GROUNDWATER LEVEL CHARACTERIZATION OF GEMETO WELL FIELD IN HAWASSA LAKE CATCHMENT

MSc THESIS

TESSEMA BUDE TIRAGO

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

MARCH, 2019

GROUNDWATER LEVEL CHARACTERIZATION OF GEMETO WELL FIELD IN HAWASSA LAKE CATCHMENT

TESSEMA BUDE TIRAGO

A THESIS SUBMITTED TO

FACULTY OF CIVEL AND BUILT ENVIROMENT,

DEPARTMENT OF CIVEL ENGINEERING

HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE

DEGREE OF

MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

(SPECIALIZATION: HYDRAULIC ENGINEERING)

MARCH, 2019

SCHOOL OF CIVIL ENGINEERING

HAWASSA UNIVERSITY

ADVISORS' APPROVAL

This is to certify that the thesis entitled "**GroundWater Level characterization of Gemeto well field in Hawassa Lake catchment"** as MSc thesis in Hydraulic Engineering submitted to School of **CIVIL ENGINEERING** and has been carried out by **TESSEMA BUDE** Id. No **PGHY 038/08** under my supervision. Therefore I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Mihret Denanto (PhD)	----------------	------------
Major Advisor	signature	Date
Ayalew Shura (MSc.)	-------------------	-----------
Co Advisor	signature	Date

ACKNOWLEDGEMENTS

First and foremost, I like to thank the Almighty of God for everything He did in my life before anything, glory and thanks be to God who gives me full health, peace, knowledge and Wisdom to accomplish this thesis work and He is still in my side throughout my life. The Secret of my success is Jesus Christ. It the Lord!! My deepest feeling of gratitude goes to my advisor Dr. Mihret Denanto, for his worthless Advice and constant encouragement helped me to complete this research work successfully. I extend my thanks for Co Advisor Ayalew Shura, and for helping me groundwater model modflow for his worthless Advice, and continuous encouragement helped me to complete this research work successfully. All of them helped me in providing valuable information and reading materials.

I would like to tank Ethiopian road authority (ERA) for sponsoring this maters program my special and sincere appreciation to my and all Hawassa University civil Department instructors who support in the Knowledge of Science. I gratefully acknowledge all organizations and individuals who directly or indirectly supported me in my study.

I am thankful to Hadiya Zone mesraq badawacho woreda Water resource and irrigation Development office, for allowing me to pursue my postgraduate studies. I am also grateful to Hawassa town water supply and sanitary Enterprise, Regional Meteorological Service, and Water Works Design Enterprise (WWDE) for providing me, well data, and relevant documents, which helped me to carry out my research work. I owe my great respect and love to Markos Mathewos who have been in my side encouragement and his appreciation and his advice. Kindness to support me from the very begging and your good wish to see my upgrade, here is the fruit.

I am very grateful to my beloved wife Bekelech and my children Mihret and solommon for their patience and encouragement while I am too far from them. I have the pleasure to thank all my lovely friends, relatives, and supporters who have been in my side encouragement and prayer which made this true.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

BOWRD	Bureau of Water Resources Development
DEM	Digital Elevation Model
EARS	East African Rift system
EC	Electrical Conductivity
EPM	Equivalent Porous Medium
ERS	Ethiopian Rift system
FDM	Finite Difference Method
FEM	Finite Element Method
GIRD	Generation Integrated Rural Development
GIS	Geographical Information System
GPS	Global Positioning System
HTWSSE	Hawassa Town Water Supply & Sanitation Enterprise
ITCZ	Inter-Tropical Convergence Zone
GSE	Geological Survey Of Ethiopia
MOWR	Ministry of Water Resources
NMSA	National Meteorological Service Agency
REV	Representative Equivalent Volume
RVLB	Rift Valley Lakes Basin
SAR	Sodium Absorption Ratio
SNNPR	Southern Nations, Nationalities and Peoples‘ Regional Stat
SWWCE	South Water Works Constriction Enterprise
USGS	United States Geological Survey

WEAP	Water Evaluation & Planning System
WHO	World Health Organization
WRSS	Water Resource System Simulation
WWDSE	Water Works Design and Supervision Enterprise

DECLARATION

I declare that this thesis is my original work and that all source of materials used for thesis have been duly acknowledged.

Name: Tessema Bude Tirago

Signature______________

Place Hawassa University

ABSTRACT

Lake Hawassa catchment is located in the central Ethiopian rift valley. The area of the study is estimated to be 415km^2.The study was intended to obtain a better understanding of the groundwater level characterization the small groundwater basin within the larger Hawassa Lake basin by applying numerical flow modeling with flow system conceptual viewpoint. In order to simplify the computation and for the purpose of analysis, the basin was modeled using two conceptual hydrogeological models. The study was set better approach for the defining of the two conceptual models which was transferred to the numerical model that has capability to imitate the field data with relatively good accuracy. This conceptual model's simulated heads contour map shows that the general hydraulic gradient in the basin pursues the surface topography and the gradient is towards Lake Hawassa. The simulated hydraulic conductivity value varies in the category from 3x10^{-5}m/s to 85x10^{-5} m/s as we go to the lake from Gemeto well field with in the model domain. From the simulated pumping rate scenario the aquifer under study responded as per the calibration using the measured data, and 1hour per day and 300 day per year of pumping it was used in the model, the 1st scenario started with 749.5 l/s and 1.3 times current pumping rate for the second, 1.4 times current pumping for the 3rd, 1.5 times current pumping rate for the 4th 1.8 times current pumping rate for the 5th finally doubled for the final scenario with 1499 l/s pumping rate for the capture zone. From the 6th scenario pumping rate the amount of water abstracted from the aquifer at 1499 l/s pumping rate is 5396.4m^3/day or 1618920m^3/year. From the above point of view and the potable water scarcity of Hawassa town and villages with in Lake Hawassa catchment the Gemeto well field Aquifer will provide Sufficient Potable water if protected from pollution. Thus, the model should be applied with caution for detail groundwater management use. The results should be interpreted and used considering all the limitations and drawbacks related to the input parameters. To improve the calibration values, groundwater level and abstraction rates should be monitored at a set of monitoring wells that are properly distributed in the area. In order to minimize measuring error, the observation wells have to be fitted with automatic water level measuring device. Once an improved steady-state model is developed and the necessary data are obtained, a transient model for the pumping scenario should be made for better predictions of pumping effect and for better recharge simulation, as recharge and groundwater outflow are strongly time dependent. However, for a better accuracy it needs further investigation as it has impact on the model simulation. For further groundwater resource development plans in Gemeto well field, it is important to take into account the balance between the groundwater recharge and the intended abstraction rates for domestic water supply to ensure the sustainability of the resource in the basin.

1. INTRODUCTION

1.1.Background

Every living things found in the universe needs water for its existence. water is the most essential of man‘s requirements for life. The amount of water necessity to society has increased day to day due to population increment and urbanization expansion. Today, conflicting interest on water issues appear frequently. There is enough fresh water to supply all the people on the earth, but the problem rise as both people and fresh water is unevenly distributed over the world. The way to water resources is of main importance for a broad spectrum of human activities, and a careful management of the water resources is of great concern to society and the environment. It is of main importance that investigation and management of the water supply goal to maximize the utilization of a common resource. Groundwater is defined as all the water contained in spaces within bedrock and regolith (Simmer, 1988).

A large urban population with a high demand for water would only be able to exploit ground water if the aquifer, typically the hydrogeology has favorable storage and transmission properties provided that the chemical composition of the water is within the acceptable range, since the quality of water is as important as its availability.

In our country rain is the purest form of water which undergo many complex chemical changes after coming in to contact with soil and other rock materials. Thus the geology of an aquifer has major influence on water quality. The occurrence and movement of ground water depends on the geohydrological characteristics of the subsurface formation, these natural formations vary greatly in their lithology, texture and structure which influence their hydrological characteristics (Seifu et al., 2007).

In our rift system the hydrogeology is the main influencing factor on the quality of the highly potential ground water resource and such a resource is limited to be used for irrigation and industrial purposes. From the point of view of water quality, the chemical composition of water is important as certain chemicals constituents become toxic beyond a particular concentration although they may be beneficial in lower amount (Seifu, 2014).

The water quality reflects the composition of the aquifers through which they pass. Gizaw (1996) suggests that the possible sources of fluoride include chemical weathering, magmatic emissions, atmospheric dust from continental sources and industrial pollution. Of these it is considered that chemical weathering of the volcanic strata is the most likely source. Shallower groundwater sources nearer to the point of recharge tend to be less susceptible to high fluoride concentration and they have a shorter residence time within the strata so there is a lesser chance for chemical reaction.

This concentration of high fluoride is a major issue for water supply in RVLB as well as in Hawassa Lake Sub Basin it has a significant negative impact on health. Fluoride in waters at a concentration of 3 mg/l will cause mild fluorosis (mottling of teeth). Higher fluoride levels in drinking waters cause both dental and skeletal fluorosis resulting serious public health problems. It is one of the most influencing chemical on water quality which is beneficial when present in small concentration (0.8-1.0mg/l) in drinking water for calcification of dental enamel but it causes dental and skeletal fluorosis if present in higher amount and also linked with cancer Simmers et al.(1997) and its permissibility depend on temperature.

The Rift Valley Lakes Basin (RVLB) which is part of the Main Ethiopian Rift (MER) covers 53,000 km^2 contains Hawassa lake sub basin on which this study concerned. As the result of this scarcity most of public facilities, hotels, government offices, factories and industries, etc. located within the city obliged to search for an alternate source of water that is to be the ground water.

1.2. Problem Statement

Hawassa city, is the capital of the SNNPRS, one of the fast growing towns of the country, is located at the center of the sub basin, has fast growing population, urbanizing, developing and tourist attracting town with international standard hotels, industries and factories. At present, the city is found under serious water supply problem due to the existing system is unable to satisfy the ever increasing water demand. As the result of this scarcity most of public facilities, hotels, government offices, factories and industries, etc., located within the city obliged to search for an alternate source of water that is to be the ground water which is plenty in quantity but poor in quality.

The occurrence of groundwater is mainly influenced by the geology, geomorphology, tectonics and climate of the site. The variability of these factors strongly influences the quantity and quality of the ground water. Therefore the goal of this thesis was to identify the extent of the Gemeto well filed aquifer that actually contributes to the water supply and the effect of pumping from this site on the water quantity of the well field.

1.3. Objectives

1.3.1. General objective

The primary objective of this study is groundwater level characterization of Gemeto well field in Hawassa Lake catchment.

1.3.2. Specific objective

The specific objectives of the research are:

1. To model Groundwater flow direction.
2. To determine aquifer characteristics of well field area.
3. To determine the effect of different water abstraction rate on groundwater table so as to establish optimum pumping rate from the Gemeto well field.

1.4. Research Questions

The current study shall address the following research questions.

1. Could the model show the groundwater flow direction of the area?

2. What are the aquifer characteristics of Gemeto well field site?

3. What is the optimum discharge capacity of Gemeto well field?

1.5 Scope of the Study

This research work will be conducted only in Gemeto well field, Hawassa watershed, SNNPR, Ethiopia. Studying some specific area in the sub-basin is great importance thorough investigation of specific bore holes in sampled wells in the study area.

1.6. Importance of the Study

The significance of assessment of groundwater level characterization has been highlighted by many researchers for planning and sustainable management of water Resources development in many part of the world. The goal of this thesis is mainly to locate, quantify and assess the groundwater level of the potable water bearing part of the groundwater (Gemeto Well Field) based on the hypothesis and the data collected on the local geology of the Hawassa city and the area under study thereby its output will provide management tools for sustainable utilization and better management in planning multipurpose projects for the ever growing Hawassa city.

2. LITRATURE REVIEW

Without water clean and sanitary environment can not seen. All living things use water for life. Facts about the Ethiopia water Resources potential indicate that the annual surface runoff from the nine river basins amounts to 122 billion cubic meters. From the largest three river basins (Abbay- Baro-Akobo and Omo-Gibe) contribute 76 percent of the total runoff from a catchment area contains only 32 percent of the total area of the country (MoWR, 2002).The groundwater potential is estimated to be 38 billions of cubic meters.

The country per capita fresh water resources is about 1,140m^{3}and of course it has the largest surface freshwater resources in sub-Sahara Africa (MoWR, 2002). The occurrence of groundwater is mainly influenced by the geology, geomorphology, tectonics and climate of the country. The variability of these factors in Ethiopia strongly influences the quantity and quality of the groundwater in different parts of the country.

The geology of the country provides usable groundwater and provides good transmission of rainfall to recharge aquifers, which produce springs and feed perennial rivers. Having all these resources Ethiopia is considered to be the water tower of Africa, however studies and assessments at different level indicate that the level of services is very low due to many reasons. The above condition is well known within the Ethiopian Rift Systems. Amongst most chemical compositions of the groundwater samples identified, the fluoride concentration of such aquifers was found exceeded from the Ethiopian and WHO standards.

Due to this high concentration of fluoride, this plenty resource couldn‘t be tapped for drinking purpose rather than for sanitary, irrigation, and industrial purposes. This is what happened and happening to Hawassa Lake Catchment groundwater resource till present times the difficulty of obtaining productive aquifers is peculiar feature of Ethiopia, which is characterized by wide heterogeneity of geology, topography, and environmental condition. In Ethiopia, there are a number of lithological units of varying age and composition including metamorphic, sedimentary and igneous rocks. In many parts of the country, groundwater is an important source of potable water. This is especially true for rural areas as well as for towns. However, the occurrence of groundwater is not uniform because it depends on various environmental and geological factors (Fetter, 1994). It may, therefore, be observed that this complete heterogeneity acts as a limiting factor for whatever hydrogeological research or exploitation program is to be carried out. Complete understanding of the limiting factors is very important for resource saving in a country, which is periodically affected by severe drought and famine. In areas where groundwater is not tapped, population depends on the rainfall, storing it in small local surface reservoirs. The stored water, however, does not last through the dry season, especially in the areas with an arid climate. Despite the importance of the enormous water resources in the development process, only very limited regional hydrogeological and river valley hydrological master plan studies have been carried out in the last few decades by the Ministry of Water Resources. However, very few detailed hydrogeological studies have been done locally in the rift valley and in some local main urban centers. The only main comprehensive source of information on groundwater resources is the Hydrogeological Map of Ethiopia at the scale of 1:2,000,000, compiled by (Chernet, 1988).

Rapid population growth, urbanization and increased demand of water in domestic, public, municipal and industrial production have led to fresh water shortage in many parts of Ethiopia and to an increasing dependence on groundwater resource. The dependency become more aggravated as urbanization, civilization, industrialization and development advances.

While discussing about groundwater, the scarcity of the potable water could be derived not only from the insufficiency of the water resource through the hydrologic and hydro geologic process but, it is also derived from the hydrogeology or the geochemistry of the aquifer contained within the given catchment or water shade. Even though there was exist plenty of water with in the aquifer, the chemical composition or the hydro geochemistry of the aquifer couldn‘t permit to use the water for drinking purposes. The water balance of Lake Hawassa has been of wider interest for years; initially because of scientific curiosity about the causes of the lake level rise but lately for its influence on the infrastructural damage of the fast growing Hawassa City located right at the eastern shore as a result of flooding. During extreme wet seasons part of the town is flooded. There has always been urgency of protecting the town from flooding. In recent years the issue of the water balance is drawing more attention to utilize the water resources of the area in sustainable manner. The surface water components may be quantified from limited hydro meteorological records. However; among the water balance components of lacustrine systems, groundwater is the most difficult to quantify. As a result, many hydrological studies of Lake Watershed systems have given little emphasis to groundwater (Jacob, 1979). Limited groundwater modeling exercise in the Ethiopian rift revealed that groundwater is one of the major components of the water balance of many Ethiopian lakes (Ayenew, 1998 and 2001).

2.1. Lake Hawassa Basin

2 .1.1 Topography

The intended study area consists of two major sub basins, namely Hawassa Lake sub basin and Chelekleka swamp, includes lake water body and the water shade of the catchment. These sub basins are important to the assessment of Lake Water to groundwater interaction.

The Lake catchment and Lake which is situated of combination of topographic such as ridges, plateau, swamps, depressions, undulating, rolling and dissecting plains. According to the study conducted by GSE the elevation of Lake Hawassa (1680m), Ziway (1636m), Langano (1585m), Abiyata (1578m), Shalla (1550m) and Abaya and Chamo (1180m) suggest that there is a ground water flow from Lake Hawassa basin to lower laying average top surface area level of Lake Hawassa is estimated to 96km^2 (Seifu, 2014).Area of Chelekleka swamp in 1972 was 12km2 and in 2005 it is about 3km2 almost changed to swampy area (WWDSE, 2001). According to 1:1000 scale maps surface area of the catchment was 1440km^2 from which Lake Hawassa covers only 7% of the total catchment. The major surface water resource draining toward the Lake, Tikur Wuha River has drainage area of 625km^2.

2.1.2 Climate

The climate of the area is dry to sub- humid climate according to the Thorns Waite‘s system of defining climate or moisture regions classified as temperate. The rain fall regime of the lake basin is described by one as per local climate classification with mean annual temperature of about 19.5^{0}c and attitude rang 1683m 2963m m.a.s. The area is predominately categorized as Weyna Degas zone and rainy season that the rainy months are contiguously distributed and the rain pattern is uni-modal type with only one dry season. The rainfall is well distributed throughout rainy season (rain fall co-efficient are in the range of 1-0.998 during eight months period and said to be moderate concentration) (Yemane, 2004).There are seven rainfall station near by the Hawassa Lake catchment of which five but two (Aje and Shashemene stations) are within the catchment..The moisture for precipitation originates from southwest equatorial air stream, which moves north wards with inter tropical convergence zone (WWDSE, 2001).The spatial and temporal variation of rainfall is strongly dominated by inter annual movement or position of inter tropical convergence zone (ITCZ). ITCZ represents a lower pressure area of convergence between Tropic Easterlies and Equatorial Westerly's along which wave disturbance takes place.

2.1.3. Geology, hydrogeology and hydro geochemistry

The study area is the central part of in the Ethiopia main rift valley system. The Ethiopia main Rift Valley Lake has many things in common with regard the geological and hydrological settings; one of the remarkable similarities is the existence of a series of Lakes filling volcano technical depression separated by volcanic hills in the floor of the rift (Ayenew and Robert, 2007).

The major inputs to Lake Hawassa comes mainly from eastern high land rainfall generating perennial and seasonal flows in the form of rivers, springs, and surface run off. Ground recharged by direct rainfall also has a great contribution to the Lake Hawassa characteristics. Lake Hawassa is highly variable in its geomorphic and morphometric settings (Ayenew, 2004; Tadesse and Zenaw, 2003), studied Hydrogeology and engineering geology of Hawassa Lake catchment. The study result of hydro geological water quality and isotope techniques show that Hawassa Lake water is mainly surface water and contribution of groundwater is insignificant that 3.2 Mm^{3}/year or less than 100 l/s. Lake Hawassa, being used for various purposes progressively, is contributing an agent role in the lives of thousands of people living the Lake basin. The Lake basin is becoming very significant area for activities of flower farming for the development of horticultural production, tourism industries and other human activities. it is in fussed around the Lake coastal area since there mentioned activities are expected to proceed in alarming way as wells the Lake, groundwater, springs and rives is proceeding without the understanding of the complex nature of the Lake basin hydrogeology and geologic system, this study tried to create water and catchment groundwater system (Ayenew and Robert, 2007). Long period records of lake, hand dug wells, bore(deep) wells, hydro meteorological data springs and river flow data used in the understanding of the interconnection characteristics of the ground water and lake water linkage.

For this reason, it is possible of the lake catchment with particular reference to the movement and occurrence of groundwater and its relation to subsurface interaction of Lake Hawassa, accordingly to the above reasons establishing the lake basin water sources management plan without the understanding of groundwater interaction behavior to the lake will be resulted in missed water use practice.

2.1.3.1. Geology

The Hawassa lake basin lies in the Main Ethiopia Rift (MER). The main Ethiopian rift is divided based on structural features in to three geographic areas and represented by the northern (Fentale, Nazareth) Central (Nazareth – Hawassa) and southern (Hawassa – Konso) sectors. The central sector where the Hawassa lake basin belongs is a symmetric rift basin where both sides the rift margins are fully defined except in the region between Guraghe and Soda regions of the western escarpment and in the Shashemene area of the eastern margin Geological survey of Ethiopia (GSE, 2000). The closed basin of nested Hawassa – Corbett caldera complex is a giant elliptical depression 30 to 40 km/s wide.

There are a number of rift system faults with north and north east trend along with the length of Lake Hawassa is oriented. These faults are expansion (normal fault) forming step faults. They are mainly dominant to the south and south western of the Lake. The volcanic collapse structure (caldera) forms nearly circular around Lake Hawassa basin. This collapse shifts some of the Central MER faults systems showing that the collapse has taken place subsequent to the rifting. In the Hawassa caldera a line of young fault affect the rift floor. These faults, the Wonji fault shattered the rift floor into several relatively small horst /up lifted part of land/ and graven /elongated depressed part of land between two faults i.e. rift floor/. Lake or swamps occupied the more depressed areas. Recent lacustrine and alluvium deposit scoria cones, Rhyolites' lava flows and associated ignimbrite tuffs and volcanic ash form the Hawassa lake basin (Tadesse and Zenaw, 2003).

According to study of lake pollution by AG consulting (2007) the geology of Lake Hawassa basin is summarized in the following ways:

Basalt and ignimbrite of the plateau trap series (late Miocene):- The most ancient rocks exposed in the area. The rocks are exposed locally near the base of the eastern caldera wall. These rocks consist of fine grained meteorite overlain by 30 to 50 m thick welded tuff dominated by collapsed pumice clasts and feldspar.

Old alkaline and per alkaline silicic rock (late Pliocene – early Pleistocene):- This unit includes the rift pyroclastic and old Rhyolites lava flows that are widely distributed in the basin. Rock of this group is exposed on the eastern side of the Caldara wall in the area where the cold springs are located. They consist of welded tuff, pumices deposits, surge deposits and the hyalite ridges at Wondogent.

Record Basaltic lava flow, basaltic hyaloclastite and scoria cones (Pleistocene to recent):- This unit is represented by small monogenic cones, which are sprinkled forming the only relied in the floor of caldera. The scoria is found mainly associated with scoracious basalt flows.

Recent acidic volcanic (Pleistocene to recent):- These rocks are distributed dominantly around the corbetti caldera north of Lake Hawassa most of them consists of pyroclastic, such as unwedded pumice flows, pumice falls, ashes and Rhyolites with associated obsidian flows. The pyroclastic deposits overlying the Pliocene deposits on the eastern and western caldera wall are included in this unit. Volcano – lacustrine deposits (Pleistocene to recent):- They cover mainly the floor of the caldera towards Lake Hawassa.

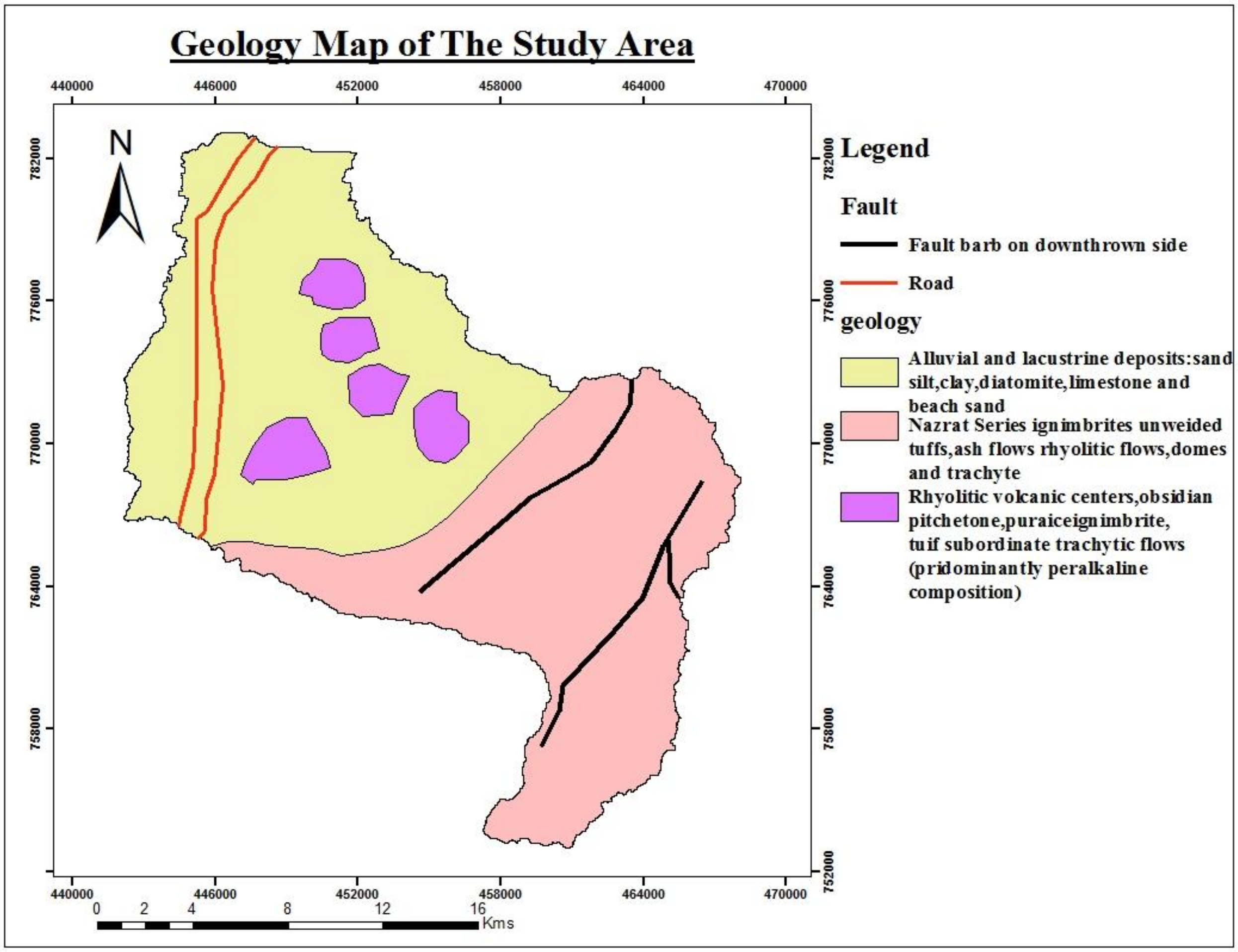

Figure 1: Geological map of the study area from Ethiopian Geological map.

2.1.3.2. Hydrogeology

Jointed ignimbrites and Fractured and the overlying volcano – lacustrine are the two major aquifers in the region. The underling, down faulted tertiary ignimbrites, if not buried too deeply, will probably incorporated the most extensive aquifer in the MER. Volcano lacustrine sediments are composed aquifers of sands, tuff, and pumice inter layered with clay aquitard. Ignimbrites are also the major water bearing formation of the geothermal fluid in the region. The lacustrine sediment serves as a cap formation, where it is not broken young Wonji faults to impend the free movement of geothermal fluid to the surface.

The occurrence of cold water is confided to shallow depth of ignimbrites aquifer and the over laying inter-granular aquifers. The lacustrine sediment has thickness ranging from 40 to 60m. Frequently one more aquifers, separated by clay aquitards, are encountered in boreholes drilled in the lacustrine sediments (Geological Survey of Ethiopia, 2000).

Hydrogeology of the Lake basin or potential of aquifer zones are categorized based on recharge capability hydraulic parameters like, permeability, hydraulic conductivity, storability, specific yield of springs, groundwater tables and aquifer thickness and topography of the catchment.

Absolute aquifer classifications can be made with the help quantitative data generated by actual pump tests and geo- physical investigation. In this study hand dug water tables, deep well water tables springs out flow levels, long term rainfall records, lake level records, rivers and calibrated hydraulic properties of aquifers will have used in the model for understanding of the behavior of Lake water – groundwater interaction of the lake basin.

Water chemistry data can be used to infer groundwater flow directions, identify sources and amounts of recharge, estimate groundwater flow rates, and define local, intermediate, and regional flow systems (Anderson and Woessner, 1992).

Underlying this hydro chemical approach is a number of assumptions including:-

(1) Natural water chemistry is a result of rock water reaction such as dissolution and precipitation/, reactions on aquifer surfaces and biological reactions occurrences

(2) Distinctive chemical signatures are related to specific sets of reactions,

(3) Dissolved concentrations generally increase along the surface flow path until a maximum value dictated by mineral equilibrium, and

(4) Hydro chemical faces are directly related to the dominant processes.

In arid or semi-arid areas where hydrological and hydrogeological data are scarce and difficult to access, hydro chemical data can be used as a valuable tool to develop conceptual models of the watershed. In this study, hydro chemical data are used.

The chemical composition of the groundwater shows considerable variation, related to the extent of mineralization, hydraulic characteristics and residence time. The extent of mineralization in its turn depends on several factors including the chemical nature of rocks and temperature. As water moves through the unsaturated zone, physical and chemical processes occur that can affect the chemical composition of water before reaching the saturated groundwater system. The concentration of carbon dioxide, which may be in part a by-product of biochemical reactions, is an important factor controlling the chemistry of the saturated zone. Deeper seated thermal waters also mix with and affect the quality of shallower waters.

2.1.4. Hydrology

Area perennial streams which have their headwater in the eastern high land and flow to the west, Hawassa caldera, crossing the Wondogenet escarpments that finally join together to form Tikur-Wuha River which subsequently leads in to Lake Hawassa. According to Geological survey of Ethiopia (2000) some of perennial ungauged streams which flow from Easter highlands through Chelelleka swamp and joining Tikur-Wuha River, which is the only tributary river to Lake Hawassa.

2.1.4.1. Tikur - Wuha River

Tikur-Wuha is the only perennial river, whose destination is the Hawassa Lake. It has been gauged since 1981 Tikur-Wuha river drainage area in the lake basin cover about 625 km^2 that contributes the lake surface recharge (AG consulting, 2007).

2.1.4.2. Lake Hawassa

Lake Hawassa is found in Ethiopia rift system which covers about 100 km^2 of surface area. Lake Hawassa is not affected by direct water abstraction; however, currently there is a potential danger of using the Lake and Tributary Rivers for irrigation in the near future (WWDSE, 2001). The average water level of Lake Hawassa measured since 1969-2008 varies from 1682.586 -1685.209m

According to the bathymetric survey carried out by Water work design and supervision Enterprise (WWDSE) showed that deepest point of Lake Hawassa measures about 21m below the average water level. The cold and hot springs, the groundwater and rivers water correlate with correlation factors varying from 0.90to0.998 indicating that there is one homogeneous water system in the Lake catchment (WWDSE, 2001).

2.1.5. Groundwater

SNNPR Regional State Water Resources Development Bureau has studied –Pollution of lakes and Rivers by AG-consult consulting hydro geologists and Engineers in 2007. From the contour map of Groundwater level it can be inferred that Hawassa town is located at a local recharge area where groundwater pollution is likely take place, in which shallow and deep groundwater are dominated by local recharge from lake Hawassa, precipitation and runoff.

Even if Lake Hawassa has been of wide interest for many years, the question matter of Lake Water balance and the causative factors which require careful study of the components of the hydrological cycle in relation to natural and anthropogenic factor that may affect the lakes has never been studied. Tenalem and Robert (2007) under took comparative study of the hydrology and hydrogeology of selected Ethio-Kenyan Rift Lakes (2002) and reports that the results elaborate the intricate nature of the sub surface hydrology of the rift and much greater role of groundwater in the water balance of most Lakes. According to Yemane (2004) assessment, since the rift floors is distributes with multi-directional fault systems, thus their relationship with the surface and groundwater flow system needs to be studied in detail.

2.2. Relevant Previous Studies

Many studies have been carried out by different agencies since early 1970‘s with respect to the development of water resource projects, hydrology and hydrogeology, natural resource management, environmental impact assessment and pollution in the Gemeto well field. These studies provide valuable information and results for Gemeto well field which covers south eastern part of Lake Hawassa catchment (Sefiu et al, 2007; Seifu, 2014).

This area of the catchment (Gemeto Well Field) become the pivot point of this study due to the fact that the geology, hydro chemistry as well as its hydrogeology is so different from the character nearby Hawassa city, the Lake itself as well as the west and northern part of the catchment. Some previous studies have conducted remarkable study on the water resource potential assessment, water balance with in the catchment, Tikur Wuha watershed management, by creating sub catchments as per the scope and specific objective of their study. The assessment of the water balance of Hawassa lake catchment Yemane (2004) sub divided the entire catchment. Secondly the RVLB Master Plan Study Phase II Part I Vol II, The Water Resource System Simulation (WRSS) has been undertaken using the Water Evaluation and Planning System (WEAP) software by creating 7 sub water shades neglecting those sub water shades having less than an area of 4 Km^2. In this sub division the Gemeto Well Field is within the three sub basins. Similarly Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project Phase 2 Final Report Part II Prefeasibility Studies Integrated Watershed Management of Lake Hawassa Sub-basin Prefeasibility Study Volume 1: Main Report March 2009 Halcrow Group Limited and Generation Integrated Rural Development (GIRD) Consultants also divided the Hawassa Lake Catchment in to 5 sub catchments (Halcrow, 2009).

A three dimensional steady-state finite difference groundwater flow model is used to quantify the groundwater fluxes and analyze the subsurface hydrodynamics in the Meki river catchment by giving emphasis to the well field that supplies water to the community. The simulated hydraulic conductivity value varies from 0.15m/day to 20.23m/day. The mean annual recharge rate over the Meki River was 119.88 mm/year while that of simulated is 110.15 mm/year with 9.73 mm/year discrepancy (Dereje, 2011).

2.3. Groundwater Modeling

A groundwater model may be defined as a simplified version of the real groundwater system that approximately simulates the excitation- response relations of the groundwater system. The real system is very complicated and difficult to use it directly for the purpose of planning and making management decisions. The simplification is introduced in the form of a set of assumptions that express our understanding of the nature of the system and its behavior. These assumptions will tend to smooth out the effect of various heterogeneities. Because the model is a simplified version of the real system, there exists no unique model for a given groundwater system (Bear and Verruijt, 1987).

A computer program or code solves a set of algebraic equations generated by approximating the partial differential equations (governing equation, boundary conditions, and initial conditions) that form the mathematical model (Anderson and Woessner, 1992).

In this section first we try to formulate the governing mathematical model and its inputs, limitation and assumptions and the numerical model is then formulated based on the mathematical theories and assumptions. Groundwater models are an attempted represents the essential feature of the actual groundwater system by means of counterpart (Todd, 2005) which have capacity to test and related model based forecasts.

Groundwater models according to Todd (2005) are physical based mathematical models derived from Darcy‘s law and law of conservation of mass. Various establish solution techniques based upon finite difference or finite element approximations or a combination of both, are available for solving equations of the model. The accuracy of the solution (model prediction) is dependent up on the reliability of the estimated model parameters and the accuracy of the prescribed boundary condition. The finite difference method requires a rectangular element shaped discretization of the aquifer and the finite element method concuss of triangular discretization is the process of subdividing the continuous hydro geologic units in to discrete segments or cells.

Finite element is easy to define boundary of irregularly shaped aquifers and to ensure that node points coincide with monitoring wells or various types of geographic features. Since finite element models are reported to be somewhat superior to finite difference models for problems that have a moving boundary, such as cross-sectional model a water table that is transient, as well as coupled problems, such as contaminant transport (Wang and Anderson, 1982).

The finite–element model also has the advantage of being much more flexible interims of mimicking the geometry of an aquifer system than the finite-difference method and requires fewer nodes (Fetter, 2001).

Groundwater flow models can be transient or steady state and one, two, or three spatial dimensions. Steady state flow occurs when at any point in flow field the magnitude and direction of the flow are constant with time (Anderson and Woessner, 1992). Selecting conceptual model for a given problem is one of the most important steps in modeling process. The key data requirement in the process of conceptualization include data about hydro-stratigraphy units, surface water bodies, physical and hydraulic boundaries recharge and discharge zones (Anderson and Woessner, 1992).

Once the conceptual model is translated into a numerical model in the form of governing equation, with associated boundary and initial condition, a solution can be obtained by transferring into a numerical model and writing a computer program (code) for solving it. This includes design of grid, setting boundary and initial conditions and preliminary selection of values for aquifer parameters. The input parameters include model grid size, layer elevations (thickness), boundary condition, hydraulic conductivity, recharge and additional model for steady state condition. Model calibration consists of changing values of model input (data) parameters in an attempt to which field condition with some acceptable criteria (Anderson and Woessner, 1992).

2.3.1. Groundwater flow equation

The basic principle of groundwater flow basically lies on Darcy's law. When this law is put together with an equation of continuity which describes, the conservation of the fluid mass during flow through a porous media will be express by the general flow equation in three dimensional for heterogeneous anisotropic material (Todd,2005).

$$\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_{zz}\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t} \qquad 1$$

Where kxx, kyy and kzz are the values of hydraulic conductivity in the x, y and z directions along Cartesian coordinate axes, which are assume to align with principal directions of hydraulic conductivity (LT^{-1}), h =head (L), W = volumetric flux/unit volume and represents sources and/or sinks of water [T^{-1}], SS = specific storage of the porous material [L^{-1}], and t = time. The functional relationship between the lake water level variation and the resulting hydraulic pressure variation in the basin can be set using any of the numerical methods for groundwater flow such as finite difference method or finite element method. The choice between the finite difference and finite element method depends on the problem to be solved and the preference of the user. Finite difference methods are easy to understand and program. Finite element methods are better able to approximate irregular shaped boundaries than the standard finite difference methods. Finite element methods are also better able to simulate point sources and sinks, seepage faces and moving water tables than the finite difference method (Anderson and Woessener, 1992).

2.3.1.1. Governing equations for saturated groundwater flow

The governing equation for water flow in saturated medium can be obtained by combining a special form of Darcy‘s law (derived from the water phase momentum balance) and the continuity equation written for the water phase. The derivation is traditionally done by referring to a cube of porous material that is large enough to be representative of the properties of the porous medium and yet small enough so that the change of head within the volume is relatively small (Anderson and Woessner, 1992). Similarly a method developed by United State Geological Survey (McDonald and Harbaugh, 1988) used to estimate flow system in basins.

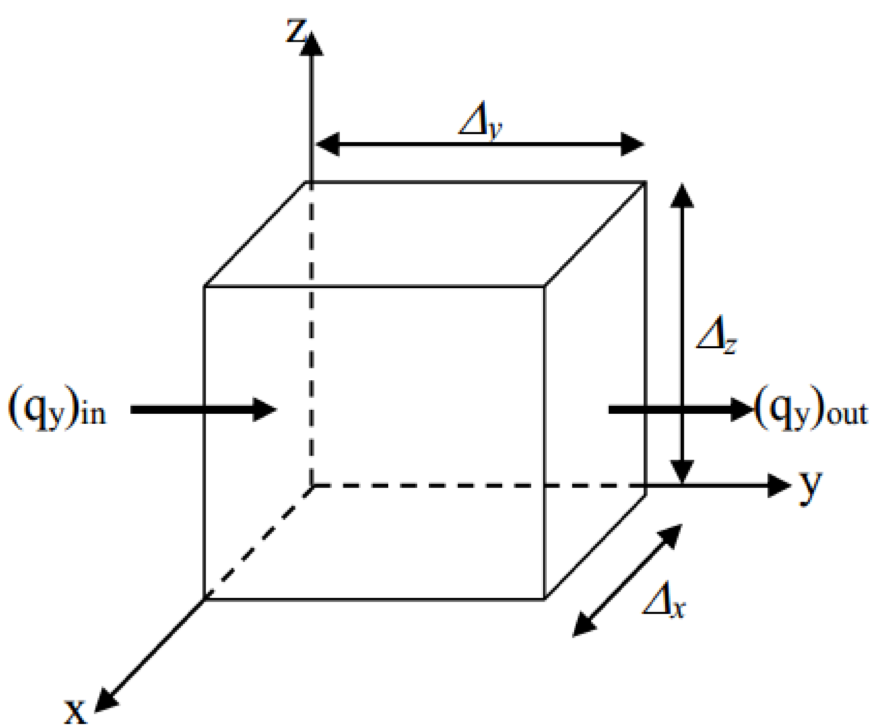

Figure 2: The representative elementary volume used in the derivation

The cube in Figure 1 is called the representative elementary volume (**REV**).

The flow of water through the REV is expressed in terms of the discharge rate (q), whose magnitude in the three coordinates will be qx, qy, and qz. The water balance equation (conservation of mass) states that: (Anderson and Woessner, 1992).

Outflow-Inflow=change in storage 2

Consider flow along the y-axis of the REV.Influx to REV occurs through the face ΔxΔz

Through the face ΔxΔz and is equal to ***(qy) in***. Flux out is ***(qy) out***.

The volumetric flow rate along the y-axis is:

$$[(qy)\,in - (qy)\,out]\Delta x\Delta z \qquad 3$$

This can also be written as:

$$\frac{(qy)in-(qy)out}{\Delta y}\Delta x\Delta y\Delta z \quad . \qquad 4$$

Dropping the in & out subscripts, the change in flow rate through the REV along the y-axis

$$\frac{\partial qx}{qy}\Delta x\Delta y\Delta z \qquad 5$$

Similar expression can be written for the change in flow rate along the *x*- and *z*- axes.

The total change in flow rate is equal to the change in storage and is expressed as: (Anderson and Woessner, 1992).

$$\left(\frac{\partial q_x}{\partial X}+\frac{\partial q_y}{\partial Y}+\frac{\partial q_z}{\partial Z}-R^*\right)\Delta X\Delta Y\Delta Z = \text{Change in storage} \qquad 6$$

The existence of sink (e.g. a pumping well) or source of water (e.g. injection well or some other source of recharge) within the REV is undeniable. The volumetric inflow rate of such sources is represented by $\boldsymbol{R}^{*}{}_{\Delta_x}\Delta_y\Delta_z$. Here the $\boldsymbol{R}^{*}$ is defined to be intrinsically positive when it is a source of water; therefore it is subtracted from the left hand side of **Eq. 6**. Therefore **Eq.6** becomes: (Anderson and Woessner, 1992).

$$\left(\frac{\partial q_x}{\partial X} + \frac{\partial q_y}{\partial Y} + \frac{\partial q_z}{\partial Z} - R^*\right)\Delta X \Delta Y \Delta Z = \text{ Change in storage} \qquad 7$$

The change in storage is represented by specific storage **(S_S)**. It is defined as the volume of water released from storage per unit change in head (*h*) per unit volume of aquifer (Anderson and Woessner, 1992).

$$Ss = -\frac{\Delta v}{\Delta h \Delta x \Delta y \Delta z} \qquad 8$$

The sign convention is that the ΔV is intrinsically positive when the Δh is negative, or in other words, water is released from the REV when head decreases. The rate of change in storage in REV will be:

$$\frac{\Delta v}{\Delta t} = -s_s \frac{\Delta h}{\Delta t} \Delta X \Delta Y \Delta Y \qquad 9$$

Combing Eq. 7 and Eq. 9

$$\frac{\partial qx}{\partial X} + \frac{\partial qy}{\partial Y} + \frac{\partial qz}{\partial Z} = -\frac{\partial h}{\partial t} + R^* \qquad 10$$

Darcy law is used to set the relationship between ***q*** and ***h***. Darcy law in three dimensions is written as (Anderson and Woessner, 1992);

$$q_x = -kx \frac{\partial_h}{\partial x},\ q_x = -kx \frac{\partial_h}{\partial x},\ q_z = -kz \frac{\partial_h}{\partial z} \qquad 11$$

By substituting **Eq. 11 in Eq. 10** the desired groundwater flow equation is:

$$\frac{\partial}{\partial_x}\left(k_x \frac{\partial_h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial_h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial_h}{\partial z}\right) = s_s \frac{\partial_h}{\partial_t} - R^* \qquad 12$$

Where K_X, K_Y, and K_Z are components of the hydraulic conductivity tensor

In the above derivation it is assumed that $\mathbf{K_X}$, $\mathbf{K_Y}$, and $\mathbf{K_Z}$ are collinear to the x, y- and z- axes (Anderson and Woessner, 1992).

2.3.1.2. Assumptions of groundwater flows

This study mainly uses a flow system conceptual viewpoint of groundwater systems. By flow system view point it means the study is not concerned with identifying aquifers and confining beds but is concerned in constructing the three dimensional distribution of heads, hydraulic conductivities, and storage properties everywhere in the system . According to Anderson and Woessner (1992) the assumptions of the flow model are as follows:

- Darcy‘s law is valid and hydraulic head gradients are the only significant driving force for fluid motion.
- Water is the only flowing fluid phase (i.e., the air phase is assumed to be inactive).
- The fluid is considered to be slightly compressible and homogeneous.
- The fractured medium maybe represented by a single continuum porous medium of spatially invariant properties.
- The porosity and saturated hydraulic conductivity are constant with time.
- Gradients of fluid density, viscosity, and temperature do not affect the velocity distribution.

2.3.2. Overview of groundwater model application

The Lake Hawassa Sub basin has been the interest of many researcher and organization, thus a number of essential works carried out over the hydrology, hydrogeology, climate, land use, Lake Pollution and Lake level rise of the basin.

The water balance components of lacustrine systems, groundwater is not easy to quantify. As a result, many hydrological studies of Lake Watershed systems like RVLB have given little emphasis to groundwater (Crowe and Schwartz, 1981; Crowe, 1990; Almendinger, 1990). Limited groundwater modeling exercise in the Ethiopian rift revealed that groundwater is one of the major components of the water balance of many Ethiopian lakes (Tenalem, 1998 and 2001).

2.4. Groundwater Model Conceptualization

Building a conceptual model requires good information on geology, hydrology, boundary conditions, and hydraulic parameters. A good conceptual model should describe reality in a simple way that satisfies modeling objectives and management requirements (Bear and Verruijt, 1987).

Once the conceptual model is translated into a numerical model in the form of governing equations, with associated boundary and initial conditions, a solution can be obtained by transferring it into a numerical model and writing a computer program (code) for solving it. This includes, design of grid, setting boundary and initial conditions and preliminary selection of values for aquifer parameters.

The input parameters include model grid size, layer elevations, boundary conditions, hydraulic conductivity, recharge, and additional model input for steady state condition. The models will be developed for describing fluid flow in fractured porous media. Fundamentally, each method can be distinguished on the basis of the storage and flow capabilities of the porous medium and the fracture. The storage characteristics are associated with porosity, and the flow characteristics are associated with permeability (Anderson and Woessner, 1992).

2.4.1. Recharge

Natural recharge to the unconfined aquifer system occurs from infiltration of runoff from elevated regions along the north and eastern boundary of the site, and precipitation falling across the Lake Hawassa basin. Natural recharge from runoff and precipitation provides a source of groundwater inflow to the area of interest. Areal recharge from precipitation falling on the study area is highly variable, both spatially and temporally, and depends on local climate, soil type, and vegetation.

Groundwater recharge is defined as the entry in to the saturated zone of water made available at the water table with the saturated zone. Freeze and Cherry (1977) quantified the rate of recharge to aquifers measures in the evaluation of groundwater resources. Estimation of groundwater recharges requires modeling of the interaction between all the important process in the hydrologic cycle, precipitation infiltration, surface run off, evapotranspiration, soil moisture & groundwater level variations (Jyrkama and Skyes, 2007).

There are many sources of recharge to groundwater aquifer system. These include recharge from precipitation, rives, irrigation losses, urban water sources and inter aquifer flow which have defined principal as direct, local and indirect recharges (Tenalem, 1998).

In many cases, combination of various types of recharge will occur (Simmers, 1997). The existence of different combination of groundwater recharge makes the quantification of Groundwater .Tenalem (1998), which leads to different recharge estimations technique e.g. direct recharge measurement, water balance methods, Darian approach, Trace techniques and empirical methods.The trial and error estimation involves finding appropriate percentage of the annual rainfall to predict the observed groundwater table throughout the lake basin.

2.4.2. Flow system boundary

This boundaries condition is a mathematical model that determines how and where the groundwater inflows or out flow in to or from the aquifer system. The boundary specifies the dependent variables or derivatives of the dependents variable at boundary problem domain (Anderson and Woessner, 1992). This boundary condition falls in to one of the following categories according to Franke et al. (1987).

- Specified head or Dirichlet condition

- Specified flux or Neumann condition
- Mixed or Cauchy boundary condition
- Free surface boundary condition and
- Seepage face boundary condition

But from these boundaries, Anderson and Woessner (1992) define three type of mathematical conditions used to represent hydrogeological boundaries:

1. Specified head boundaries (Dirichlet condition)
2. Specific flow boundaries (Neumann condition)
3. Head dependent flow boundary (Cauchy or mixed condition)

If the head is known at the boundary of the flow region the boundary is specified condition is Dirichlet. If the flux across a boundary to the flow region is known the boundary condition is Newman condition. In some cases the boundary condition will be mixed that is, with some portion having known flux (Wang and Anderson, 1982).

3. METHODOLOGY

3.1. Description of the Study Area

3.1.1. Location

The Gemeto well field was situated at the eastern side of Lake Hawassa which lies roughly between 437042 m to 456204 m Easting and 768975 m to 783513 m Northing UTM Zone 37^o Northern Hemisphere with Indian Mean Datum. The Gemeto well field is a sub basin having a total area of 415 km^2 which is 26.4% of the area covered by Lake Hawassa catchment. The Gemeto well field sub basin, since it is part of Hawassa Lake basin, categorized as Central Part of the Rift Valleys lakes Basin's sub-basin and is drained mainly from the eastern escarpment by the Gomesho and from south east by Kerama, Abosa and Wedesa main rivers which flow into Lake Chelelleka and then to Lake Hawassa. Elevation in the study area falls from roughly 1711masl in the south eastern margin of the study area to 1765 masl in the valley floor near Lake Hawassa.

The Gemeto well field area is bounded by the physical surface water divides in the east and south and Gomesho river, Tikur Wuha River and Hawassa Lake the north and west boundaries. Kerama, Wedesa and Abosa rivers are the main rivers within the well field draining to Lake Hawassa via Tikur Wuha River having Burara, Bedeso, Weshare, Elto, Kedo, Boga, Decata and Haro streams as tributary.

The sub-basin is essentially a caldera with steep sides enclosing a broad, flat floor which contains Lake Hawassa and the rapidly silting-up Lake Chelelleka, both of which were once connected the larger Lake Shalla. The study area totally occurs east in the Hawassa Basin‘s caldera. Administratively the sub-basin is divided between SNNPRS in the south and Oromiya in the north with SNNPRS making up larger portion of the area than that of Oromiya. In terms of its development and environmental issues the Lake Hawassa sub-basin is little different from many other sub-basins both in the RVLB and highland Ethiopia, however its environmental setting does differ from most, in that it contains at its Centre, a rapidly growing regional capital situated on a terminal Lake, the fluctuation of the level of which has been the cause of some damage in the recent past.

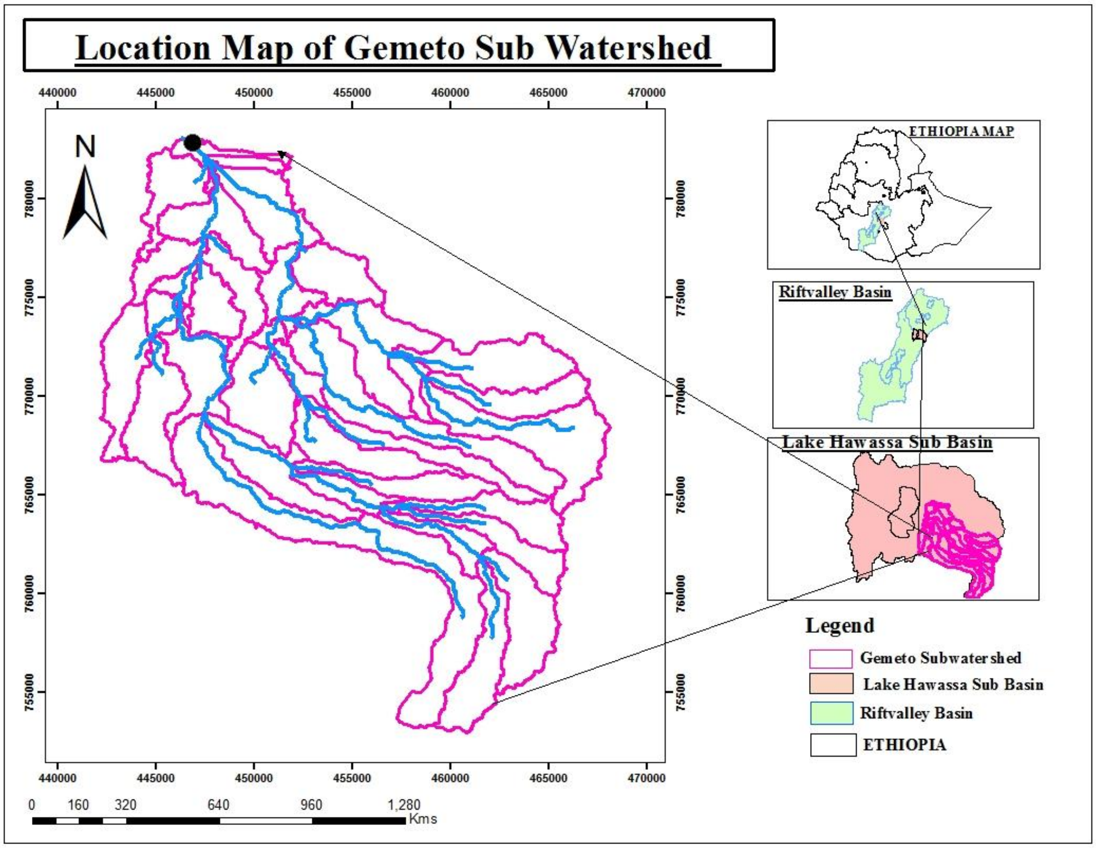

Figure 3: Location map of Gemeto well field relative to Hawassa Lake Basin

3.1.2.Climate

Using the data obtained from National Meteorological Services Agency (NMSA),

Various Climatological parameters of the study area have been summarized below.

3.1.2.1. Rainfall distribution

Precipitation is any form of water that falls on the surface of the earth by the process of condensation & sublimation. There are different forms of precipitation. Out of this Rainfall is the important form of precipitation in hydrologic cycle. The study area is characterized by

According to the data obtained from National meteorology service agency (NMSA), the area obtains the highest rainfall in the months of July and August. This can easily be shown on the mean monthly rainfall in millimeters for the area over a time of 10 years.

Estimation of the areal rainfall over a given catchment is useful for estimating the total recharge that could occur over the entire catchment. Various methods can be implemented to estimate the areal rainfall amount in the intervening catchment. These are Arithmetic mean average method, Thiessen polygon method and Isohytal method but the most famous method is the Thiessen Polygon, where by the influence of each rainfall station is determined and the weighted average rainfall estimated.

The Thiessen polygon, generated on the basis of the three stations described above, in the Lake Hawassa basin is as shown in Figure 5. The area of the Thiessen polygon bounding each station received the same average annual rainfall recorded over the station.

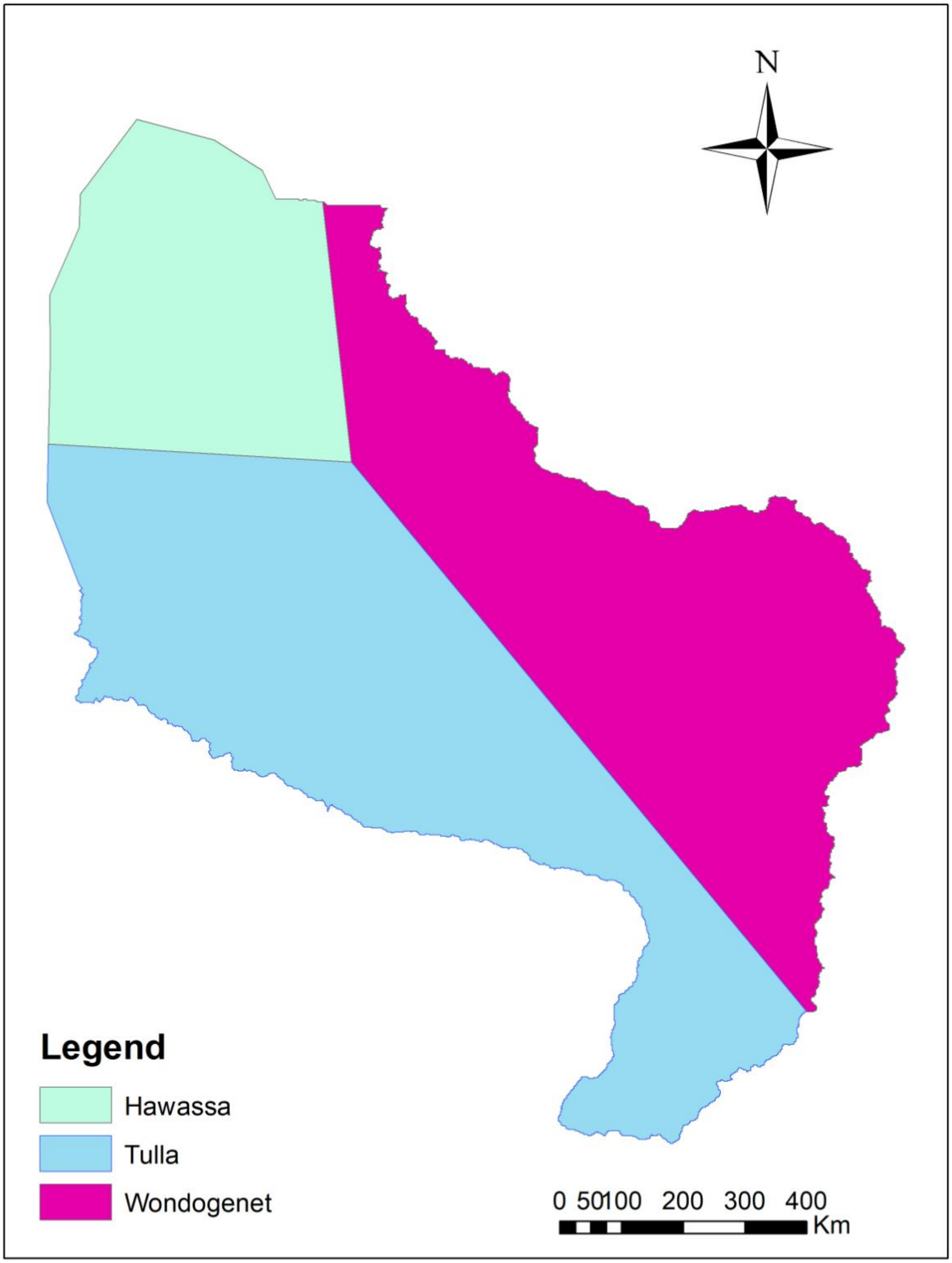

Figure 4: Thiessen Polygon Map of the Area.

Table1: Annual weighted rainfall depth using Thiessen polygon

Meteorological Station	Area of influence (km^2)	Mean rainfall (mm)	Weighted Area%	Weighted RF(mm)
Hawassa	79.11	936.02	19.02	178.03
Tulla	177.36	930.70	42.64	396.85
Wondogenet	159.47	1068.97	38.34	409.84
Total	415.94	2935.69	100%	984.72

Table 2:Meteorological stations with Rainfall data around the study area.

	Location		
Station	Latitude, N	Longitude ,E	Mean rainfall(mm)
Hawassa	780414.6	442572	936.02
Tulla	769138	441897	930.70
Wondogenet	782057	457493	1068.97

Table 3: Monthly average Rainfall of three stations (2008—2017)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wondogenet	24.63	27.28	88.72	101	131	91.71	155.98	162	126.7	95.7	46.24	18.3
Hawassa	19.66	20.81	61.52	95.77	153.2	91.19	130.06	127.08	118.15	62.79	36.85	18.94
Tulla	23.92	33.77	71.83	94.1	102.96	99.17	108.07	113	140.7	57.3	63.97	22.4

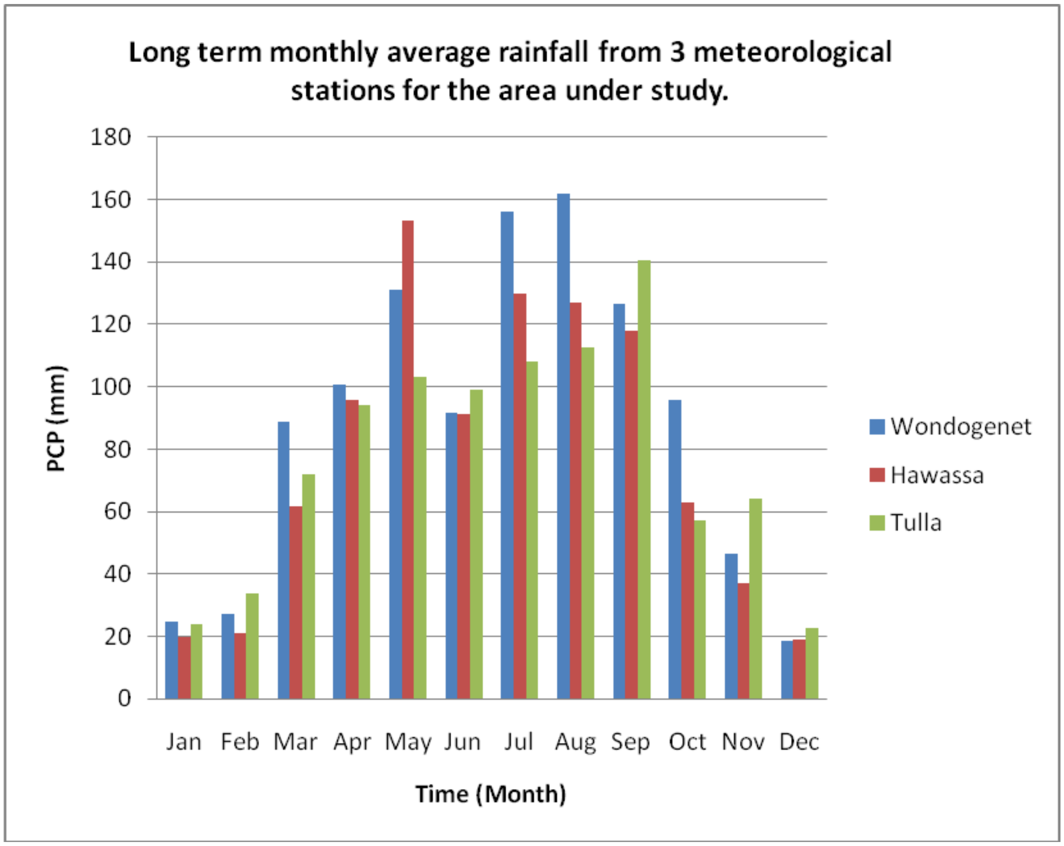

Figure 5. Rainfall station and their coverage in the study area (2008-2017)

3.1.2.2. Temperature

Mean monthly temperature was computed as the arithmetic average of 10 years (2008-2017) from Hawassa station. The study area has an average temperature of 20.84^0c with mean monthly minimum temperatures of 10.99^0c and mean monthly maximum temperature 30.68^0c. Maximum temperature values were recorded in the month of March and while minimum temperature record was obtained in the month of December.

Table 4 :Mean monthly minimum, maximum and average temperature at Hawassa station

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Max.T(0^c)	27.1	30.1	30.6	29.1	27.5	26.2	25.1	25.2	25.8	27.4	28.2	28
MinT(0^c)	12.2	12.9	13.7	14.7	15.0	14.9	15.	14.9	14.6	13.3	12.0	11.
Mean(0^c)	20.6	21.5	22.2	21.9	21.3	20.6	20.0	20.1	20.2	20.3	20.1	19.5

Max. T (^{0}c) = mean monthly maximum Temperature of the study area

Min. T (^{o}c) = mean monthly minimum temperature

Mean. T (^{o}c) = mean monthly temperature of the study area

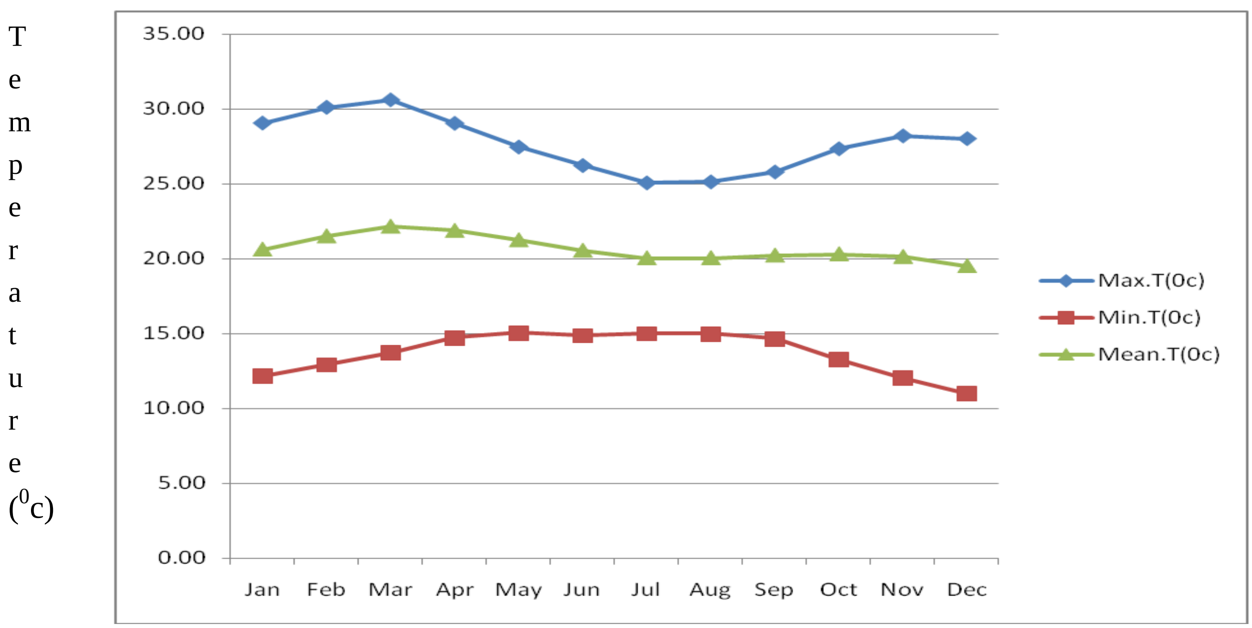

Figure 6 :Mean monthly temperature in

3.2. Data Acquisition (Collection)

For this study, various data are required that include secondary data of well/bore hole data such as static water level, well depth, elevation of well and pump test data was obtained from the Hawassa town Water supply and Sanitation Enterprise and Bureau of water resources development. Climate data such as rainfall and temperature was obtained from the regional meteorological agency and national meteorological agency of Ethiopia. Well inventory data was collected from the Hawassa town Water supply and Sanitation Enterprise.

3.3. Conceptual Model Creation

The finite difference method (FDM) is probably the oldest, most popular, and conceptually simplest of the numerical procedures governing groundwater behavior. The finite difference method consists of discrediting the problem area into rectangular elements which are identified with discrete points or nodes. It is based on the Taylor series expansions in order to determine approximations of the first-order and the second-order derivatives of the variable in question (Todd, 1980).

The finite element method (FEM) is a very well-known method to solve the governing partial differential equations. It was already applied in the early 1950's to problems of solid mechanics, whereas by the mid of the late 1960's it was being used to solve the groundwater flow equation with some success. When groundwater modellers began to look at transport problems in the early 1970's, they noticed that solving the advection-dispersion equation by the finite difference method encountered numerical dispersion to a certain extent. As such, they turned to the finite element approach, as the occurrence of numerical dispersion was less dominant (though still possible).

Both the finite difference method and the finite element method are most widely used numerical techniques for solving mathematical models. These two groups have the division of the domain into elements in common and the generation of one difference equation for each element node. In the case of finite difference models, the elements have to be rectangular1, whereas in case of finite element models, not only rectangular but also triangular elements may be used (Gualbert, 2000).

Since it is not ease to deduce assumptions for study area solve analytically, the numerical solution technique was chosen. The numerical approximations of the groundwater flow equations describing fully three dimensional problems were obtained using the finite Difference technique. In this study MODFLOW groundwater flow modeling is carried out by using finite difference method (FDM).

In the approximation procedure, the flow region is first discretized into a network of finite Difference, and an interpolating trial function is used to represent the unknown dependent variable (hydraulic head) over the discretized region. For a steady-state simulation, these nodal equations are algebraic equations. For a transient simulation, the nodal equations are first-order in time ordinary differential equations (and possibly nonlinear) that are integrated using a finite difference approximation.

The potential Assessment of the Gemeto well field in Lake Hawassa Catchment aquifer system is simulated using two or three dimensional steady state FDM groundwater flow model. The steady-state flow of groundwater is described by a form of the Laplace equation, which is a form of potential flow and has analogs in numerous fields. A mass balance is done on the water flowing in and out of this small volume, the flux terms in the relationship being expressed in terms of head by using the constitutive equation called Darcy's law. Mathematical model is applied to this case with the exception of using the storage terms and time dependent terms. To solve such groundwater flow problem, it is necessary to create the conceptual model of the study area. In general to accomplish the intended result the following flow-chart for modeling by modflow 2005 was used.

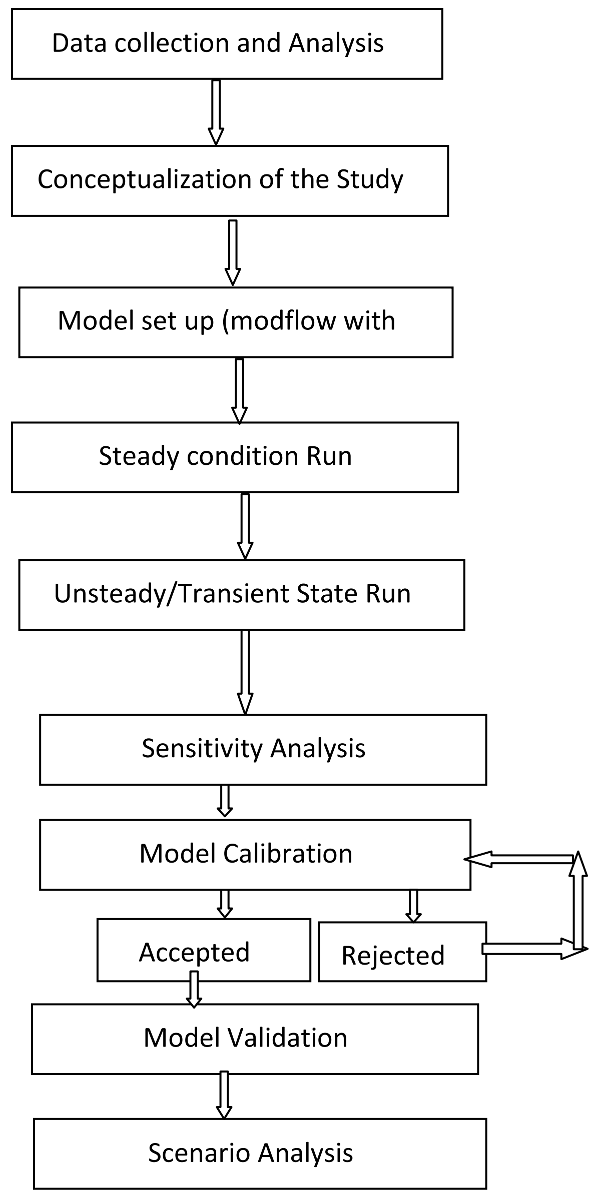

Figure **7:** Model calculation flow chart.

3.3.1 Geologic/hydro geologic conceptualization

According to AG consult, the geologic and hydro geologic model of the study area is composed of three geologic units (AG consultant, 2007). In this study these three geologic units are conceptualized as hydro geologic units having different hydraulic parameters. These parameters are fixed by trial and error method so that the observed hydraulic heads (Well inventory data) are estimated accurately.

To see if the groundwater nearby Hawassa city and Gemeto well field the following conceptual hydrogeological model is also considered. In this modified conceptual model additional geologic structure (A fault) is included.

3.4. Numerical Groundwater Modeling

3.4.1 Spatial discretization

This study was employed a right-handed Cartesian coordinate system (x, y, z) to generate a three dimensional Rectangular grid for finite difference. The grid was oriented such that the z-axis points in the vertical upward direction (the elevation of the nodes above sea level). In the area extent the grid is confined to be comprised of triangular elements, while in the vertical direction distorted elements are handled. Varying levels of spatial discretization of the solution domain was performed prior to the main model execution.

3.4.2. Hydraulic properties

Hydraulic properties are important to the three dimensional conceptual model which include both horizontal and vertical hydraulic conductivities, specific storage coefficient and porosity. To apply a numerical model, the distribution of these parameters was specified for each hydro-geological unit. However since the model would be based on the principles of equivalent porous medium, Hydraulic properties have replace by equivalent or effective values. To achieve this, a conceptual model having three (for the first) and four (for the second conceptual models) different sections which have different effective values of hydraulic properties is adopt. The value of these hydraulic parameters was obtained during the calibration process of the steady state saturated ground water flow model designed for the study area.

3.5. Borehole Investigations

Borehole investigations are one of the most important methods to investigate the hydrogeology of the site. These investigations allow collection of core samples, groundwater sampling and measuring the hydro-geological and rock mass properties to depth. However for this study objective point of view well location, its elevation and the water table depths data will collect from SWWCE and BOWRD. The well inventory in this thesis includes collecting the above information on hand dug wells, deep wells and springs.

3.6. Groundwater Potential

First arbitrary combinations of vertical (K_Z) and horizontal (K_Y K_X) hydraulic conductivity will be given in the one layer hydro- geological model. Then a dynamic steady state pore pressure distribution was calculated for predicting the pore pressure distribution. Measured water levels in the wells will compare with the calculated values. K_Y K_Z and K_X values of having better approximation will select. After getting the head distribution and the corresponding vertical and horizontal hydraulic conductivity values, was analyzed for effect of pumping from Gemeto well field on the groundwater potential.

3.7. Model Calibration

The process of adjusting the model input values to reduce the model error is as model calibration (Konikow and Bredehoeft, 1992; Oreskes et al., 1994).Model calibration for the modeler is a means of correcting gaps between the measure head values and simulated values of groundwater levels and the model relays or the measured head to match the simulated. In this model calibration, inverse groundwater modeling to be used in this method hydraulic parameters and recharge values are given to the model till the model predicts the measured water levels accurately. According to Anderson and Woessner (1992), there are two calibration techniques. The Manual trial and error calibration and automated parameter estimation.

The Manual Trial and error calibration was the first technique to be used and is still the technique preferred by most users (Anderson and Woessner, 1992). It is the process of manual adjustment of input parameters until the model simulated value shows similarities with the measured head and range of error values. Assuming constant recharge and discharge, the model was calibrated under steady state condition. Calibration was conducted by varying the hydraulic conductivity of the aquifer system with trial and error. Trial and error calibration was continued until the result comes in the range of predetermined residual (error) criteria the result of the calibration should be evaluated both qualitatively and quantitatively (Anderson and Woessner, 1992). The target of calibration is to bring the matching of measured simulated head difference or residual value to the permissible gap of 10 m. According to Simmers (1988), the error should be 1.5 of the maximum and minimum head difference of the measured ground water level. Besides, the mean of the observed and simulated head differences was used to quantify the average error in the calibration process. The differences between measured (h_m) and simulated heads (h_s) respectively can be expressed by the mean error (ME).

$$ME=\frac{1}{n}\sum_{i=1}^{n}(hm-hs) \quad 13$$

$$R^2=\frac{\sum(\hat{Yi}-\bar{Y})^2}{\sum(Yi-\bar{Y})^2} \quad 14$$

The objective of calibration is to minimize these error estimates.RMSE is the best method to measure error. The maximum acceptable value of calibration criterion depends on the magnitude of the change in head over the problem domain (Anderson and Woessner, 1992). The scatter diagram generated by model also shows the matching property of the measured simulated head. The scatter plot is usually examined by the position of points scattered in the graph away from the straight line, that is; random distribution of point in the plot shows the deviation between measured and simulated groundwater heads.

3.8 Model Validation

It is natural for people who apply groundwater models, as well as those who make decisions based on model results, to want assurance that the model is valid. Groundwater models are embodiments of various scientific theories and hypotheses (Konikow and Bredehoeft, 1992; Oreskes et al., 1994).

The criteria for labeling a model as validated are inherently subjective. In practice, validation is attempted through the same process that is typically and more correctly identified as calibration that non uniqueness of model solutions means that a good comparison can be achieved with an inadequate or erroneous model.

Also, because the definition of “good” is subjective, under the common operational definitions of validation, one competent and reasonable scientist may declare a model as validated while another may use the same data to demonstrate that the model is invalid. To the general public, proclaiming that a groundwater model is validated carries with it an aura of correctness that many modelers would not claim (Bredehoeft and Konikow, 1993).

Because labeling a model as having been validated has very little objective or scientific meaning, such “certification” does little beyond instilling a false sense of confidence in such models. Konikow and Bredehoeft (1992) recommend that the term “validated” not be applied to groundwater models.

3.9 Determination Aquifer Characteristics of Gemeto Well Field

The aquifer characteristics such as hydraulic conductivities, specific storage coefficient, transmisivity and porosity will be determined in such a way that initial parameters are to be used from surrounding well pumping test. The final optimal value can be determined up on calibration and Validation process. The aquifer parameters to be calibrated include the hydraulic conductivity and river bed conductance. River bed conductance was obtained from literature initial guess and show different scenario.

3.10 Determination of the Effect of Different Water Abstraction Rate on Groundwater

To analyze the effect of different extraction level on groundwater head, the existing wells in the study area was used. In this analysis, the optimal pumping rate was identified.

4. RESULTS AND DISCUSSION

4.1. General

The final result of the model was calibrated steady state groundwater flow model with simulated head of groundwater surface. The model can be manipulated and simulated with user defined interest. The primary result is to satisfy the theme of the paper stated on the objective. The whole effort was to make the following major output listed below.

4.2. Model Area Discretization

The study area, which is part of Lake Hawassa catchment covering about 415 Sq.Km. the mesh, is composed of the nearly same dimensioned elements. The average Grid size 400 X 400 meters of rectangular elements were used.

The model configuration on the vertical direction was conceptualized as follows.

Model Layer =2

Model Top = DEM

Layer 1 Bottom = Model Top -100m

Layer 2 Bottom = Model Top -200m

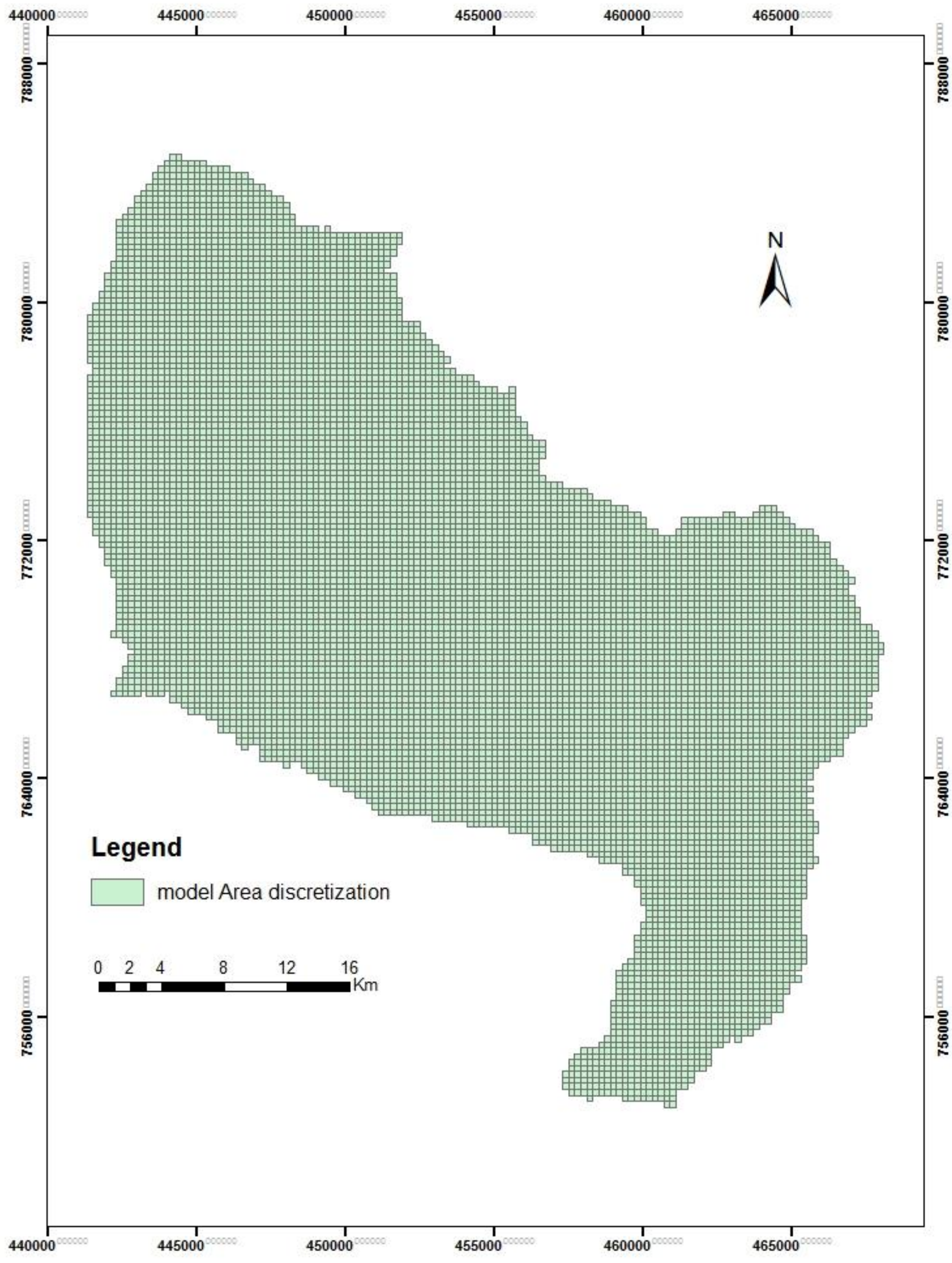

Figure 8: Discritized model area

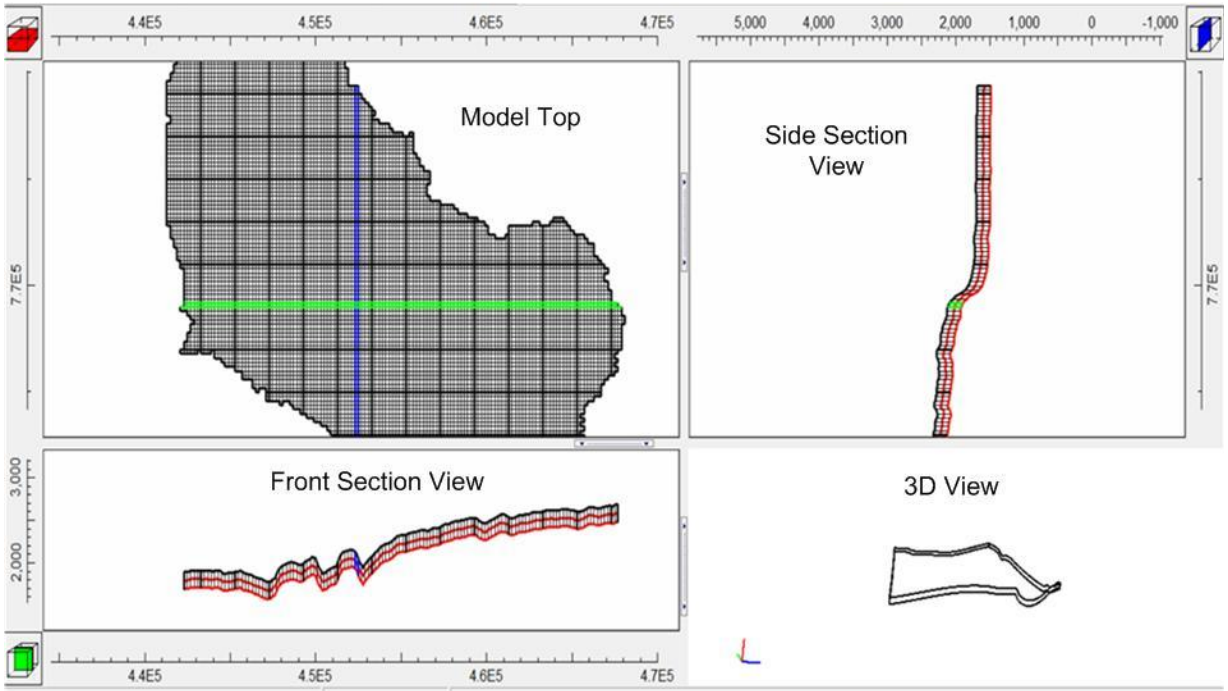

Figure 9: Model Muse Graphical user interface showing Model Setup

4.3.Aquifer Characteristics

Hydraulic properties important to the three dimensional conceptual model include both Horizontal and vertical hydraulic conductivities, specific storage coefficient and porosity. To apply a numerical model, the distribution of these parameters must be specified for each hydrogeological unit. However since the model is based on the principles of equivalent porous medium, Hydraulic properties have been replaced by equivalent or effective values. To achieve this, a conceptual model having five different sections which will have different effective values of hydraulic properties is adopted. The value of these hydraulic parameters is obtained during the calibration process of the steady state saturated ground water flow model designed for the study area. The result obtained from model the highest value of horizontal hydraulic conductivity from the figure 10 was $85x10^{-5}$m/s and the lowest value $3x10^{-5}$m/s and there by the transmissivity could be calculated by multiplying with aquifer thickness and expected to vary from 345.6m^2/d to 15552m^2/d.

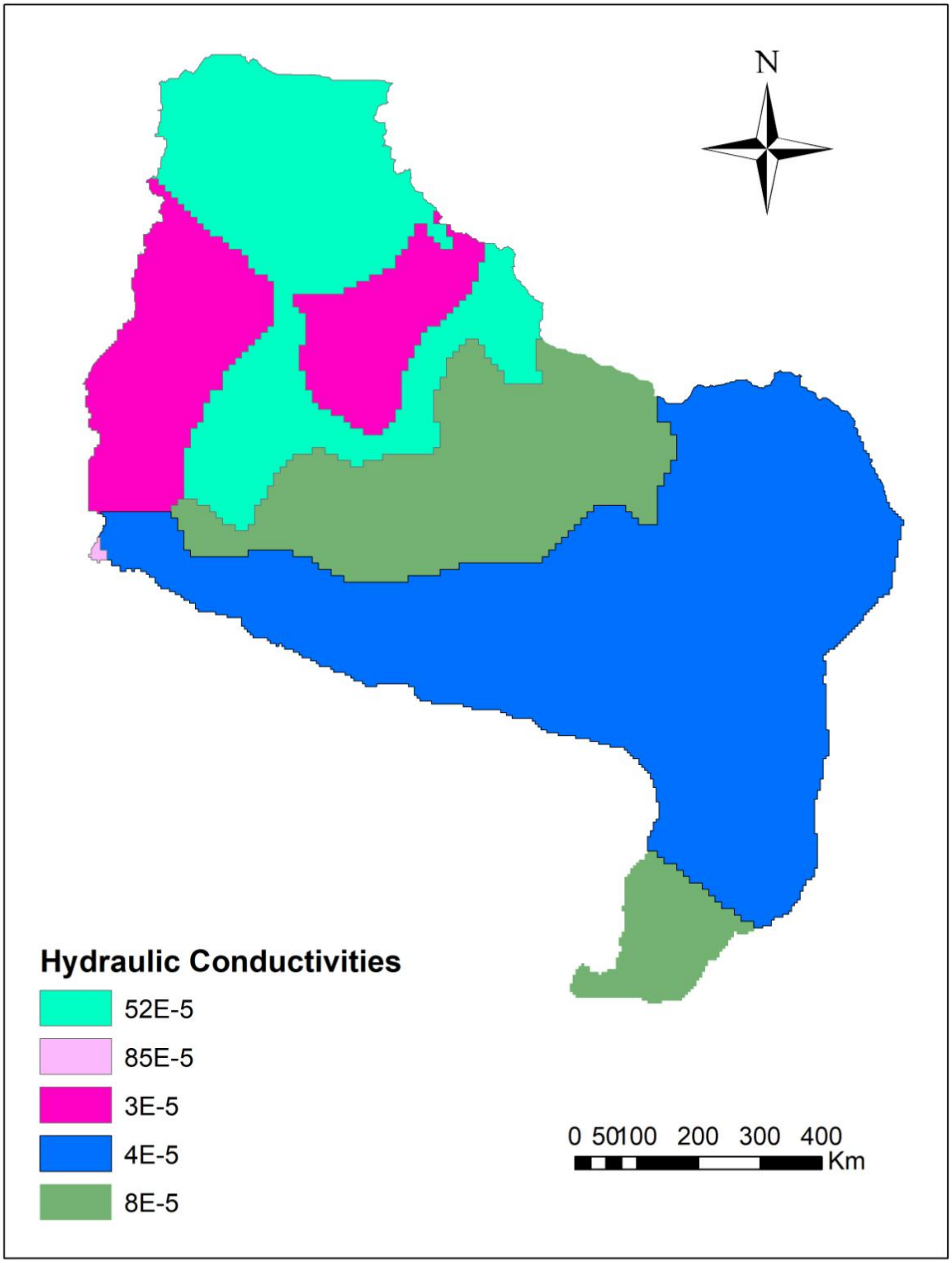

Figure 10: Aquifer characteristics Map of the study Area.

.

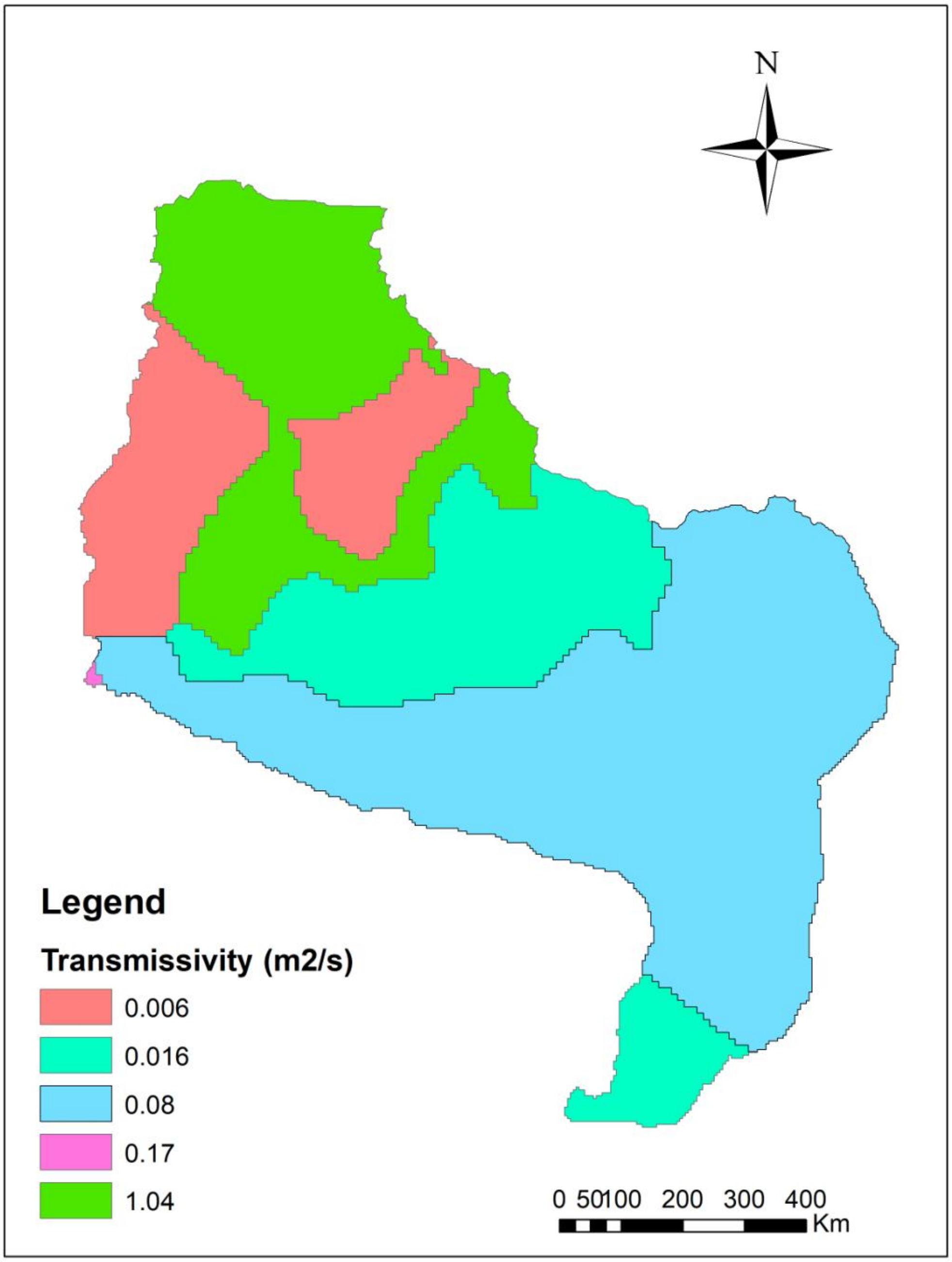

Figure 11: Transmissivity map of the study Area.

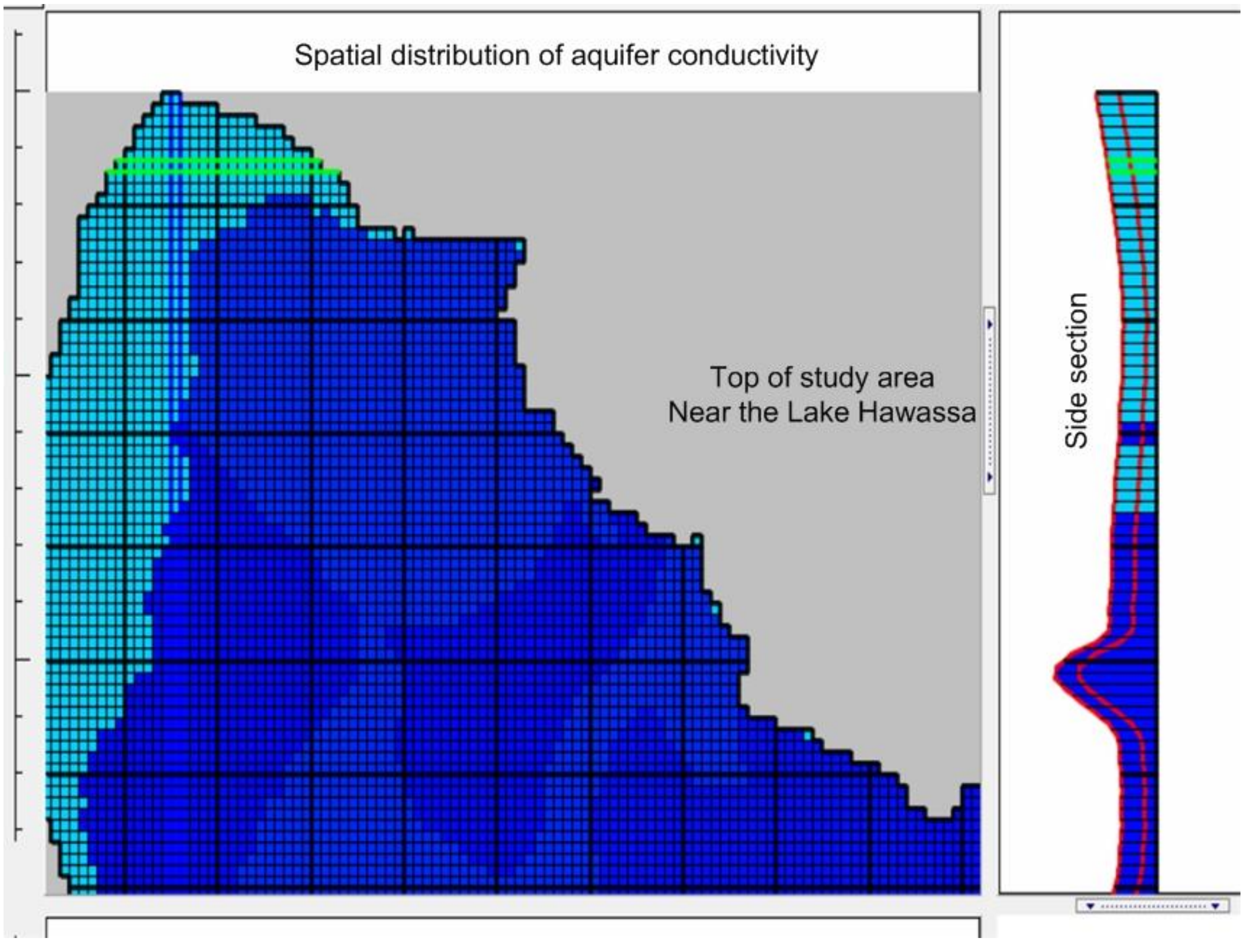

Figure 12:Spatial distribution of aquifer conductivity near Lake Hawassa

4.4. Flow System Boundary

The main perennial stream flowing to Chelelleka swamp and Lake Hawassa are significant river boundaries which describes ground water flow behavior of Gemeto well field. Streams from the foot of Wondogent Guguma escarpments are main contributes of groundwater recharge to Chelelleka during dry period. During wet period when these rivers head exceeds the head of the nearby ground surface, those rivers recharge the nearby aquifer.

The Gemeto well field is first expanded to find clear hydraulic boundaries that could have influence on the ground water recharge and discharge. The well field is bounded by the physical surface water divides in the east and south and Gomesho river, Tikur Wuha and Hawassa lake the north and west boundaries as shown in the figure below.

To include the natural hydraulic boundaries like rivers and groundwater divides nearby around the Gemeto well field, the analyzed domain was extended towards the watershed divide. The wells locations in within the study domain are represented by nodes. The site unconfined aquifer system is also bounded by the Tikur-Wuha River, Lake Hawassa and Lake Chelelleka, shown in the following Fig. 4.5. Both the Rivers and the Lakes represent point of regional discharge for the unconfined aquifer. The amount of groundwater discharging to the river and Lakes is a function of the local hydraulic properties of the aquifer and of the hydraulic gradient between the groundwater elevation alongside or beneath the river/Lakes, and the river/Lakes stage. This hydraulic gradient is variable at any given time, since the river stage is affected by seasonal variations in precipitation and temperatures in other regions of the river drainage system. In this three dimensional modeling effort, the surface nodes at the river edge and Lakes were simulated as constant-head boundary conditions reflective of the assumed river stage or Lake water level.

The nodes below the surface and along the center of the river were simulated as no-flow boundaries. This design leads to a more accurate approximation of the upward movement of groundwater as the groundwater flow is controlled by the hydraulic gradient between the aquifer and the river/Lakes. Therefore the Lakes and Tikur-Wuha River are constant head boundary nodes (Dirichlet nodes); the head value being equal to the water level at that specific node. In the same manner the foot of mountainous ridges (watershed divides) bounding the model area are General Head Boundaries in which modflow to the model.

The boundary at 250.0 m below the surface was set to be a no flow boundary. The whole drainage surface area, with the exception of the Lakes and Tikur-Wuha River, is top surface boundary takes precipitation, evaporation and run-off into consideration. Recharge rate of 5 to 25% is given to the model for proper estimation of the water levels measured in the wells. Side boundaries along the ridges could be assumed as the groundwater divides and hence no flow boundary condition was given. Side boundaries along the rivers are also set as no flow boundary conditions. Bottom boundary assumed at 250 m below the surface was set as a no-flow boundary, so that at such depth bed rock is assumed to exist. The constant head boundaries are the Lake Hawassa and the Chelelleka swamp. The dotted line connecting these two water bodies is the Tikur-Wuha River which is also a constant head boundary.

The boundary conditions discussed above had been used in the steady state simulation of the groundwater flow which is coded to set the initial condition for the transient simulation. In the

Transient simulation, in addition to the above boundaries, time dependent boundaries are also necessary.

4.5. Model Calibration

In the study area more than 41 measured water levels (springs, deep and shallow wells) have been inventoried. 37 boreholes have been selected in this research. 2 spring 13 Shallow wells (depths range up to 40m) and 37 boreholes (having depth range up to 201 meters). Their location in the study area can be seen in Figure 13 below .Since the study focuses on collecting already existing wells the distribution seems concentrated towards the location of Hawassa city and Gemeto well field.

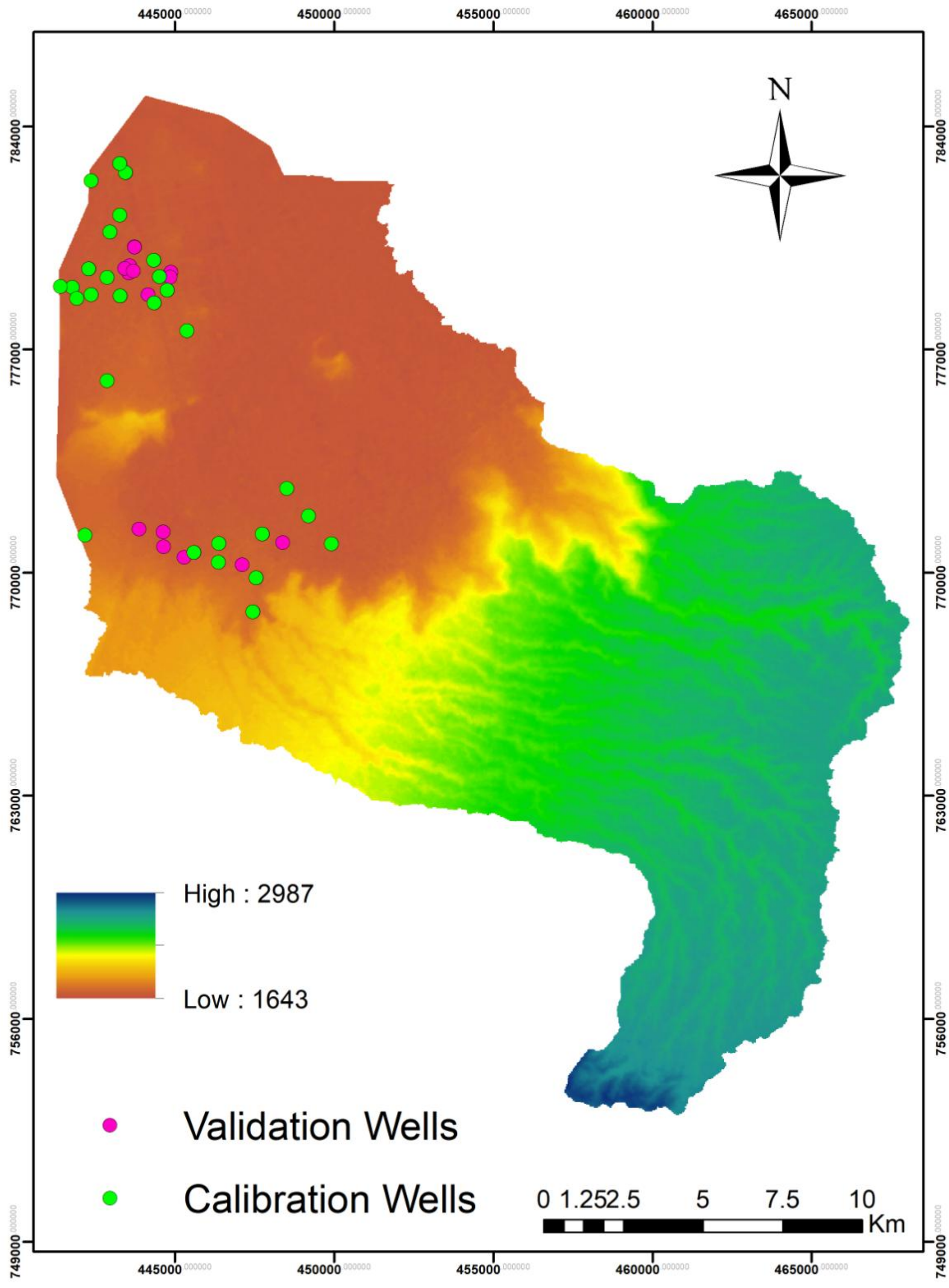

Figure 13: Gemeto Well field basin and inventoried Well location.

Among the two ways, Manual trial & error and Automated parameter estimation methods, of finding model parameters to achieve calibrations. In this study the manual trial and error adjustment of parameters is used. The model calibration is performed to data observed at wells inventoried (Dotes in Figure 14 above.). The observed data at these boreholes describes the water level variation in the boreholes from January till end of March 2018. For the lake level observed in 2018 the developed model is computed by varying the hydraulic conductivity and the recharge. The conceptual model of different hydraulic conductivity and recharge values were given to the conceptual models. Selection of a set of hydraulic parameters and recharge for the model zones has been made after a number of trial and error iteration.

For the above hydraulic conductivity and recharge values the modeled and the measured values comparison can be seen. In the figure the best fit equation obtained between the modeled and Measured (well inventory data) is made by making the intercept at the origin. The average indicator between modeled and calibrated results is shown in the table .h_m and h_s are measured and simulated results and n is the number of well data.

For error normally distributed data, RMSE is the best method to measure error. The maximum acceptable value of calibration criterion depends on the magnitude of the change in head over the problem domain (Anderson and Woessner, 1992). Owing to the accuracy of the well inventory data collection method, the topographic map of the basin being created from 30 m by 30 m digital elevation model, the hydrogeological classification with respect to the basin size, the numerical error that would occur due to the inherent approximations and assumptions, the RMSE, ME and MAE obtained are acceptable.

Thus this conceptual model will be used for further analysis.. The simulated head distribution shows the groundwater surface flow from eastern escarpment (Wijigra and Girja) to chelekleka swamp and southern part of the lake catchment to the lake via Tikur Wuha River to west directions .

Table 5: Well model Calibration

Wells	Observed level (m)	Simulated level (m)	error	
1	1703.4	1708.116577	-4.716552734	
2	1706.47	1723.664307	-17.19433594	
3	1702.5	1707.91919	-5.419189453	
4	1708.5	1741.111694	-32.61169434	
5	1677.7	1716.349487	-38.64953613	
6	1688	1716.650269	-28.65026856	
7	1688.4	1725.256104	-36.8560791	
8	1699	1734.824707	-35.82470703	
9	1715	1731.493042	-16.49304199	
10	1679	1717.79773	-38.79772949	
11	1685	1716.908691	-31.90869141	
12	1683	1716.686279	-33.6862793	
13	1685	1717.964478	-32.96447754	
14	1692.6	1712.153931	-19.55395508	
15	1683	1719.746704	-36.7467041	
16	1703.87	1709.338013	-5.468017578	
17	1738.8	1756.733154	-17.93310547	
18	1695.9	1727.293701	-31.39367676	
19	1687.7	1716.109131	-28.40917969	
20	1683	1719.277832	-36.27783203	
21	1686.7	1716.641724	-29.94177246	
22	1688.6	1733.681274	-45.08129883	
23	1680.9	1767.906372	-87.00634766	
24	1705	1709.761108	-4.761108398	
Total	2130.8999	2200.319336	-69.41943359	

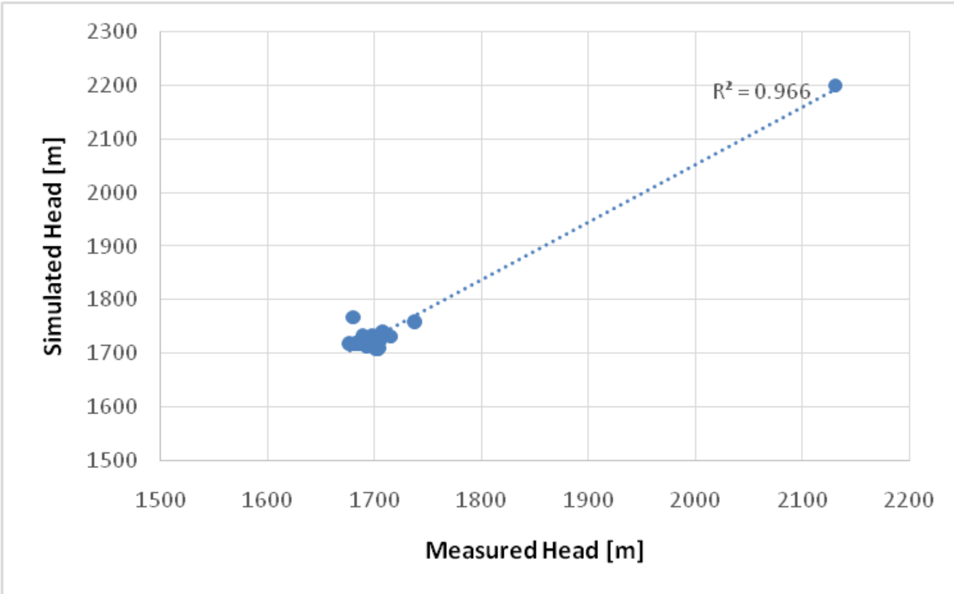

Figure 14: Measured Vs. simulated Groundwater during calibration.

Table 6:Well model validation.

Wells	Observed level (m)	Simulated level (m)	Error
1	1700.54	1708.428	-7.88782
2	1727.1	1749.842	-22.7422
3	1705	1700.816	4.184204
4	1684.4	1704.913	-20.5129
5	1698.4	1701.465	-3.06543
6	1709	1706.942	2.05835
7	1694.3	1707.132	-12.8324
8	1700.35	1704.449	-4.09937
9	1677	1700.916	-23.9155
10	1705.37	1707.194	-1.82397
11	1698	1721.391	-23.3915
12	1746	1751.691	-5.69128

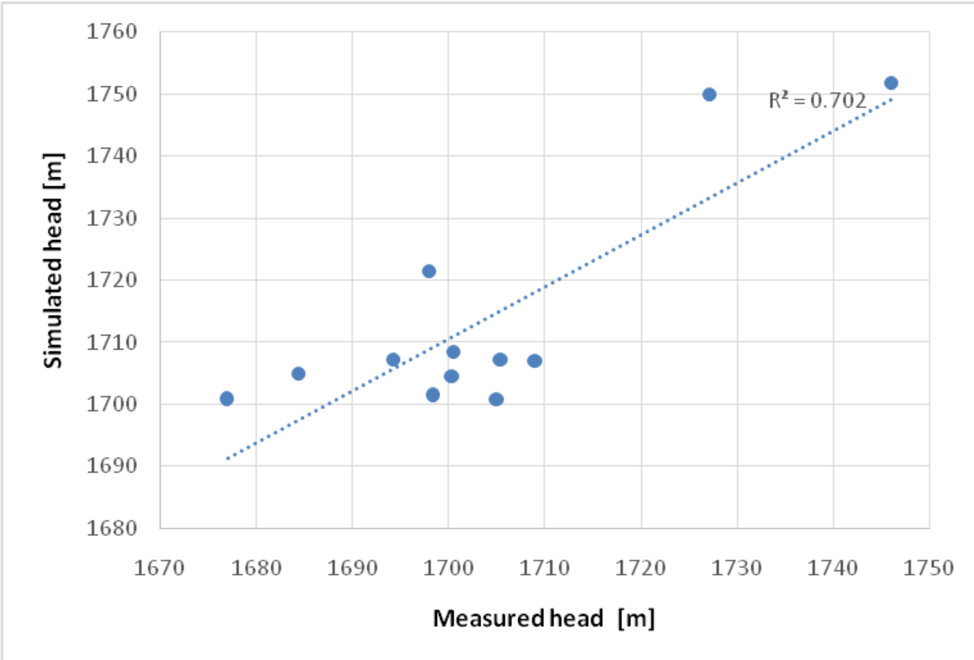

Figure15: Measured Vs. simulated Groundwater model during validation.

4.6. Groundwater Level and Movement

Ground water flows from areas of recharge to area of discharge. Discharge may occur to the atmosphere by transpiration from plants rooted below the water table, to streams, Lakes, and other surface water bodies, or pumping wells.

Groundwater flow directions have been estimated based on the available data. The groundwater flow within the study area is mainly from the eastern escarpment towards Lake Hawassa and limited amount to Lake Chelekleka The groundwater level is generally flat to gentle slope except at central part of the study area ridge and cinder cone areas. In these areas the groundwater contour shows steep slope showing lower permeability, probably due to the nature of the rocks or the fault systems separating these zone.

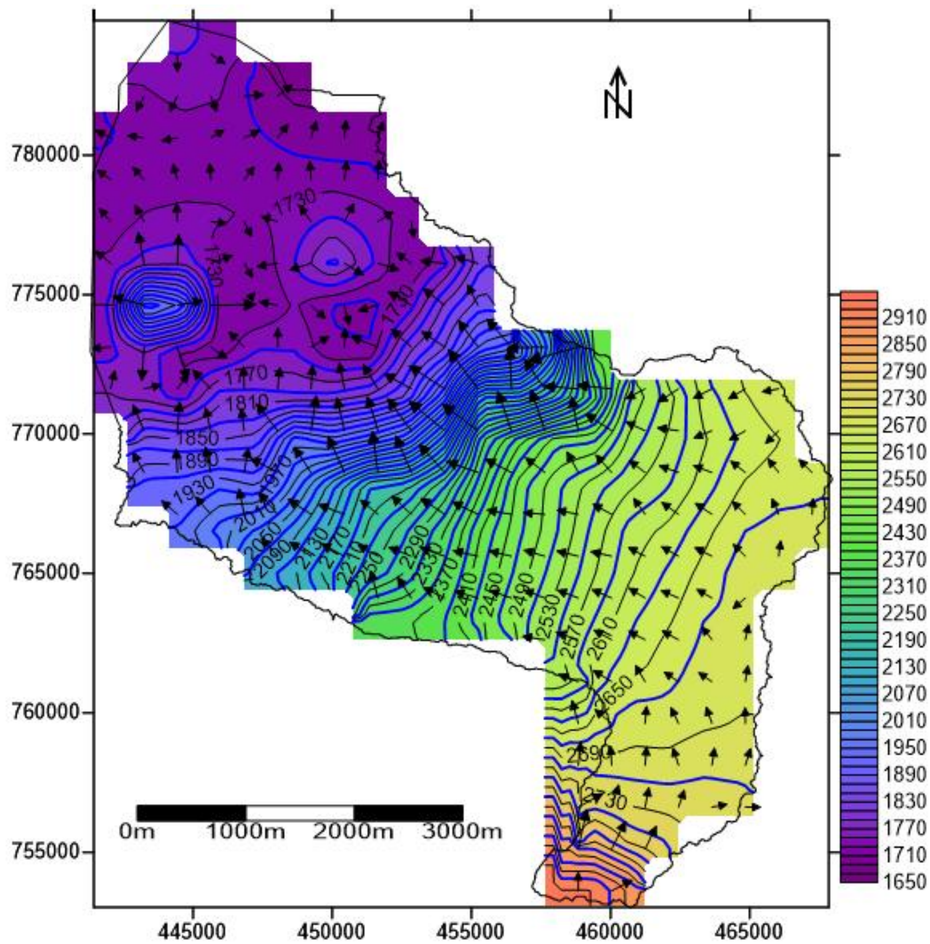

Figure 16: Groundwater flow direction

4.7. Pumping Rate and its Effect on the Capture Zone

Pumping scenarios were used to evaluate the response of the groundwater system under variable groundwater abstraction rates. The system response was compared with resulting changes in water level and groundwater outflow from the model domain. For this analysis, 41 water supply boreholes which were drilled at Gemeto well field that tap the extrusive and alluvial deposits aquifer, extracted from volcanic rocks on the valley floor, were used. To understand the effect of pumping and its capture zone around Gemeto well field a number of pumping rates were tried. The minimum of which is the current pumping rate by the city as shown in the following table. The procedure for the pumping test started by scenario 1 using the actual pumping rate as initial condition and it is assumed that 1hr/day for 300 days/year is considered for all the 41 wells in the well field.

Table 7: Pumping rate used for the capture zone analysis

wells	pumping rate scenarios (m^3/s)					
	1	2	3	4	5	6
	ic	icx1.3	icx1.4	icx1.5	icx1.8	icx2
Well 1	-0.0204	-0.027	-0.02856	-0.031	-0.04	-0.0408
Well 2	-0.061	-0.079	-0.0854	-0.092	-0.11	-0.122
Well 3	-0.066	-0.086	-0.0924	-0.099	-0.12	-0.132
Well 4	-0.0636	-0.083	-0.08904	-0.095	-0.11	-0.1272
Well 5	-0.0645	-0.084	-0.0903	-0.097	-0.12	-0.129
Well 6	-0.047	-0.061	-0.0658	-0.071	-0.08	-0.094
Well 7	-0.0204	-0.027	-0.02856	-0.031	-0.04	-0.0408
Well 8	-0.047	-0.061	-0.0658	-0.071	-0.08	-0.094
Well 9	-0.006	-0.008	-0.0084	-0.009	-0.01	-0.012
Well 110	-0.017	-0.022	-0.0238	-0.026	-0.03	-0.034
Well 11	-0.0084	-0.011	-0.01176	-0.013	-0.02	-0.0168
Well 12	-0.0077	-0.01	-0.01078	-0.012	-0.01	-0.0154
Well 13	-0.0128	-0.017	-0.01792	-0.019	-0.02	-0.0256
Well 14	-0.0073	-0.009	-0.01022	-0.011	-0.01	-0.0146
Well 15	-0.0066	-0.009	-0.00924	-0.01	-0.01	-0.0132
Well 16	-0.00524	-0.007	-0.00734	-0.008	-0.01	-0.01048
Well 17	-0.022	-0.029	-0.0308	-0.033	-0.04	-0.044
Well 18	-0.022	-0.029	-0.0308	-0.033	-0.04	-0.044
Well 19	-0.022	-0.029	-0.0308	-0.033	-0.04	-0.044
Well 20	-0.005	-0.007	-0.007	-0.008	-0.01	-0.01
Well 21	-0.00666	-0.009	-0.00932	-0.01	-0.01	-0.01332
Well 22	-0.00733	-0.01	-0.01026	-0.011	-0.01	-0.01466
Well 23	-0.007	-0.009	-0.0098	-0.011	-0.01	-0.014
Well 24	-0.00875	-0.011	-0.01225	-0.013	-0.02	-0.0175
Well 25	-0.005	-0.007	-0.007	-0.008	-0.01	-0.01
Well 26	-0.022	-0.029	-0.0308	-0.033	-0.04	-0.044

Well 27	-0.022	-0.029	-0.0308	-0.033	-0.04	-0.044
Well 28	-0.022	-0.029	-0.0308	-0.033	-0.04	-0.044
Well 29	-0.006	-0.008	-0.0084	-0.009	-0.01	-0.012
Well 30	-0.00366	-0.005	-0.00512	-0.005	-0.01	-0.00732
Well 31	-0.003	-0.004	-0.0042	-0.005	-0.01	-0.006
Well 32	-0.007	-0.009	-0.0098	-0.011	-0.01	-0.014
Well 33	-0.00611	-0.008	-0.00855	-0.009	-0.01	-0.01222
Well 34	-0.006	-0.008	-0.0084	-0.009	-0.01	-0.012
Well 35	-0.00594	-0.008	-0.00832	-0.009	-0.01	-0.01188
Well 36	-0.0056	-0.007	-0.00784	-0.008	-0.01	-0.0112
Well 37	-0.00583	-0.008	-0.00816	-0.009	-0.01	-0.01166
Well 38	-0.00536	-0.007	-0.0075	-0.008	-0.01	-0.01072
Well 39	-0.00446	-0.006	-0.00624	-0.007	-0.01	-0.00892
Well 40	-0.013	-0.017	-0.0182	-0.02	-0.02	-0.026
Well 41	-0.045	-0.059	-0.063	-0.068	-0.08	-0.09
Total	0.75	0.975	1.049	1.124	1.349	1.499

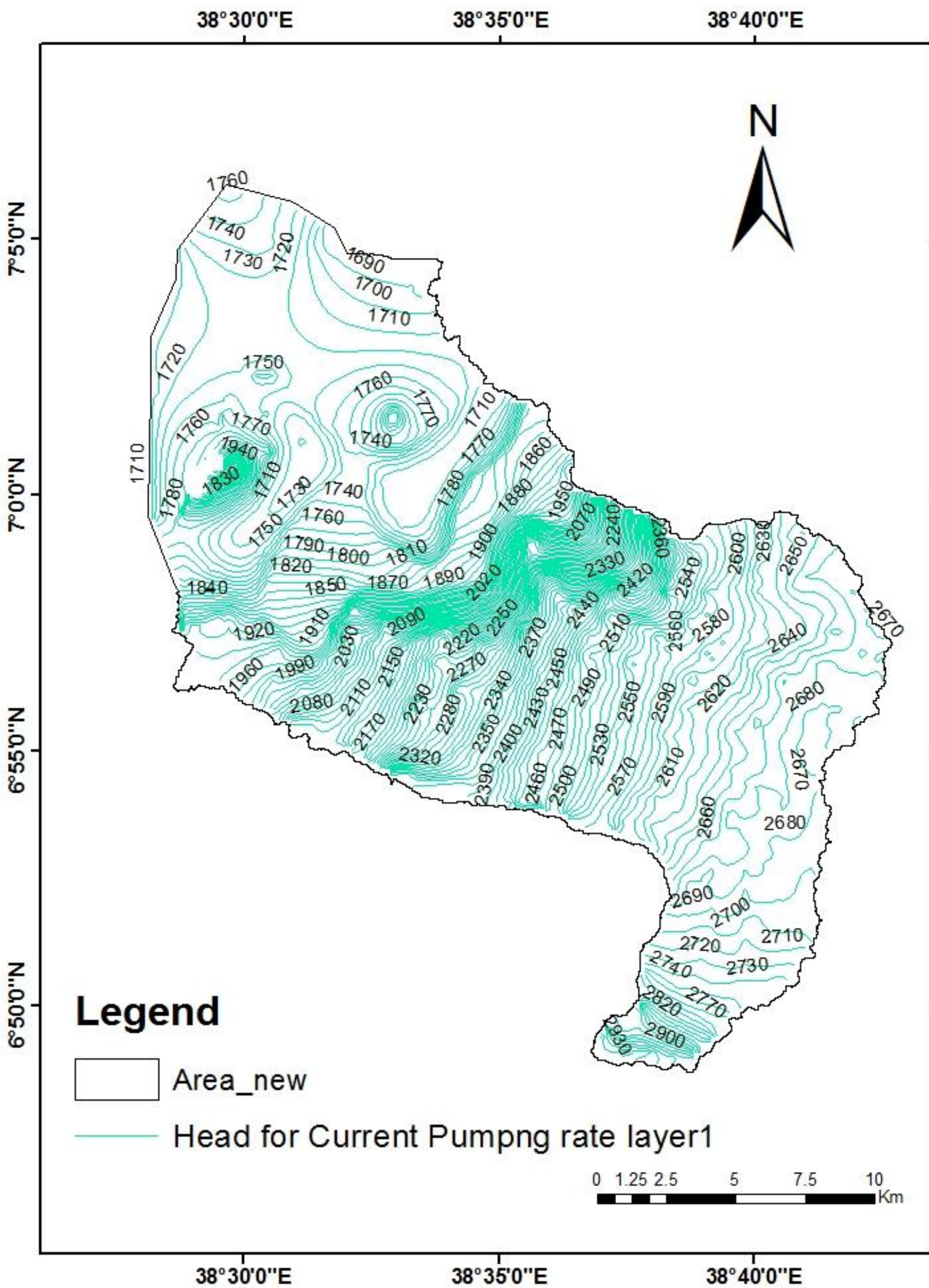

Figure 17: Groundwater head for current pumping rate

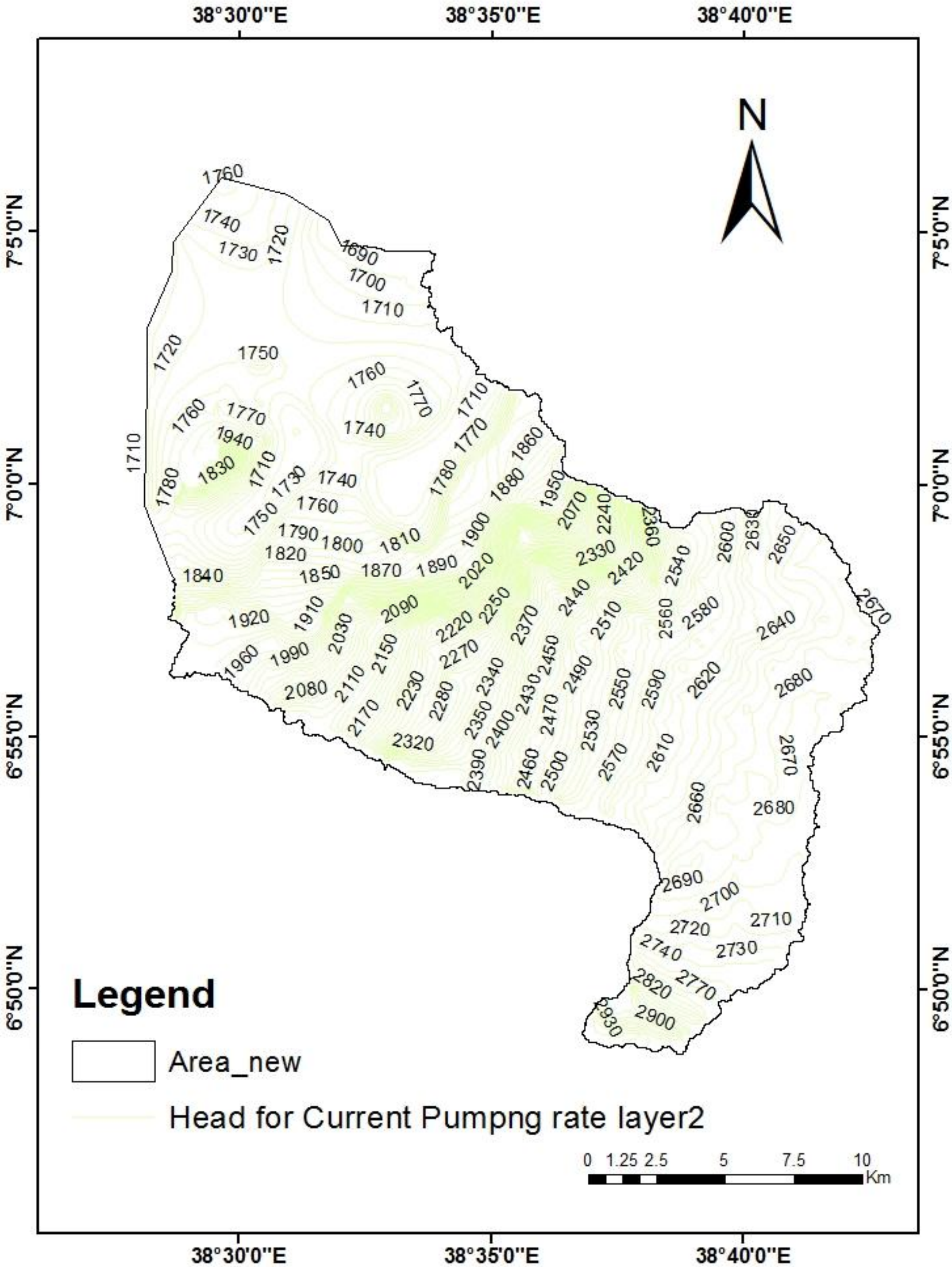

Figure 18: Groundwater head for current pumping layer 2

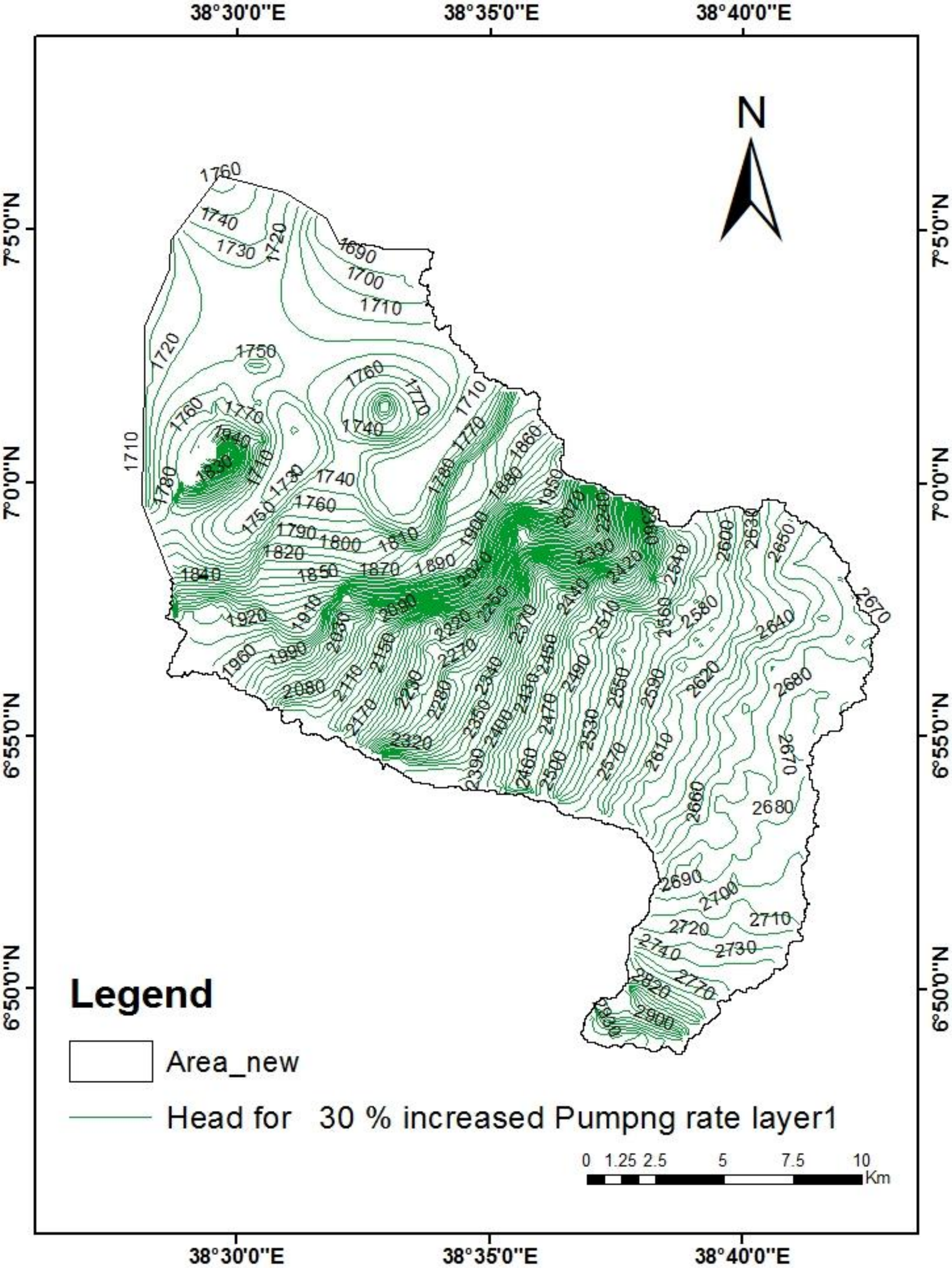

Figure 19: Groundwater head for pumping rate of increase by 30%

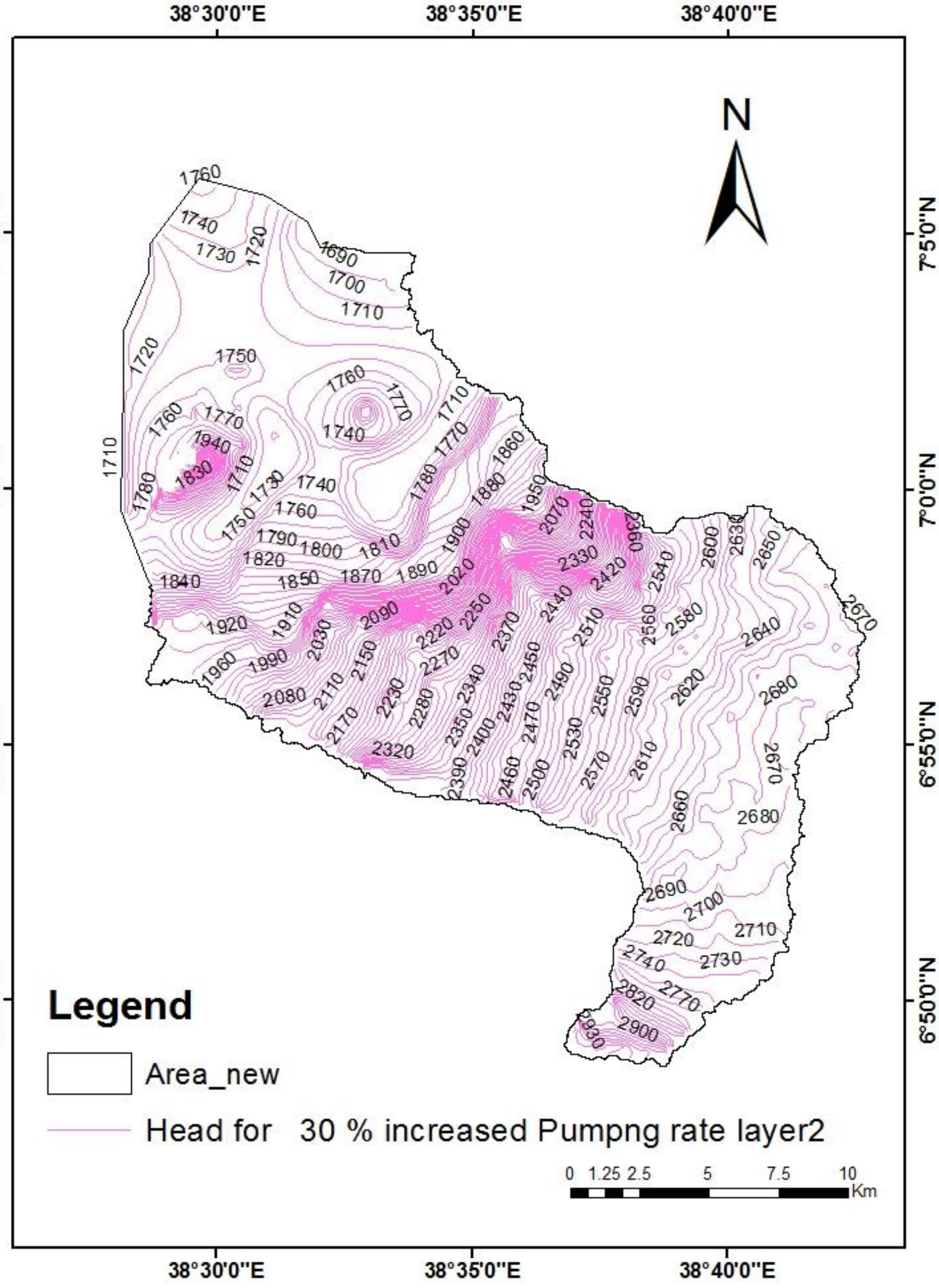

Figure 20: Groundwater head for pumping rate increase by 30%

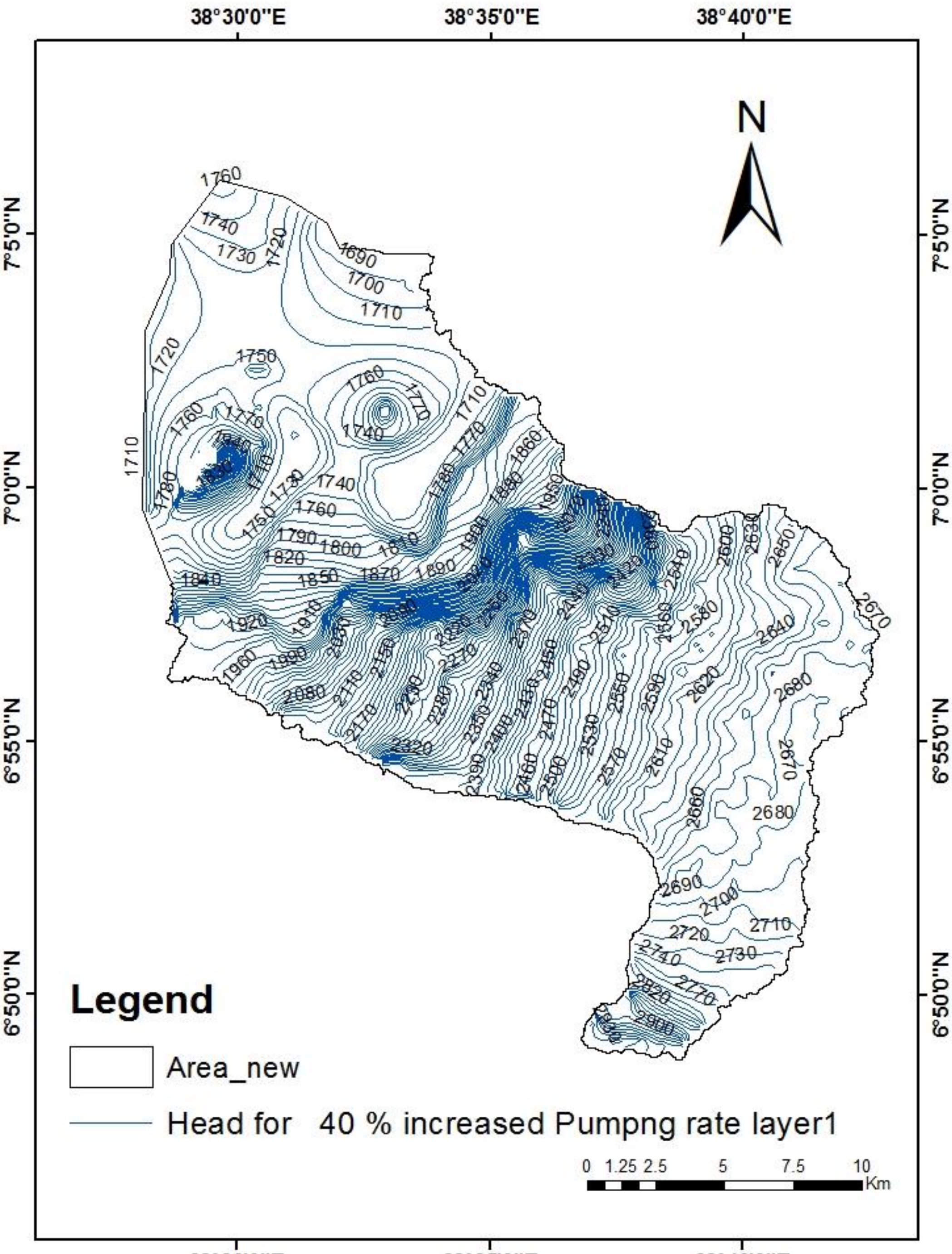

Figure 21:Groundwater head for pumping rate increase by 40%

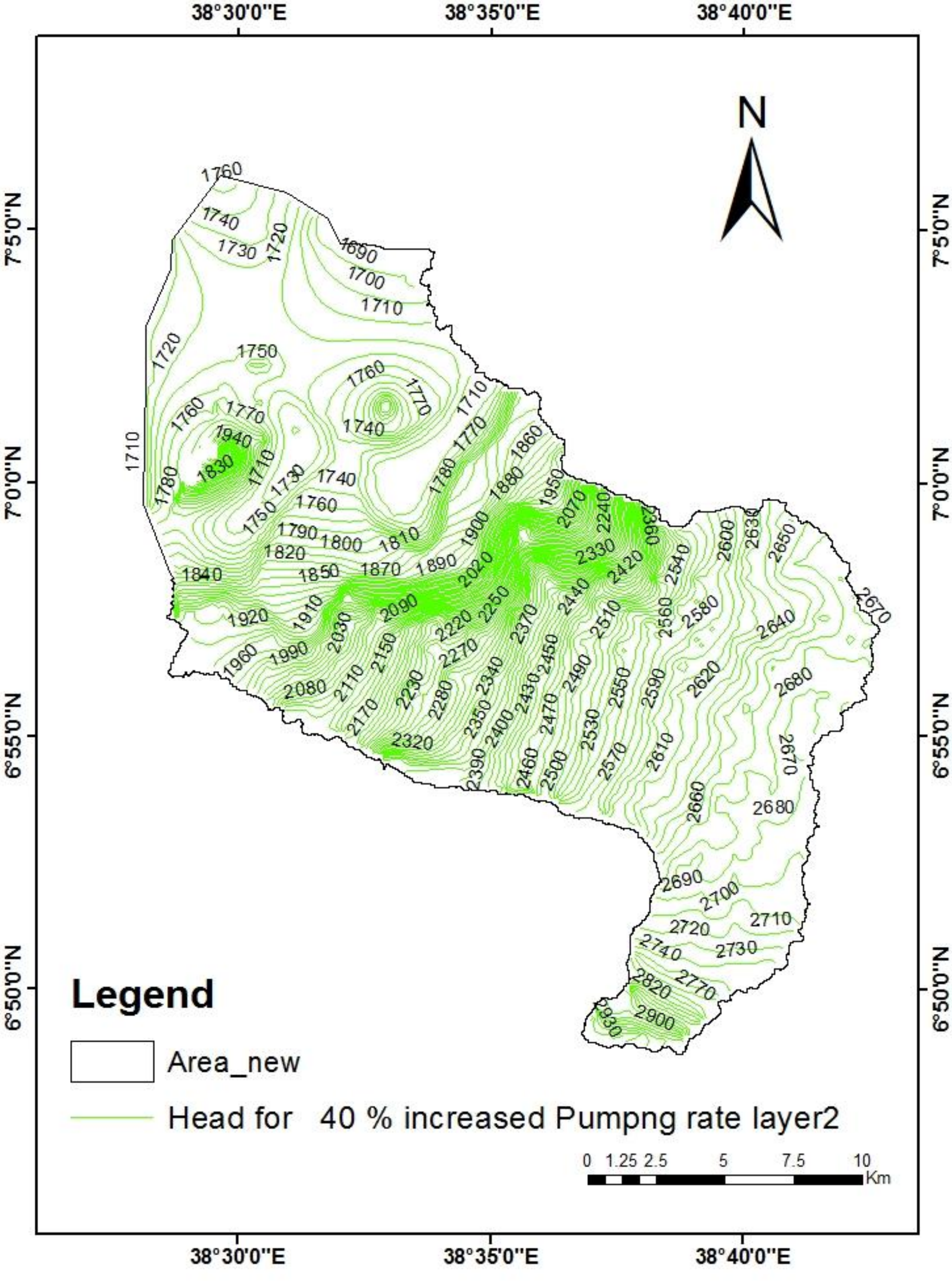

Figure 22: Groundwater head for pumping rate increased by 40%

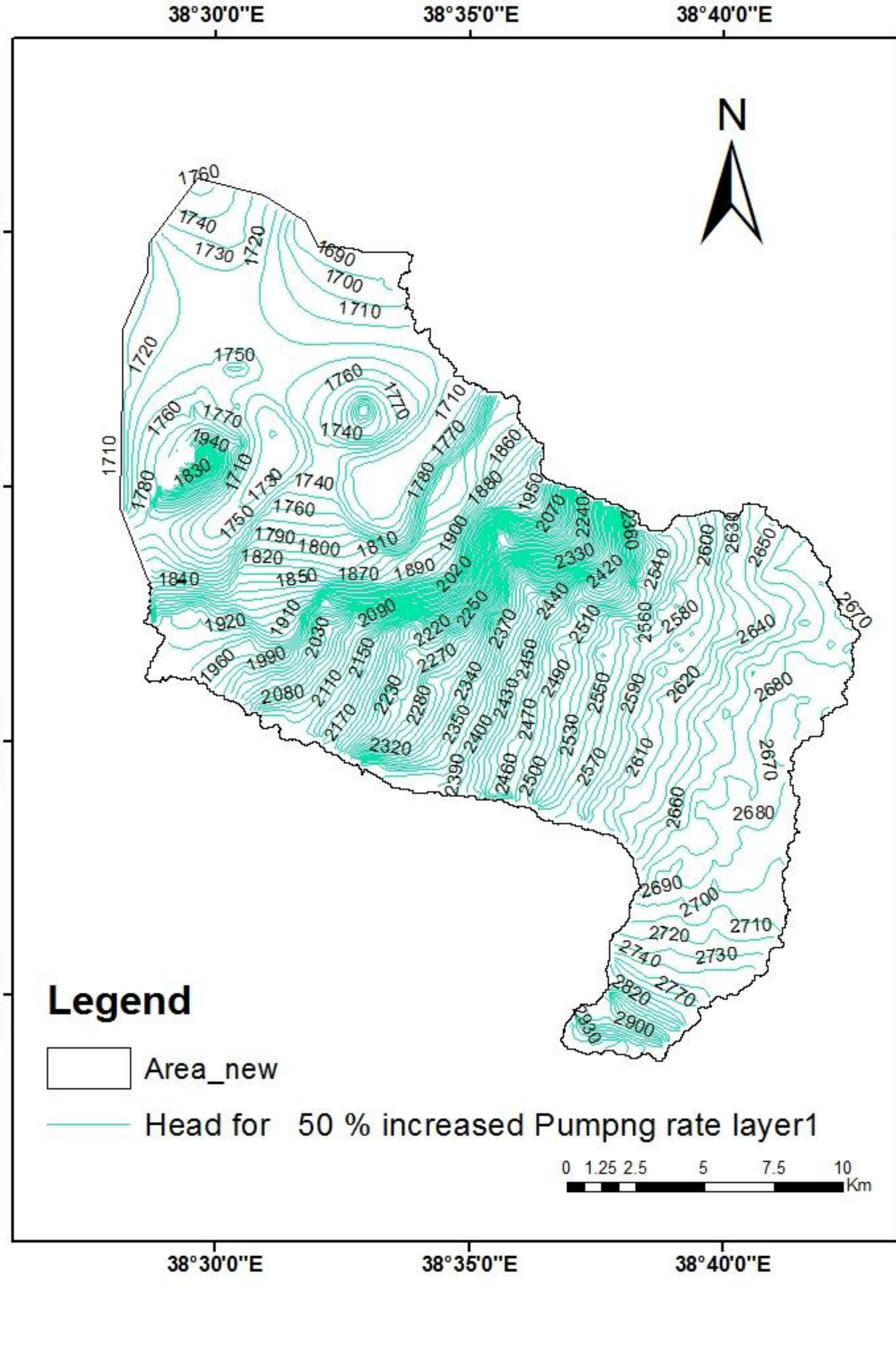

Figure 23: Groundwater head for pumping rate increased by 50%

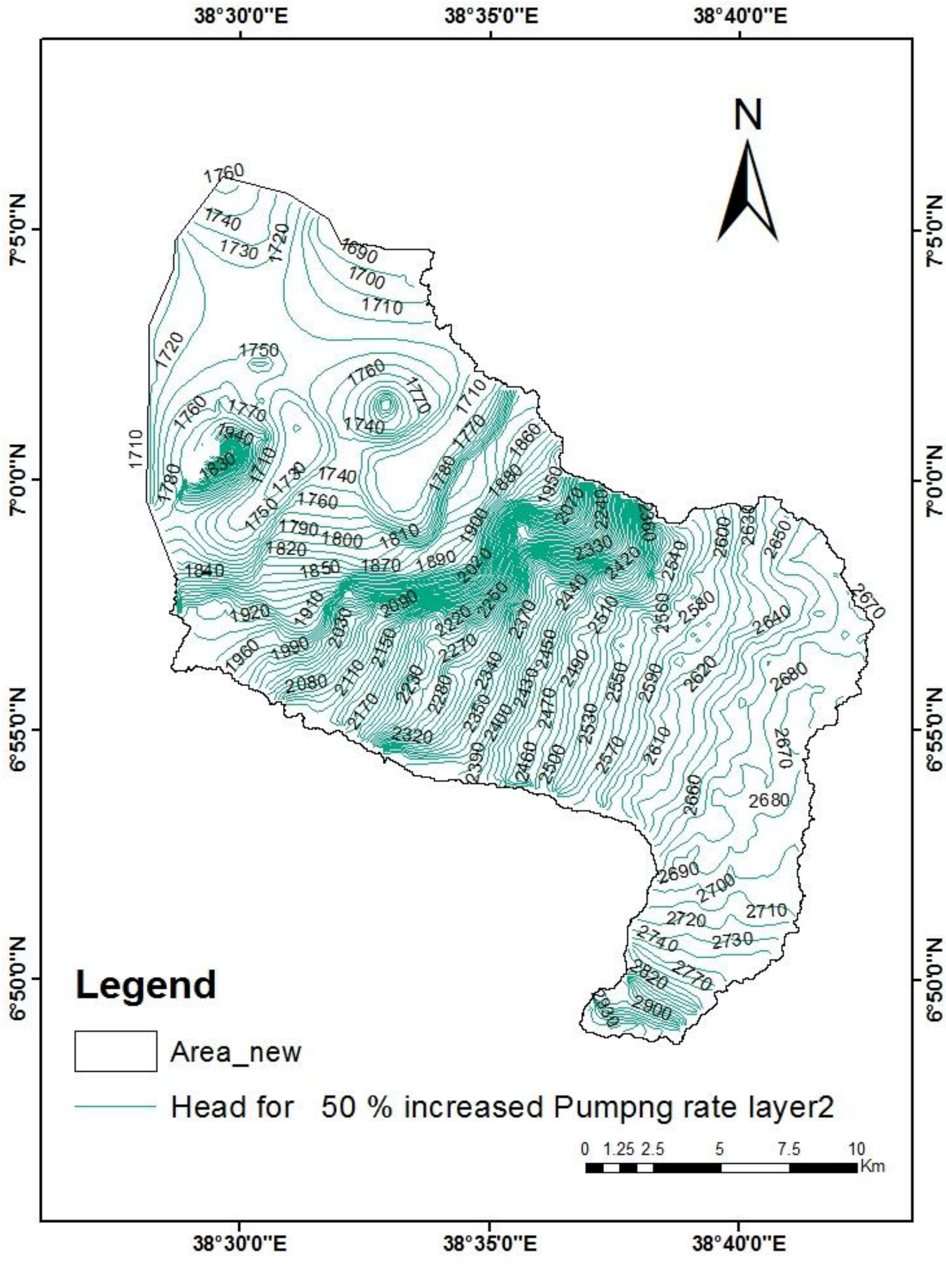

Figure 24: Groundwater head for pumping rate of increased by 50%

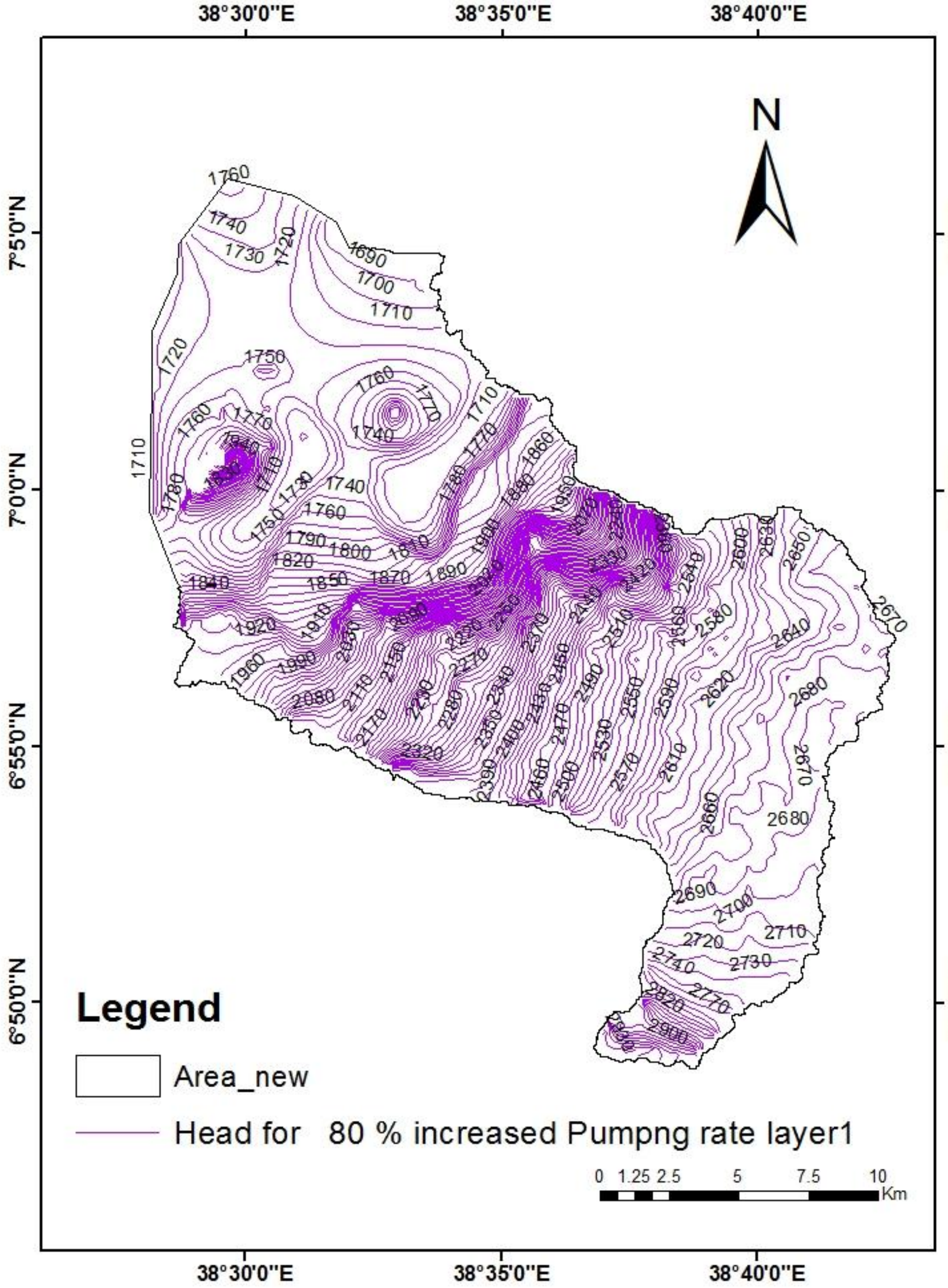

Figure 25: Groundwater head for pumping rate of increased by 80%

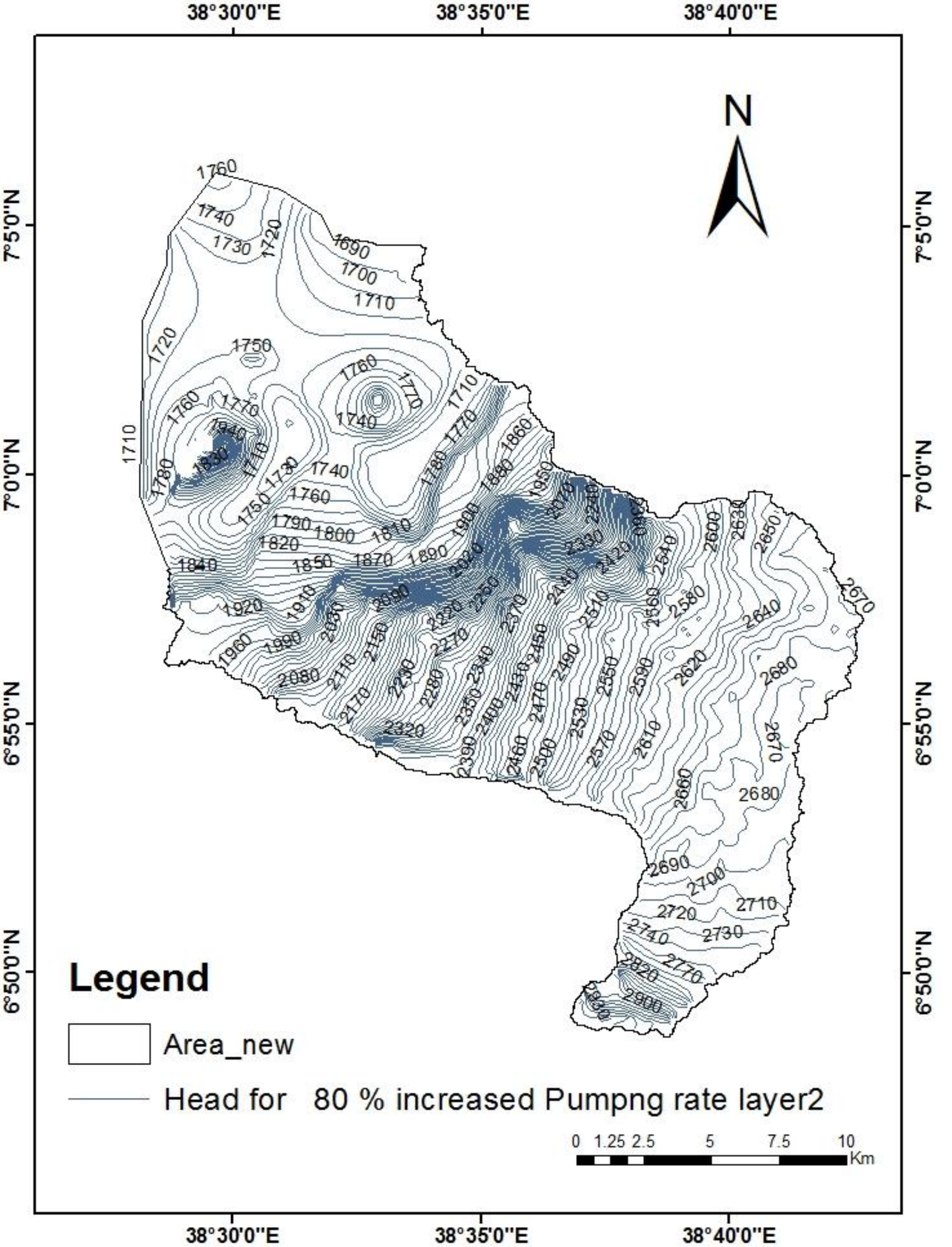

Figure 26: Groundwater head for pumping rate of increased by 80%

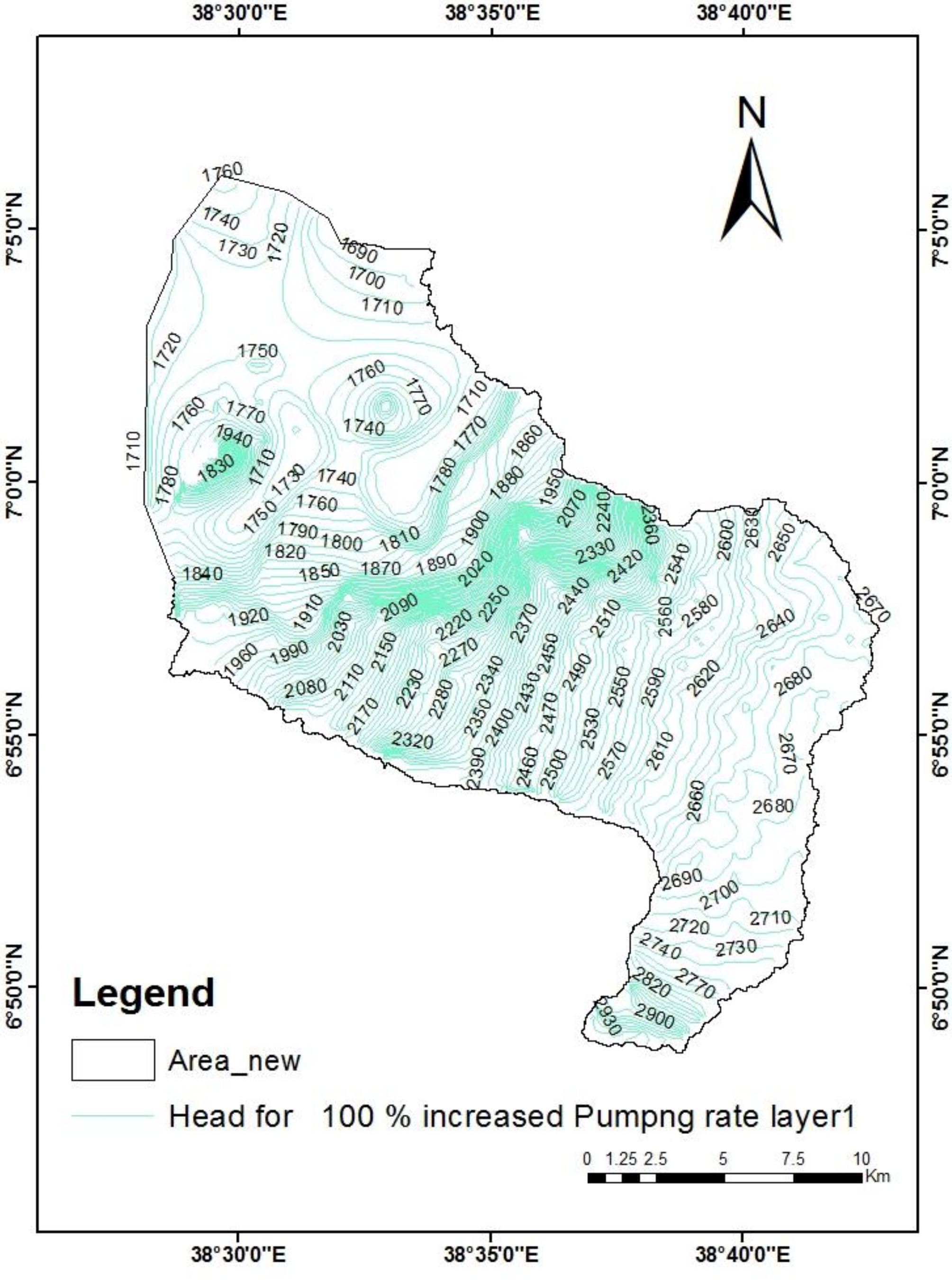

Figure 27: Groundwater head for pumping rate of increased by 100%

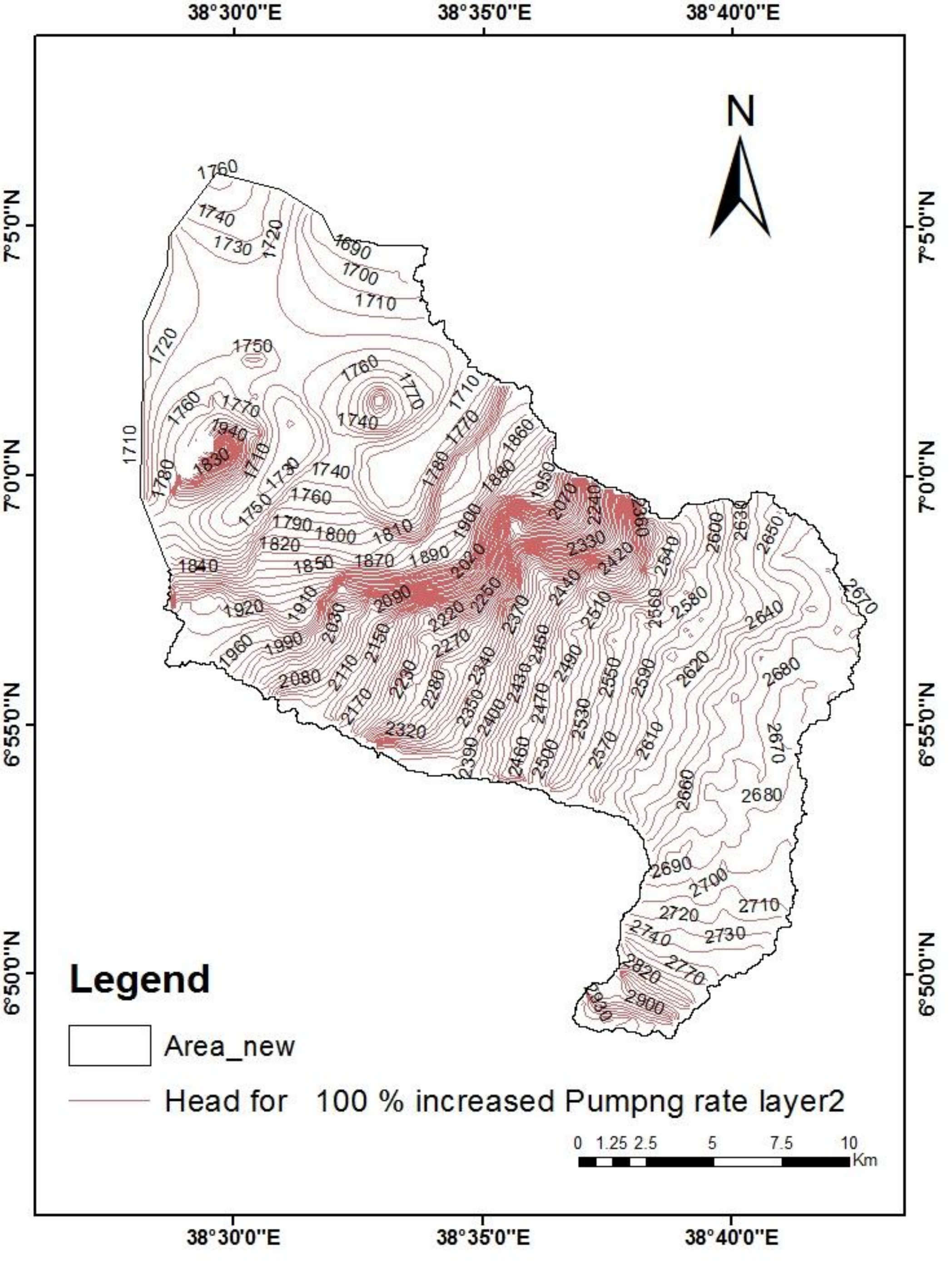

Figure 28: Groundwater head for pumping rate of increased by 100%

Accordingly the calibrated model results for the six scenarios were as depicted in the above figures. From the above figures (figure 17 to figure 28) it is evident that the discharge rate being larger increases the capture zone of the well field. Any further pumping will create a small hydraulic head near by the Gemeto well field which ultimately draws groundwater around the city. From the 6th scenario pumping rate the amount of water abstracted from the aquifer was 1499l/s or 5396.4m^3/day or 1618920m^3/year.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Generally, the aim of the study was to obtain a better understanding of the Groundwater flow system and well level characterization of the small Groundwater basin within the larger Hawassa Lake basin by applying numerical flow modeling modflow 2005 by using finite difference method.

The study was set better way for the defining of the models which was transferred to the numerical model that has capability to imitate the field data with relatively good accuracy. The field observation together with the model result can be used to realize the aquifers system under transit state condition despite of the uncertainties of the result. This conceptual models simulated heads contour map shows that the general hydraulic gradient in the basin follow the surface topography and the gradient is towards Lake Hawassa. The simulated hydraulic conductivity values varies in the category from 0.00002m/s to 0.0009m/s shown in the figure 12 as you go to the Lake from Gemeto well field within the model domain. The aquifer character by maximum value is 0.00085m/s and the minimum value is 0.00003m/s.

The general groundwater flow direction is estimated to be more towards Lake Hawassa and limited amount to Lake Chelelleka. From the simulated pumping rate scenario the aquifer under study responded as per the calibration using the measured data, and 1hpd and 300dpy of pumping it was used in the model, the 1st scenario started with 750l/s, 2nd scenario 975l/s, 3rd scenario 1049l/s, 4th scenario 1124l/s, 5th scenario 1349l/s and finally 6th scenario with 1499l/s pumping rate was captured.

5.2 Recommendations

Based on the finding of the study outcomes the following recommendations were drawn.

- To get more detailed analysis more extensive monitoring well data are required.
- In addition the geophysical analysis on sample of the geologic log should be available to get some initial better insight on the aquifer material in the area.

REFERENCES

AG consult consulting hydrologists and Engineers. 2007. The study pollution of Lake and Rivers report, Addis Ababa, Ethiopia, pp. 100.

Anderson, M. P., and Woessner, W. W. 1992. Applied Groundwater Modeling. Acad. Press, San Diego, USA.

Ayenew and Robert B. 2007. Comparative study of the hydrology and hydrogeology of selected Ethio –Kenyan rift lakes. Addis Ababa dep. of earth Sciences & interactional institute for Geo information science and earth observation.

Ayenew and Tamiru Alemayehu. 2001. Principle of hydrogeology, Addis Ababa University, Addis Ababa, Ethiopia.

Ayenew, Robert Becht, Arno van Lieshout, Yemane Gebreegziabher, Dagnachew Legesse and Japheth Onyando. 2007. Hydrodynamics of topographically closed lakes in the Ethio-Kenyan Rift: The case of lakes Awassa and Naivasha. Journal of Spatial Hydrology. 81-100.

Ayenew. 1998. The hydrogeological system of the Lake District basin, central main Ethiopia rift. PhD Thesis, Free University of Amsterdam.

Ayenew. 2001. Numerical groundwater flow modeling of the central main Ethiopian rift Lakes basin, SINET: Ethiopian. Journal of Science 24 (2), 167 – 184.

Ayenew. and Yemane G. 2010. Application of spreadsheet hydro geological model for computing the longtime water balance of Lake HAWASSA

Bear, J. and Verruijt, A. 1987. Modeling Groundwater Flow and Pollution. Springer, 432p

Bredehoeft, J. D. and Konikow, L. F. 1993. Ground-water models: Validate or invalidate. Ground Water. 31(2):178-179.

Chernet, T. 1982. Hydrogeological map of the lakes region (with memo). Ethiopian Institute of Geological Survey. Addis Ababa, Ethiopia

Crowe, A.S. 1990. Numerical modeling of the groundwater contribution to the hydrological budget of lakes. In: Selected Papers on Hydrogeology. (Simpson, E.S. and Sharp, J.M., Eds.). IAH Pub.1:283-294.

Crowe, A.S. and Schwartz, F.W. 1981. Simulation of Lake Watershed systems. I. Description and sensitivity of the model. Journal of Hydrology. 52: 71-105.

Dereje B. 2011. Numerical Groundwater Flow Modeling of theMeki River Catchment, Central Ethiopia. MSc thesis, Addis Ababa, 110p.

Fetter, C.W. 1994. Applied hydrogeology, Prince hall in New jersey, USA 604 pp

Franke, O.L., T.E. Reilly, and G.D. Bennett. 1987. Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems - an introduction, U.S. Geological Survey, Techniques of Water Resources Investigations, Book 3, Chapter B5, 15 pp.

Freeze, R.A. & Cherry, J.A. 1997. Prentice-Hall, Englewood Cliffs, N.J., USA.604pp.

Geological survey of Ethiopia. 2000. Engineering Geological study of Hawassa basin and its surroundings.

Gizaw B. 1996. The origin of high bicarbonate and fluoride concentrations in waters of the main Ethiopian Rift Valley. J Afr Earth Sci 22(4):391–402.

Gualbert, E. 2000. Groundwater Modelling, Utrecht University, 201p

Halcrow Group Limited and GIRD consultants, 2009. Rift Valley Lakes Bain Integrated Resources Development Master Plan Study Project, Vol. II, Appendix C&D, Addis Ababa, Ethiopia

Jacob Bear and Arnold Verruijt. 1987. Modeling groundwater flow and pollution: with computer programs for sample cases D. Reidel Pub. Co. (Theory and applications of transport in porous media). pp. 27-84 & 247-315

Japan international cooperation Agency KOKUSAIKOGYO. 2012. Study on groundwater resources assessment in the rift valley lakes basin Ethiopia, Addis Ababa.

Jyrkama, M. I. and. Sykes, J. F. 2007. The impact of climate change on spatially varying groundwater recharge in the Grand River watershed (Ontario). Journal of Hydrology, vol 338:237-250.

Konikow, L. F. and Bredehoeft, J. D. 1992. Ground-water models cannot be validated. Advances in Water Resources.15 (1):75-83.

McDonald, M.G. and A.W. Harbaugh, 1988. A Modular Three-Dimensional Finite-*Difference*

Ground-Water Flow Model, USGS TWRI Chapter 6-A1, 586 p.

MOWR, 2002. Water sector development program 2002-2016, Volume II: Main Report. Ministry of Water Resources, Federal Democratic Republic of Ethiopia,Addis Ababa, October 2002.

Oreskes, N., Shrader-Frechette, K., and Belitz, K. 1994. Verification, validation, and confirmation of numerical models in the earth sciences. Science.263:641-646.

Seifu Kebede, Travi, Y., Asfawessen Asrat, Tamiru Alemayehu, Tenalem Ayenew, and Zenaw Tessema. 2007. Groundwater origin and flow along selected transects in Ethiopian rift volcanic aquifers. Hydrogeology Journal

Seifu, T. 2014. Groundwater potential assessement of gemeto well field in lake Hawassa basin. MSc thesis, Addis Abeba University, Ethiopia, 72p.

Simmers, I. 1988. Estimation of natural groundwater recharge. NATO ASI Series C: Mathematical and Physical Sciences; 222. D. Reidel, Dordrecht etc., 510pp.

Simmers, I., Hendrickx, J.M.H., Kruseman, G.P. And Rushton, K.R. 1997. Recharge of phreatic aquifers in semi-arid areas. International contributions to hydrogeology: IAH International Association of Hydro geologists; 19. Balkema, Rotterdam etc., 277pp.

Tadesse D. and Zenaw T. 2003. Hydrogeology and Engineering geology Ethiopia, hydrogeology, Engineering geology and geothermal department, Addis Ababa.

Todd, D.K. 1980. Groundwater Hydrology. John Wiley & Sons, New York.

Todd, D.K. 2005. Groundwater hydrology. Wiley, Hoboken, NJ, 636pp.

Wang, H.F., and Anderson, M.P. 1982. Introduction to groundwater modeling-finite difference and fine element methods. San Fransisco: W.H. Ffeeman.

WWDSE, 2001. The study on Lake HAWASSA level rise, Addis Ababa.

Yemane G. 2004. Assessment of the water balance of Lake Hawassa catchment thesis for the partial fulfillment of the requirement of degree of masters, AAU, Addis Ababa.