Addis Ababa University

School of Earth Sciences

College of Natural Science

Steady State Numerical Ground Flow Modeling of Ada’a Plain Aquifer, Upper Awash Basin

A Thesis Research Submitted to School of Earth Sciences of Addis Ababa University in The Partial Fulfillment of the Requirement for The Master of Science Degree in Hydrogeology

By

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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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This is to certify that the thesis prepared by Gashahun Etefa, entitled: Steady State Numerical Groundwater Modeling of Ada'a Plain Aquifer 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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Abstract

The Ada'a plain is located within the upper awash basin, East of Addis Ababa City, Central Ethiopia. The Steady state Numerical groundwater flow modelling was carried out to understand present groundwater conditions in the Ada'a Plain and to help estimate groundwater availability and water levels in response to present withdrawal and potential future development.

In this thesis a WetSpass modeling was used to estimate the groundwater recharge. Results of the study showed that the total groundwater recharge in the study area is 119mm/year (13.45% of the mean annual rainfall).

The study area was modelled with a grid of 266 columns x 301 rows with one-layer unconfined aquifer extending up to 450m depth. All the grid size has uniform lateral dimensions of 200m by 200m. Natural recharge due to rainfall and groundwater inflow from specified flux formed the main input to the aquifer system and the output was made of abstraction from pumping wells and base flow to the south eastern direction towards the rift valley.

The simulation was carried out using Visual MODFLOW software and calibrated for the 2007 groundwater levels at 69 observation wells. The Water levels in the model are most sensitive to recharge and the horizontal hydraulic conductivity. The computed groundwater level contours have been following the trend of observed ones.

The numerical simulation model developed was applied to assess the responses of the Ada'a plain aquifer water level under different pumping scenarios during the next 20 years. Analysis of two different development schemes were formulated to predict the future response of the aquifer under long-term water stress.

The computed groundwater budget based on analysis of two different groundwater abstraction scenarios that were formulated to predict the future response of the aquifer under long-term water stress is indicated that the groundwater pumping declined groundwater level and groundwater storage of the plain. Natural recharge due to rainfall and groundwater inflow from specified flux it is an important factor for the sustainability of the groundwater of the plain; however, the intensive abstraction of aquifer decreases the groundwater out flow to the rift valley.

Key Words: Groundwater; numerical modelling; Groundwater recharge, Ada'a Plain aquifer; Model Calibration,

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Above all I thank the lord God for his mercy, without his support and blessings this piece of work would never have been accomplished.

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I am grateful to Oromia Water and Energy Bureau, in particularly Modjo town Water Supply and Sewerage Service Enterprise, Bishoftu town Water Supply and Sewerage Service Enterprise Engineering Corporation of Oromia and Oromia Construction Corporation of for contribution in providing me valuable data.

Last but not least, thanks go to my beloved wife, Adanu Haile for her support and encouragements, and also, I would like to express my gratitude for my children Milk and Moti.

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Acronyms

BARE_AREA	Bare Area
Dbf	Data base files
ETP	Evapotranspiration
EVAPODEPTH	Bare soil evaporation depth
FAO	Food and Agricultural Organization of the United Nation
FIELDCAPAC	Field capacity
GHB	General Head boundary
GIS	Geographic Information Systems
IMP_AREA	Impervious Area
INTERC_PER.	Interception Percentage
LAI	Leaf Area Index
LANDUSENUM	Number of runoff class for land use
LANDUSERO.	Runoff class for land use
LUSE_TYPE.	Land Use Type
m.a.s.l	Meters above sea level
m/s	Meters per second
m^2/d	Meter square per day
m^3/d.	Meter cubic per day
MER.	Main Ethiopian Rift
MIN_STOM.	Minimum Stomatal Opening
NUM_IMP_RO. I	Impervious Runoff class for impervious area types
NUM_VEG__RO .	Runoff class for vegetation type
OPENW_AREA	Open-water Area
P_FRAC_SUM	Fraction of summer precipitation contributing to Hortonian runoff
P_FRAC_WIN	Fraction of winter precipitation contributing to Hortonian runoff
PAW	Plant available water content
PET	Potential evapotranspiration
PPT Precipitation	Residual water content
RE	Recharge
RF	Rain Fall
RO	Runoff
ROOT_DEPTH	Root depth

RUNOFF_VEG	Runoff Vegetation
RUNOFFCOEF	Runoff coefficient
SLOPE_ [%]	Slope
SLOPENUM.	Slope class
SOILNUM	Soil class
SRTM	Shuttle Radar Topography Mission
Std dev	Standard deviation
TENSIONHHT	Tension saturated height
UTM	Universal Transvers Mercator
VEG_AREA	Vegetated Area
VEG_HEIGHT.	Vegetation Height
WetSpass	Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State

CHAPTER ONE

1 Introduction

1.1 Background

Groundwater use is a common practice throughout Ethiopia. Groundwater is of principal importance source for many uses in developing countries to supplement the available surface water resources by providing drinking water to its population and for economic development of agriculture, livestock, industry and tourism (Foster et al., 2012). In the Ethiopia, groundwater use for irrigation is gradually getting more attention due to increasing population growth with increasing food demand.

The Ada'a plain is known by potential aquifer in the upper Awash basin. It is an important source of groundwater for both domestic water needs and for crop production for most of villages and towns in the plain.

Due to extended drought condition, increase in population size and advancement in civilizations, groundwater development plan for crop production and domestic use have increased interest in the Ada'a plain aquifer and have heightened concerns how current and future pumping will affect water levels over the long term and impact groundwater resources and the environment.

The impact of groundwater abstraction 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. If the groundwater is abstracted in optimum way the final results would be unbalanced supply, which may create unsustainable groundwater use.

This paper is part of a study aimed to develop steady state groundwater flow model for the Ada'a Plain in upper Awash basin as a tool to evaluate groundwater potential, conceptual understanding of groundwater flow in the study area, and develop a management tool to support water resource managers.

General approach involved developing the conceptual model, organizing aquifer information for entering into the model, calibrating a steady-state model for model prediction for different scenario.

1.2 Statement of Problem

Groundwater is a valuable resource both in Ethiopia and throughout the world. Where surface water, such as lakes and rivers, are scarce or inaccessible, groundwater supplies many of the hydrologic needs of people everywhere. In the Ethiopia, it is the source of drinking water for those living in urban areas, small urban and rural areas. Groundwater use for irrigation purpose is also gradually getting more attention due to increasing population growth with increasing food demand.

In the Ada'a Plain, upper Awash basin, many boreholes have been drilled for irrigation purpose and it is expected to increase significantly due to its suitability for irrigation and development plan in this area. However, groundwater level declines caused by sustained groundwater pumping is a key issue associated with groundwater use. There is no enough well-organized system to monitor and manage groundwater level of the study area. Thus, the effect of ground water abstraction with respect to groundwater recharge and water level is not well known. This thesis is intended to understand the sensitivity of the groundwater system with respect to well abstraction, recharge and aquifer storativity, and helps to assess the hydrogeological properties of the groundwater flow system using a model for present and future prediction and to generate greater public awareness of the issues.

1.3 Objectives

1.3.1 General Objective

The main objective of this study is to assess the regional groundwater flow system in Ada'a plain under steady state and to evaluate the response of the aquifer system to different future abstraction Scenario.

1.3.2 Specific Objectives

As specific objectives; the research work is expected to address the following: -

- To estimate average groundwater recharge of the study area
- Conceptualize the general groundwater flow system to simulate the groundwater flow pattern under steady - state condition

- To construct numerical groundwater flow model which will be used to simulate groundwater flow pattern under Steady State condition and predict future groundwater pumping scenarios.

1.4 Research questions

- What is the regional groundwater flow system in Ada'a plain under steady state?
- What is the response of the aquifer system to different future abstraction Scenario?
- What is the average groundwater recharge of the study area?

CHAPTER TWO

2. Literature review and previous work

2.1. Literature review

Models have become an essential tool in the modern world of water management. They are used extensively and play an important auxiliary role in fulfilling the core tasks of water management, in policy preparation, operational water management and research, and in the collection of basic data (monitoring), among other things

The applications of MODFLOW, a modular three-dimensional finite-difference groundwater model of the U. S. Geological Survey, to the description and prediction of the behavior of groundwater systems have increased significantly over the last few years.

Most groundwater models in use today are deterministic mathematical models. Deterministic models are based on conservation of mass, momentum, and energy and describe cause and effect relations. The underlying assumption is that given a high degree of understanding of the processes by which stresses on a system produce subsequent responses in that system, the system's response to any set of stresses can be predetermined. Deterministic groundwater models like MODFLOW generally require the solution of partial differential equations. A general form of the equation describing the transient flow of a compressible fluid in a non-homogeneous anisotropic aquifer is derived by combining Darcy's law with the continuity equation. The three-dimensional movement of groundwater of constant density through porous medium may be described by the partial-differential equation (McDonald and Harbaugh, 1988):

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

Where; Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity [L/T]; h is the potentiometric head [L]; W is a volumetric flux per unit volume representing sources and/or sinks of water, with W0.0 for flow into the system, S_S is the specific storage of the porous material; and t is time.

Equation describes groundwater flow under non-equilibrium conditions in a heterogeneous and anisotropic medium.

Equation together with specification of flow and/or head conditions at the boundaries of an aquifer system and specification of initial-head conditions constitutes a mathematical representation of a groundwater flow system (McDonald and Harbaugh, 1988).

MODFLOW uses iterative approach and integrated finite-difference approximation with block centered formulation to solve groundwater flow equation.

Developing the appropriate conceptual model for a given problem is one of the most imperative steps in the modeling process. A conceptual model describes how water enters an aquifer system, flows through the aquifer system and leaves the aquifer system. Briefly, it describes the hydrologic system with respect to aquifer properties, flow characteristics and boundary conditions.

2.2. Previous Work

A number of hydrogeological studies have been performed in upper Awash basin and adjacent area of study area.

Ministry of Water Resources (1980) have conducted Hydrogeological studies in connection with the water supply of the towns of Debre Zeit and Modjo. Based on these studies, wells were drilled in the vicinity of the two towns. The boreholes are shallow having a maximum depth of 90m. The lithological logs of these wells show that lacustrine sediments form good aquifers. The lacustrine deposit has a thickness varying from 50 to 80 meters and is underlain by vesicular basalt. These wells represented the lacustrine aquifer of the central part of the study area.

Berhane Melaku (1982) studied Hydrogeology of the upper Awash Basin. The study was aimed to understand the occurrence, movement and chemical nature of groundwater in the Upper Awash River basin. The area from Awash River source Ginchi area up to Koka dam having about 9500 km^2 was covered in the study. Getahun Kebede (1987) studied Hydrogeology of the Nazaret area. This study partly encompasses the northeastern part of Ada'a plain groundwater basin (Modjo, Wedecha and Belebela rivers catchment and around Koka reservoir). The most dominant formations, which have wide distribution in this part of the project area, are lacustrine sediment, Pleistocene to sub-recent Basalts and Nazaret group ignimbrites.

Adane (1999) have conducted on Surface Water and Groundwater Pollution Problems in the Upper Awash River Basin, Ethiopia. His study showed that the scoraceous and vesicular basalts that outcrop in the vicinity of Debre Zeit and Akaki are highly permeable due to interconnection of pore space and high fracture system.

Behailu Berehanu et al. (2017) focused on inter-basin groundwater transfer and multiple approach recharge estimation of the upper Awash aquifer. The estimated recharge of the 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 basin

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.

CHAPTER THREE

3. Methodology

3.1. Data Acquisition and Methodology

The approach combines information and procedures from various backgrounds to understand the prevailing hydrogeological condition and to simulate the steady state groundwater flow of the study area. Literature review helped to collect useful information about the geology and hydrogeology of the study area. The water table data and pumping test analysis result of various boreholes were collected from different organization WWDSE (2008), Engineering Corporation of Oromia, Oromia Construction Corporation and East Shawa zone Water and Energy office). Achieved and collected data were analyzed by means of statistical methods to obtain water-level contour map, he hydraulic conductivity and transmissivity.

Hydrological and meteorological data of meteorological stations represented the study area and surrounding were selected and analyzed for metrological parameters of the study area. 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 spatial grid (ASCII) with ArcGIS for WetSpass modelling for groundwater recharge estimation of the study area.

The modelling process began with data integration and description of the hydrogeological situation of the study area, such as the boundary conditions, then definition of the conceptual framework of the area for analysis and finally the numerical simulation. To establish a predictive model, the groundwater flow model was calibrated for steady-state conditions to match water levels for steady-state conditions using the simplest possible conceptual model.

Once the steady-state model was completed, the framework of the model was used for predictive simulations, using available water-use data available at the time and development plan in the area.

General methodological approach for the study

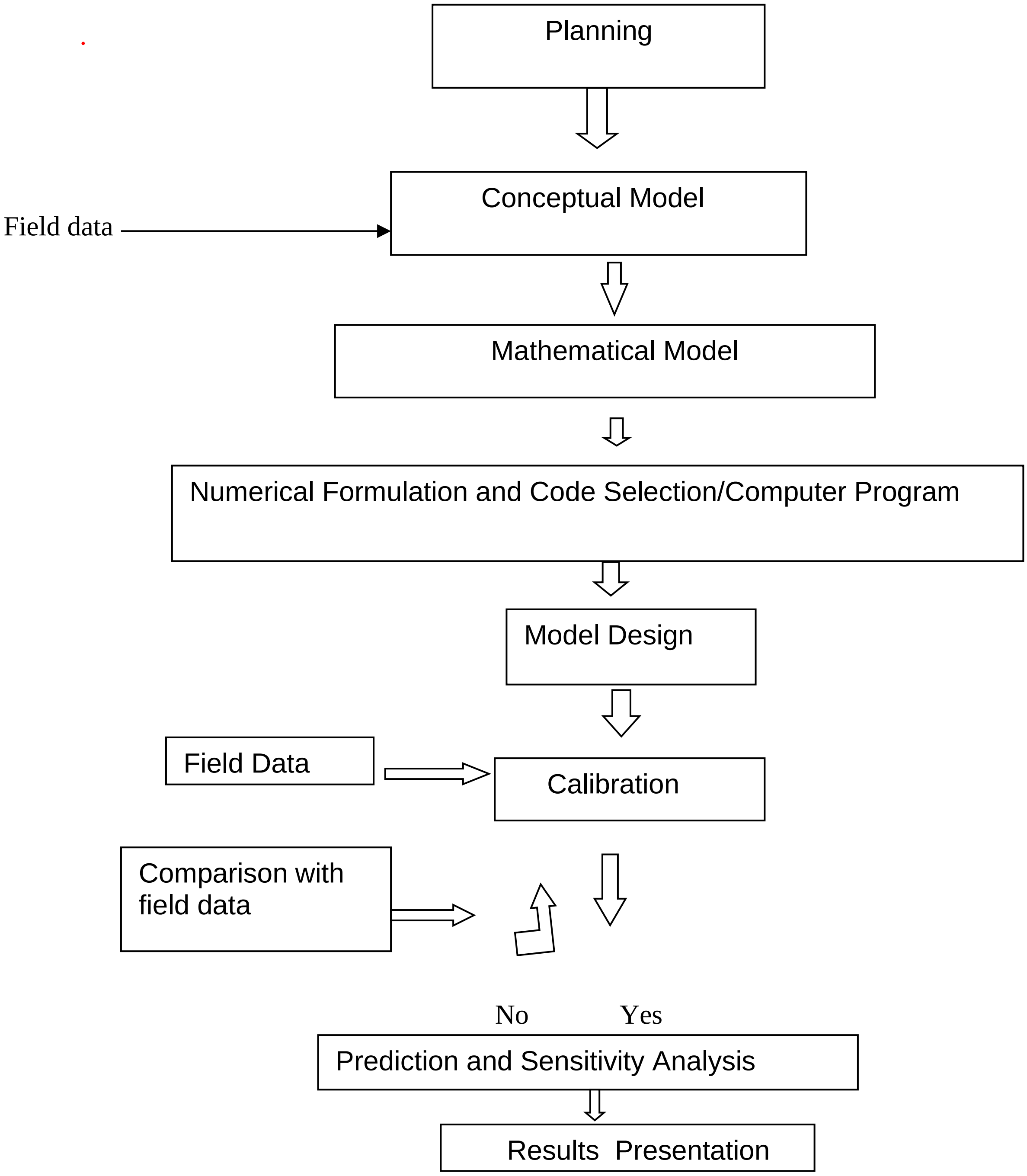


Figure 1: Flow chart of methodological approach

CHAPTER FOUR

4. Description of Study area

4.1. Location Map

The study area is located in the upper part of Awash River Basin, in the east-central part of the country, in Oromia regional State, East Shoa Administrative zone. It lies between 921184 to 977335mN and 470554 to 514342m E within 75 km road distance from the capital city, as shown in Figure 2.1. The plain is delineated based on surface water divide using topographic maps of scale 1:50,000. Ada'a plain covers about 1737km^2.sq.km. The area is bordered with Ererer Mountain and Kesem river basin Water shed divide in the north, and Koka reservoir in the south.

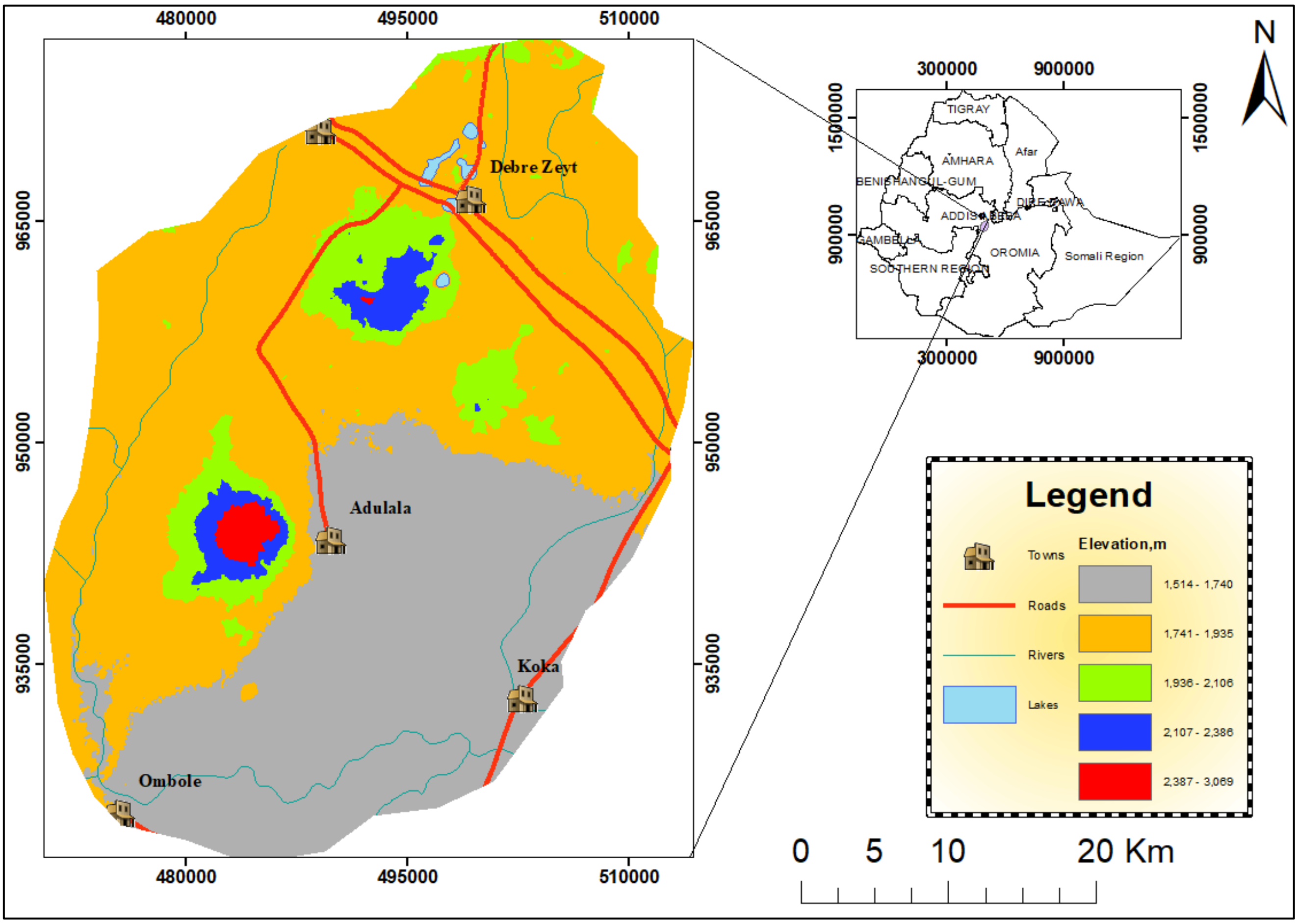


Figure 2: Location of the study area

4.2. Physiography

The Ada'a plain area is bordered with Ererer Mountain and Kesem river basin Water shed divide in the north, and Koka reservoir in the south. The plain is an extensive lacustrine deposit of flat area with isolated hills and mountain like mountain Ziquala and a number of Lakes concentrated at and nearby Debre Zeit town with a recharge area that can be divided into five physiographic units i.e., the plateau of Abay River basin, rugged highland area, central plain, escarpment and the rift floor, Ada'a plain.

4.3. Climate

The climatic characteristics of the study area is determined largely by the yearly movements of the Inter Tropical Convergence Zone (ITCZ) that allows dry wind from east or moist winds from the west dominates the climate of this part of Ethiopia. In the month of March, the ITCZ advances across the Awash Basin bringing spring rains in the 'Belg' season. The ITCZ reaches its most northern position when heavy summer rains come from the west. This season is the main rainy season called 'Kiremt' and lasts until September. The dry season called 'Bega' extends from October to February (Yitbarek et al., 2012). Mean annual areal rainfall in the study area 884.7 mm per year. Above 70% of the total rainfall occurs in the main rainy season from June to September. The mean annual temperature in the study area ranges from 15.2 to 21.1^{o}C.

4.4. Geological and Hydrogeological Characterization

Literature review helped to collect preliminary useful information about the geology and hydrogeology of the study area. Mainly, the geological and hydrogeological description of the study area was based on previous work (Berhane Melaku, 1982, WWDSE, 2008) and local studies conducted from drilling report in the area. These additional studies included defining water-level maps, assembling structure maps, and investigating recharge.

4.4.1. Geology

The geology in the study area consists of Quaternary volcanic and sedimentary formations. Trachytes and ryholites form peaks and ridges while the alluvial plains and basic volcanic formation forms calderas and plains.

Ryholites and Trachytes forms Ziquala and Bede Gebaba mountains. Bishoftu volcanic units is composed of spatter cones and scoria. Alluvial and Lacustrine deposits occupy large part of Ada'a plain. The alluvial deposit are sandy clay and silty clay with gravel at the lower bed. The lacustrine sediments are distributed around Debre Zeit lakes.

Tarmaber Basalt

The Tarma Ber Basalt which is the minor unit exposed in the northeastern part of the study area. It is consisting of mainly Scoriaceous lava flows and at places it is columnar olivine bearing basalt as pockets within the Scoriaceous components. It is highly weathered, fractured and pinkish to grayish in color. The age of this unit is Miocene, 27-5Ma.

Nazret units

The Nazret unit is widely present in the northeastern and eastern parts of the study area. This unit comprises numerous rhyolitic and trachytic domes. The age of Nazret unit is between 9.5 and 3Ma (Kazmin and Berhe., 1978). Welded ignimbrite with well-developed vertical joint and fracture provide high to moderate permeability (Adane, 1999).

Addis Ababa Ignimbrite

This unit is exposed in northwestern part of the study area and make up the minor portion of the volcanic rocks. It is composed of welded Tuff (Ignimbrite) and non-welded pyroclastic fall (ash and tuff). This unit is moderately to strongly welded, characterized by developed vertical joins and fractures which provide for high to moderate permeability (Adane, 1999). The age of this unit is 5.11-3.26 Ma (Morton et al 1979).

Central volcano

Central volcano units are mainly trachytic lavas exposed at Yerer Mountain forming an elevated ridges or mountain picks and found in the northern, western and central part of the study area. It occurs occupying a series of NE-SW aligned ridges and domes within the largest Yerer volcanic edifies with relief of 1000m difference from the plain. This volcanic edifies is 14km wide along E-W direction. The age of the central volcanic is 3.9-3.3 Ma (Chernet et al 1999).

Tulu Rie Basalt

Tulu Rie basalt is outcropped in the eastern and northern section of the study area. It is lava flow coarse grained basalt with olivine and plagioclase phenocrysts with rare clinopyroxene. The age of this rock is 2.7 to 1.44 Ma. This unit when it is massive has low permeability whereas with well-developed structural features, they are good and productive aquifers (Adane, 1999).

Chefe Donsa Unit

This map unit is exposed in the south-eastern, eastern and north-eastern parts of the study area. It occurs mainly along the border of the central plain of the study area. Chefe Donsa unit consists of fall deposits (ash, tuff and pumice) and poorly welded ignimbrites of rhyolitic composition. In the southwest, the lacustrine deposit in southeast overlies this unit, while in the eastern and northeastern parts; it overlies Nazret unit and Tulu Rie basalt. The age of this unit ranges 2.24 to 1.71 Ma (Morton etal 1979).

Bede Gababa Volcanic Unit

This unit is a circular volcanic complex outcropped western part of the study area with maximum elevation of 400m above the surrounding plane. Its morphology dominated by the occurrence of several coalescent caldera structures. Spatter cones and basaltic lava flows belonging to younger Bishoftu Volcanics are present in the central part of the volcanic complex. The most recent products are represented by rhyolitic obsidians whose age is 0.36 Ma (Leeds University in Abebe et al 1999). Pumice and lavas show a composition ranging from rhyolites to minor trachytes. According to Gasperon et al (1993) the lava contains microphenocrysts and rare phenocrysts of sanadine and quartz as well as scattered plagioclase and clinopyroxene set in glassy to microcrystalline groundmass.

Bishoftu Volcanics

This unit forms a NNE trending belt outcropping mainly in the central flat areas of Debre Zeit. In the Bishoftu Volcanic spatter and cinder cones with associated tabular basaltic lavas flows and phreatomagmatic deposits are distinguished. The basalt is vesicular and coarse grained with olivine phenocrysts. According to (Adane, 1999), this unit has high porosity and permeability due to secondary structures and the interconnection of the pore spaces.

Lacustrine Deposits

The deposits are exposed in the central section of the area. Lacustrine environment started after the Bede Gebaba volcano unit and continued during the eruptive activity of Bishoftu (Abebe, 1999). The lacustrine sedimentations are the results of deposition in this large ancestral lake (Mohr, 1967 and Abebe, et al., 1999) and they are interbedded with Pliocene-Pleistocene ignimbrite in lakes region and on the rift shoulders in general, and within These fine-grained deposits are generally brown-yellowish.

4.4.2. Structure

The study 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 WWDSE (2008), Tilahun Azagegn (2015). Four principal fault systems have been identified in the area.

North West Fault System

The NW fault system, the oldest fault system has 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).

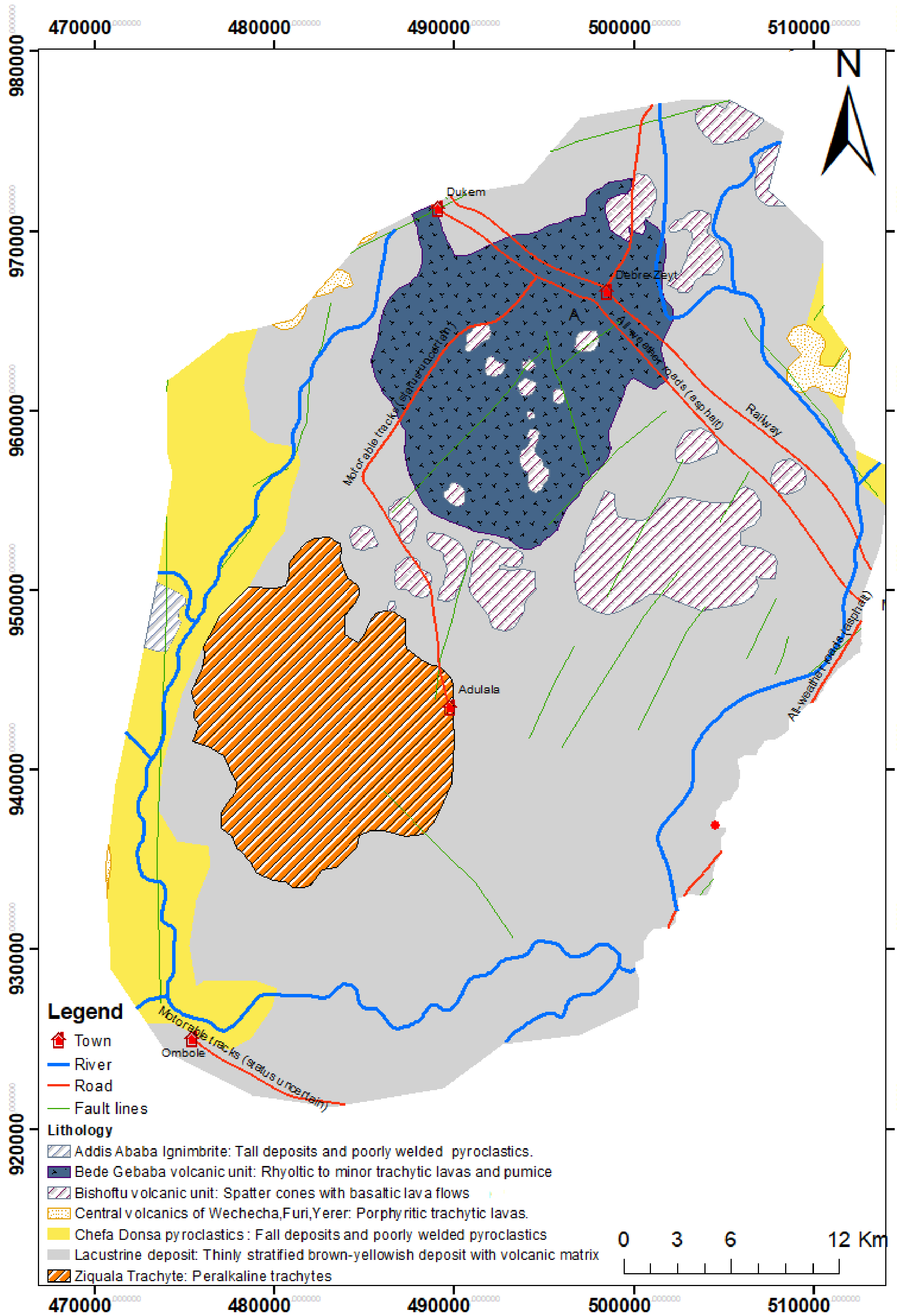


Figure 3: Geological Map of the study area (Simplified from WWDSE, 2008)

4.4.3. Hydrogeological Characterization

The hydrogeologic characterization for the Ada’a plain was based on previous work (WWDSE, 2008) and additional studies conducted in support of the modeling effort. The surficial geological mapping units (WWDSE, 2008) in the Ada’a plain groundwater system were differentiated at depth based on previously drilled boreholes, 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. The aquifers in the plain were classified in to four broad categories based on their permeability as shown in Hydrogeological map of the study area.

Alluvial Aquifers form one aquifer system with basalt aquifer (Moderate Permeability group)

The alluvial and lacustrine deposits at Adaa plain especially around the Debre Zeit lakes area have thickness up to 80 meters and composed of course sediments. The alluvial aquifers do not form an independent aquifer but, it is interconnected with the basalt aquifer. The static water level varies from 7 to 39 meters deep. The static water level is shallower at the Debre Zeit Lake areas and becomes deeper to Mojo area.

Tertiary and Quaternary Volcanic Ridges and Volcanic Centers of Beda Gebaba and Yerer (very low permeability groups)

These are localized acidic volcanic units of Quaternary Bede Gebaba volcanic unit: Rhyolitic to minor trachytic lavas and central Volcanics of Yerer: porphyritic trachytic lavas. The formations have low permeability, except along weathered and fractured zones. These formations are less fractured and faulted.

Nazareth Group, Welded Ignimbrite, Chefe Donsa Pyroclastic and Addis Ababa Ignimbrite (Low permeability groups).

Chefe Donsa Pyroclastics, Nazaret unit (Welded ignimbrites) of low productive aquifers along the weathered and fractured zone. Acts as a regional aquiclude which separates the upper and lower volcanic aquifer. The formations have poor permeability except at the weathered and fractured zone.

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

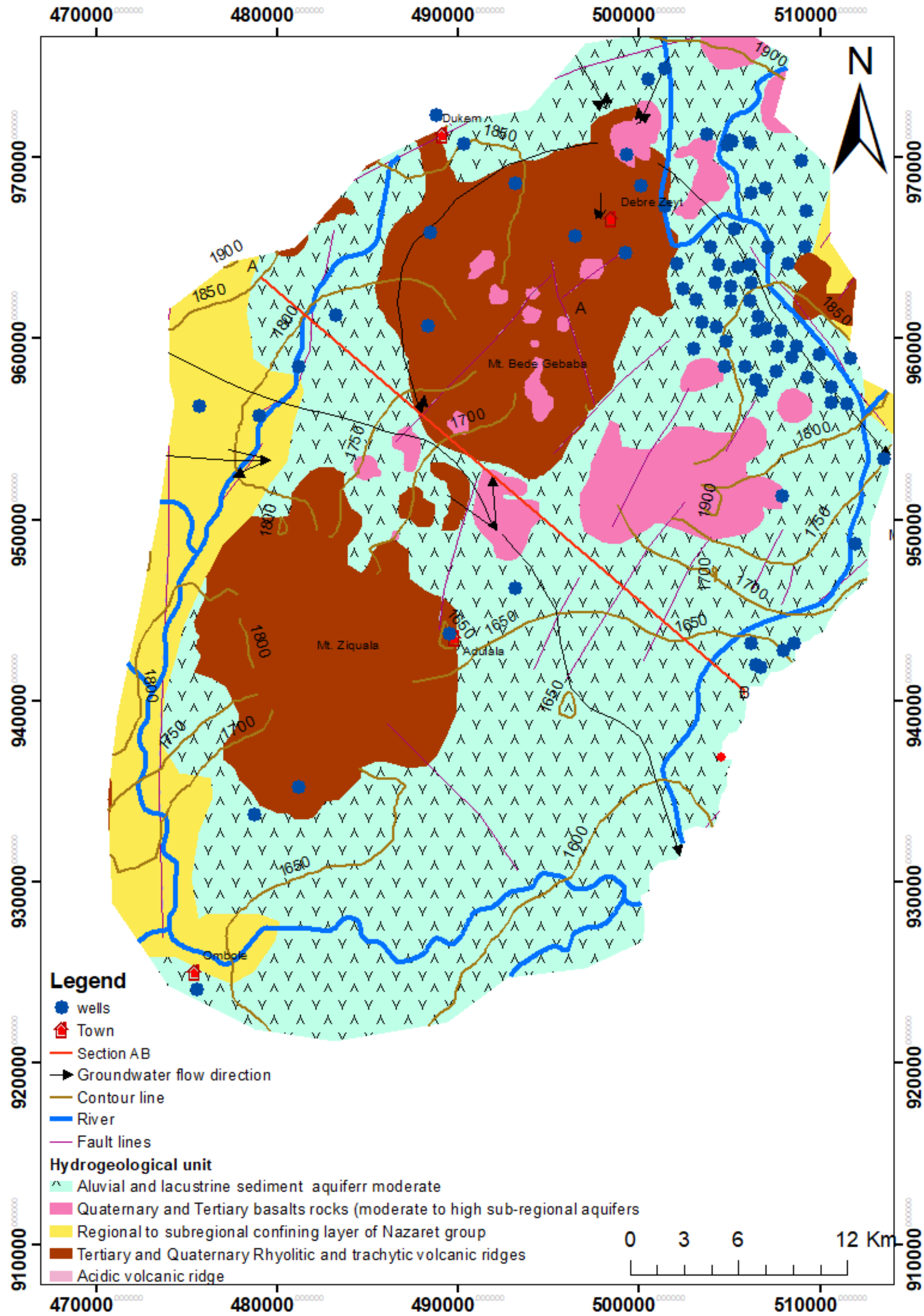


Figure 4: Hydrogeological map of the study area (Simplified from WWDSE, 2008)

CHAPTER FIVE

5. GROUNDWATER FLOW MODELLING

5.1. Development of the Conceptual Model and Model Input Data Preparation

The development of a conceptual groundwater flow model requires the detail of the three main components: defining hydro stratigraphic units, preparing a water budget and defining the flow system. Also, the aquifer homogeneity, fracture system, boundary conditions and recharge are needed.

5.1.1. Defining Hydrostratigraphic units and Hydrogeological setting

The Ada'a plain area is bordered with Ererer Mountain and Kesem river basin Water shed divide in the north, and Koka reservoir in the south. The plain is an extensive lacustrine deposit of flat area with isolated hills and mountain like mountain Ziquala and a number of Lakes concentrated at and nearby Debre Zeit town. The aquifers in the plain were classified in to four broad categories based on their permeability (WWDSE, 2008) as shown in Hydrogeological map of the study area and Hydrogeological cross-sections Hydrogeological map (figure 4.) and Hydrogeological cross-sections (Figure 5 & 6).

The alluvial and lacustrine deposits at Adaa plain especially around the Debre Zeit lakes area have thickness up to 80 meters and composed of course sediments. The alluvial aquifers do not form an independent aquifer but, it is interconnected with the basalt aquifer. The static water level varies from 7 to 39 meters deep. The static water level is shallower at the Debre Zeit Lake areas and becomes deeper to Mojo area.

These are localized acidic volcanic units of Quaternary Bede Gebaba volcanic unit: Rhyolitic to minor trachytic lavas and central Volcanics of Yerer: porphyritic trachytic lavas. The formations have low permeability, except along weathered and fractured zones. These formations are less fractured and faulted.

Chefe Donsa Pyroclastics, Nazaret unit (Welded ignimbrites) of low productive aquifers along the weathered and fractured zone. Acts as a regional aquiclude which separates the upper and lower volcanic aquifer. The formations have poor permeability except at the weathered and fractured zone.

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 drilled wells log data enabled to draw hydrogeological x-sections in two different directions mainly along the groundwater flow direction and perpendicular to the flow direction to understand the three-dimensional configuration of the groundwater system.

Shallow depth water levels are distributed at northeastern part of Ada’a plain (where the lakes are concentrated) and south of Ada’a plain near Koka Reservoir. The transmissivity at the lake’s areas and the area between Mountains Ziquala and Bedegebaba is relatively high which highly favors storage due to the wide distribution of scoria and scoraceous basalt and the main transit for groundwater flow. Between mountains Bedegebaba and Ziquala the groundwater level is deep varying from 60 to 120 meters as a function of surface elevation of the place. From the hydrogeological map and x-sections the Ada’a plain aquifer as whole considered as one-layer unconfined aquifer for current modeling purpose.

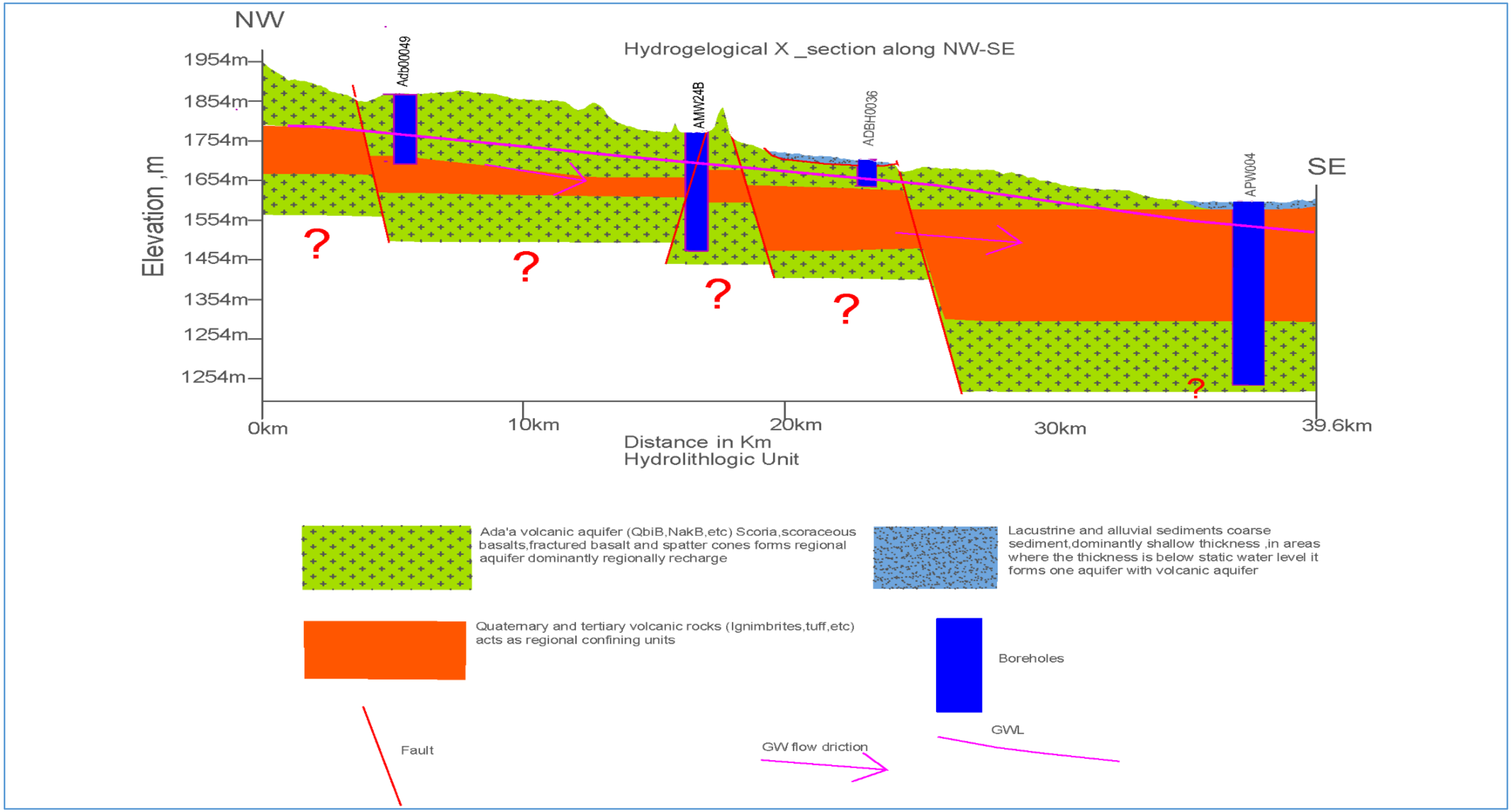


Figure 5: Hydrogeological x-section along section AB (northwest-southeast)

5.1.2. Hydraulic Properties

The Hydraulic conductivity indicate the connectivity of pore spaces. Therefore, they are a measure of extractable groundwater from geological materials. To determine hydraulic properties the study area, compiled available information on aquifer properties or tests from various well completion reports and well records, conducted and analyzed aquifer tests in the study area, and in areas where no data exist, the hydraulic conductivity was assigned within values gathered from the available hydrogeological information and also used specific-capacity information to estimate transmissivity, and use statistics to summarize the results of analysis(figure 7).

The hydraulic conductivity of Ada'a plain aquifer ranges from $1m^2$/day to $13m^2$/day. The map shows that the south west and north west of the plain have low hydraulic conductivity zone and central part and eastern part of the plain is mapped as high hydraulic conductivity zone.

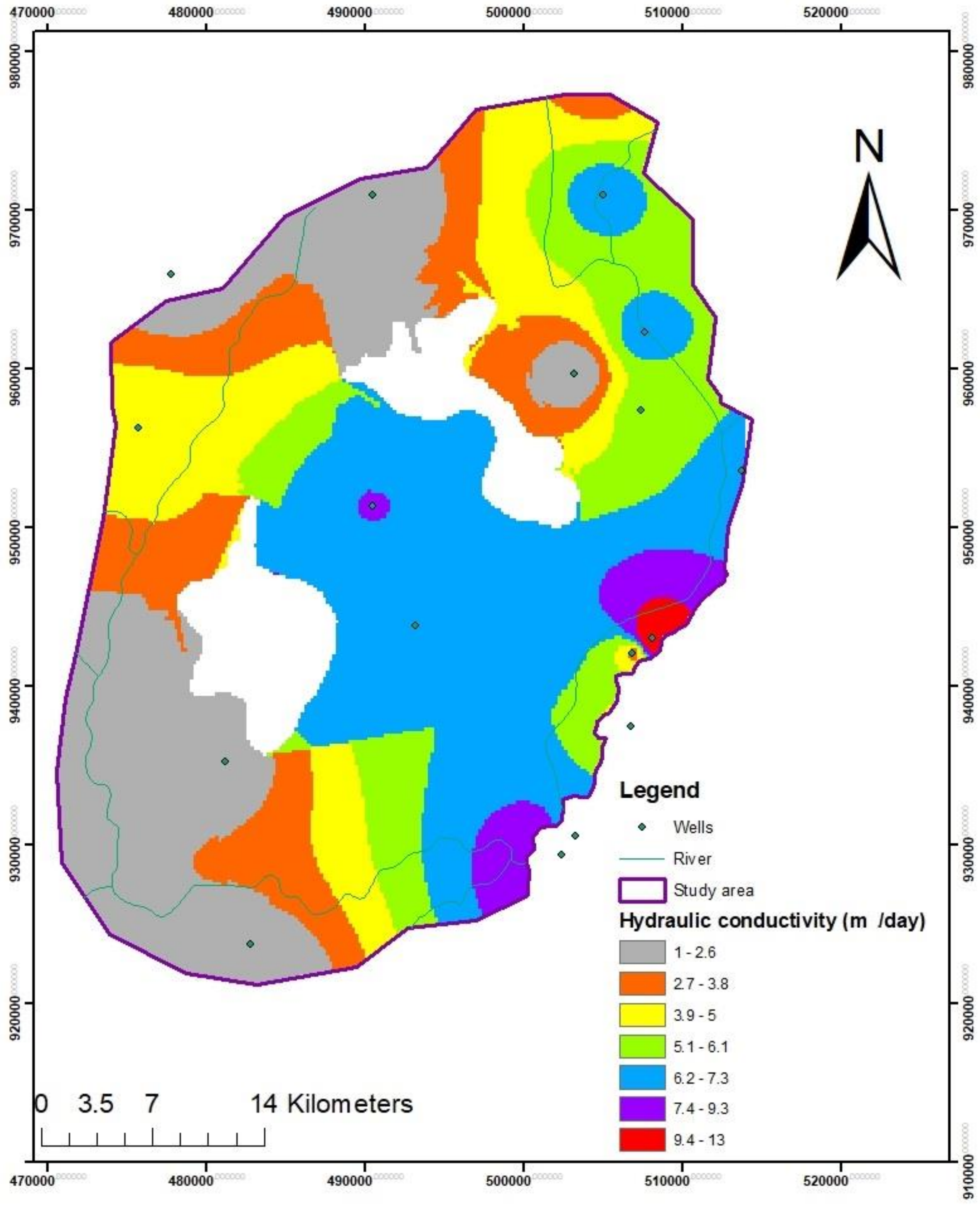


Figure. 6: Hydraulic conductivity map of the study area

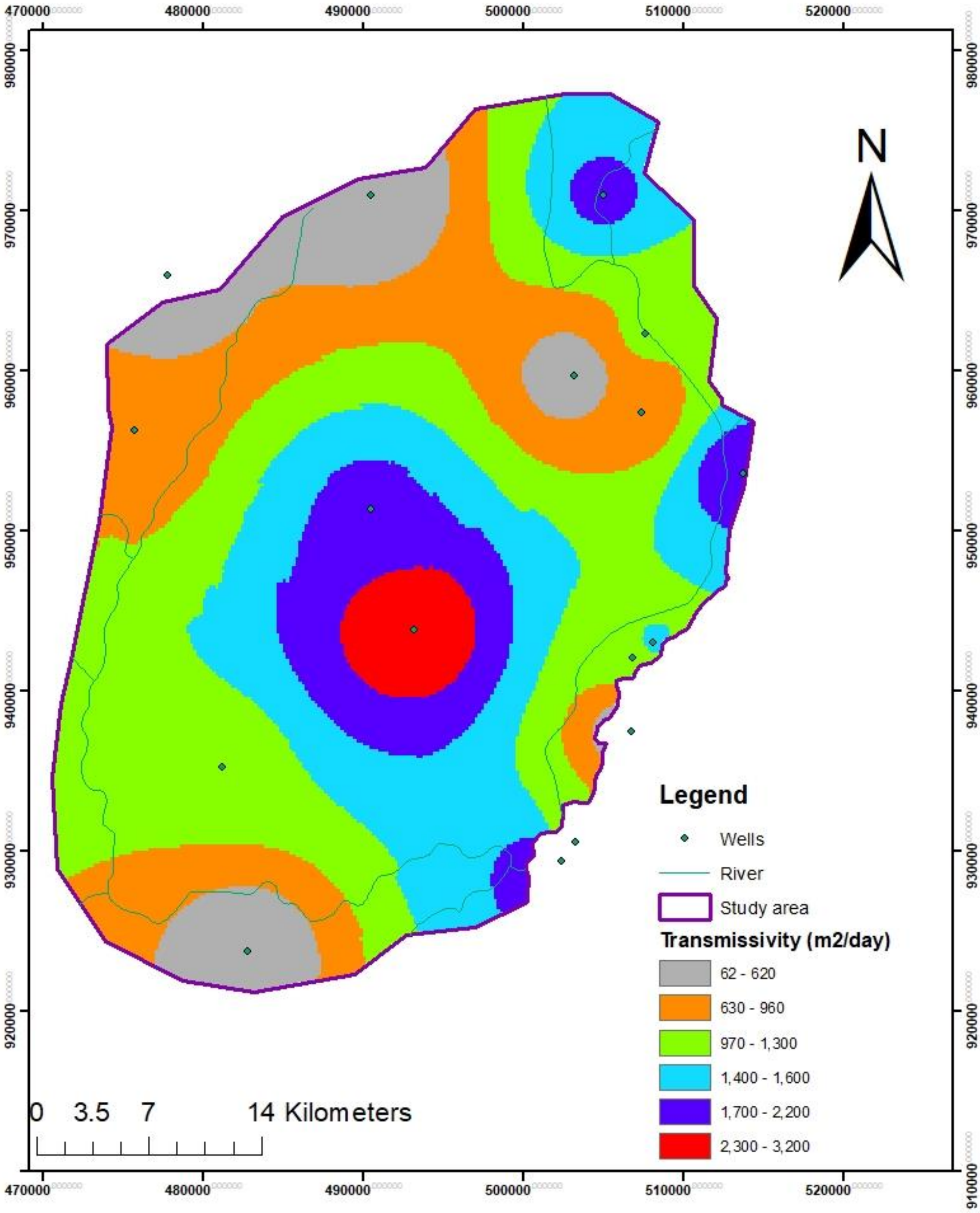


Figure. 7: Transmissivity map of the study area

5.2. Groundwater Recharge Estimation

5.2.1. Input Data Preparation for Wetspass Modeling and methodology

Groundwater is recharged from rainfall in mountains and hills, plains and from lakes stream in the Study Area, then recharge groundwater gradually infiltrates into deep aquifers. It 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).

WetSpass modeling techniques is use for estimating spatially distributed, long-term average groundwater recharge. The method was developed by Batelaan, O. and De Smedt, F. (2001, 2007). It uses long-term average climatic data together with elevation, land use and soil map of an area to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area.

A better understanding of the temporal and spatial variations of water balance components, especially actual evapotranspiration, surface runoff, and recharge, is crucial for a sustainable, and efficient management of water resources in the Ada’a plain. It is used as an input for developing the groundwater model in the study area. The WetSpass model requires a set of basic input data, including meteorological data (precipitation, air temperature, wind speed, and potential evapotranspiration), distributed groundwater depth, LAI, soil types, topography (DEM and slope), and land use/land cover of the investigated area. Such input data are prepared as grid maps using Geographic Information Systems (ARCGIS), 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) to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area. The method is mainly applied for basin. As the study is located in the upper Awash basin, during analysis inputs data in the upper awash basin were considered.

Methodology

WetSpass is an acronym for water and energy transfer between soil, plants and Atmosphere under quasi steady state, integrates a water balance in a geographical information system (GIS) (Batelaan Desmedt, 2001).

The WetSpass model treats a basin or region as a regular pattern of raster cells. Every raster cell is further sub-divided in a vegetated, bare soil, open water, and impervious surface fraction, for which independent water balance maintained. The total water balance per raster cell and hydrological season, calculated as follows: -

$$ETc = avEtv + asEs + aoEo + aiEi$$

$$Sc = avSv + asSs + aoSo + aiSi$$

$$Rc = avRv + asRs + aiR$$

Where the index c refers to raster cell, with ETc, Sc, Rc the total evapotranspiration, surface runoff and recharge in a raster cell and av, as, ao and ai respectively the vegetated, bare soil, open water and impervious area fractions of a raster cell.

Grid map

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.

Land use

Land use is an important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration. 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, modified FAO Land use/land cover and soil maps of Ethiopia (FAO, 2016) were used. 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.

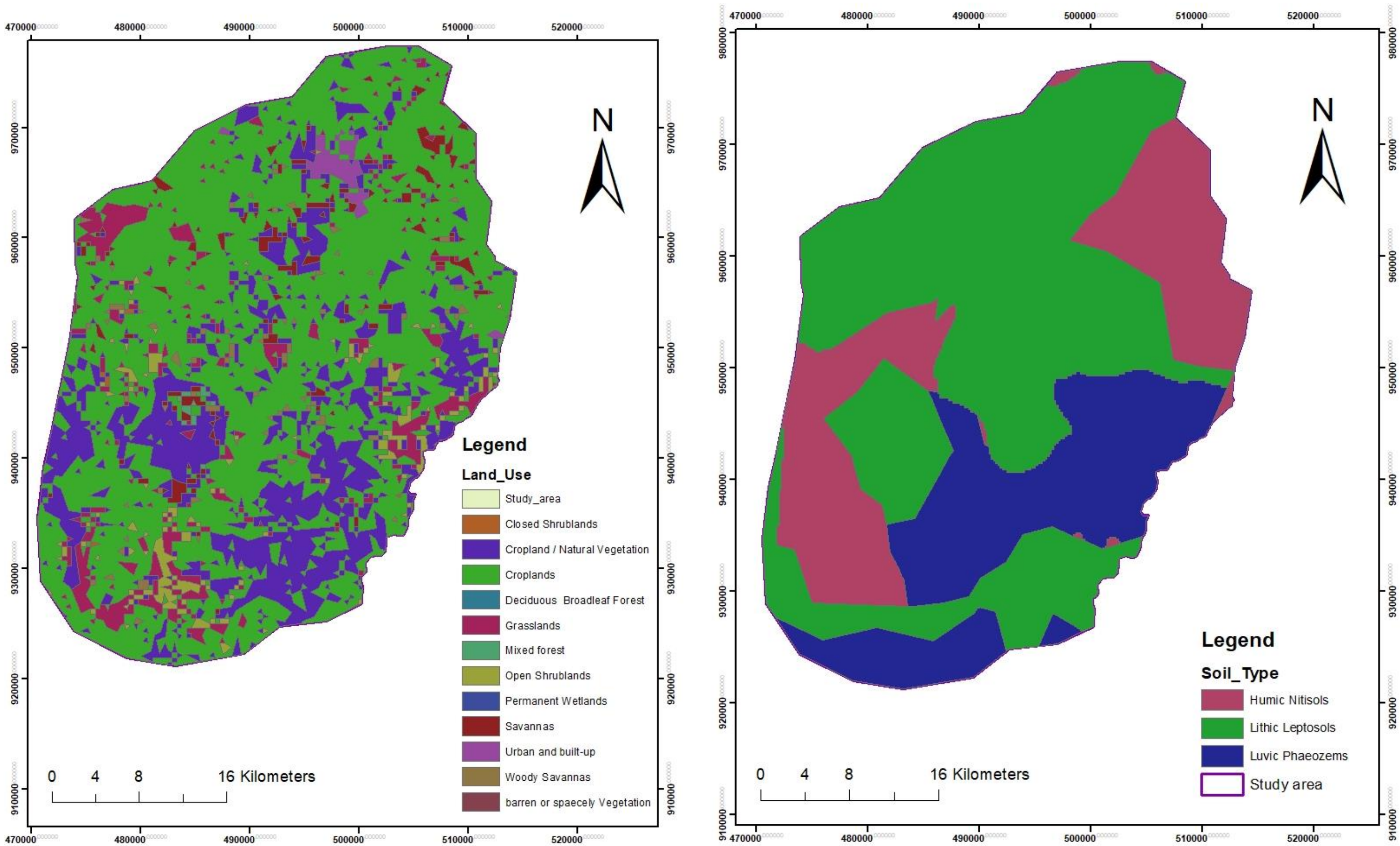


Figure 8: Land use and Soil type map of the study area

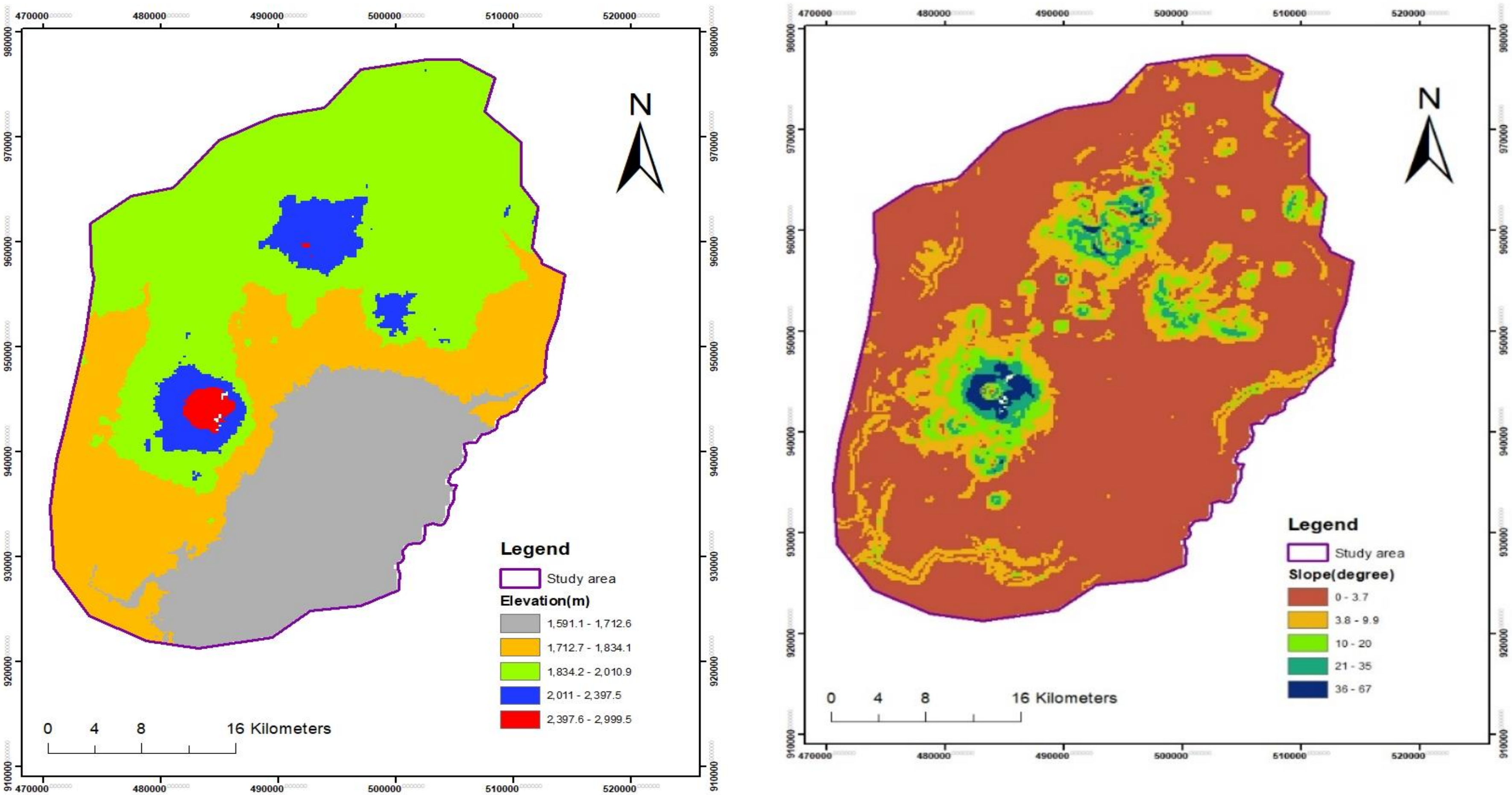


Figure 9: Elevation and Slope map of the study area

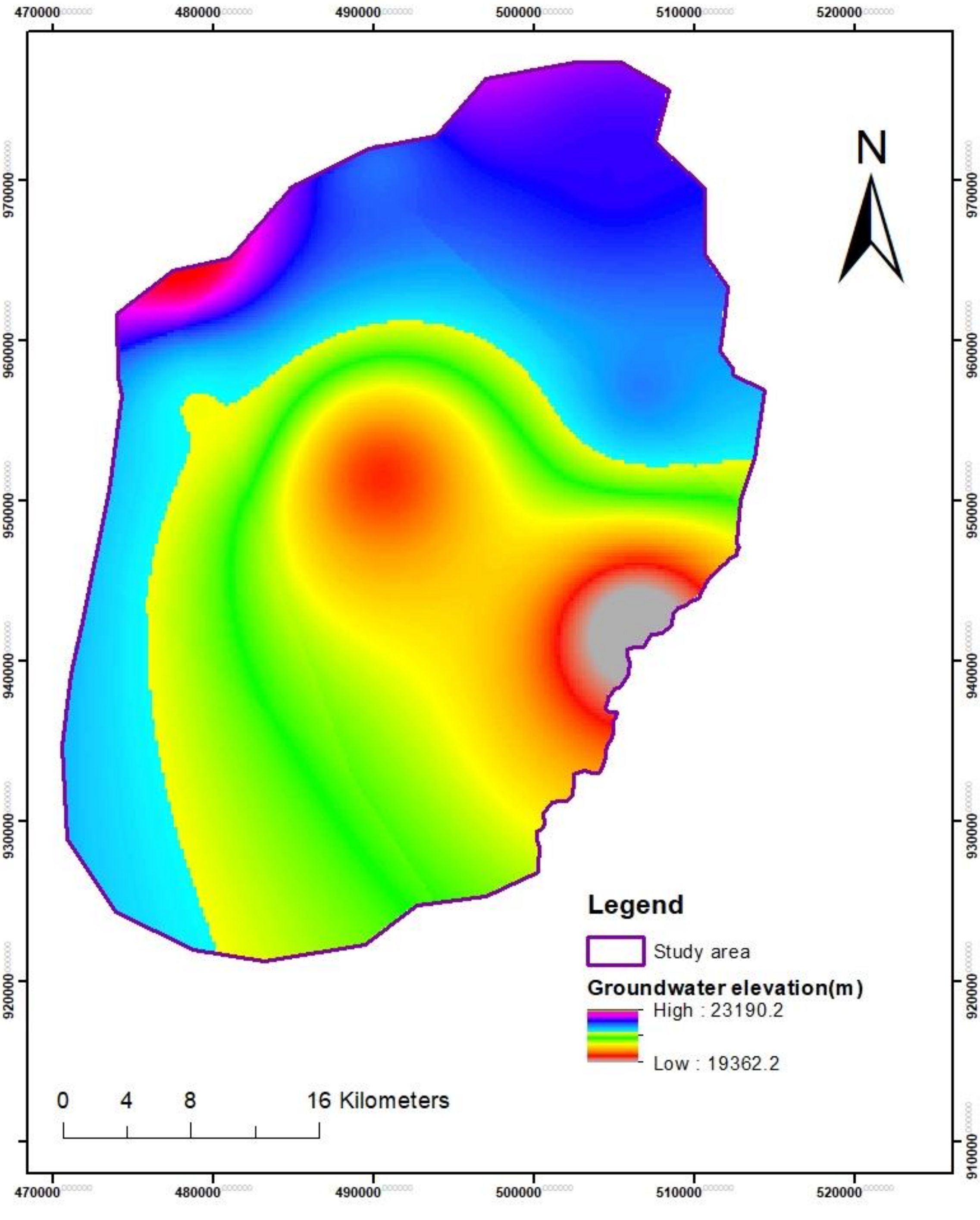


Figure 10: Groundwater Elevation map of the study area

Soil attribute table

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

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 3)

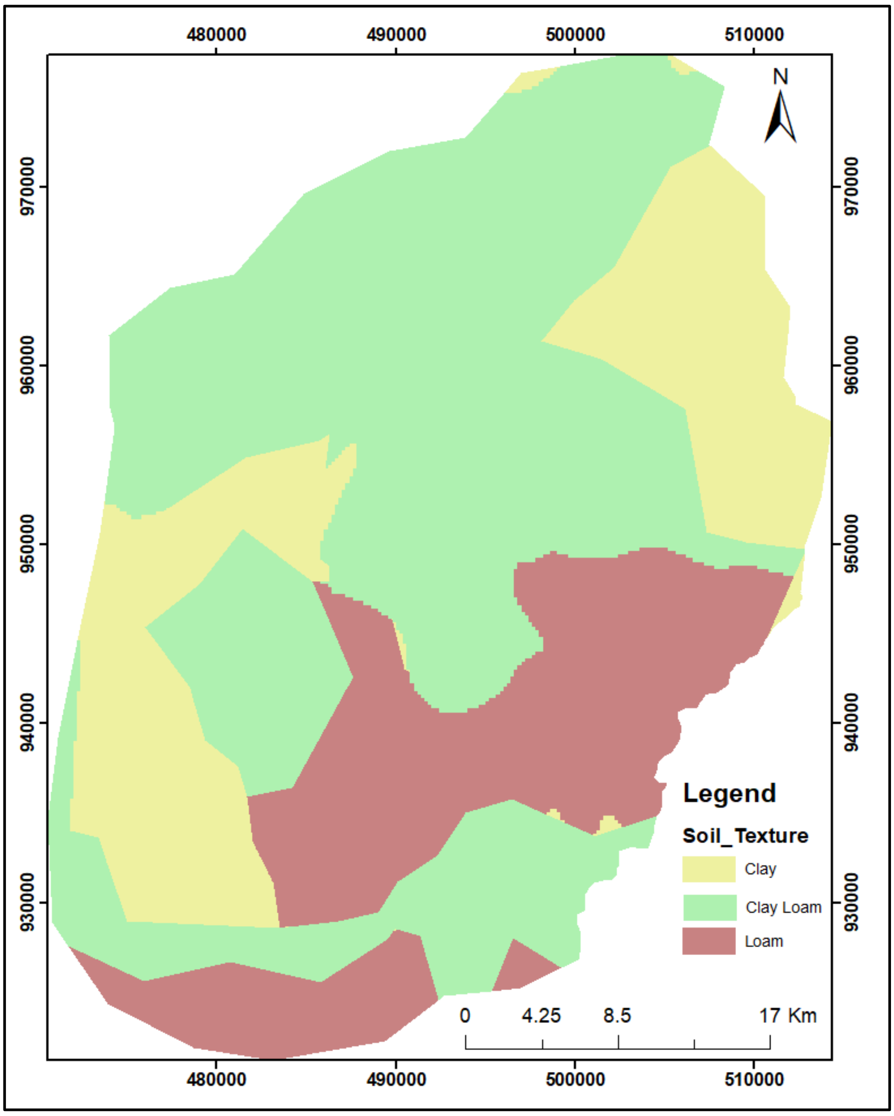


Figure 11: Soil texture map of the study area

Hydro-meteorological data

Meteorological stations represent the study area and surrounding were selected and analyzed for metrological parameters of the study area. Hydrological and meteorological data used for this analysis are observation data for 38 years from 1981 to 2019. The monthly meteorological data, are converted to special grid (ASCII) with ArcGIS for WetSpass modeling.

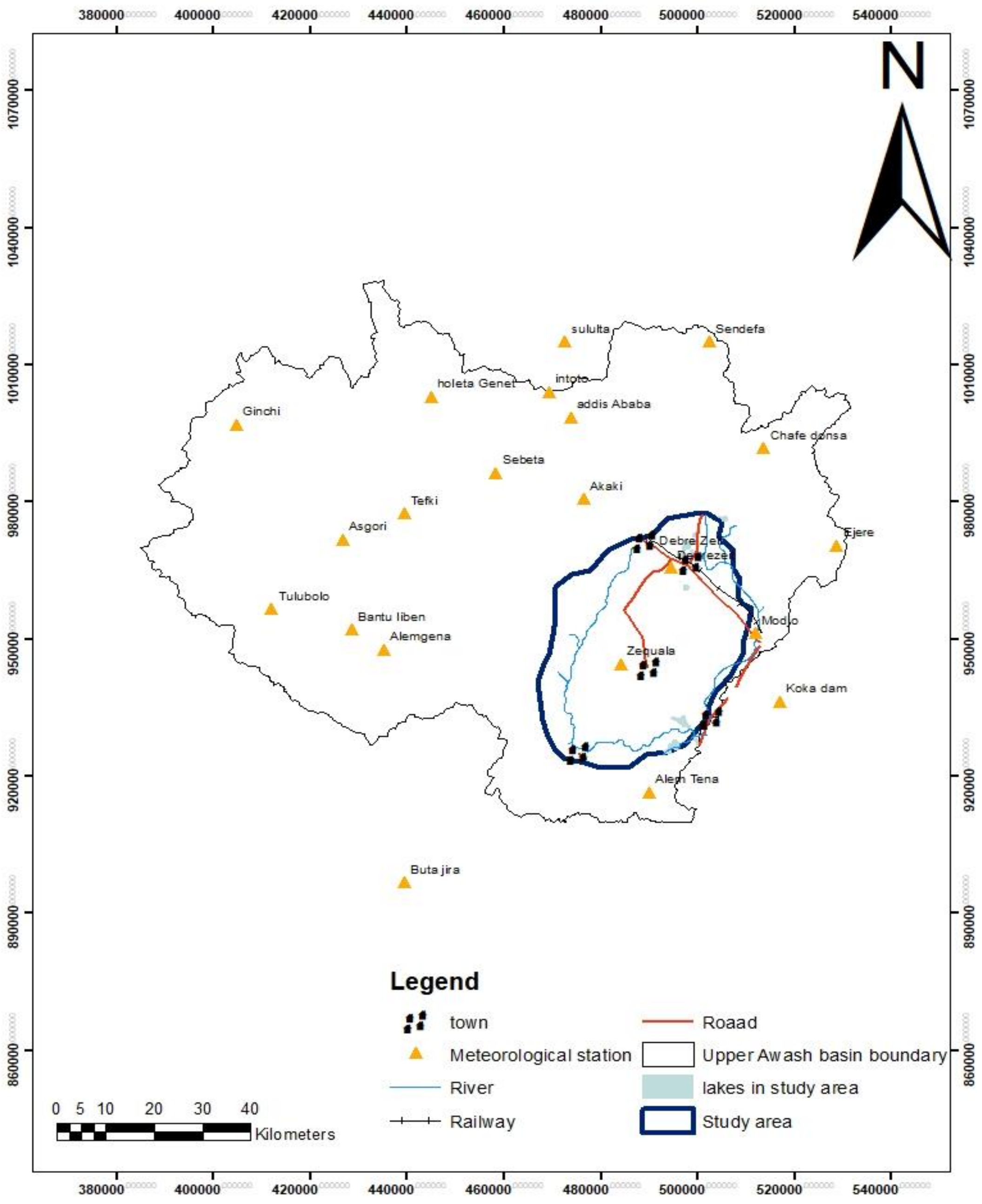


Figure 12: Meteorological and Gauge Stations of the study area

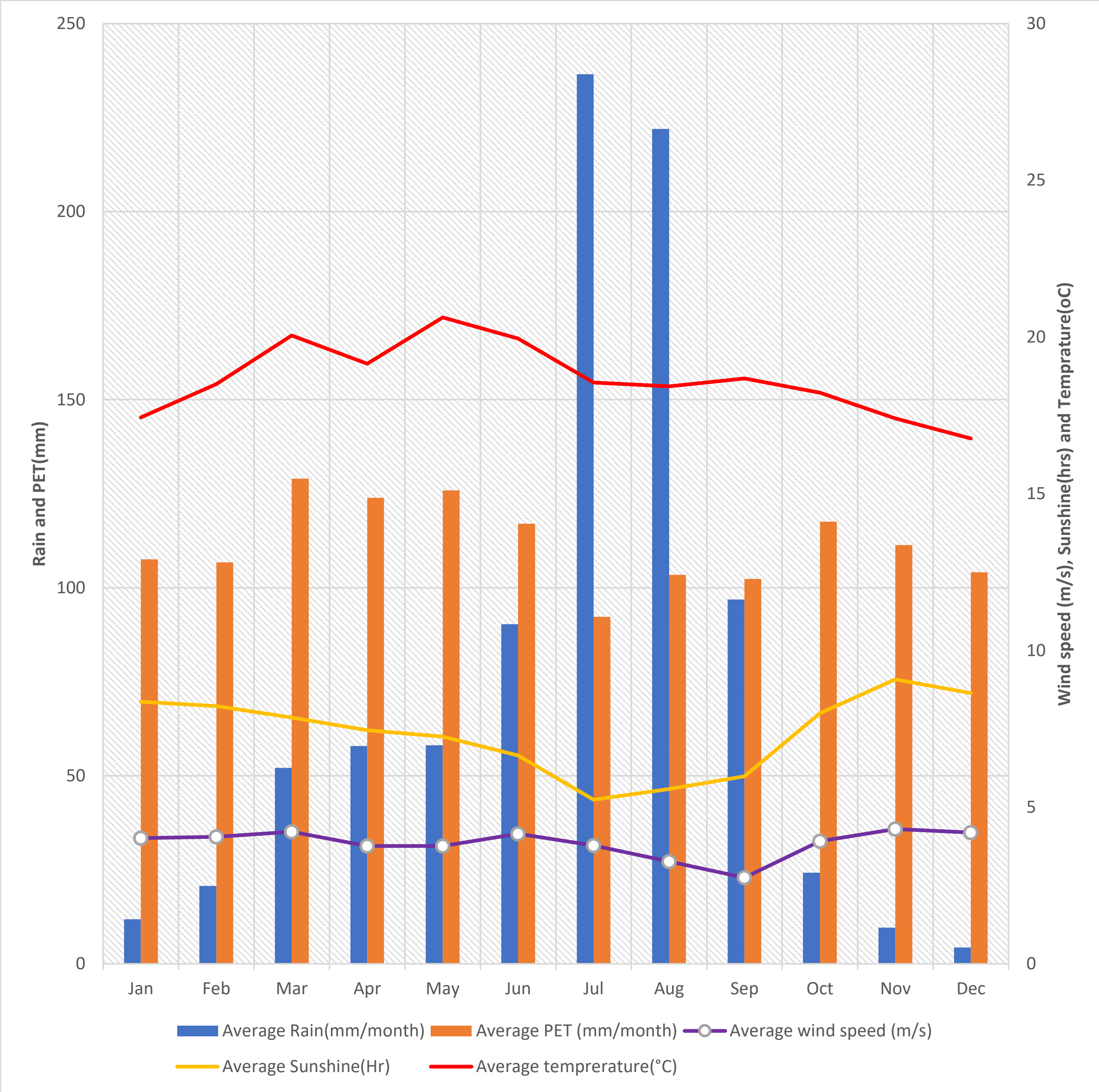


Figure 13: Meteorological data graph representation of the study area.

Rainfall

The precipitation distribution of the study is variable through the year. The analyses show that most of the rainfall occur in summer from Jun to mid-September. To calculate aerial depth of rainfall of the study area, point measurements with complete data found in each station were averaged by using arithmetic mean method. Average annual precipitation of the Study area is 884.7 mm (Annex 5)

Mean Annual Temperature of the study area

The mean annual temperature of the study area is about 18.6°C and with a fluctuation of 16.6°C in December to 21.1 °C recorded during the month of May. Average annual Temperature of the Study area is 18.5mm. The mean monthly temperature variation at all station is shown on graph (Figure:14).

Wind Speed

Wind speed is the driving force for water vapor removal, hence, strongly affect rate of evaporation, and evapotranspiration in the area. 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). The average annual wind speed 2m above the surface of the earth of the study area is 3.84m/s. Monthly and annual means of wind speed in the study area were taken from available point data (Annex 5).

Sunshine hours

Sunshine is also factor affect recharge amount. Evaporation takes place almost without interruption during the day light and the night, the process is most active under direct radiation from the sun. 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 programmed provides estimates of Meteorological data with potential evapotranspiration. So, PET data from New_Loc Clim_1.10 is 520mm/year.

Rainy Days per month parameter table

The rainy days characteristics parameter table contains three months for each corresponding frequency of rain per day. Values in these tables are modified based on average stations Meteorological data. Parameters of these tables (Anne 4).

Actual evapotranspiration

Actual evapotranspiration accounts 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

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

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)

S/no.	Station name	Average Annual Precipitation rate(mm)	Average Annual Temprature(°c)	Annual Evapotranspiration(ETA) using Turc method
1	Akaki	992.8	18.6	549.0
2	Alem Tena	820.4	18.8	518.9
3	Chafe donsa	902.0	18.6	560.5
4	Denrezeit	547.5	18.6	373.4
5	Koka dam	881.3	19.0	554.1
6	Modjo	988.8	18.4	595.2
7	Zequala	1059.9	18.6	627.8
Average ETA of the study area using Turc method(mm/year)				**539.84**
Average ETA of the study area using Wetspass(mm/year)				**520.00**

Table 1: Turc method estimate of evapotranspiration

5.2.2. Wetspass Model Result

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 520mm of water is lost through evapotranspiration from the study area. This accounts for 49.06% of the study area annual precipitation. According to the WetSpass simulated results of evapotranspiration, its value ranges from 260 to 630 mm with standard deviation of 52 in the study area. The output of annual evapotranspiration map is displayed in (figure: 15). Precipitation and land-use/land-cover are the main controlling factors of evapotranspiration.

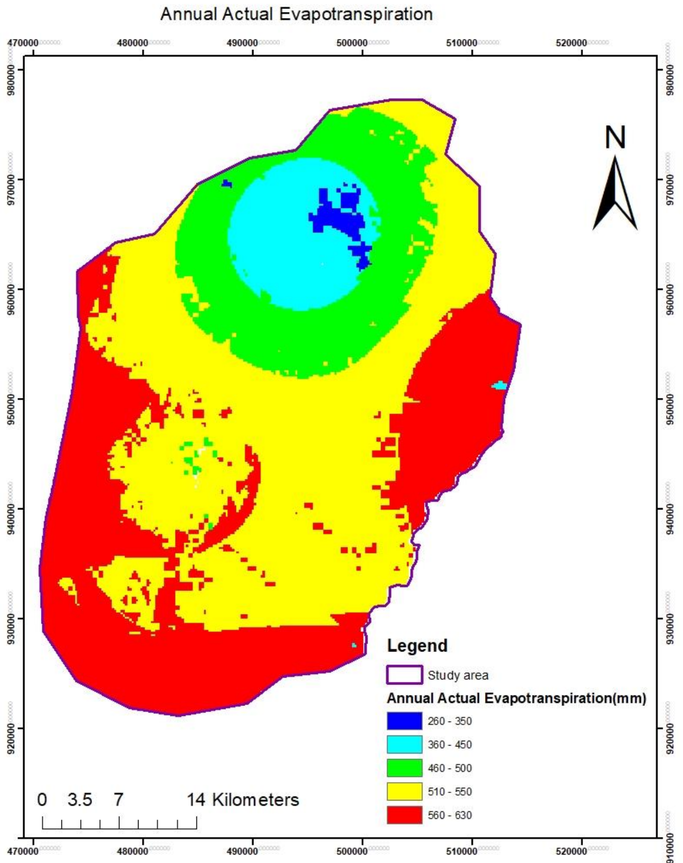
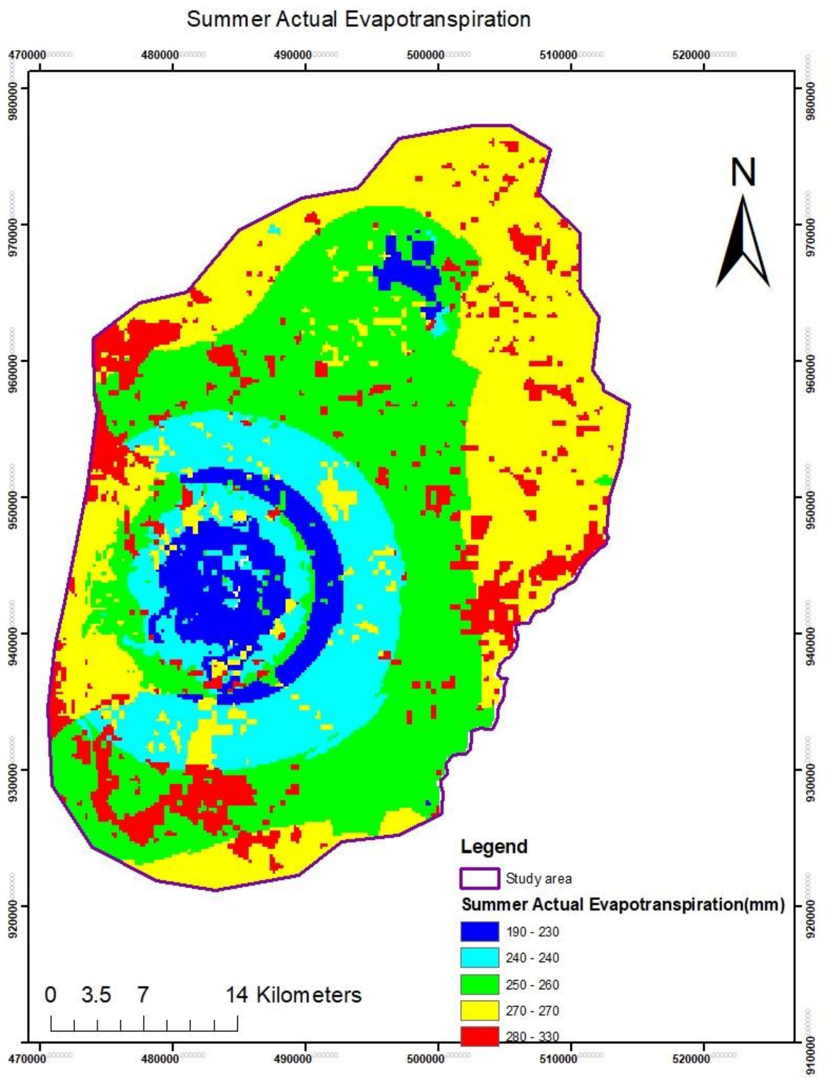
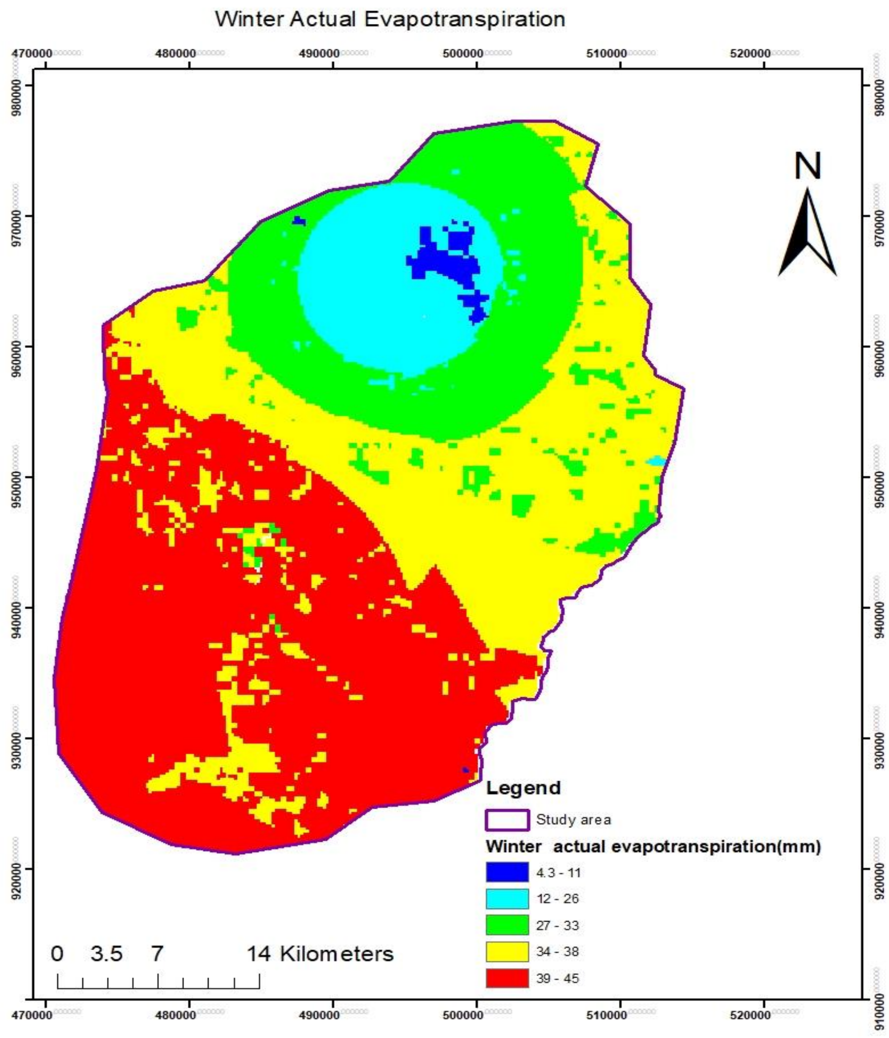


Figure 14: Annual Actual Evapotranspiration map of the study area


Summer Actual Evapotranspiration
N
Legend
Study area
Summer Actual Evapotranspiration(mm)
190 - 230
240 - 240
250 - 260
270 - 270
280 - 330
0 3.5 7 14 Kilometers


Winter Actual Evapotranspiration
N
Legend
Study area
Winter actual evapotranspiration(mm)
4.3 - 11
12 - 26
27 - 33
34 - 38
39 - 45
0 3.5 7 14 Kilometers

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: 16). The amount of mean annual Surface runoff in the study area is 290mm which ranges monthly from 69 to 630 mm with standard deviation of 87. The value represents 27.36% of the total annual precipitations of the study area.

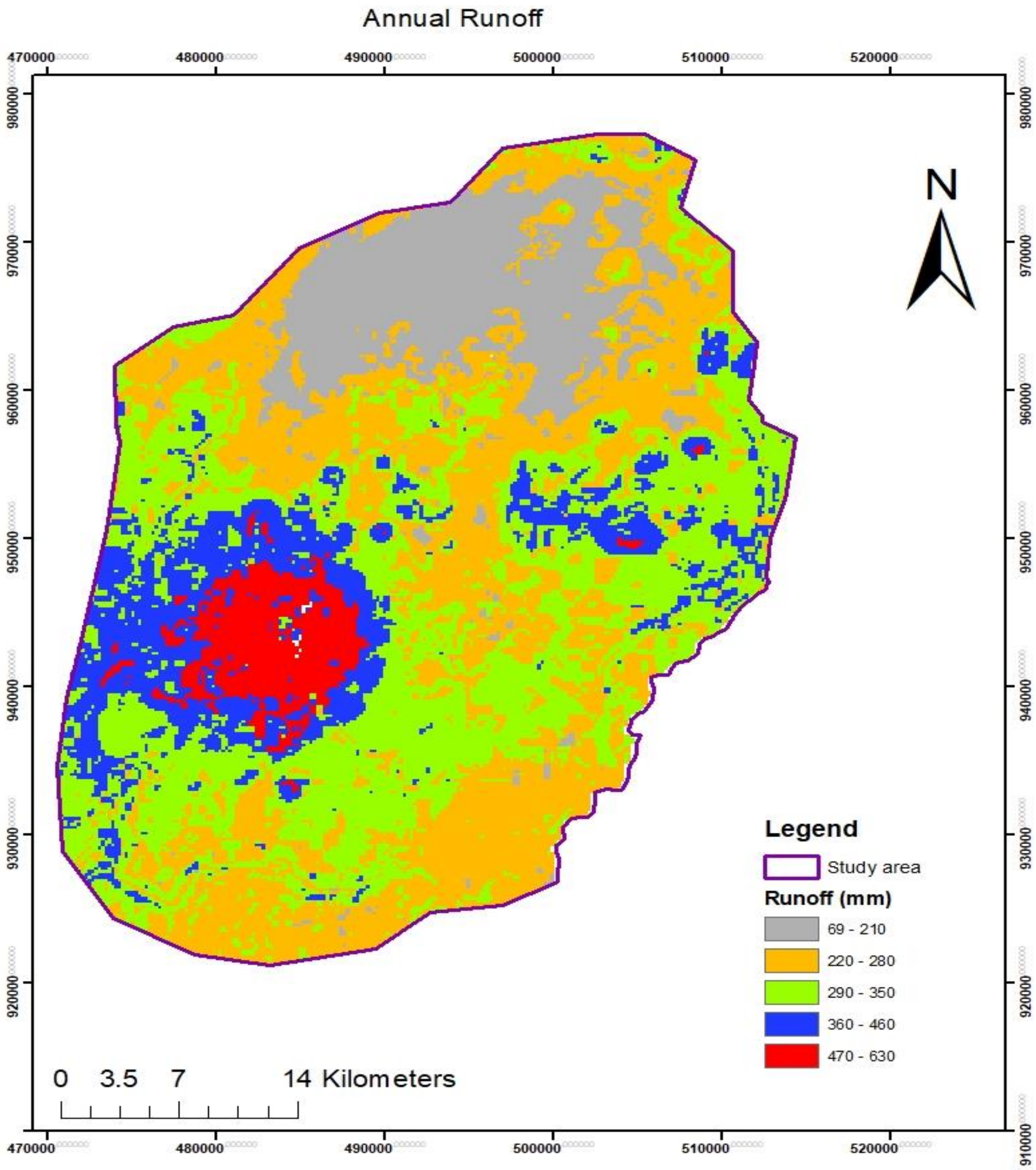
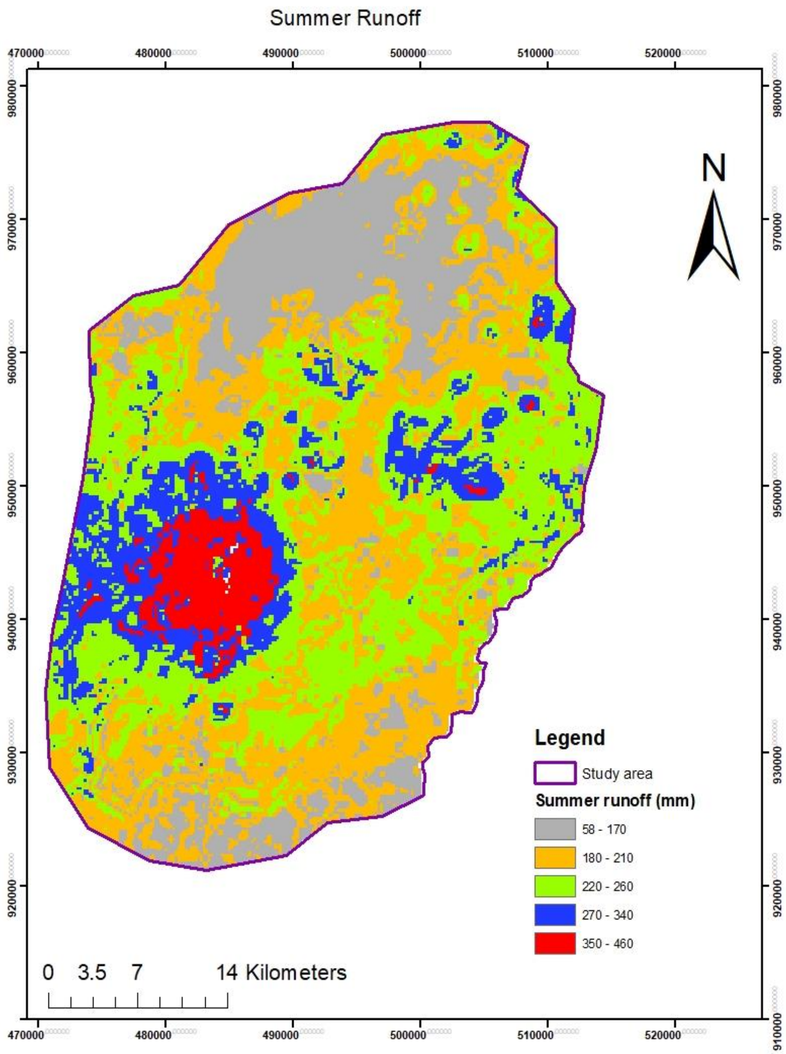
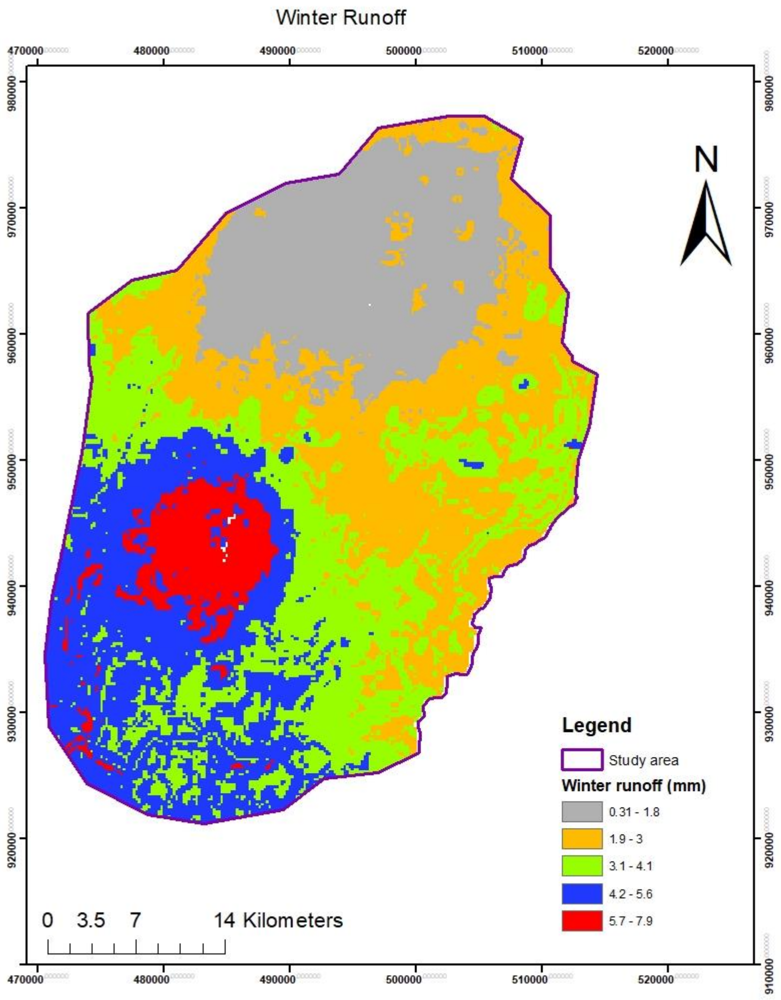


Figure 15: Annual Runoff map of the study area


Summer Runoff
N
Legend
Study area
Summer runoff (mm)
58 - 170
180 - 210
220 - 260
270 - 340
350 - 460
0 3.5 7 14 Kilometers
470000
480000
490000
500000
510000
520000
980000
970000
960000
950000
940000
930000
920000
910000


Winter Runoff
N
Legend
Study area
Winter runoff (mm)
0.31 - 1.8
1.9 - 3
3.1 - 4.1
4.2 - 5.6
5.7 - 7.9
0 3.5 7 14 Kilometers
470000
480000
490000
500000
510000
520000
980000
970000
960000
950000
940000
930000
920000
910000

Groundwater Recharge

The annual groundwater recharge of Ada'a plain varies from 0 to 370 mm. The mean annual groundwater recharge of the study area estimated by using WetSpass modeling is 119mm with standard deviation of 46 which is 13.45% of total annual rainfall.

Area	Plain Area (km^2)	Groundwater Recharge	
		mm/year	m3 /s
Study area	1737	119	6.55

Table 2 Total Groundwater Recharge of the Study Area

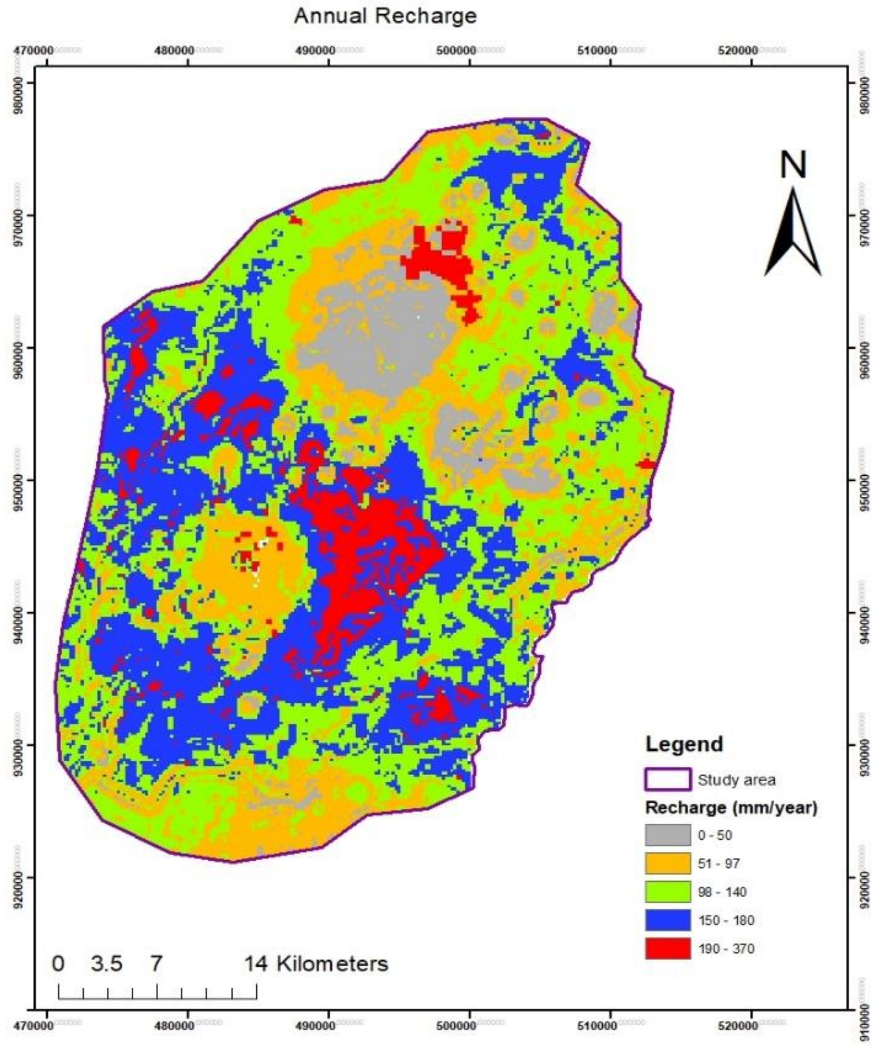
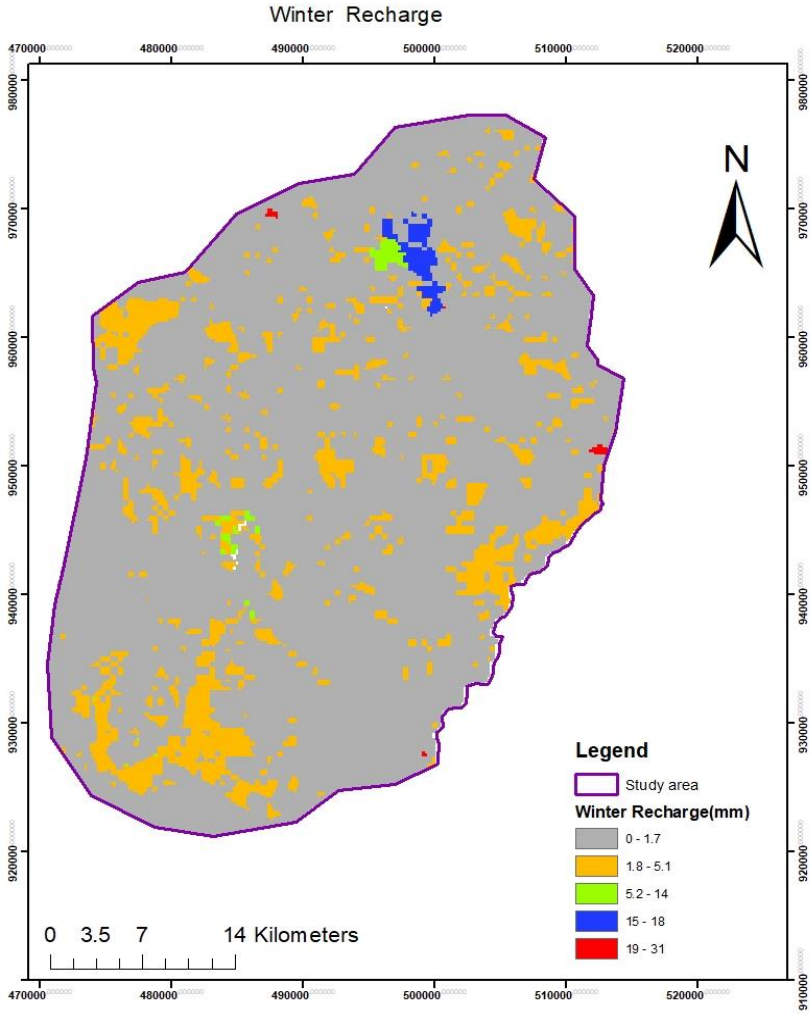
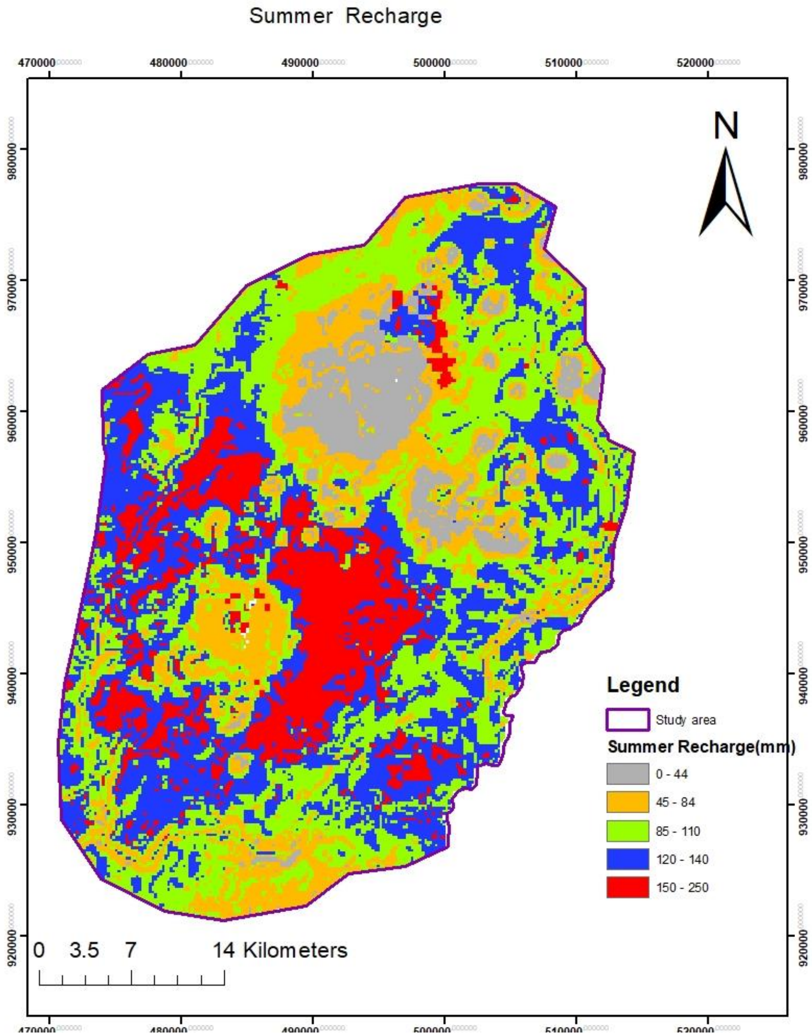


Figure 16: Annual groundwater recharge estimated with WetSapass


Winter Recharge
470000
480000
490000
500000
510000
520000
980000
970000
960000
950000
940000
930000
920000
910000
N
Legend
Study area
Winter Recharge(mm)
0 - 1.7
1.8 - 5.1
5.2 - 14
15 - 18
19 - 31
0 3.5 7 14 Kilometers


Summer Recharge
470000
480000
490000
500000
510000
520000
980000
970000
960000
950000
940000
930000
920000
N
Legend
Study area
Summer Recharge(mm)
0 - 44
45 - 84
85 - 110
120 - 140
150 - 250
0 3.5 7 14 Kilometers

The wetspass result are provided in the form grid map 200m resolution. The mean annual recharge, evapotranspiration and runoff of the study area is 119mm,520mm and 290mm respectively. Water balance of the simulated WetSpass model of the plain is shown in the table 3 below.

Mean Precipitation(mm)	Mean Recharge(mm)	Mean Runoff(mm)	Mean ETA (mm)	Water balance= (P-Ruoff-Recharge-ETA)
884.68	119	290	520	-44.32

Table 3: Annual water balance of the study area based on the WetSpass model

5.3. Numerical groundwater flow modeling of the study area

Numerical groundwater flow modeling helps to have a good understanding of the current or to predict the long-term tendencies of a hydrogeological system and it allows an analysis of the movement of water through hydrogeologic unit that constitute the groundwater flow system. The hydrogeologic setup and aquifer parameters discussed in the previous chapters were applied to construct the numerical model of Ada'a plain groundwater system. It has been assumed that the groundwater system in the modelled area occurred in steady-state conditions, with negligible head variations prior to 2007. So, a steady-state model can be used to simulate the initial conditions. The governing equations for flow are described by:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

Kx, Ky and Kz are the value of hydraulic conductivity along x, y and z coordinates axes and are assumed to be parallel to the major axes of hydraulic conductivity, in meters per day h – is the potentiometric head, in meters W – is a volumetric flux per unit volume and represents sources or sinks, or both of water, such as well discharge, recharge and water removed from the aquifer by springs, per day Ss – is storage coefficient of the porous material per meter, and t - is time, in days.

5.3.1. Model Design

The design of the model includes the choice of code and processor, the discretization of the aquifer into layers and cells, and the assignment of model parameters. The model is designed to agree as much as possible with the conceptual model of groundwater flow in the aquifer.

Code and Processor

Quasi three-dimensional finite difference visual MODFLOW Flex 15.1 copyright @2016 Water Hydrogeologic, Inc computer software is used to model Steady state groundwater flow of the study area. visual MODFLOW Flex 15. were chosen because it has the numerical features necessary to model the study area. The model was developed and ran on Intel(R) Core (TM) i5-7200U CPU @ 2.50GHz 2.71 GHz and 8.0 GB RAM running Windows 10 Pro.

Model Discretization

Layers and Grid

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. The lateral extent of the model corresponds to natural hydrologic boundaries, that coincide with groundwater divides.

The Model area has a total 3,202.64 km2 elongated in north – south direction with a length of about 60.2km and width 53.2km and contain the entire of Ada'a plain which has a total area of 1737km (see Figure 2). According to the hydro stratigraphy and conceptual model, the model was designed to have 1 layer. The layer has 301 rows and 266 columns for a total of 80,066.00 cells in the model. All the cells have uniform lateral dimensions of 200m by 200m. This cell size is chosen to be small enough to reflect the density of input data and the desired output detail and large enough for the model to be manageable. The uniform cell size allowed us to use spreadsheets and grid-based contouring programs to easily manipulate input data. Cell thickness depended on the elevation of the layers.

Boundary Conditions

The following physical and hydraulic boundary conditions were considered for the model: Mount Ziqual, Mt. Bedegebaba and Mount Yerer are considered as physical boundary of no flow due to the damming effect on the groundwater flow. Model boundaries that overlap with watershed boundaries at south and southwest of the plain, northern and north-eastern part of the plain were defined as no flow boundaries(figure 18). Ada'a plain is recharged dominantly from the regionally along Yerer-Guji, Bede Gebaba-Ziquala, Ombole-Ziquala as flux and general head boundary (GHB) is used to simulate flow through the boundary to the rift valley aquifer.

Rainfall infiltration in the plain, runoff infiltration of rivers and form the mountains in the plain are considered as recharge boundary conditions. Debre Zeit Lakes are considered constant head boundary condition.

The groundwater outflow from Ada’a plain to the rift valley is considered as general head boundary (GHB) and it is used to simulate the groundwater out flow from Ada’a groundwater basin.

Model Parameters

Model parameters are distributed to the IBOUND (active and inactive cells), elevations of the top and bottom of layer, horizontal and vertical hydraulic conductivity, specific storage, recharge, initial hydraulic heads, and pumping.

The IBOUND was defined by first establishing the lateral extent of the layer. A cell is assigned as active if covered more than 50 percent of the cell area.

Top and bottom elevations were defined for layer from the surface elevations from digital elevation models. Bottom elevations were obtained by subtracting aquifer thickness from layer top elevations. Aquifer thickness of 450m 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. ArcGIS was used to assign top and bottom elevations.

Initial hydraulic heads at constant head cells are used as specified head values of those cells and

remain constant throughout the flow simulation. The value groundwater level depth map was given as an initial heads for active cells.

Hydraulic conductivity is property that, in conjunction with the horizontal hydraulic gradient,control horizontal flow of groundwater. Groundwater flow within the model layer was assumed to be horizontal. The hydraulic conductivity of the study area was estimated from pumping test data of boreholes drilled in the study area. The horizontal hydraulic conductivity was assigned to layer according to geostatistical interpretation (figure: 5 and 6). Vertical hydraulic conductivity was assigned to be 100 times less than the horizontal hydraulic conductivity due to the presence of low-permeability interbed

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 recharge map in

ASCII form was applied to the top most active cell using the recharge package of Visual MODFLOW.

The River Package allows streams to gain and lose water. The River Package in the study area 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 0.2m and river widths range from 2 to 6m. River length in a cell has been roughly considered to be equal to the side of the cell size (200m), 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 hydraulicconductivity of the underlying formation has been considered. The hydraulic conductance of the river bed sediments has been calculated using the relation:

CRIV=Kr *L*W/M.

The river package uses the river bed conductance (CRIV) 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).

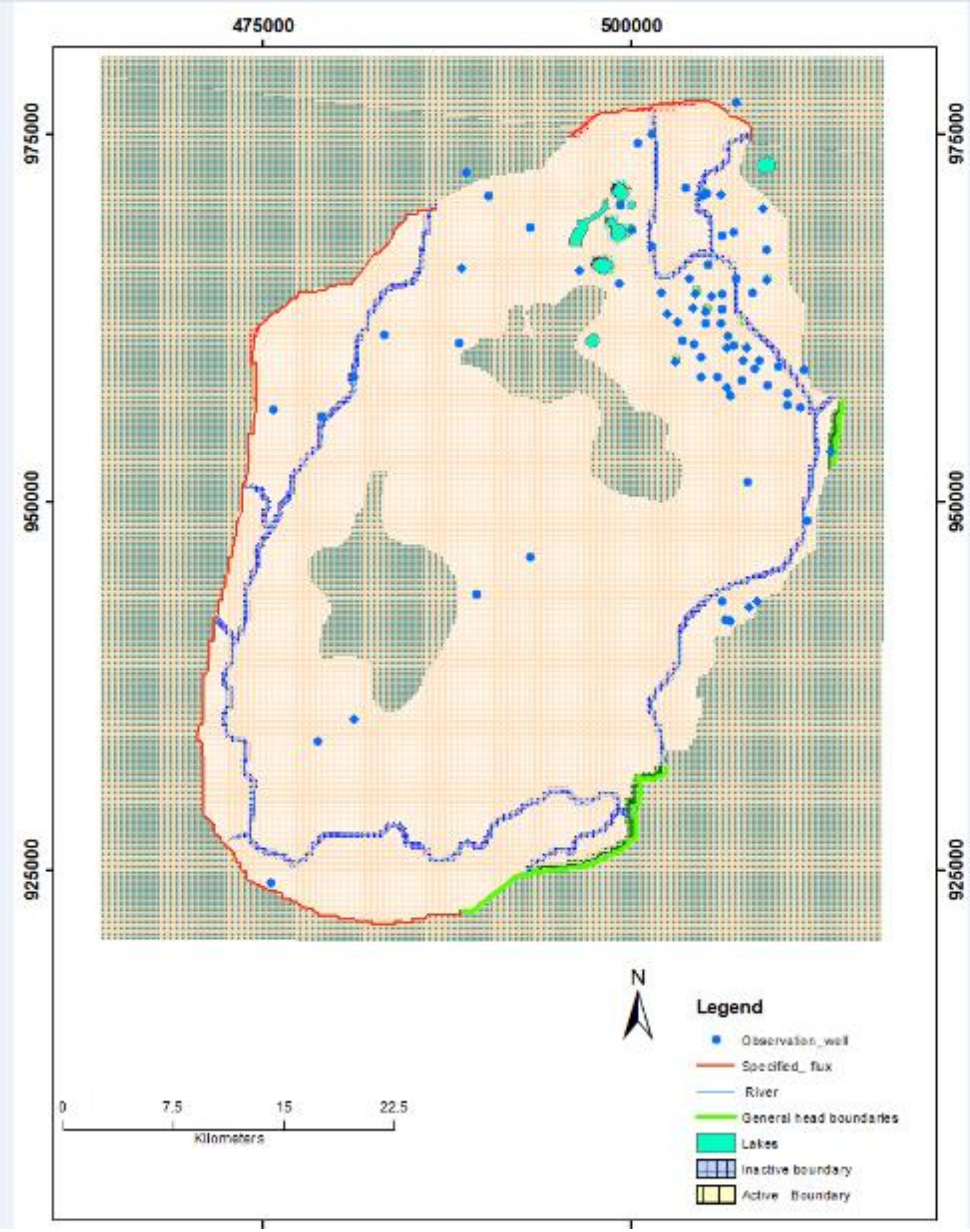


Figure 17: Model Grid and Boundary Conditions of the study area

5.3.2. Modeling Approach

Approach for modeling included two major steps: Developing a steady-state model and assembling the datasets and running the model for predictive runs. The steady-state model was developed for aquifer conditions in 2007. This year was chosen because the aquifer had approximately the same water levels at the beginning and end of the year and pumping from the aquifer was relatively low.

Once the steady-state model was completed, the framework of the model was used for predictive simulations, using available water-use data available at the time and development plan.

Approach for calibrating the model was to match water levels for steady-state conditions using the simplest possible conceptual model.

5.3.3. Steady-State Model

Once the input datasets assembled and the framework of the model was constructed, the steady-state model was calibrated and the sensitivity of the model to different hydrologic parameters were assessed.

Steady state calibration

The groundwater flow model has been constructed for computation of hydraulic head distribution. As minor fluctuation is observed in groundwater level in the area, this indicates that hydraulic gradients do not change significantly with time. Thus, groundwater flow was assumed to be under steady state condition represented by groundwater condition of 2007. For steady state simulation, 30 observation wells were included on the calculated versus observed heads graph(Table.4)). The ground water levels measured in 2007 were used as initial water level configuration for the Ada’a plain groundwater flow model.

The purpose of the calibration of a groundwater flow model is to demonstrate that the model can response field measured heads and flows. To calibrate the model, different model parameters were first adjusted to determine which parameters had the most effect on simulated water levels. Through this initial sensitivity analysis, it was determined that the model was most sensitive to the recharge rate; flux and the hydraulic conductivity of the aquifer. A trial-and-error calibration technique has been used. The flow model was calibrated by adjusting the recharge rate, flux and the hydraulic conductivity of the aquifer within a narrow range of values until the best fit was obtained between the observed heads and simulated heads. The accuracy of the computed groundwater levels was judged by a mean error, mean absolute error and root mean square error of computed values for points on the graph (Anderson and Woessner 1992)

The final, calibrated model does a good job of reproducing the spatial distribution of water levels in the study area (figure 20). The model reproduces the interpreted direction of groundwater flow and approximates water levels in most parts of the study area. The root-mean squared (RMS) error is about 6.98(figure 19).

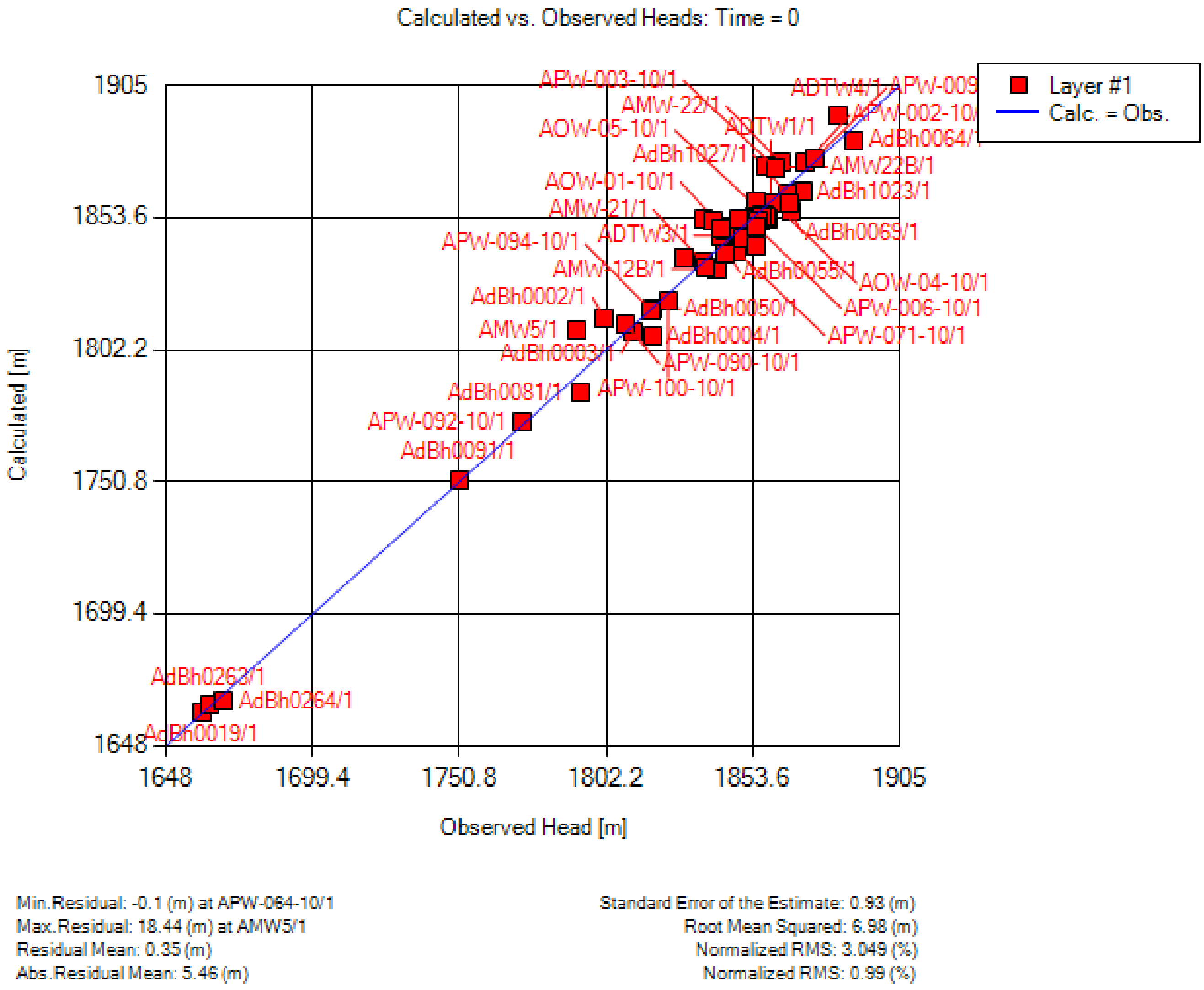


Figure 18: Comparison of simulated to measured water levels

Observed Well ID	X	Y	Z	Calculated head	Observed head	Calc.-Obs.
AdBh0002/1	475710	956270	1906	1814.1	1801.7	12.436
AdBh0003/1	481180	958490	1870	1809.1	1811.7	-2.579
AdBh0004/1	488310	960750	1939	1807.2	1818.4	-11.239
AdBh0019/1	475570	924070	1752	1660.9	1660.4	0.53162
AdBh0050/1	488460	965890	1912	1818.1	1818.5	-0.37708
AdBh0055/1	493180	968610	1919	1840.6	1844.6	-3.985
AdBh0064/1	500490	974380	1914	1883.8	1889.1	-5.3003
AdBh0069/1	499230	964800	1910	1855.8	1866.9	-11.151
AdBh0081/1	507950	951360	1819	1785.7	1793.5	-7.795
AdBh0091/1	511980	948670	1786	1751.5	1750.7	0.82926
AdBh0263/1	481160	935230	1815	1663.9	1663.1	0.81248
AdBh0264/1	478740	933710	1785	1665.2	1668.2	-3.0071
AdBh1023/1	499320	970180	1890	1863.6	1871.1	-7.5128
AdBh1027/1	500080	968510	1880	1862.8	1865.5	-2.6996
ADTW1/1	507010	968320	1881	1859.3	1859.9	-0.64719
ADTW3/1	507860	960490	1848	1846.5	1842.7	3.8323
ADTW4/1	501420	974990	1904	1893	1883.2	9.783
AMW-12B/1	490340	970790	1924	1833.3	1840.8	-7.4539
AMW-21/1	506770	957180	1836	1836.2	1836.1	0.13657
AMW-22/1	505010	970970	1879	1874.8	1863.5	11.305
AMW22B/1	504880	970770	1879	1873.3	1858.6	14.755
AMW5/1	478990	955800	1830	1810	1791.5	18.438
AOW-01-10/1	506500	960460	1870	1848.6	1843.9	4.6815
AOW-04-10/1	501440	967330	1876	1859	1861	-2.0217
AOW-05-10/1	505460	963970	1873	1853.2	1859	-5.8119
APW-002-10/1	505170	970960	1895	1874.8	1872.1	2.7453
APW-003-10/1	506140	970850	1886	1872.6	1862	10.614
APW-005-10/1	507560	958250	1855	1837.8	1829.2	8.5846
APW-006-10/1	504300	960690	1872	1851.1	1853.8	-2.6014
APW-007-10/1	503480	960960	1879	1852.4	1856.4	-3.9806
APW-009-10/1	503720	971360	1897	1876.8	1875.5	1.2815
APW-014-10/1	508990	969900	1917	1860.2	1855	5.1954
APW-020-10/1	508430	959040	1850	1838.2	1829.2	9.0073
APW-028-10/1	506220	968100	1880	1859.1	1866.3	-7.2095
APW-046-10/1	505270	966110	1882	1854.8	1856.7	-1.9401
APW-058-10/1	507150	965140	1844	1853	1836.6	16.371
APW-060-10/1	509190	965090	1856	1852.5	1839.5	12.978
APW-063-10/1	502090	964210	1873	1854.7	1857.8	-3.0612
APW-064-10/1	504380	964130	1880	1853.8	1853.9	-0.10157
APW-069-10/1	504780	959860	1863	1848.9	1845.1	3.8344
APW-071-10/1	508700	959620	1850	1840.4	1848.1	-7.6476
APW-073-10/1	502450	962790	1884	1854.2	1858.2	-4.0883
APW-074-10/1	504200	963160	1875	1853.5	1857.2	-3.7008
APW-075-10/1	505100	962950	1863	1853.1	1851	2.0632
APW-079-10/1	504750	958480	1874	1845.2	1850.4	-5.1447
APW-080-10/1	505860	958510	1874	1842.7	1854.8	-12.139
APW-082-10/1	503190	962170	1884	1853.7	1857	-3.2422
APW-084-10/1	505080	962100	1872	1852.8	1848.4	4.432
APW-085-10/1	506110	962140	1880	1852.3	1855.2	-2.8771
APW-088-10/1	503020	959480	1880	1850.4	1855.1	-4.7078
APW-089-10/1	506490	957770	1861	1839.1	1844.1	-5.0443
APW-090-10/1	511520	956440	1824	1812	1809	3.0316
APW-092-10/1	513550	953370	1801	1774.2	1773	1.1705
APW-094-10/1	510600	956530	1841	1817.6	1817.9	-0.25559
APW-095-10/1	509970	959180	1850	1834	1837.4	-3.3758
APW-096-10/1	506990	960630	1858	1849	1842.3	6.6942
APW-100-10/1	510660	957390	1841	1821.1	1824	-2.8677
Residual mean						0.35
Min Residual						**-0.1**
Max Residual						**18.44**
Root Mean Squared (RMS)						**6.98**
Absolute Residual mean						**5.46**

Table 4: Measured water level and simulated water level Data

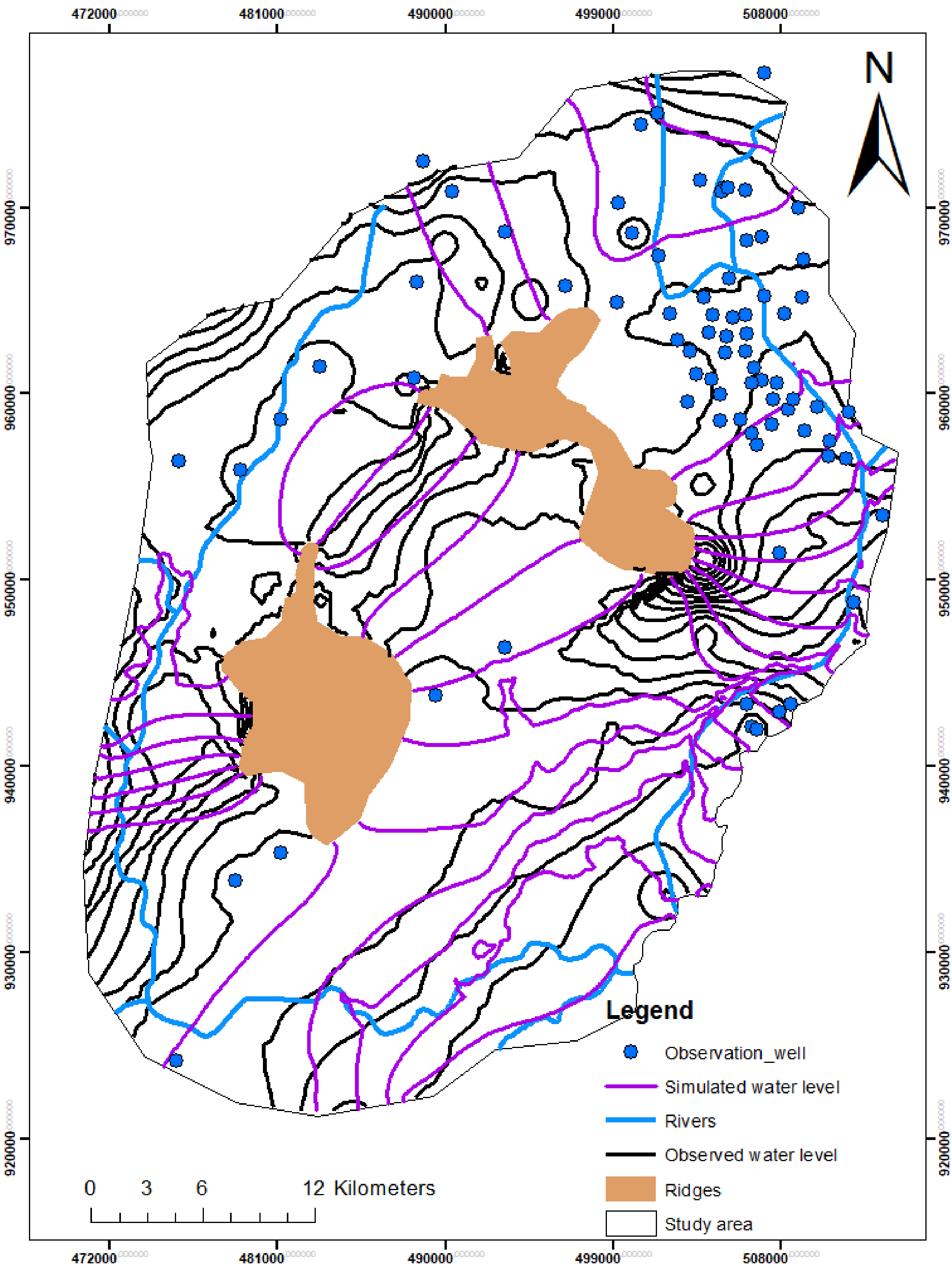


Figure 19: Comparison of simulated to measured water levels for the Ada'a Plain for the steady-state model.

5.3.4. Sensitivity Analysis

After the model was calibrated, a formal sensitivity analysis on the different parameters was performed to evaluate uncertainty in the calibrated model caused by uncertainty in the estimates of aquifer parameters and boundary conditions. It is observed that recharge, flux and horizontal hydraulic conductivity of the study area aquifer had the most effect on model results. Conductance for the river bed and general-head boundary were large enough that relative changes had little effect on water levels in the model.

During simulation when the effect of one parameter was being tested, the other parameters were kept to steady state calibrated value and each parameter was change by specified percent uniformly over the whole area. The magnitude of changes in heads or fluxes from the calibrated solution was used as a measure of the sensitivity of the model to the particular parameters. The calibrated value of recharge, flux and hydraulic conductivity were varied -50% to 50% to test the sensitivity of the model to the parameters. The result of simulation is given in table 6 and figure 20 below.

	Resulting change		
Parameter Varied in %	**Hydraulic Conductivity, m/day**	**Recharge, m/d**	**Flux, m/day**
50	11.9	8.33	10.05
25	8.46	7.44	9.21
0	6.98	6.98	6.98
-25	10.49	7.16	8.67
-50	19.12	8.00	14.8

Table 5: Result of sensitivity analysis of Ada'a plain aquifer

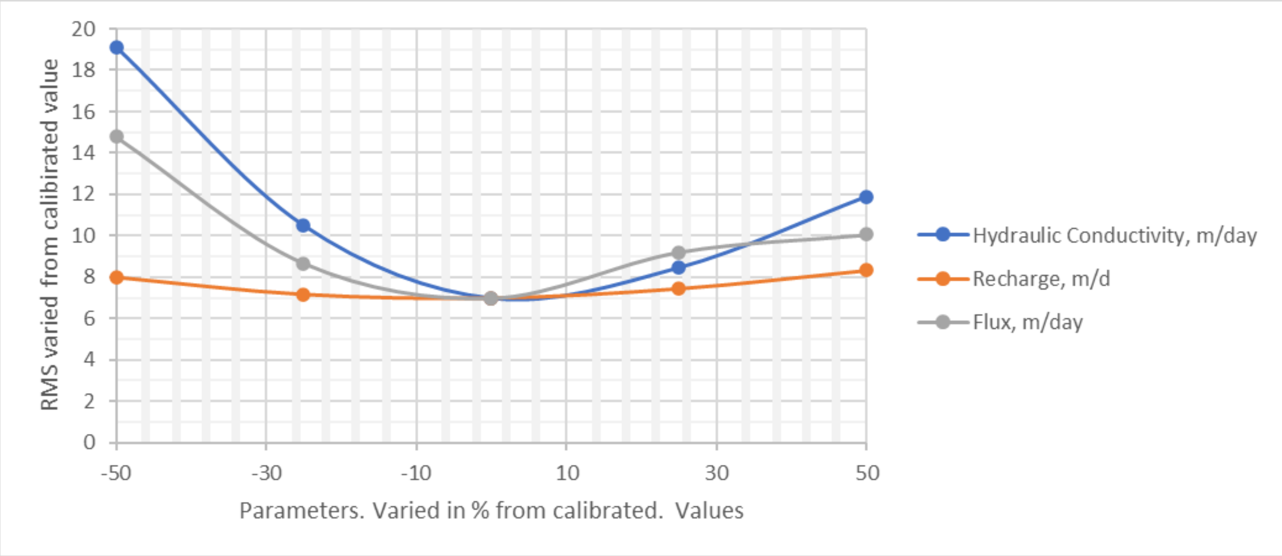


Figure 20: Sensitivity analysis result of the effect varying aquifer parameters

CHAPTER SIX

6. Result ad Discussion

6.1. SteadyState Groundwater flow budget

Visual modflow calculates a volumetric water budget for the entire model at the end of each time step. The water budget provides an indication of the overall acceptability of the numerical solution. Change in storage in water balance approach to zero assures calibration quality, for steady state models (Rushton, 2005). The out flow from and the inflow into the groundwater subbasin are nearly equal, with percent discrepancy 0.00%. The water balance error, assures good level of the model calibration (Table 5).

Item	Groundwater balance	
	Groundwater In (m3/day)	**Groundwater out (m3/day)**
STORAGE	-	-
CONSTANT HEAD	111,302.75	23,584.35
WELLS	-	-
RIVER LEAKAGE	169,631.16	684,084.44
HEAD DEP BOUNDS	-	1,351,088.13
RECHARGE	540,495.25	-
SPECIFIED FLOWS	1,237,320.00	-
Total	**2,058,749.16**	**2,058,756.91**
IN - OUT		**(7.75)**

Table-6: Calculated steady state Groundwater Balance

6.2. Scenario development

A successfully calibrated and verified simulation model can be used for formulating various different water development schemes. The systems can be compared in terms of their feasibility for efficient utilization of the available groundwater resources. It should be noted that the results of the scenarios or their accuracy depend on the validity of the assumptions behind the scenarios. Limitations associated with the model also affect the results of the scenarios and should be taken into considerations during interpretation and application of results.

Two scenarios were considered to predict the consequences of future development in the model area. A planning period of 20 years (2021–2041) was used for the two scenarios, related to development plans. The starting conditions in each scenario were those obtained from the steady state simulation a year of 2007. Estimation of abstraction rates for the planning period (2021–2041) was used in establishing reliable alternative schemes. Two scenarios, which might be realistic as an increase in pumping rate is directly proportional to the increase in population, agriculture and other developments, are as follows:

Scenario I: The first scenario assumes that the groundwater abstraction observed during 2021 continues without modification up to 2025, i.e., 74,929.6406m^3 day^{-1}, (from about 50 water supply wells and from four irrigation wells, and the irrigated area is nearly 264 hectares.

This Scenario assumes the 4 irrigation wells will be pumped for 6 months annual during dry season from January to July. The pumping rate are computed based on the assumption that all 4 irrigation wells and water supply wells pumped for 16 and 12 hours daily respectively based on the safe yield of each well. The model prediction was carried out by placing 69 observation wells at different part of the plain. The resulting model prediction of Scenario 1 showed the following

Item	Groundwater balance at 2021	
	In m3/day	Out m3/day
STORAGE	465,925.19	-
CONSTANT HEAD	63,844.04	34,564.15
WELLS	-	74,929.64
RIVER LEAKAGE	154,530.59	898,885.50
HEAD DEP BOUNDS	-	1,453,424.25
RECHARGE	540,133.56	-
SPECIFIED FLOWS	1,237,320.00	-
Total	**2,461,753.38**	**2,461,803.54**
IN - OUT		**(50.16)**

Table 7: Groundwater balance
at 2021 (4 irrigation and 50 water supply wells abstracting a total discharge of 74,929.6406 m^3 day^{-1})

Item	Groundwater balance at 2024	
	In m3/day	Out m3/day
STORAGE	412,552.06	-
CONSTANT HEAD	71,323.20	31,473.76
WELLS	-	74,929.64
RIVER LEAKAGE	156,495.86	868,365.75
HEAD DEP BOUNDS	-	1,443,116.13
RECHARGE	540,133.56	-
SPECIFIED FLOWS	1,237,320.00	-
Total	**2,417,824.69**	**2,417,885.28**
IN - OUT		**(60.59)**

Table 8: Groundwater balance
at 2024 (4 irrigation and 40 water supply wells abstracting a total discharge of 74,929.6406 m^3 day^{-1})

In the first year of simulation period, due to abstraction of 74,929.6406 m^3 day^{-1} groundwater head declined in the system, 465,925.13 m3 /day declined from groundwater reserve(storage) and in flow through river leakage increased by 154,530.39 m3 /day. Groundwater out flow to the next sub basin decreased by 895, 85m3 /day and 1,443,116.13 m3 /day through river leakage and head dependent boundaries respectively. At the end of simulation period of scenario, I 2024, with the same abstraction of 74,929.6406 m^3 day^{-1} about 412,552.06 m3 /day declined from groundwater reserve(storage) and in flow through constant head and river leakage increased by 71,323.20 m3 /day and 156,495.86 m3 /day respectively. Groundwater out flow to the next sub basin decreased by 868,365.75 m3 /day and 1,443,116.13 m3 /day through river leakage and head dependent boundaries respectively.

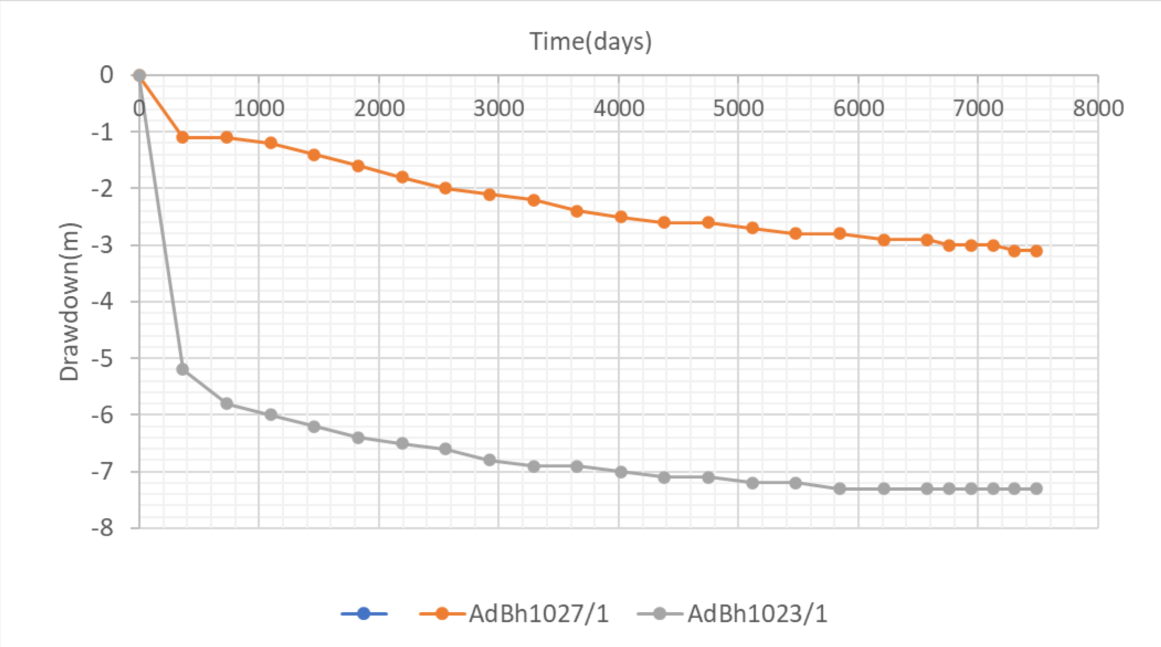


Figure 21: Groundwater level prediction graph of northern part of the plain

observed at Adbh1023/1 and Adbh1027/1 wells with 74,929.6406m^3 day^{-1}abstraction rate

Time of Abstraction(year)	Drawdown(m)		
	AdBh1023/1	AdBh1027/1	
1	-5.2	-1.1	
5	-6.4	-1.6	
10	-6.9	-2.4	
15	-7.2	-2.8	

Table 9: Drawdown observed at norther part of the plain
observed at Adbh1023/1 and Adbh1027/1 wells with 74,929.6406m^3 day^{-1}abstraction rate

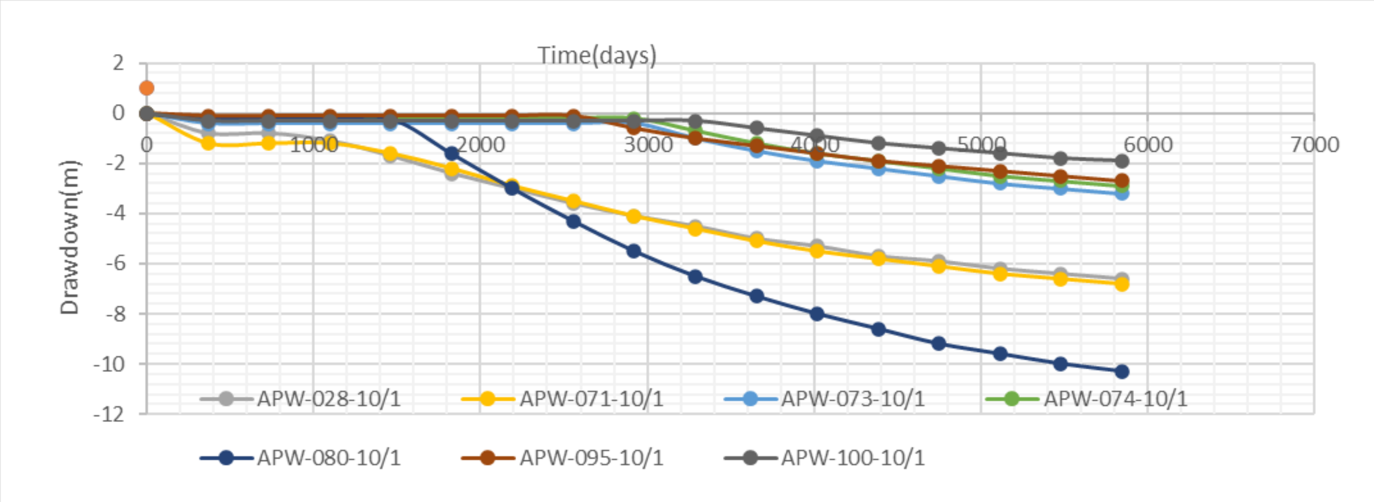


Figure 22: Groundwater level prediction graph at central and eastern part of the plain

observed at different wells with 74,929.6406m^3 day^{-1}abstraction rate

Time of Abstraction (year)	Drawdown(m)						
	APW-028-10	APW-071-10/1	APW-073-10/1	APW-074-10/1	APW-080-10/1	APW-095-10/1	APW-100-10/1
1	-0.8	-1.2	-0.4	-0.2	-0.2	-0.1	-0.3
5	-2.4	-2.2	-0.4	-0.2	-1.6	-0.1	-0.3
10	-5	-5.1	-1.5	-1.2	-7.3	-1.3	-0.6
15	-6.4	-6.6	-3	-2.7	-10	-2.5	-1.8

Table 10: Drawdown observed at central and eastern part of the plain
observed at different wells with 74,929.640 6m3 day-1abstraction rate

Scenario II: Abstractions are assumed to increase to 419,887.250 m3/day from those of Scenario I; about 10 irrigation wells pump house is under construction to increase cultivated areas to 585 hectares in the next five years and it is assumed the other about 55 irrigation wells will be operational. In this Scenario, effect of intensive abstraction rate due to increase in number of irrigations is analyzed. The simulation is carried out by considering 50 water supply wells and 65 irrigation wells, which implies an increase in groundwater pumping from 74,929.640 m^3 day in 2024 to 419,887.250 by the end of 2040.The pumping rate are computed based on the assumption that all irrigation wells and water supply wells will be pumped for 16 and 12 hours daily respectively. The resulting model prediction of Scenario II showed the following simulation results:

Item	Groundwater balance at 2025	
	In m3/day	Out m3/day
STORAGE	1,008,589.25	4,908.60
CONSTANT HEAD	35,913.20	67,069.75
WELLS	-	419,887.25
RIVER LEAKAGE	150,338.95	993,236.94
HEAD DEP BOUNDS	-	1,487,244.50
RECHARGE	540,133.56	-
SPECIFIED FLOWS	1,237,320.00	-
Total	**2,972,294.96**	**2,972,347.03**
IN - OUT		**(52.07)**

Table 11: Groundwater balance at 2025 (scenario II)
(65 irrigation and 50 water supply wells abstracting a total discharge of 419,887.25 m^3 day^{-1})

Item	Groundwater balance at 2040	
	In m3/day	Out m3/day
STORAGE	375,482.09	
CONSTANT HEAD	147,270.14	11,937.76
WELLS	-	419,887.25
RIVER LEAKAGE	176,767.67	658,774.81
HEAD DEP BOUNDS	-	1,386,424.13
RECHARGE	540,133.56	-
SPECIFIED FLOWS	1,237,320.00	-
Total	**2,476,973.47**	**2,477,023.95**
IN - OUT		**(50.48)**

Table 12: Groundwater balance at 2040 (scenario II)
(65 irrigation and 50 water supply wells abstracting a total discharge of 419,887.25 m^3 day^{-1})

The resulting model prediction of Scenario II showed maximum drawdown 20.4m at APW-080-10/1, 15.m at APW-071-10/1 and 14.3m at APW-028-10/1 at Eastern and North Eastern part of the plain where pumping wells are concentrated.

- The drawdown at north eastern part of plain is varying from 4.1m to 7.7m at end of 20-year pumping. The reasonable groundwater level decline is computed due to sparse distribution of boreholes in the north eastern part of the plain.

- In the first year of simulation period, due to increased well abstraction, the groundwater storage quantity declined by 1,008,589.25 m3 /day (48% of the recharge quantity). To maintain decline in ground water level in flow from constant head and river leakage increased by 33,5913.1953m3 /day and 150,338.95 m3 /day respectively and groundwater out flow to the next sub basin through river leakage and head dependent boundaries decreased by 868,365.75 m3 /day and 1,443,116.13 m3 /day respectively.

At the end of simulation period of this scenario, 2040, with the same abstraction rate of 419,887.25 m3 day-1 about 375,482.09 m^3 /day declined from groundwater reserve(storage) and in flow through constant head and river leakage increased by 147,270.14 m3 /day and 176,767.67 m3 /day respectively. Groundwater out flow to the next sub basin decreased by 658,774.81 m3 /day and 1,386,424.13 m^3 /day through river leakage and head dependent boundaries respectively. The groundwater budget indicated that the effect of abstraction amount is replenished particularly by specified flux, direct recharge and river leakage. And it is an important factor for the sustainability of the groundwater the plain; however, the intensive abstraction of aquifer decreases the groundwater out flow the next subbasin through base flow.

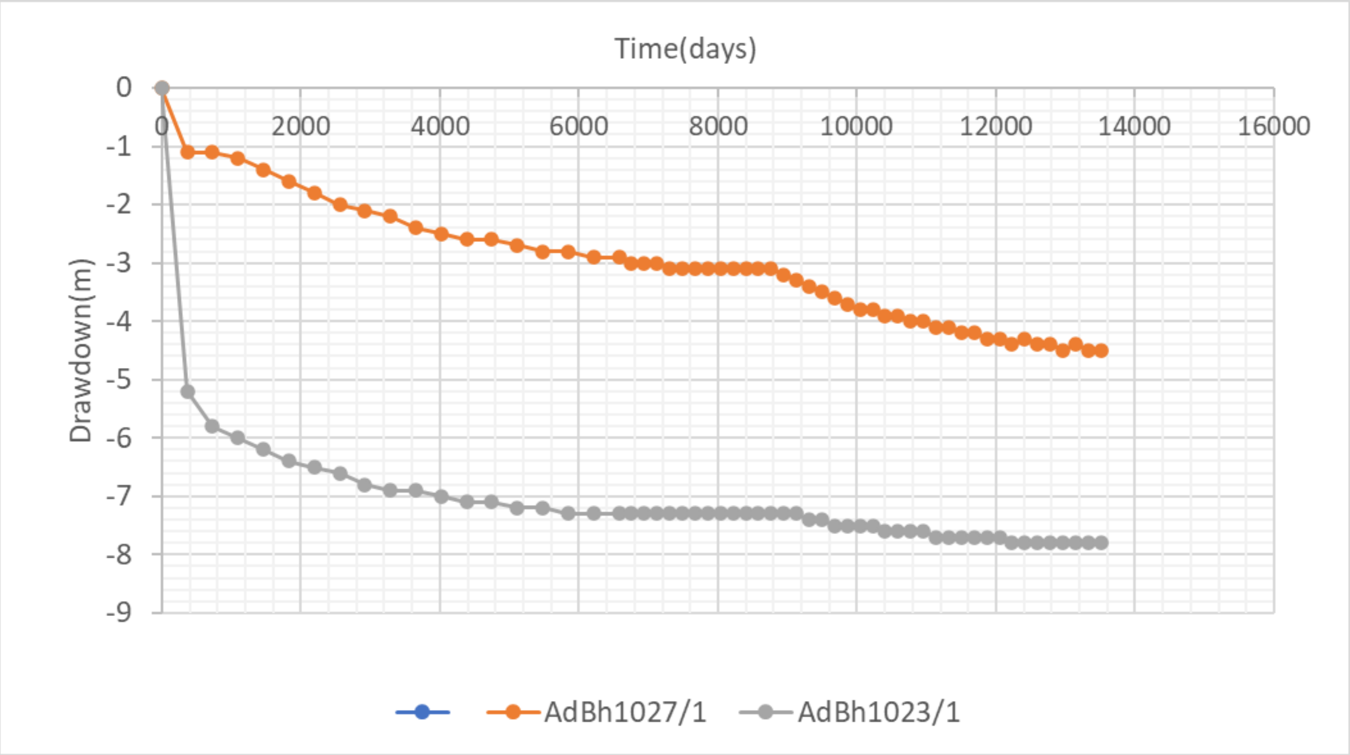


Figure 23: Groundwater level prediction graph of northern part of the plain (scenario II) observed at Adbh01027/1 and Adbh01023/1 wells with 419,887.25 m3 day-1 abstraction rate

Time of Abstraction(year)	Drawdown(m)	
	AdBh1023/1	AdBh1027/1
1	-7.3	-3.1
5	-7.3	-3.1
10	-7.4	-3.4
15	-7.5	-3.8
20	-7.7	-4.1

Table 14: Drawdown observed at northern part of the plain (scenario II) with 419,887.25 m^3 day^{-1} abstraction rate

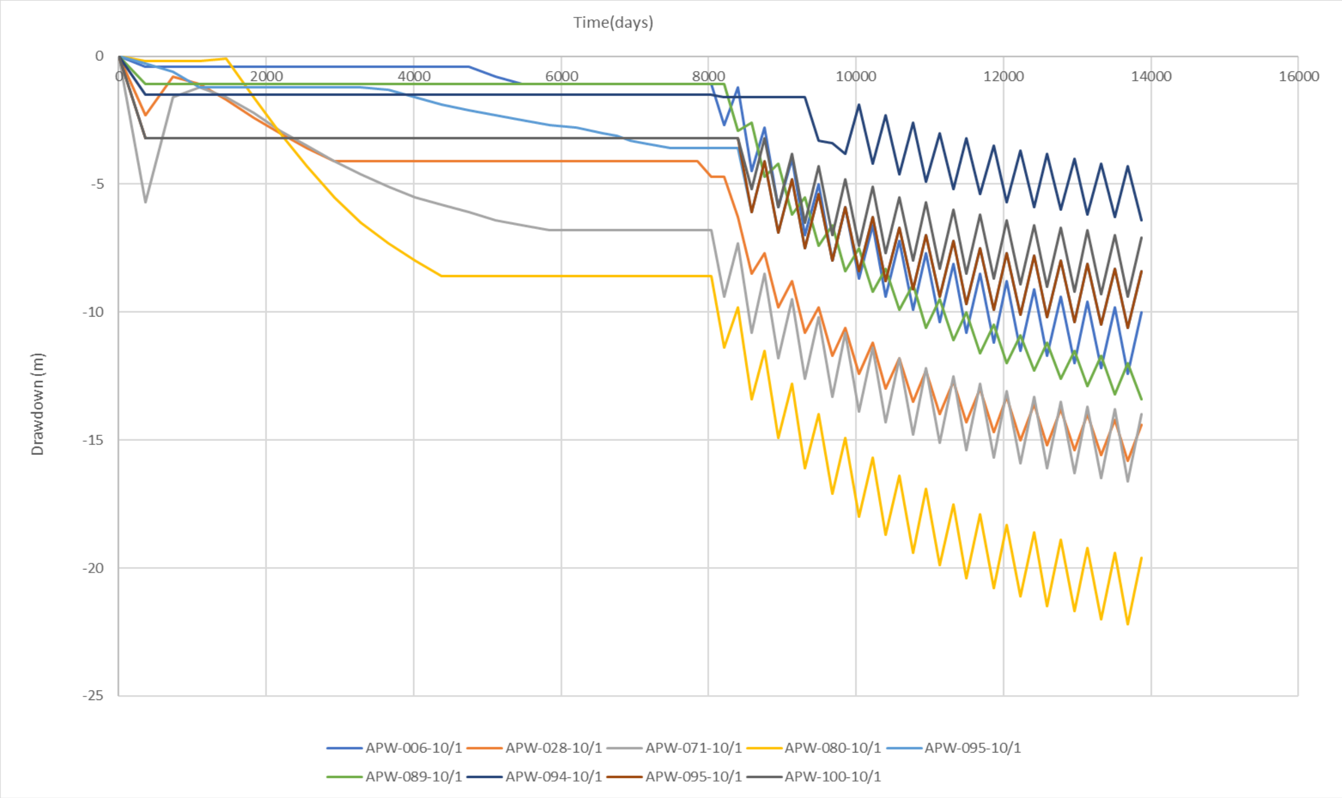


Figure 24: Groundwater level prediction graph at central and eastern part of the plain (scenario ll)

observed at different wells with 419,887.25 m3 day-1 abstraction rate

Time of Abstraction (year)	Drawdown(m)								
	APW-006-10	APW-028-10/1	APW-071-10/1	APW-080-10/1	APW-095-10/1	APW-089-10/1	APW-094-10/1	APW-095-10/1	APW-100-10/1
1	-1.1	-4.7	-6.8	-8.6	-3.6	-1.1	-1.5	-3.2	-3.2
5	-2.8	-7.7	-8.5	-11.5	-4.1	-4.7	-1.6	-4.1	-3.2
10	-8	-11.7	-13.3	-17.1	-8	-6.6	-3.4	-8	-7
15	-9.4	-13	-14.3	-18.7	-8.8	-8.3	-2.3	-8.8	-7.7
20	-10.8	-14.3	-15.4	-20.4	-9.7	-10	-3.2	-9.7	-8.5

Table 15: Drawdown observed at central and eastern part of the plain (scenario II) with 419,887.25 m^3 day^{-1} abstraction rate.

-

6.3. Limitation of the model

All numerical groundwater flow models have limitations. These limitations are usually associated with: the quality and quantity of input data, assumptions and simplifications used to develop the conceptual and numerical models, and the scale of application of the model.

Several of the input data sets for the model are based on limited information. Hydraulic properties of the study area were prepared based on limited data by using geostatistical application, recharge rates, both the amount and the areal distribution, are limited because they are prepared based on limited metrological station data and parameters. Therefore, there may be underestimating or overestimating recharge in years with different amounts. Current distribution of recharge is based on basins. Local attributes, such as soil type and topography, may control recharge at a smaller-than-basin scale. structure maps simplification may cause the model to not accurately represent structural control on local groundwater flow in these areas. Water-level maps are affected by limited data. Eastern part of the model has the relatively great number of measurements, but not many in the western, southern, south western and north-eastern parts of the model. Limited water-level measurements biases model calibration to areas where water levels have been measured. Several assumptions are used to simplify construction of the model.

CHAPTER SEVEN

6. Conclusion and Recommendation

6.2. Conclusion

The Ada'a plain aquifer in the upper Awash Basin is an important source of groundwater in the study area. Numerical groundwater modelling is a powerful tool for assessment, development and management of groundwater resources. A numerical groundwater model for the Ada'a plain in upper awash Basin was developed using visual MODFLOW software to simulate groundwater flow in the Ada'a plain aquifer under Steady State conditions that can be used to predict water levels in response to pumping and potential future development in the plain.

Conceptual model of groundwater was developed and model input parameter was assigned based on a review of previous work and studies conducted on water levels, recharge, and hydraulic properties in support of the model. All available measurements of water level, and hydraulic parameters were used for model calibration. The calibrated model does a reasonable job of matching the water-level distribution and water-level fluctuations in the aquifer (RMS error is 6.98m across the study area). Water levels in the model are most sensitive to changes in recharge and horizontal hydraulic conductivity the aquifer.

Two different groundwater abstraction scenarios were developed and assessed to test Ada'a plain aquifer under current and long-term pumping stress. In the first year of simulation period, due to abstraction of 74,929.6406 m3 day-1 groundwater head declined in the system, 465,925.13 m3 /day declined from groundwater reserve(storage) and in flow through river leakage increased by 154,530.39 m3 /day. Groundwater out flow to the next sub basin decreased by 895, 85m3 /day and 1,443,116.13 m3 /day through river leakage and head dependent boundaries respectively. At the end of simulation period of scenario, I 2024, with the same abstraction of 74,929.6406 m3 day-1 about 412,552.06 m3 /day declined from groundwater reserve(storage) and in flow through constant head and river leakage increased by 71,323.20 m3 /day and 156,495.86 m3 /day respectively. Scenario II, with a gradual increase of pumping for agricultural purposes over the next 15 years, in the first year of simulation period, due to increased well abstraction, the groundwater storage quantity declined by 1,008,589.25 m3 /day (48% of the recharge quantity). to maintain decline in ground water level from the aquifer system in flow from constant head and river leakage increased by 33,5913.1953m3 /day and 150,338.95 m3 /day respectively and groundwater out flow to the next sub basin through river leakage and head dependent boundaries decreased by 868,365.75 m3 /day and 1,443,116.13 m3 /day respectively.

At the end of simulation period of this scenario, 2040, with the same abstraction rate of 419,887.25 m3 day-1 about 375,482.09 m^3 /day declined from groundwater reserve(storage). In both scenarios, the groundwater budget indicated that the effect of abstraction amount is replenished particularly by specified flux, direct recharge and through river leakage. And it is an important factor for the sustainability of the groundwater of the plain; however, the intensive abstraction of aquifer decreases the groundwater out flow the next subbasin through base flow.

6.3. Recommendation

As groundwater development will always cause lowering of groundwater level and the current lowering of groundwater level of the Study area seems to be allowable as compared to groundwater recharge amount. Groundwater budget analysis of the plain is shown that the effect of groundwater abstraction amount is replenished particularly by specified flux, direct recharge and it is assumed to be an important factor for the sustainability of the groundwater flow the plain. However, further intensive abstraction of aquifer may increase instruction between aquifer and lake in the plain and as a result groundwater water quality will be affected and decreases the groundwater out flow to the next subbasin (rift valley) through base flow. Therefore, it is recommended that further studies on environmental hazard caused on next subbasin due to the intensive abstraction of aquifer of the plain would help to better define base level for a safe yield that maintains a balance between groundwater inflow and outflow in the study area with advancing groundwater development. It is also recommended to encourage modern irrigation techniques, which could easily lead to a major reduction in agricultural water use. Limitations of the input data, assumptions, and scale limit the accuracy and applicability of the model.

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Annexes

Annex.1. Borehole data

S/No.	Site name	X	Y	Z	Depth	SWL	Q(m3/day)	Hydraulic Conductivity (K), m/day	Transmissivity (T), m2/day
1	Koka	506728	937459	1669	129.66	53.27	345.6	4	158.11
2	Ziquala-Annate	481162	935226	1815	200	151.9	198.72	1.02	241.12
3	Shimbira Meda	500494	974376	1914	80.5	24.87	1442.88	3.07	2540.02
4	Ziquala-Abusera	475705	956271	1906	220	104.3	630.72	4.62	30.11
5	D/Z-Oxford	493179	968613	1919	108	74.37	172.8		22.22
6	Red Fox Flowers	503210	930527	1610	100	7.8	1900.8	5	348.89
7	APW-002-10	505259.64	971168.03	1895	350	22.94	4320	1.48	276.00
8	APW-003-10	506233	971047.86	1886	350	24.05	2073.6	0.33	64.60
9	APW-004-10	507937.21	943553.63	1884	462	71.87	3456	8.17	1100.00
10	APW-005-10	507647.10	958445.00	1855	400	25.77	998.784	2.48	250.55
11	APW-006-10	504396.30	960886.22	1872	364	18.25	4320	13.8	2700.00
12	APW-007-10	503567.33	961178.50	1879	361	22.6	7920.288	3.83	737.00
13	APW-008-10	509416.07	958136.25	1841	420	14.45	5011.2	34.2	4860.00
14	APW-009-10	503820.27	971559.77	1897	356	21.51	4665.6	0.41	85.30
15	APW-010-10	509416.07	958136.25	1801	351	27.26	5616	11.7	1220.00
16	APW-011-10	508750.68	943390.92	1884	455	77.5	3352.32	6.96	954.00
17	APW-012-10	511522.75	957561.00	1816	266	(+0.25m)	5369.76	44.2	4100.00
18	APW-014-10	509083.36	970103.08	1917	350	62.02	2769.984	8.95	1980.00
19	APW-017-10	505951.00	960688.00	1877	422	33.65	3888	3.65	473.00
20	APW-019-10	510098.11	957592.87		370	27.25	5011.2	8.94	2020.00
21	APW-020-10	508565.80	959257.16	1850	420	20.8	4326.912	6.37	825.00
22	APW-021-10	506775.33	961520.47	1841	365	20.75	5788.8	9.83	440.00
23	APW-022-10	508570.83	961349.75	1851	422	7.53	7776	5.28	1140.00
24	APW-023-10	507645.32	961277.19	1855	208	10.49	8640	6.52	537.00
25	APW-024-10	511693.69	959223.44	1842	420	10.42	9072	13.5	1640.00
26	APW-028-10	506298.70	968314.50	1880	366	13.67	4492.8	6.75	2930.00
27	APW-039-10	507427.12	976959.80	1877	366.87	14.07	3888	47.8	6120.00
28	APW-040-10	508514.60	967493.91		396	23.27	4579.2	0.68	100.00
29	APW-041-10	509360.02	967190.78	1841	420	36.37	4093.632	1.8	256.00
30	APW-045-10	491142.22	972025.62		420	33.2	3888	1.5	200.00
31	APW-046-10	505373.24	966303.90	1882	420	25.3	5356.8	2.46	225.00
32	APW-047-10	506265.69	966324.23		420	16.95	5011.2	5.21	771.00
33	APW-049-10	508224.33	966414.35		382	24.93	4579.2	5	562.00
34	APW-053-10	501604.30	968045.60		207	18.56	5356.8	14.1	8240.00
35	APW-054-10	497952.50	973072.55		420	27.66	2592	1.22	93.25
36	APW-056-10	505426.88	965286.85		360	30	4492.8	1.06	981.00
37	APW-058-10	507162.54	965376.81	1844	356	7.4	5529.6	8.98	6490.00
38	APW-059-10	508283.07	965463.29		358	23.24	4579.2	8.7	3970.00
39	APW-060-10	509303.80	965180.70	1856	350	16.5	5572.8	8.7	1130.00
40	APW-063-10	502182.36	964419.70	1873	343.81	15.25	7575.552	4.32	9610.00
41	APW-064-10	504470.02	964325.97	1880	456	26.13	5555.52	15.8	2150.00
42	APW-066-10	506257.59	964356.86	1820	414	14.97	3352.32	7.92	9830.00
43	APW-067-10	507270.41	964344.11		300	2.92	5184	9	994.00
44	APW-068-10	508259.45	964551.54	1841	420	12.3	5529.6	13.6	1960.00
45	APW-069-10	504789.51	959857.00	1863	340	17.9	7418.304	4.11	637.00
46	APW-071-10	508697.00	959616.00	1850	420	1.94	5529.6	2.31	635.00
47	APW-072-10	507721.42	959797.11	1882	430	9.11	4795.2	8.45	248.00

48	APW-073-10	502549.05	963000.91	1884	348.26	25.76	7097.76	5.61	6640.00
49	APW-074-10	504203.00	963366.00	1875	359.06	17.82	6337.44	9.71	2570.00
50	APW-075-10	505191.63	963154.10	1863	420	12	5927.04	19.3	6990.00
51	APW-076-10	506303.15	963318.52	1886	397.2	9.05	8899.2	9.39	1700.00
52	APW-079-10	504844.91	958680.62	1874	400	23.65	4924.8	1.37	388.00
53	APW-080-10	505948.61	958710.34	1874	360	19.2	6912	7.32	2410.00
54	APW-082-10	503318.61	962327.91	1884	364	27.05	6912	6.53	1210.00
55	APW-083-10	503318.61	962327.91		358	16	6912	7.4	860.00
56	APW-084-10	505077.00	962314.32	1872	354	23.65	3888	13.5	1520.00
57	APW-085-10	506200.53	962350.68	1880	340	24.81	7007.04	4.56	841.00
58	APW-086-10	507557.00	962302.00	1850	400	10.05	7603.2	6.99	1030.00
59	APW-088-10	503105.03	959685.02	1880	333	24.88	2207.52	1.02	246.00
60	APW-089-10	506575.14	957977.75	1861	366	16.9	1681.344	0.78	217.00
61	APW-090-10	511613.74	956641.51	1824	424	15	1933.632	6.15	781.00
62	APW-092-10	513677.00	953555.00	1801	420	28	4147.2	10.3	9610.00
63	APW-093-10	493128.00	943793.00		374	8.02	10074.24	6.5	3200.00
64	APW-094-10	510705.02	956674.64	1841	424	23.1	5011.2	36.2	8170.00
65	APW-095-10	510058.95	959387.49	1850	420	12.65	5011.2	13.2	1990.00
66	APW-096-10	507076.83	960831.00	1858	157	15.72	4924.8	34.5	2130.00
67	APW-098-10	506814.74	942064.74	1700	342.5	50.9	9417.6	3.34	1090.00
68	APW-099-10	508097.55	943036.63	1714	340	71.4	3888	13.2	1340.00
69	APW-100-10	510747.00	958191.00	1841	414	17	5702.4	20.2	1348.00
70	AMW-12B	490409.41	970989.91	1924	282	90.87	1123.2	1.02	62.10
71	AMW-21	507343.05	957381.65	1836	278	19.2	1442.88	5.4	710.00
72	AMW-22B	504972.00	970974.27	1879	300	20.45	3067.2	6.8	1770.00
73	AMW-25	506464.00	942018.43	1697	264	74.6	731.808	2	66.90
74	Dukem TWS-New	488798	972371	1965	132	30			
75	D/Z-Dire	488305	960746	1939	180	120.6			
76	Shimbira Meda	500494	974376	1914	80.5	24.87			
77	Gafat#10	507950	951364	1819	150	25.55			
78	Modjo#2	511976	948671	1786	80	35.34	1,105.92		
79	Shoki Ziquala M. Mision Si	483243	961360	1884	170	99.02			
80	D/Z-Cheleba	481178.00	958488	1870.00	140	58.32			
81	D/Z-Becheko	493185.00	946241	1707.00	67	35.92			
82	D/Z-Dombosco	496479	965700	1930	104	56.56			
83	D/Z-Airforce Next to main gate	499228	964796	1910	80	43.07			
84	AMW5	478990	955803	1830	86.4		345.6		
85	AdBh0101	474683	942441	1710	80	65			
86	AdBh0264	478740	933707	1785	155	116.8			
87	AdBh0019	475571.00	924071	1752.00	154	91.62	604.8		
88	AdBh0017	484764.00	920771	1690.00	165	90.20			
89	AdBh0147	502329	929321	1606	130	5.4	2160		
90	AdBh0032	489485	943724	1731	140	74.75			
91	AdBh1023	499320	970175	1890	68	18.9	518.4		
92	AdBh1027	500078	968505	1880	56	14.5	1330.56		
93	AdBh0029	503210	930527	1610	100	7.8	1900.8		
94	AdBh0263	481162.00	935226	1815.00	200	151.90	198.72		
95	ADTW1	507013	968324	1881			1598.4		
96	ADTW2	503928	965114	1883.2			2030.4		
97	ADTW3	507861	960487	1849.9			2592		
98	ADTW4	501420	974992.00	1904			2462.4		
99	AdBh0002	475705	956271	1906			315.36		
100	AdBh0055	493179	968613	1919			86.4		

Annex.2. land use parameter table

Code	LUSE_TYPE	RUNOFF_VEG	VEG_AREA	BARE_AREA	IMP_AREA	OPENW_AREA	ROOT_DEPTH	LAI	MIN_STOM	VEG_HEIGHT	nManing	LandFactor	AerodynResistance
1	city center build up	grass	0.2	0	0.8	0	0.3	2	100	0.12	0.03	0.667	212.0135336
2	build up	grass	0.5	0	0.5	0	0.3	2	100	0.12	0.04	0.5	212.0135336
3	industry	grass	0.4	0	0.6	0	0.3	2	100	0.12	0.035	0.571	212.0135336
4	infrastructure	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.04	0.5	212.0135336
5	sea harbour	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.045	0.444	212.0135336
6	airport	grass	0.2	0	0.8	0	0.3	2	100	0.12	0.03	0.667	212.0135336
7	excavation	bare soil	0	1	0	0	0.05	0	110	0.001	0.09	0.222	426.6675763
10	open build up	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.045	0.444	212.0135336
21	agriculture	crop	0	1	0	0	0.35	4	180	0.6	0.037	0.541	115.0131136
23	meadow	grass	1	0	0	0	0.3	2	100	0.2	0.07	0.286	177.4676321
27	maize and tuberous p	crop	0	1	0	0	0.4	4	180	1.5	0.05	0.4	76.02445568
28	wet meadow	grass	1	0	0	0	0.3	2	100	0.3	0.055	0.364	152.4954008
29	orchard	forest	0.8	0.2	0	0	0.8	6	150	3	0.05	0.4	54.69944736
31	deciduous forest	forest	0.2	0.8	0	0	2	5	250	18	0.1	0.2	27.19617047
32	coniferous forest	forest	1	0	0	0	2	6	500	15	0.1	0.2	28.63060022
33	mixed forest	forest	0.4	0.6	0	0	2	5	375	16	0.1	0.2	28.09756947
35	heather	grass	1	0	0	0	0.2	6	110	0.75	0.05	0.4	104.3903884
36	shrub	grass	0.3	0.7	0	0	0.6	6	110	2	0.05	0.4	66.32866791
37	beach/dune	bare soil	0.3	0.7	0	0	0.5	2	110	1	0.04	0.5	91.76072902
44	mud flat/salt marsh	open water	0.4	0.2	0	0.4	0.3	2	110	0.5	0.035	0.571	124.2208894
51	navigable river	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
52	lake	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
53	estuary	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
54	sea	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
55	unnavigable river	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
201	highway	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.025	0.8	212.0135336
202	district road	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.04	0.5	212.0135336
301	spruce	forest	1	0	0	0	2	12	320	13	0.4	0.05	29.91872197
302	pine	forest	1	0	0	0	2	6	550	15	0.4	0.05	28.63060022
303	beech	forest	1	0	0	0	2	6	320	20	0.4	0.05	26.4629516
304	birch	forest	1	0	0	0	2	5	320	16	0.4	0.05	28.09756947
305	oak	forest	1	0	0	0	2	4	150	17	0.4	0.05	27.62241558
306	poplar	forest	1	0	0	0	2	5	250	18	0.4	0.05	27.19617047
307	reference grass	grass	1	0	0	0	0.3	2	140	0.12	0.035	0.571	212.0135336

Annex. 3. Soil parameter table

Code	SOIL	FIELDCAPAC	WILTINGPNT	PAW	RESIDUALWC	A1	EVAPODEPTH	TENSIONHHT	P_FRAC_SUM	P_FRAC_WIN	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 sand	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. 4 Rainy Days Data

Code	Rainy Days	Code	Rainy Days	Code	Rainy Days	Code	Rainy Days	Code	Rainy Days
1	1	11	7	21	18	31	24	41	1
2	2	12	3	22	8	32	27	42	8
3	2	13	1	23	7	33	18	43	24
4	5	14	2	24	4	34	8	44	27
5	1	15	2	25	1	35	7	45	18
6	8	16	5	26	2	36	4	46	8
7	24	17	1	27	2	37	1	47	7
8	27	18	8	28	5	38	2	48	4
9	18	19	24	29	1	39	2		
10	8	20	27	30	8	40	5		

Annex. 5. Meteorology data

S/no.	Station name	X	Y	Z	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Rainfall
1	Akaki	476399	980257	2260	8.9	26.4	54.1	83.7	70.9	110.3	241.9	246.2	123.4	16.6	5.5	4.8	992.8
2	Alem Tena	489758	916152	1660	14.3	27.1	60.3	63.7	64.9	76.9	203.0	167.7	107.6	25.9	6.7	2.4	820.4
3	Chafe donsa	513450	991331	2460	7.5	22.8	44.3	58.2	62.9	95.0	224.5	251.5	108.0	16.7	6.2	4.5	902.0
4	Denrezeit	494408	965164	2100	2.2	10.6	22.2	21.2	15.8	51.2	183.1	175.4	36.5	4.9	19.2	5.3	547.5
5	Koka dam	516880	935980	1600	13.5	16.3	46.6	43.7	60.5	74.4	238.4	235.8	99.9	32.2	11.4	8.6	881.3
6	Modjo	511809	951014	1840	10.8	23.9	50.3	57.2	71.6	95.1	280.7	244.7	112.0	31.5	8.2	2.8	988.8
7	Zequala	483959	944219	3050	25.7	17.9	87.1	77.6	60.2	129.2	284.2	232.9	90.8	42.0	10.2	2.2	1059.9
	Average Rainfall (mm/month)				**11.83**	**20.71**	**52.13**	**57.90**	**58.11**	**90.32**	**236.53**	**222.01**	**96.88**	**24.25**	**9.62**	**4.37**	**884.68**

S/no.	Station name	X	Y	Z	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Temprature
1	Akaki	476399	980257	2260	17.3	18.5	20	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
2	Alem Tena	489758	916152	1660	17.6	18.6	20	20.5	20.6	20.1	18.8	18.6	18.7	18.4	17.5	16.7	18.8
3	Chafe donsa	513450	991331	2460	17.2	18.3	19.8	20.1	20.6	19.9	18.3	18.3	18.6	17.9	17.2	16.6	18.6
4	Denrezeit	494408	965164	2100	17.3	18.5	20	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
5	Dukem	489003	972742	2240	17.3	18.5	20	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
6	Koka dam	516880	935980	1600	17.7	18.6	20.1	20.5	20.7	20.3	19	18.8	19	18.4	17.5	16.9	19.0
7	Modjo	511809	951014	1840	17.8	18.9	20.5	10.9	21.1	20.5	19.1	18.9	19.1	18.7	17.8	17.1	18.4
8	Zequala	483959	944219	3050	17.3	18.1	20	20.3	20.5	19.7	18.3	18.2	18.5	18.1	17.3	16.7	18.6
	Average temprerature(°c)				17.4	18.5	20.1	19.2	20.6	20	18.6	18.4	18.7	18.2	17.4	16.8	18.6

S/no.	Station name	X	Y	Z	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual wind speed
1	Akaki	476399	980257	2260	4.1	4.3	4.4	3.9	4	3.9	3.6	3.1	2.7	4.3	4.6	4.5	3.95
2	Alem Tena	489758	916152	1660	4	4	4.2	3.7	3.7	4.1	3.7	3.2	2.7	3.9	4.3	4.2	3.81
3	Chafe donsa	513450	991331	2460	3.9	3.9	4.1	3.7	3.7	4.4	4	3.4	2.7	3.6	4	4	3.78
4	Denrezeit	494408	965164	2100	4	4	4.2	3.7	3.7	4.1	3.7	3.2	2.7	3.9	4.3	4.2	3.81
5	Dukem	489003	972742	2240	4	4.1	4.3	3.8	3.9	4	3.6	3.1	2.7	4.1	4.5	4.3	3.87
6	Koka dam	516880	935980	1600	4.1	4.1	4.2	3.9	3.8	4.3	3.9	3.5	3	3.9	4.3	4.1	3.93
7	Modjo	511809	951014	1840	4	4	4.1	3.7	3.6	4.3	4	3.4	2.8	3.7	4.1	4	3.81
8	Zequala	483959	944219	3050	4	4	4.2	3.7	3.7	4.1	3.7	3.2	2.7	3.9	4.3	4.2	3.81
	Average wind speed (m/s)				4.01	4.05	4.21	3.76	3.76	4.15	3.78	3.26	2.75	3.91	4.3	4.19	3.84

S/no.	Station name	X	Y	Z	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Potential evapotranspiration(PET)
1	Akaki	476399	980257	2260	107.3	106.7	129.2	123.3	125.3	114.5	102	101.6	101.3	117.8	111.3	104.5	112.07
2	Alem Tena	489758	916152	1660	107.2	106.7	128	123.4	124.7	117.4	105	104.2	101.1	116.1	110.4	103.2	112.28
3	Chafe donsa	513450	991331	2460	106.8	106	129.3	124.1	128	119.9	107	105.8	106	118.7	111.3	104	113.91
4	Denrezeit	494408	965164	2100	108.2	107.6	130.3	125	126.9	117.3	104	103.4	102.5	118.7	112.5	105	113.45
5	Dukem	489003	972742	2240	108.2	107.6	130.3	125	126.9	117.3	104	103.4	102.5	118.6	112.5	105	113.44
6	Koka dam	516880	935980	1600	107.3	105.9	126.8	122.8	123.9	117.7	105	104	101.3	115.1	109.7	102.5	111.83
7	Modjo	511809	951014	1840	107.5	105.9	128	122.6	124.6	114.8	101	101.5	101.5	116.8	110.6	103.9	111.56
8	Zequala	483959	944219	3050	108.2	107.6	130.3	125	126.9	117.3	10	103.4	102.5	118.6	112.5	105	105.61
	Average PET (mm/month)				107.59	106.75	129.03	123.90	125.90	117.03	92.25	103.41	102.34	117.55	111.35	104.14	111.77

S/no.	Station nam	X	Y	Z	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Sunshine
1	Akaki	476399	980257	2260	8.4	8.1	7.8	7.4	7.2	6.2	4.8	5.4	6	8	9.2	8.7	7.27
2	Alem Tena	489758	916152	1660	8.4	8.1	8	7.4	7.1	6.2	4.7	5.4	5.8	8.2	9.1	8.9	7.28
3	Chafe donsa	513450	991331	2460	8.2	8.2	7.8	7.4	7.3	6.7	5.4	5.7	6.2	8	9.1	8.6	7.38
4	Denrezeit	494408	965164	2100	8.4	8.3	7.9	7.5	7.3	6.8	5.4	5.6	6	8	9.1	8.6	7.41
5	Dukem	489003	972742	2240	8.4	8.3	7.9	7.5	7.3	6.8	5.4	5.6	6	8	9.1	8.6	7.41
6	Koka dam	516880	935980	1600	8.4	8.3	7.8	7.5	7.3	7	5.6	5.8	5.9	7.9	8.9	8.5	7.41
7	Modjo	511809	951014	1840	8.3	8.2	7.8	7.4	7.2	6.7	5.2	5.5	6	7.9	9	8.6	7.32
8	Zequala	483959	944219	3050	8.4	8.3	7.9	7.5	7.3	6.8	5.4	5.6	6	8	9.1	8.6	7.41
	Aversge Sunshine(hour)				8.36	8.23	7.86	7.45	7.25	6.65	5.24	5.58	5.99	8	9.08	8.64	7.36