deep wells of one year water level data that has been recorded with data logger and recharge estimated by WetSpass model with twelve month and with abstraction scenarios.

4.1.4.1 Specific Storage and Specific Yield

For transient flow simulations, MODFLOW requires dimensionless storage terms for the model. In a confined layer, the storage term is given by storativity or confined storage coefficient (= specific storage [L^{-1}] *layer thickness [L]) and in unconfined aquifer the storage term is given as specific yield. The storativity is a function of the compressibility of the water and the elastic property of the soil matrix. The specific storage or specific storativity is defined as the volume fraction of water that a unit column of aquifer releases from storage under a unit decline in hydraulic head. since group or distance drawdown pumping test were not conducted specific storage and specific yield values used within the range of the specified aquifers for different aquifer type.

4.1.4.2 Hydraulic conductivity

When the transient model was run for the first time, the hydraulic conductivity value was continued unchanged as calibrated in the steady state model. Withal, the hydraulic conductivity was also set during the calibration of the transient state model.

4.1.4.3 Time discretization

Time discretization into stress periods and discretization into time steps is an important step in transient modeling as it strongly influences the numerical results Fresilassie, (2002 as cited in Gebrehawaria Gebrekistos Teferie, 2009). The stress period in MODFLOW is the blocks of time of variable lengths used in simulations of each time step. Stress period and time steps should not be too large to miss important changes in hydraulic heads, has also they should not be too small either, as this may be result in too detailed calculations and the model solution will take a long time (Magombedze, 2002). The length of stress period was chosen after analysis of recorded water levels, rainfall and groundwater recharge. By taking into consideration the water level record, the period from July 2016 to August 2017 was divided into 12 stress period of each stress period also divided into one month length time step.

4.1.4.5 Transient state model calibration

Calibration is achieved by obtaining a lot of parameters, boundary conditions and stresses that produce simulated heads and fluxes that match the field measured values within pre-proven range of error (Anderson and Woessner, 1992). Calibration can be carried out by manual trial and error or by automatic parameter estimation like PEST and the model must be run several times in order to obtain the most optimal solution. Because of many uncertainties to calibrate the model trial and error was applied.

Although the model appeared to perform well at steady-state, most practical applications of modeling in groundwater management are dynamic, involving a decision over time. The transient calibration was conducted based on the groundwater level information of two piezometer wells. The transient state model calibration was performed by trial and error adjustment of recharge (R) and Hydraulic Conductivity (K). The adjustment of recharge was based on between recharge obtained from WetSpass model and base flow separation using River Analysis Package 3.0.3 time series analysis.

The purpose of transient state model calibration was not solely to obtain the lowest root mean squared error of the divergence between the calculated and observed heads, but also to induce a good fit to the pattern of ascent and decline of groundwater levels as measured in the piezometer wells. The final calibrated and measured groundwater heads are described in

(Figure20:4) and drawdown graph is indicated in Figure 21:4.

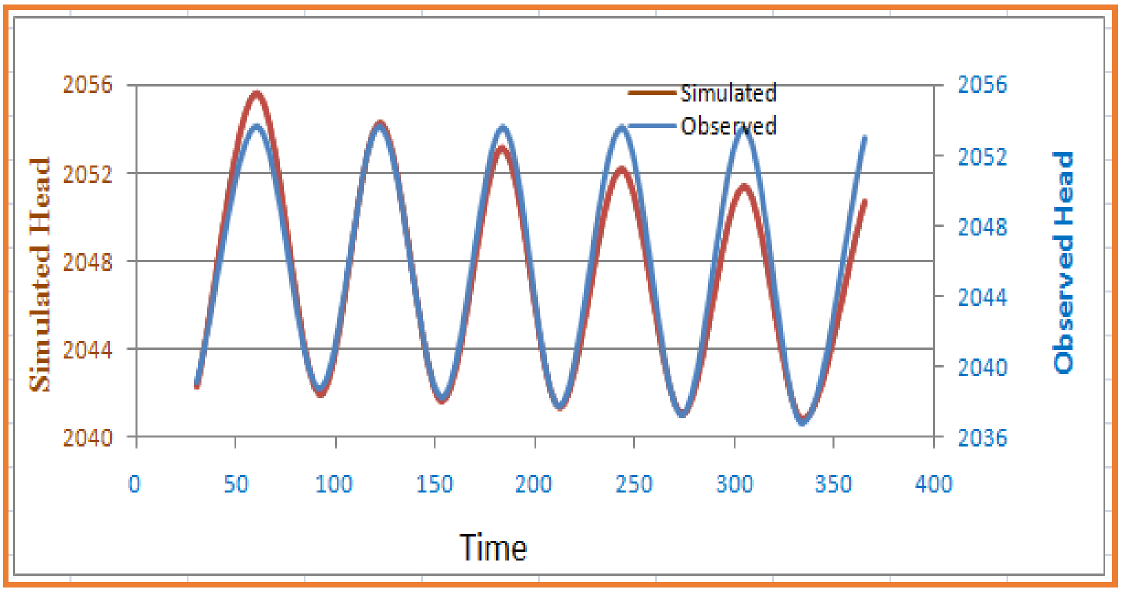


Figure 20:4 Average Observed and Simulated head of transient state model

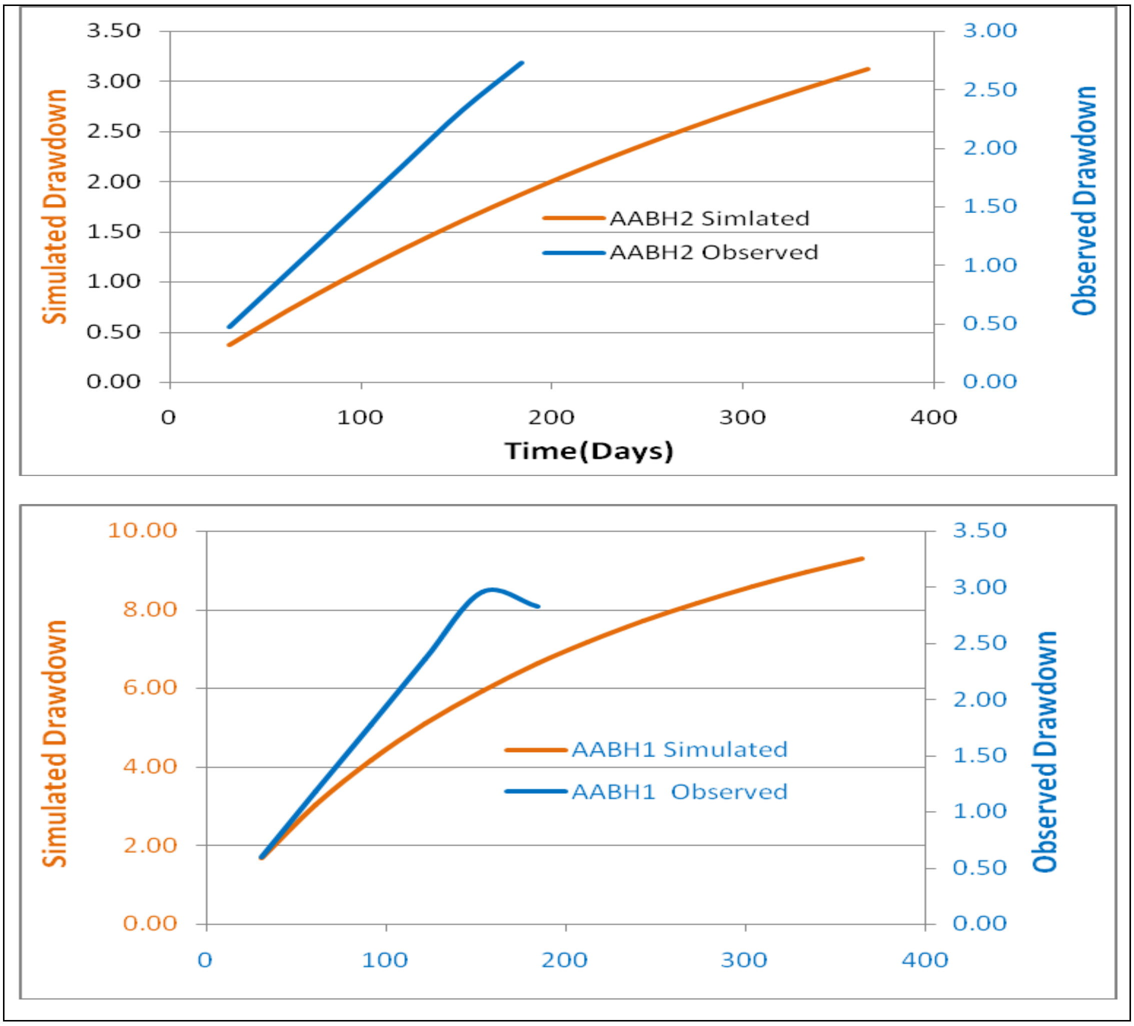


Figure 21:4 Observed and Simulated Groundwater drawdown of transient state model

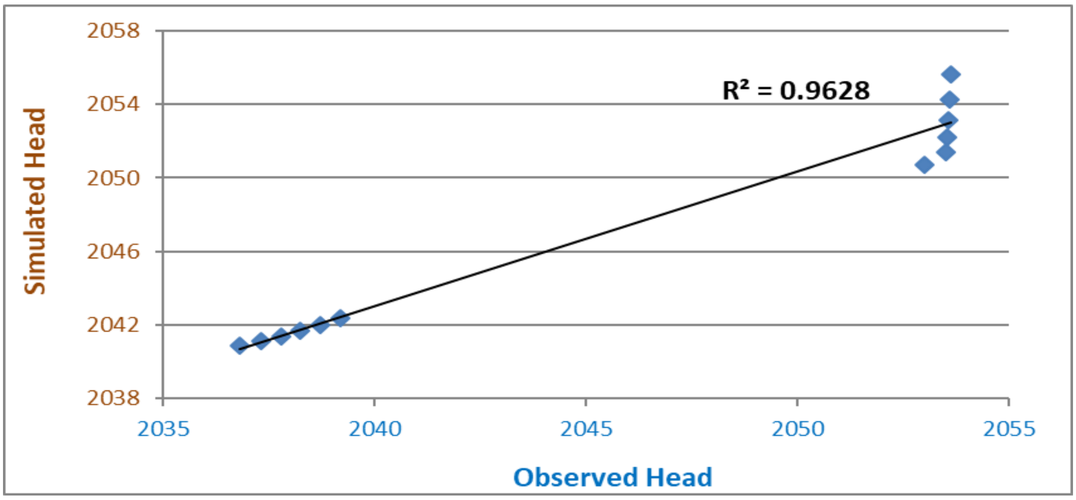


Figure 22:4 Scatter plot of Observed and Simulated Groundwater heads of transient state model

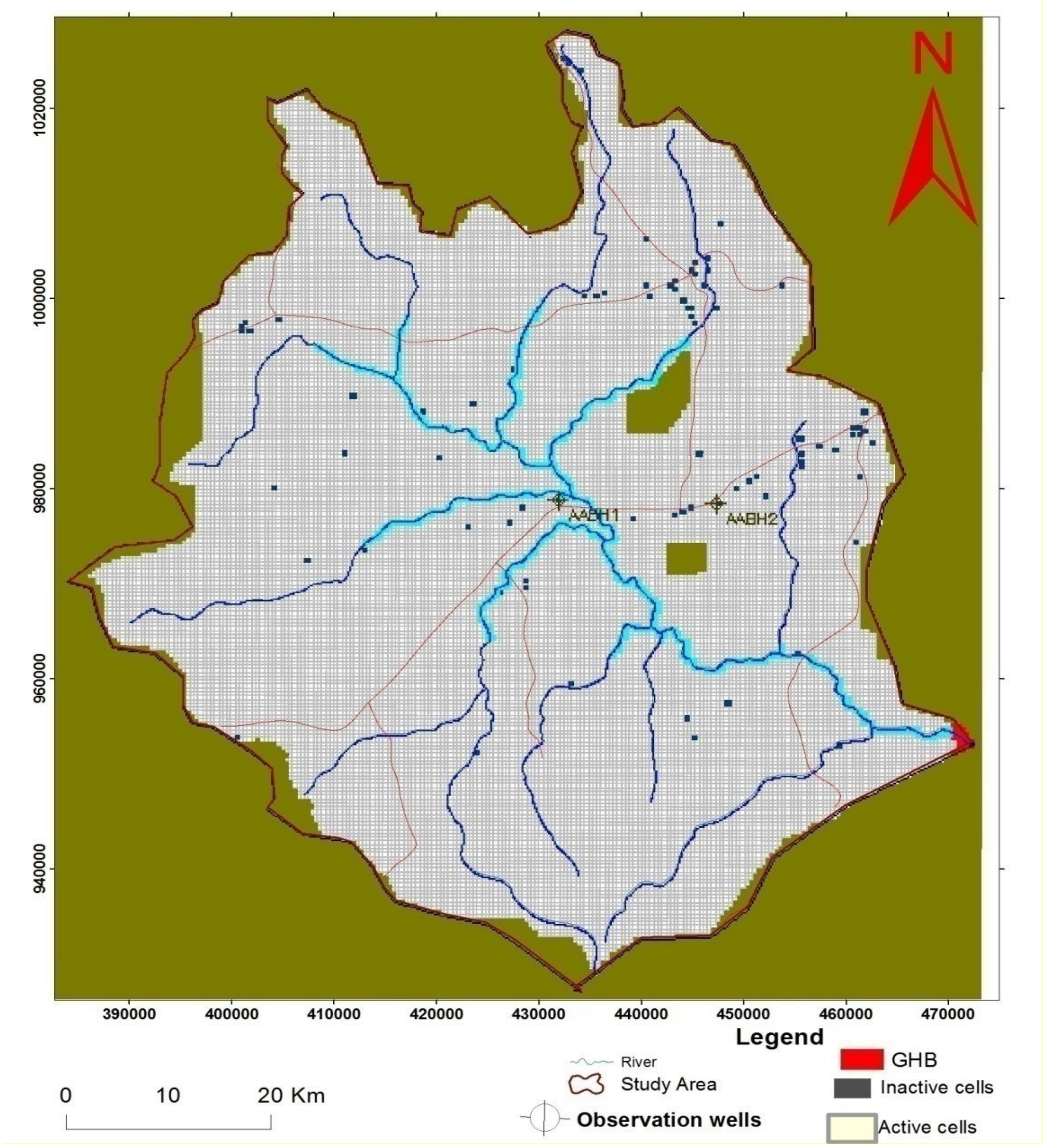


Figure 23:4 Location of observation wells

4.2 Discussions

4.2.1. Introduction

Predictive Modeling facilitates assessment of the response of the aquifer to different stress conditions and provides a predictive tool for the management of the resources in terms of temporal and spatial distribution of abstraction. Scenarios are an important tool for decision making in situation of high uncertainty. They can assist in evaluation of different possible future circumstances and their implications for decision making in the present. Due to increase abstraction of groundwater and less recharge in the Becho Aquifer, the water table is declining and partial shortage of water has occurred. To predict the aquifer response for different stress conditions two scenarios were developed.

4.2.2 Water Budget

4.2.2.1 Steady state model water budget

Groundwater recharge

The groundwater recharge was estimated using WetSpass Model method which is 120 mm year^{-1} and with base flow separation is 85.78mm/year. The recharge obtained after model optimizing is 80 mm year-1. The difference between inflow and outflow in this study may be due to under estimation of recharge or it might be during calibration process.

Groundwater discharge

In general groundwater abstractions from deep wells are the main groundwater discharge. Groundwater is also discharged from the study area is through, seepage as spring into Awash River and swamps and groundwater flow through the south eastern outlet. On average 194,693.19 m^{3}day^{-1} groundwater is abstracted from the study area daily. Groundwater outflow through the south eastern outlet at (Meleka Kunture) outlet by a saturated aquifer depending on the hydraulic gradient in the plain under natural condition is about 638,384.96 m^{3}day^{-1}.

Groundwater of the study area was quantified on the basis of the steady-state calibrated model output for non-pumping scenario. The water budget components include recharge which is the only inflow and outflow to the river, a head dependent outflow through the South-East boundary and well abstraction (for the pumping scenario) which are outflow components.

The calibrated model can be applied to derive components of the groundwater budget or estimate the response of the regional system to new stresses such as alternative groundwater management strategies. Water resource managers can use that information to make informed decisions to plan for future groundwater development.

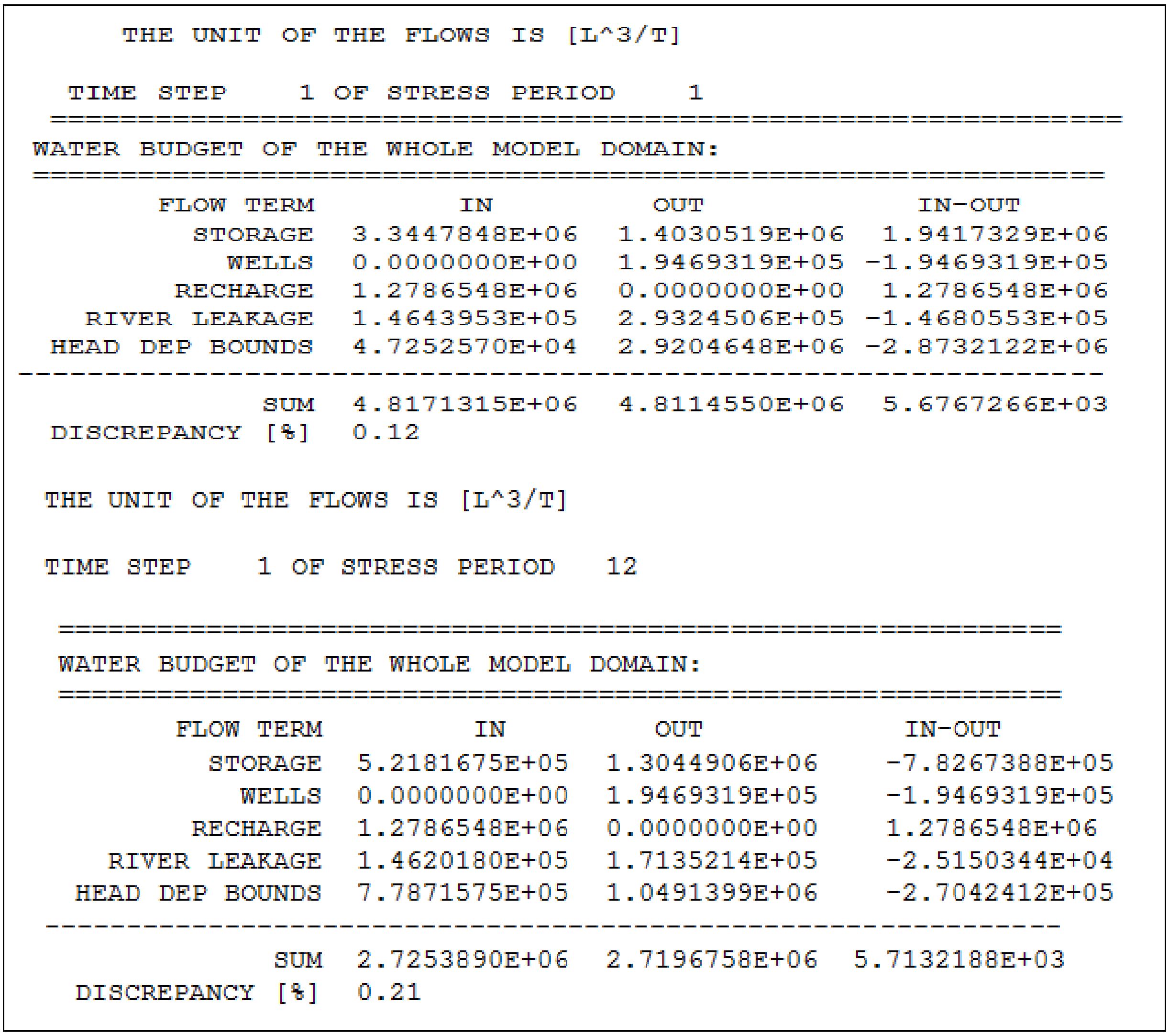
Table 7:4 Simulation Water Budget Result

THE UNIT OF THE FLOWS IS [m^3/day]			
Flow Term	**IN**	**OUT**	**IN-OUT**
Wells	0.0000E+00	0.0000E+00	0.0000E+00
Recharge	1.2645404E+06	0.0000E+00	1.2645404E+06
RIVER LEAKAGE	6.6931900E+05	1.6736581E+06	-1.0043391E+06
HEAD DEP BOUNDS	6.0669648E+04	3.1929388E+05	-2.5862423E+05
Sum	**1.9945290E+06**	**1.9929519E+06**	**1.5771080E+03**
DISCREPANCY [%]	**0.07**		

4.2.2.2 Transient state model water balance

The water balance of Becho aquifer was evaluated from the transient state model of MODFLOW groundwater flows such as recharge, groundwater storage, groundwater abstraction, base flow to river (river package), groundwater outflow at the downstream end of the catchment was assigned as general head boundary. The increase of groundwater abstraction from the aquifer, results in a decrease of the hydraulic gradient. As a result the flow of water to rivers and through the outlet was declining. The water budget generated by the transient state is shown in Table 8:4.

Table 8:4 Water budget generated by transient state modeling



```
     THE UNIT OF THE FLOWS IS [L^3/T]

   TIME STEP     1 OF STRESS PERIOD     1
  ============================================================
 WATER BUDGET OF THE WHOLE MODEL DOMAIN:
 ============================================================
          FLOW TERM          IN           OUT            IN-OUT
            STORAGE  3.3447848E+06  1.4030519E+06  1.9417329E+06
              WELLS  0.0000000E+00  1.9469319E+05 -1.9469319E+05
           RECHARGE  1.2786548E+06  0.0000000E+00  1.2786548E+06
      RIVER LEAKAGE  1.4643953E+05  2.9324506E+05 -1.4680553E+05
    HEAD DEP BOUNDS  4.7252570E+04  2.9204648E+06 -2.8732122E+06
 -------------------------------------------------------------
                SUM  4.8171315E+06  4.8114550E+06  5.6767266E+03
   DISCREPANCY [%]   0.12

  THE UNIT OF THE FLOWS IS [L^3/T]

  TIME STEP     1 OF STRESS PERIOD   12

   ==========================================================
   WATER BUDGET OF THE WHOLE MODEL DOMAIN:
   ==========================================================
          FLOW TERM           IN          OUT           IN-OUT
            STORAGE  5.2181675E+05  1.3044906E+06    -7.8267388E+05
              WELLS  0.0000000E+00  1.9469319E+05    -1.9469319E+05
           RECHARGE  1.2786548E+06  0.0000000E+00    1.2786548E+06
      RIVER LEAKAGE  1.4620180E+05  1.7135214E+05    -2.5150344E+04
    HEAD DEP BOUNDS  7.7871575E+05  1.0491399E+06    -2.7042412E+05
  ----------------------------------------------------------
                SUM  2.7253890E+06  2.7196758E+06  5.7132188E+03
    DISCREPANCY [%]  0.21
```

4.2.3. Model Sensitivity Analysis

4.2.3.1 Steady State Model Sensitivity Analysis

The model is considered sensitive to parameter when a change of parameter value changes the distribution of the simulated hydraulic head. When the model is sensitive to an input parameter, the value of that parameter within the model is more accurately determined during model calibration because small changes to the parameter value cause large change in hydraulic head.

The determination of sensitivity analysis is to quantify the uncertainties in the calibrated model caused by uncertainty in the estimates of aquifer parameters, stresses and boundary conditions (Anderson and Woessner, 1992). During simulation when the impression of single parameter was being examined, the other parameters were maintained in the steady state calibrated value and each parameter was changed uniform over the modeled area. The magnitude of changes in heads or fluxes from the calibrated solution was applied as a criterion of the sensitivity of the model to that particular parameter. Sensitivity analysis was done using recharge and hydraulic conductivities.

A aggregate of more than thirty model runs has been gained by changing the hydraulic conductivity & recharge by the specified percent and the root mean squared head changes from the calibrated value are presented in Table9:4 & Figure24:4.

Table 9:4 Sensitivity Analysis of the Effect of selected parameters on the RMS Value of Water Level

parameters change in %	Recharge	Hydraulic Conductivity
-30	26.09	31.62
-25	22.4	25.12
-20	18.97	19.65
0	0	0
20	16.9	16.73
25	20.11	18.91
30	23.46	21.02

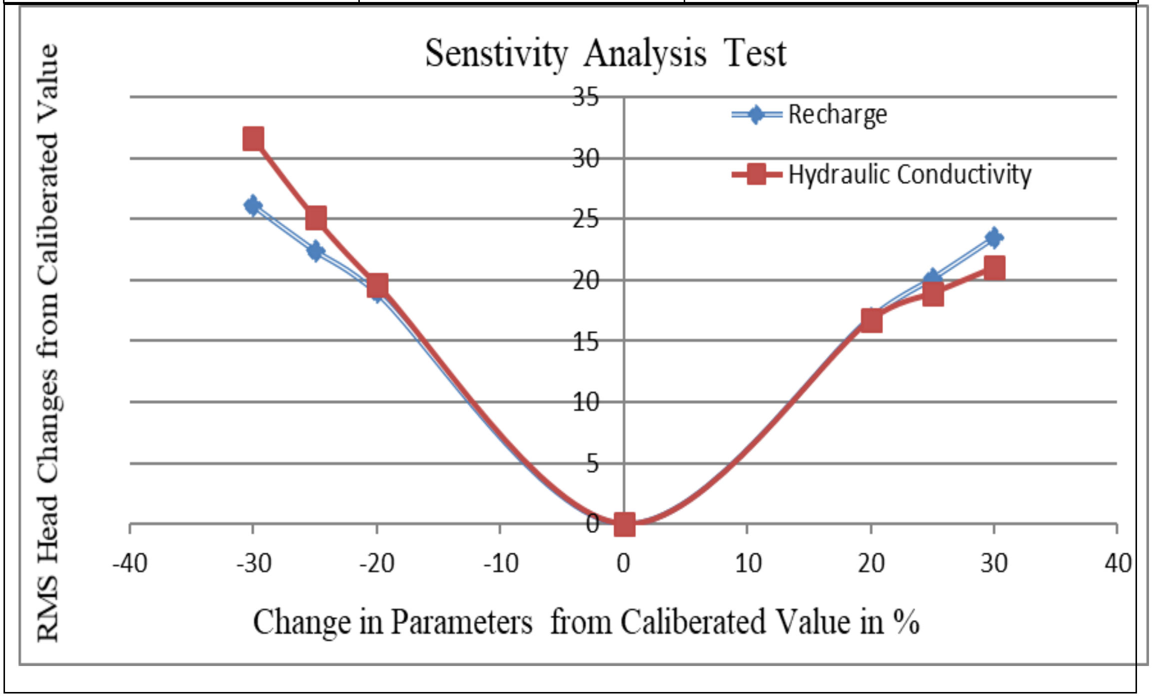


Figure 24:4 Sensitivity Analysis of the Effect of selected parameters on the RMS Value of Water Level

4.2.3.2 Transient state model Sensitivity analysis

The sensitivity analysis was performed by systematically changing aquifer and hydrologic parameters from the optimized values and evaluating the change on the model result. Groundwater recharge and hydraulic conductivity were each varied separately to assess the impact on the model output. To observe the change of the groundwater table by changing these parameters, put an observation well at the centre of the study area assuming that the change in groundwater table in the observation well represents the average change in the study area. Since the plain has one outlet, flat topography, geometrically simple, uniform recharge, the change of groundwater table in the observation well can give an estimation of the plain.

The parameter values were changed from the average simulated values by 20%, 35% and 50% to compare the change in hydraulic gradient in the observation well located at centre of the study area. A small change of hydraulic conductivity and recharge from the simulated average values has influence on the water table. Change of hydraulic conductivity by 50% from the simulated values the water tables changes in magnitude with average values 1.97 meter and indicated in (Figure 25:4) and the sensitivity analysis graph for the aquifer parameters are indicated in Figure26:4. The sensitivity result indicates that the transient modeling is very well capable of producing accurate storage values.

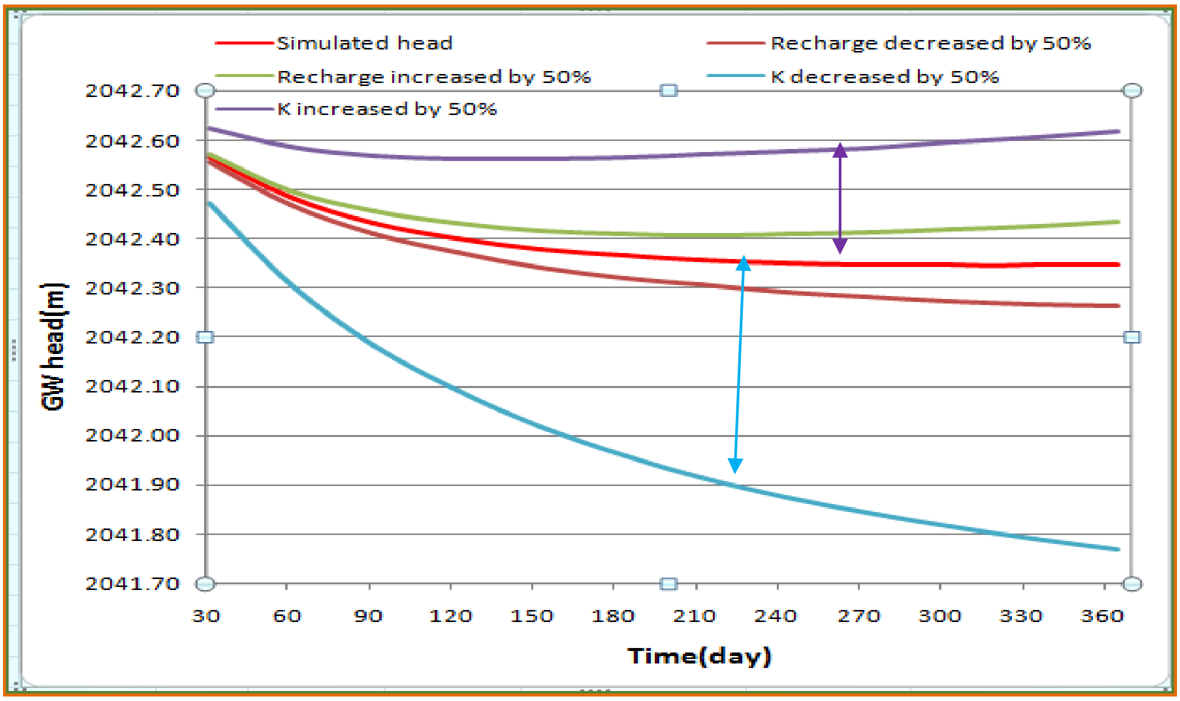


Figure 25:4 Groundwater depth result by changing recharge and hydraulic conductivity by 50%

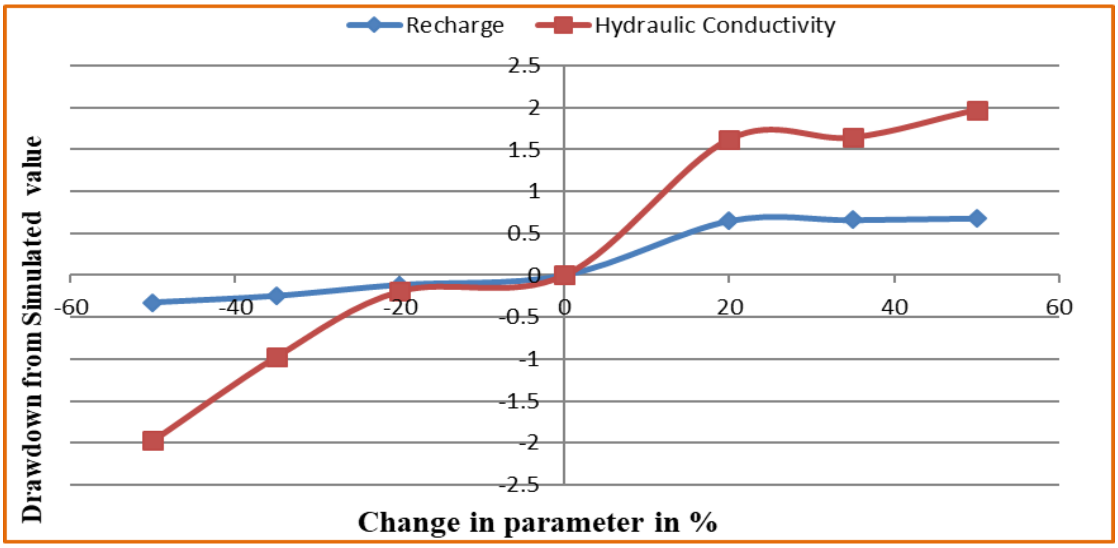


Figure 26:4 Sensitivity analysis of recharge and hydraulic conductivity

4.2.4. Scenario development

The calibrated groundwater flow model can be used to simulate the potential effect of alternative water management plans on hydraulic head and groundwater movement in the study area. It can also be used as a tool to evaluate and compare the responses of an aquifer system to potential future stresses.

It should be noted that the results of the scenarios depend on future land use, population growth, weather conditions, hydrologic stresses etc, and may not be used as a predictive tool to generate absolute amounts in the future, but used primarily to test the groundwater level response. In general, the results of the scenarios or their accuracy depend on the validity of the assumptions behind the scenarios. Moreover, errors introduced due to limitations associated with the model also affect the results of the scenarios and should be taken into considerations during interpretation and application of results.

These observed changes simply represented regional effects of the proposed groundwater withdrawals. In fact, water levels in individual pumped wells are likely lowered depending on local aquifer properties, well construction and well location relative to surface water bodies. In this scenario development high drawdown is recorded wells located around high elevation with abstraction rate 194,693.19m^3/day. Water level changes in individual wells can be exaggerated or diminished relative to the regional representative value. From the lower simulation results, one can observe that the construction of new groundwater around the highland will cause high drawdown.

4.2.4.1 Steady state model scenario

Table 10:5 parameters response to increased groundwater withdrawal

Groundwater withdrawal from calibrated steady state value, in %	Average Head change (m)
20	28.7
35	31.69
50	34.74

4.2.4.2 Transient state model scenario

Transient model calibration was used to evaluate the aquifer response to different stress conditions like groundwater abstractions and recharge with the objective of predicting water table drawdown. Two scenarios are used to evaluate the aquifer response to different times, recharge and for future abstraction of the aquifer in the catchment.

- Scenario one: effect of abstraction for five and ten years
- Scenario two: effect of adding new wells

The assumptions applied for the simulation of the different scenarios are:

- Groundwater heads and flux values of the calibrated transient state model are considered as initial condition for each scenarios,
- Groundwater recharge is equal to as in the simulation period in transient state model
- Pumping rate will be average abstraction rate of each well
- The average drawdown in observation wells would be the average drawdown of the water table in the study area.

Scenario one

In the Becho plain groundwater is abstracted with more than fifteen operational wells but abstraction data is not well monitored. To predict the groundwater level for the next five and ten years of period with continuous abstractions groundwater from the existing wells and assuming that abstraction data will be well monitored. Depending on the distribution of pumping wells two observation wells are put to observe the drawdown for five and ten years of abstractions. After pumping for these years with an abstraction rate of 194,693.19 m^3day^{-1} (with the same recharge to the periods of transient model simulations) the groundwater table declines on average 30.77 and 60.05 meters respectively. Observation well one (AABH1) placed in the centre of the plain, shows higher drawdown.

The results of each observation well are indicated in the Table 11:4 and Figure 27:4 below.

Table 11:6 Groundwater heads after 5 and10 years continuous abstraction for the existing wells

	Groundwater head					Drawdown (m)	
ID	X	Y	Initial	After 5 years	After 10 years	After 5 years	After 10 years
AABH2	447217	978521	2048	2027.812	2012.645	19.84	35.01
AABH1	431871	978993	2056	2014.292	1970.909	41.71	85.09
Average Drawdown(m)						30.77	60.05

Scenario two

In the Becho plain new wells are being drilled. Scenario two was simulated to observe the drawdown of groundwater table for the coming five and ten years with abstraction groundwater by existing wells and adding of some planned new wells. Pumping 275376 m^3day^{-1} shows that the drawdown reaches 46.17 m after five years and 90.87 meter after ten year.

Table 12:6 Groundwater head after 5 and 10 years with additional wells

	Groundwater head after additional wells drilled					Drawdown (m)	
ID	X	Y	Initial	After 5 years	After 10 years	After 5 years	After 10 years
AABH2	447217	978521	2048	2019.835	1996.69	27.82	50.96
AABH1	431871	978993	2056	1991.481	1925.225	64.52	130.78
Average Drawdown(m)						46.17	90.87

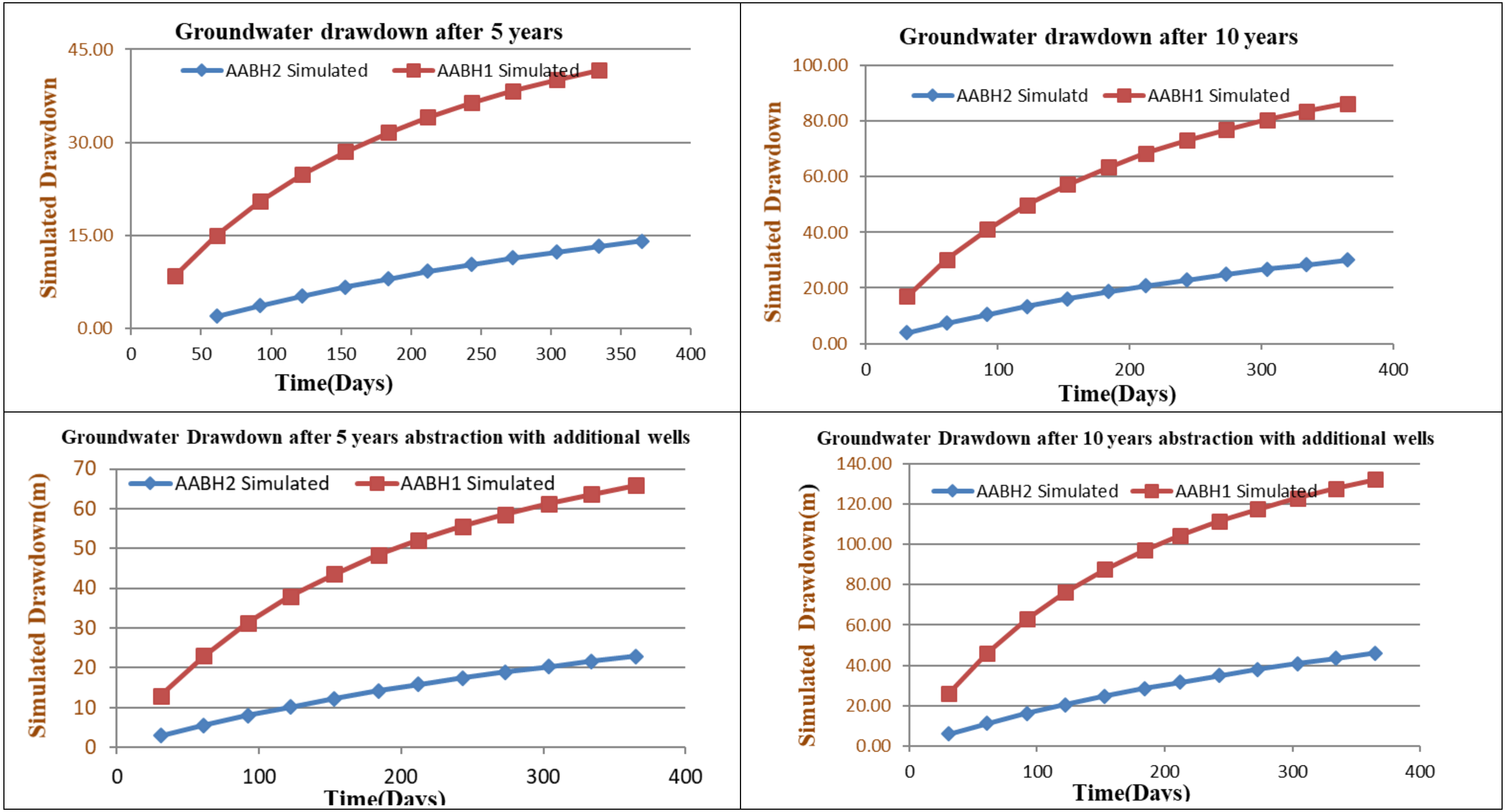


Figure 27:6 Groundwater head conditions after different scenarios development

Chapter Five

5. Conclusion and Recommendation

The objective of this study was to assess the groundwater resources and groundwater level response using transient state modeling follow from steady state model. The transient state modeling was developed from steady state by data integration of different sources with spatial and temporal variable water level. Based on the results obtained the following comments are made.

5.1. Conclusion

The objectives of developing a transient groundwater model and calibrating this model by comparing the simulated with observed groundwater heads have been achieved. The study answered the research question of developing a groundwater level responses of the aquifer. For this study the transient groundwater model, the spatio-temporal data includes groundwater level, groundwater abstraction, groundwater flow to rivers and groundwater base flow. All the groundwater fluxes were found reliable in the calibration of the transient state model.

Even though, the data logger data is not showing high drawdown because of current low abstraction rate, the transient simulation shows there is a local drawdown in the plain. It seems necessary to minimize operation time and manage the study area properly to minimize local pressure drops. Otherwise groundwater abstraction will lead to groundwater mining. Long period drought will cause a serious decline of groundwater levels and possible unrecoverable collapse of groundwater reserves locally.

Decline of groundwater levels is caused by increased groundwater abstractions with less recharge. Both steady and transient state model shows that due to increase pumping of groundwater, there is a local drawdown of water table in the plain. To reduce this drawdown, abstract with only existing well with full recovery time. On the other hand groundwater pumping with additional wells abstracting 275416 m^3/day from the aquifer shows an average drawdown of 90.87 m with transient state after ten years and the groundwater level in the plain then becomes decline with present recharge amount.

The results of the models show that important water balance components are groundwater recharge and groundwater abstraction from pumping wells.

5.2. Recommendation

Both steady and transient Modeling of the Becho aquifer has been formulated and the model was calibrated aligned with actual monitoring data. Finally, for future studies the following recommendations have been made.

- Groundwater monitoring data is vital in calibration of transient model and to understand the aquifer response with abstraction and recharge. For better prediction of the aquifer it is important to establish baseline data for new drilled wells, new and existing abstraction rate and that has to be easily available for researchers.
- Monitor wells with good measuring instruments to avoid data failure. Pump wells with full recovery time and apply all possible management Measures
- The Government, Institutions and stakeholders must give great attention for groundwater monitoring.
- Existing wells are mainly situated in the Central part of the plain which creates a local drop in groundwater level. It is necessary to stop drilling of new wells in this area.
- For better prediction of the groundwater sustainability it is advisable to start groundwater modeling more than one layer model.
- The transient model is limited only to one layer aquifer for 550 m thickness. Complete modeling of the aquifer dividing the shallow and deep aquifer would provide better prediction of aquifer response to recharge and abstraction. It would be therefore helpful for future studies if a hydrogeological database is established which can provide the required data for research and groundwater managers and users.
- Distance drawdown and group pumping tests shall be conducted during pumping test to determine aquifer storativity, to determine effect of one well over the other.
- For better assessment of the groundwater monitoring by automatic level recorders has to be implemented. Continuous recording of abstraction rate and water level with SCADA system and professional follow up is also necessary.
- The government should prepare a policy to use the aquifer in a sustainable manner. Unless we may face groundwater mining.

Reference

Addis Ababa Water and Sewerage Authority (AAWSA) (2013). Supplement to Task Force Report on Aquifer Management for Addis Ababa and vicinity, Addis Ababa, Ethiopia.

Alemu Mesele. (2017). Groundwater dynamics and aquifer characterization of the shallow aquifers of Becho and Koka area. Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia .

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

Anderson, M. P. and Woessner, W. W., 1992. Applied Groundwater Modeling Simulation of Flow and Advective Transport. Academic Press, New York, pp 381.

Ashiber Giberie. (2016). Numerical analysis of the groundwater flow system in modjo area for groundwater resource management planning . Unpublished MSc Thesis, Mekelle University,Mekelle, Ethipia.

Behailu Berehanu et al. (2017), focused on inter-basin groundwater transfer and multiple approach recharge estimation of the upper Awash aquifer system, Journal of Geosciences and Environment Protection.

Bentley, R., 2007. A regional-scale groundwater flow model for the Leon-Chinandega aquifer, Nicaragua. Hydrogeology journal.: 1457-1472.

Chiang, W.-H. and Kinzelbach, W., 1998. Processing Modflow a simulation system for modeling groundwater flow and pollution. Software manual.: 325.

Daniel Nuramo. (2016). Temporal changes in Groundwater Recharge in the Upper Awash Basin with particular emphasis to Becho and Koka areas, Central Ethiopia. Unpublished MSc Thesis, Addis Ababa University,Addis Ababa,Ethiopia.

Fetter, C.W., 2001. Applied Hydrogeology. University of Wisconsin Oshkesh, USA,598p

Freeze R. And Cherry A. (1979). Groundwater. A Simon and Schuster Company Englewood Cliffs. New Jersey, USA.

Gebrehaweria Gebrekirstos Teferi (March, 2009) Groundwater resource Assessment of the Aynalem Well field through Transient flow Modeling following from steady state modeling. Mekele University, Mekele, Ethiopia.

Gebrerufael, H., 2008. Groundwater resource assessment through distributed steady - state flow modeling, Aynalem Wellfield, Mekele, Ethiopia, MSc Thesis, ITC, Enschede, 106 pp.

Igboekwe, M.U., Rao, G. and Okwueze, E.E., 2008. Groundwater flow modelling of Kwa Ibo River watershed, southeastern Nigeria. Hydrological Processes, 22(10): 1523-1531.

Jones, P. M., (2005). Simulated effects of water-level changes in the Mississippi River
and Pokegama Reservoir on groundwater-levels, Grand Rapids area, Minnesota:
U. S. Geological Survey Scientific Investigations Report 2005 – 5139, 13 p.

Kruseman, G.P., 2000. Analysis and Evaluation of Pumping Test Data (2nd edition), International Institute for Land Reclamation and Improvement, the Netherlands. pp 372.

Kazmin, V. and Seifemichael, B. (1978). Geology and Development of the Nazerat area. Unpublished report, EIGS 821-451-04.

Lubczynski, M., 2006. Fluxes, numerical models and sustainability of groundwater resources. IAHS, Enschede, pp. 67-77.

McDonald, M.G. and Harbaugh, A.W., 2000. A modular three dimensions finite difference groundwater flow model. U.S., Geological survey.

Reys Asfaw .(2016). worked on ground water potential evaluation and use trends in upper Awash basin, unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Rientjes, T.H.M., 2007. Modelling in hydrology. Department of water resources,ITC, Enschede.: 233.

Shaw, E.M. (1994). Hydrology in practice. Third edition, Chapman and Hall, New York, 539pp.

Seifu Kebede (2013). Cause of Lake Beseka level rise, its impact and proposed mitigation measures: chemical modeling and Isotopic approach. Unpublished technical report, Addis Ababa University, Ethiopia.

Seifu Kebede (2013). Groundwaters in Ethiopia. Springer, Berlin Heidelberg, 65pp

Seifu Kebede, Abdalla O., Sefelnasr A., Tindimugaya and Mustafa O. (2016). Interaction of surface water and groundwater in the Nile River Basin: Isotopic and Pizeometeric evidence, Hydrogeol. *Hydrol.* Published online.

Seifu Kebede, Yves T., Tamiru Alemayehu and Tenalem Ayenew (2005). Groundwatersrecharge, circulation and geochemical evolution in the source region of the Blue Nile River, Ethiopia, Hydrogeol. *Hydrol*. **20**: 1658–1676

Sintayehu Mulu .(2017) Groundwater Flow Modeling of Upper Fafan Sub Basin for Managed Groundwater System. Unpublished Msc Thesis, Addsis Ababa University, Addis Ababa, Ethiopia.

Tamiru Alemayehu (2006). Groundwater occurrence in Ethiopia, Addis Ababa University press,Addis Ababa, 230 pp.

Tilahun Azagegn, Asfawossen Asrat ,Tenalem Ayenew, and Seifu Kebede (2015). Litho-structural control on inter basin groundwater transfer in central Ethiopia. Journal of African Earth Sciences. 101: 383–395.

Tenalem Ayenew, Molla Demlie,and Stefan,W.(2008). Hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers. Journal of African Earth Sciences. 52: 97–113.

United Nations Educational, Scientific and Cultural Organization (UNESCO) (1975). *Groundwater studies*. Belgium, Brussels.

Wagari Furi (2011). Hydrogeological System analysis of the Middle Awash Basin, Ethiopia Unpublished Ph.D. Thesis, University of Poitiers, France

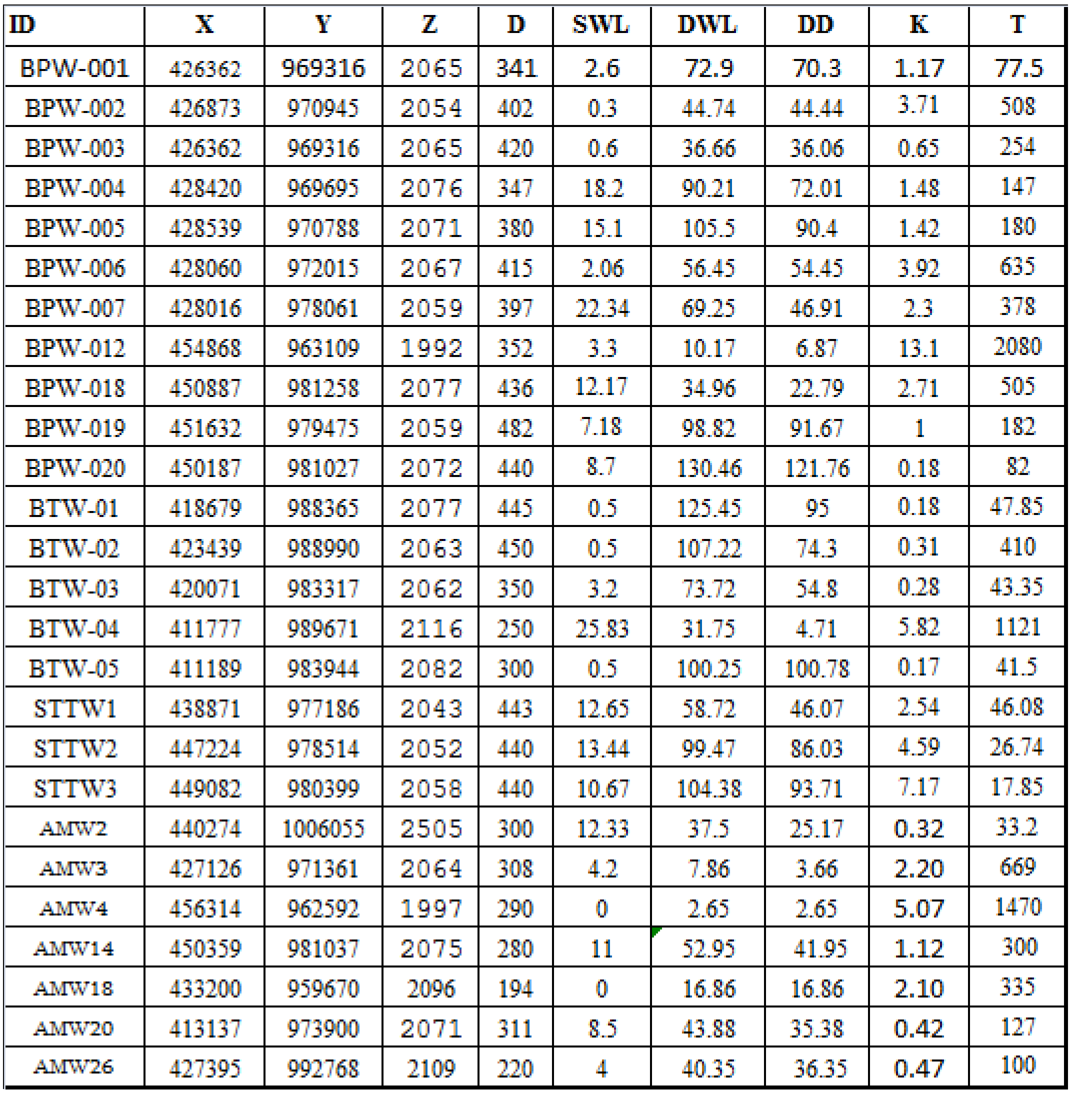
Water Works Design and Supervision Enterprise (WWDSE) (2000). Study of Lake Beseka. Unpublished final technical Report, WWDSE, Addis Ababa, Ethiopia.

Water Works Design and Supervision Enterprise (WWDSE) (2009). Evaluation of water resources of the Ada‟a and Becho plains ground water basin for irrigation development project. Unpublished technical report, WWDSE, Addis Ababa, Ethiopia.

Water Works Design and Supervision Enterprise (WWDSE) (2016). Geomorphological andgeological mapping around Addis Ababa city. Unpublished technical report, WWDSE,Addis Ababa, Ethiopia.

Annexes

Annex I Hydraulic Conductivity(K) and Transmissivity (m^2/day)



ID	X	Y	Z	D	SWL	DWL	DD	K	T
BPW-001	426362	969316	2065	341	2.6	72.9	70.3	1.17	77.5
BPW-002	426873	970945	2054	402	0.3	44.74	44.44	3.71	508
BPW-003	426362	969316	2065	420	0.6	36.66	36.06	0.65	254
BPW-004	428420	969695	2076	347	18.2	90.21	72.01	1.48	147
BPW-005	428539	970788	2071	380	15.1	105.5	90.4	1.42	180
BPW-006	428060	972015	2067	415	2.06	56.45	54.45	3.92	635
BPW-007	428016	978061	2059	397	22.34	69.25	46.91	2.3	378
BPW-012	454868	963109	1992	352	3.3	10.17	6.87	13.1	2080
BPW-018	450887	981258	2077	436	12.17	34.96	22.79	2.71	505
BPW-019	451632	979475	2059	482	7.18	98.82	91.67	1	182
BPW-020	450187	981027	2072	440	8.7	130.46	121.76	0.18	82
BTW-01	418679	988365	2077	445	0.5	125.45	95	0.18	47.85
BTW-02	423439	988990	2063	450	0.5	107.22	74.3	0.31	410
BTW-03	420071	983317	2062	350	3.2	73.72	54.8	0.28	43.35
BTW-04	411777	989671	2116	250	25.83	31.75	4.71	5.82	1121
BTW-05	411189	983944	2082	300	0.5	100.25	100.78	0.17	41.5
STTW1	438871	977186	2043	443	12.65	58.72	46.07	2.54	46.08
STTW2	447224	978514	2052	440	13.44	99.47	86.03	4.59	26.74
STTW3	449082	980399	2058	440	10.67	104.38	93.71	7.17	17.85
AMW2	440274	1006055	2505	300	12.33	37.5	25.17	0.32	33.2
AMW3	427126	971361	2064	308	4.2	7.86	3.66	2.20	669
AMW4	456314	962592	1997	290	0	2.65	2.65	5.07	1470
AMW14	450359	981037	2075	280	11	52.95	41.95	1.12	300
AMW18	433200	959670	2096	194	0	16.86	16.86	2.10	335
AMW20	413137	973900	2071	311	8.5	43.88	35.38	0.42	127
AMW26	427395	992768	2109	220	4	40.35	36.35	0.47	100

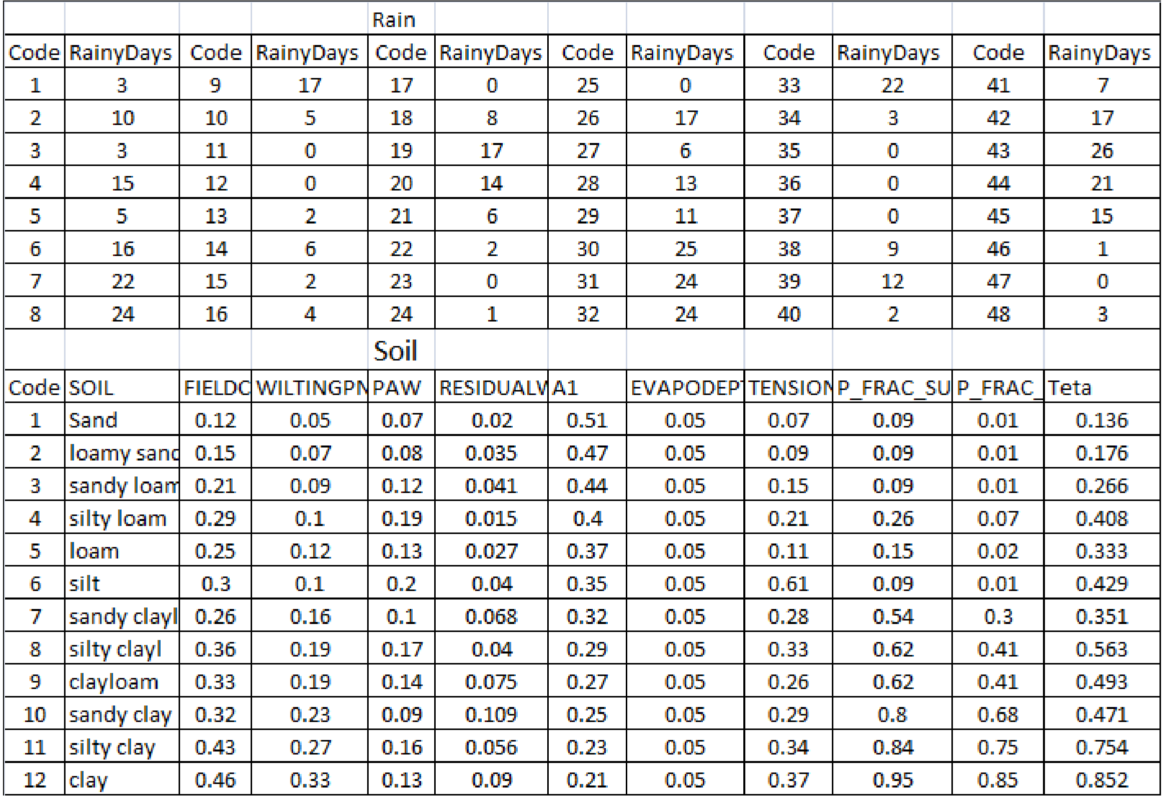
Annex II Meteorology Data

Climate station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
			Mean Rainfall(mm)										
Ambo	19.8	32.5	50.0	80.5	101.8	158.6	207.1	189.8	91.6	28.3	8.4	9.2	**977.5**
Akaki	15.4	26.9	51.0	66.9	57.5	82.7	228.3	232.3	123.0	24.1	10.6	8.3	**927.0**
Asgori	18.4	28.3	63.1	87.7	74.6	148.3	239.1	237.9	106.9	19.2	9.3	4.7	**1037.5**
Alem Gena	19.9	39.9	64.7	87.7	86.1	123.3	220.0	223.9	133.9	24.9	7.8	10.0	**1042.1**
Bantu liben	14.5	20.8	58.2	86.8	74.9	206.5	281.7	304.6	148.4	22.0	23.3	7.6	**1249.2**
Holeta	16.9	44.5	60.8	85.7	69.9	115.6	240.7	258.0	132.5	19.5	7.3	8.7	**1060.1**
Ginchi	24.2	44.0	67.2	86.9	87.2	137.5	237.4	232.3	147.5	38.0	12.4	10.8	**1125.5**
Sebeta	16.0	52.8	73.9	96.3	92.2	165.5	304.0	328.6	137.1	35.9	9.2	7.0	**1318.5**
Tulubolo	17.6	17.5	54.4	63.3	72.2	202.5	291.5	282.5	105.3	22.9	7.5	7.3	**1144.6**
Teji	12.0	28.4	48.6	72.0	70.7	129.2	216.8	220.1	101.8	20.3	6.4	6.1	**932.3**
Wolelkomi	24.0	36.2	73.6	71.9	88.7	137.1	244.9	233.3	124.7	41.7	11.8	10.1	**1097.9**
Woliso	19.2	32.2	67.0	90.8	103.5	171.7	262.8	245.4	146.6	45.4	9.1	9.8	**1203.6**
Average	**18.2**	**33.7**	**61.0**	**81.4**	**81.6**	**148.2**	**247.9**	**249.1**	**124.9**	**28.5**	**10.3**	**8.3**	1093.0
			Mean Temperature(°c)										
Ambo	17.7	18.4	19.3	19.2	19.1	17.6	16.6	16.6	16.9	17.1	16.8	16.9	**17.7**
Akaki	17.3	18.5	20.0	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	**18.6**
Asgori	16.1	17.4	18.1	18.9	19.5	20.1	18.6	18.0	18.2	17.3	16.2	15.8	**17.8**
Alem Gena	17.2	18.2	19.1	19.1	19.2	18.1	16.9	16.8	17.2	17.4	16.9	16.7	**17.7**
Holeta	17.0	17.9	19.1	19.2	19.1	17.9	16.7	16.5	16.8	16.9	16.3	16.0	**17.4**
Ginchi	17.3	18.0	19.0	18.9	19.1	17.7	16.6	16.5	16.8	16.9	16.5	16.5	**17.4**
Sebeta	17.6	18.7	20.0	20.2	20.3	19.3	17.9	17.9	18.2	18.0	17.4	16.9	**18.5**
Tulubolo	17.1	17.5	18.2	18.4	18.3	17.7	17.0	17.0	16.9	16.6	16.2	16.0	**17.2**
Wolelkomi	17.3	18.0	19.0	18.9	19.1	17.7	16.6	16.5	16.8	16.9	16.5	16.5	**17.4**
Woliso	18.0	18.8	19.4	19.1	18.8	17.6	16.8	16.6	17.0	17.3	17.3	17.3	**17.8**
Average	**17.3**	**18.1**	**19.1**	**19.2**	**19.3**	**18.3**	**17.2**	**17.0**	**17.3**	**17.2**	**16.7**	**16.5**	
			Sunshine Duration(hrs)										
Ambo	6.9	6.54	6.15	5.9	5.4	4.35	3.0	35.8	3.6	6.5	7.4	7.3	**8.2**
Akaki	7.0	6.91	6.62	6.3	6.1	5.58	4.5	46.5	4.7	6.7	7.6	7.2	**9.6**
Asgori	6.3	6.37	5.58	5.6	5.9	4.88	3.4	38.2	3.8	6.3	7.3	6.7	**8.4**
Alem Gena	7.0	6.77	6.63	6.2	5.9	5.14	4.0	45.3	4.5	6.8	7.6	7.4	**9.4**
Holeta	7.0	6.76	6.5	6.1	6.0	5.11	3.9	44.4	4.4	6.8	7.7	7.4	**9.3**
Ginchi	6.9	6.61	6.23	5.9	5.6	4.55	3.1	37.4	3.7	6.6	7.6	7.4	**8.5**
Sebeta	6.9	6.48	6.27	5.9	5.6	4.65	3.3	39.5	4.0	6.5	7.3	7.2	**8.6**
Wolelkomi	6.9	6.61	6.23	5.9	5.6	4.55	3.1	37.4	3.7	6.6	7.6	7.4	**8.5**
Woliso	6.9	6.48	6.27	5.9	5.6	4.65	3.3	39.5	4.0	6.5	7.3	7.2	**8.6**
Average	**6.9**	**6.6**	**6.3**	**6.0**	**5.8**	**4.9**	**3.6**	**41.0**	**4.1**	**6.6**	**7.5**	**7.2**	**8.9**
			Windspeed(m/sec)										
Ambo	5.3	5.4	5.6	5.3	5.2	4.1	3.8	3.5	4.0	5.8	5.8	5.5	**4.9**
Akaki	4.1	4.3	4.4	3.9	4.0	3.9	3.6	3.1	2.7	4.3	4.6	4.5	**3.9**
Asgori	5.4	5.7	6.1	5.6	6.3	6.2	5.5	4.7	4.4	5.2	5.2	5.6	**5.5**
Alem Gena	4.6	4.6	4.6	4.3	4.3	4.2	3.7	3.1	2.7	4.4	4.9	4.9	**4.1**
Holeta	4.4	4.4	4.4	4.2	4.3	3.9	3.6	2.9	2.7	4.3	4.6	4.8	**4.0**
Ginchi	5.2	5.4	5.3	5.2	5.2	4.0	3.8	3.4	3.9	5.8	6.1	5.7	**4.9**
Sebeta	4.4	4.4	4.4	4.2	4.3	3.9	3.6	2.9	2.7	4.3	4.6	4.8	**4.0**
Wolelkomi	5.2	5.4	5.3	5.2	5.2	4.0	3.8	3.4	3.9	5.8	6.1	5.7	**4.9**
Woliso	5.2	5.6	5.2	4.9	4.2	3.8	3.5	3.7	5.0	5.1	5.2	4.6	**4.7**
Average	**4.9**	**5.0**	**5.0**	**4.7**	**4.8**	**4.2**	**3.9**	**3.4**	**3.5**	**5.0**	**5.2**	**5.1**	**4.5**

Annex III Estimated Abstraction

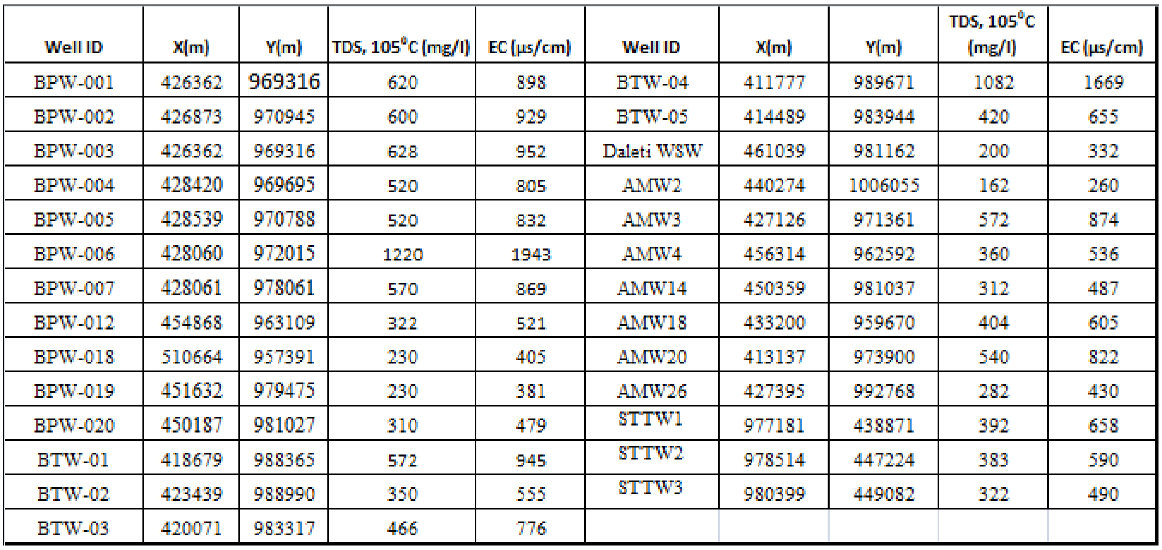
Well ID	X	Y	Q(M3/Day)	Well ID	X	Y	Q(M3/Day)
Holota-Garad Flowers	443050	1001649	492.5	AdBh0193	434015	1000129	129.6
Holota-Garad Flowers#2	442635	1001366	250.6	AdBh0194	440110	1001337	129.6
Holota-Hayelom Camp-old	444642	1002960	380.2	AdBh0196	460810	981473	345.6
Holota-Hayelom New	443984	999625	527.0	AdBh0197	460464	974637	302.4
Holota-Jerico flowers	453522	1001474	1468.8	AdBh0198	461930	970844	198.7
Holota-Marginpar Flo plc	447549	1007893	898.6	AdBh0200	454852	962780	3283.2
Holota-MetroLux Flower	445942	1001323	1417.0	AdBh0203	458959	953532	432.0
Holota-Rose	444577	998364	725.8	AdBh0207	444924	954222	345.6
Holota-Top International	444677	998215	691.2	AdBh0208	448328	957872	280.8
Holota-Tsedey	447200	998889	1417.0	AdBh0212	444245	956023	172.8
Kelecho Gerbi	407400	972711	553.0	AdBh0249	455450	983014	570.2
Kersa Warko	458959	953532	639.4	AdBh0250	455426	982736	462.2
Meta Abo Brewery	455000	985200	509.8	AdBh0255	444624	978143	64.8
Meta Abo Brewery BH5	455300	985250	596.2	AdBh0300	442842	977555	293.8
Meta abo brewery BH9	455550	983750	553.0	AdBh0314	404050	980200	691.2
Muger Ada	433672	1023691	985.0	AdBh0318	407400	972711	345.6
Sebeta Agro No.1,	460850	985850	769.0	AdBh0324	461412	986324	345.6
Sebeta Agro No.2	460500	986500	993.6	AdBh0326	460937	986565	1684.8
Sebeta Tal Flowers	455450	983014	777.6	AdBh0334	427635	994816	1296.0
Sebeta Tal Flowers#1	455426	982736	673.9	AdBh0339	436160	1000453	129.6
Sebeta-Dragados	457030	984617	639.4	AdBh0340	435382	1000251	681.7
Sebeta-Nuri Diary Farm	458646	984363	682.6	AdBh0357	445180	1002459	302.4
Supra Flowers	427635	994816	1503.4	AdBh0362	432432	1024464	216.0
BH	432020	1025151	380.2	AdBh0426	440595	1000333	639.4
Tafki golden Rose#	442842	977555	501.1	AdBh0434	400409	954207	345.6
Tefki	444624	978143	276.5	AdBh0444	424000	952736	864.0
Tefki-Golden Rose#1	444000	977700	241.9	AdBh0723	455000	985200	302.4
AG Hafde plc	461412	986324	553.0	AdBh0889	455300	985250	384.5
AG ODA	460937	986565	1892.2	AdBh0891	455550	983750	345.6
AG Balz	460121	985966	786.2	AdBh0892	444000	977700	34.6
AG bonoya	460464	974637	509.8	AdBh0895	460850	985850	561.6
AG Daleti	460810	981473	553.0	AdBh0896	460500	986500	786.2
AG Geja Dera	461930	970844	406.1	AdBh0981	460121	985966	576.3
Ginchi1	401157	996412	1676.2	AdBh1037	457030	984617	432.0
Ginchi2	401801	996640	1935.4	AdBh1044	458646	984363	475.2
Ginchi3	401587	997298	2505.6	AdBh1103	462260	984901	576.3
Ginchi4	400975	997008	2626.6	AdBh1152	460295	986769	1468.8
Ginchi5	404656	997733	509.8	BPW-001-10	426362	969316	3456.0
Holeta1	446266	1004147	812.2	BPW-002-10	426873	970945	8467.2
Holeta2	446155	1003073	639.4	BPW-003-10	426362	969316	7283.5
Holeta3	440110	1001337	337.0	BPW-004-10	428420	969695	4838.4
Hoeta4	445180	1002459	509.8	BPW-005-10	428539	970788	3640.0
Holeta5	444168	998992	639.4	BPW-006-10	428060	972015	5875.2
Holeta6	444677	998808	691.2	BPW-007-10	428016	978061	6480.0
Holeta7	445773	1001323	475.2	BPW-012-10	454868	963109	5477.8
Holeta8	443132	1000869	380.2	BPW-018-10	450887	981258	5011.2
Holeta Dairy	445099	1003816	812.2	BPW-019-10	451632	979475	2160.0
Holeta7	440595	1000333	846.7	BPW-020-10	450187	981027	691.2
super Fiber	461537	988194	682.6	BTW-01	418679	988365	4752.0
Adbh0153	447200	998889	1209.6	BTW-02	423439	988990	2592.0
AdBh0156	453522	1001474	1261.4	BTW-03	420071	983317	1296.0
AdBh0159	446266	1004147	604.8	BTW-04	411777	989671	4320.0
AdBh0160	446155	1003073	432.0	BTW-05	411189	983944	3024.0
AdBh0163	444168	998992	432.0	STTW1	438871	977186	3542.4
AdBh0164	444577	998364	518.4	STTW2	447224	978514	1728.0
AdBh0165	445168	997226	1209.6	STTW3	449082	980399	1133.6
AdBh0166	445942	1001323	1209.6	STHTW4	445565	983665	4924.8
AdBh0167	445773	1001323	267.8	STHTW6	427193	976742	4320.0
AdBh0168	445099	1003816	604.8	STHTW9	431871	978993	4752.0
AdBh0169	443050	1001649	285.1	STHTW10	422802	976337	4320.0
AdBh0170	442635	1001366	43.2	AMW2	440274	1006055	3067.2
AdBh0171	443132	1000869	172.8	AMW3	427126	971361	3067.2
AdBh0172	444677	998215	483.8	AMW4	456314	962592	3067.2
AdBh0173	444677	998808	483.8	AMW14	450359	981037	1641.6
AdBh0174	444642	1002960	172.8	AMW18	433200	959670	1658.9
AdBh0175	443984	999625	319.7	AMW20	413137	973900	1446.3
AdBh0187	404656	997733	302.4	AMW26	427395	992768	1509.4

Annex IV RainyDays and Soil



				Rain							
Code	RainyDays	Code	RainyDays	Code	RainyDays	Code	RainyDays	Code	RainyDays	Code	RainyDays
1	3	9	17	17	0	25	0	33	22	41	7
2	10	10	5	18	8	26	17	34	3	42	17
3	3	11	0	19	17	27	6	35	0	43	26
4	15	12	0	20	14	28	13	36	0	44	21
5	5	13	2	21	6	29	11	37	0	45	15
6	16	14	6	22	2	30	25	38	9	46	1
7	22	15	2	23	0	31	24	39	12	47	0
8	24	16	4	24	1	32	24	40	2	48	3
				Soil							
Code	SOIL	FIELDC	WILTINGPN	PAW	RESIDUALV	A1	EVAPODEP	TENSION	P_FRAC_SU	P_FRAC_	Teta
1	Sand	0.12	0.05	0.07	0.02	0.51	0.05	0.07	0.09	0.01	0.136
2	loamy sanc	0.15	0.07	0.08	0.035	0.47	0.05	0.09	0.09	0.01	0.176
3	sandy loam	0.21	0.09	0.12	0.041	0.44	0.05	0.15	0.09	0.01	0.266
4	silty loam	0.29	0.1	0.19	0.015	0.4	0.05	0.21	0.26	0.07	0.408
5	loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02	0.333
6	silt	0.3	0.1	0.2	0.04	0.35	0.05	0.61	0.09	0.01	0.429
7	sandy clayl	0.26	0.16	0.1	0.068	0.32	0.05	0.28	0.54	0.3	0.351
8	silty clayl	0.36	0.19	0.17	0.04	0.29	0.05	0.33	0.62	0.41	0.563
9	clayloam	0.33	0.19	0.14	0.075	0.27	0.05	0.26	0.62	0.41	0.493
10	sandy clay	0.32	0.23	0.09	0.109	0.25	0.05	0.29	0.8	0.68	0.471
11	silty clay	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75	0.754
12	clay	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85	0.852

Annex V Total dissolved solid, Electrical Conductivity



Well ID	X(m)	Y(m)	TDS, 105°C (mg/l)	EC (µs/cm)	Well ID	X(m)	Y(m)	TDS, 105°C (mg/l)	EC (µs/cm)
BPW-001	426362	969316	620	898	BTW-04	411777	989671	1082	1669
BPW-002	426873	970945	600	929	BTW-05	414489	983944	420	655
BPW-003	426362	969316	628	952	Daleti WSW	461039	981162	200	332
BPW-004	428420	969695	520	805	AMW2	440274	1006055	162	260
BPW-005	428539	970788	520	832	AMW3	427126	971361	572	874
BPW-006	428060	972015	1220	1943	AMW4	456314	962592	360	536
BPW-007	428061	978061	570	869	AMW14	450359	981037	312	487
BPW-012	454868	963109	322	521	AMW18	433200	959670	404	605
BPW-018	510664	957391	230	405	AMW20	413137	973900	540	822
BPW-019	451632	979475	230	381	AMW26	427395	992768	282	430
BPW-020	450187	981027	310	479	STTW1	977181	438871	392	658
BTW-01	418679	988365	572	945	STTW2	978514	447224	383	590
BTW-02	423439	988990	350	555	STTW3	980399	449082	322	490
BTW-03	420071	983317	466	776					

Photo1: Measuring River width, bed thickness and sand/sediment

Gauge Station at the outlet

Awash River on March 6,2019