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ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAIT)

IMPACT OF PUMPING FOR IRRIGATION ON GROUNDWATER POTENTIAL

(The Case of Eastern part of Guraghe Zone)

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in partial Fulfillment of the Requirement for the Degree of Master Science in CivilEngineering (Hydraulic Engineering stream)

By: zekarias Banda

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Addis Ababa

July, 2015

Impact of pumping for irrigation on groundwater potential: Case of Eastern part of Guraghe Zone

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A Thesis Submitted to

The School of Civil and Environmental Engineering

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School of Graduate Studies

This is to certify that the thesis prepared by Zekarias Banda, entitled: Impact of pumping for irrigation on groundwater potential: in Case of Eastern part of Guraghe Zone in partial fulfillment of the requirements for the degree of Master of Science (Hydraulic Engineering) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Declaration

I, the undersigned person, declare that this thesis is my original work and that all sources of materials used for this thesis have been duly acknowledged.

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ABSTRACT

In the eastern part of Guraghe, bounded by Meki and Weja River, Irrigation practice increases using pumping technology. This alarming increasing of pumping groundwater for irrigation purpose has resulted in:-The reduction of groundwater potential in the groundwater basin and dry up of streams, rivers nearby. Such aggressive groundwater abstraction will result conflicts between the users of groundwater and rivers. Thus it is vital to understand the impact of such groundwater abstraction on its availability and decide on the optimum abstraction rate.

To assess the impact of groundwater abstraction in its availability and nearby rivers a 3D conceptual groundwater model is created. This conceptual model consists of the catchment divide in the west (guraghe High Mountain) and two adjacent rivers (Weja and Meki rivers). The catchment divide is taken as a hydraulic –Neumann-boundary and the two adjoin rivers are taken as dirichelet- boundary. The bottom and groundwater surface is between these boundaries is taken as a flux-boundary. Whereby the top ground takes recharge while the bottom is taken as a no-flow boundary. The four different geological strictures found are consider as different hydro geologic settings where by hydraulic conductivity is assigned as a trial value, to make sure that the hydraulic heads collected in 94 hand dug wells in the study area are estimated reasonably.

The above conceptual model is used as an input of TAGSAC software whereby the model area is decertified in to 22301 nodes and 21710 triangular prism elements of 200mx200mx200m all the 94 inventoried wells were represented by nodes. Thiesson polygon based on rainfall distribution is also used as an input but with a reduced rate to represent the effective recharge. The four different geologic setting were also represented by the finite elements generated, so that different hydraulic conductivity is given to each of the four geologic settings.

The model is calibrated with, 8.74m, 7.45m, 0.83 RMSE, ME and R^2 values respectively. After calibration the impact of pumping is analyzed by assigning the current groundwater abstraction rate 21,186,913m^3/year to the nodes representing the impact zone. The result clearly shows that the region of influence reaches the existing perennial river. Thus the current trend of pumping will result in drying up of these rivers. To come up with optimum pumping rate trial values were given to the model area representing the pumping site. An optimum pumping rate of 16,666,214m^3/year would minimize the impact of pumping on the adjacent rivers.

Keywords: Groundwater, Guraghe Zone, Numerical modeling, Optimum pumping rate, TAGSAC

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Acronyms

DEM = Digital Elevation Model

GPS= Global Positioning System

EWTEC = Ethiopian Water Technology Centre

MoWR /MWR = Ministry of Water Resources (present former of ministry of Water, irrigation and energy)

USGS = United State Geological Survey

SNNPR= Southern Nations Nationalities and Peoples Region

UTM = Universal Transverse Mercator

K = hydraulic conductivity

m = meter

m/sec = meter per second

m^3/year = meter cubic per year

L/Sec = litter per second

EG.GWM = East Guraghe Groundwater model

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Ground water systems are affected by natural processes and human activity, and require targeted and ongoing management to maintain the condition of ground water resources within acceptable limits, while providing desired economic and social benefits. Ground water management and policy decisions must be based on knowledge of the past and present behavior of the ground water system, the likely response to future changes and the understanding of the uncertainty in those responses. The location, timing and magnitude of hydrologic responses to natural or human-induced events depend on a wide range of factors - for example, the nature and duration of the event that is impacting ground water, the subsurface properties and the connection with surface water features such as rivers and oceans. Through observation of these characteristics, a conceptual understanding of the system can be developed, but often observational data is scarce (both in space and time), so our understanding of the system remains limited and uncertain.

It is not possible to see into the sub-surface, and observe the geological structure and the ground water flow processes. The best we can do is to construct bores, use them for pumping and monitoring, and measure the effects on water levels and other physical aspects of the system. It is for this reason that ground water flow models have been, and will continue to be, used to investigate the important features of ground water systems, and to predict their behavior under particular conditions.

Ground water models provide additional insight into the complex system behavior and (when appropriately designed) can assist in developing conceptual understanding. Furthermore, once they have been demonstrated to reasonably reproduce past behavior, they can forecast the outcome of future ground water behavior, support decision-making and allow the exploration of alternative management approaches. However, there should be no expectation of a single ‘true’ model, and model outputs will always be uncertain. As such, all model outputs presented to decision-makers benefit from the inclusion of some estimate of how good or uncertain the modeler considers the results. (Kumer C.P, 2013)

Models also form an integral part of decision support systems in the process of managing water resources, salinity and drainage, and should not be regarded as just an end point in themselves. The development and evaluation of resource management strategies for sustainable water allocation, and for control of land and water resource degradation, are heavily dependent on ground water model predictions. Regional scale ground water flow modeling studies are commonly used for water resource evaluation and to help quantify sustainable yields and allocations to end-users. Typical model purposes include:

- Improving hydro geological understanding (synthesis of data);
- Aquifer simulation (evaluation of aquifer behavior);
- Designing practical solutions to meet specified goals (engineering design);
- Optimizing designs for economic efficiency and account for environmental effects (optimization);
- Evaluating recharge, discharge and aquifer storage processes (water resources assessment);
- Predicting impacts of alternative hydrological or development scenarios (to assist decision-making);
- Quantifying the sustainable yield (economically and environmentally sound allocation policies);
- Resource management (assessment of alternative policies);
- Sensitivity and uncertainty analysis (to guide data collection and risk-based decision-making);
- Visualization (to communicate aquifer behavior).

A ground water model is a computer-based representation of the essential features of a natural hydro geological system that uses the laws of science and mathematics. Its two key components are a conceptual model and a mathematical model. Conceptual model is an idealized representation (i.e. a picture) of our hydro geological understanding of the key flow processes of the system. A mathematical model is a set of equations, which, subject to certain assumptions, quantifies the physical processes active in the aquifer system(s) being modeled. While the model itself obviously lacks the detailed reality of the ground water system, the behavior of a valid model approximates that of the aquifer(s). A ground water model provides a scientific means to draw together with the available data into a numerical characterization of a ground water system. The model represents the ground water system to an adequate level of detail, and provides a predictive scientific tool to quantify the impacts on the system of specified hydrological, pumping or irrigation stresses. (Indian journal of science, 2013)

Ground water models can be classified as physical or mathematical. A physical model (e.g. a sand tank) replicates physical processes, usually on a smaller scale than encountered in the field. A mathematical model describes the physical processes and boundaries of a ground water system using one or more governing equations. An analytical model makes simplifying assumptions (e.g. properties of the aquifer are considered to be constant in space and time) to enable solution of a given problem. Analytical models are usually solved rapidly, sometimes using a computer, but sometimes by hand. A numerical model divides space and/or time into discrete pieces. Features of the governing equations and boundary conditions (e.g. aquifer geometry, hydrogeologogical properties, pumping rates or sources of solute) can be specified as varying over space and time. This enables more complex, and potentially more realistic, representation of a ground water system than could be achieved with an analytical model. Numerical models are usually solved by a computer and are usually more computationally demanding than analytical models.

A ground water flow model simulates hydraulic heads (and water table elevations in the case of unconfined aquifers) and ground water flow rates within and across the boundaries of the system under consideration. It can provide estimates of water balance and travel times along flow paths.

The applicability of a ground water model to a real situation depends on the accuracy of the input data and the parameters. Determination of these requires considerable study, like collection of hydrological data (rainfall, evapotranspiration, irrigation, drainage) and determination of the model parameters including pumping tests. As many parameters are quite variable in space, expert judgment is needed to arrive at representative values. The models can also be used for the if-then analysis: if the value of a parameter is A, then what is the result, and if the value of the parameter is B instead, what is the influence? This analysis may be sufficient to obtain a rough impression of the ground water behavior, but it can also serve to do a sensitivity analysis to answer the question: which factors have a great influence and which have less influence. With such information, one may direct the efforts of investigation more to the influential factors.

When sufficient data have been assembled, it is possible to determine some of missing information by calibration. This implies that one assumes a range of values for the unknown or doubtful value of a certain parameter and one runs the model repeatedly while comparing results with known corresponding data. For example, if salinity figures of the ground water are available and the value of hydraulic conductivity is uncertain, one assumes a range of conductivities and the selects that value of conductivity as "true" that yields salinity results close to the observed values, meaning that the ground water flow as governed by the hydraulic conductivity is in agreement with the salinity conditions.

A ground water flow model is a mathematical representation of ground water flow through an aquifer, which is composed of saturated sediment and rock. In order to solve the equations that constitute the flow model, it is necessary to make simplifying assumptions about the aquifer and the physical processes governing ground water flow. The most important of these assumptions are embodied in the conceptual model of the aquifer. Although ground water flow models can't be as detailed or as complex as the real system, models are useful in at least four ways:

- Models integrate and assure consistency among aquifer properties, recharge, discharge, and ground water levels.
- Models can be used to estimate flows and aquifer characteristics for which direct measurements are not available.
- Models can be used to simulate response of the aquifer under hypothetical conditions.
- Models can identify sensitive areas where additional hydrologic information could improve understanding.(Indian journal of science, 2013)

1.2 STATEMENT OF THE PROBLEM

Before a few years ago the study area specially, Meskan, Endegegn, Sodo and some part of Mareko Woreda were potential water resource area. People use running water. There was surface water: - rivers, springs streams and enough groundwater (Addisu Etifu, 2013). But know a day sources of water are decreased gradually (streams were dryied, eg. Derek wenze). People use groundwater for irrigation purpose. 104km^2 area is irrigated without any gap in a year except during summer season. In the study area, People use groundwater for irrigation purpose. Irrigation practice increases using pumping technology. This alarming increasing of pumping groundwater for irrigation purpose has resulted in:-The reduction of groundwater potential in the groundwater basin and dry up of streams, rivers nearby. Such aggressive groundwater abstraction will result conflicts between the users of groundwater and rivers. Thus it is vital to understand the impact of such groundwater abstraction on its availability and decide on the optimum abstraction rate.

1.3 Research questions

- What are the impacts of pumping on groundwater potential?
- What is the amount of annual groundwater abstraction?
- Optimum pumping rate?

1.4 OBJECTIVE OF THE RESEARCH

- The general objective of the study is to determine the impact of pumping for irrigation on groundwater potential and determine the optimum pumping rate.
- The following are the Specific objectives of the research.
  - ✓ Determining the amount of annual Groundwater abstraction.
  - ✓ Indicate optimum pumping from the aquifer.
  - ✓ Identifying the recharge and discharge area of the study site.
  - ✓ Groundwater flow direction
  - ✓ To recommend appropriate solution for groundwater potential affected by groundwater over drafting.

CHAPTER TWO

2. LETERATURE REVIEW

2.1 GROUNDWATER MODELING

Groundwater Modeling is one of the main tools used in the hydro geological science for the assessment of the resource potential and prediction of future impact under different circumstances/stresses. Its predictive capacity makes it the most useful tool for planning, design, implementation and management of the groundwater resources.

The main aim of the groundwater model is to determine the extent of groundwater availability and whether exploitation of the groundwater resource, for irrigation and other purposes, is possible and feasible.

In general, the following aspects help to define the scope of a groundwater resources evaluation:

Location of production wells, and achievable pumping rates,

- Effect of the proposed pumping scheme on the regional groundwater levels and flow conditions,
- Long-term yield capabilities of the aquifer,
- Influence of the groundwater resources development on other components of the hydrologic cycle,
- Negative side effects of the proposed development scheme,

The first step in the groundwater resources evaluation using models will concern study of the available potential at current development and stress conditions.

Another important aspect of groundwater resource evaluation is to predict the aquifer yield under different scenarios. The analysis and prediction of aquifer performance can be achieved by carrying out flow computations using numerical modeling techniques. Numerical models are normally preferred because they are able to account for multiple-well systems in heterogeneous aquifers of irregular shape.

Wells and piezometers are needed to obtain information about the hydraulic parameters of the aquifer and the levels of the groundwater table in the area of study. All available information will have to be carefully analyzed before specifying model conditions.For the modeling the main work was assembling data relevant to the modeling work.

Therefore, the following were considered.

- Identify recharge areas, amount of recharge,
- Identify aquifer types and number of layers,
- Define lateral and vertical extension of aquifer layers and associated thickness,
- Define aquifer parameters, for the modeling work,
- Assemble relevant data and identify the groundwater flow direction based on inventory of water level elevations and results of test drilling,
- Geologic information including geologic maps, cross sections and well logs are combined with information on hydro geologic properties to define hydrostratigraphic units for conceptual model.

Based on available data identify how the aquifer system is functioning and the interaction between different hydrogeological components.

- The source of water to the system, which includes, recharge from precipitation, recharge from surface water bodies, underflow or flux into the system.
- Expected flow directions of the groundwater
- Expected outflow direction
- Points of interaction with surface water bodies, or exit points.
- Number of hydrostratigraphic layers and interaction between them o Boundary conditions and locations

Based on the conceptualization the model was designed and input of data such as model extent, grids cells size, boundaries and aquifer parameters were prepared.

For the model design the UTM coordinate was used in order to relate the model to actual geographic coordinate and also make easy data access from GIS and other geographical spatial data sources.

The groundwater model was calibrated in steady condition based on observed aquifer and hydraulic parameters. The aquifer parameters, such as hydraulic conductivity and transmissivity computed from field data were used as an initial input to the model. The computed recharge and discharge from the water balance study used as input to the model. (MoWR, 2005). The groundwater environment that comes close to the actual conditions is established by groundwater modeling using hydro geological situations, aquifer units, and aquifer coefficient in the target sub-basin. The groundwater model plays a role in groundwater management by the predicting groundwater fluctuations when usage of groundwater increases or decreases. (Japan international cooperation Agency, 2012).

A **model** is a simplified representation of an object, structure or process that cannot be studied directly because it is too large, too small, or too complicated, or because direct study or observation is, for other reasons, not possible or feasible. It is of more importance to us as scientists and hydrogeologists to be able to develop process models, or models that simulate physical processes. These models have to contain some component of the geometry of the system, but they also have some component that describes how the system 'acts' (i.e., how it responds to changes in certain conditions, how it changes with time, etc.) This component can be an actual physical thing, or it could be a mathematical component (i.e., an equation or a set of equations). Process models can simulate things like: Aquifers and groundwater flow systems such as Simulate changes in head with response to pumping, Calculate well yields. (Matthew M. 2012)

2.2 GOUNDWATER FLOW

Groundwater is always flowing, and the direction of flow is determined by the location of higher groundwater elevation. Note, however, that groundwater does not flow downhill; rather, it flows from higher hydraulic heads (or higher water elevation) to lower hydraulic heads. The distribution of hydraulic heads in the saturated zone determines the direction in which the water will flow.

The velocity with which groundwater flows, also called the flux, is determined by the difference in hydraulic head and the permeability of the sediment or rock through which it flows. Permeability is a number which describes the ease with which a fluid (like water) will move through a porous medium (i.e. a rock, soil, or sediment which has enough pore space to allow water to move through it).

2.3 MATHEMATICAL MODELS

Any equation that represents some physical process is a model of that process. Darcy's law is a model that represents the flow of groundwater in one dimension. Because it is a model, it tells us something about how the system behaves (flow is linearly proportional to the hydraulic gradient) and it can be used to make predictions about the system (calculating travel times and flow velocities). (Matthew M, 2012)

2.4 GOVERNING EQUATION

Darcy’s law describes a steady uniform flow of constant velocity in which net force on any fluid element is zero. For unconfined saturated flow, the two forces are gravity and friction. For the study area, based on the conceptual model the steady state condition the equation is given by:

The general governing equation for steady-state

$$\boxed{\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)=0} \quad \text{………………1}$$

Where K_x, K_y and K_z : are the values of hydraulic conductivity along x, y and z coordinate axes (David Keith Todd, 2005)

The movement of groundwater through porous media is described and solved on the basis of partial differential equation, governing equation. It is the representation of physical law that controls the groundwater flow, which is based on Darcy’s law and the law of mass conservation.

2.4.1 NUMERICAL METHODS TO SOLVE EQUATIONS

If an analytical solution is not possible, we may have to simplify the system in another way and develop an approximation called a numerical solution. The basic idea behind a numerical solution is that you first determine your boundary conditions, then reduce the infinite number of points (and corresponding equations) in the system to a finite number of points, and then use an iterative method to solve the equations at those points. The process of reducing the system to a finite number of points is called **discretization**; i.e., making a continuous function into a discrete function.

The partial differential equations describing groundwater flow and transport can be solved mathematically using either analytical or numerical solutions. The advantages of an analytical solution, when it is possible to apply one, are that it usually provides an exact solution to the governing equation and is often relatively simple and efficient to use. Many analytical solutions have been developed for the flow equation; however, most applications have been limited to well hydraulics problems involving radial symmetry and to 1D and 2D problems involving stream–aquifer interactions. The familiar Theis type curve represents the solution of one such analytical model. In general, obtaining the exact analytical solution to the partial differential equation requires that the properties and boundaries of the flow system be highly and perhaps unrealistically idealized. For modeling most field problems, the mathematical benefits of obtaining an exact analytical solution can be outweighed by the errors introduced by the simplifying assumptions required to apply the analytical approach to the field setting.
For problems where simplified analytical models cannot describe the physics of the situation, the partial differential equations of groundwater flow and transport can be approximated numerically. In so doing, the continuous variables are replaced with discrete variables that are defined throughout a spatial grid. Thus, the continuous differential equation, which defines hydraulic head or solute concentration everywhere in the groundwater system, is replaced by a finite number of algebraic equations that defines the hydraulic head or concentration at specific points. This system of algebraic equations generally is solved using matrix techniques. This approach constitutes a numerical model. Two major classes of numerical methods have come to be the most widely used and accepted for solving the groundwater-flow equation. These classes are finite-difference and finite-element methods.

Each method described here has advantages and disadvantages, but there are very few groundwater problems for which either is clearly superior. In general, the finite-difference methods are conceptually and mathematically simpler, and are easier to program.

The finite-difference equations typically are derived for a relatively simple, rectangular grid, which also eases data entry. Finite-element methods generally require the use of more sophisticated mathematics but, for some problems, may be more accurate numerically than standard finite difference methods. A major advantage of the finite-element methods is the flexibility of the finite-element grid, which allows a close spatial approximation of irregular boundaries of the aquifer and (or) of parameter zones within the aquifer when they are considered. However, the

Construction and specification of an input data set are much more difficult for an irregular finite-element grid than for a regular rectangular finite-difference grid. (Charles R. Fitts, 2013).

2.4.2. FINITE-ELEMENT METHODS

The finite-element method (FEM) is a numerical analysis technique for obtaining approximate solutions to a wide variety of problems in physics and engineering. The method was originally applied to structural mechanics but is now used in all fields of continuum mechanics. There are four different approaches to formulate the finite-element method for a problem, which are, the direct approach, the variation approach, the weighted residual approach, and the energy balance approach. In groundwater problems, the approach frequently used is either the weighted residual or variation approach. The concept of “piecewise approximation” is used in the FEM. The domain of the problem, that is, the extent of the groundwater system to be simulated, is divided into a set of elements or pieces. In theory, the elements can be of different shapes and sizes. Most FEM computer programs use one shape element, most commonly either triangular or quadrilateral elements. Point values of the dependent variable (e.g., head) is calculated at nodes, which are the corners or vertices of the elements; a simple equation is used to describe the value of the dependent variable within the element.

This simple equation is called a basis function and each node that is part of an element has an associated basis function. The simplest basis functions that are usually used are linear functions. The solution to the differential equation for groundwater flow equation is approximated by a set of elements in which the dependent variable only varies linearly within the element, but the entire set of elements approximates the complex distribution of head.

In the method of weighted residuals, the “piecewise” continuous surface is obtained by minimizing the difference between the approximate surface and the continuous surface. The method of weighted residuals is summarized as follows. Any differential equation L (h), such as the steady-state form (the groundwater-flow equation) can be written as

$$L(h) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Over the domain of the problem. The first step in obtaining the approximate solution is to define the approximate solution as the sum of all the simple basis functions as

$$h^{\wedge} = \sum_{i=1}^{n} Ni * Zi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where hˆ is the approximate solution, n is the number of linearly independent basis functions, Ni are the linearly independent basis functions defined over the entire domain, and Zi are the unknown coefficients to be determined (there is one coefficient for each node in the finite-element mesh). The trial function hˆ is an approximation, so that when it is substituted into groundwater flow equation there will be some error, £, defined as

$$£ = L(\hat{h}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

The method of weighted residuals determines the unknown coefficients by minimizing the error. This minimization is accomplished by weighting the error, integrating the error, and setting the error equal to zero over the entire domain. A weighting function, Wi, can be specified for each basis function and the resulting integration is

$$\int_R Wi * £ dR = \int_R Wi * L\,\hat{h} * dR = 0, \; i = 1, 2, 3 \ldots\ldots\ldots\ldots \quad (5)$$

Equation 7 is substituted into Equation 9 and weighting functions are specified. There are then n equations and n unknowns. The selection of the weighting functions and the simplification of the integral in Equation 9 into a linear algebraic equation is mathematically straightforward, but not intuitive. In the Galerkin method, the weighting functions are chosen to be identical to the basis functions and Equation 9 is simplified by using integration by parts. Because the basis functions and weighting functions are defined to be of a specific algebraic form (e.g., linear basis functions), the modified integral is straightforward to solve and becomes a set of n simultaneous algebraic equations. After 9 is mathematically evaluated into a set of n simultaneous equations, they are solved using matrix solution techniques for the n unknown coefficients Zi , and the approximate solution hˆ is determined at each node.(Jacques W. Delleur, 2007).

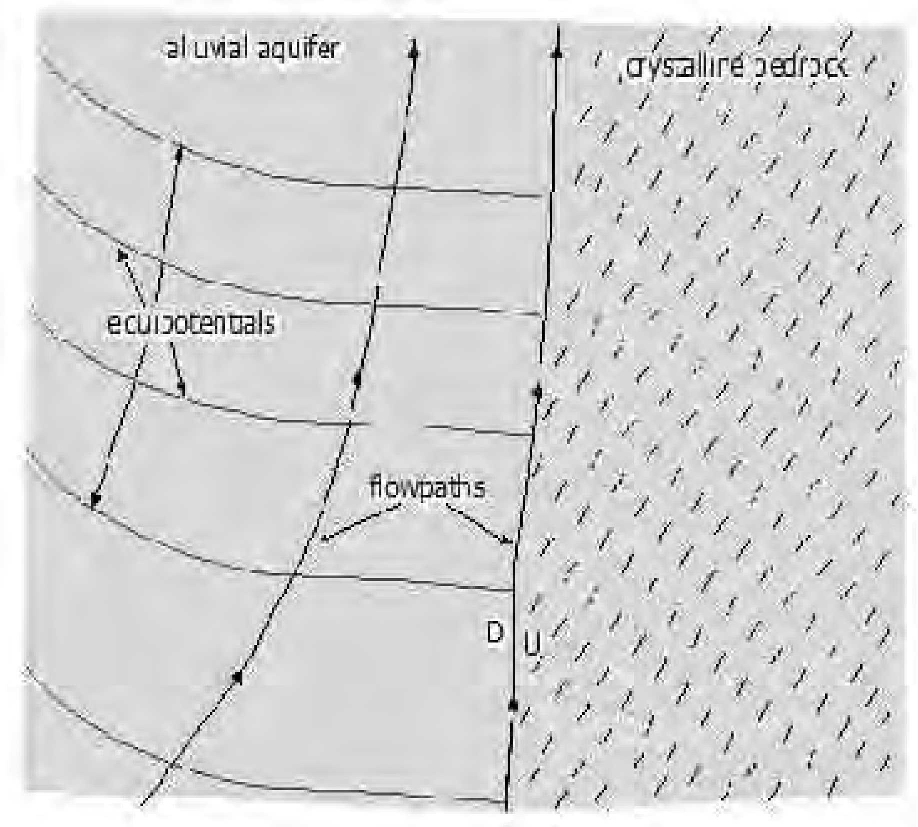
2.5 BOUNDARY CONDITIONS

A groundwater flow systems is a three-dimensional entity that has the following components:

Boundary Conditions – has some physical dimensions and some real boundaries
Recharge – some area where water is getting into the flow system
Discharge – some area where water is exiting the system

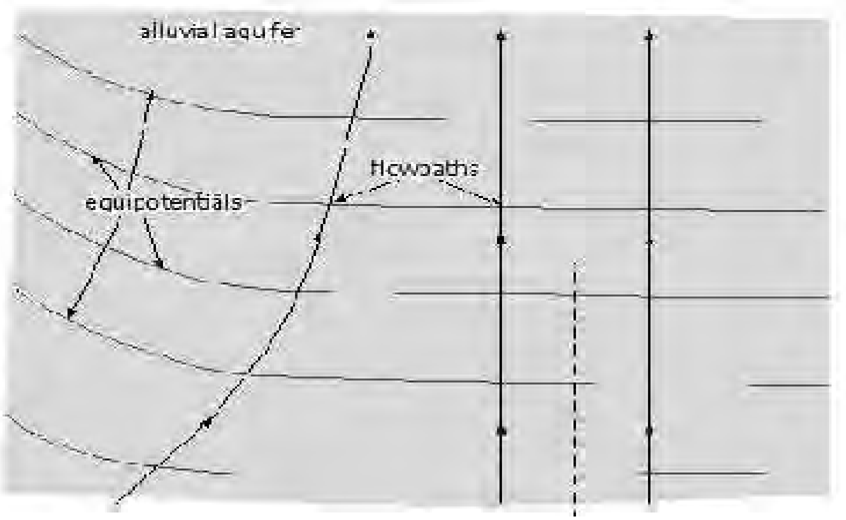
As we said flow systems are three dimensional bodies and have boundaries. There are two basic boundaries, or boundary conditions, that we use to characterize the limits of our flow systems.

- No -Flow boundary: There is no-flow across the boundary (h/x = 0). Examples:



Permeable aquifer units could be in contact with low K crystalline rocks

Figure 1. No-flow boundary (Uliana, 2001, 2012).



Flow does not cross flow lines; wherever there are parallel flow lines, we have a symmetry boundary

Fig 2. No-flow symmetry boundary (Uliana2001,

Locally high groundwater levels
Can produce a groundwater divide;
This is also a no-flow boundary

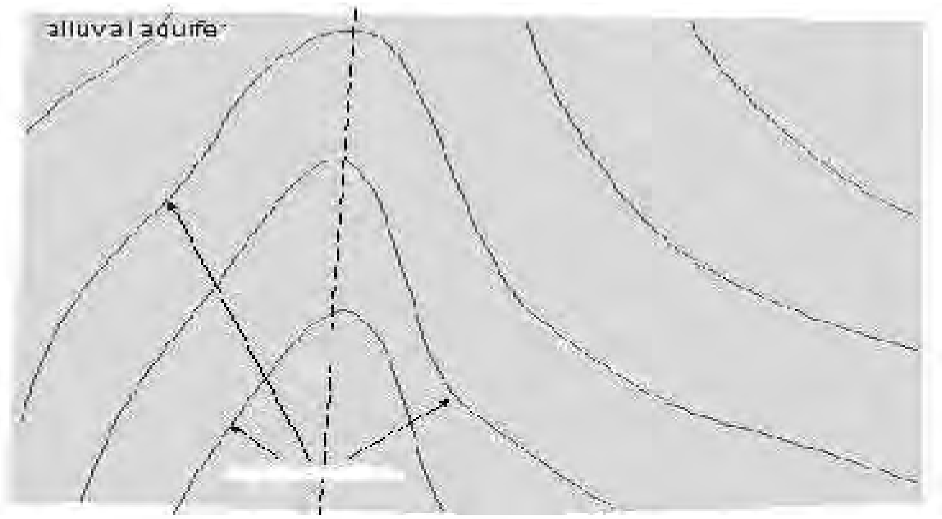


Fig 3. No-flow boundary – Groundwater divides (Uliana, 2001, 2012)

As shown from the above figure 3 topographic (watershed divide) is the indicator of Groundwater divide based of groundwater hydraulic head distribution and geological formation.

- Constant Head: the head does not change (e.g., river, lake). Examples:

When a non-flowing body of water (lake, pond) creates a constant head boundary, the shore of the lake represents a single equipotential line. Water is therefore flowing into the lake perpendicular to the shoreline (Figure 10-4).

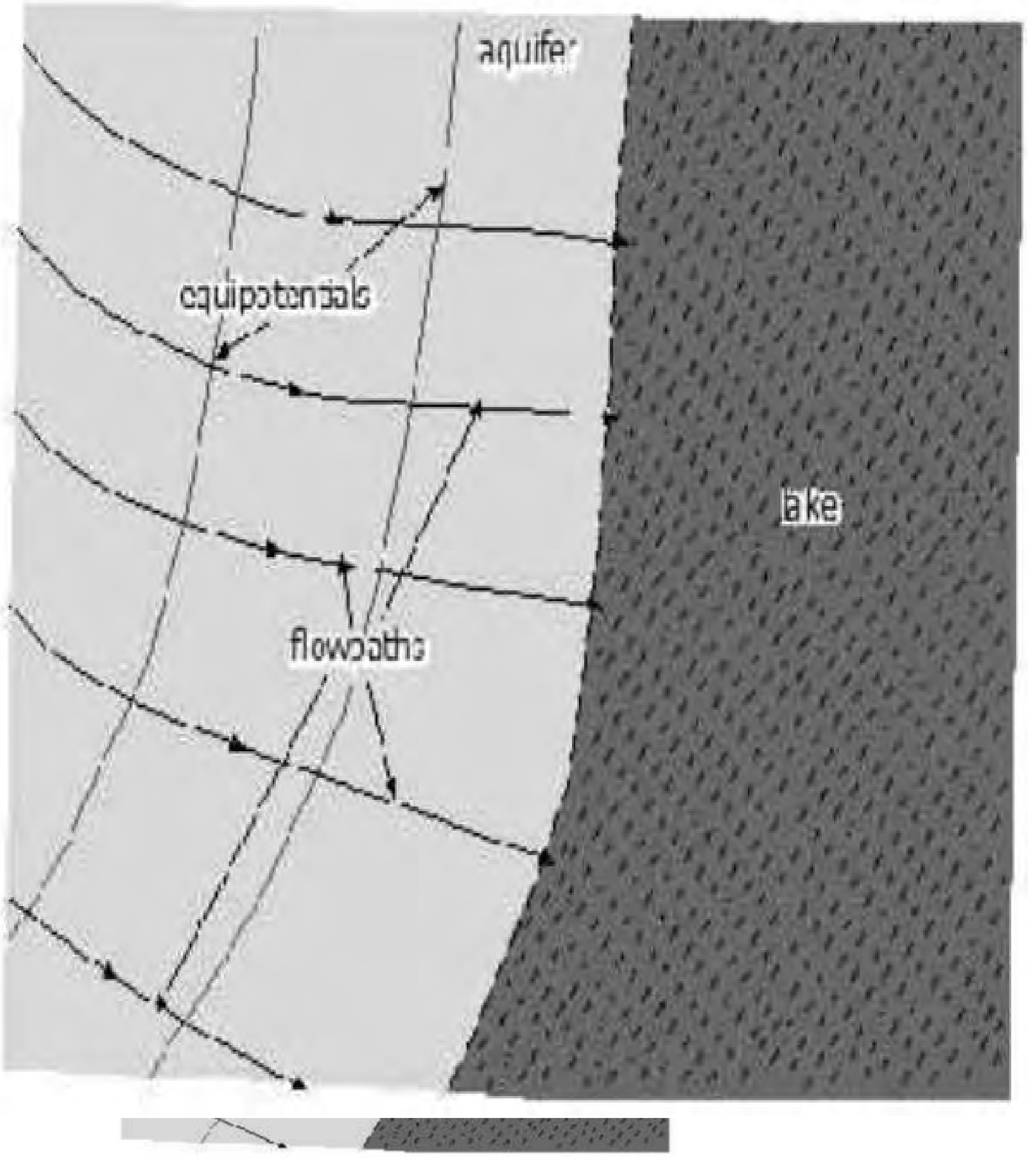


Figure 4. Constant head boundary – lake (Uliana, 2001, 2012).

With a river boundary, the heads vary along the boundary, but are still considered constant. Each point along the river represents a point on an equipotential fig 5

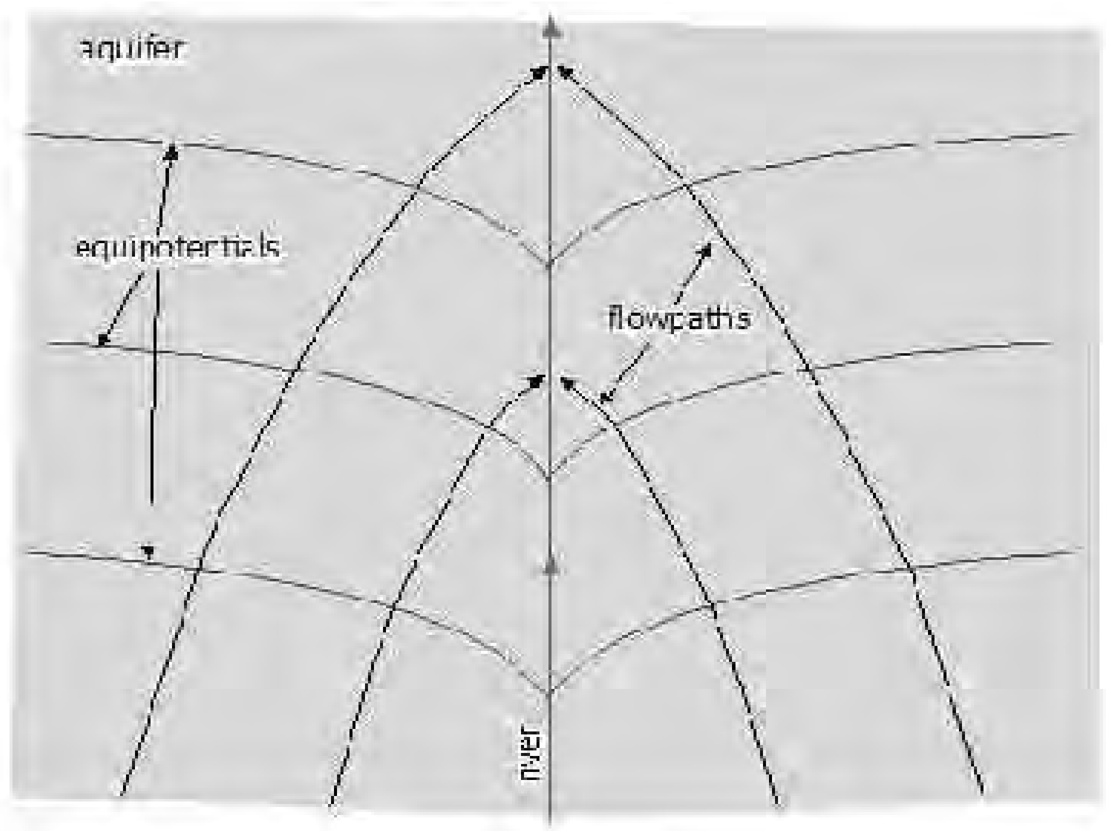


Fig 5. Constant head boundary – river (Uliana, 2001, 2012).

2.6 GROUNDWATER RECHARGE

Recharge refers to the water that is entering a groundwater system. Areas where recharge is occurring are called recharge areas or recharge zones. Topography: can indicate recharge areas and give general indications of flow system boundaries (not applicable when dealing with confined aquifers). Distributions of heads suggest flow paths and probable recharge/discharge areas. There are several different ways that recharge gets into a flow system.

- Direct infiltration on the outcrop – some percentage of rainwater seeps into the ground and makes its way to the water table.
- Infiltration through the beds of losing streams or reservoirs – in some parts of the world (especially arid regions), this is the dominant form or recharge to any system
- Interformational flow – usually flow through leaky confining layers; either where water is drawn in by drawdown at wells or where underlying aquifers have significant over pressuring and are forcing water up.

Recharge is generally thought of as some percentage of precipitation. When it rains, some percentage of the water runs off on the surface, some evaporates back into the atmosphere, some is taken up by plants and animals (transpiration), and the remainder gets to the water table and recharges the aquifer.

2.7 GROUNDWATER DISCHARGE

There are several ways that water discharges from a flow system.
They include:

- Discreet discharge to a spring or seep
- Discharge into a gaining stream or lake
- Pumping from a well
- Interformational flow (leakage through a confining layer)
- Evaporation – in some arid areas, this is the primary mechanism for discharge from the flow systems.

Discharge can also be hard to quantify, especially in areas dominated by well pumping or evaporation. Interformational flow is generally small compared to the other mechanisms. Springs and gaining streams can be gaged, and changes in flow across a certain area can be attributed to either recharge or discharge.

2.8 GEOLOGY

Occurrence of ground water in Ethiopia is on the basis of four major categories of rocks. These rocks are volcanic rock, sedimentary rock, metamorphic rock, and alluvio lacustrine sediments. All the four major categories of rocks hold ground water at different specific capacities. Owing to their stratigraphic position, volcanic rocks form the most accessible aquifers in central Ethiopia. Sedimentary rocks forms aquifers in areas where they are exhumed by erosion of the volcanic caps. In localities such as the Ambo to guder valley, the escarpment facing Afar from Dire Dawa, and the Didssa valley, sedimentary rocks are exposed to surface owing to regional tectonic down cutting. Basement rocks form most of the western peripheral lowlands and northern Ethiopia. The loose Miocene –quaternary sediments occupy the vast plains of Rift valley. Occurrence of ground water in the geologic formation differs in different types of geologic formation.

In volcanic rocks groundwater occurs in fractures, and joints formed during formation or after the formation of the rocks. In sedimentary rock groundwater occurs in pores, fractures, or cavities, as the result sedimentary rocks are considered as dual porosity aquifers. In terms of their storage potential, metamorphic rocks in Ethiopia are known for their low storage and transmission porosity. The occurrence of alluvio – lacustrine sediment is vast regions of the central Rift valley. They occur at alluvial fans, deltas, alluvial plains. Typical feature of alluvio lacustrine sediment is that groundwater occurs in primary porosity; shallow water table is mostly shown. (Seifu Kebede, 2013).

2.8.1 AQUIFERS AND AQUIFER PROPERTIES

Butajira pediment/crescent area is situated at the foot (pediment plain) of the western rift escarpment, and shallow groundwater and springs characterize it. The depth to water level varies from surface to about 20 m meters below the ground. As a result of the shallow groundwater there are a number of family owned dug wells and community wells in the area.

This area is characterized by a complex mixture of sediments composed of unsorted to poorly sorted alluvial, talus or fan deposits, debris flow and volcano-classic deposits emanating from the basaltic volcanic centers in the east and around Koto. The sediment thickness varies from 80 m to about 120m. This plain receives groundwater recharge mainly from rainfall, groundwater flow from the escarpment and the runoff emanating from the rainfall in the mountains. The sediment is underlain by Tertiary Volcanic formations.

These formations have fracture permeability and can be good aquifers in fracture zones. However, there is no data on these aquifers. Mesozoic Sedimentary formations are expected to occur deep under these formations; however their productivity and water quality require exploration for these aquifers.

The test drilling results and existing borehole data indicates the shallow aquifer (80 to 120 m deep) is composed of alluvial and talus/debris sediment derived from the escarpment. The sediment is mainly made up of gravels, sands and boulders with inter-fingering of some clay deposits. Towards the escarpment the sediment is poorly sorted and dominated by coarse sediments. Further away from the base of the escarpment, the sorting increases and the sediment size also decrease to sand and gravel size. The aquifer type is unconfined aquifer. This plain has generally poor aquifer property. The test drilling result and existing data shows its Transmissivity ranges from 1 m^2/day to 137m^2/day and hydraulic conductivity from 0.02m/day to 3.8 m/day. The transmissivity of aquifer gets poor towards the escarpment base and improves further away from the escarpment. This is directly related to the sorting of the sediment material.

Table 1 previous study of aquifer property for upper part of the area.

Borehole	Location in UTM		Transmissivity M2/day	Hydraulic conductivity m/day
Kachaber test well	424544	894351	1.02	0.02
Butajira Town Test well 1	430838	899162	137.00	3.80
Butajira Town Test well 2	430990	896373	95.60	2.66
Butajira Hospital	431086	898842	30.00	0.96

Basaltic cinder cones region: This area is situated to the east of Butajira pediment and dominantly composed of scoria cones and associated vesicular basalts. Groundwater occurs at relatively deeper level with respect to surface topography as compared with Butajira pediment and Kontane-Inseno-kela plain.

Quaternary volcanic rocks and sediments underlay the scoria cones and associated vesicular basalts. Tertiary and Mesozoic Sedimentary formations are expected to occur deep under the Quaternary formations in this area. Due to the relatively deep water table, most wells constructed in this region use motorized pumps. Groundwater recharge is from subsurface groundwater flow from the Butajira Crescent area and direct recharge from rainfall. However the major source is the groundwater inflow. The test drilling results and existing borehole data indicates the aquifers are composed of scoria vesicular basalt and at some places sand and gravel deposit underlying thin layer of flows. The thickness of the basaltic flow is highly variable. In the central part of this area where the volcanic centers and vents are located the thickness of the lava flow is high over 100 m thickness. Further away from the volcanic centers, the lava flow is thin and in the areas, such as Shereshera Ile, Dirama Shershera, Shershera Jole areas the underlying sand and gravel deposits contribute to the aquifer. The available data shows that this region has relatively better transmissivity than Butajira Crescent. The test drilling result and existing data shows its Transmissivity ranges from 16 m^2/day to 242m^2/day and hydraulic conductivity from 0.9m/day to 20 m/day. This transmissivity data is for the areas away from the volcanic centers. In general the transmissivity of the aquifer in this region is poor. This can also be explained by the existence of a crater lake high above the groundwater elevation of Kuntane-Inseno-Kela Plain and the water level elevation difference between the Butajira Crescent and Kuntane-Inseno-Kela Plain. The aquifer varies from unconfined to semi confined. The aquifer within the basaltic formation is unconfined and the one in the underlying sediment is semi confined.

Table 2 Previous study of Aquifer property for middle part of the area.

Borehole	Location in UTM		Transmissivity M2/day	Hydraulic conductivity M/day
Butajira Town BH2	432756	897440	69.26	
Semen Shershera	436926	899049	187.76	20.86
Kibet town BH2	426927	887719	37.80	0.90

The dominant lacustrine deposit occurs in Ziway plain area. This deposit is composed of clay and silts. The second area of sediment deposition was the Kuntane – Inseno-Kela plain. This plain is characterized by sediment deposits composed of lacustrine, fluvial, pyroclastic, talus and fan deposits. It has thick sediment deposits of over 200 m. This area is also major aquifer zone in the study area. The third sediment deposition area is the Butajira Crescent. This area is characterized by gravel and sand deposits with clay and silt derived from fan, talus (debris flow) and river deposits with an average thickness of about 80 m. This area is also considered area of good aquifer in spite of its limited areal extent. Kuntane inseno plain is separated from the Butajira Pediment plain by the scoria cones region. This plain receives recharge from several streams from the western escarpment and direct rainfall and groundwater inflow. It is covered by pyroclastic fall and reworked water lain pyroclastic deposits, lacustrine, alluvial, debris flow or talus deposits and fan deposits. The lacustrine deposits vary from clayey silt to fine sand deposits and whereas the fluvial deposits vary from silt to cobble size and sometimes up to boulder size. The base of the western escarpment around Kela is mainly characterized talus or debris flow and fan deposits. The thickness of these sediments varies from few meters in the west to several meters (more than 260 meters and more) in the centre and along Weja River; however the thickness of the sediment along Koshe-Dugda ridge shows abrupt pinch out. The quaternary sediments are underlain by Quaternary and Tertiary volcanic formations. Mesozoic Sedimentary formations are also expected to occur in deeper parts. This trough is bounded to the west by scoria cones and associated vesicular basalts and to the east by Tora-Koshe Dugda horst (ridge). The surface water from Butajira and Kibet areas drains to Kontane Marsh and Little Abaya while surface water from Kela and Bui areas drains to the east to this plain and forms Meki River. The overflow from little Abaya (Lake) and Kontane Marsh and Dobena River forms Woja River, which flows towards North east of this plain to join Meki River. Meki River later discharges its water at Ziway Lake. The groundwater in this zone is generally shallow and abundant; many dug and shallow wells are found in this plain. Thermal springs are also observed in two localities of the plain. Thermal springs have multiple sources (eyes), and both are situated in Kontane marsh indicating that they are probably related to the formation of the young volcanic of the cinder cones and basaltic centers heating up the groundwater. The test drilling results and existing borehole data indicates the aquifers are composed of pyroclastic fall and reworked water lain pyroclastic deposits, lacustrine, alluvial, debris flow or talus deposits and fan deposits. The thickness of these sediments varies from few meters in the west to several meters (more than 260 meters and more) in the centre. The aquifer is basically unconfined; however, since the aquifer materials are variable it is possible that some confined or semi confined layers might occur at some localities.

The test pumping result in the 168 m deep test well at Kuno Kertafa has shown very low drawdown, which is about 1.1 m. The, transmissivity computed from this test indicates a value in the order of 500 m^2/day. The 60 m deep test borehole drilled close to Weja River has provided transmissivity value 219 m^2/day. This could be the minimum value of the area because this borehole is shallow and is situated at the boundary of this aquifer and Tora-koshe- Dugda ridge. (MoWR, 2005).

2.8.2 UNCONFINED AND CONFINED AQUIFER

An **aquifer** is a geologic unit that can store and transmit a sufficient amount of water to supply a well. The factors that determine if a geologic unit is an aquifer include the following:

1. The permeability must be high enough that flow can be maintained.
2. The aquifer dimensions must be great enough (i.e., there must be a significant saturated thickness) to supply water to a well
3. The quality of the water must be good enough for the intended use.

An unconfined aquifer is one in which a water table varies in undulating form and in slope depending on areas of recharge and discharge, pumpage from wells, and permeability. Rises and falls in the water table correspond to changes in the volume of water in storage within an aquifer.

Confined aquifer also known as artisian or pressure aquifers, occur where ground water is confined under pressure greater than atmospheric by overlaying relatively impermeable strata. The piezometric surface or potentiometric surface of a confined aquifer is an imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer. The water level penetrating a confined aquifer defines the elevation of the piezometric surface at that point. (Larry W. Mays, 2012).

Geologic materials (i.e., rock, soil, and sediment) always have some amount of empty space in them. This empty space is called the pore space, and the percentage of pore space by volume in a rock or sediment is called the porosity. Within all naturally-occurring geologic units, the pore space always contains some amount of moisture. Below the surface of the Earth, in the soil and upper layers of rock, the sediments and rock contain moisture; however, not all of the pore space is full (i.e. there is both air and moisture within the pore spaces).

Just below the surface, the amount of moisture is small, and the amount of moisture tends to increase with depth. Eventually, the amount of moisture becomes so great that the pore space is completely with water and the soil or sediment is saturated**.** Therefore**,** in the subsurface, we can distinguish between two basic zones. These are the unsaturated zone, and the saturated zone. The boundary between the two zones is often called the **water table**. (Matthew M. 2012)

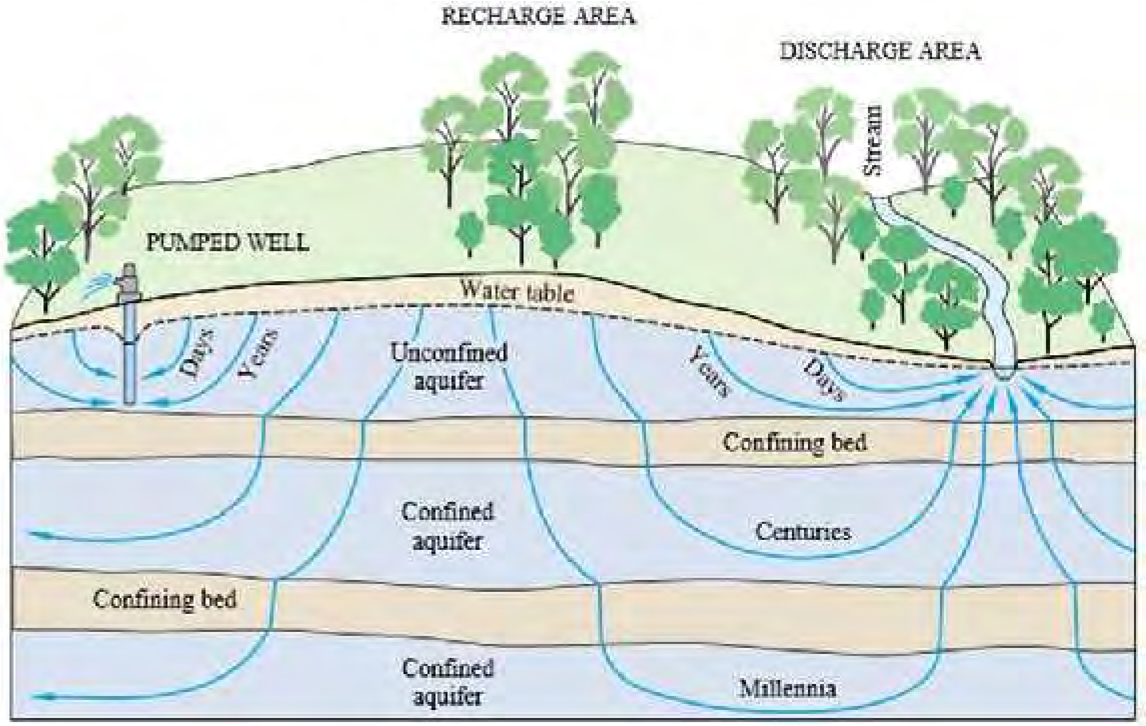


Fig 6 Confined and Unconfined aquifer

2.9 Surface Water versus Groundwater

Actually surface water (in lake and streams) and groundwater (in aquifers) are not necessarily separate and independent water resources. Consider for example interrelations between a river or lake and an adjacent aquifer. The management of groundwater resource, alone or conjunctively with a surface water one, aims at achieving certain goals through a set of decision (=policy) related to the development and/or operation of the system. (Jacob Bear, 1979). Where a stream channel is in direct contact with an unconfined aquifer, the stream may recharge the groundwater or receive discharge from the groundwater, depending on the relative levels. A gaining stream is one receiving groundwater discharge; a losing stream is one recharging groundwater.

Often a gaining stream may become a losing one, and conversely, as the stream stage changes. The term rising water is applied to marked increases in stream flow in reaches where a subsurface restriction forces groundwater to the surface. (David Keith Todd, 2005)

According to Addisu Etifu Most of the households of the study area responded that they are using running water while those who use private pipe water represent only 0.7%. Next to running water, unprotected spring water and public tap (bono water) account 23.1% and 6.6%, respectively. Other sources such as pond accounted 1.1%. The statistics across Woredas draws more or less similar situation. Sodo Woreda records the highest points in river water consumption followed by Endegagn and Geta Woredas (77.7% and 69.1%, respectively) while Endegagn Woredas record the high points in consuming both river and unprotected spring waters (Addisu Etifu, 2013)

2.10 EFFECTS OF INCREASED GROUNDWATER WITHDRAWALS

The steady state withdrawal rates were increased by 15%, 35%, 55%, 75% and 100% to study the response of the system in this scenario. These increased are equivalent to withdrawing 5384.1, 6320.4, 7256.8, 8193.15, and 8336.6 m^3/day over the whole catchment respectively and the increased withdrawal rate distributed among the exciting wells. Model simulated results of stream base flow and water table elevations in the scenarios were compared with the model calculated steady state results, and the difference showed the response of the system to the assumed scenarios.(Nigussie Ayehu, 2010).

Pumping groundwater at a faster rate than it can be recharged can have some negative effects of the environment and the people who make use of the water

- Lowering of the water table

The most severe consequence of excessive groundwater pumping is that the water table, below which the ground is saturated with water, can be lowered. For water to be withdrawn from the ground, water must be pumped from a well that reaches below the water table. If groundwater levels decline too far, then the well owner might have to deepen the well, drill a new well, or, at least, attempt to lower the pump. Also, as water levels decline, the rate of water the well can yield may decline.

- Increased costs for the user

As the depth to water increases, the water must be lifted higher to reach the land surface. If pumps are used to lift the water (as opposed to artesian wells), more energy is required to drive the pump. Using the well can become prohibitively expensive.

- Reduction of water in streams and rivers

There is more of an interaction between the water in streams and rivers and groundwater than most people think. Some, and often a great deal, of the water flowing in rivers come from seepage of groundwater into the streambed. Groundwater contributes to streams in most physiographic and climatic settings. The proportion of stream water that comes from groundwater inflow varies according to a region's geography, geology, and climate.

Groundwater pumping can alter how water moves between an aquifer and a stream, lake, or wetland by either intercepting groundwater flow that discharges into the surface-water body under natural conditions, or by increasing the rate of water movement from the surface-water body into an aquifer. A related effect of groundwater pumping is the lowering of groundwater levels below the depth that streamside or wetland vegetation needs to survive. The overall effect is a loss of riparian vegetation and wildlife habitat.

2.11 GROUNDWATER HYDRAULIC HEAD

A groundwater level, whether it is the water table of an unconfined aquifer or the piezometric surface of a confined aquifer, indicates the elevation of atmospheric pressure of the aquifer. Any phenomenon that produces a change in pressure on groundwater will cause the ground•water level to vary. Differences between supply and withdrawal of groundwater cause levels to fluctuate. Stream flow variations are closely related to groundwater levels. Other diverse influences on groundwater levels include meteorological and tidal phenomena, urbanization, earthquakes, and external loads. Finally, subsidence of the land surface can occur due to changes in underlying groundwater conditions.

Many groundwater levels show a seasonal pattern of fluctuation. This results from influences such as rainfall and irrigation pumping that follow well-defined seasonal cycles. Highest levels occur in late spring and are lowest in winter. In irrigated areas where frozen ground is not a factor, lowest levels normally occur during fall at the end of the irrigation season. The amplitude depends on recharge, pumpage, and the type of aquifer; confined aquifers normally display a greater range in levels than do unconfined aquifers.

Ground water moves from higher elevations to lower elevations and from locations of higher pressure to locations of lower pressure. Typically, this movement is quite slow, on the order of less than one foot per day to a few tens of feet per day. In groundwater hydraulics (the science of groundwater movement), water pressure surface and water table elevation are referred to as the hydraulic head. Hydraulic head is the driving force behind groundwater movement. Groundwater movement is always in the downward direction of the hydraulic head gradient. If there is no hydraulic head gradient, there is no flow. (David Keith Todd, 2005)

Hydraulic head can be determined by measuring the depth of the water table in a groundwater well, usually a piezometer. A piezometer is a non-pumping well, typically with a small diameter and a short well screen through which water can enter. A piezometer nest is a group of two or more piezometers which are set very close to each other but are screened at different depths. The use of a piezometer nest is an excellent way to determine the vertical hydraulic gradient (vertical change in hydraulic head) at a location. There are different techniques to determine the hydraulic head. The following example illustrates how hydraulic head (and other related parameters) would be calculated from the depth of a water table in a piezometer: The data below were collected from a piezometer nest:

Table 3 hydraulic head distribution

	Piezometer A	Piezometer B	Piezometer C
Elevation at Surface (m.a.s.l.)	250	250	250
Depth of piezometer (m)	150	100	80
Depth to Water Table (m.b.s.)	84	79	65

The hydraulic head is the elevation of the water in the piezometer. It is calculated by subtracting the depth to water from the surface elevation: A: 250 - 84 = 166 m , B: 250 - 79 = 171 m , C: 250 - 65 = 185 m

The pressure head is the height of the water above the depth of the piezometer. Hence it is calculated by: A: 150 - 84 = 66 m B: 100 - 79 = 21 m C: 80 - 65 = 15 m The elevation head is the height of the measuring point (i.e. the piezometer depth) above the datum.

In this case we have taken our datum to be mean sea level, therefore the elevation head for each well is calculated as: A: 250 - 150 = 100m B: 250 - 100 = 150 m C: 250 - 80 = 170 m

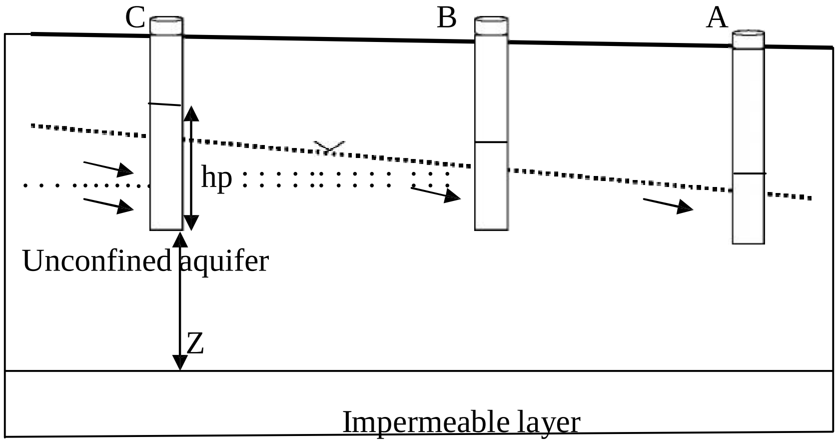


Fig 7Groundwater hydraulic head distribution

In every day practice the hydraulic head is determined in monitoring wells or piezometers by subtracting measured depth to water level from the surveyed elevation of the top of casing:

$$H = Z + h_p + v^2/2g \tag{6}$$

Where Z is evaluation above datum (datum is usually mean sea level, but it could any reference level), h_p is pressure head due to pressure of fluid(ground water) above that point, v is groundwater velocity, and g is acceleration of gravity.

Since the ground water velocity in most case is very low, the third member on the right hand side may be ignored for practical purpose and equation xx becomes

$$H= h= Z + h_p \tag{7}$$

Where h= hydraulic head, sometimes called piezometric head. Pressure head represents pressure of fluid (P) of constant density (p) at that point in aquifer.

The hydraulic gradient (i) between two well is obtained by dividing change in hydraulic head between two well to distance (L) between two wells.

$$i = \Delta h / L \quad \text{……………………………………….. (8)}$$

Where (i) = hydraulic gradient, Δh is change in head and L is distance between two heads.

It is important to understand that the ground water flow takes place from higher hydraulic head towards lower hydraulic head. Measuring hydraulic heads and subsequently determining hydraulic gradients and groundwater flow directions is by no means straight forward task and requires good planning by an experienced hydrologist. Ultimately, the number of monitoring wells their depths, screen lengths, and frequency of water level recordings will be based on the final goal of the study. One common mistake is to apply the same approach of hydraulic head measurements in different types of aquifers. For example fractured rock, karst aquifers present great challenge even more experienced professionals. In general, the hydraulic head measurements should be combined with hydro geologic mapping, dye tracing, and certainly, a thorough understanding of various hydraulic factors such as flow through interconnected fractures and pipes. When planning field measurements of hydraulic head, the following factors should always be taken in to consideration.

Hydraulic head changes in response to aquifer recharge, both seasonally and spatially. Especially in unconfined aquifer, after each recharge episode (rainfall). Measurements in multiple wells should therefore be performed with in short test time interval feasible (so called synoptic measurements). To accurately assess seasonal influences, at least one round of synoptic measurements should be performed per season.

1. Hydraulic head in confined aquifers change in response to barometric pressure fluctuations; this may also true for unconfined aquifer in some cases. The only reasonable method to accurately determine the magnitude and importance of such changes is to measure the hydraulic head and barometric pressure continuously using pressure tranducers and data loggers.
2. Hydraulic head in coastal aquifers response to harmonic tidal fluctuations. These changes can be accurately quantified only by performing continues measurements.
3. Hydraulic head may change in response to some local hydraulic stresses on aquifer, such as cyclic operation of extraction wells in the vicinity.(Kresic, Neven, 2007)

CHAPTER THREE

3. APPROACH AND METHODOLOGY

3.1 DESCRIPTION OF THE STUDY AREA

Location of the study area is found in the eastern part of Guraghe Zone of the South Nation nationalities people regional state. Using DEM data and Global mapper software, this area is located about 135km and160km from Addis Ababa and Hawassa respectively. Geographically it lies between coordinates of 8^0N-$8^0$15'N latitude and $38^0$15'E-$38^0$37'E longitude with an approximation altitude range 1806m to 3400m above sea level. The whole study area is found within Meki River Catchment and it covers parts or whole of four woredas, namely: Meskan, Mareko, Soddo and Siltie, The first three Woredas are located in Gurage Zone of Southern Nations Nationalities, and Peoples Region (SNNPR). Silte is located in Silti zone of SNNPR.

As shown from DEM the study area is found between the following coordinates

Table 4. Study area coordinates

	UTM E (m)	UTM N (m)
A	451467.136	910139.728
B	452284.439	884666.500
C	416323.107	884394.066
D	416459.324	910411.544

Using global mapper v15 software, the area covers a total surface of **384.65** km^2. The western part of the catchment has characterized by very steep slope topography and the eastern part of the catchment is characterized by gently sloping and plain surface. The study area is bounded by two rivers from northern, eastern and southern part. These are two major perennial rivers in the area. And the western part of the area is bounded by guraghe highland called Zebider Mountain.

The main road that connects Addis Ababa city with Hosanna and Arbaminch passes through the study area. And Butajira to Ziway road also crosses this study area. The area is accessible for the vehicles, especially the eastern part of the area because of its gentility.

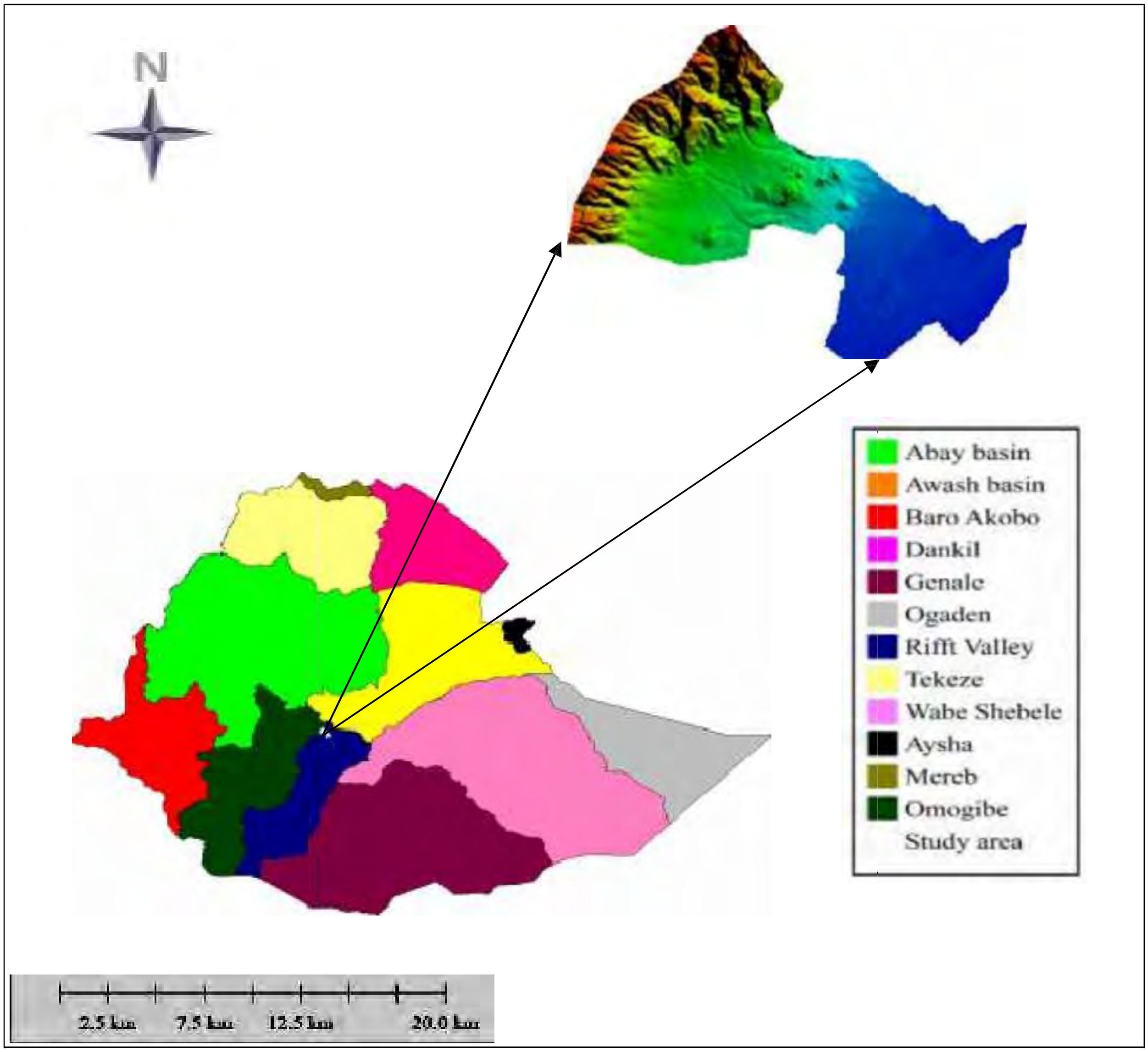


Fig 8 location of the study area within Ethiopian basins

The above figure 8 shows the 12 Ethiopian basins. The study area is found within Rift valley basin. The Rift valley is a basin which is found at the southern part of Ethiopia.

3.1.1TOPOGRAPHY

One important aspect of geomorphology is that on regional scale, natural directions of groundwater flow can be related to surface water topography. Just like surface water, groundwater flow from higher hydraulic head towards a lower hydraulic head. That is from pronounced topographic (high) to pronounced topographic lower (valleys) respectively. This is generally true regardless of the underlying geology (rock type) with the occasional exceptions Of confined aquifer when observed locally. (Neven Kresic,2013)

The topography of eastern part of Guraghe zone which is sub watershed of Meki river catchment its major land forms of flat plain at eastern part, undulating plain hilly and mountainous at western part. Two rivers drain to Meki River and then join to Ziway Lake. The average slop of the western part of the area is 30%.

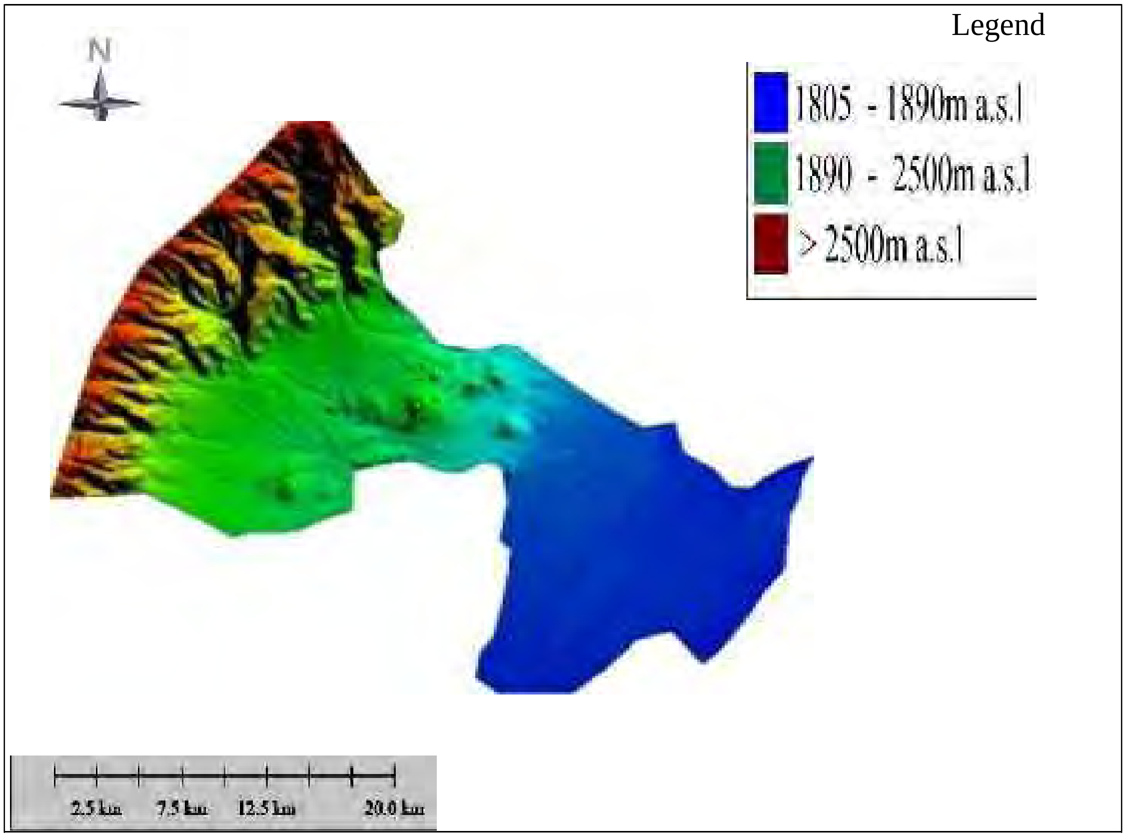


Fig 9 topographic map of the study area

As shown in the figure 10 above, at low land of the area (1805-1890m.a.s.l) very dens population is there because of the availability of ground water. Whereas, the area above 1890m. a. m.s.l, the population settlement is scattered.

3.1.2 LAND USE AND LAND COVER

The quantity and quality of groundwater are profoundly affected by historic and current land use and land cover at both regional and local scales. Understanding historic land use/ land cover and comparing it with current land use/land cover is therefore of critical important to the project at hand. Three main trends in land use associated human induced changes in land cover have been taking place worldwide and disrupting natural hydrologic cycles.

1. Conversion of forest in to agricultural land, mostly practice in un developing countries.
2. Rapid urbanization in undeveloped and developing countries converting all other land uses in to urban land.
3. Sub urbanization (decentralization of cities) particularly in united state and other developed countries).

Agricultural activities have had direct and indirect effect on groundwater recharge and aquifer biochemistry. Direct effect include: dissolution and transport of excess quantity of fertilizers and associated materials. Some indirect effect include: change in water rock reaction in soils and aquifer caused by increased concentration of dissolved oxidants, protons and major ions. (Neven Kresic,2013) .

The upper part of the study area has generally steep slope and has good vegetation cover; this is upstream of Addis Ababa to Hossana road that crosses the study area. And downstream of the above-mentioned road, the catchment area becomes flat, no vegetation cover. This part of the catchment area is typically characterized by marshy area and a land setup that is suitable for crop cultivation. A lot of irrigation activity is also taking place in this part of the catchment. In the eastern part of the area the population size is very denser than the other part. This is due to its flatness and comfort to live. In addition to this the area is very good for irrigation practice and for agricultural activities. Because of this many people came to the area for their benefits. Especially people came from urban area for irrigation activities.

3.1.3 SOIL TYPE

Because of flatness of the area, the study area is sensitive for deposition of the eroded materials. In the area alluvial soil, silts and clay soil are dominant. Sand and gravels are known in some part of the area.

3.1.4 HYDROLOGY

3.1.4.1CLIMATE

The study area has a wet season from July to September, dry season from October to January, and a season of highly variable rainfall from February to June. Over 50% of the annual rainfall is received during the 3-month wet season, rainfall distribution is variable. (Ethiopian Water Technology Centre, MoWR, 2005)

3.1.4.2 PRECIPITATION

The analysis of the components of the hydrologic cycle in the study area, an average of 35years rain fall data has been collected from Ethiopian meteorological agency for four stations located within and in the vicinity of the study area. The stations are located at Meki river watershed, Bui rainfall station located at the north of the study area, Meki and koshe rainfall station located at east of the study area, and Butajira rainfall station located inside of the study area. Both Meki and Bui rainfall station are found far from the study area. According to the thissen polygon technique to find area rainfall distribution, Meki and Bui rainfall station are ignored. In the study area surface runoff is towards Lake Ziway.

The most important data that was calculated and used to achieve the objective of the research is rainfall:

Precipitation is any form of water that falls on the surface of the earth by the process of condensation and sublimation. There are different forms of precipitation. Out of this rain fall is the important form of precipitation in hydrologic cycle. The study area is characterized by bimodal rain fall pattern and the main rainy season is June – September. Bimodality of rain fall is more pronounced at Butajira. (MoWR, 2005)

3.1.5 DRAINAGE

Western part of the study area comprises of numerous small streams. Out of them some are drain in to Waja River and some are drain in two Meki river. Most of the streams originate from the surrounding Guraghe highland,. The drainage patterns are dense in the high topographic and less dense in the lowland area. The drainage of an area is affected by numerous factors among which, rainfall, slope, rock type and tectonic activity, vegetation, soil type and thickness, infiltration capacity etc. In the western part of the catchment the drainage forms relatively steep narrow gorges that can attributed to high rainfall, small depth soil and high topographic elevation. Where there are volcanic ridges,

Meki River originates in the highlands of Gurage and travels a distance of about 100 Km from the highlands at altitude of 2,600 m to 1, 636 m before draining into Lake Ziway. Although the headwaters of the Meki River are at an altitude of about 3000 m, the river rapidly descends the rift valley escarpment to below 2,000m.a.s.l before being joined by several major tributaries, including the Lebu, the Akamuja, and the Weja. In Meki River catchment there are only two stations. The station on the main Meki River; at Meki Town, which is the gauge station before the river enters the lake and the second station, is situated at the Irinzaf stream, which is tributary of Meki River. This station (Irinzaf stream) is at Butajira Town; currently it is disrupted by a pipeline crossing the river and requires recalibration. The catchment area of Meki River has two distinctive features: 1, upstream of the Addis Ababa - Butajira - Hosaina Road, the catchment area has generally steep slope and has good vegetation cover; and 2, Downstream of the above-mentioned road, the catchment area becomes flat. Waja River Originates in the highlands of Gurage. It is tributary of Meki River and travel towards North east direction to meet with Meki River before join to Ziway Lake. Weja River travels a distance of about 87 Km from the highlands at altitude of 2,500 m to lowland altitude of 1805m.a.s.l before joining to Meki River. (MoWR, 2005)

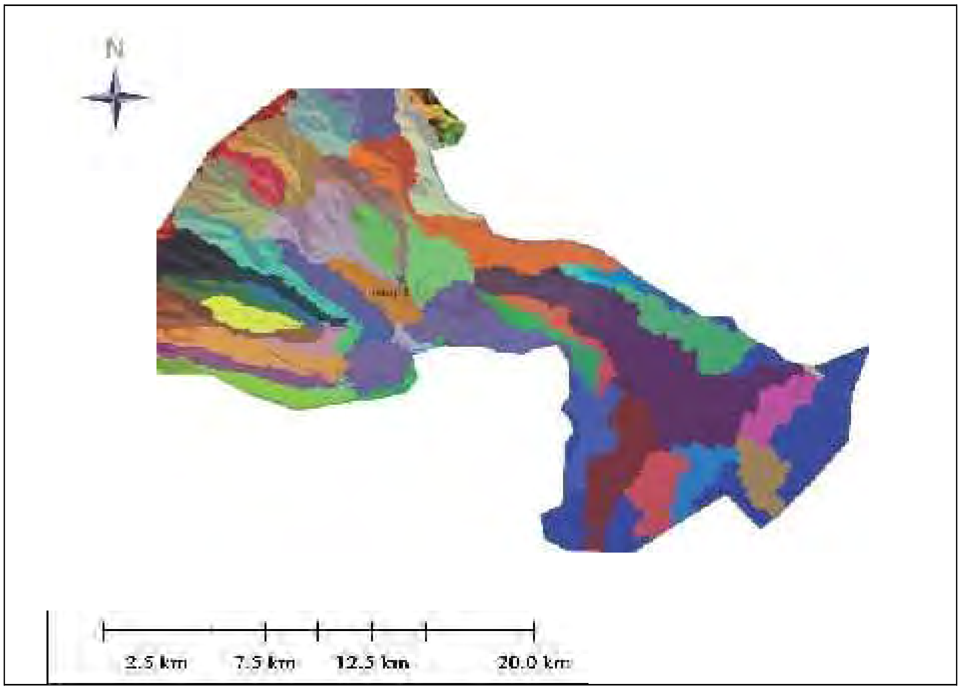


Fig 10 Surface drainage map

3.2 DATA COLLECTION AND MATERIALS USED

Identification, collection and compilation all available hydro geological information such as maps, existing borehole data, about the aquifer type and property, information about land use / land cover etc. for determining the impact of pumping for irrigation on groundwater potential. To accomplish the objectives of the research, the following materials were used:

- Digital elevation model (DEM) of Ethiopia which is 90m x 90m resolution.
- GPS used to record specific location of boreholes. Because (X, Y, Z) coordinates of boreholes are needed for computing elements and nodes of the study area for TAGSAC software in order to compute groundwater hydraulic head.
- Various types of computer software (TAGSAC, MATLAB).
  - ✓ Software for processing spatial data, such as global mapper software (GMS)
  - ✓ MATLAB it is computer programming that is used to statistical data analysis, calibration process. Used to prepare model parameters such as hydraulic conductivity, elements and nodes are calculated.
  - ✓ Software that supports model calibration, and uncertainty analysis(Surfer v12 , spreadsheet)
  - ✓ Programming and scripting software that allows additional calculations
- Meter; used to measure water level in the well. This is done by tying loaded substances at the end of the meter and releasing it in to the borehole up to water level in the borehole.
- Motorcycle : used to travel when data were collected
- Meteorological Data (annual rain fall) from the Ethiopian Meteorological Agency.
- Study report review document
- Pictures were taken using digital camera
- Geological maps with relevance and available scale was collected from Ethiopian Geological survey Agency.

The field work was conducted to perform the following activities:

- Visual observation of geological structures.
- Observing Land use/ land cover practices.

The data collection has started in February 09/06/2015 and end 09/07/2015 for one month. The first activity done was the reconnaissance survey in order to get the general insight of the basin. During that Water Use Associations (WUAs), Professional staffs (DA) development agent and some farmers were consulted about groundwater use practices.

Based on the information gathered:

- Primary data (measuring the water level on representative well, Collecting information on the boreholes and such as; owner of the well, usage of the well, depth, annual pumping rate data, pumping hours, appropriate location using GPS) were collected.

- Secondary data that used for this research were collected as much as possible from responsible bodies and officials. These data include meteorological data from National Meteorological Agency. Geological data collected from Ministry of Water, irrigation and Energy and Ethiopian Geological survey Agency.

3.3 GROUNDWATER MODELING

Groundwater Modeling is one of the main tools used in the hydro geological science for the assessment of the resource potential and prediction of future impact under different circumstances/stresses. Its predictive capacity makes it the most useful tool for planning, design, implementation and management of the groundwater resources.

The main aim of the groundwater model is to determine the extent of groundwater availability and whether exploitation of the groundwater resource, for irrigation and other purposes, is possible and feasible.

The first step in the groundwater resources evaluation using models will concern study of the available potential at current development and stress conditions.

Wells and piezometers were needed to obtain information about the hydraulic parameters of the aquifer and the levels of the groundwater table in the area of study. All available information will have to be carefully analyzed before specifying model conditions.

For the modeling the main work was assembling data relevant to the modeling work.

- Define lateral and vertical extension of aquifer layers and associated thickness,
- Define aquifer parameters, for the modeling work,
- Geologic information including geologic maps,
- Identify recharge areas
- Identify aquifer types and number of layers,
- Boundary conditions and locations

Based on the conceptualization the model was designed and input of data such as model extent, grids element size, boundaries and aquifer parameters were prepared. The groundwater model was calibrated in steady condition based on observed hydraulic parameters such as measured and simulated hydraulic head (water table head).

3.4. MODEL ASSUMPTIONS

- The modeling is steady state
- Based on the past studied document reviewing, Aquifer is assumed to be a single layer.
- The width between nodes and depth of aquifer is taken as 200m by considering different factors such as depth of boreholes that farmers drill, distance from one borehole to the other borehole.
- The study area is recharged from direct rainfall, flood coming from the western part from gurage highland and recharge from streams and two rivers flowing to east to join Lake Ziway.
- Pumping for water supply is significant impact on groundwater potential

3.5 GOVERNING EQUATION

Darcy's law describes a steady uniform flow of constant velocity in which net force on any fluid element is zero. For unconfined saturated flow, the two forces are gravity and friction. For the study area, based on the conceptual model the steady state condition the equation is given by:

$$\boxed{\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) = 0} \quad \ldots\ldots\ldots\ldots\ldots (9)$$

Where K_x, K_y and K_z : are the values of hydraulic conductivity along x, y and z coordinate axes in meters per day; h is hydraulic head, in meter (David Keith Todd, 2005).

The movement of groundwater through porous media is described and solved on the basis of partial differential equation, governing equation. It is the representation of physical law that controls the groundwater flow, which is based on Darcy's law and the law of mass conservation.

3.6 TOP OF MODEL LAYER

Top layer is the top elevation of the aquifer under considerations. The top layer of unconfined aquifer is the water table and not the land surface (topography). In this model, the aquifer was assumed to be a single layer unconfined aquifer. Generally, the top layer elevation was considered to be the elevation of water table. The nodal values of ground surface elevation were interpolated from DEM data. The interpolation was done at the resolution of 200m X 200m x200m and then loaded in to the TAGSAC software of MATLAB v14 computer program with the help of surfer software dot.dat file; this is done by subtracting the surface elevations above from the interpolated water table. At the top of the model layer groundwater hydraulic head is calculated at each node.

3.7 BOTTOM OF MODEL LAYER

Bottom layer is the bottom elevation of the aquifer layer being modeled. In this study, for the model the aquifer thickness is taken as to be 200m. This is because the users of groundwater were drilling the boreholes approximately 200m far away from each other. Most parts of the catchment surface elevation lies between 1806m and 2000m above sea level except at western part of guraghe highland its surface elevation is above 2000m a.s.l. However most part of the study area is below 2000m at sea level, due to this for all zones the same aquifer thickness is taken.

3.8 GRID ELEMENT SIZE AND MODEL EXTENT

In the Finite element model, the grid is formed by three sets of lines crossed each other. The triangles formed by these lines are called element. At the end of each element the point is called node. At the end of the element, model calculates hydraulic head. In this study the grid mesh is approximately uniform. This uniformity is depending on the number of nodes and elements size.

The modeled area extends 108 km in the east direction and 68.44 km in the north direction. To minimize variety of sources of numerical errors, the model grid should be designed using finest mesh spacing and time steps that are possible, given limitation on computer memory and computational time. In this study the model element size varies from 200 m X 200 m for all elements. This is based on the collected borehole data. When grids are designed, element sizes were approximately uniform in the domain. The total number of nodes and elements of the study area are 22301 and 21710 respectively.

The entire study area from surface to the bottom of the model has been divided into a horizontal layer having dimension of 200 meters height. A total of 21710 triangular prism elements are formed from 22301 nodes distributed all over the study area. These nodes and elements are shown in the Figure 11 below.

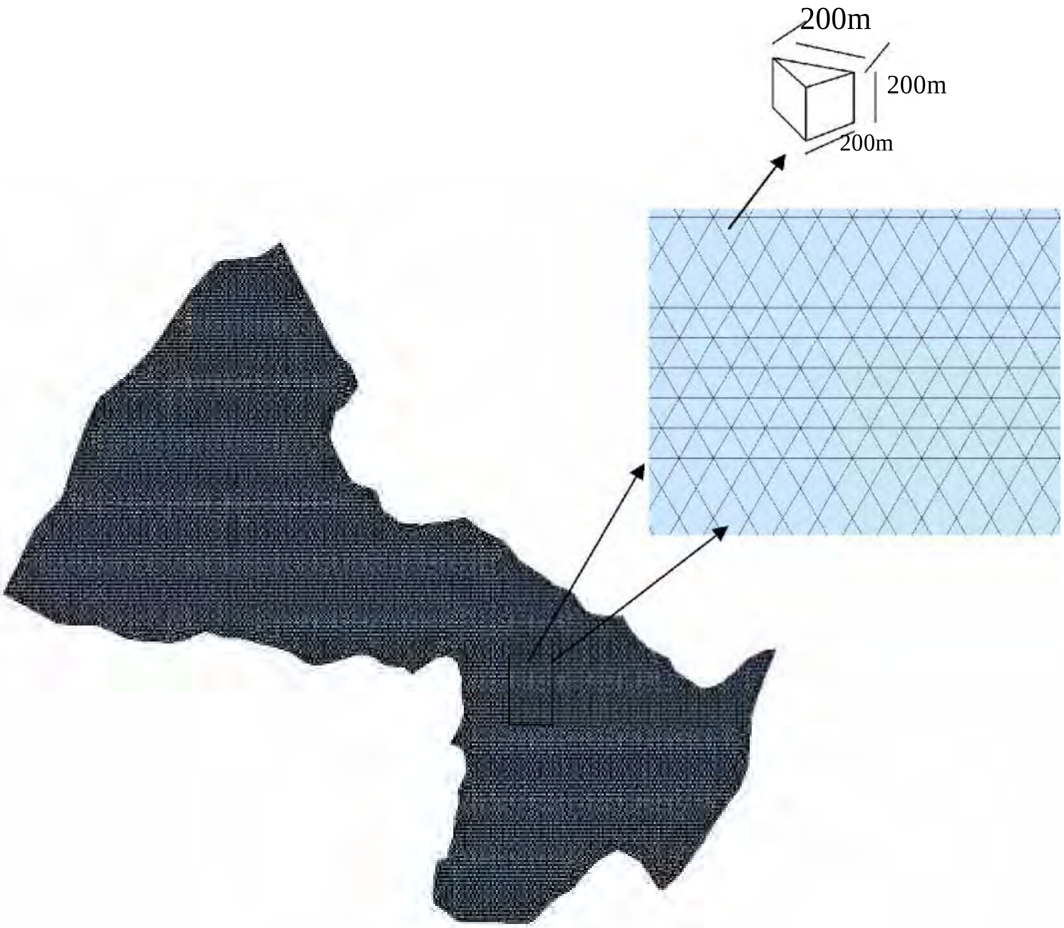


Figure 11 Model structures that show finite-element grids of the basin.

In the above figure 11 the continuous dependent variable hydraulic head (h) is replaced by discrete dependent variable (hydraulic head)

The grid spacing is selected considering different factors such as: Desired detail around sources and sinks (e.g., rivers, streams), wells, pumping well intervals (distance from one pumping well to the other pumping well).

3.9 HYDRAULIC CONDUCTIVITY

The permeability of the soils or rock material consist the porous media is a function of their effective porosity, structure, texture and geological history. Hydraulic conductivity (K) is a measure of the ability of fluid to move through interconnected void spaces in the sediment or rock. It is a function of both the medium and the fluid.

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. 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 four 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.

3.10 FLOW BOUNDARY SYSTEM

To obtain a unique solution to a partial differential equation corresponding to a given physical process, additional information about the physical state of the process is required. This information is supplied by boundary and initial conditions. Physical boundaries are well defined geologic and hydrologic features that permanently influence the pattern of groundwater flow (faults, geologic units, contact with surface water etc.)

For steady-state problems, only boundary conditions are required. Mathematically, the boundary conditions include the geometry of the boundary and the values of the dependent variable or its derivative normal to the boundary. Internal sources and sinks are also considered as boundary conditions in the solution to the governing equations. In physical terms, for groundwater-model applications, the boundary conditions are generally of three types: (1) specified value (head), (2) Specified flux (corresponding to a specified gradient of head), or (3) value-dependent flux (or mixed boundary condition, in which the flux across a boundary is related to both the normal derivative and the value.

For the study area the boundary conditions are shown in Figures 12 below. The major part of the boundary is river boundary (constant head), except the western part that is groundwater divide boundary (no follow boundary).

One of the most important aspects of creating contours map in alluvial aquifers is to determine the relationship between ground water and surface water features. In hydraulic terms, the contact between an aquifer and surface water is an equipotential boundary. In case of lakes and wetlands, this contact can be approximated with the same hydraulic head. In case of flowing streams, the hydraulic head along the contact decreases in the down gradient direction (both surface water and groundwater flow down gradient) (Neven Kresic, 2013).

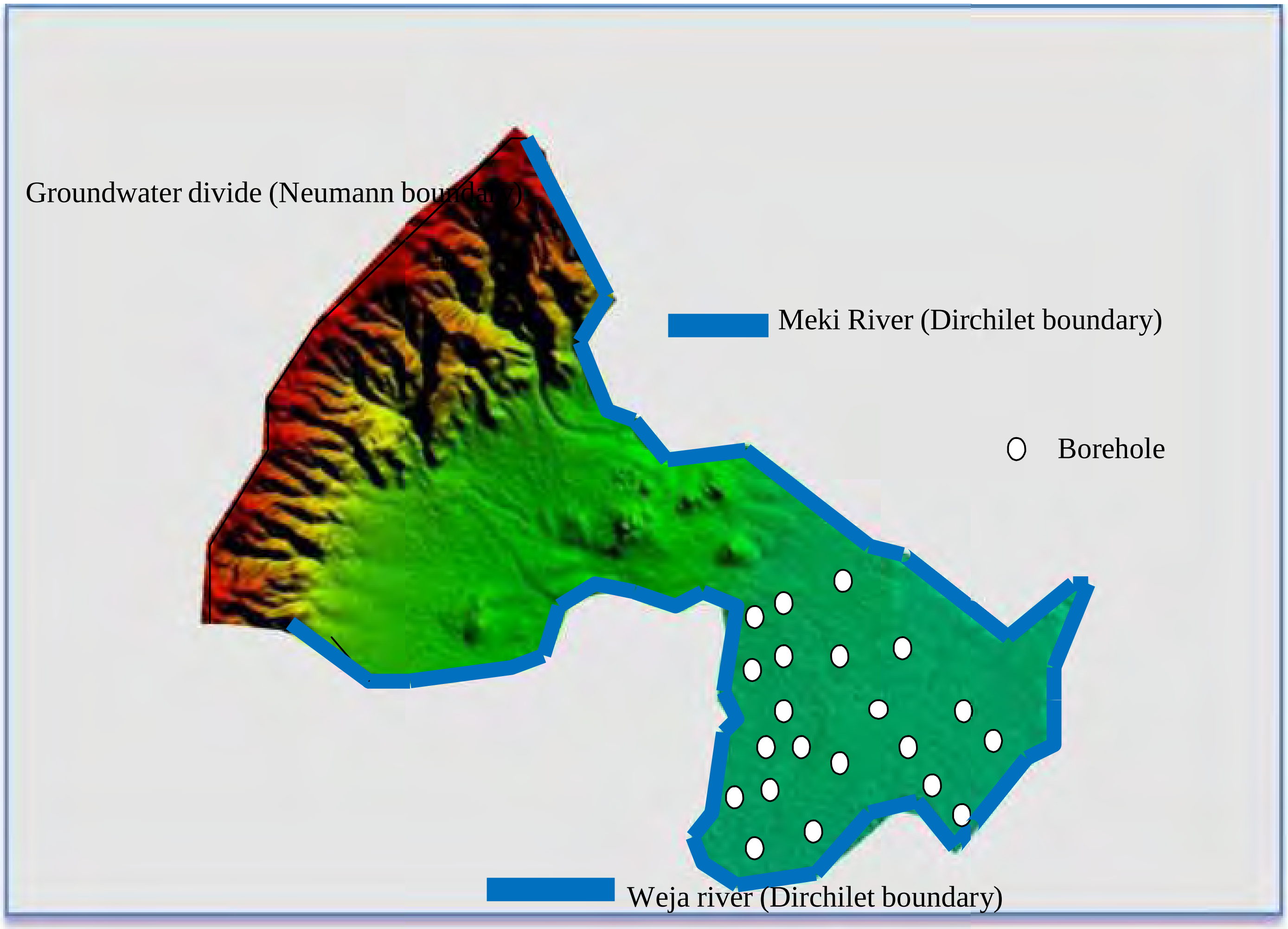


Figure 12 boundary condition

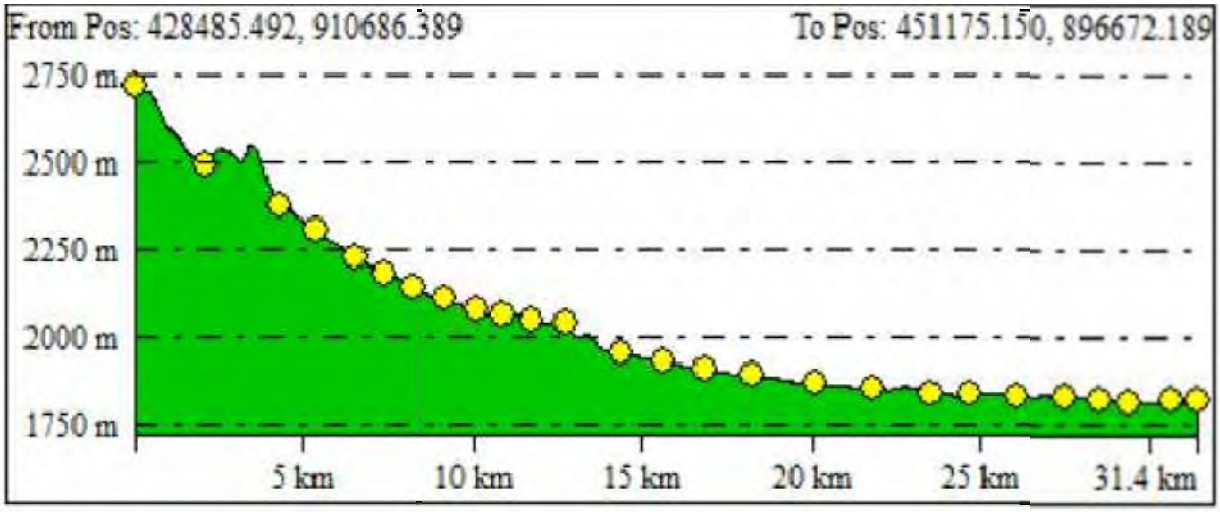


Fig. 13 Meki River distance and River surface level section

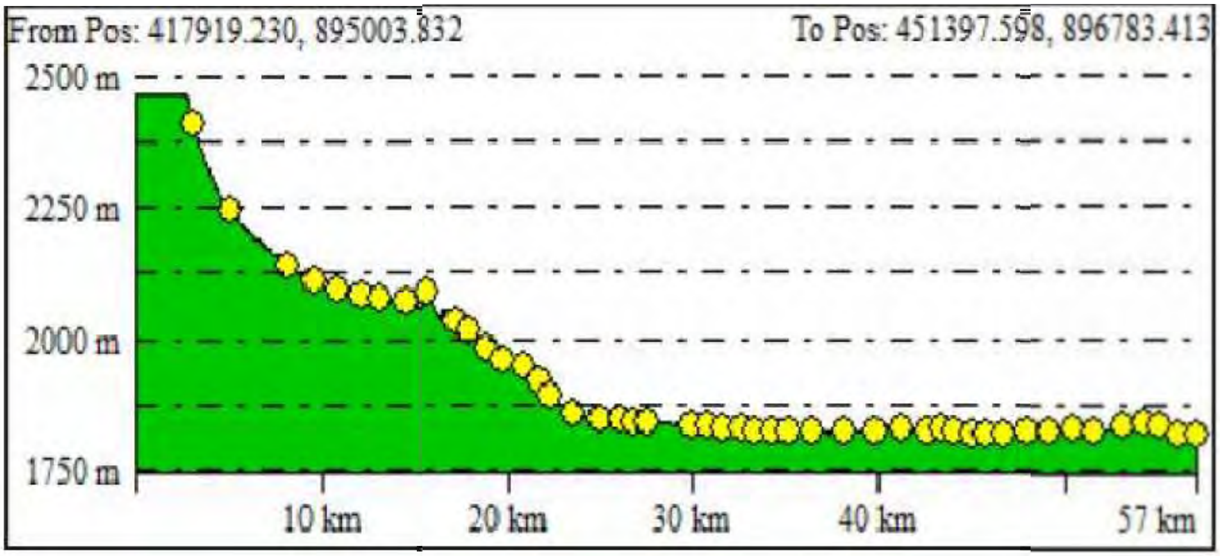


Fig 14 Weja River distance and River surface level section

The two Rivers meet at a place called Lemeja before joining to Ziway Lake. After along travel it joins to Ziway Lake.

3.11 WELL INVENTORY

Borehole investigations are one of the most important methods to investigate the hydrogeology of the site. These investigations allow collection of borehole samples, groundwater sampling and measuring the hydrogeological and rock mass properties to depth. However from this study objective point of view well location its elevation and the water table depths are collected. The well inventory in this research includes collecting the above information on hand dug wells, deep wells. These data are used in optimizing the aquifer hydraulic properties. During well inventory and observation and measuring the location using GPS, the error for most of observation points Was about ± 10. For the few observation points the error was between ±10 - ±15.

3.12 RAINFALL DISTRIBUTION

In order to represent point rainfall data for the study area, the thiessen polygon method is employed by drawing the polygon using global mapper software. This method gives good result when the rain gauges are not evenly distributed over the area in both flat and hilly terrain. This method considers point rain fall measurement represents half way up to adjacent gauges.
It is formed around each precipitation station by drawing perpendicular bisector of the lines joining adjacent stations. (H.M.Raghunath, 2006)

Rain gauges represent only point measurements. in practice however, hydrological analysis requires knowledge of the precipitation over an area. Several approaches have been devised for estimating areal precipitation from point measurements. The arithmetic mean, the Thiessen polygon and the Isohyetal method are some the approaches.

In the Thiessen polygon method, the rainfall recorded at each station is given a weightage on the basis of an area closest to the station. The average rainfall over the catchment is computed by considering the precipitation from each gauge multiplied by the percentage of enclosed area by the Thiessen polygon. The total average areal rainfall is the summation averages from all the stations. The Thiessen polygon method gives more accurate estimation than the simple arithmetic mean estimation as the method introduces a weighting factor on rational basis. Furthermore, rain gauge stations outside the catchment area can be considered effectively by this method.

The average depth of precipitation over the total area is given by:

$$P_A = \sum_{n=1}^{n} \frac{Pi \times Ai}{At} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where P_{A} – average areal rainfall
A_t = total study area = 384.65km^2
P_i : Mean annual rainfall at rainfall station
n- Number of rain gauge
A_i- The area of polygon associated with Pi

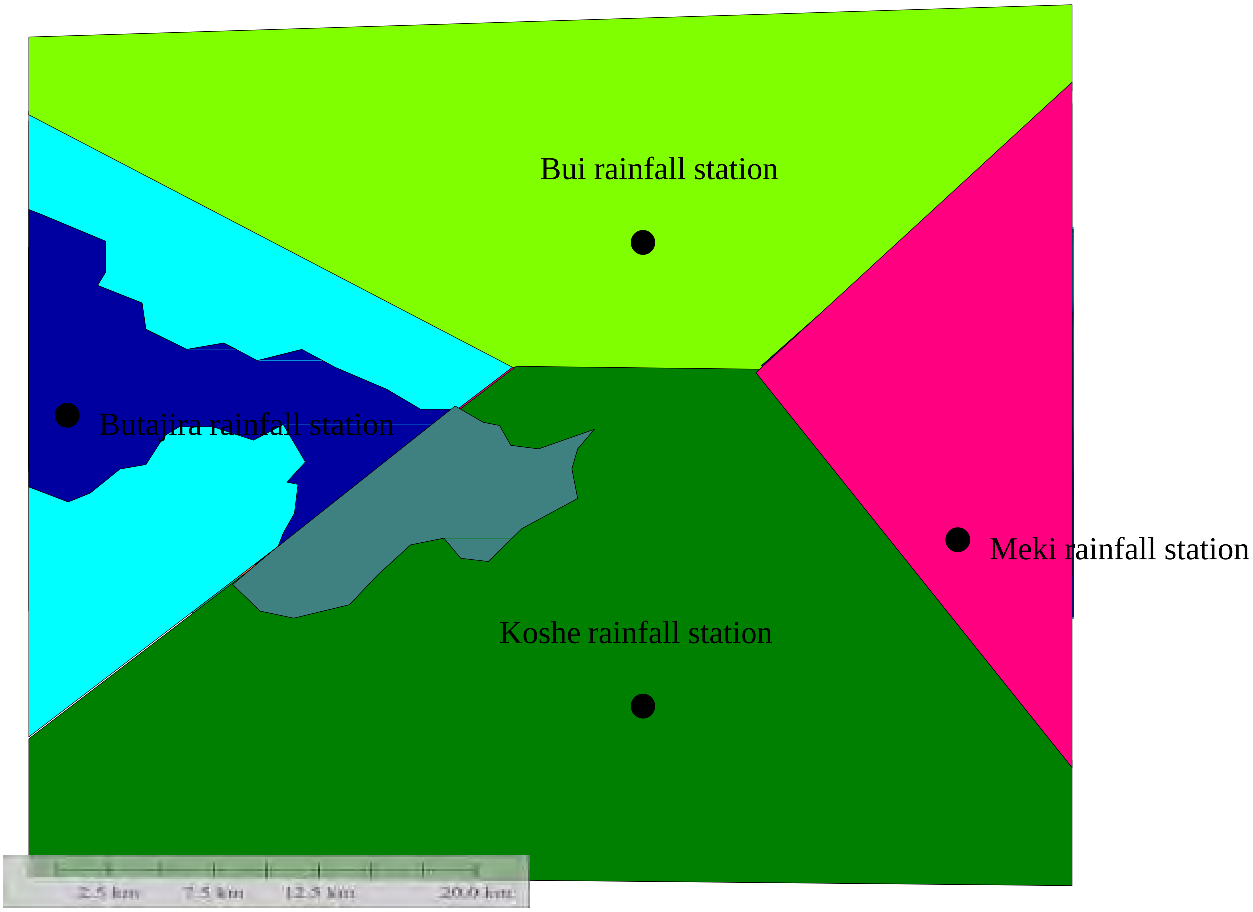


Figure 15 Thissessn polygon

Methods for estimation of missing rainfall data are present here:-

Some precipitation station may have short breaks in the records because of absence of the observer or because of the instrumental failures. It is often necessary to estimate this missing record. (H.M.Raghunath, 2006)

There are two methods for estimation of missing rainfall data. These are:

1. Simple arithmetic mean method
2. Normal ratio method

In this study the missing rainfall data were filled using simple arithmetic mean method. The collected data from Ethiopian national meteorological agency for the study area, its mean monthly distribution of rainfall is shown below in table.

1. Simple arithmetic mean method

According to the simple arithmetic mean method the missing precipitation 'Px' is given as:

$$P_x = 1/n \sum_{i=1}^{i=n} Pi \quad \text{...} \quad (11)$$

Where Px is the missing precipitation for any storm at the interpolation station 'x', Pi is the precipitation for the same period for the same storm at the "ith" station of a group of index stations, Nx the normal annual precipitation value for the 'x' station and Ni the normal annual precipitation value for 'ith' station.

3.13 DATA USED FOR CALIBRATION

The model is calibrated to steady state condition with observed head measured at the available production wells. Sample Location of Observation points used for head calibration is shown in figure16 below. The boreholes that are taken for the model calibration were not uniform throughout the modeling area. But it is uniform in the area where the irrigation activities take place by pumping groundwater well. Such data will bring about good result around the abstraction well location but may result is in accurate values away from the observed data location.

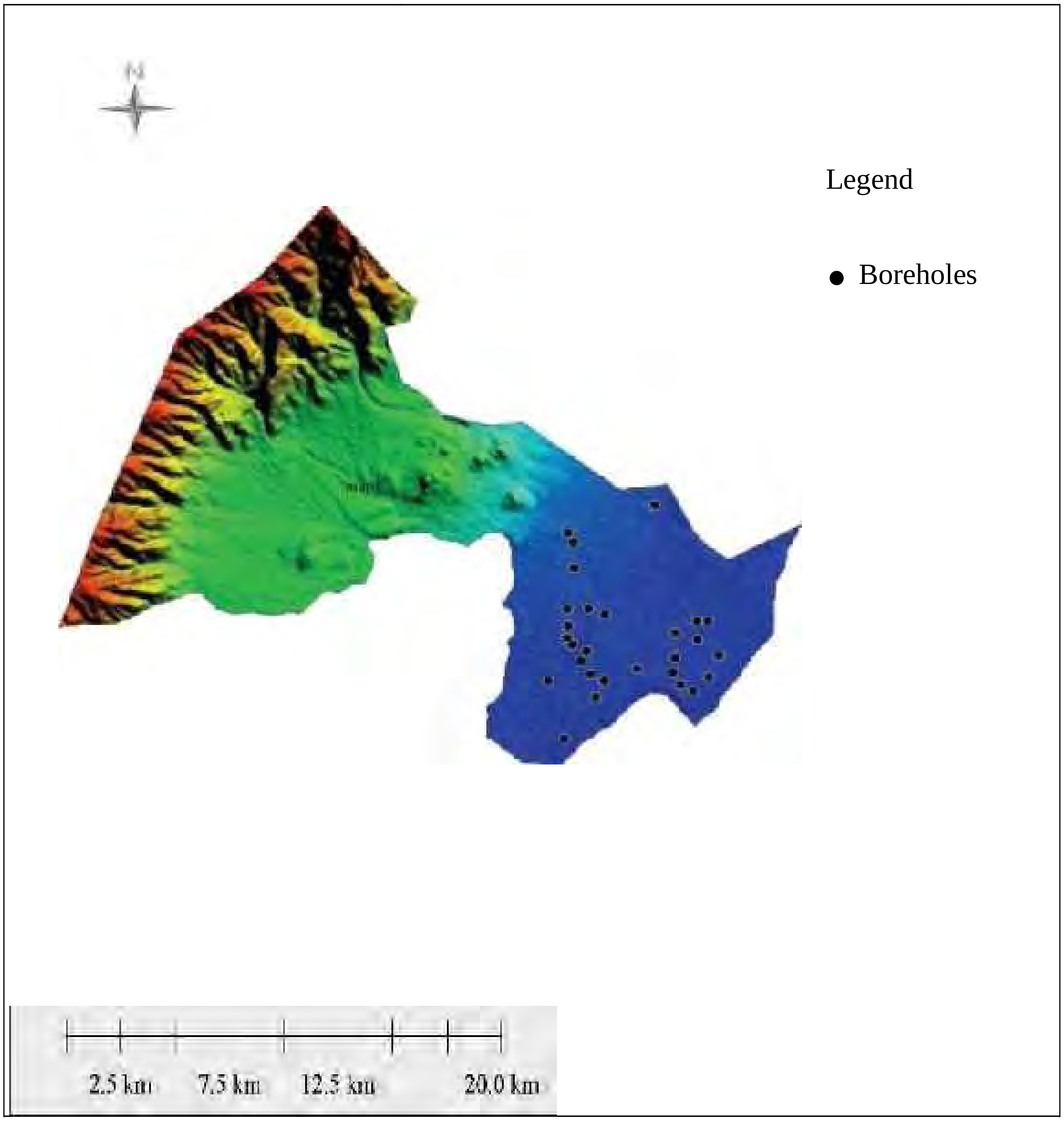


Figure 16 Location of Observation points used for head calibration

Location of the borehole data were collected using GPS. The depth to water in the groundwater well was measured using meter. All the collected borehole locations were inserted in to software called TAGSAC. In order to generate hydraulic head and to calibrate the simulated head and measured head.

3.13.1 CALIBRATED STATISTICS

Quantitative techniques for comparing model result (simulation) to sit specific information including residual, assessing correlation among the residuals, and plotting residuals on maps and graphs. Individual residuals are calculated by subtracting the model calculated values from the targets (values recorded in the field, not extrapolated or assumed). They are calculated in the same way for hydraulic head, draw down, concentration or flows; for example the hydraulic head residuals are differences between the computed heads and the heads actually measured in the field. A listing of measured and simulated heads with their differences and some type of average of the differences is common way of reporting the calibration result. This difference is called error or residual. It is computed by subtracting the model computed value (head) from the target value. Negative residual indicates that the model is calculating the dependent value too high and the positive residual is where model value is too low. . (Charles R. Fitts, 2013).

$$R_i = h_m - h_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Where R_i is residual, h_m is measured head, h_s is simulated head

The following types of statistics computed to express the average difference between simulated and measured heads are commonly used.

- Mean Error (ME) is the mean difference between the measured heads (h_m) and simulated heads (h_s). n is the number of calibration value.

$$ME = \sum (h_m - h_s)/n \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

The ME is simple to calculate but is usually not a wise because both negative and positive differences are incorporated in the mean and may cancel out of the error. Hence a small mean may not indicate a good calibration. The model of the area under investigation has a mean error of 7.45 that is not too far to be good calibrated model. It is good calibrated.

- Mean Absolute Error (MAE) is the mean absolute value of the difference in measured and simulated heads.

$$\text{MAE} = \sum \left| (h_m - h_s) \right| / n \quad \text{……………………………….} \ (14)$$

It is the measure of the average errors in the model. The model results an absolute residual mean of 7.488 which is the residual criteria set before the calibration process.

In this study the Root Mean Square error is computed by using MATLAB software and excel window.

- The Root Mean Squared (RMS) Error or the standard deviation is the average of squared differences in measured and simulated heads.

$$\text{RMS} = [1/n\textstyle\sum_i^n (h_m - hs)^2]^{1/2} \quad \text{……………………………………..….. } (15)$$

Where h_m and are measured and h_s simulated results and n is the number of data.

It is the measure of the overall spread of errors. It can be compared the overall range of in the observed value as further comparison. For head observations, this value show errors related to the overall gradient across the model. The model has resulted (8.74) error of standard deviation which is good range in calibrations.

The coefficient of determination, R^2, compares estimated and actual groundwater level - values, and ranges in value from 0 to 1. If it is 1, there is a perfect correlation between the modeled and measured values; there is no difference between the estimated and measured values. At the other extreme, if the coefficient of determination is 0, the regression equation is not helpful in predicting the groundwater level-value.(Rawlings, 1932)

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 EFFECT OF PUMPING ON GROUNDWATER POTENTIAL

The withdrawal of ground water by pumping is the most significant human activity that alters the amount of ground water in storage and the rate of discharge from an aquifer. The removal of water stored in geologic materials near the well sets up hydraulic gradients that induce flow from more distant parts of the aquifer. As ground-water storage is depleted within the radius of influence of pumping, water levels in the aquifer decline. In this study model result is simulated hydraulic head in order to check whether the groundwater potential is affected by pumping for irrigation or not. This is checked by seeing the head differences before pumping and after pumping the groundwater and drawing the contour map before pumping and after pumping the groundwater using surfer software. Down streams of the study area is impacted by over drafting groundwater for irrigation practices. This is shown clearly by drawing water table elevation on contour map. The effect of pumping groundwater on groundwater potential is shown by drawing contour map of the differences between water table elevation before pumping the groundwater and water table elevation after pumping the groundwater.

Groundwater depletion is primarily caused by sustained groundwater pumping. These negative effects of groundwater depletion are:

- draying up of wells
- Reduction of water in streams and rivers
- increasing of pumping costs

4.2 WELL INVENTORY

In the study area **109** boreholes (shallow wells, see annex 1) have been inventoried however due to inconsistency in data generation and inaccuracies during observation and measuring, 94 boreholes have been selected in this research. All are shallow boreholes (having 34 meters or less). These boreholes are found at downstream in the study area. Because, at downstream most boreholes are drilled for irrigation purpose. The location of these boreholes is the coordinates of the pumped borehole that is recorded by using GPS.

4.3 RAINFALL DISTRIBUTION

Rainfall location and annual mean rain fall of the study area is again the other parameter for the model. Daily and monthly rainfall is taken from the Ethiopian meteorological agency. After filling the missing data by using arithmetic mean method, mean monthly rainfall

Table 5 the result of the Mean annual rain fall

No.	Station name	x-coordinate	y-coordinate	Mean annual RF (mm) p_i
1	Butajira	382200	80900	1110.57
2	koshe	383131	80023	922.80

Mean annual rainfall of each station is used in thissen polygon in order to calculate areal depth of rain fall. This is shown in table 7 below.

Table 6 the result of the Mean monthly rain fall

Station	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	mean
Butajira	44.7	12.6	34.8	35	45	50	86	177	186	176	129	175	95.93
koshe	11.0	50.6	5.4	5.2	23.1	52.5	75	93	90	97	170	170	70.23

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 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 four rainfall stations theses are Butajira, Bui, Koshe and Meki. According to Thiessen polygon, the two stations Bui and Meki do not contribute for the study area. These stations are far from the study area.(see figure 15).

According to thiessen polygon method analysis the mean annual rainfall of the study area is **1060.00**mm/year. Thissessn polygon is constructed by global mapper software using rainfall station location.

Table 7 the Annual weighted rainfall of study area based on Thiesen Polygon Method

Station name	Mean annual RF (mm) p_i	Enclosed area (km^2 Ai	Thissen polygon Area (km2)	Weighted Area Ai/At	Annual weighted RF (mm)Ai
Butajira	1110.57	283.20	620.71	0.735	816.268
koshe	922.80	101.65	380.25	0.264	243.378
Total At		384.85	1000.96		
Areal rainfall					**1060.00**

4.4 FLOW SYSTEM BOUNDARY

In this three-dimensional modeling effort, the surface nodes at the river edge were simulated as constant-head boundary conditions reflective of the assumed river stage. 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.

Therefore the in this study Rivers 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 mountainous ridges (watershed divides); (guraghe highland) bounding the model area are hydraulic berrier boundaries (groundwater divides); (no-flow boundary) in which nodes at the water table are taken to be constant flux nodes (Neumann nodes) with flux equal to zero.

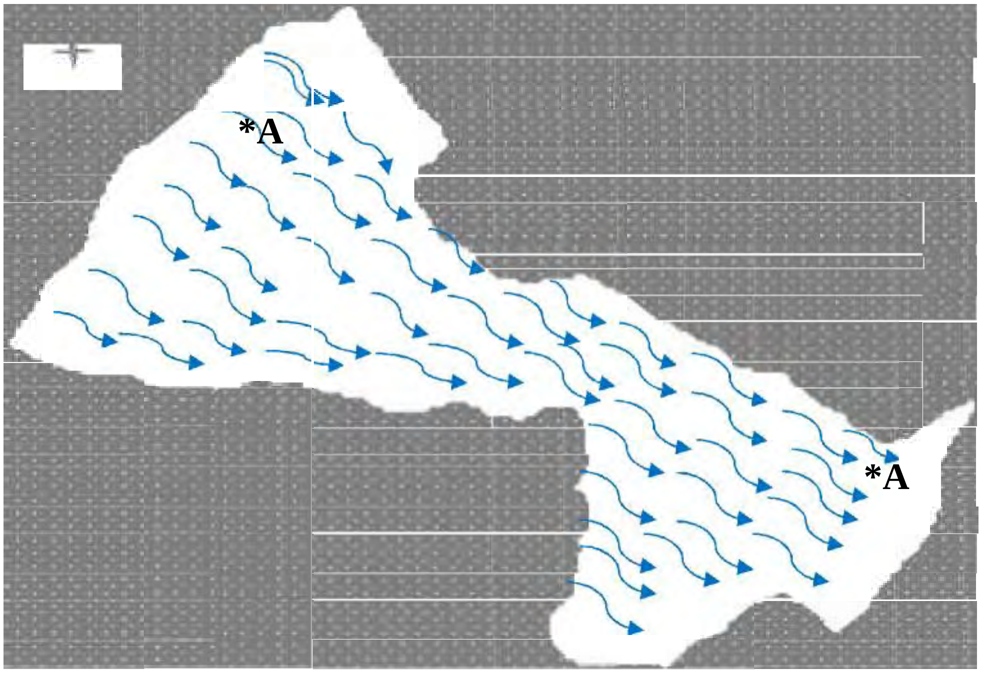


Fig 17 Ground water flow direction

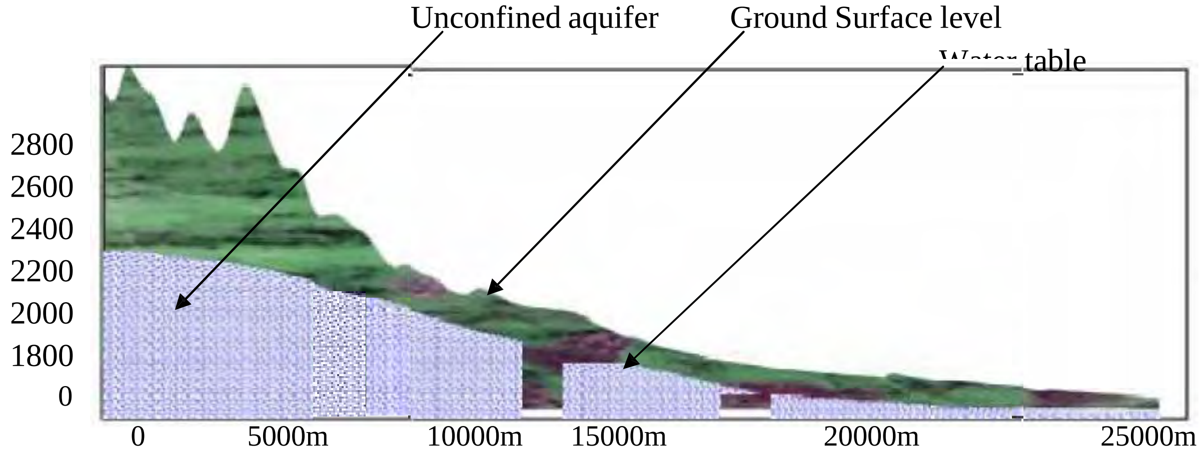


Figure 18. Groundwater Section from A - A

4.5 MODEL CALIBRATION

In this study, calibration was performed by trial and error estimation processes. In the study, calibration of the steady state model was performed by comparing simulated heads with that of observed water level heads. For calibration technique the well around abstraction area were inventoried. The trial values are the hydraulic conductivities of the geologic formation in the study area (see figure 19)

The model calibration accounts the matching of the 109 observation point with simulated head with a permissible residual head error of ±10m. The model was assumed calibrated when the fit between observed and simulated heads was within this criteria and calibration evaluated based on final spatial distribution of the difference between the observed and simulated heads. During calibration 109 observation points became to 94 observation points. This was because of observation error. The rest 15 observations data show great error value. The RMS value was very high because of these observation points. During observation and measuring the location using GPS, the error for most of observation points was about ± 10. For the rest observation points the error were between ±10 - ±15.

4.5.1 HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is the most essential parameter that determines the flow of the system of a model. It is obtained through pump test analysis, laboratory, etc. The spatial distribution of the hydraulic conductivity of the basin is the very important input of the model.

Material type (geological material) is prepared by overlapping the geological map and topographical map of the study area. After overlapping these maps, the geological path profile is generated by DEM data and GMS, surfer software. Then using MATLAB program, element numbers are generated and coded as 1 for geology one, 2 for geology two, 3 for geology three and 4 for geology four. After this process, the value of hydraulic conductivity is calculated by using MATLAB program by changing the multipliers until we get the adjusted RMS value during the calibration process. Transmissivity is obtained by taking the depth of aquifer as 200m which is model depth and multiplying by hydraulic conductivity in each zone. The result in the table 11 shows that geology one and geology four have the same property. According to previous studied document the area of geological materials are identified for each zone. This is shown in the table 8 below. The red lines on Geological map of the study area in figure below indicate the faults which are found downstream of the study area. This faults also challenges for the movement of water in the aquifer.

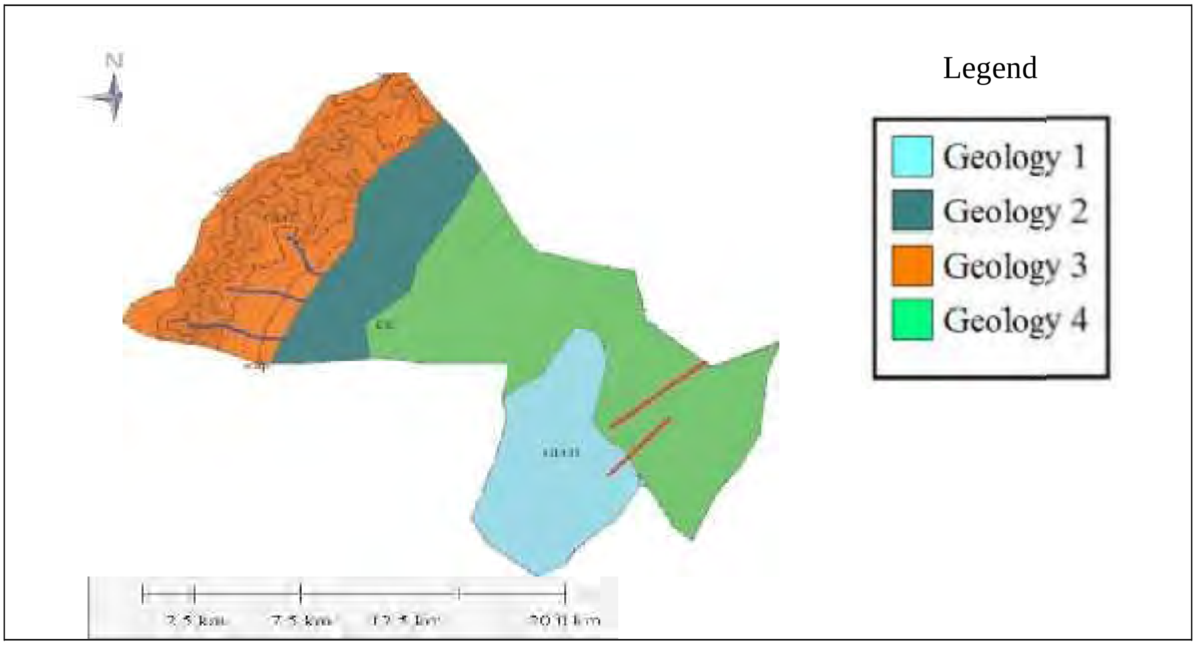


Fig 19 Geological map of the study area

Table 13 Aquifer property

Geological features	Symbols	hydraulic conductivity m/year	Tranmissivity m2 /year	Geologic formation
Geology 1	K_X	2.59	518	Pyroclastic, deposits, lacustrine, alluvial, debris flow or talus deposits and fan deposits.
	K_Y	2.16	432	
	K_Z	2.16	432	
Geology 2	K_X	1.29	518	Tertiary and Mesozoic Sedimentary
	K_Y	0.216	432	
	K_Z	0.216	128	
Geology 3	K_X	1.296	432	Tertiary and Mesozoic Sedimentary
	K_Y	0.008	128	
	K_Z	0.008	42	
Geology 4	K_X	2.59	518	Pyroclastic, deposits, lacustrine, alluvial, debris flow or talus deposits and fan deposits.
	K_Y	2.16	432	
	K_Z	2.16	432	

4.5.2 CALIBRATED RESULTS

The plots are useful in assessing the quality of calibration simulations. Scatter plots where observed values are plotted versus the value computed by the model. In an ideal calibration the points will fall on the straight line with a 45 degree slope that means the computed value equals with the measured value. In this model, it was difficult to match the two lines, but follows a straight line and lies within +18 residual and -1 residual. This is shown using scatter plot in the figure 20 below.

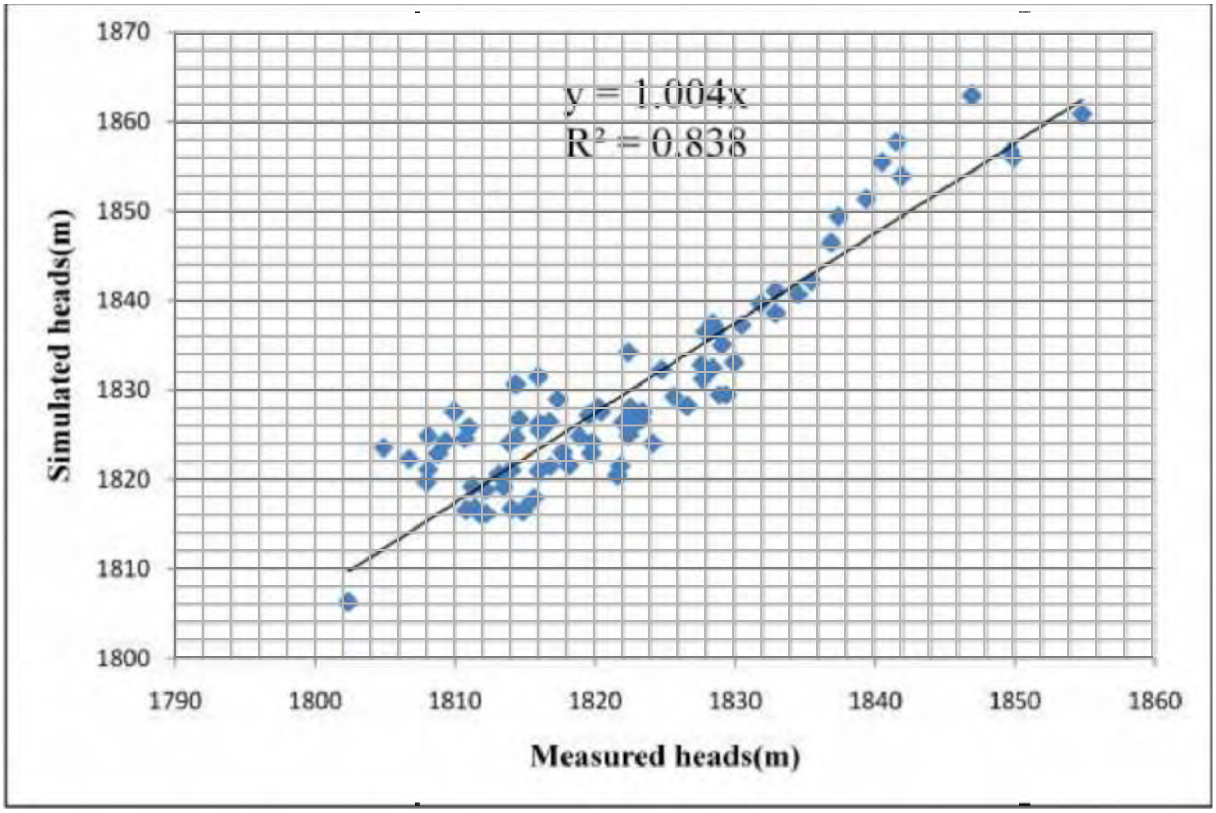


Figure 20 Scatter Plot of Head Distribution of Calibrated Model

Table 8 summary of calibrated result

Model	ME $= \sum (h_m - h_s)/n$	MAE $= \sum \lvert (h_m - h_s) \rvert /n$	RMSE $= [1/n\sum_i^n (h_m - hs)^2]^{1/2}$	R^2
EG.GWM	7.45	7.488	8.74	0.838

4.6 GROUNDWATER RECHARGE

Recharge is the process by which ground water is replenished. A recharge area is where water from precipitation is transmitted downward to an aquifer. Most areas, unless composed of solid rock or covered by development, allow a certain percentage of total precipitation to reach the water table. However, in some areas more precipitation will infiltrate than in others. Areas which transmit the most precipitation are often referred to as "high" or "critical" recharge areas.

The area is recharged directly from rainfall. The recharge area for the groundwater is the highland of gurage Mountain. Rivers and streams are originating from this area and flow to the east direction. The same to that of Rivers the ground water is flow from higher head to lower head.

4.7 GROUND WATER DISCHARGE

Discharge areas are the opposite of recharge areas. They are the locations at which ground water leaves the aquifer and flows to the surface. Ground water discharge occurs where the water table or potentiometric surface intersects the land surface. Where this happens, springs or seeps are found. Springs and seeps may flow into fresh water bodies, such as lakes or streams, or they may flow into saltwater bodies.

Under the force of gravity, ground water generally flows from high areas to low areas. Consequently, high areas-such as hills or plateaus-are typically where aquifers are recharged and low areas-such as river valleys-are where they discharge. However, in many instances aquifers occur beneath river valleys, so river valleys can also be important recharge areas.

Groundwater discharged by spring or seepage effluent streams (base flow), dug wells, boreholes, evaporation, springs and where the water table is expected to the surface (swamps) are the most important sources of discharge on the high relief areas. In this study Groundwater abstraction by boreholes is considered as the main sources for groundwater discharge.

Based on the simulated head the flow direction is also known. The flow direction is from recharge area towards discharge area. The discharge area is the area that has lower water table elevation.

Table 9 groundwater discharge estimation

Trials	Litter	Sec	Q (Lit/Sec)	Remark
Tr_1	12	45	0.267	Data taken from 7 kebeles. Waja, Dida, Kertefa, Alemena, batefuto, Ensenousme, Batelejano
Tr_2	10	10	1.000	
Tr_3	5	3	1.667	
Tr_4	3	3	1.000	
Tr_5	15	14	1.074	
Tr_6	20	18	1.111	
Tr_7	25	25	1.000	
Average			1.017	

For the above table 9, the following information is taken from field observation, measuring the discharge while the groundwater is discharged at certain point and interviewing the users in the field.

1. Working hours per day: 12:00-4:00 in the morning and 8:00-12:00 in the afternoon. For 8hrs in a day.
2. Working days: 6 days in a week. Except 7th day that is Holyday.
3. 8hrs/days x 6days = 48hrs in a week.
4. Working weeks in a month is 4 weeks
5. 4x48hrs = 192hrs in a month.
6. Working month is 10 months in a year. The rest two month is very highly rain fall period. Even if the raining season is bimodal, the first raining season is not sufficient for irrigation. Because of this farmers use groundwater for irrigation and disease protection.
7. 10x192 = 1920hrs in a year = 1920x60x60 = 6912000sec.
8. 1sec = 1.017lit, 6912000sec = 6796460.177lit. = 7029.50m^3
9. Annual groundwater discharge Q_a= 7029.50m3/year.
10. 7029.50m^3/year. This discharge estimation is considered only in one node.
11. Total study area (At) = 384.65km^2 = 384.65 x$10^6 m^2$.
12. Total surface node (Nn) = 11151
13. Area of one node (A_n) = A_t /N_n = 384.65 x106m2/11151 = 34,494. 66m^2.
14. q = annual discharge in one node divided by area of one node was calculated as:
    = Q_a/A_n= (7029.50m3/year.) / (34,494. 66m^2) = O.20m/year is unit discharge
15. The total node number at the pumping area is 3014.
16. In the study, area the current total annual discharge was 7029.50m3/year.) x 3014 = 21,186,913m^3/year. Where 3014 is the total nodes representing pumping site.

Table 10 Trial value to estimate optimum pumping from pumping area

	Trial1	Trial2	Trial 3	Trial 3	Trial 4
Q (m3/sec)	0.3	0.5	0.8	1.00	**1.017**
q (m)	0.06	0.10	0.16	0.2	**0.20**

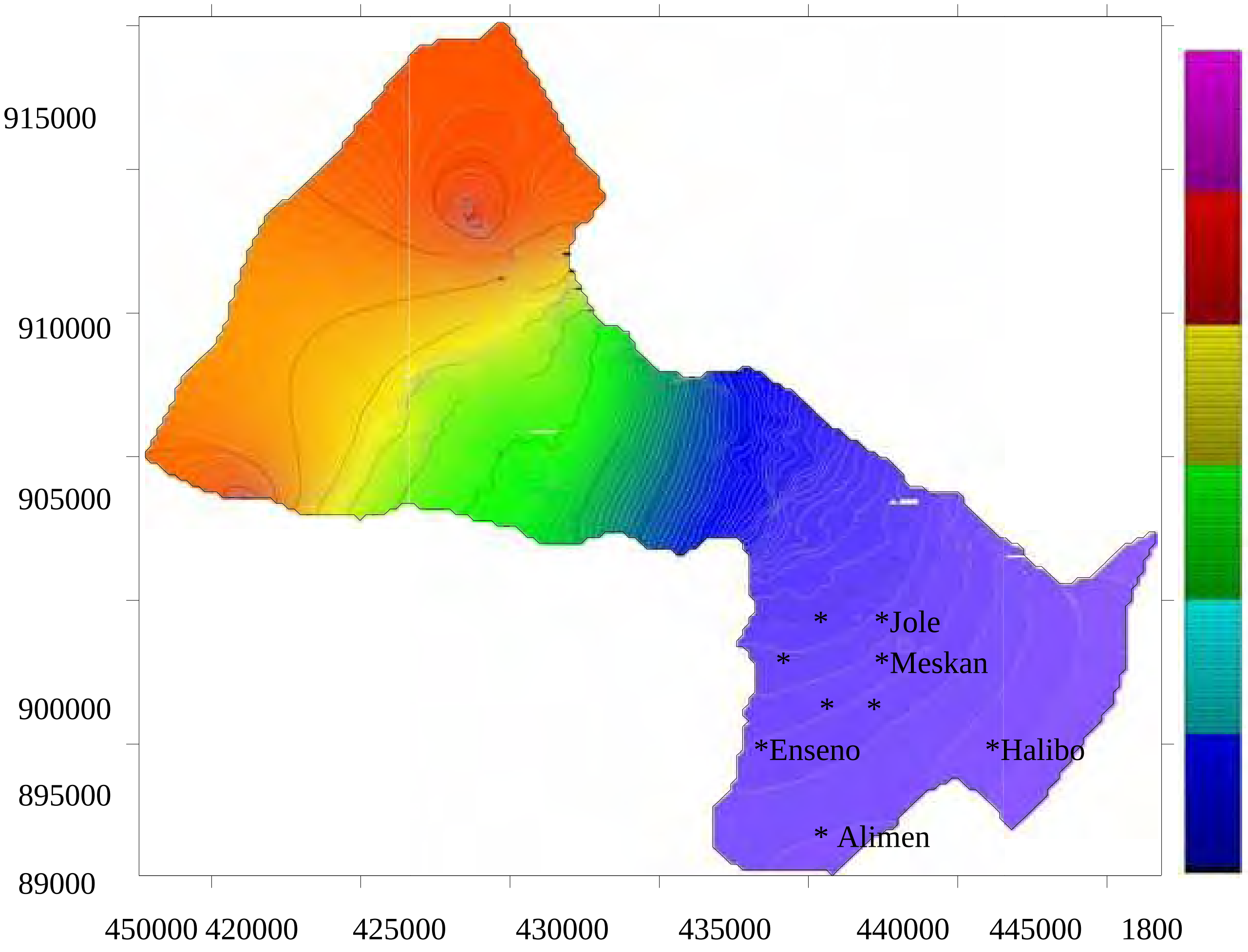


Figure 19 Groundwater table contour maps before pumping the groundwater

For the above figure 19, the minimum and maximum contour levels are 1800m and 2500m respectively. The contour interval is 5m. The water table contour is decreasing down ward from west to east. This indicates that flow direction is from west to east (from higher water table head to lower water table head. Water table contour lines are similar to topographic lines on a map. They essentially represent "elevations" in the subsurface. These elevations are called the hydraulic head mentioned above. Water table contour lines can be used to tell which way groundwater will flow in a given region. Groundwater always moves from an area of higher hydraulic head to an area of lower hydraulic head. Lots of wells are drilled and hydraulic head is measured in each one. Water table contours are drawn that join areas of equal head (like "connect-the-dots"!). These water table contours lines are also called equipotential lines. Groundwater contour maps can primarily be thought of as geometric models, but they also give us qualitative information about the processes. We can look at a groundwater contour map and infer the direction of groundwater flow

Table 11 the modeled water table head distribution before pumping the groundwater

	Alemena	Halibo	meskan	jole	Enseno
Elevation at Surface (m.a.s.l.)	1818.2868	1808.5089	1813.295	1816.305	1811.312
Hydraulic head (water table head) (m)	1810.7219	1808.5089	1808.303	1816.305	1810.626
Depth to Water Table (m.b.s.)	-7.5649207	0	-4.99203	0	-0.6864

In the table 11 above, the zero value of depth to water indicated that the surface and groundwater meet each other at the surface of the ground. Whereas the negative value indicated that the groundwater level is decreased from surface level.

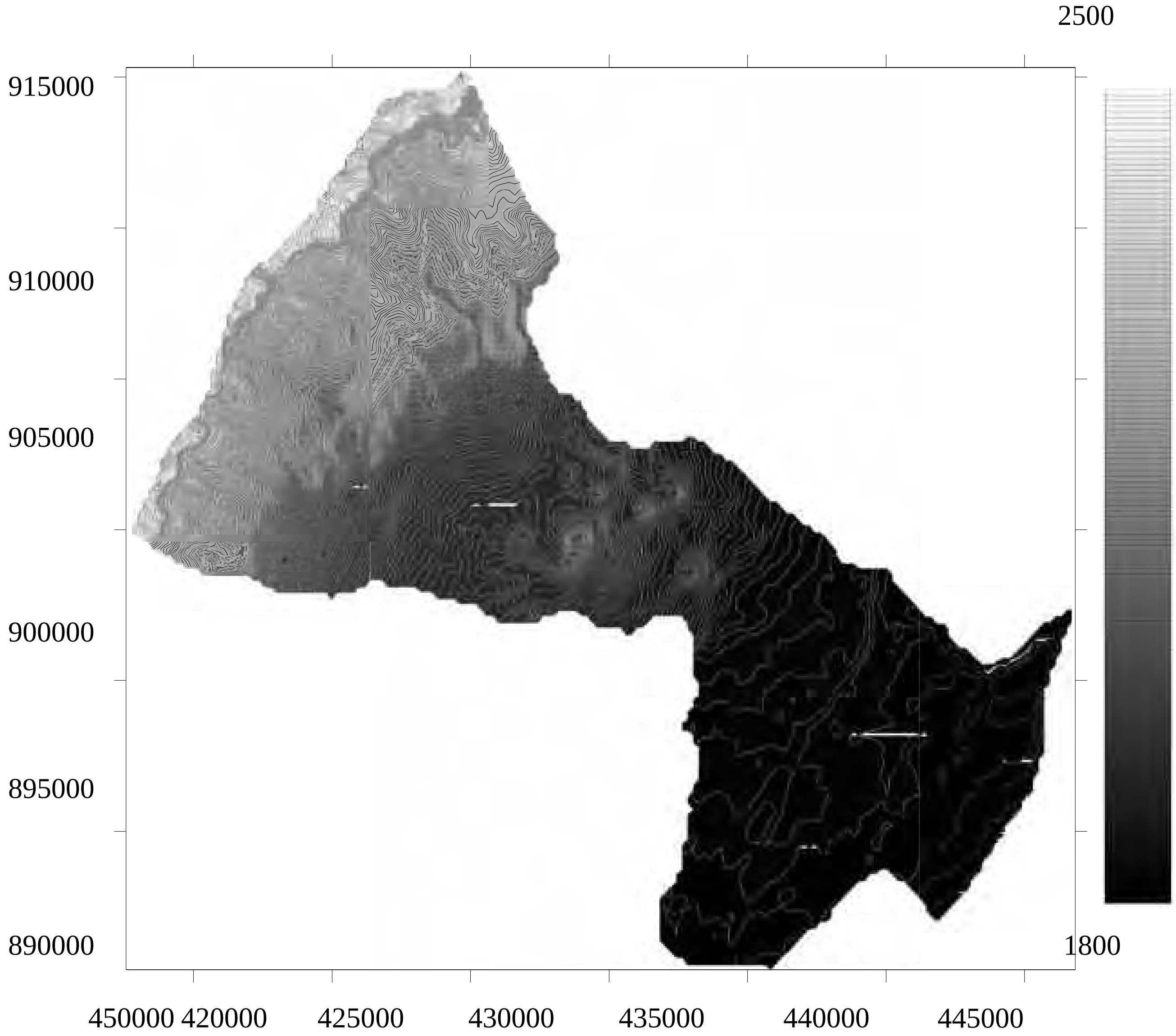


Figure 20 Groundwater table contour maps after pumping the groundwater

For the above figure 20, the minimum and maximum contour levels are 1800m and 2500m respectively. The contour interval is 5m. The water table contour is decreasing down ward from west to east. The increasing or decreasing order of water table elevation after pumping is not the same to that of water table elevation before pumping the groundwater. It is somewhat disordered.

Surface water bodies are hydraulically connected to ground water in most types of landscapes; as a result, surface-water bodies are integral parts of ground-water flow systems. Even if a surface water body is separated from the ground-water system by an unsaturated zone, seepage from the surface water may recharge ground water. Because of the interchange of water between these two components of the hydrologic system, development or contamination of one commonly affects the other. The movement of surface water and ground water is controlled to a large extent by the physiography (land-surface form and geology) of an area. In addition, climate, through the effects of precipitation and evapotranspiration, affects the distribution of water to—and removal from—landscapes. Therefore, it is necessary to understand the effects of physiography and climate on surface water runoff and ground-water flow systems in order to understand the interaction of ground water and surface water. (USEPA, 2000)

Groundwater and surface water are essentially one resource, physically connected by the hydrologic cycle. Although water law and water policy often consider groundwater and surface water as separate resources, groundwater and surface water are functionally inter-dependent. Groundwater and surface water interactions are controlled by their hydraulic connection. (Willis D. Weight, 2008).

Basic hydraulic relationship between surface water and groundwater is shown using hydraulic head contour lines.

- If the hydraulic head of groundwater near the stream or river is less than the level of flowing river, the river or stream loses water to the aquifer.
- If the hydraulic head of groundwater near the river is greater than the level of flowing river then the river gain water from the aquifer.

The over pumping of the groundwater affect the river around the aquifer.

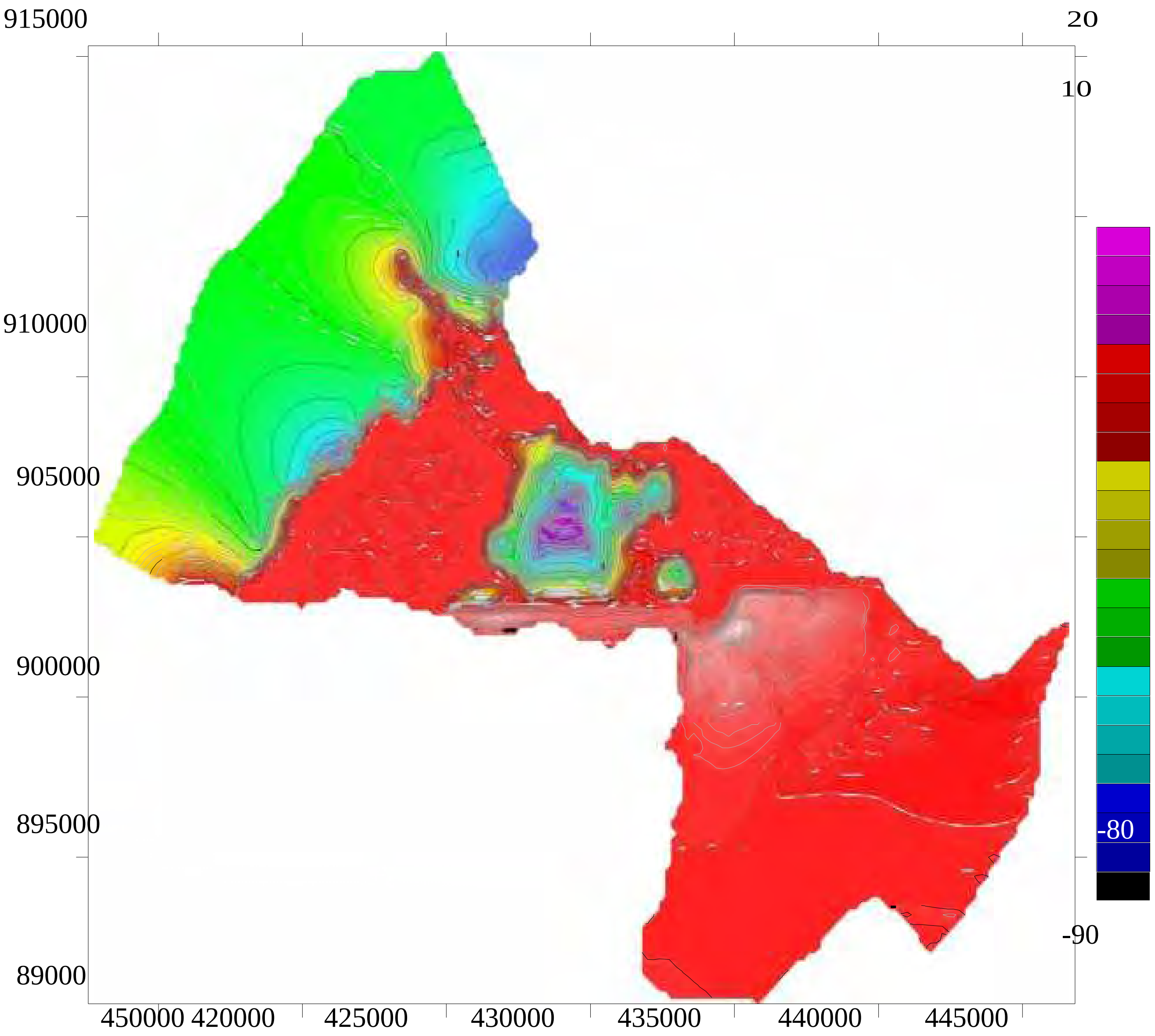


Figure 21 Contour map of the head difference between before pumping and after pumping.

Maximum contour levels = 20, Minimum contour levels= -90, Contour interval is = 1m. In this case the negative sign of minimum contour level indicate the red color is the area by which groundwater is extracted. But this is not indicating the real contour map of water level because of numerical error.

This is not indicated current condition of the minimum and maximum contour level. In figure 21 above the contour map of the head difference between head before pumping and head after pumping show that the two rivers are totally altered by over pumping of groundwater. But in surfer software the minimum contour should be decided be changing numbers in maximum and minimum contour level, in order to remove numerical error, the next step is done. In proceed to the the above figure 21, because of negative sign of minimum contour level, the map is not indicating the current condition of the study area. Therefore we should have to next step by changing the minimum contour level in order to minimize numerical error.

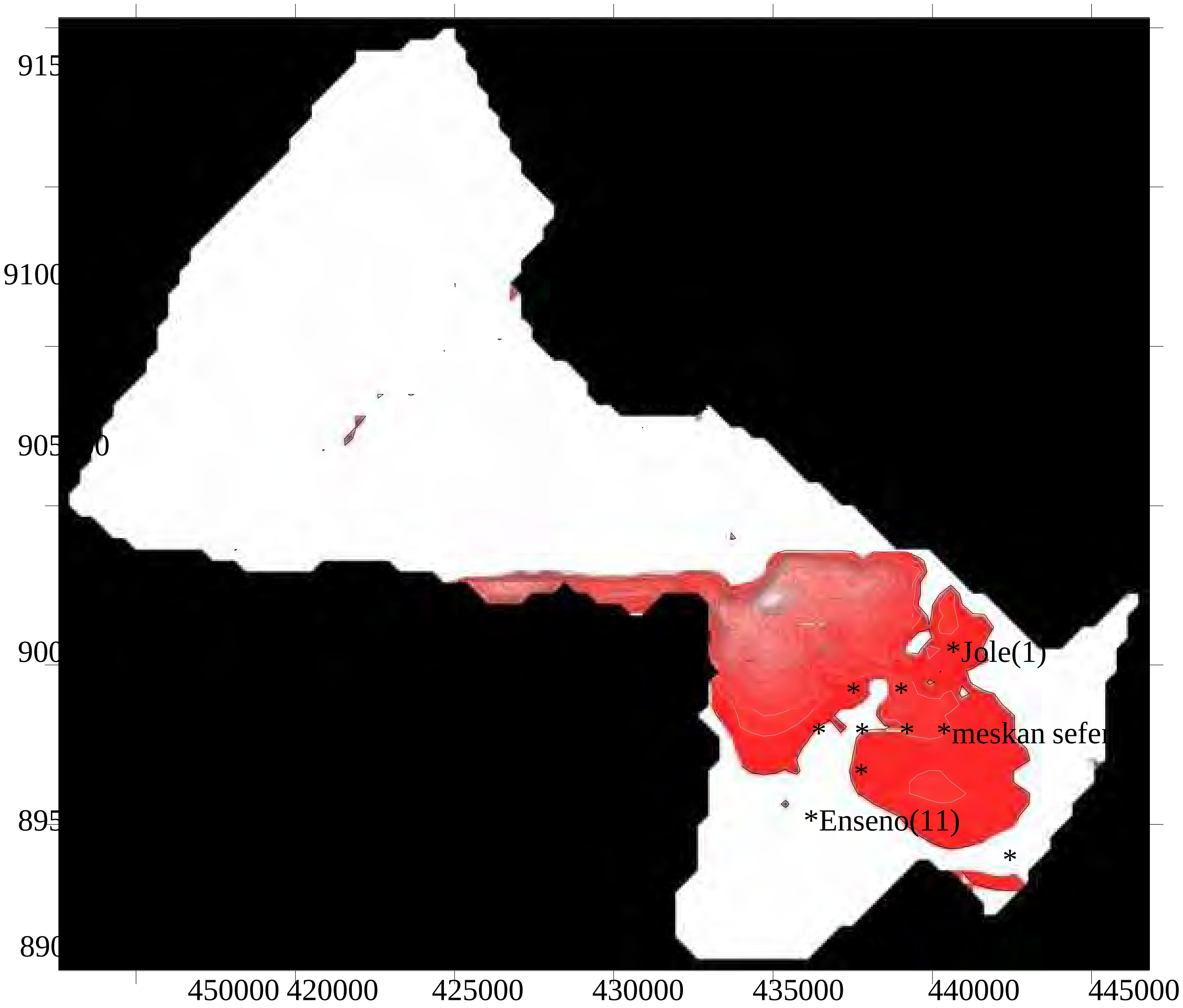


Figure 22 region of affected by current condition pumping rate

In the figure 22 above the contour map shows that waja river is altered by pumping. Because the head difference contour map touch the river level.

Using the surfer v12 software, the minimum and maximum contour levels were 0.5m and 20m respectively and the contour interval was 1m. Then the above figure 22 contour map is drawn. Head difference between head before pumping and head after pumping the groundwater shown.
In the study, current annual pumping rate from the aquifer around abstraction area is 21,186,913m^3/year. By this pumping rate, the weja River in the south direction is impacted. If in the area annual pumping rate is more than the optimum estimated value, the two rivers will totally dry. In this study due to over pumping of groundwater, Waja River is partially impacted. The increasing of pumping rate from the aquifer also caused for lowering of water table.

In this study the groundwater hydraulic head is computed using TAGSAC software with the help of MATLAB computer program. Ground water hydraulic head in the domain is calculated at each node. Groundwater hydraulic head are computed at each point of 11151 nodes in the domain. The computed head are shown in annex 2. From the computed head the following heads are shown as an example.

Table 12 the modeled water table head distribution with coded borehole number after pumping the groundwater

	Alemena (92)	Halibo (108)	meskan sefer(28)	Jole(1)	Ensenous me(11)
Elevation at Surface (m.a.s.l.)	1832	1830	1857	1860.837	1844
Hydraulic head (water table head) (m)	1821.593	1819.203	1824.873	1830.2	1842.168
Depth to Water Table (m.b.s.)	-10.407	-10.797	-32.1	-30.2	-1.89

The discharge estimated in one node is about 7029.50m3/year. The total node for the study area is 11151. The geological and hydrogeological condition of the aquifer is also disturbed.

Due to decreasing the water table, farmers can not found the water at near the surface as usual. Instead of this they dig two well at some interval in order to minimize the depth up to the well from surface. One well is for groundwater well pump and the other is to put the generator (motor pump). The second well is not up to the water in the well. It is for putting motor pump. The two wells are connected by the suction pipe. But in this system the aquifer totally disturbed.

Fig 23 Disturbed aquifer

The current trend of pumping will result in drying up of rivers near the aquifer. To come up with optimum pumping rate trial values were given to the model area representing the pumping site. An optimum pumping rate of 16,666,214.4m3/year would minimize the impact of pumping on the adjacent rivers.

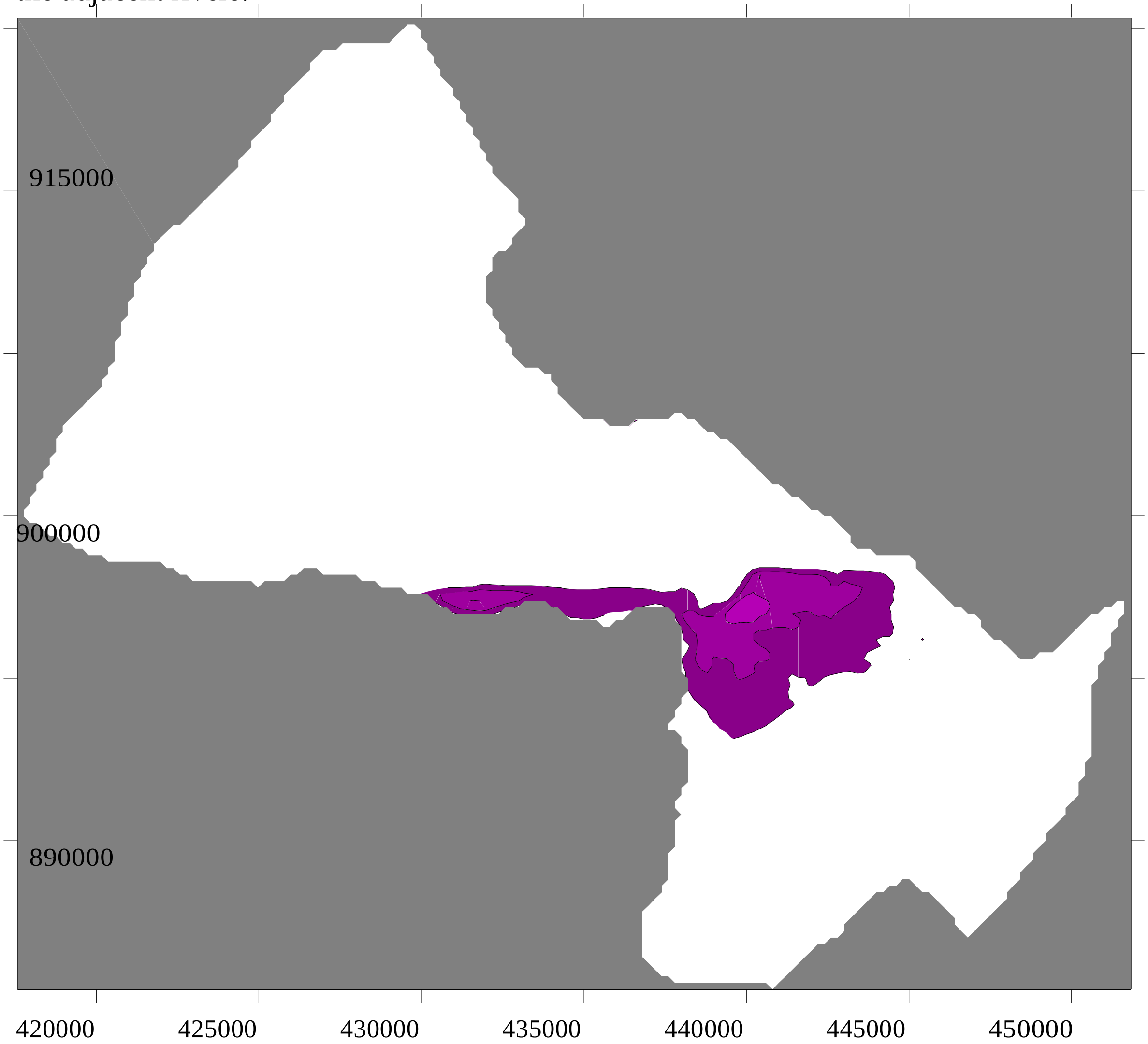


Figure 24 region of influenced

In this figure minimum contour do not touch the river based on this, the optimum pumping rate should be decided. The above figure 24 clearly shows that the contour map of head difference before and after pumping is not reach the two Rivers. This indicates that optimum pumping rate is reached. The Farmers should not pump the groundwater beyond the estimated optimum pumping rate value.

4.8 MODEL LIMITATION

Limitations and uncertainties exist in any modeling study in regard to our hydro geological understanding, the conceptual model design, and model calibration and prediction simulations.
Since model is a tool that represents an approximation of the real situation, there may be limitation associated with it. Numerical groundwater models are approximation of a natural system and have uncertainties. So it is important to any groundwater model to be interpreted. Some of the associated model limitations are as follows:

- The system was represented as steady state condition.
- Assumed model thickness was 200m for single layer.
- The model was calibrated with target wells mostly found at the east part of the study area. So uncertainties are expected due to unevenly distribution of well.
- Calibration relies more on residual errors that matching the simulated and observed head distribution.

In general the model output should be interpreted and applied by considering the limitations

CHAPTER FIFE

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study area boundary was delineated from 90m Shutter Radar Terrain Mapping (SRTM) digital elevation model (DEM) using Global Mapper 12 software. Its total surface area is 384.65km^2. The boundary at western part was served as the divide line of groundwater flow while stream networks were used as internal drainage lines. The rest boundaries are taken as constant head boundary (river boundary).

The modeled area was extended 108 km in the east direction and 68.44 km in the north direction. To minimize variety of sources of numerical errors, the model grid were designed using finest mesh spacing and time steps that are possible, given limitation on computer memory and computational time. In this study the model element size varied from 200 m X 200 m x200m for all elements. This was based on the collected borehole data. The grid and element size were designed. When grids were designed, element sizes were approximately uniform in the domain.

Input parameters like well location, discharge rate, mean rain fall, of the study area has been taken from field investigation. The other parameters were prepared using the software. Such as node numbers and element numbers, existing Pumping area and rivers head, were prepared. Recharge and discharge area were identified. For the model the recharge area is the gurage highland area and the main source of recharge for groundwater is direct rain fall. The main discharge area is downstream of the area that is comfort for irrigation activity

For the geological zones, hydraulic conductivity was determined using equivalent porous media approach. In this case for the geology four and geology one the same hydraulic conductivity was investigated. Generally the transmissivity of geology four and geology one was relatively higher than geology two and three.

In this study the groundwater hydraulic head is computed using TAGSAC software with the help of MATLAB computer program and others software. Ground water hydraulic head in the domain is calculated at each node. Groundwater hydraulic head are computed at each point of 11151 nodes in the domain. The total number of node 2nd and node 3rd are 11151 and 22,302 respectively.

The model calibration accounts the matching of the 94 observation point with simulated head with a permissible residual head of ±10m. The model was calibrated with mean error 8.74.

The calibration was done by adjusting collected borehole location and hydraulic conductivity. While adjusting these parameters, the simulated head and observation head were followed 45^o straight line approximately on the scatter plot diagram.

Annual pumping rate from one node is estimated as 7029.50m^3/year. In this study the current annual groundwater abstraction from the aquifer was estimated as 21,186,913m3/year. This estimation is only for the area of representing pumping for irrigation. In this condition the rivers are altered. For this reason the optimum pumping for the area is estimated by trial value. This optimum pumping is estimated as 16,666,214m^3/year.

5.2 RECOMMENDATION

The general objective of the research is impact of pumping for irrigation on groundwater potential. As the result is investigated and discussed in the last chapter in result and discussion, over pumping of groundwater following Waja River altered the Waja River and this may be bring completely drying of waja River for the future. And the lowering of groundwater table studied area. The current study only considers impact of pump on groundwater potential. There for the following recommendations were forwarded for groundwater management and further study.

- For the groundwater development in the study area, the recharge area (gurage highland) by which springs, streams were generated should be conserved and protected from deforestation. In the recharge area biological and physical soil and water conservation structures should be takes place.

- In order to save Waja River from completely drying, the local water policy should be organized by the administrators in order not to pump beyond the potential pumping from the aquifer. Community awareness for the organized water policy should be takes place.

- For the evaluation of the groundwater potential and its stress in the study area, it is very important to grasp the amount of groundwater recharge. There for amount of recharge estimates has to be carried out by combining different methodology like Soil water budget model and catchment water balance method to conduct detail model stress simulation.
- Continue water level observations by installing appropriate automatic recorders in each hydro geological zone should be carried out.
- Although Irrigation practice has great advantages in economic development of the country, it has its own disadvantage. During irrigation practice using excess fertilizer for irrigation land may affect the groundwater quality and quantity. Therefore, in the study area further study on groundwater quality should be takes place.

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Annex 1 collected borehole location in the study area

1	jole2&3	445605	903771	6
2	lobamo1	439579	889744	10.5
3	jole2&3	444850	903004	6
4	mekicho 1	444726	898403	7
5	mekicho	428360	900279	24
6	jole1	440592	906869	29
7	jole 1	440765	906338	22
8	yimerwacho- 2	442210	897728	16.2
9	gedena aborat	426651	893194	6
10	bate lejano	442856	895335	12
11	ensenousme	440452	892845	10
12	yimerwacho- 3	445262	898450	3.2
13	Kufa Misebo	440327	885936	5
14	Mohammed Antele	439431	884108	2
15	FTC	440430	886660	6
16	Temesgen Alemu	440865	887742	10
17	Desse Deboch	44024	888283	12.5
18	FTC	0439963	88279	15
19	Mutunje	438656	887471	10.5
20	Kuno sefer	439035	888021	15
21	Got buraya(3)	440041	888116	10
22	Lobamo(3)	439913	889759	10
23	Hylu Araso	044072	8809228	22
24	semon sefer	441593	889370	12
25	Badmolo	442270	889009	9

26	Aboso	440437	888732	8.5
27	lejano sefer	441018	887621	10
28	Meskan sefer	441662	887058	10
29	Shemena sefer	441296	886640	8
30	Lembico sefer	442092	888168	15.5
31	Hashim sefer	442134	888657	13
32	Dida midore got 3	445700	890279	9
33	>> >> (1)	443851	889674	10
34	>> >> (2)	440437	888732	8.5
35	Edewo Degaga	446774	891229	17
36	Negash bora	445976	892197	20
37	Abdi Bekele	445730	891579	25
38	Sani Jemal	445737	890889	22
39	Girma wshebe	445602	889475	24
40	Esmael Sirmolo	445505	888578	24
41	Abegaz Gizatu	447497	891229	35
42	Neju Fereja	447287	892225	30
43	Assefa Mosa	446763	892243	18
44	Shibiru kebede	447330	889247	15
45	temam aliye	446962	886855	5
46	Jemal Ahimed	447568	887237	3
47	Gadissa Alemu	446419	886964	4
48	Musema Bedrula	447197	887281	6.5
49	Mustefa Usman	447205	887242	6

50	Endeshaw Amele	445939	887679	3
51	Solomon	446503	886714	3
52	Abu	447047	887062	5.5
53	Mohammed	446290	887100	4.0
54	Shemsu Husen	44o786	895644	15
55	Adem Adero	440644	895417	12
56	Werkicho Besher	440545	895745	17
57	Tesfaye welde	440978	894736	12
58	Lakew welde	440814	895042	12
59	Darmulo Dedigeba	441446	893007	12
60	Sebawdin Awel	441496	892883	8
61	Bedru Gudeta	441743	892827	10
62	Fikadu welde	442297	892554	8
63	Mohamme Hissabo	442950	892620	11
64	Nega Degu	443065	893664	6
65	Meke sode	443206	893775	6
66	Sultan hyredin	440492	891968	10
67	Shifa erato	44144	891587	12
68	Muktar shifa	440170	891553	14
69	Bobaso Anbesa	440469	891312	12
70	Mongu Deboch	440711	890956	12
71	Mesele negaso	441403	890633	15
72	Mesfin bekele	441114	890068	15
73	kunokertefa	439913	889759	10
74	lobamo3	439579	889744	10.5
75	kuno	441002	888510	15

76	kunokertefa 1	440884	889612	4
77	qoricha sefer	439533	889018	21
78	qoricha 1	439531	889394	21
79	mutunje	438215	887057	48
80	mutune 1	438656	887471	21
81	kertefa buraya	440041	888116	10
82	buraya	439035	888021	15
83	kono alemena	440770	896395	6
84	alemena	440470	896925	16
85	alemena 3	439871	886531	18
86	alemena 3	439368	886118	14
87	alemena 2	440502	886921	56
88	alemena1	440642	887414	15
89	alemena 1	439529	886696	15
90	kuno alemena 3	439346	884903	7
91	kuno 3	439172	885939	19
92	alimena 2	439884	884344	4.5
93	alemena 2	440177	883924	6
94	simon sefer	441593	889370	12
95	got 3 simonsefer	442270	889009	9
96	aboso	440437	888732	9
97	aboso no. 1	441162	8888385	8.9
98	hobe jaredemka	440987	888242	14
99	abosa sefer	441848	888155	9
100	hobe lejano sefer	442092	888168	15.5
101	didahalibo	447320	888853	31
102	dida halibo 1	446435	887733	11
103	didahalibo 2	446044	888343	15
104	halibo	445935	888821	17
105	halibo 1	446577	882700	26
106	halibo 2	447813	890378	21
107	halibo 3	447229	8888338	33
108	halibo 4	446559	888457	12
109	Dida midore	445706	890843	34

Annex 2 Observed Vs Simulated Water Level (head) of Target Wells

x-coordinate	y-coordinate	observed value	calculated valu	resiual	code
445605	903771	1854.837	1860.8373	6	1
439579	889744	1827.576	1832.8367	5.261143	2
444850	903004	1854.836	1860.8364	6	3
444726	898403	1830.465	1837.2677	6.803195	4
442210	897728	1841.536	1857.736	16.2	8
426651	893194	2162.297	2167.8962	5.598945	9
442856	895335	1836.843	1846.4713	9.627887	10
440452	892845	1835.424	1842.1679	6.743938	11
445262	898450	1829.941	1833.112	3.171522	12
440327	885936	1819.742	1822.9561	3.214527	13
439431	884108	1821.812	1821.534	-0.27774	14
440430	886660	1822.404	1824.9622	2.557888	15
440865	887742	1822.271	1826.8911	4.620035	16
440824	888283	1822.524	1828.0526	5.528868	17
439963	882791	1808.08	1821.1324	13.0524	18
438656	887471	1820.447	1827.5833	7.135954	19
439035	888021	1817.337	1828.9668	11.62997	20
440041	888116	1826.58	1828.2459	1.665836	21
439913	889759	1824.765	1832.284	7.518844	22
441593	889370	1825.634	1829.2751	3.641601	24
442270	889009	1823.365	1827.5655	4.200071	25
441018	887621	1821.968	1826.4145	4.446323	27
441662	887058	1818.878	1824.873	5.995447	28
441296	886640	1819.78	1824.2047	4.424381	29

442092	888168	1816.734	1826.5067	9.772978	30
442134	888657	1819.543	1827.2409	7.697861	31
445700	890279	1824.13	1824.0627	-0.06715	32
443851	889674	1822.812	1826.168	3.356355	33
440437	888732	1829.363	1829.4688	0.106024	34
446774	891229	1817.679	1823.031	5.351685	35
445976	892197	1814.587	1826.7639	12.17713	36
445730	891579	1810.987	1825.8559	14.86908	37
445737	890889	1810.705	1824.61	13.90451	38
445602	889475	1808.778	1822.9298	14.15186	39
445505	888578	1806.686	1822.3238	15.63797	40
447287	892225	1804.858	1823.5468	18.68855	42
446763	892243	1814.363	1824.6576	10.29468	43
447330	889247	1811.253	1819.251	7.997811	44
446962	886855	1812.256	1816.2165	3.960687	45
447568	887237	1814.843	1816.4133	1.570778	46
446419	886964	1814.04	1816.7507	2.710695	47
447197	887281	1810.809	1816.6403	5.831056	48
447205	887242	1811.415	1816.809	5.393878	49
445939	887679	1821.602	1820.4863	-1.11579	50
446503	886714	1814.939	1816.7285	1.789651	51
447047	887062	1811.79	1816.1796	4.389806	52
446290	887100	1815.669	1817.9963	2.327755	53
440786	895644	1840.483	1855.4829	15	54
440644	895417	1841.875	1853.8748	12	55
440545	895745	1849.692	1856.6915	7	56
440978	894736	1837.381	1849.3809	12	57
440814	895042	1839.353	1851.353	12	58

441446	893007	1832.887	1841.0824	8.195309	59
441496	892883	1834.485	1840.7148	6.229866	60
441743	892827	1831.798	1839.657	7.858742	61
442297	892554	1828.705	1836.7052	8	62
443065	893664	1829.023	1835.0228	6	64
443206	893775	1829.119	1835.1186	6	65
440492	891968	1832.897	1838.6084	5.711589	66
440170	891553	1828.393	1837.4647	9.071496	68
440469	891312	1827.885	1836.5036	8.618587	69
440711	890956	1822.377	1834.2419	11.86446	70
441403	890633	1828.391	1832.4785	4.08792	71
441114	890068	1827.674	1831.2512	3.576933	72
439913	889759	1824.765	1832.284	7.518844	73
439579	889744	1827.576	1832.8367	5.261143	74
441002	888510	1820.198	1828.0274	7.829329	75
440884	889612	1802.342	1806.3418	4	76
439533	889018	1814.353	1830.6563	16.30335	77
439531	889394	1815.943	1831.4941	15.55081	78
438656	887471	1809.947	1827.5833	17.63595	80
440041	888116	1826.58	1828.2459	1.665836	81
439035	888021	1817.337	1828.9668	11.62997	82
440770	896395	1849.903	1855.9032	6	83
440470	896925	1846.894	1862.8943	16	84
439871	886531	1808.086	1824.8749	16.78901	85
439368	886118	1813.87	1824.1336	10.26402	86
440642	887414	1816.029	1826.2931	10.26456	88

439529	886696	1816.061	1825.491	9.429631	89
439346	884903	1816.794	1821.5041	4.710184	90
439172	885939	1809.334	1824.3116	14.9777	91
439884	884344	1818.152	1821.5927	3.440605	92
440177	883924	1815.978	1820.9802	5.002159	93
441593	889370	1825.634	1829.2751	3.641601	94
442270	889009	1823.365	1827.5655	4.200071	95
440437	888732	1828.863	1829.4688	0.606024	96
440987	888242	1820.346	1827.9051	7.5591	98
441848	888155	1823.229	1826.6636	3.434226	99
442092	888168	1816.734	1826.5067	9.772978	100
446435	887733	1812.209	1818.883	6.674095	102
446044	888343	1813.134	1820.5957	7.461215	103
445935	888821	1814.004	1821.0964	7.092031	104
447813	890378	1807.969	1819.7105	11.74156	106
446559	888457	1813.466	1819.203	5.736902	108
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