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Characterizing the Ground Water Resources Potential in Omo Gibe River Basin

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ABSTRACT

Groundwater characterization and potential assessment across a river basin plays a vital role in quality control, occurrence, extraction and management of the groundwater resources. In this study a three dimensional (3D) steady state FEM based groundwater modeling code (TAGSAC) was used to characterize and assess the groundwater potential and the groundwater aquifer system in omo gibe river basin. This model needs the hydro geologic, recharge and boundary conditions as its input. Thus a simplified one layer conceptual model is created by the perennial rivers in the basin as constant head boundary, omo gibe catchment divided and bottom boundary as no flow boundary, and the top surface as a recharge boundary. This conceptual groundwater model includes the geologic map of the basin as input, so that its hydro geologic parameters were adjusted manually to bring about inventoried well hydraulic heads. In the calibration 603 boreholes, protected spot springs, dug wells, springs and shallow wells were used. The calibration was made to a level of 10m, root mean square error value. The result has 6.56m, 7.8m and 0.9986 mean errors mean absolute error and correlation coefficient between the measured and computed hydraulic head respectively. The calibrated model clearly shows the groundwater flow direction follows the general topography of the basin. Besides by looking into the porosity of the geologic medium in the basin, the monthly groundwater tables and stream flow variation the groundwater potential is about 4.38 billion m^3. The groundwater resources variation shows that the minimum groundwater recharge occurs in January and the maximum groundwater recharge occurs in August. The limitation of the groundwater model developed to represent the basin by FEM has the same element dimensions (3 km by 3 km) which is very large and one groundwater model layer having large thickness, which uses equivalent porous medium approach to determine the hydraulic property of the geologic medium & gives the same hydraulic property for the geologic medium from the surface up to the bottom boundary conditions.

Keywords: - groundwater resources potential, Hydraulic head, OGRB, TAGSAC, groundwater model,Omo Gibe ,Ethiopia

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

OGRB: Omo Gibe River Basin

MoWIE: Ministry of Water, Irrigation and Energy

REV: Representative Elementary Volume

FEM: Finite Element Method

FDM: Finite Different Method

FVM: Finite Volume Method

DEM: Digital Elevation Model

N-S: North South

NNE: North North East

NNW: North North West

SNNPR: South nation nationalities people republic

WWDSE: Water Works Design and Supervision

NMSA: National Metrological Service Agency

GIS: Geographical information System

RMSE: Root Mean Square Error

ME: Mean Error

MAE: Mean Absolute Error

R^2: correlation Coefficient

1.0 INTRODUCTION

Beneath the surface of the earth lies a tremendous resource that many of the living things depend on for existence. This precious resource is groundwater. Groundwater is the very essential and basic components of human life. It is the most essential resources affecting municipal, agricultural and economic activities. Any development is related either directly or in directly with water utilization. Groundwater is valuable and most widely distributed resource of the earth and unlikely any other mineral resources it gets its replenishment from precipitation.

Groundwater is of paramount importance source for many uses in developing countries to supplement the available surface water resources by providing drinking water to its population and for economic development of agriculture, livestock, industry and tourism (Foster, 2012). Groundwater, water below the ground surface, has recently become a major source of water supply in almost every sector. It makes up a significant part of world’s water resource systems, supplying water for agriculture, industry and domestic use (Sangole et al 2012). Over-dependence on the groundwater resources for many purposes has led to its’ over-exploitation, and this has led to much concern for groundwater characterization, potential assessment and management. The groundwater characterization and potential assessment system is an issue, which involves various critical decisions, such as; determination of the quantity of water to be withdrawn periodically, location of pumping wells, rate of artificial recharge, maintenance of water quality in aquifer and the control conditions for aquifer boundaries.

The knowledge of hydrogeology and hydrology of the study area has great importance to characterize and to assess the groundwater resource potential which is available in the study area. Moreover it helps to know more about watershed to generate the stream network, geological character (hydraulic conductivity and porosity) in the study area, and to assess the groundwater resources potential in the study area. Pinpointing and considerate of this hydrological process must be adapted in the study area for well-organized study to estimate the groundwater resources potential and a better groundwater resources characterization in the study area.

Groundwater potential assessment and characterization in the study area is performed by Finite Element numerical groundwater modeling techniques. The groundwater resources potential in the study area is estimated with TAGSAC in mat lab, by iterating the geologic medium (hydraulic conductivity) value and different groundwater modeling input parameters. The TAGSAC in mat lab program iterates the hydraulic head in the study area at the nodes of each element. Subsequently the determination of the hydraulic head at a steady state conditions, the average hydraulic head is taken at the triangular prism of every one element generated to represent the study area. The average hydraulic head is used to determine the saturated groundwater volume at every single element in the study area. The actual groundwater volume in the study area is taken from the average hydraulic head, the area of each element and the interconnected void space (porosity) of the geologic medium. Analysis of the groundwater character and potential assessment in the study area is generally made by relevant physical principles of Darcy's law. Towards estimation of the groundwater character and groundwater resources potential assessment in the study area for different geological formation more perfectly, many analytical solutions for partial differential equations exist, so it is difficult to obtain analytical solutions directly, the numerical solutions are better to use depend on the groundwater problem domain. Groundwater models are applied to a range of ecological problems mainly for understanding and the clarification of issues having complex contact with many variables in the groundwater aquifer system which is present in the study area. Groundwater models are not exact descriptions of physical systems or processes of the study area; however the groundwater models are mathematically representing a simplified version of a groundwater aquifer system in the study area. Simulation is a mathematical calculation to identify the hydraulic head at the nodes of every single element in the study area. The groundwater models are used to calculate the hydraulic heads and the groundwater resources potential which is available in the study area.

Numerically or scientifically the study area geological conditions, metrological condition can be represented to estimate and to characterize the total groundwater resources potential in the study area. Mathematical equations simplify the complex hydro geologic and topographic conditions of the study area designed for a better and appropriate estimation of the groundwater resources potential in the study area.

Finite element groundwater models are predictive tools to characterize and estimate the groundwater resources potential in the study area. The partial differential mathematical equations are used to characterize and assess the groundwater resources potential which is available in the study area based on definite simple groundwater modeling assumptions. Simple groundwater assumptions are set in the partial differential mathematical equations and the several doubts in the values of data required by the groundwater characterization and potential assessment model. The groundwater characterization and potential assessment model must be observed as an estimate and not an accurate imitation of surrounding arena. The groundwater characterization and potential assessment modeling numerical solutions are regularly more problematic to legalize, therefore groundwater characterization and potential assessment mathematical model inaccuracy has to be set aside as trivial as likely. Groundwater character and potential assessment models in the study area represent or approximates an actual scheme, are useful investigation tools in many applications to solve the sophisticated and complex groundwater potential assessment problems in the study area.

1.1 Statement of the problem

The water demand of the nation increase from time to time due to population growth and the industrial development in the country, so characterization of groundwater resource potential and potential assessment of both groundwater and surface water in the study area is better to satisfy the water demand of the country and it support the fast and sustainable economic growth of the country. Groundwater potential in OGRB has never been estimated without the knowledge of groundwater potential approach; it usually creates problems related to water allocation and management. This research tried to fill the knowledge gap by estimating the groundwater resources potential in the study area using direct groundwater modeling approach.

Ethiopia has an immense groundwater resources potential, but there was no valuable research conducted before that characterizes and assesses the groundwater resources potential in the study area, using direct groundwater potential assessment technique or finite element numerical groundwater modeling techniques. This paper will study about characterization and groundwater resource potential assessment using finite element numerical groundwater modeling technique which is not applied in study area in the previous research by different groundwater research scholars. The main issue that initiates to study on groundwater characterization and groundwater resources potential assessment in the study area is absence of valuable research that gives great weight about groundwater to implement groundwater resource development projects, like water supply and some small scale irrigation methods. Most of the groundwater development projects are side by side study with project development, this borne inoperative groundwater development projects, this leads to conduct this valuable research and to contribute in creation of strong groundwater database.

1.2 Objectives of the study

The general objective of the study is to characterize and assess the rechargeable groundwater resource potential in the study area.

1.2.1 Specific objectives the study

- To estimate groundwater resource potential in the study area by the annual recharge
- To estimate the recharge groundwater potential in the study area at different season.
- To predict groundwater table variation in the study area.
- To show the groundwater flow direction in the study area.

1.3 Organization of the thesis

This research paper is organized in six chapters. The first chapter deals with the general introduction, statement of the problem, the general and specific objectives of the research and the groundwater modeling approach. The second chapter bounces the literature review about groundwater characterization and the groundwater potential assessment in the study area. It also includes the description of, groundwater potential, and groundwater recharge assumption of groundwater in the study area, Limitations, boundary conditions,, hydraulic conductivity and porosity. The third chapter discusses on methodology of the research, solution techniques, processing and analysis. The fourth chapter talks about the result of this research work. Chapter five is the conclusion and recommendation section of this research. Lastly in chapter six lists of the references are included.

2.0 LITERATURE REVIEW

On this paper the literature review focuses on related groundwater characterization and potential assessment literature reviews or research's conducted before by different scholars on the study area about the character and potential assessment of the groundwater. Different documents reviewed for this research, which can help to know more about the groundwater potential, geology, hydrology, hydrogeology, about the intermittent and the perennial rivers, surface topography, water sources and others) are reviewed. There are some studies in the study area; typically most of the researches are conducted in governmental level and personal researchers. Groundwater research's conducted before on the study area was limited on sub catchment level or focuses on single tributary river groundwater potential which was present in study area. Even if there are some studies on the groundwater potential of study area, most of the studies are on surface water and limited studies on groundwater. The groundwater research conducted before in the study area uses indirect method to estimate the groundwater potential. Almost all studies on surface and groundwater resources are based on the generally accepted concept that most hydrologic systems are coextensive. The study area are the most utilized basins due to the availability of sufficient ground and surface water potential for different water resources development projects (like water supply from groundwater resources, irrigation and hydropower) to eradicate different problems across the nations.

2.1 Groundwater potential

The groundwater potential means the amount of water, which is stored in the subsurface of the groundwater reservoirs (Aquifers), recharged from rainfall, internal groundwater flow from one aquifer having a better hydraulic head to another aquifer having lower hydraulic head. Currently there is very little regional development of groundwater resources within the Study area. Assuming that 10% of the available recharge can be obstructed, the total groundwater potential that may be developed is estimated to be 1.0 x 10^9m3/year (MoWIE). Ethiopia has enormous surface water and groundwater resources, although the distribution is uneven in regional or national level. Very little has been done in this field and development of the water resources, particularly in areas of groundwater resources. Groundwater utilization has been limited to community water supply using shallow hand dug wells and unprotected springs.

The occurrence of the groundwater resources potential in the study area were done by different researchers at different times using different groundwater resources potential assessment approach. Different studies have been conducted to evaluate the groundwater potential of the study area aquifer. Among the most comprehensive studies conducted are studying the national water master plan, WAPCOS (1990) made an effort to quantify the total groundwater potential using various direct and indirect empirical approaches.

The methods adopted to assess the ground water potential in the previous studies were listed below.

- Base flow separation approach,
- Subsurface drainage approach,
- Recharge area approach,
- Water balance simulation techniques
- Base flow separation method.

By using the above five approaches the groundwater resource potential in the study area was estimated by different governmental and non-governmental organizations. firstly base flow separation approach was used to separate stream flow of omo gibe main and tributary rivers which originates from stored groundwater is referred to as groundwater runoff or base flow. This approach is the indirect way to estimate the groundwater resources potential. To study the total groundwater resources potential in the study area, different researchers take this method as basic tool and estimated the groundwater potential. Finite element numerical groundwater model (TAGSAC in mat lab) is a better way to estimate the groundwater resources potential compared to the base flow separation approach. The finite element numerical groundwater model (TAGSAC in mat lab) uses more groundwater input data (well inventory data, rainfall as a recharge, hydro geologic data, river head and others), but base flow separation approach uses only the stream flow data. The total groundwater potential of the study area estimated by the scholars using the base flow separation approach was seen in the table below.

TABLE 1 BASE FLOW VOLUMES OF STUDY AREA

Basins	Stream flow data used (number of years)	Base flow Volume: B (Mm3)
Omo gibe river basin (OGRB)	21	2785

Source: WAPCOS 1990, P.AII -27

Subsurface drainage approach was the second method that the pervious study used to estimate the groundwater potential in the study area. The method used generated groundwater runoff contour map of Ethiopia and the groundwater runoff contour map is superimposed in to the study area, then the groundwater represents the replenish able recharge of the study area. This approach is also the indirect approach to estimate the groundwater potential of the study area Mostly the indirect approaches are not better to estimate the groundwater potential of a given river basin compared to the direct method like FEM, because indirect methods are conducted due to the absence of data in the study area. The estimated groundwater potential of the study area by the subsurface drainage approach was listed in the table below.

TABLE 2 STUDY AREA REPLENISHABLE RECHARGE (SUB-SURFACE DRAINAGE APPROACH)

Basin	Area (Km^2)	Groundwater runoff (l/sec/Km2)	Annual recharge, QG (Mm3)
Omo gibe river basin (OGRB)	78200	1.35	3,329

Source: WAPCOS 1990, P.AII -29

Recharge area approach was the third methods that the previous researchers used to estimate groundwater potential in the study area. Groundwater recharges in the study area come due to infiltration of precipitation, and seepage from streams and other water bodies. Major groundwater replenishment in the study area takes place through direct precipitation over the upland areas of the watershed. The seasonal fluctuations of water level in the study area depend on the rate of replenishment of the saturated zone. This rate is a function of precipitation, surface run-off, permeability of soil, drainage network, and antecedent moisture content of the soil and the slope of the land surface.

This approach is also used to identify the discharge and recharge zones of the study area. The total estimated groundwater storage volume of the study area is shown in the table below.

TABLE 3 OGRB REPLENISH ABLE RECHARGE (RECHARGE AREA APPROACH)

Basin	Mean annual rainfall (mm)	Extent of recharge area	% of rainfall recharging GW	Replenishable recharge QG (Mm3)
Omo gibe river basin (OGRB)	1,469	35,811	8	4,208

Source: WAPCOS 1990, P.AII -32

All the above groundwater potential of the study area was estimated indirectly, means the pervious study does not consider the groundwater sources like springs, hand dug wells, shallow and deep wells developed before for different purposes in the study area.

2.1.1 Groundwater Recharge

The groundwater recharge in the study area is defined as the process of downward movement of water through the saturated zone under the force of gravity or in the direction determined by hydraulic conditions. The groundwater recharge varies in a wide range governed by the rainfall distribution, topography, land use and geology. The major recharge to the aquifer comes from precipitation and river channel losses. Main direct recharge is assumed to take place in all areas except where low permeable lacustrine soils exist (Tenalem et.al. 2008).

Maximum groundwater potential originates as recharge from the highland areas. The precipitations are infiltrates into the groundwater aquifer zone. Some water enters the subsurface by seeping out of the bottom of surface waters, a situation more common in arid climates than in humid climates. Groundwater discharges from the saturated zone back to the ground surface in low-lying areas, usually at springs or the bottom of surface waters. Since groundwater always moves towards lower head, these exit points are always at a lower elevation than the water table where groundwater enters the system as recharge. Recharge is highest in areas with wet climates and permeable soil or rock types. In permeable materials, the rate of recharge can be as much as half the precipitation rate, with little overland flow. On the other hand in low permeability materials only a small fraction of the precipitation becomes recharge. With massive clay soils, the recharge rate can be less than 1% of the precipitation rate (Fitts, 2002)

The downstream catchment of the study area is lowland, so there is maximum recharge from highlands in to this lowland catchment. The northern and the western portion of the study area are highly rainfall region, due to this region the maximum recharge is in the lowland area. In the highlands portion of the study area there is a steep slope, so maximum runoff is present compared to the lowland area.

2.2 Groundwater modeling approach

Groundwater model for the study area is very powerful tool used in the right conditions, when groundwater models in the study area are properly built. The groundwater character and potential assessment modeling approach are essential to become appropriate for the particular study area conditions and the stated study goals depend on the available date collected from the study area. The groundwater modeling input data should be accurate and reliable for a better groundwater characterization and groundwater potential assessment in a defined study area.

A groundwater model used in this study is a computer-based (TAGSAC in mat lab) program represents the essential groundwater features or natural hydrogeological system that uses the laws of science and mathematics which is implemented in the study area. Groundwater modeling has two components:-

- Conceptual groundwater model is an idealized illustration of the hydrogeological sympathetic for the groundwater characterization and potential assessment of the aquifer system in the study area.
- Mathematical groundwater model is a set of equations, which, subject to certain assumptions, calculates the physical processes active in the study area aquifer system is being modeled. The mathematical groundwater model clearly lacks the detailed truth of the groundwater system; the behavior of a valid model approximates that of the aquifer(s). A groundwater model provides a scientific means to draw together the available data into a numerical characterization of a groundwater system. The groundwater model characterizes the groundwater aquifer system of the study area to a satisfactory level of detail, and delivers a predictive scientific tool to calculate the potential residual hydraulic head in the study area aquifer system.

Groundwater modeling requires knowledge about groundwater hydraulics, hydrology, hydrogeology, geology, metrology, the relationship between surface water interaction with groundwater and engineering skill for interpretation as well as for a better description of a groundwater aquifer system in the study area. The groundwater modeling also requires a creative thinker to signify a groundwater model by a simple computer-based (TAGSAC in mat lab) program for a complex natural groundwater aquifer system of the particular study area.

This groundwater model problem needs a detail understanding of groundwater hydrology and groundwater hydrogeology in the study area which is determined with their proper answers, relates to the residual hydraulic head potential of the groundwater aquifer system for the study area will be studied. During groundwater modeling the local groundwater system includes both the rocks and groundwater in the study area such us recharge. To characterize and assess the groundwater resources potential in the study area the following measures should be under consideration:-

- The relative hydro geologic property of the rocks in the study area
- The groundwater resources potential from the average residual hydraulic heads, porosity and area of each triangle generated to represent the study area
- The distribution and amounts of estimated annual and monthly average recharge in the study area.

The groundwater model developed for the study area is complex enough to represent the hydro geologic and groundwater with a better way; Due to this reason real system of the groundwater a three-dimensional steady state model is selected. Then for this study a finite element three-dimensional conceptual and numerical model of groundwater characterization and potential assessment in the unconfined aquifer and flow system approach is integrated for the study area. During the groundwater model calibration the modeled with the observed data at the boreholes a trial and error method has been used. The method requires a trial set of real hydraulic parameters and surface recharge are given to the groundwater model and the result is estimated according to its suitability with the measured data.

2.3 Groundwater model formulation

Groundwater models provide a scientific and predictive tool for determining appropriate solutions to groundwater characterization, groundwater potential assessment, groundwater interaction, landscape management or impact of new development scenarios. Numerical groundwater models are one of the most important predictive tools available for managing water resources in aquifers. These models can be used to test or refine different conceptual models, estimate hydraulic parameters, and, most importantly for water-resource management, predict how the aquifer might respond to changes in pumping and climate. Numerical groundwater character and potential assessment models can sometimes simulate hydraulic heads, groundwater fluxes, and spring discharge.

Several methods are available for describing groundwater character and estimating the groundwater potential in the aquifers. From this several methods, numerical models are best suited for analysis of basin wide groundwater character and potential assessment because of flexibility and speed of analysis (Waltz, 1972). To model the groundwater character and groundwater potential in the study area, means to improve mathematical and numerical models of the aquifer system being studied and use numerical models to predict the value of average hydraulic head at the nodes of the generated mesh for the study area (and times) the area of the triangle with porosity interest (Istok, 1989). Because of the complex interdisciplinary interests in groundwater, models differ markedly in purpose, information requirements, assumptions, usefulness, and the mathematical schemes incorporated (one-, two-, and three dimensional models; steady-state, saturated flow models; transient, unsaturated flow models; fracture flow models) to study groundwater character and potential assessment of the aquifer system. Real groundwater problems are three-dimensional in space and time-variant (Rushton, 2003).

The Groundwater assessment model is selected based on a particular field (study area) problem mainly governed by, the availability of field data in the study area, accuracy required in the result and the boundary conditions of the study area, based on the site condition of the study area, the general and specific objective this study on the study area FEM three dimensional steady state groundwater models is selected to characterize and to assess the ground water resources potential of the study area.

Groundwater modeling involves formulating a correct conceptual model through selection of those parameters and their values, which help to describe spatial and temporal variability within the groundwater character and potential assessment aquifer system more accurately (Jacob et.al. 1992). The attraction of groundwater modeling is that it combines the refinement of human judgment with the power of a digital computer programs. Most of the groundwater models are aimed at predicting the consequences of a proposed action; they can also be used as interpreters to assimilate the controlling parameters or as framework for systematizing and collecting data and formulating ideas regarding system dynamics; as in this study (predict the character of the geologic material in the study area and assess the groundwater resources potential). Simulate the groundwater character and the groundwater potential indirectly by means of governing equations or mathematical models that describe the hydraulic heads at nodes of each element of the study area. Mathematical modeling involves estimation of the differential equations to describe systems that have variable properties and irregular geometry.

Numerical procedures used to describe groundwater problems create system of equations that must be solved simultaneously to produce accurate results with greater efficiency. Either finite difference method (FDM) or finite element method (FEM) has been involved for development of most of the groundwater models; nevertheless, FEM is more favored than FDM since it can treat the complex boundaries and irregular geometry more effectively than the FDM. It is also a common practice to solve the spatial portion of the flow equation through FEM, and the time marching portion through the FDM (Istok, 1989). The domain discretization of FDM models is limited to an orthogonal grid of rectangular blocks, which is less flexible than the triangular or quadrilateral elements of FEM models. Because of this difference, the approximation of boundary conditions can be more accurate in an FEM model than in an FDM model (Fitts, 2002). In addition to that, the method has several advantages:

- Irregular or curved aquifer boundaries, anisotropic and heterogeneous aquifer properties, and sloping soil and rock layers can be easily incorporated into the numerical model,
- The accuracy of solutions to groundwater flow is very good (exact in some cases),
- The finite element method lends itself to modular computer programming wherein a wide variety of types of problems can be solved using a small set of identical computer procedures.

- Additionally finite element method is flexible; solve complicated geometries, evaluate high-order approximations, require strong mathematical foundation (Vrushali et.al. 2007).

A Groundwater model is a demonstration which attempts to explain the behavior of some aspect of the prototype groundwater aquifer system of the study area. It is always less complex than the real system it represents. According to (Herbert and Mary P, 1982) groundwater model formulation can be summarized in the figure 1 below.

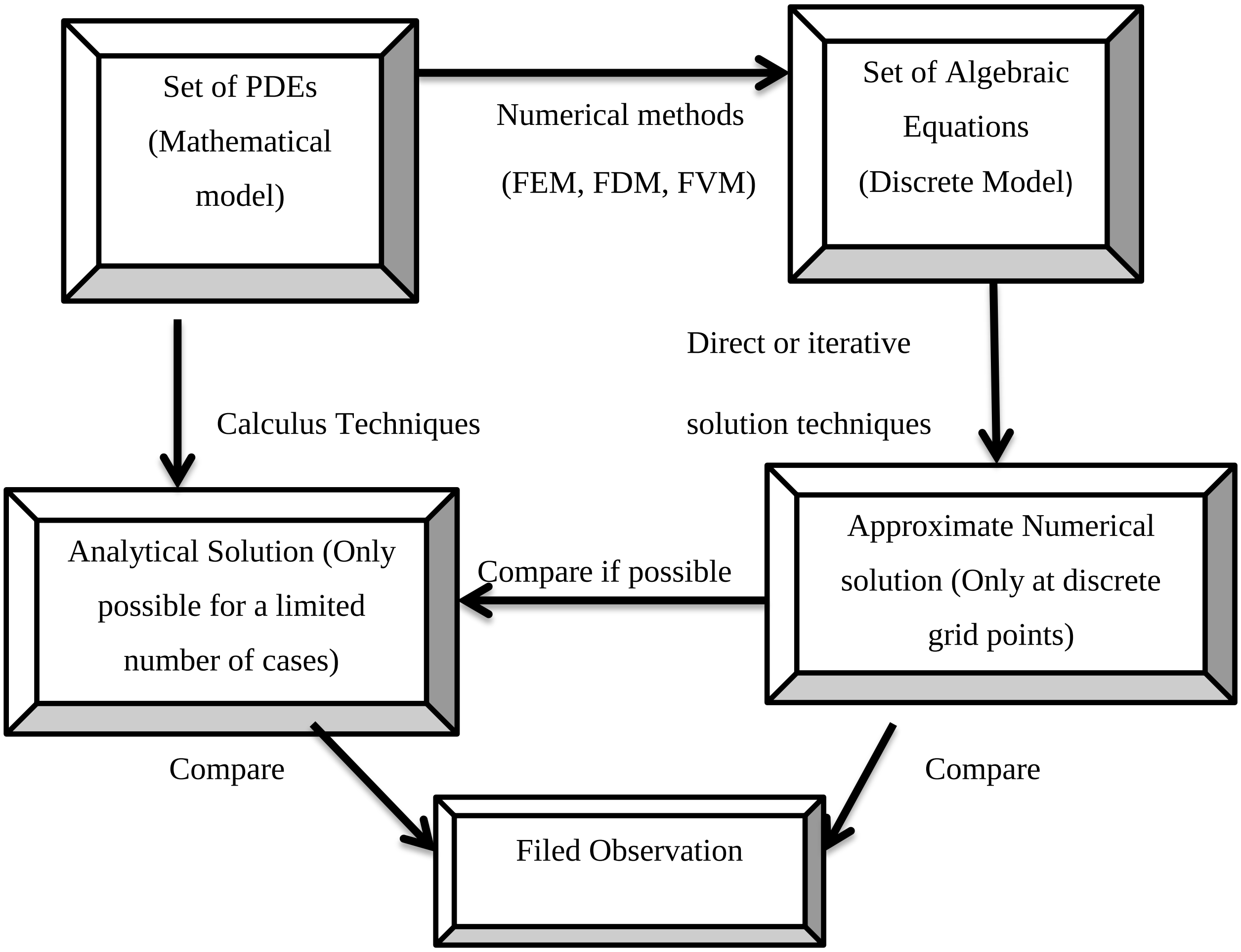


FIGURE 1 GENERAL FLOW CHART OF NUMERICAL GROUNDWATER MODELING PROCESS AFTER (HERBERT, 1982)

The finite element method is now widely used to solve a variety of important problems in the field of groundwater hydrology. Thus a clear understanding of the method is essential to scientists and engineers working in this field. The goal of this research is to characterize and assess the groundwater potential with the basic skills needed to use the finite element method to solve "real-world" problems. On this study area different software are used throughout the research to illustrate each step in the solution process (Istok , 2013).

Groundwater models provide a scientific and predictive tool for determining appropriate solutions to groundwater characterization, groundwater potential assessment – groundwater interaction, landscape management or impact of new development scenarios. However, if the modeling studies are not well designed from the outset or the model doesn't adequately represent the natural system being modeled, the modeling effort may be largely wasted, or decisions may be based on flawed model results, and long term adverse consequences may result. This study presents an overview of the groundwater modeling technique and application of finite element (TAGSAC in mat lab) program, a modular three-dimensional groundwater to characterize and assess the groundwater resources potential in the study area (Kumar CP ,2013)

The finite element method can also be used to solve the groundwater equation. There are several codes available; (TAGSAC in mat lab) uses a finite element (triangular) mesh to represent the model domain. The use of triangles allows for a more efficient refinement around wells and boundaries. The triangular mesh can more easily adapt to variable stratigraphy such as sloping or pinch outs, and allows for versatile discretization of non-rectangular model domains. Finite element methods provide a better representation of anisotropy (fully represents conductivity tensor – each triangular element is given its own coordinate system, whereas MODFLOW requires conductivity to be perpendicular to the faces of the finite difference cells (horizontally rectangular).

A finite element numerical solution is presented for groundwater models discretized by triangular element to characterize and estimate the groundwater resources potential in study area. An equivalent porous medium approach is considered to use the groundwater models for characterization and groundwater potential assessment. Thus, TAGSAC in mat lab program is developed for this purpose to obtain primarily the unknown surface node hydraulic heads at the nodes of triangular elements, the total head means (residual hydraulic head) at the nodes of each triangular element and the calibration error of the actual measured data with the modeled one by providing the boundary conditions. By analysis of the hydraulic head solution results, one can easily obtain the total volume of water in the saturated zone, the recharge amount per each month, and the actual amount of groundwater in volume present in study area.

2.4 Equivalent porous medium approach

Various approaches can be used to simulate groundwater potential and characterize the groundwater; including equivalent porous media distributed parameter, lumped parameter, and dual porosity approaches, as well as discrete fracture or conduit approaches.

In this approach, individual fractures are not explicitly treated in the model but rather the heterogeneity of the fractured rock system is modeled using a number of elements, each of which is modeled as an equivalent porous medium. The porosity and the hydraulic conductivity distribution are replaced with a continuous porous medium having equivalent hydraulic properties in the basin across the model thickness. An equivalent porous media approach makes the assumption that a representative elementary volume (REV) of material characterized by equivalent hydraulic parameters in the study area. Modeling results are only valid at scales larger than the REV. groundwater modeling requires the definition of effective values for hydraulic conductivity, and porosity at the scale of the REV element in the study area. These parameters can be determined from either by iterations of the aquifers or calculated from detailed field descriptions of porous medium and fracture apertures, lengths and interconnections as well as fractured rock volumes, porosity and permeability. Clearly, an issue is how to determine values at much larger scales on the order of thousands of meters relevant to basin or sub-basin groundwater studies. At the scale of thousands of meters or more, hydro geologic simulation models calibrated to estimates of recharge rates, the hydraulic conductivity, the surface node hydraulic head and the all node hydraulic head at steady state conditions for each element in the study area (Glen, 2003).

Water table positions and potentiometric head data may be the most suitable and reliable way of estimating the large scale hydraulic conductivity of the fractured rock aquifer. The single porosity approach is best used when predicting bulk average features of the flow system and may best be employed in steady state analyses. Here, a clear distinction needs to be made between fluid present in the fractures and that present in the matrix. In the case where fracture densities are very high and intermediate matrix units are very small it may be possible to treat the system as one continuum where the hydraulic storage and transmissivity are represented by a lumped sum accounting for both fractures and matrix.

This study shows the ability of equivalent porous media models to characterize and estimate groundwater potential in the study area, which is important for groundwater resources development. The study area is a wide spread, due to this the element length is taken 3km and the thickness of the model is half of the element length 1.5 km. The model thickness requires model layer, but it is difficult to identify the hydro geologic character of each layer, to avoid this, equivalent porous medium approach is adopted for this study. The equivalent porous medium approach assumes the same hydraulic parameters for the model layer from the top surface up to the impervious floor of the aquifer. Finite element methods are used throughout this research to solve a range of different problems, using in particular the Galerkin weighted residual approach based on triangular prismatic elements. Special emphasis is made on steady state groundwater character and potential assessment problems with affecting interfaces, such as the hydraulic heads. A generalized fast updating Procedure technique is developed for these situations, which presents a number of advantageous features in comparison to classic computational techniques used to deal with such problems in order to characterize and assess the groundwater resources potential available in the study area.

In the method of weighted residuals, an approximate solution to the boundary or initial value problem is defined. When this approximate solution is substituted into the governing differential equation, an error or residual occurs at each point in the problem domain. We then force the weighted average of the residuals for each node in the finite element mesh to equal to zero. Galerkin's Method is the subset of the method of weighted residuals that is most commonly used to solve groundwater flow and solute transport problems (Istok, 1989). Before the approximating equation the general three dimensional groundwater flow equation for steady state is summarized follows.

The general three dimensional groundwater equations at steady state conditions to characterize and to assess the groundwater resources potential for the study area is as follows:-

$\frac{\partial}{\partial x}\left(K_x \frac{\partial y}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y \frac{\partial y}{\partial x}\right)+\frac{\partial}{\partial z}\left(k_z \frac{\partial y}{\partial x}\right) \pm q=0$ …… (2.1) Steady state with recharge

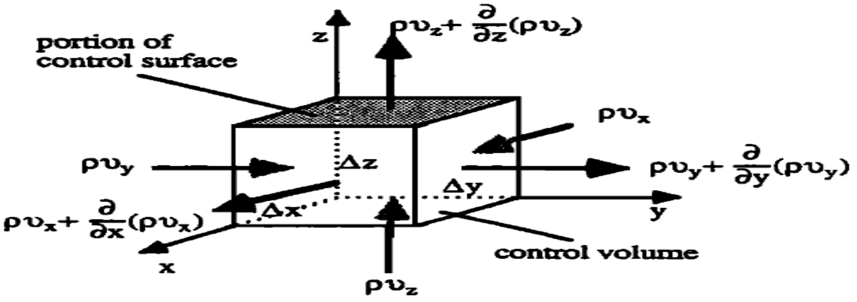


FIGURE 2 REPRESENTATIVE ELEMENTARY VOLUME

Where K_x, K_y, and K_z are the saturated hydraulic conductivity of the porous media in the x, y, and z coordinate directions, h is hydraulic head and q is the recharge. The character and groundwater potential through equivalent porous media is described and solved, for a one layer saturated groundwater aquifer system under a steady state flow (as used in this study), on the basis of the following partial differential equation, which is based on Darcy’s law and the law of mass conservation (McDonald and Harbaugh, 1988).

$$\frac{\partial}{\partial x}\left(kx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(ky\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\mathrm{z}\frac{\partial h}{\partial z}\right)=0 \ldots\ldots (2.2)\ \text{Steady state condtion without recharge}$$

The study area is divided into discrete triangular mesh, known as elements and the properties of the geologic material in each triangular element is expected to be heterogeneous and having different hydraulic conductivity, porosity values to characterize and approximation of the total groundwater resources potential in the study area.

Most groundwater models in use today are deterministic mathematical models. Deterministic models are based on conservation of mass, momentum, and energy and describe cause and effect relations. The underlying assumption is that given a high degree of understanding of the processes by which stresses on a system produce subsequent responses in that system. Deterministic groundwater models generally require the solution of partial differential equations. Exact solutions can often be obtained analytically, but analytical models require that the parameters and boundaries be highly idealized.

A number of deterministic models treat the properties of porous media as lumped parameters (essentially, as a black box), but this precludes the representation of heterogeneous hydraulic properties in the model. Heterogeneity, or variability in aquifer properties, is characteristic of all geologic systems and is now recognized as playing a key role in influencing groundwater character and potential assessment. Thus, it is often preferable to apply distributed-parameter models, which allow the representation of more realistic distributions of system properties. Numerical methods yield approximate solutions to the governing equation (or equations) through the discretization of space and time. Within the discretized problem domain, the variable internal properties, boundaries, and stresses of the groundwater aquifer system are approximated.

2.5 Hydraulic conductivity and porosity

2.5.1 Hydraulic conductivity

Hydraulic conductivity, K [L/T]: It is measurement of the ease of a particular fluid passing through the pore space of a porous medium (i.e., conductive properties of a porous medium for a particular fluid) (Obasi et.al. 2013). The proportionality constant in Darcy’s law, which depends on medium and fluid properties i.e. grain size, density and viscosity of fluid. Additionally the hydraulic conductivity is defined as the flow volume per unit cross-sectional area of porous medium under the influence of a unit hydraulic gradient. It is empirical constant to be measured in laboratory. Real subsurface materials always have a complex and irregular distribution of hydraulic conductivity. The hydraulic conductivity distribution in the study area is described by using the heterogeneity and anisotropy. When the geologic medium in the study area is a heterogeneous material the value of hydraulic conductivity (K) varies spatially, and in a homogeneous material K is independent of location. Anisotropy in the study area implies that the value of hydraulic conductivity (K) at a given location depends on direction. Isotropy implies that hydraulic conductivity (K) is independent of direction at a given location (Fitts, 2002). The hydraulic conductivity of a given medium is a function of the properties of the medium and the properties of the fluid. If hydraulic conductivity is dependent on the direction of groundwater movement the aquifer is anisotropic and the hydraulic conductivity is a second rank tensor.

$$K = \frac{Cd^2 \rho g}{\mu}$$

Where

C: shape factor, a medium property

d: representative grain diameter, a medium property

ρ : fluid density, g : gravity

γ = rg: specific weight of fluid, driving force exerted by gravity on a unit volume of the fluid ([g] = $kg/m^3 \cdot m/s^2 = (kg \cdot m/s^2)/m^3 = N/m^3 \equiv$ force per unit volume)

μ: Dynamic viscosity, resistance of the fluid to shearing

Groundwater model is three dimensional, the hydraulic conductivity of the study area is as follows:-

$$\begin{bmatrix} \boldsymbol{k_{xx}} & \boldsymbol{k_{xy}} & \boldsymbol{k_{xz}} \\ \boldsymbol{k_{yx}} & \boldsymbol{k_{yy}} & \boldsymbol{k_{yz}} \\ \boldsymbol{k_{zx}} & \boldsymbol{k_{zy}} & \boldsymbol{k_{zz}} \end{bmatrix} = \mathrm{K}$$

2.5.2 Porosity

Porosity or pore space (voids, pores, or interstices) is the portion of a geologic formation that is not occupied by solid matter such as soil grain or rock matrix lay on the study area. Porosity is Effective or interconnected pore space of the geologic medium that forms a continuous phase through which water or solute can move from one region to the other region. The study area porosity is taken from the standard porosity table as per the type of rocks and soil materials in the site. The porosity has a vital role to characterize and to assess the groundwater resources potential in the study area. To determine the total recharge groundwater volume the saturated groundwater volume of each element in the mesh generated for the study area should be multiplied with the porosity of the geologic medium in each element in the mesh generated for the study area.

2.6 Groundwater Modeling Assumption

Groundwater modeling for the study area requires some assumptions that can be modeled by the researcher are:-

- Darcy’s law is valid which means the groundwater flow in the study area is assumed to laminar. Fortunately, most underground flow occurs with NR <1(laminar, NR is Reynolds number) so Darcy’s law is applicable (Todd, 2005).
- The fluid is considered to be slightly compressible and homogeneous. The fractured and the continuum medium of the study area maybe represented by equivalent porous medium of having the same hydraulic properties.
- The porosity and saturated hydraulic conductivity are constant with time.
- The model takes only one layer having the same hydraulic conductivity and porosity value from the surface up to the impervious floor of the model.
- The rivers in the study area is taken us a constant head boundary and the boreholes are a constant flux boundary.

2.7 Limitations of the Groundwater Model

Different groundwater modeling approaches have their own limitations. Unrealistic expectations and inappropriate applications of models can greatly reduce confidence to use numerical models. The equivalent porous media models developed in this study cannot be used to estimate different hydraulic parameters or assumes only one hydraulic property across a massive geologic medium in the study area, The models are restricted only for evaluation of regional groundwater character and potential assessment issue. The model was discretized using element size of 3X3X3 kilometer due to the wide spread study area. As a result of this discretization, the conditions within the node, such as groundwater level is reduced to one average value for the entire node. Therefore, the model is not suitable for analysis of site-specific problems or issues. Hydrologic parameters and aquifer unit geometry in portions of the model area are not well known at this scale. For instance, aquifer thickness and hydraulic conductivity can change at intervals smaller than the current model resolution. Some of the limitations in this model are:-

- Since the study area is very wide, element dimension is large; this brings to leave some lakes or artificial reservoirs in the study area, so it is impossible to digitize the water bodies (reservoirs) in the study area.
- The hydraulic conductivity is the iterative value to estimate the actual hydraulic head in the study area.

3.0 METHODOLOGY OF THE RESEARCH

The objective of the study is to characterize and assess the groundwater resources potential in the study area. To achieve this objective a numerical groundwater modeling technique is selected. Accordingly this chapter was describing the methodology that defines the input data needs and the procedures adopted in creating the numerical groundwater model. To model a given groundwater aquifer system and to solve the groundwater potential assessment problems, there are three important steps in the computational groundwater modeling of any physical process, (Peir´o and Sherwin, 2005).

- Groundwater modeling problem definition,
- Mathematical model, and
- Computer simulation

The methods used for this research includes literature review, collection and organization of the previous works inside the study area from all possible sources such as site survey reports, maps, well inventories and well construction repots, springs, hydro meteorological records (daily and monthly rainfall records), river discharge data. To achieve this research goals and to use a groundwater model, interpretation of 3-D global maps, topographic maps should be conducted and use global mapper or GIS software application to delineate the study area, land cover map of the basin, land use map, geological map and groundwater region.

3.1 Description of the study area

Ethiopia is the water tower of east Africa and has twelve river basins, Omo gibe river basin is one among the twelve. The figure 3 below shows the river basins in Ethiopia and the omo gibe river basin used for this study.

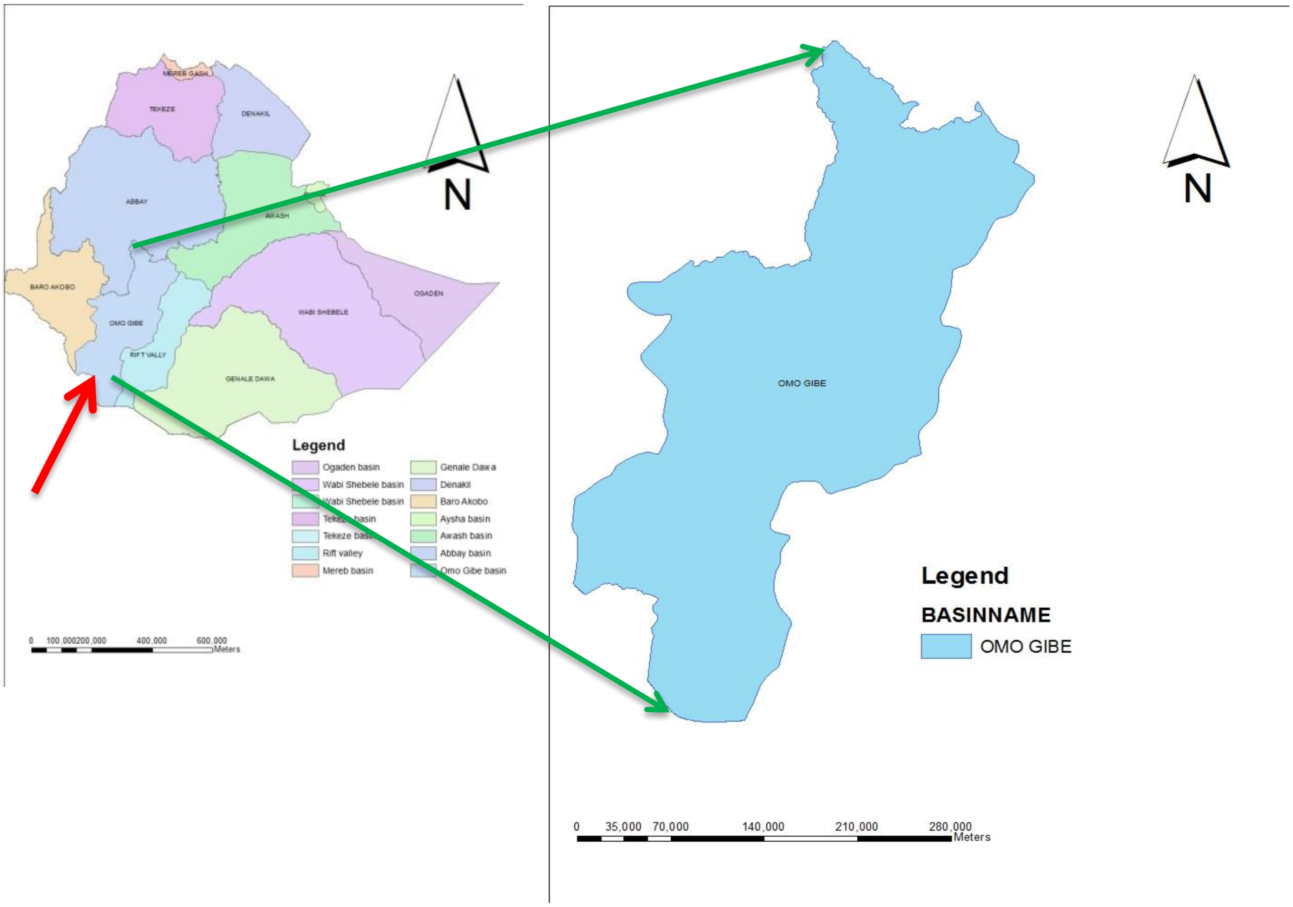


Figure 3 Ethiopian and Omo GIBE RIVER basins (Source: Mowie)

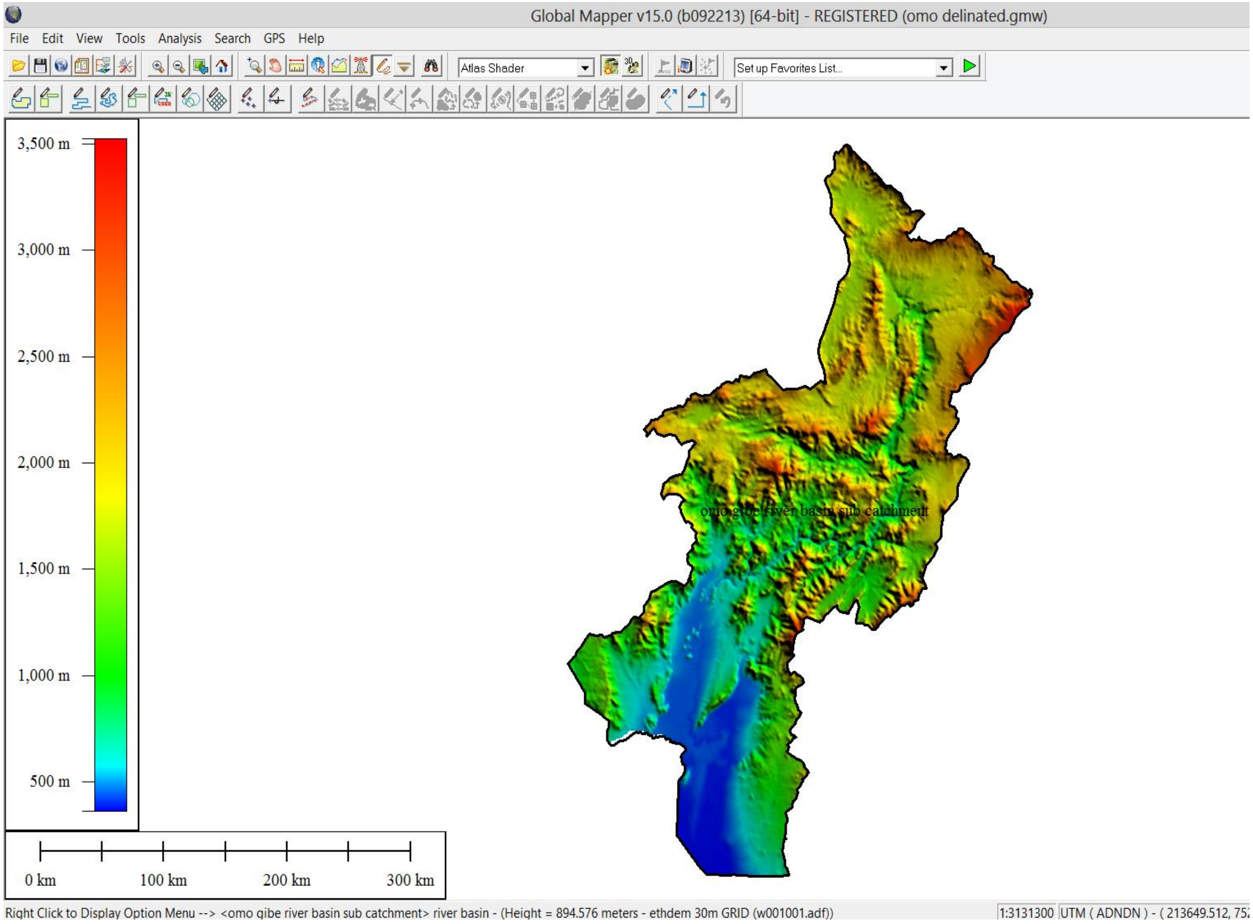
3.1.1 Location of Omo-Gibe River Basin

The Omo-Gibe river basin is one of the major river basins in Ethiopia and is situated in the southern part of the country. It lies between 4˚00'N & 9˚22'N latitude and between 34˚44'E &38 24'E longitude and covers an area of some 79,213 km^2 with a length of 550 km and an average width of 140 km. It is an enclosed river basin that flows in to the Lake Turkana in Kenya which forms its southern boundary. The western watershed is the range of hills and mountains that separate the Omo-Gibe Basin from the Baro-Akobo Basin. To the north and northwest the basin is bounded by the Blue- Nile Basin with small area in the northeast bordering the Awash Basin. The whole of the eastern side borders the Rift Valley Lakes Basin.

Gilgel gibe , Gojeb, halele warebesa, wabe ,weybe, rebu rivers are major tributaries to the main river which drains the western high lands (Richard and Associates, 1996).

3.2 Surface topography of the study area

The study area divides sharply and almost exactly into highlands in the northern half and lowlands in the southern half. This division is reflected in almost all other aspects of the basin. The northern highlands are deeply dissected and drained by the Gibe and Gojeb river systems merging to form the Omo in a deeply entrenched gorge. Steep slopes with dissected hills characterize the highlands while the lowlands are characterized by relatively gentle and undulating slopes. The highland areas have elevations as high as 3625 m.a.sl on Mount Ghuge while the lowland areas fall in the altitudes up to 235 m.a.sl. The digital elevation model of the study area is shown in the figure 4 below, which is used for groundwater modeling.



Right Click to Display Option Menu --> <omo gibe river basin sub catchment> river basin - (Height = 894.576 meters - ethdem 30m GRID (w001001.adf))

1:3131300 UTM (ADNDN) - (213649.512, 75

FIGURE 4 STUDY AREA DEM

The head waters of the Great-Gibe River are at an elevation of about 2200 masl. Although there are some important tributaries from different directions, the general direction of flow of the Gibe River is southwards, towards the Omo River. The Gibe River is known as the Omo River in its lower reaches, south-westwards from the confluence with the Gojeb River, (Richard and Associates, 1996). The figure 5 below shows the longitudinal profile of the study area and it shows the total topographic features and arrangement used for this study.

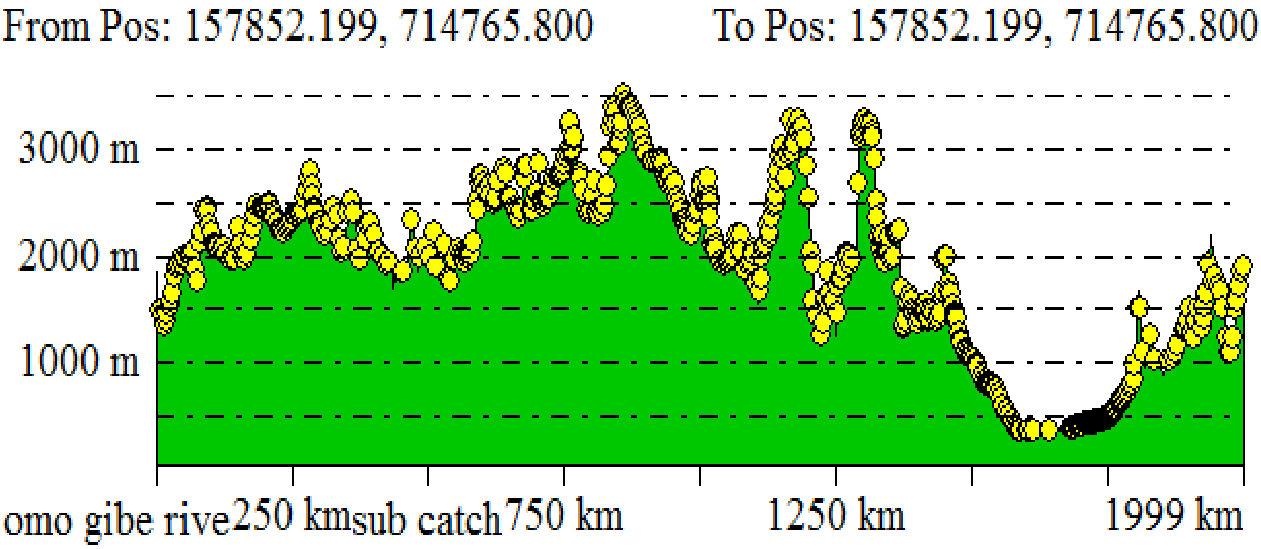


FIGURE 5 LONGITUDINAL PROFILE OF THE STUDY AREA

3.3 Metrology of the study area

3.3.1 Rainfall

In terms of rainfall the basin can be split in to four regions, three of them having a unimodal and one is a bimodal rainfall regime. The northern part of the basin, including Bako, Weliso, Welkite and south to just north of Jima, has rainfall for about seven months, from March to September with a range of 1100-2500 mm per annum. The small rains are from March to May and the main from June to September with a marked increase in July and august.

The north-center area, including bonga, jima and Sodo, has a more even distribution of rainfall over March to September without any peak in July and august. The region generally receives more than 1200mm, rising to 2000 mm on the western fringes north of Bonga.

The southern-center area, including Maji, Jinka and Sawla, has a prolonged rainy season of nine months. The amount varies from 600 mm in the lower valleys to about 1800 mm in the hilly areas around Maji and in the west. Field observations and local experience indicate that around Sawla, at least, the rainfall pattern is different to the north with the major rains in February and March rather than later in the year. The evidence for this prolonged rainy season was confirmed by field experience with wet conditions experienced from March through November. The isohyet of the rainfall distribution in the study area is shown in the figure 6 below, for a groundwater model necessary to estimate the groundwater resources potential in the study area.

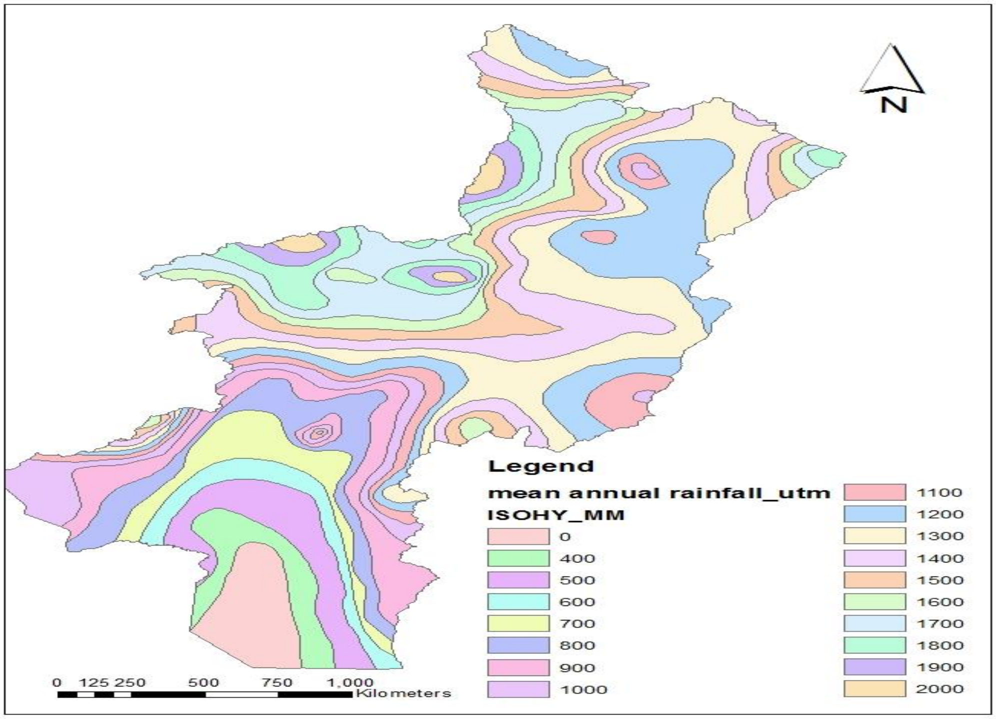


FIGURE 6 STUDY AREA ISOHYET RAINFALL DISTRIBUTION (SOURCE: MOWIE)

3.3.2 Temperature

The mean annual temperature in the in the study area (OGRB) varies from 16°C in the highlands to the north to over 29°C to the south, reflecting the correlation between temperature and elevation. There is little variation in the minimum temperature (around 10°C for most of the year) but the maximum drops markedly during July and August to 20°C compared to a maximum of 27°C.Wishwish, to the west of the study area shows this pattern with slightly slower values and less variation in the maximum. Jinka, to the south of the basin, has the highest average temperatures and shows increased variability in the period November to March, when rainfall is the lowest.

3.3.3 Relative humidity

The highest relative humidity occurs when the rainfall is the highest, reaching an average of over 80% in the high ground to the west of the study area. To the south of the basin the average value drops below 65%.The seasonal variation in humidity follows a similar pattern to the rainfall.

3.3.4 Sunshine

As the major factor affecting the average daily hours of sunshine on the study area is the cloud factor, with relatively little effect due to the seasonal movement of the earth. Thus there are relatively low sunshine levels in the west highlands to the west of the basin. There are marked minima for all stations in June and September. Jinka has the longest hour of sunshine, with a minimum in August, but this is less marked than for other stations.

3.4 Geology and hydrogeology of the study area

The characterization and assessment of the groundwater resources potential studies require a detail studies about the geology and hydrogeology of the study area. The occurrence of groundwater is mainly influenced by the geology, geomorphology, tectonics and the climatic conditions and others which are present in the study area. The geology of the study area delivers serviceable groundwater resources potential and delivers upright diffusion of rainfall to recharge aquifers, which produce springs and feed perennial rivers. The difficulty of obtaining productive aquifers is peculiar feature of Ethiopia, which is characterized by wide heterogeneity of geology, topography, and environmental condition (Alemayehu, 2006).

3.4.1 Geological setting

The geological history of the study area constructed by previous workers indicates that the region is built up of >1000 meter, and perhaps as much as 2000 m, thick successions of volcanic lava flows, uncomfortably overlying scattered fluvial-lacustrine sediments and Precambrian crystalline basement rocks, as well as more widely distributed Tertiary ‘flood basalts’. Unlike conditions in northern and eastern Ethiopia, Mesozoic marine deposits have not, so far, been encountered in south-western Ethiopia including the study area instead, terrestrial sedimentation; rifting and volcanism seem to have dominated geological process during the Mesozoic era. In general, several structural trends are recognized in and around the study area. Structural analysis suggests that N-S striking features are younger than NNE structures which in turn are younger than the NNW features. The facts that recent eruptive volcanic centers and a concentration of earthquake epicenters are associated with local basins bounded by N-S faults suggest that other NNE and NNW trends are older, (Richard and Associates, 1996).

Groundwater resources potential could happen in interstitial openings or in fractures of the rocks which lay across the study area . The opening may have been formed at the time the rocks were placed or at a subsequent time by fracturing, weathering, or solution. The distribution and nature of these openings may relate generally to other physical and chemical characteristics of formations or group of rocks. Thus the general nature and distribution of the rocks in the study area allows certain implications regarding the occurrence of groundwater. The groundwater occurrence and its reservoir are mainly controlled by the degree of geological weathering or geological structures (Natan et.al. 2010).

The pervious scholars classified the geology of the study area, tentatively in to five groups of rocks according to their age relationships.

These groups are:

- The pre-Cambrian crystalline basement rocks
- The early ’flood basalts’ of late Eocene to early Miocene age
- A transitional series of intercalated basaltic and felsic volcanic of late Oligocene to early Miocene age
- A series of felsic volcanics ranging from early Miocene to late Miocene in age
- The post-rift sediments and volcanics, of Poliocene and Quaternary age

Nearly 11% of the study area is underlain by Pre-cambrian metamorphic gneisses consisting of felsic meta-sediments and mafic meta-volcanic that represent the older ‘cratonic’ granite-gneiss terrain to the west and a younger ‘oceanic’ to the east. The younger oceanic ‘greenstones’ have been over thrust to the west onto the older craton. The main thrust zone, in the Sharma region west of the lower Omo River is marked by intense shearing and cataclasis. Around 80% of study area is underlain by Tertiary volcanic rocks. Also the Basin occupies the combined Omo and Usno rift valleys which are failed north extension of the lake Turkana-Ethiopian Rift system. In the north part of the basin, the rivers have exploited the extensive fault zones to cut deep gorges. The eroded material has been deposited in the lower part of the basin as a thick sequence of quaternary alluvial deposits (Bogale, 2011).

The geology of the study area was classified based on the age of rocks across the geologic layer in the study area. For this study the geology of the study area as shown in the figure 7 is classified in to fifteen groups as sourcing the ministry of water irrigation and energy (MoWIE).

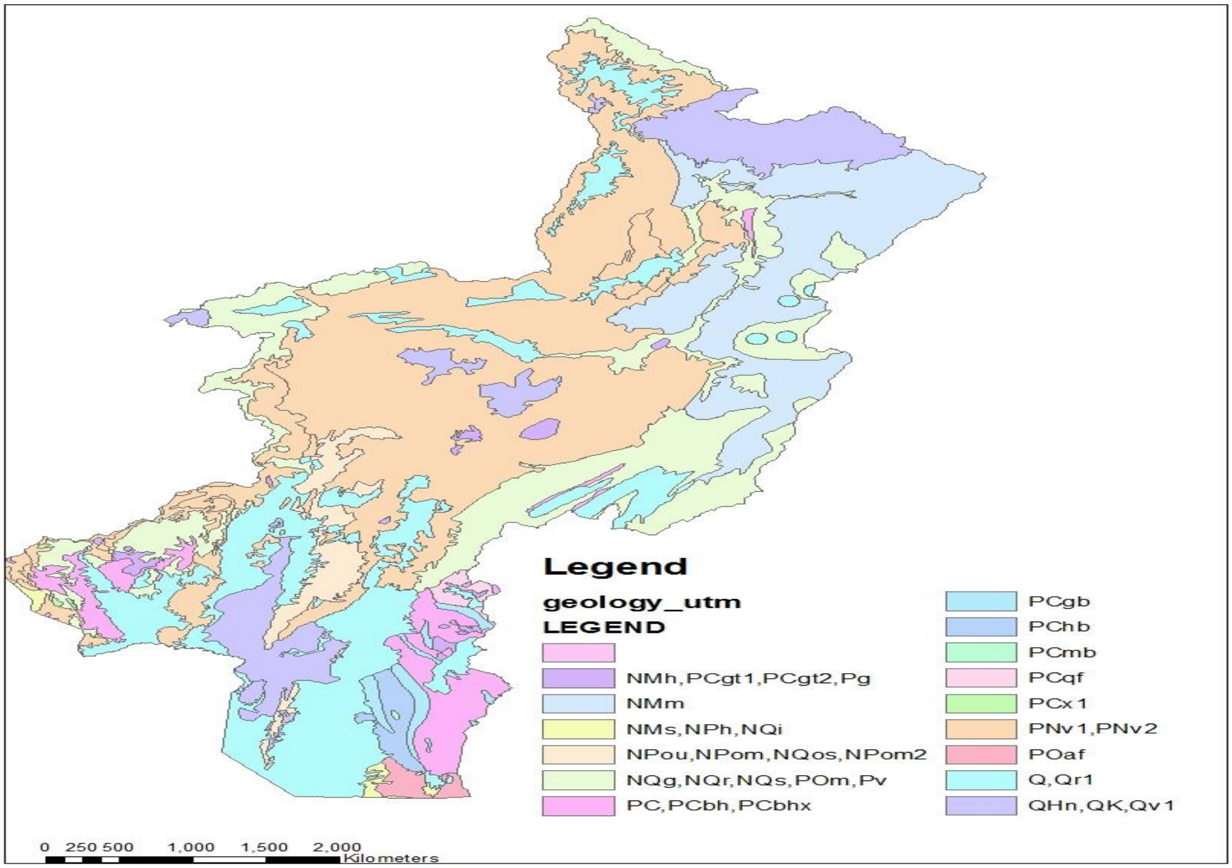


Figure 7 Geological map of the study area (Source: MoWIE)

3.5 Hydrogeology of the study area

The hydrogeology of the study area is the main constrained factor to characterize and to estimate the groundwater resources potential. The geology of the study area is quite complex, it is difficult to characterize and estimate the groundwater resources potential, which is stored in the basin. The complexity of geology of the study area has a direct impact on its hydrogeological characteristics (Karimi et.al. 2014). There are complex relationships between groundwater recharge, flow, storage and discharge and the surface water system. The frequent occurrence of groundwater as discreet bodies, which may not be readily identified, makes evaluation of the available groundwater resource extremely difficult (Jordi et.al. 2014).

Groundwater plays a great role for the people who settle in the study area. The rural and urban water supply is taken from the groundwater resources potential which are stored in the groundwater aquifer in the study area. Additionally the groundwater is used for small scale agriculture. The study area covers more than 80 woreda in both SNNPR and oromia region. Based on the various geological units in the study area are broadly classified into three aquifer systems, namely:

- Single permeability-storativity
- Double permeability-storativity
- Inter-granular permeability-storativity systems

3.6 Hydrology of the study area

The study area is characterized by numerous perennial and intermittent rivers. The main source of water to the rivers is the rainfall from the northern highlands. Gojeb, Gilgelgibe, Omo ,Halaele wrabesa,Weyb,Wabe,Soke,Zegna,Alenga,Tunjo rivers are the main perennial rivers in the study area. The study area groundwater resources potential is affected by variation of perennial river stages. Water flows from the river into the aquifer and the groundwater potential and the groundwater table rises when there is an increase in river stage with respect to the altitude of the groundwater resources potential storage and groundwater table. The groundwater potential in the study area is increase, due to surface rainfall recharge, infiltration, deep percolation and diffusion of groundwater from one region to the other region. The rivers which are found in the study area are taken as a constant head boundary. Aquifer nearest to the rivers have the great chance to increase groundwater table and the potential to holed a large amount of groundwater potential compared to an aquifer which is far apart from the river. The hydrology of the study area is well established, because different surface water researches and water resource development projects were conducted by different researchers and Ethiopian government.

3.7 Data collection and Data type

To conduct this research work the geological map of Ethiopia, daily rainfall data, and well inventory are collected from different governmental organizations. The well inventories data are taken from ministry of water irrigation and energy (MoWIE), Oromia water works construction enterprise, south water works construction enterprise and water works design and supervision enterprise(WWDSE).

To characterize and to assess the groundwater resources potential in the study area using a finite element computer based (TAGSAC in mat lab) groundwater modeling program the following model input data's were collected for this research work.

3.7.1 Well inventory data

The well inventories data are the constraint input parameters for groundwater model; therefore collecting these well inventories data is a base line survey for this research basically focusing on groundwater characterization and groundwater potential assessment.

- Hand dug wells inventory for water supply,
- Shallow wells inventory, for water supply
- Deep wells inventory for irrigation and water supply
- Springs inventory for irrigation and water supply

The well inventories data includes:-

- The location, X and Y coordinates of (borehole, wells and springs) in UTM
- The water table depth (the static water level of the well).
- The well yield, geology of the borehole site is also essential for more clarity of the data

3.7.2 Rainfall data

In addition to the well inventories data the model need the rainfall (the annual and the monthly rainfall records, which are essential to define the recharge in the study area. The rainfall records are taken from the national metrological agency (NMSA) in daily, monthly and grid rainfall data basis as per the accessibility of the data from the organization. The study area is widespread area; therefore fifty five (55) rainfall gauging stations are taken for fair distribution of aerial rainfall, for better characterization and assessment of the groundwater resources potential in detail. The national metrological agency (NMSA) deliver the data as per the requisite of the study for forty seven (47) station daily rainfall for more than fifteen years record and six station monthly rainfall for more than fifteen years and two stations grid rainfall data due to scarcity and nonappearance of records.

Hydro metrological records have some missing values, to fill the missing rainfall records, there are standard methods be governed by the records and areal coverage of the rainfall gauging station.

The Digital Elevation model (DEM) of Ethiopia is used to get the topographic data of the study area. DEM is essential to demarcate the particular study area.

Geology of the study area is input model constraint parameters to determine the hydraulic conductivity and porosity in the study area. Around fifteen types of geology are present in the study area as per the data taken from ministry of mines and ministry of water, irrigation and energy (MoWIE).

The equivalent porous medium approach is applied to characterize and assess the groundwater resources potential in the study area. In this approach, individual fractures are not explicitly treated in the model but rather the heterogeneity of the fractured rock system is modeled using a small number of regions (elements), each of which is modeled as an equivalent porous medium and gives equivalent hydraulic properties across a layer. The primary and secondary porosity and the hydraulic conductivity distribution are replaced with a continuous porous medium having equivalent hydraulic properties. An equivalent porous media approach makes the assumption that a representative elementary volume (*REV*) of material characterized by equivalent hydraulic parameters. Modeling results are only valid at scales larger than the *REV*. The finite element groundwater character and potential assessment model requires the definition of effective values for hydraulic conductivity, specific storage and porosity at the scale of the *REV*.

3.8 Groundwater Modeling

To characterize and assess the groundwater resources potential the geologic, topographic, hydrologic conditions in the study area must be studied. This part of the work followed the modeling protocol like conceptual model development, defining model geometry and boundary conditions, defining hydrogeological parameters, simulation run the model and calibration.

Commonly, the groundwater model takes the form of a set of numerical mathematical equations, including partial differential equations. However the preferred technique solution of the numerical mathematical groundwater model of a given problem is the logical solution, for most practical problems, since the heterogeneity of the considered groundwater study area domain, the irregular shape of study area boundaries and the non-analytic form of the numerous functions, answering the mathematical groundwater models analytically is not possible. Instead, transformation of the mathematical groundwater model into a numerical one, to get a solutions by TAGSAC in mat lab computer program.

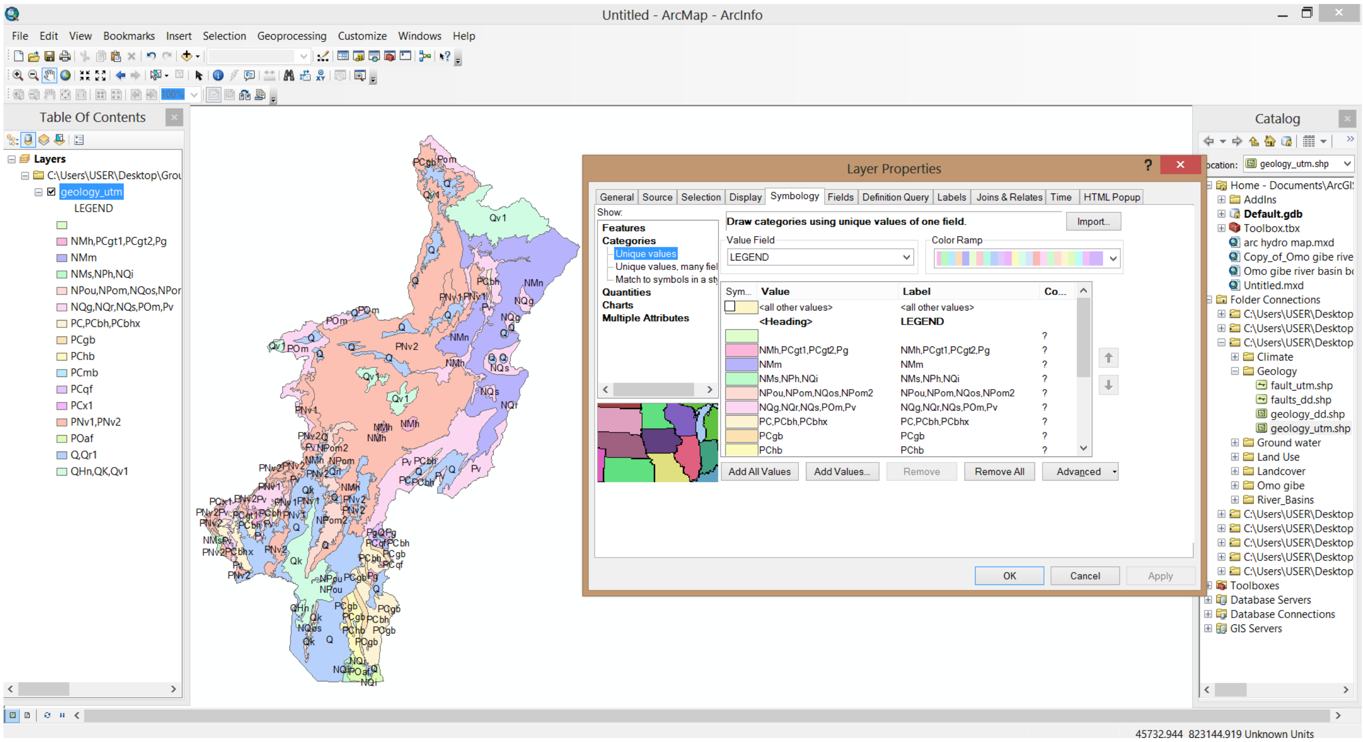
Hydrogeological studies usually involve mathematical modeling of groundwater characterization and potential assessment. Mathematical models consist of a set of differential equations which govern the groundwater potential flow in a given groundwater system. In computer programming mathematical models are implemented using different approaches among which the finite difference, finite element and finite volume methods are most common (Herbert, 1982). For the first two methods (Finite difference and finite element) a system of nodal points is superimposed over the problem domain. The difference between the two methods is in the distribution of nodes. The finite difference nodes are in a regular grid order where nodes can be block-centered or mesh-centered. For both Finite Difference and Finite Element methods, the horizontal discretization (number of cells/elements) must be the same in all model layers; this is quite inefficient, because it means that you end up with a large number of cells/elements in layers outside the area of interest; with Finite Volume, MODFLOW-USG, each layer can have its own discretization; this means that you can refine upper layers around rivers and streams, and have coarser refinement in lower layers; likewise, you can refine around wells screens in lower layers. The finite element methods, on the other hand, can have an irregular distribution of nodes which are connected together to form triangular sub-areas called elements.

3.8 .1 Materials used for groundwater modeling

This study uses different types of software for data analysis and explanation with their updated version is expressed in this paragraph software like, Global Mapper (12 and 15), Mat Lab (R2013a), GIS (10) and surfer (10) were used depend on the objective and the type of data to be simulated to characterize and to assess the ground water resources potential in the study area. The application of each software's are listed below during the thesis work with corresponding groundwater modeling approach.

3.8.1.1 Use of GIS software

- To clip or extract the geology of the study area from the Ethiopian geological map and to create the geological map of the study area. Groundwater potential assessment and characterization is relay on the type of geologic medium. To use finite element groundwater modeling for the study area, interpretation of the GIS geological data is one of the main responsibilities to be performed by the scholars. Groundwater modeling is directly related with geology of the study area or the hydraulic conductivity and the porosity of the study area is the geologic medium character. The geology of the study area is as follows. The geologic medium for the study area is interpreted in the figure 8 below to characterize and assess the groundwater resources potential in the study area. Geologic data were used as a groundwater input to determine the hydraulic conductivity, for hydraulic head simulation at each node and element in the study area.



Draw categories using unique values of one field.

Value Field: LEGEND

Sym...	Value	Label	Co...
☐	<all other values>	<all other values>	
	<Heading>	LEGEND	
			?
	NMh,PCgt1,PCgt2,Pg	NMh,PCgt1,PCgt2,Pg	?
	NMm	NMm	?
	NMs,NPh,NQi	NMs,NPh,NQi	?
	NPou,NPom,NQos,NPom2	NPou,NPom,NQos,NPom2	?
	NQg,NQr,NQs,POm,Pv	NQg,NQr,NQs,POm,Pv	?
	PC,PCbh,PCbhx	PC,PCbh,PCbhx	?
	PCgb	PCgb	?
	PChb	PChb	?

FIGURE 8 GEOLOGY DATA INTERPRETATION USING GIS

- To organize and manage the data taken from ministry of water, irrigation and energy (MoWIE), GIS has a great importance for this study, because it is used to interpret the climate data, the hydrogeology of the study area, the pervious groundwater borehole data's, the topographic data, the land use and land cover data are managed and organized by this software for this groundwater modeling work.
- GIS is also used to generate the stream network, means different perennial and intermittent rivers are present in the study area. The perennial rivers will be taken for groundwater model as a constant head boundary.
- To find the location of the boreholes, rainfall gauging stations and river gauging stations.

3.8.1.2Use of Surfer software

Groundwater modeling can be preprocessed by surfer and the surfer was, (a) used to create the model data as per the requirement of the groundwater model. All the groundwater modeling input parameters are preprocessed by surfer, (b) to outright the XYZ grid global mapper data by the global mapper path profile documents can be changed to model input and blanked file formats respectively to check the uniform distribution of the terrain profile in the basin,(c) to enticement or plot the topography uniformity map of the river basin(d) to adjust excel files format into surfer model input files (e)Used to design the model grid of the study area.

3.9 Groundwater Modeling Problem Discretization

3.9.1 Spatial discretization

Not like investigative methods, numerical methods yield approximate solutions to the governing equation through the discretization of space and time. The groundwater character and potential assessment (FEM) uses a concept of piecewise estimate technique to obtain solutions to a wide variety of problems. The domain of the problem that is the extent of the aquifer to be simulated is divided into a set of elements or pieces. Accordingly the first step in the solution of a groundwater character and potential assessment by the finite element method is to discretize the problem domain of the study area. This is done by replacing the problem domain in the study area with a collection of nodes (or nodal points) and elements referred to as the finite element mesh. In the finite element analysis the precision of the solution obtained and the level of computational effort required to obtain a solution will be determined to a great extent by the number of nodes in the mesh. A model mesh has a smaller number of nodes and will give a lower precision than a fine mesh. The size and shape of the elements in a mesh is determined primarily by the size and shape of the problem domain, the wideness of the study area, the number of different types of aquifer materials, and by the number of nodes in the mesh. In problems that have a complex geometry or geologic materials many elements will be required. Even if the problem domain contains different irregular boundaries or edges different types of elements the model must use single type of elements for simplicity.

The most common shapes for finite elements are triangles and trapezoids for two-dimensional flow, and triangular and trapezoidal prisms for three-dimensional flow (Fitts, 2002). When drawing the finite element mesh, each element is assigned a unique element number. The element numbers begin with one and continue sequentially to the number of elements in the mesh for the study area. Every element in the model mesh is described using six nodes; the nodal coordinates define the size and shape of the element. On behalf of this reason the node numbers for every one element are listed. The material properties are specified for each element in the mesh. The properties for each material set are then listed once.

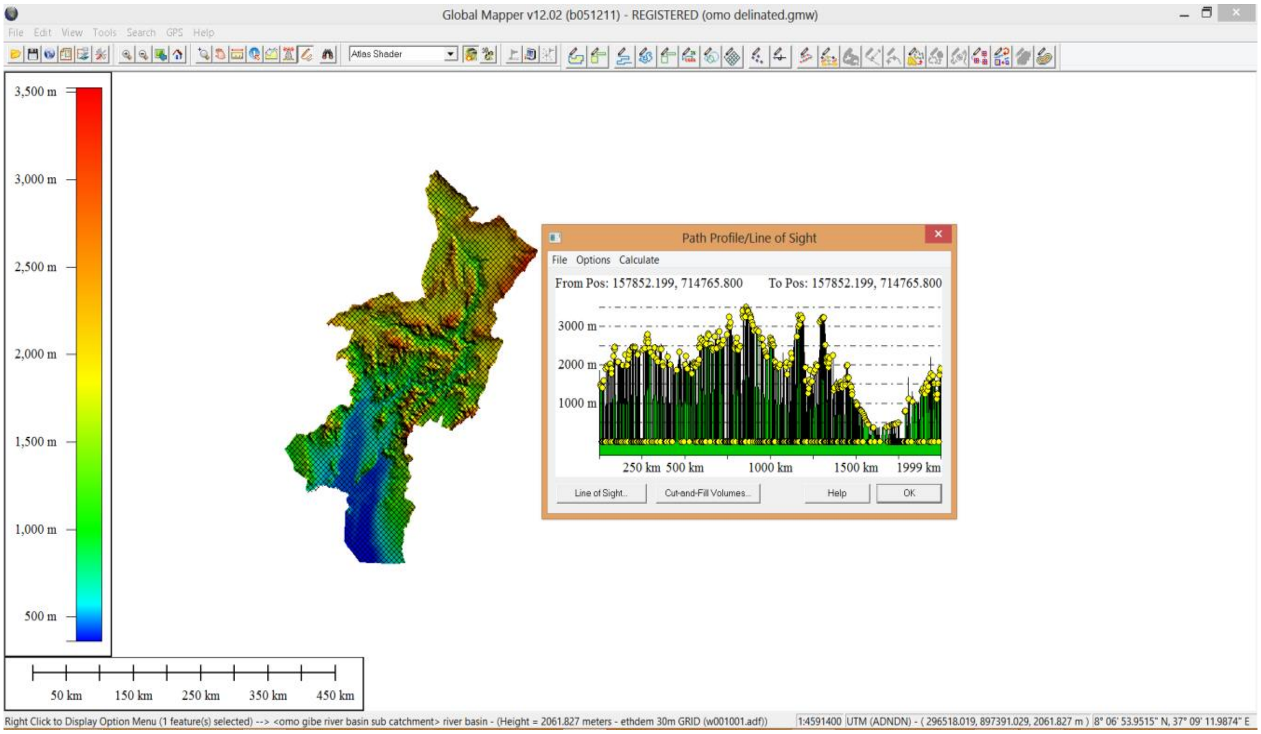
By considering the wide spread study area, the problem domain in the study area and the capacity of the computer memory to generate the model mesh the element length is taken as 3kilometers. The elements are triangular prism and the nodes have right-handed Cartesian coordinates (x, y, z), z-axis points in the vertical upward direction (the elevation of the nodes above sea level). The finite element mesh consists of several nodes for the study area but each node is assigned a unique node number. Node numbers range from one to the number of nodes in the mesh; no "misses" in the node numbers are allowed and no two nodes can have the same node number in the groundwater model. The overall problem domain discretization of the study area follows the procedures listed below.

3.9.2 Use of Global mapper

The groundwater problem in the study area can be discretized by global mapper software. The global mapper can be used in the way by discretizing the groundwater problem by delineating the study area. Since global mapper software is stress-free for delineation and interpretation of DEM. Delineation of the study area takes several procedures, (a)The initial step is opening the digital elevation model of the country (Ethiopian DEM) on global mapper software working window. The digital elevation model (DEM) has 30m*30m resolution, taken from Ethiopian mapping agency, (b) subsequently opining of the DEM on the global mapper working space, click on global mapper toolbar file menu and, exporting the file in global mapper package format, (c) once exporting the file there is dialogue box display on the global mapper working space, then we can select export bounds, (d) as a final point select the box delineation instruction menu from the dialogue box and delineate our study area in box size and save the values at any place,(e) the demarcated box is not the particular study area, however it shows the study area is surrounded by the box.

3.9.2.1 Study area Boundary profile

The study area is modeled by finite element groundwater modeling technique; hence to practice this groundwater modeling technique for the study area, mesh generation is compulsory task. The mesh is generated from the edge profile of the study area. The boundary profile is taken from the study area which is defined by global mapper software. This border profile of the study area is used to fix the model input constraints like external node and all-inclusive element of the study area. The node and element documents are in use from mat lab software packages Mesh generator .m as input constraints the border profile of the study area. The border profile for the study area plays a vital role, to reduce the groundwater problem domains by creating a mesh for the study area. The generated mesh contains triangular element of the study area and the nodes that avoid the complicated and sophisticated groundwater character and potential assessment problems. The overall border profile generation for the study area is shown in the figure 9 below. As seen from the figure 9 the border profile for the study area is taken from the topographic map (DEM) of the study area.



From Pos: 157852.199, 714765.800 To Pos: 157852.199, 714765.800

Right Click to Display Option Menu (1 feature(s) selected) --> <omo gibe river basin sub catchment> river basin - (Height = 2061.827 meters - ethdem 30m GRID (w001001.adf)) 1:4591400 UTM (ADNDN) - (296518.019, 897391.029, 2061.827 m) 8° 06' 53.9515" N, 37° 09' 11.9874" E

FIGURE 9 STUDY AREA BORDER PROFILE

3.9.3 Use of mat lab software

The finite element numerical groundwater model is used to assess and characterize the groundwater resource potential in study area; To achieve this research goal TAGSAC in mat lab computer based groundwater modeling program were preferable in order to discretize the groundwater modeling problem in the study area. For this study different computer based programs in mat lab will be used to determine different groundwater modeling input parameters necessary for characterization and groundwater potential in the study area. The software will use to generate the model mesh for the study area. The model mesh contains number of elements and the total number of node in the study area. The input data necessary to generate the model mesh is taken from the study area path profile.

3.9.3.1 Model Mesh Design

The generated mesh designed for groundwater modeling is used to simplify complex geometries in the study area, including barriers, aquifers, and recharge and discharge areas by sensing the code to make simple the complex mathematical and numerical groundwater problems. An automated mesh-generation program was used to construct the initial mesh. Triangular elements were generated because they could be easily rearranged manually and still maintain a proper element-aspect ratio (element dimensions).

The number of elements and the number of nodes are obtained after we generate the mesh for the study area. The study area is represented by a mesh having twenty one thousand five hundred four (21504) total number of elements and a total number of nodes (surface node and bottom node) twenty two thousand seven hundred ninety two (22792).The basic procedures to design the model mesh for the study area are, (a) generating the path profile of the study area using global mapper application, (b) the generated path profile should be put in to a given folder in the form of mat lab file format

After the documents are taken into mat lab editor the mesh can be generated to reduce the groundwater modeling problem domain. The model files contain only the coordinates of the study area in UTM and are saved into mat lab preprocessing document. The study area is a wide spread, the element dimension should be large enough for computer process and the dimension should be the reflection of the study area. The computer based meshgenerater.m in mat lab program is simulated by fixing the element dimension depends on the wideness of the study area. The first simulation result from the program is the total number of surface node and the triangular surface elements (node and element).The figure 10 below shows the generated mesh, which represents the complex, topographic, hydro geologic and groundwater aquifer boundary conditions of the study area. In the figure 10 the element and node are the groundwater modeling input parameters and taken from the generated mesh.

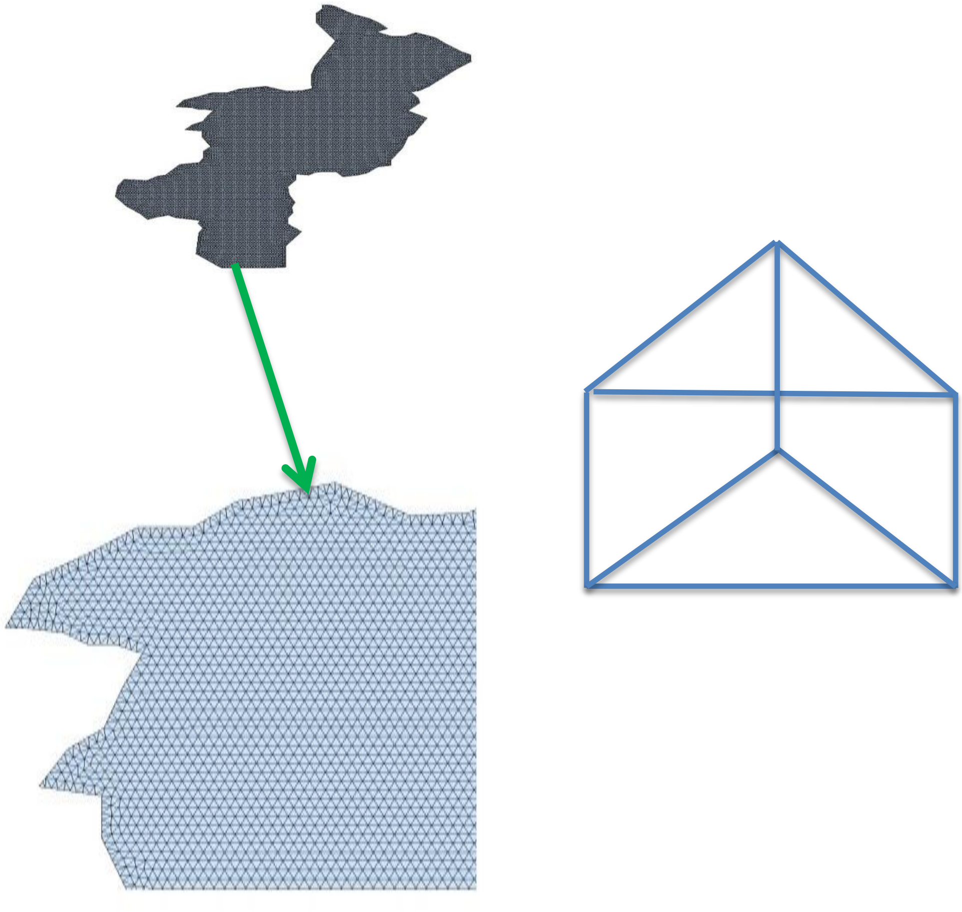


FIGURE 10 GENERATED MESH FOR THE STUDY AREA

- Total number of surface node is 11396 for study area
- Total number of element is 21504 for study area
- All nodes (surface node + bottom node) is 22792 is generated

To represent and to discretize the groundwater modeling problems in the study area, the groundwater model can be used to estimate the groundwater resources potential in the study area. The node1st2.dat has only coordinates of each node that is longitude and latitude (x coordinate and y coordinate). The nodes taken from the simulation run of the program are only surface nodes of the study area.

3.10 Hydraulic Head Approximating equations

Groundwater model (TAGSAC in mat lab) equation which leads a system of algebraic equations that can be solved for hydraulic head is done by different methods. The method of weighted residuals is a more general approach that is widely used in groundwater modeling. In the method of weighted residuals, an approximate solution to the boundary or initial value problem is defined. When this approximate solution is substituted into the governing differential mathematical equation, an error or residual occurs at each point in the problem domain. The weighted average of the residuals for each node should be forced in the finite element mesh to equal to zero. Galerkin's Method is the subset of the method of weighted residuals that is most commonly used to solve groundwater flow and solute transport problems (Istok, 1989). In Galerkin's Method the weighting function for a node is identical to the interpolation function used to define the approximate solution. And head (h) can be approximated as;

$$\hat{h}(e) = \sum_{i=1}^{n} N_i^{(e)} h_i \qquad 3.1$$

Where, $\hat{h}^{(e)}$ is the approximate solution for hydraulic head within element e, $N_i^{(e)}$ are the interpolation functions for each node within element e, n is the number of nodes within element e, and h_i are the unknown values of hydraulic head for each node within element e.

The contribution of any element e to the residual at a node i to the element am joined like;

$$Ri(e) = -\iiint W_i^{(e)}(x,y,z) \left[\frac{\partial}{\partial x}\left(k_x \frac{\partial \hat{h}^{(e)}}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial \hat{h}^{(e)}}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial \hat{h}^{(e)}}{\partial z}\right)\right] dxdydz \qquad 3.2$$

Where, $W_i^{(e)}$ is the weighting function for node i and the limits of the integration are chosen to represent the volume of element e and R is the residual or error due to the approximate solution. In Galerkin's method we choose the weighting function for each node in the element to be equal to the interpolation function for that node, $W_i^{(e)} = N_i^{(e)}$. The residual varies from point-to-point within the problem domain. At some points it may be large and at other points it may be small (the sign of the residual also can vary from point-to-point).Therefore we cannot force R to be zero at certain specified points because the residual may then become unacceptably large elsewhere in the problem domain. The saturated hydraulic conductivity in the three coordinate directions is constant within an element and can be written as;

$$\mathrm{Ri(e)} = -\iiint_{v(e)} \left(W_i^{(e)}(x,y,z) \left[\left(k_x^{(e)} \frac{\partial^2 \hat{h}^{(e)}}{\partial x^2} \right) + \left(k_y^{(e)} \frac{\partial^2 \hat{h}^{(e)}}{\partial y^2} \right) + \left(k_z^{(e)} \frac{\partial^2 \hat{h}^{(e)}}{\partial z^2} \right) \pm q^{(e)} \right] \right) dxdydz \qquad 3.3$$

Where, $k_x^{(e)}$, $k_y^{(e)}$ and $k_z^{(e)}$ are the value of simulated hydraulic conductivity in the x, y and z direction within element e. Equation 3.3, using integration by parts it can be written as;

$$\mathrm{Ri(e)} = -\iiint N_i^{(e)} \left[\left(k_x^{(e)} \frac{\partial N_i^{(e)}}{\partial x} \frac{\partial \hat{h}^{(e)}}{\partial x} \right) + \left(k_y^{(e)} \frac{\partial N_i^{(e)}}{\partial y} \frac{\partial \hat{h}^{(e)}}{\partial y} \right) + \left(k_z^{(e)} \frac{\partial N_i^{(e)}}{\partial z} \frac{\partial \hat{h}^{(e)}}{\partial z} \right) + q^{(e)} \right] dxdydz \qquad 3.4$$

The most general formulation for [K(e)] (element conductance matrix) can be written for the case of a three-dimensional problem being solved using elements with n nodes.

$$k^{(e)} = \iiint_{V(e)} \begin{bmatrix} \frac{\partial N_i^{(e)}}{\partial x} & \frac{\partial N_i^{(e)}}{\partial y} & \frac{\partial N_i^{(e)}}{\partial z} \\ \vdots & \vdots & \vdots \\ \frac{\partial N_n^{(e)}}{\partial x} & \frac{\partial N_n^{(e)}}{\partial y} & \frac{\partial N_n^{(e)}}{\partial z} \end{bmatrix} \begin{bmatrix} k_x^{(e)} & 0 & 0 \\ 0 & k_y^{(e)} & 0 \\ 0 & 0 & k_z^{(e)} \end{bmatrix} \begin{bmatrix} \frac{\partial N_i^{(e)}}{\partial x} & \dots & \frac{\partial N_n^{(e)}}{\partial x} \\ \frac{\partial N_i^{(e)}}{\partial y} & \dots & \frac{\partial N_n^{(e)}}{\partial y} \\ \frac{\partial N_i^{(e)}}{\partial z} & \dots & \frac{\partial N_n^{(e)}}{\partial z} \end{bmatrix} dxdydz \qquad 3.5$$

TAGSAC in mat lab is selected to solve the groundwater equation. TAGSAC in mat lab is proofed to be applicable in a number of researches done all over the globe (Mebruk et.al, 2010). The numerical approximations of the groundwater equations describing fully three dimensional problems are obtained using the Galerkin finite element technique. The integral approximation of the groundwater equation is then obtained using the Galerkin weighted residual criterion. Spatial integration is performed piecewise over each element. For a steady-state hydraulic head simulation, the nodal equations are algebraic equations.

3.11 Groundwater model Conceptualization

A conceptual groundwater model is a pictorial representation of the groundwater flow system, frequently in the form of a block diagram or a cross-section (Anderson and Woessner, 1992). Groundwater models attempt to represent an actual groundwater aquifer system with a mathematical counterpart, and the dimensions of the numerical model and the grid design depend on the nature of the conceptual model. Conceptual groundwater models describe how water enters an aquifer system, store through the aquifer system. A conceptual model is a hypothetical simplified description of the groundwater aquifer system to be studied. Features often described in conceptual models include the following:-

- Define the groundwater potential and groundwater aquifer flow system.
- Define aquifer material properties (porosity, hydraulic conductivity).
- Potentiometric surfaces.
- Define boundary locations
- System stresses (withdrawal wells, infiltration trenches, etc.) (U.S. Army Corps Engineers, 1999).

3.11.1 Aquifer classification

In an area where there is inadequate subsurface information to define the hydraulic characteristics of the individual lithology's, it is not easy to decide in advance which geological unit is a useful aquifer or a useful aquiclude. This problem is more pronounced when dealing with non-sedimentary rocks. This problem can be approached conceptually in terms of the likely characteristics of the permeability-storativity system in the rocks. For example, sedimentary rocks, and some volcaniclastic rocks, are generally considered to have an inter-granular permeability-storativity system, whereas non-sedimentary rocks may have a range of characteristics (Richard & Associates, 1996).

- The presence of permeable, granular sediments inter-bedded with the lavas
- Jointed blocks, forming a relatively small scale fracture network.

These components act in conjunction with the main permeable fracture and fault systems to form the double permeability-storativity system. Basement crystalline rocks and acidic volcanic rocks are considered as having a single permeability-storativity system. The groundwater flow in these rocks is controlled by the network of open fissures, with the mass permeability depending on factors such as the number, length, width, depth and the degree of inter-communication between the fractures. Based on the above concepts, the various geological units in the study area are broadly classified into three aquifer systems, namely:

- Single permeability-storativity
- Double permeability-storativity
- Inter-granular permeability-storativity systems

Each system in turn could be sub-divided further depending on recorded yield, areal extent, topographical features and availability of recharge, thicknesses of lava flows, fracture characteristics, thicknesses of clay mantle, etc. In the present analysis, all these factors are taken into consideration while classifying the permeability and productivity of the rock unit (Richard & Associates, 1996).

3.11.1.1 Inter-granular aquifer system

The quaternary superficial deposits and the sediments of the Omo group represent this aquifer system. The permeability of these sediments is generally high to moderate, but the depth to the saturated aquifer, productivity and quality of water could vary from one unit to the other.

- Very highly permeable
- Highly permeable,.
- Moderately permeable sediments
- Poorly permeable, thinly stratified

Inter-granular aquifers occur dominantly in the southern part of the omo gibe river basin, although the potentially important volcanic sand unit (Q4) occurs in the northern part of the basin, (Richard & Associates, 1996)

3.11.1.2 Double permeability-storativity aquifer system

In this category are basic volcanic rocks and ignimbrites that could be divided into aquifer sub-classes ranging from very low to very high permeability and productivity potentials.

- Highly permeable Makonnen Basalt (Pom),
- Highly permeable volcanic sand of the Nazareth Group (NMn
- Highly permeable, ’undifferentiated Flood Basalts’ (Pv),.
- Highly permeable Mursi Basalt (NPom2)

- Moderate permeability Lower Felsic Volcanics and Sedimentary Formation (PNv1),
- Moderately permeable sandy pyroclastic sediments of the Pleistocene-Holocene Volcanic group (Qv1),
- Poorly permeable - Upper Felsic Volcanics (PNv2)

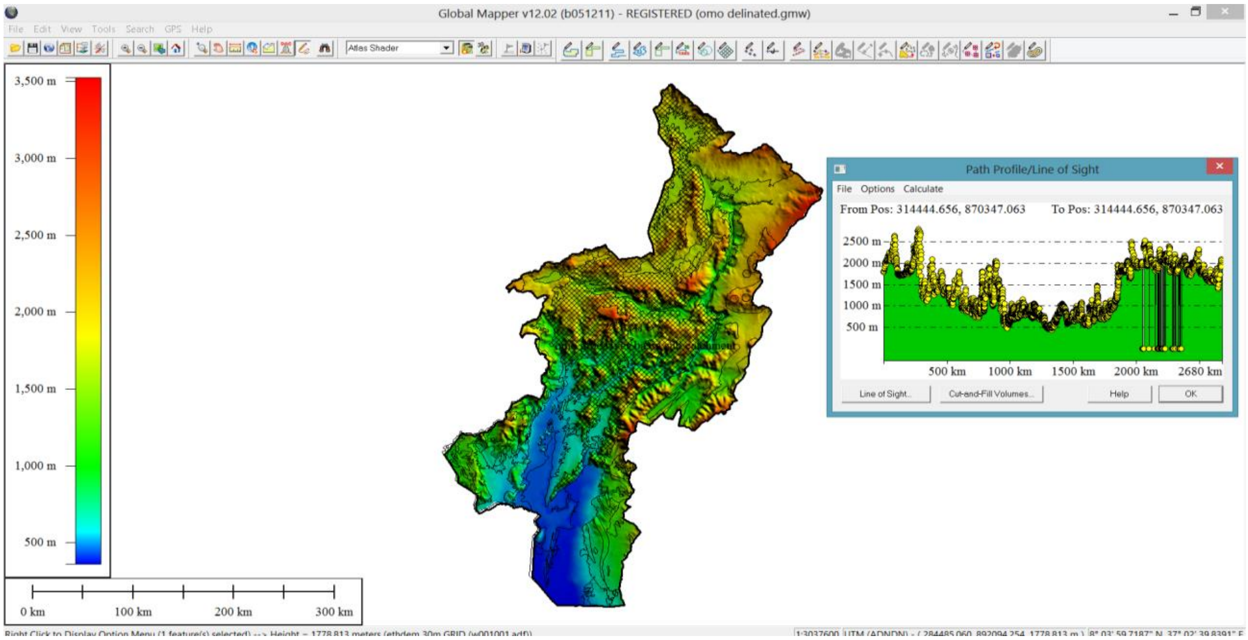
The geographical distribution of these double permeability-storativity aquifer systems is dominantly in the central and northern part of the study area (Richard & Associates, 1996)

3.11.1.3 Single permeability-storativity fissured hard rock aquifers

All Precambrian basement rocks are considered to be poorly permeable. However, fractures in granite, diorite, pegmatite and gneiss of the high plateau and their weathered products yield large quantities of very good quality water (Richard & Associates, 1996).

The geology of the study area is essential to determine the porosity and the hydraulic conductivity of the study area. Using the hydraulic conductivity and the porosity of the rock in the study area, the characterization and groundwater potential assessment will be conducted. The data after inboundry.m in mat lab program gives the type of geology and the element number of the study area.

The hydraulic conductivity and porosity value for the aquifer in the study area has been determined from the geologic medium. Geologic material type in the study area is one input parameter for finite element groundwater model. To identify the type of geology for each element in the study area are, (a) the first procedures to generate geology path profile of study area is overlaying the geological map of Ethiopia into study area DEM using GIS software, then by opening the delineated map of study area by global mapper software overlay the geological data from GIS, (b) after overlaying we can generate the path profile of geology in the study area. The study area has fifteen different types of geology, so at most 15 set of hydraulic conductivity is required for characterization and groundwater potential groundwater model. The figure 11 shows that the geologic boundary profile on the global mapper, to preprocess the geologic data as a groundwater model input parameters for a better characterization and groundwater potential assessment in the study area.


Global Mapper v12.02 (b051211) - REGISTERED (omo delinated.gmw)

From Pos: 314444.656, 870347.063 To Pos: 314444.656, 870347.063

Right Click to Display Option Menu (1 feature(s) selected) --> Height = 1778.813 meters (ethdem 30m GRID (w001001.adf))

1:3037600 UTM (ADNDN) - (284485.060, 892094.254, 1778.813 m) 8° 03' 59.7187" N, 37° 02' 39.8391" E

FIGURE 11 GEOLOGIC BOUNDARY PROFILE OF THE STUDY AREA

The geologic path profile is used to determine the elemental geology in the study area; this helps us to determine the hydraulic conductivity and porosity of rock in the study area as per the type of geology. By using computer based inboundary.m in mat lab program the distribution of geological rock types with the generated mesh elements has been performed. The program will help to determine the type of geology per each element generated in the river basin. To determine the type of geology for each element are, (a) extract the study area geology from Ethiopian geological map,(b)overlay the extracted geological map into DEM of the study area,(c) generate the path profile for each type of geology as per the polygon, (d)Prepare the data in the mat lab program file format means in dot.dat forms, (e)finally determine the type of geology as per the element in the mesh.

3.12 Boundary conditions

The initial step in any groundwater modeling is the definition of the boundary conditions for the study area. To have a good conceptualization of a hydrologic system in the study area, it is essential to identify and assign system boundaries appropriately. System boundaries are classified in to two: physical boundaries and hydraulic boundaries (Anderson and Woessner, 1992). Physical boundaries of groundwater aquifer systems are formed by the physical presence of an impermeable body of rock or a large body of surface water. Hydraulic boundaries are result of hydrologic conditions, are invisible and they may include groundwater divides and streamlines

To obtain a single solution for the problems that faced in the study area during modeling, in addition to mathematical equations evidence about the physical state of the process is required. This information is supplied by boundary and initial conditions. Boundary conditions are required for steady-state problems (Thomas E. Reilly 2001).

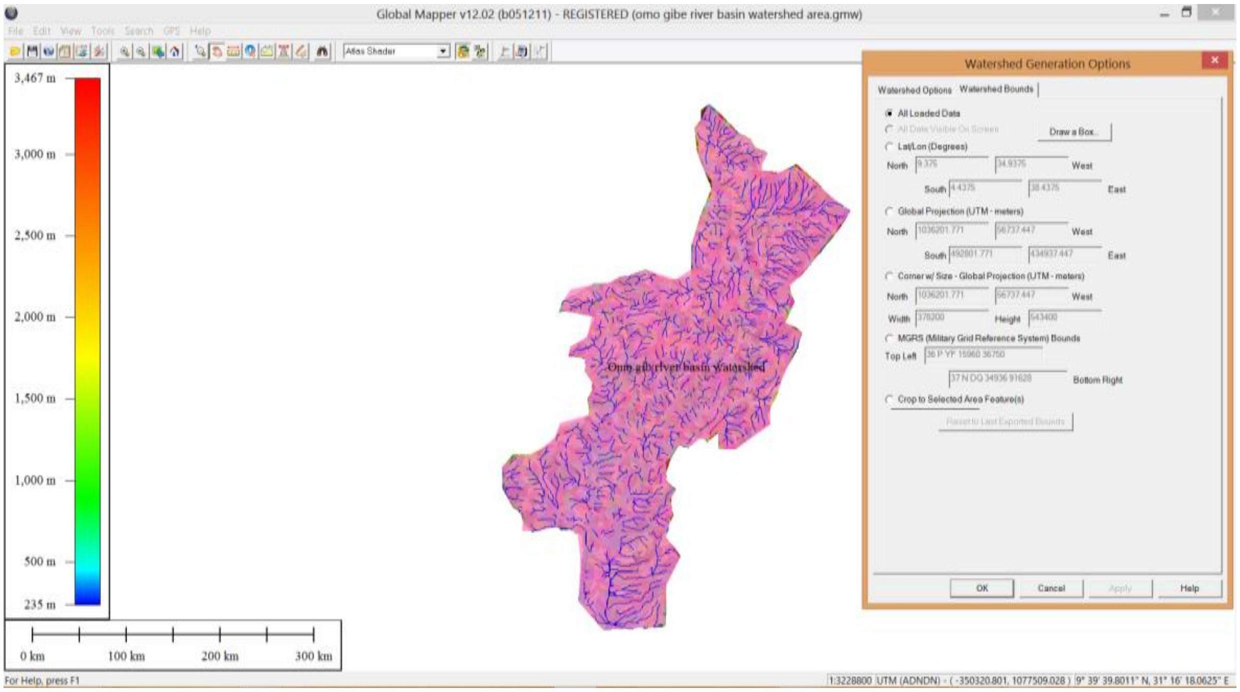
The two most basic types of boundary conditions in flow nets are constant head boundaries and no-flow boundaries. Constant head boundaries occur along the boundary of water bodies like lakes or reservoirs. In a flow net, a constant head boundary has a line of constant head along it and streamlines are perpendicular to it. No-flow boundaries occur at the interface between the aquifer and materials with markedly lower hydraulic conductivity. A no-flow boundary is a streamline and constant head lines are perpendicular to it (Fitts, 2002).

Boundary conditions indicate how an aquifer interacts with the environment outside the groundwater model domain. They include things such as heads at surface waters in contact with the aquifer, the location and discharge rate of a pumping well. For a distinct solution, at least one distinctive boundary condition is specified. There are four types of boundary conditions which are derived from the most common two.

I. Constant Head Boundary: This is a type of specified head boundary condition, in which the head is known and the source of water has a constant water level at the groundwater model boundary. This condition is used in modeling an aquifer that is in good interaction with a lake, river or another external aquifer. These are usually where the groundwater is in direct contact with surface water such as a lake or a river and drains interact freely with the aquifer. It is mathematically known as Dirichlet boundary. In case of study area the following is taken to fix the constant head boundary. To fix the constant head boundary for the study area the following procedures has been done.

3.12.1 Stream generation for the study area

Generation of the watershed of the study area is used to decide the stream network or the waterway in the study area. In addition to this watershed generation is better to define the particular study area and to distinct the study zone catchments. The figure 12 below explains the watershed calculation preview and leads to the streams network generation in the study area, which have a great impact on groundwater modeling to characterize and to assess the groundwater resources potential.



● All Loaded Data
○ All Data Visible On Screen
○ Lat/Lon (Degrees)
North 9.375 34.9375 West
South 4.4375 38.4375 East
○ Global Projection (UTM - meters)
North 1036201.771 56737.447 West
South 492801.771 434937.447 East
○ Corner w/ Size - Global Projection (UTM - meters)
North 1036201.771 56737.447 West
Width 378200 Height 543400
○ MGRS (Military Grid Reference System) Bounds
Top Left 36 P YF 15960 36750
37 N DQ 34936 91628 Bottom Right
○ Crop to Selected Area Feature(s)

1:3228800 UTM (ADNDN) - (-350320.801, 1077509.028) 9° 39' 39.8011" N, 31° 16' 18.0625" E

FIGURE 12 WATERSHED GENERATION FOR THE STUDY AREA

- To generate the long profile of the perennial river in study area. Finite element groundwater modeling entails the waterway border data or the waterway boundary is one of the input constraints for finite element groundwater modeling. The channel boundary head is determined from the river basin, perennial rivers. From the figure 13 below the river watercourse network is taken from the produced watershed of the study area. Each stream network from the figure 13 has its own groundwater contribution during the groundwater modeling. The stream networks are the perennial rivers ,which originates from the groundwater and they have a vital role in the form of the boundary conditions to characterize and to assess the groundwater resources potential

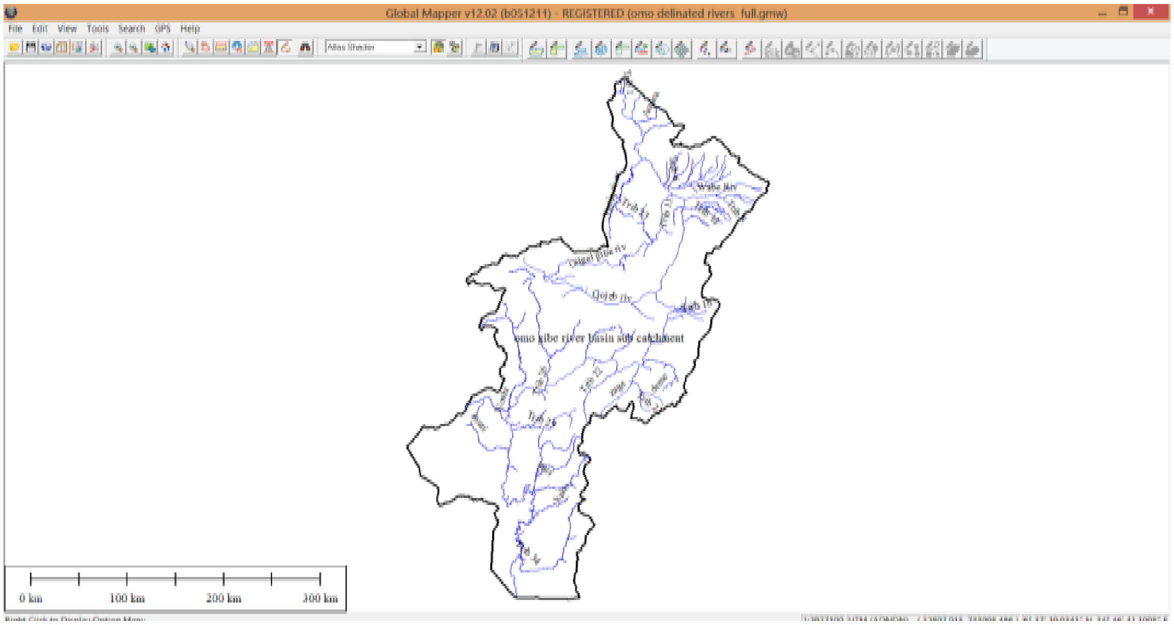
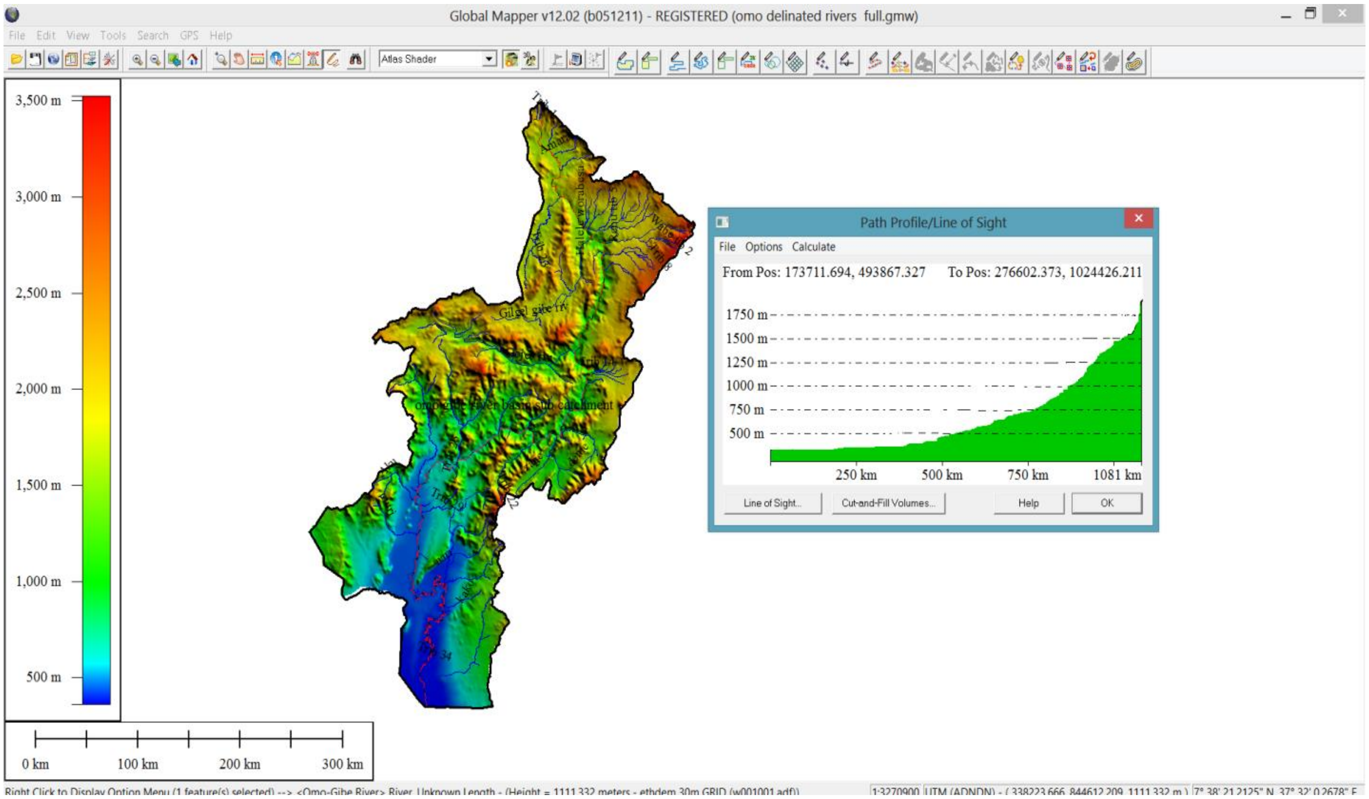


FIGURE 13 STREAM NETWORK IN THE STUDY AREA

The study area has a number of perennial and intermittent rivers/streams/which contributes their water for groundwater occurrence. The major perennial rivers are, Omo, Gibe, Gilgelgibe, Gojeb ,Halele warebesa,Tunjo,Wabe,Wybe and other rivers are present in the study area. All rivers listed above plays a great role in characterization and groundwater potential assessment by finite element groundwater modeling approach. Channel head is input constraints for finite element groundwater modeling, so the head of this river is taken into consideration to conduct the research. To determine the channel head of the model the long profile of each perennial river in the basin is taken and prepared as a modeling input files. The perennial river long profile is taken as shown in the figure 14 to create the constant head boundary conditions for the groundwater model. The figure 14 below shows only the main (Omo and gibe) river long profiles, the other long profiles of the perennial rivers are computed in the same way to preprocess the groundwater modeling inputs.



From Pos: 173711.694, 493867.327 To Pos: 276602.373, 1024426.211

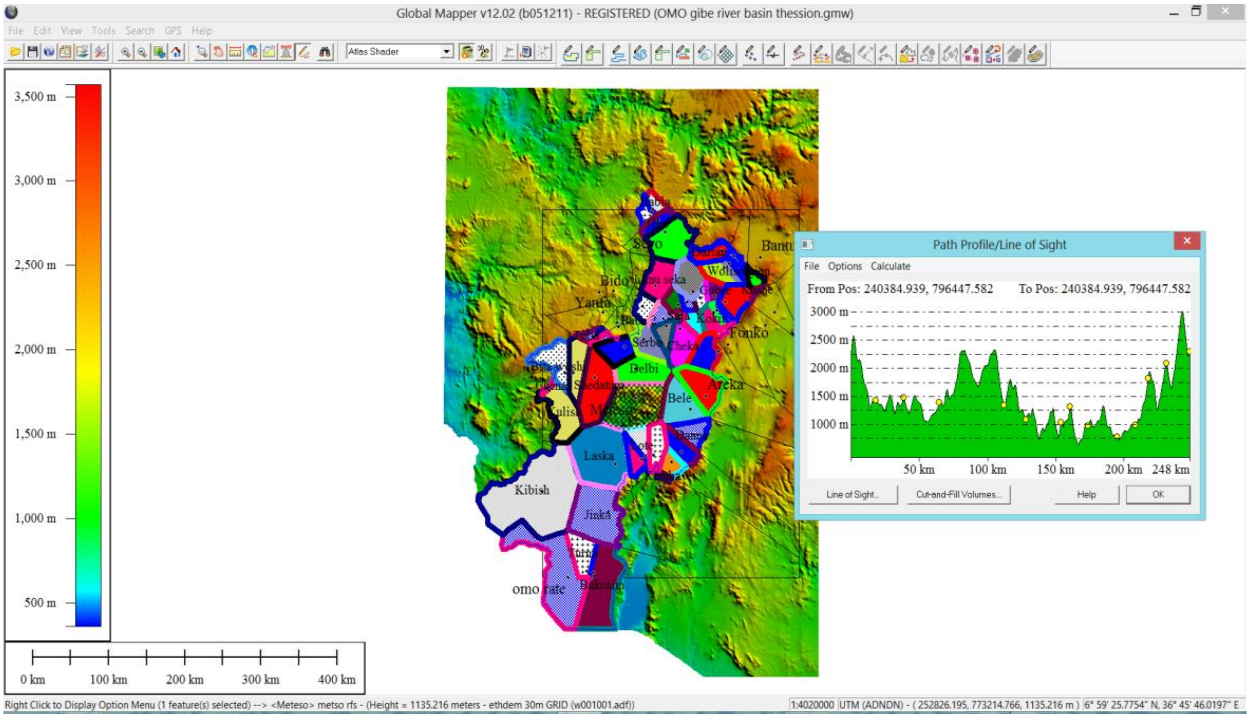
Right Click to Display Option Menu (1 feature(s) selected) --> <Omo-Gibe River> River, Unknown Length - (Height = 1111.332 meters - ethdem 30m GRID (w001001.adf)) 1:3270900 UTM (ADNDN) - (338223.666, 844612.209, 1111.332 m) 7° 38' 21.2125" N, 37° 32' 0.2678" E

FIGURE 14 RIVER LONG PROFILE IN THE STUDY AREA

It furthermore will use to decide the nearest one node for Perennial River and nearest three nodes for the wells by its syntax program near node identification. The channel/rivers/ are the input modeling parameters. The study area has perennial rivers with a greater head, so it is better to take this river head for the study. The node of the river lies out of the nodes of the triangular mesh. The node of the river must lie on to the nearest node of the basin mesh; to do this task the nearest nod application program is used as a tool to solve the problem. The rivers are represented by only one adjacent node in the basin, each node have their own coordinates and elevations.

II. Constant Flux Boundary: This is a type of specified flux boundary condition also known as the second type of boundary condition, and mathematically known as Neumann's condition or recharge boundaries. Entering or leaving the aquifer is prescribed/constant flux. This boundary condition is used in simulating rainfall or distributed discharge for instance evaporation and also used in specifying known recharge to the aquifer owing to induced recharge or reticulation.

To fix the constant flux boundary for study area groundwater model the following head fixing process are done,(a)digitize the coordinates and elevation of each rainfall gauging station on the study area using global mapper digitizer tools menu,(b) the 2nd step use analysis tool bars to construct the thiessen polygon of the study area from point coordinate features of each rainfall gauging stations in the study area,(c)The study area is wide the thiessen polygon may not cover the whole, so extending is the better solution to cover and solve the problem,(d)The rainfall gauging stations are present at the center of each polygon. Next to the construction of the thiessen polygon map, the border profile of each rainfall gauging stations are produced, to determine the combination of the rainfall gauging station id and the node created during the mesh generation for finite element ground water modeling. Figure 15 below shows that the long profile of each rainfall gauging stations created to know the correspondent modeling input node for the study area is specific with node denoted by rainfall gauging stations, so the route profile of each rainfall gauging station should be used.



From Pos: 240384.939, 796447.582 To Pos: 240384.939, 796447.582

Right Click to Display Option Menu (1 feature(s) selected) --> <Meteso> metso rfs - (Height = 1135.216 meters - ethdem 30m GRID (w001001.adf)) 1:4020000 UTM (ADNDN) - (252826.195, 773214.766, 1135.216 m) 6° 59' 25.7754" N, 36° 45' 46.0197" E

FIGURE 15 AREAL RAINFALL GAUGING STATION PATH PROFILE

Since the study area is extensive, to represent this widespread area fifty five rainfall gauging stations are used for this study. The path profile of each gauging stations are generated and used for finite element groundwater modeling to represent each node at a point by rainfall gauging stations. The rainfall data is used to estimate the recharge amount in the study area. The rivers and boreholes are the finite element groundwater modeling input parameters. The boreholes are the drilled water wells which are distributed on all over the study area. The node for each well is not fairly joined with the node of the triangular network generated for study area. For wells three nearest node are selected from the triangular mesh of the study area. The first node is the better than the other two for wells and the second and the third also nodes which are better among the other nodes of the triangular mesh. The discharge is taken from the borehole and the spring from the so to fix the flux boundary, the head of each borehole and the nearest node should be specified.

Using harmonic Fourier serious in mat lab the missing hydro metrological rainfall data of the study area gauge should be filled with, to estimate a groundwater potential from the rainfall recharge or the rainfall is one of the recharge flux boundary in the study area.

The finite element groundwater modeling requires the rainfall data as input parameters. The rainfall data taken from national metrological agency have some missing values. The missing rainfall may happen due to in proper placement of rain gauge stations, instrumental error/measurement failure/ and personal error. To fill this missed rainfall data for data analysis and interpretation, there are some scientific approach to fill the missing values. The scientific approach includes station average method, normal ratio method, and regression approach and harmonic Fourier serious approach. The first there methods are common to fill the missing rainfall values by researchers. Harmonic Fourier’s serious are mathematical approach to fill the missing rainfall values.

$$a0 + \sum_{i}^{\infty} ancos\frac{n\pi}{c} + \sum_{i}^{\infty} bnsin\frac{n\pi}{c} \ldots..3.6 \text{ Harmonic Fourier serious equation.}$$

The harmonic Fourier series in mat lab computer program is used to fill the missing rainfall values. The graph below is developed by harmonic Fourier series application to fill the missing data using mat lab. The graph has the red and blue color (1) the blue represents the measured values of rainfall data taken from the national metrological agency and, (2) the red is the computed value taken from mat lab application to fill missing data. Some of the basic procedures to prepare the rainfall data to fill the missing values are (a) arrange the rainfall data vertically and give identification numbers for the missing and the present rainfall data,(b) put the model file in mat lab file format and preprocessing document,(c) finally run the document and take the missing value to fill.

Compute the harmonic Fourier series mat lab syntax program by changing the iterations to fit the computed and the measured rainfall values and take the exact data to fill and continue the next step of the research. Different computer based programs are written to discretize the groundwater character and potential assessment problems in mat lab software. The followings are some of the computer program application to fix the groundwater problem integrated with mat lab software are, (a) to show the distribution of the calibration well in the study area and to overlay the borehole data into the actual border of the study area, (b) the software will use to determine the rainfall station distribution with the generated mesh node by its syntax program inboundry. m the program will help to determine the type of rainfall pattern per each node generated in the river basin. Fit the rainfall gauging station and the node of the study area to simulate the hydraulic head by considering the recharge from the areal rainfall. The basic groundwater modeling steps for this are (a) digitize the rainfall stations, (b) use analysis tool and construct the thiessen polygon, (c) create areal features for the polygon,(d) generate the path profile of each polygon (e) rearrange the data in the form of mat lab files, (f) Run the program and obtain the data (g) finally the rainfall polygon coordinate and the node of the mesh are taken into the model for final ground water modeling. After the end of running the computer program in mat lab, the node number, coordinates, elevation and rainfall gauging station id is obtained.

III. No flow Boundary (across which no flow occurs): This is a very special type of the prescribed flux boundary and is referred to as no-flux, zero flux, impermeable, reflective or barrier boundary. No flow boundaries are impermeable boundaries that allow zero flux. They are physical or hydrological barriers which inhibit the inflow or outflow of water in the model domain. No flow boundaries are specified either when defining the boundary of the model grid or by setting grid blocks as inactive (i.e hydraulic conductivity = 0). The impervious floors are taken as a no flow boundary for this study. The finite element method can handle all manner of boundary conditions, including no-flow boundaries, specified head boundaries, specified flux boundaries, and leakage boundaries (Fitts, 2002).

3.13 Groundwater modeling protocol

Mathematical groundwater model simulates groundwater flow and/or solute fate and transport indirectly by means of a set of governing equations thought to represent the physical processes that occur in the system (Anderson & Woessner, 1992). This study approaches the problem of understanding the groundwater character and potential in the study area with the actual deterministic and numerical groundwater model which approximates physical law with finite element method by conceptualizing the study area by groundwater model. Numerical models describe the entire groundwater character and groundwater potential in the study area at the same time by providing solutions for as many data points as specified by the user. The area of interest is subdivided into many small areas (usually referred as elements) and a basic groundwater problem equation is selected to solve for every elements in the study area. The solution of a numerical groundwater model is the distribution of hydraulic heads at points representing individual prismatic elements. Similar to most numerical groundwater models, the study area groundwater model developed in this thesis was simulated to study the response of the system to different hypothetical scenarios of geologic materials hydraulic property, recharge or any other parameter under a steady state condition.

Model calibration for the modeler is a means of correcting gaps between the measured head values and simulated values of groundwater levels and the model relays or the measured head to match the simulated. The figure 16 below shows trial and error calibration, which was the first technique to be used and is still the technique preferred by most users (Ne- Zheng, 1994)). It is the process of manual adjustment of input parameters until the model simulated value shows similarities with the measured head and range of error values. Assuming constant recharge and discharge, the model was calibrated under steady state condition. Calibration was conducted with trial and error by varying the hydraulic conductivity of the aquifer system. Trial and error calibration was continued until the result comes in the range of predetermined residual (error) criteria. The hydro geologic map of the study area was divided in to 15 regions hydraulic conductivity zones depending on the previous studies in the study area, and the best fit results were achieved by trying different hydraulic conductivity vales in these different zones with their respective parameters. The figure 16 adapted from (Ne- Zheng, 1994) shows procedure of trial and error calibration process.

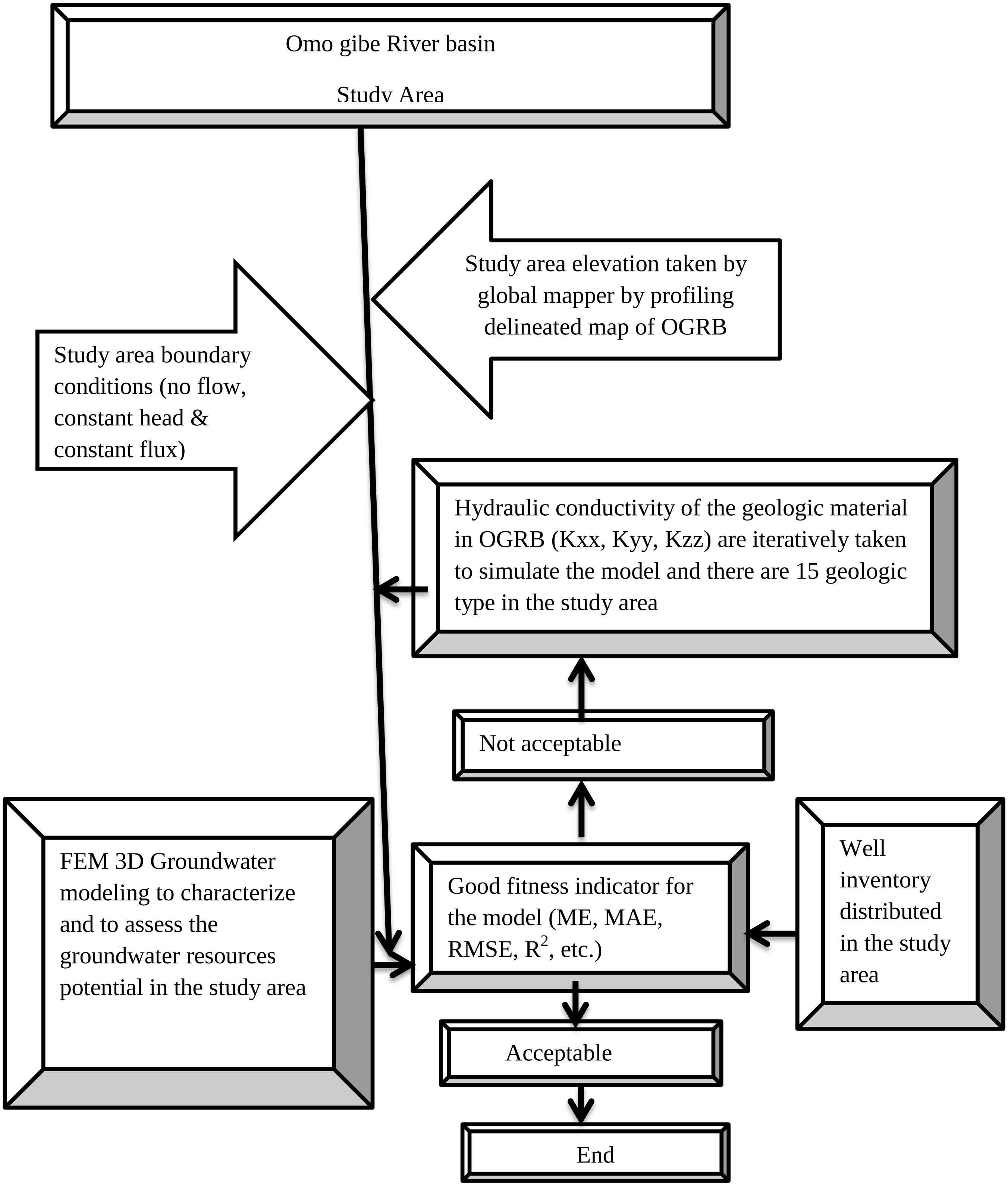


FIGURE 16 TRIAL AND ERROR CALIBRATION PROCEDURE (NE- ZHENG, 1994)

The result of the calibration should be evaluated both qualitatively and quantitatively (Anderson and Woessner 1992). The mean of the observed and simulated head differences was used to quantify the average error in the calibration process. The differences between measured (hm) and simulated heads (hs) respectively can be expressed by the mean error (ME) and the root of mean square error (RMSE). The objective of calibration is to minimize these error estimates.

$$\mathrm{ME}=\frac{1}{n}\sum_{i=1}^{n}(h_m-h_s)_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{3.7}$$

The MAE measures the average magnitude of the errors in a set of forecasts, without considering their direction. The root mean square (RMSE) error is the square root of the average of the squared differences between measured heads and simulated heads:

$$\mathrm{MAE}=\frac{1}{n}\sum_{i=1}^{n}|(h_m-h_s)_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3.8$$

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

$$\mathrm{RMSE}=\left(\frac{1}{n}\sum_{i=1}^{n}(h_m-h_s)_i{}^2\right)^{0.5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{3.9}$$

4.0 RESULT AND DISCUSSION

The purpose of the groundwater model is to characterize and assess the groundwater resources potential in the study area by simulating the node, element, borehole, rainfall records and geology (material properties) of the study area at each prismatic triangular element.

Finite Element numerical groundwater models (TAGSAC in mat lab) is one of the most important predictive tools available for assessing and characterizing groundwater resources potential in the study area. These models can be used to estimate hydraulic parameters (surface node hydraulic head and bottom node hydraulic heads), by using the iterative hydraulic conductivity value for each geological materials in the study area. Finite element numerical groundwater modeling (TAGSAC in mat lab) aids to have a good sympathetic of the present-day or to predict the long term tendencies of a groundwater character ,potential and it permits analysis of the movement of groundwater through hydro geologic unit that constitute the groundwater aquifer system.

The situation is compulsory to have good initial data on boundary conditions, fluxes and parameters for a groundwater model to give simulation out put that approaches the real situation. In other words, models can only be good if the input data is good enough. Especially, input parameters that have the most control on the model output have to be carefully investigated and correctly estimated. In this study, a shortage of standard, well inventories and metrological data have been encountered in some parts of the catchment to have good estimates of these parameters but collection and assemblage of relevant metrological and well inventories data has been made.

In recent years finite element numerical (TAGSAC in mat lab) groundwater modeling has become a major part of projects dealing with groundwater exploitation, potential assessment and characterization and it is the most useful tool to study the character of a groundwater resources system to any hypothetical scenario or to forecast groundwater potential. Finite element numerical groundwater models describe the total flow arena of interest at the same time providing solutions for as many data points as specified by the user. The area of interest is subdivided into many small areas (usually referred to triangular elements) and a basic groundwater potential equation is selected to solve for each triangular elements. The solution of a finite element numerical groundwater model is the distribution of hydraulic heads at nodes representing individual triangular elements.

Analogous to most Finite element numerical groundwater potential models, the study area groundwater model developed in this thesis was to study the groundwater resources potential and characterizing groundwater system to different hypothetical scenarios of recharge or any other parameter under a steady state condition.

A TAGSAC in mat lab program is used to facilitate finite element modeling to estimate the groundwater character and to assess the groundwater resources potential, thus the complex aquifer geometry and irregularly distributed aquifer system can be modeled easily. The complex arrangements of nodes and elements and other model input parameter values are represented by TAGSAC in mat lab program to provide input for the character and potential assessment groundwater model.

The study area groundwater characterization and potential assessment has been done to determine the surface node hydraulic head and the bottom node hydraulic head and the recharge volume of groundwater for every element in the study area or element in the mesh generated for the study area. Using the total node hydraulic head and the area of each element in the basin, the existed saturated groundwater potential can be estimated. The mesh generated for the study area has a total element of twenty one thousand five hundred four (21504) and a total number of node twenty two thousand seven hundred ninety two (22792).The hydraulic head at each node is average (head at the surface node and head at the bottom node) become average to determine the volume of water existed annually. The study was conducted for steady state condition; it obeys the Darcy groundwater flow principle. The result shows that there is variation of hydraulic head in the study area. This variation of hydraulic head is due to the topographic conditions of the study area, the geologic formations and the total rainfall available annually in the study area.

The equivalent porous medium approach followed to develop finite element numerical groundwater modeling includes definition of system boundaries, compilation and examination of previously investigated geological and hydro geological conditions in the study area to determine the hydraulic conductivity, compilation of well water level data , selection of an appropriate computer code (TAGSAC in mat lab),governing equation for simulation, calibration of calculated hydraulic heads /fluxes and simulation under different scenarios to understand the response of the groundwater aquifer system. The underlying concept of the equivalent porous medium approach used was that an understanding of related basic principles and an accurate description of the specific groundwater potential system under study will enable an accurate qualitative and quantitative description of the groundwater characterization and groundwater potential assessment respectively. This qualitative and quantitative description of the groundwater character and potential allows one to understand the response of the groundwater aquifer system in the study area under consideration to any proposed scenario or to make predictions for any defined set of conditions.

TAGSAC in mat lab program is used to display computed all node hydraulic heads at each node and the calibration error at each borehole. The computer program simplifies the complex geologic and hydro geologic system in the study area by using simple and reliable mathematical equations. Mostly the partial differential equations are used in relation to solve the complex and complicated groundwater potential assessment and characterization problems. TAGSAC in mat lab simulate different groundwater modeling inputs parameters and gives a satisfactory result to estimate the rechargeable groundwater potential in the study area.

4.1 Model Layer

The study area groundwater potential and character have been done with a model having only one layer thickness of 1500m.The thickness of the model is so much immense, requires additional layer due to great change of the hydraulic properties of rock or soil across a layer .The maximum thickness of the model helps for the study to avoid the leaky aquifer zones. To avoid the layers for this model having maximum model thickness, equivalent porous medium approach technique is applied. Equivalent porous medium approach includes both fracture and porous medium and assumes the same hydraulic properties of the rock and the soil across the layer up to the model thickness.

4.2 Model Input Parameters

The model input consists of element numbers, node incidents (surface node and bottom node of each element in the study area), and annual rainfall records with their corresponding coordinates of each gauging station in the study area, near node of the channel (river head in the study area),boreholes (with their coordinate and the nearest three near nodes from element nodes) and the geological material type of each element in the study area are the basic inputs to run the model and obtain the result. The model input constraint parameters are expressed on by one below.

4.2.1 Nodes

It is the preliminary stage at which groundwater modeling requires to characterize and estimate the groundwater resources potential of the study area. Finite element TAGSAC in mat lab, program matrix processer needs the coordinates, elevations and rainfall gauging stations id to of the study area to start simulation. For this simulation, it was obtained by profiling the study area topographic (DEM) map to get the elevation. The first nodes are taken from the mesh generation output and have only the coordinates of the study area. The second node is taken from the first node and the elevation grid of the study area by interpolation to obtain the elevation. The actual difference between the first node and the second node of the study area is the second nodes have elevation of the study area The third nodes of the study area is generated from the second node by including the bottom node of the study area the bottom node elevation of the study area is obtained from the node2nd.dat files by subtracting the thickness of the model from the top elevation only since the coordinates are the same for bottom and surface nodes. The node2nd.dat files have only the surface node of the study area. Node3rd.dat files contain the coordinates of each node, elevation at each node (surface and bottom node elevation) the rainfall gauging stations id distributed all over the study area. Each triangular element in the study area is represented by six nodes, the nodal rainfall is considered during the simulation of the model.

4.2.2 Elements

It is the Second groundwater modeling constraints to characterize and estimate the groundwater resources potential in the study area. The element 3rd.dat files are booked from element1st 2, which was obtained from the study area mesh. The simulated study area mesh has only the surface node elements. To determine the bottom elements the study area, the surface flux number is added to each individual surface element number. The dimensions of each element are decided to be 3km by 3km by considering the wideness of the study area. The total number of element that represent the study area is twenty one thousand five hundred four taken from mat lab output during mesh generation for the study area., the element from mat lab syntax is only the surface element, to get the bottom element number the surface node number is added. The surface node of the study area is eleven thousand three hundred ninety six (11396); this value should be added to the surface element to obtain the bottom element of the study area.

4.2.3 Well inventory (boreholes)

It the third groundwater modeling input constraint parameters. The borehole water table depth and coordinates are taken from ministry of water, irrigation and energy. Borehole data contains coordinate of each borehole in the study area, the three nearest node from the finite element mesh of the study area, the actual water table depth and the borehole id. The borehole data also used to calibrate the finite element groundwater model to assess and characterize the groundwater resources potential in the basin. The total numbers of borehole are six hundred three (603) are used to represent the study area for modeling. The boreholes are used to calibrate the FEM groundwater model in the study area. The distribution of the borehole in the study area is shown below in the figure 17. There are 78 boreholes for modeling and most of the inventories are protected spot springs to model the groundwater resources potential in the study area.

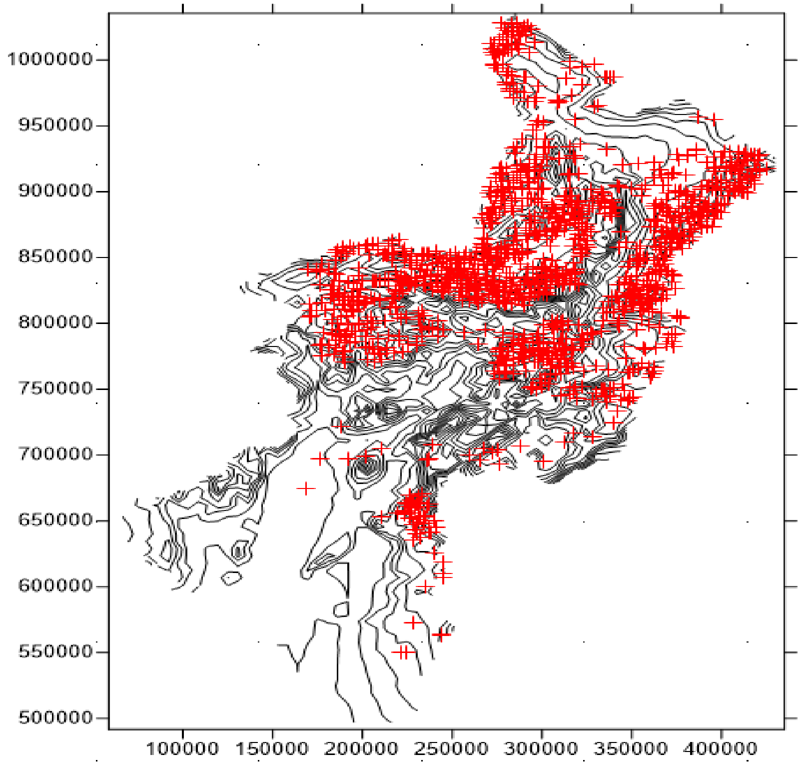


FIGURE 17 GROUNDWATER MODEL CALIBRATION WELL DISTRIBUTION IN THE STUDY AREA

4.2.4 Constant heads (channel head boundary)

This is another modeling input parameter, which is taken from the rivers, which is present in the study area by near nodding to the finite element mesh node in the study area using mat lab syntax program. The perennial rivers are considered during competition of nodes as they give the water to the basin throughout the year.one thousand one hundred sixty two (1162) near nodes are represent the constant head boundary of rivers in the study area. The elevation of the river is adjusted with the node of the element to avoid the error.

4.2.5 Omo gibe river basin geology (Material types)

The study area groundwater potential can be assessed and characterized by the geology or the type of soils and rocks, which is available in the study area. The geology of the study area is one of the constraint modeling input parameters for this study, so detailed assessment and information about the geology of the study area is conducted. The geology of the study area is fifteen (15) types and each type of geology is preprocessed before they become modeling inputs. The geology is the main constraint during the characterization and potential assessment, to get the exact hydraulic conductivity and porosity of the geologic material. Simulation of the model is conducted by changing the hydraulic conductivity of each Fifteen (15) type of geology to obtain the surface node hydraulic head, all node hydraulic head at steady state conditions and the calibration result of the model with the integration of the boreholes.

4.2.6 Rainfall distribution (Recharge inputs)

Rainfall is one of the six constraint modeling input parameters which contribute a lot recharge for the groundwater in the study area. To know the weighted average areal rainfall distribution in the study area the collected rainfall data from the National Meteorological Service Agency (NMSA) is analyzed by thiessen polygon method. From NMSA fifty five (55) metrological stations in the OGRB and out of the OGRB but, very close to OGRB which have full record except some daily missing recordings have been taken for model, which characterize and assess the groundwater resources potential in OGRB. The daily rainfall data of these selected stations are pre analyzed (missed data are filled, and averaged to its monthly and yearly) and analyzed using the selected method to know and use in the model to estimate or use as surface recharge of the aquifer.

Thiessen polygon method attempts to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge. The stations are plotted on a base map and are connected by straight lines. Perpendicular bisectors are drawn to the straight lines, joining adjacent stations to form polygons, known as thiessen polygons. Each polygon area is assumed to be influenced by the rain gauge station inside it, i.e., if P_1, P_2, $P_{3,}$ ... P_n are the rainfalls at the individual stations, and A_1, A_2, A_3, ... A_n are the areas of the polygons surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by;

$$\mathbf{P_{ave}} = \frac{\sum \mathbf{A_i p_i}}{\sum \mathbf{A_i}}$$

Where, P_i mean annual rainfalls recorded at each rain gauge stations, P_{av} Average aerial depth of rainfall of the basin and $\sum A_i = A$ Total area of the basin under concern. (Ragunath, 2006)

The figure 18 shown below is the thession polygon developed for the study area, in order to determine the areal rainfall distribution on the modeling area. To constructed thiessen polygon as shown in the figure 18 is developed using the rainfall gauging stations coordinate in UTM and elevation. The coordinate of each rainfall gauging station is digitized on the Global mapper, and using Global mapper analysis tool the polygon developed. There are some areas out of the rainfall gauging stations ,so this stations areal rainfall distribution were estimated by using the nearest rainfall gauging station and include the area of the ungagged using Global mapper area development tools.

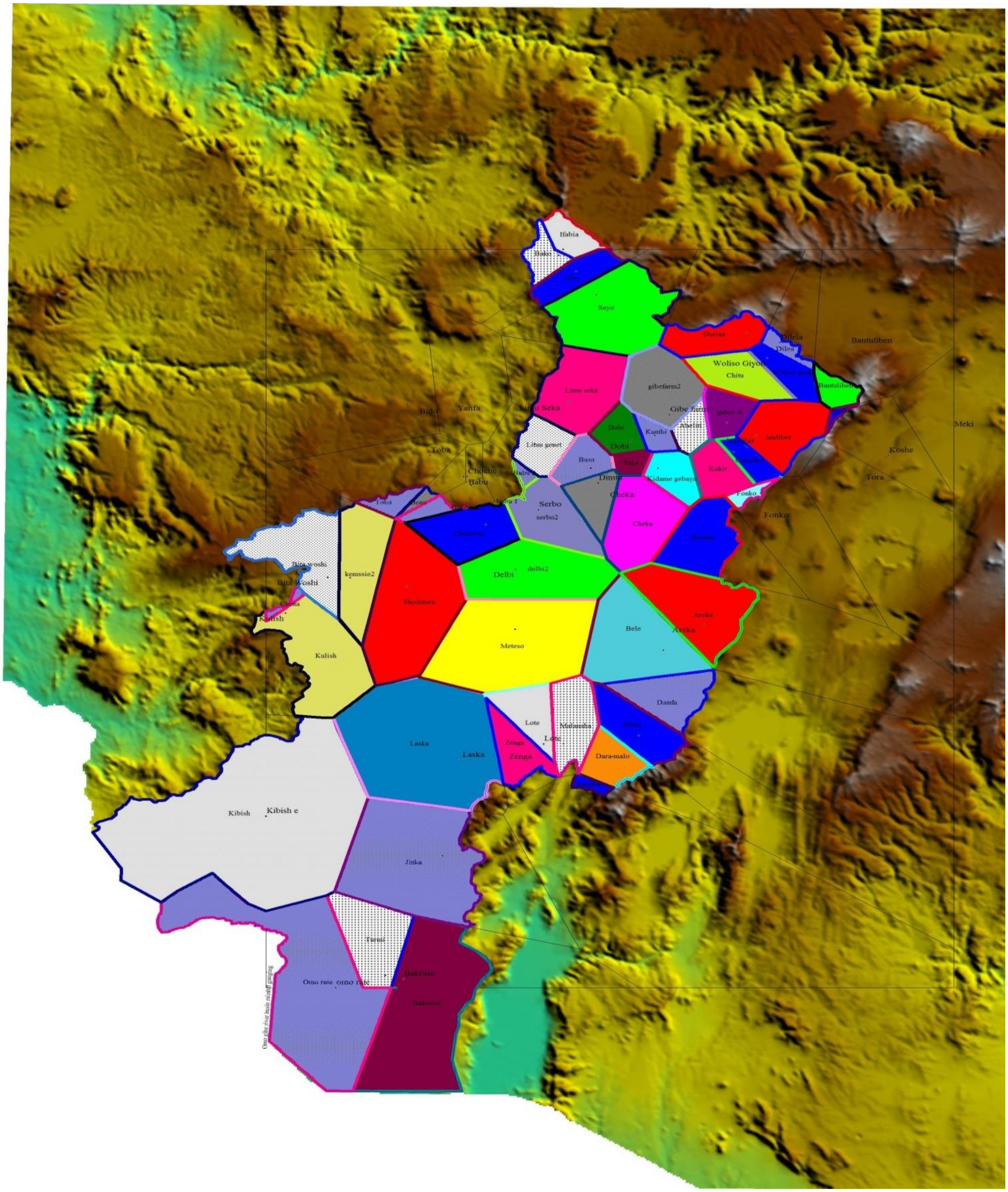


FIGURE 18 CONSTRUCTED THIESSEN POLYGON FOR THE STUDY AREA

Built up on the methods and the availability of the above listed model input parameters, the type model has been selected to solve the complicated and sophisticated groundwater character and potential assessment problem by considering the problem domains and objectives of the research, all the above necessary model input parameters are prepared as per the requirements of the FEM groundwater model (TAGSAC in mat lab) program to simulate hydraulic head, the total annual and the monthly average groundwater volume of the particular study area.

4.3 Groundwater Aquifer geometry

The study area aquifer is selected in a way that to be bounded by the perennial rivers (omo,gibe,gilgelgibe,tunjo,gojeb,zegna,soke,wabe,weybo,alenga,halelewrabesa and others) which are present in the study area. For the steady state groundwater modeling the surface nodes near to the perennial rivers is taken as constant-head boundary conditions. The longitudinal profile of the perennial rivers is taken from DEM to represent the surface water level. The bottom nodes (near nodes) of the generated mesh for the study area were also simulated as no-flow boundaries. The thickness of the model is 1.5 kilo meters away from the ground surface vertically downward, the nodes 1.5 kilo meters below the ground surface are considered as no flow boundary and the nodes at the surface are recharge boundaries.

4.4 Hydraulic head

The hydraulic head is the elevation to which water will naturally rise in a groundwater aquifer/reservoir due to the recharge of rain fall and other subsurface groundwater flow from one region to the other region, which have the groundwater head difference between the two aquifer systems. In another case the hydraulic head is the rise of water table in the well field, or the point at which the groundwater table is located vertically downward from the actual ground surface. This study entails us about the simulation of the hydraulic head of the study area at each node under steady state groundwater conditions to characterize and to estimate the groundwater potential of the whole study area by considering the precipitations. The study area hydraulic head is simulated from the actual surface and bottom node elevation of the study area, the element generated from the study area by using the generated topographic coordinate, the perennial river constant head boundary which is present in the study area, the rainfall which is precipitations, the borehole (the well inventory) data which is drilled for different purpose in the basin and the geology of the study area.

The hydraulic head in every node in the mesh generated for this study is simulated by changing the geologic material type (iterative hydraulic conductivity value) and by taking 20% of recharge from annual average and monthly average precipitation

Initially the study area surface node elevation is known and the bottom node elevation is taken by subtracting the model thickness from actual surface node elevation which is obtain by interpolating the elevation grid of the study area and the node having only coordinates.

The total number of node in the generated mesh is twenty two thousand seven hundred ninety two (22792).For all the nodes in the study area mesh the hydraulic head is simulated by changing the model sensitive parameters to obtain the a satisfactory modeling result to achieve the goal of this research

The prismatic triangular element contains six nodes means (the surface three nodes and the bottom three nodes) are present, so to determine the total volume of the groundwater which is present in each element is not sophisticated after simulating the average hydraulic head at each six nodes of triangular prismatic element.

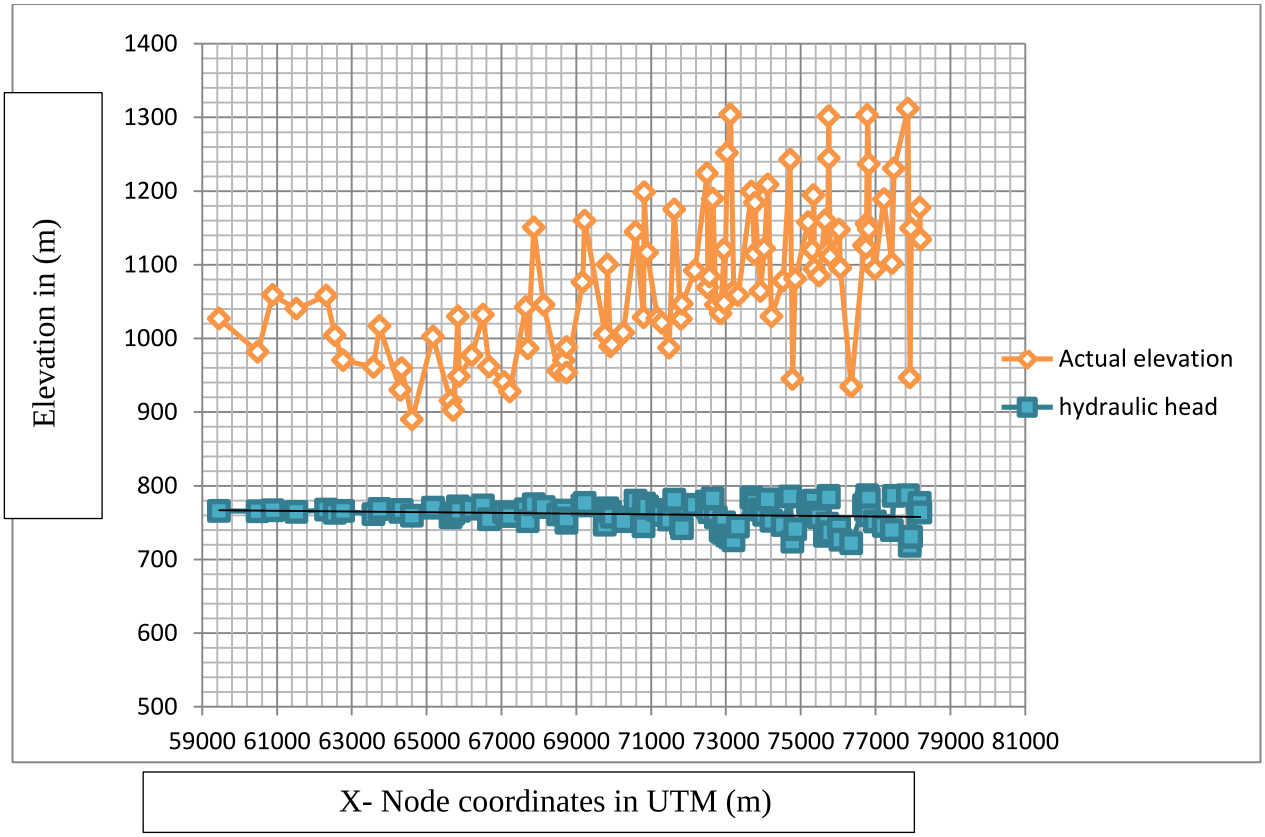


FIGURE 19 SAMPLE HYDRAULIC HEAD AND ACTUAL GROUND ELEVATION IN THE STUDY AREA

4.5 Model calibration and results

Model is systematic representation of the real world, since the representation of the real world in a systematic way always may not be certain or sometimes it is not error free. Model is essential to study hard science and to simplify complex and sophisticated problems which are impossible to solve manually and traditionally.

Groundwater characterization and groundwater potential assessment is hard and complex problem findings due to the variation of the hydraulic parameters across a geologic layer, irregular and complex rugged topography of the study area, shortage and scarcity of essential research input data to study without model leads this research to use finite element numerical mathematical (mat lab TAGSAC) program is used to model the widespread study area to find characteristics of the groundwater flow system and to assess the groundwater resources potential for further groundwater resources development project in the basin at large.

Calibration of groundwater model is the way to compute the error between the actual measured data taken from the study area and the computed hydraulic head generated by the finite element numerical groundwater modeling (TAGSAC in Mat lab) computer program technique to characterize and to assess the groundwater resources potential in the whole basin

Calibration of a groundwater model refers to a demonstration that the model is capable of producing field measured heads and flows which are the calibration values (Anderson and Woessner, 1992). It involves adjustment and refinement of parameter structure and parameter values to provide the best match between measured and simulated values of hydraulic heads. Calibration is carried out to demonstrate that the calibrated model can reproduce measured heads or fluxes, and groundwater potential modeling is usually intended to produce a model that can accurately simulate future condition for which no head data are available. Therefore, to make good forecasts and to understand groundwater potential and character, model calibration was done to acceptable error range by taking realities in the area in to considerations.

Calibration is the process of modifying model parameters (material properties or geology of the study area and boundary conditions) up to:-

- The model is consistent with the analyst's understanding of the groundwater flow system and with all available data, and
- Computed values of hydraulic head closely contest measured values at selected points in the aquifer (locations of wells and springs).

The technique is basically an exercise in trial and miscalculation where an acceptable set of model parameters are suggested, calculated and measured values of hydraulic heads are compared, and model parameters are adjusted to improve the fit (Istok, 1989). A groundwater character and potential model is considered calibrated when it can replicate, to a tolerable degree, the hydraulic heads of the natural system being modeled.

Basically, calibration can be achieved in two ways. That are, the forward and inverse problem solutions. In an inverse solution method one determines values for a given parameter structure and hydrologic stress using a mathematical technique, such as nonlinear regression from information about head distribution (Anderson and Woessner, 1992). This technique is sometimes called parameter estimation & it finds the set of parameter values that minimize the difference between simulated and measured quantities such as hydraulic heads; where as in the forward problem system parameters such as hydraulic conductivity and hydrologic stresses are specified and the model calculates the head distribution.

The model used for this study is calibrated by forward problem system parameter means (the iterative hydraulic conductivity and the flux specified initially and apply root mean square (RMSE) to calibrate the actual and the computed hydraulic head distribution across the study area. Mode calibration was performed by the TAGSAC in mat lab program by mathematical and scientific way to reduce the error between the actual and the computed/simulated hydraulic head/ by adjusting model input parameters which affect the simulated hydraulic head within reasonable limits of the existing secondary well inventories data. To reach a best model fit for the study area available rainfall recharge was used as a control during calibration of the model to bring a change at the hydraulic head distribution by lowering and raising the water level. Calibration methods solve a problem inversely by iteratively adjusting the unknowns up to the solution matches the hydraulic heads.

Normally, thousands of iterations are made to attain a satisfactory calibration result for study area groundwater model. Usually, the inputs to be attuned are hydraulic conductivity of each geologic material type and the amount of recharge in percent, which are distributed all over the study area.

The model used for this study is calibrated by forward problem system parameter means manual trial-and-error calibration processes are used to obtain a good and acceptable calibration result. The following procedures are used to calibrate groundwater character and potential model:-

- Developing groundwater model and set the boundary conditions and fluxes in the study area.
- Classifying the model input parameters to be used for model calibration to get a tolerable and acceptable calibration result.
- Identify the locations and values for the target points forming the calibration set. Groundwater flow models are usually calibrated to a set of observed potentiometric head levels.
- Iteratively run the groundwater modeling software (TAGSAC in Mat lab) program and correct input parameters, the hydraulic conductivity for each geologic zone and surface recharge, up to an acceptable match between observed and calculated values at the target points is attained. In the meantime the model is calibrated for a set of observed head values; the computed and predictable boundary fluxes are compared.

The study area groundwater model was calibrated to steady state condition of heads generated for the whole basin by global mapper. Channel head observations for calibration of different tributary and main Omo Gibe River, groundwater model consisted of water level measurements data for 603 wells, fairly distributed in the study area. In addition to this the calibration is undertaken by considering the node, channel head, annual areal rainfall recharge, element and the geologic material which is present in the study area .Different factors affect the model calibration result, trial and-error adjustment may become a highly individual and inefficient procedure. So to obtain acceptable calibration result pessimistic way of automated calibration is used in combination with manual trial and error method. This method operates with an objective function, such as minimization of the incorrect well inventory records' which was taken from concerning groundwater development organizations and relate to the node head(residuals) and pessimistically estimate the actual hydraulic conductivity value for geologic material in the study area from standards or pervious literature. Automated calibration methods have some potential advantages over trial-and-error methods. They can provide a systematic approach to calibration, allowing for efficiencies within individual modeling jobs and a basis for comparison between different modeling jobs. Statistical measurements are available from some automated approaches that are not usually performed in trial-and error approaches. In the model hydraulic head is computed for the model basins by varying the hydraulic conductivity for the fifteen geologic zones of the study area and the surface recharge from the rainfall. After several trial and error works selection of a set of hydraulic parameters and recharge for the model developed in the study area should be set. The following parameter values are selected as the best among other combinations for groundwater model. The table 4 below shows the simulated hydraulic conductivity value to predict the groundwater hydraulic head and characterization has been done by this hydraulic conductivity value.

TABLE 4 HYDRAULIC CONDUCTIVITY OF THE GEOLOGIC MEDIUM IN THE STUDY AREA

Basin	Geologic number	K_{XX} (m/s)	K_{YY} (m/s)	K_{ZZ} (m/s)	Surface recharge %
Omo Gibe River Basin	1	0.1296	0.0864	0.0864	20
	2	0.1296	0.01728	0.10368	20
	3	0.10368	0.0864	0.09504	20
	4	0.1296	0.01728	0.0864	20
	5	0.07776	0.02592	0.10368	20
	6	0.11232	0.07776	0.10368	20
	7	0.05184	0.0432	0.06912	20
	8	0.0864	0.07776	0.06912	20
	9	0.09504	0.03456	0.0432	20
	10	0.11232	0.06912	0.07776	20
	11	0.10368	0.02592	0.0432	20
	12	0.11232	0.0864	0.11232	20
	13	0.1296	0.06912	0.0864	20
	14	0.00864	0.00864	0.00864	20
	15	0.1296	0.09504	0.07776	20

Measurements values are plotted with the values simulated or computed by the groundwater model. In an ultimate calibration, the points will fall on a straight line with a 45 degree slope; i.e., the simulated run computed value equals the measured value. The degree of scatter about this theoretical line is a measure of overall calibration quality (Anderson & Woessner, 1992). The best fit equation obtained between the modeled and measured hydraulic head are made for the study area.

The correlation coefficient (R^2) value compares estimated and measured hydraulic head, and the value ranges from 0 to 1. If it is 1, there is a perfect correlation in the between the modeled and measured values or there is no difference between the estimated and measured values.

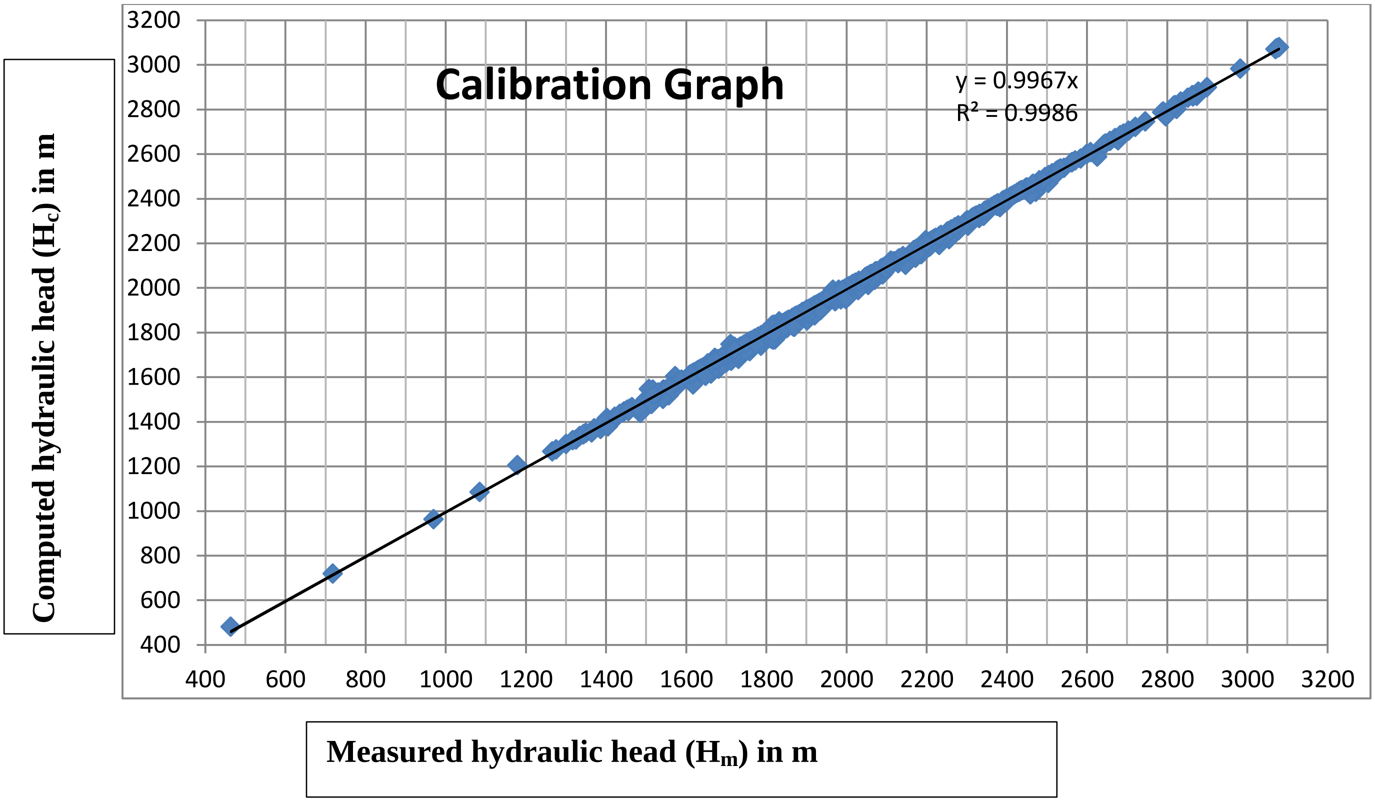


FIGURE 20 PLOT (REGRESSION GRAPH) OF MEASURED HEAD VERSUS MODELED HEAD FOR STUDY AREA

Calibration results are evaluated by using qualitative and quantitative performance measures. Qualitative assessment (pattern matching) involves comparisons of contour maps and hydrograph of measured and simulated head, while quantitative performance measure involves mathematical or statistical description of residuals. The primary calibration target in groundwater modeling is hydraulic head (water level). Accordingly, in this study, steady-state calibration was made using static water level observations of 603 wells in the study area fairly distributed. The effectiveness of calibration was evaluated by visual matching of measured groundwater level contours and lumped quantitative performance measures such as the mean error, the mean absolute error, and the root mean square error are done. The mean error (ME) is the mean of the differences between measured heads (h_m) and simulated heads (h_s):

$$ME=\frac{1}{n}\sum_{i=1}^{n}(h_m-h_s)_i \qquad 4.1$$

Where h_m and h_s are measured and simulated results and n is the number of data. Because both positive and negative residuals are resulted in the calculation, this value should be close to zero for a good calibration. In other words, the positive and negative errors should balance each other. The mean absolute error (MAE) is the mean of the absolute value of the differences between measured heads and simulated heads:

$$\mathrm{MAE}=\frac{1}{n}\sum_{i=1}^{n}|(h_m-h_s)_i| \qquad 4.2$$

The MAE measures the average magnitude of the errors in a set of forecasts, without considering their direction. The root mean square (RMSE) error is the square root of the average of the squared differences between measured heads and simulated heads:

$$\mathrm{RMSE}=\left(\frac{1}{n}\sum_{i=1}^{n}(h_m-h_s)_i^{2}\right)^{0.5} \qquad 4.3$$

The RMSE is used as the basic measure of calibration for heads. Uncertainty in head measurements can be the result of many factors including, measurement error, scale errors, and various types of averaging errors, and accuracy of GPS in use both spatial and temporal. The maximum acceptable value of calibration criterion depends on the magnitude of the change in head over the problem domain. As a general calibration criteria RMSE equal to or less than 10 percent of the observed head range in the aquifer being simulated is better (Anderson & Woessner, 1992). The mean error (ME) and the mean absolute error (MAE) are characterized by low values indicating that the model was well calibrated. The value of the correlation coefficient (R^2) indicates a good performance of the model. But due to the accuracy of GPS and the element dimensions in use RMSE slightly greater than 10 are taken as acceptable errors.

TABLE 5 CALIBRATION ERRORS SUMMARY

Modeled study area	Mean error (ME)	Mean Absolute Error (MAE)	Root Mean Square Error (RMSE)	Correlation coefficient (R^2)
Omo gibe river basin	6.559	7.815649	15.0096	0.9986

4.6 Groundwater potential in the study area

The rechargeable groundwater potential in the study area is estimated by doing the volume of water in every element in the study area and by considering the annual and monthly precipitation of the study area which were recorded by fifty five (55) rainfall gauging stations as a recharge to get the groundwater table (hydraulic head) variation due to the recharge. The recharge value is taken by considering the standard as 20% from the total rainfall for each annual rainfall and monthly average rainfall for twenty years recorded by the fifty five rainfall gauging stations. The recharge is used to simulate the hydraulic head the next sequence is determining the actual area of each triangular prismatic element and averaging the hydraulic head which is present at the six nodes and estimate the saturated recharged volume of groundwater per annual in the saturated zone of aquifer in the study area.

The actual groundwater potential due to recharge is taken by multiplying the saturated recharge groundwater potential with the porosity of the geologic material in the triangular prismatic element in the study area.

The porosity of each geological material is taken from the porosity and hydraulic conductivity standard for different types of rocks and soil materials. The surface triangular element is shown below

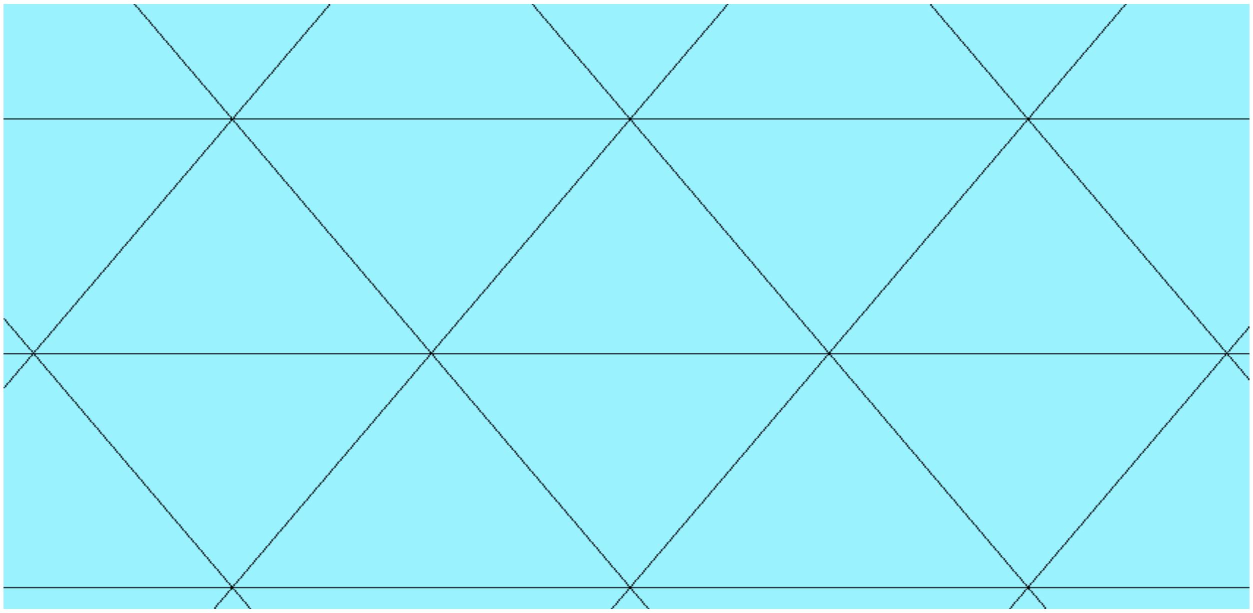


FIGURE 21 THE SURFACE TRIANGULAR ELEMENT OF THE STUDY AREA

At the beginning one prismatic triangular element has six nodes and the triangular element at the surface has three nodes and the triangular prismatic element has its own coordinates (x, y and elevation) so to determine the area of each element is as follows:-

X_1= x coordinate for the first node of one triangular element

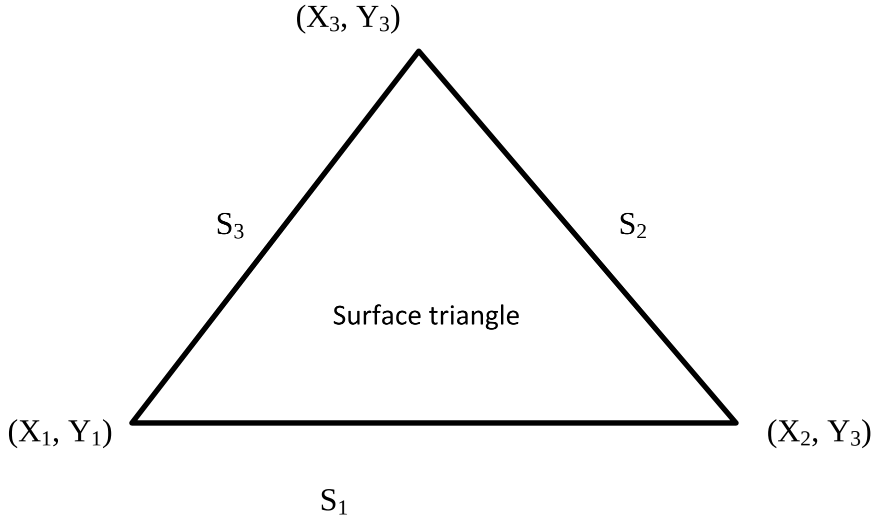
X_2= x coordinate for the second node of one triangular element

X_3=x coordinate for the third node of one triangular element

Y_1=y coordinates for the first node of one triangular element

Y_2=y coordinates for the second node of one triangular element

Y_3=y coordinates for the third node of one triangular element.



S_1 =the distance between the first and the second node of one triangular element

$S_1 =\sqrt{((X2-X1)^2+(Y2-Y1)^2)}$ S_1= the first side of the triangle

S_2 = the distance between the second and the third node of one triangular element

$S_2 =\sqrt{((X3-X2)^2+(Y3-Y2)^2)}$ S_2 =the second side of the triangle

S_3= the distance between the first and the third node of one triangular element

$S_3 =\sqrt{((X3-X1)^2+(Y3-Y1)^2)}$ S_3 = the third side of the triangle

Perimeter of the triangle

$S = (S_1+ S_2 + S_3) /2$

Area of the triangle by side triangle mathematical postulate

A= $\sqrt{}(S * (S - S1) * (S - S2) * (S - S3))$

Then after the total rechargeable volume of groundwater from the precipitation for the whole saturated aquifer zone in the study area is estimated as follows

Total Saturated volume = area of each triangular prismatic element * the average hydraulic head of the six node of triangular prismatic element

V_t =A * He A = area of each triangular element in the mesh

He =average hydraulic head at steady state conditions.

$V_t = \left(\sqrt{S * (S - S1) * (S - S2) * (S - S3)}\right) * \mathrm{He}$

The volume is the total volume in the saturated zone, since in the saturated zone of the aquifer there is a geologic materials having avoid space to pass the groundwater from one layer to another geologic layer either horizontally or vertically. The above volume is not the actual volume of groundwater present in the aquifer system.

To get the actual rechargeable groundwater potential in the study area the hydraulic properties of the soil or the rock in general the geologic media must be known. The final rechargeable groundwater potential is taken by multiplying the total groundwater volume in a saturated aquifer by the porosity of the geologic medium. The porosity of the geologic medium of the study area is taken from different literatures and standard porosity manuals by relating and grouping our study area geology into the standard that is taken from different research literatures and manuals. The actual rechargeable groundwater potential in the study area is taken in the following manner.

V_w = total rechargeable groundwater potential in a saturated zone of aquifer in the study area * the porosity of each geologic medium type of the particular triangular prismatic element

V_w = Vt *ŋ

Where

$V_{w\,=}$ actual rechargeable groundwater volume of the study area

Vt =total rechargeable groundwater volume in the saturated zone of the aquifer ŋ = the porosity of the geologic material in the study area

To avoid estimation error during the determination of the rechargeable groundwater volume in the study area, an average rechargeable groundwater volume is taken. The average groundwater volume is determined in such a way that the rechargeable groundwater potential of the study area by the maximum porosity and the rechargeable groundwater potential by the minimum porosity is taken and average them to get the total rechargeable groundwater potential in the study area. The table below shows the monthly average recharge groundwater potential in the study area, fifty five rainfall gauging station twenty years rainfall records are used for computation.

Annually the total groundwater potential due to the recharge and base flow volume is presented below by the table.

TABLE 6 TOTAL GROUNDWATER VOLUME (BASE VOLUME + RAINFALL RECHARGE)

Basin	Mean annual rainfall	Extent of recharge area in (km^2)	% of rainfall recharging to GW	Total annual recharge (m^3)
Omo gibe river basin	1444	79213	20	4384917320

The total amount of recharge shows that the value is very big compared to the previous studies, because this study takes almost all the rainfall gauging station which are distributed all over in the study area. Additionally this research also uses better inventory data, topographic data and new approach to model the groundwater character and potential of the aquifer system in the study area. This paper also considers the channel boundary means more all perennial rivers are considered during the hydraulic head simulation.

TABLE 7 TOTAL GROUNDWATER BASE FLOW AND RECHARGE VOLUME OF THE STUDY AREA

Month	Groundwater volume in (m^3)		Total groundwater volume
	Recharge volume	Base flow volume	
January	1.8352E+13	4.38E+09	1.84E+13
February	1.8352E+13	4.38E+09	1.84E+13
March	1.8352E+13	4.38E+09	1.84E+13
April	1.8352E+13	4.38E+09	1.84E+13
may	1.8352E+13	4.38E+09	1.84E+13
June	1.8352E+13	4.38E+09	1.84E+13
July	1.8352E+13	4.38E+09	1.84E+13
August	1.8352E+13	4.38E+09	1.84E+13
September	1.8352E+13	4.38E+09	1.84E+13
October	1.8352E+13	4.38E+09	1.84E+13
November	1.8352E+13	4.38E+09	1.84E+13
December	1.8352E+13	4.38E+09	1.84E+13

The amounts of groundwater recharge differ from month to month with the consideration of the amount of precipitation and include the base flow volume. The graph below shows the monthly groundwater recharge, since the study area is very wide and some parts of the (especially north western) of study area lays on the equator, gets more rainfall and the downstream portion is somehow dry compared to the upstream. The figure 22 shows the monthly average groundwater recharge variation the vertical axis plus the minimum recharge volume from the month.

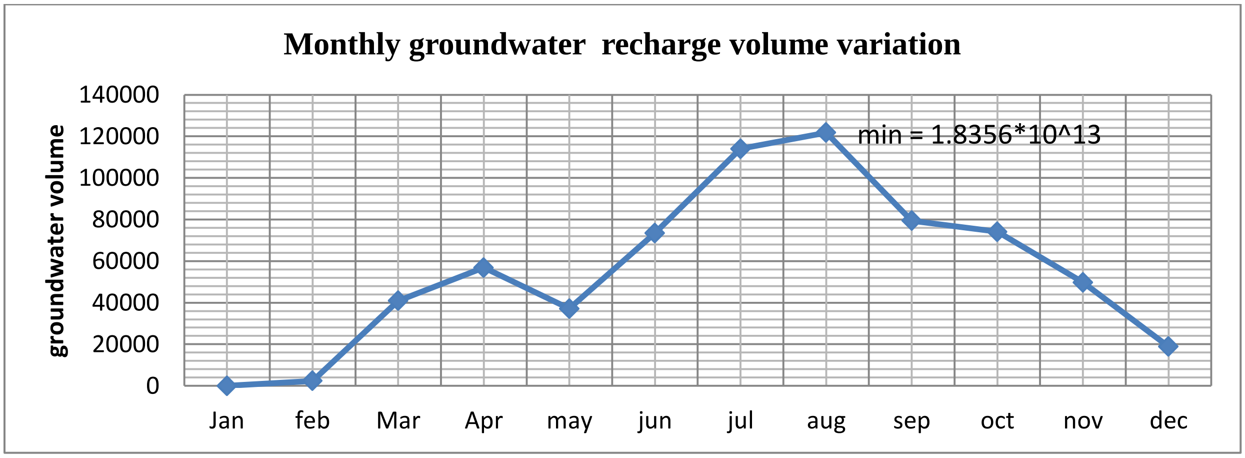


FIGURE 22 MONTHLY AVERAGE GROUNDWATER RECHARGE VARIATION IN THE STUDY AREA

The groundwater potential from recharge vary from time to time, this variation of the groundwater potential is due to scarcity or shortage of rainfall, maximum evaporation, higher runoff due to the absence of forests. This study area is naturally reach and covered with different plant species the infiltration and percolation is very high compared from bare land. Mostly the rainfall is also having a good distribution in the study area; due to this the groundwater potential in the basin is well. The average monthly variation of the groundwater potential from recharge is shown in the table below.

TABLE 8 MONTHLY GROUNDWATER VOLUME FROM RAINFALL RECHARGE

Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	2410.4	40939.5	56812.1	37107.2	73459.5	121819.6	113994.3	79387.6	74066.1	49797.7	18851.3

The groundwater potential variation due to recharge can be shown in the graph below for each month with cumulative recharge variation of the volume. The base flow volume of the neri near jinka gauging station base flow volume is added to estimate the total groundwater potential in the study area, the graph below shows the total groundwater recharge and base flow volume, which is available to implement different groundwater resource development projects. The figure 23 below shows the groundwater resources potential in the study area including the base flow from the river. The base flow volume should be added to the cumulative rechargeable groundwater volume at the end to know the total groundwater volume in the study area.

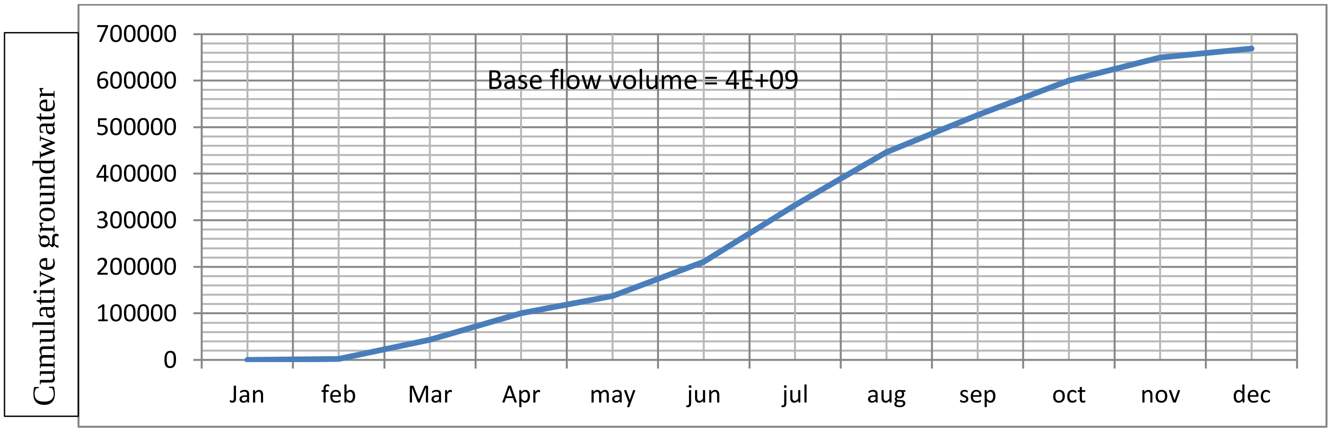


FIGURE 23 TOTAL GROUNDWATER RESOURCES POTENTIAL IN THE STUDY AREA

Groundwater potential characterization means determining the groundwater resources in the study area in depth, location, groundwater flow direction and estimating some hydraulic parameters like(hydraulic conductivity and porosity) of the geologic medium that is present in the study area. Characterization of the groundwater resource potential has been done in this paper. On this research the hydraulic conductivity and porosity of the geologic material in the study area is estimated iteratively during hydraulic head simulation. In addition to the hydraulic parameters the groundwater resources potential from recharge is expressed in volume for characterization of the potential.

The groundwater resources potential flow direction in the study area is determined from the surface node hydraulic head. The figure 24 below shows the groundwater flow direction in the study area and it shows the groundwater potential and the groundwater divide in the study area.

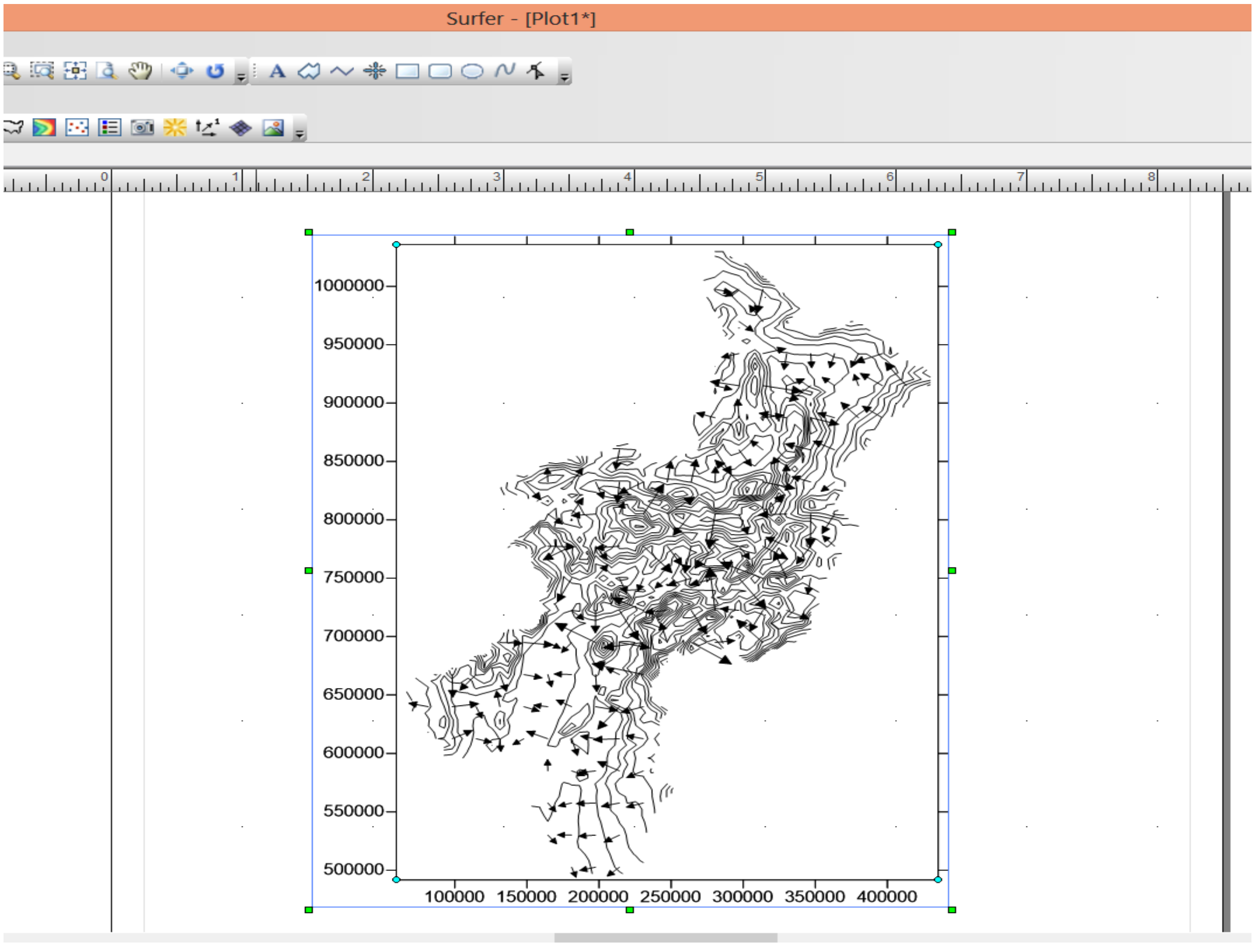


FIGURE 24 GROUNDWATER FLOW DIRECTION OF THE STUDY AREA

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

To utilize the existing groundwater resources, appropriate management and rules should be applied at large in different groundwater resource potential zones of the country. In the study area there is enough amount of the groundwater resources potential for planning and implementation of different groundwater resource development projects. Groundwater characterization and potential assessment across the river basin plays a vital role in case of groundwater quality control, occurrence, extraction and management of the resources in the study area as per the objectives of this research. Three-dimensional groundwater models (FEM, FDM, and FVM) have been used extensively for groundwater potential assessment in Ethiopia and are generally adequate for predicting aquifer hydraulic head changes. Finite element groundwater modeling code (TAGSAC in mat lab) is used in this report to characterize and estimate the groundwater resources potential in the study area.

To determine the hydraulic head for the generated mesh that represent the study area, certain constraints parameters were applied regarding the groundwater aquifer property that needed as attribute in the groundwater model. The hydraulic head is approximated at the node of each triangular prismatic element. Groundwater hydraulic head simulation requires different hydro-geological, metrological and topographical data for simulation run at a steady state condition.

The groundwater potential in the basin is estimated based on the hydraulic conductivity of geologic medium, residual hydraulic head, and areal rainfall. Characterization of the groundwater resources is determined with reference to the hydraulic conductivity, groundwater potential in depth, and porosity value of the geologic medium in the study area. The total groundwater resource potential in the study area is estimated with the average hydraulic head distribution obtained, and found to be 4.38 billon m^3.

The groundwater flow direction is determined from the simulated hydraulic head and the measured surface elevation of the study area. Girded simulated residual hydraulic head and surface elevations of the study area are preprocessed to show the groundwater flow direction. The result clearly shows that the groundwater moves following the topographic slope.

The finite element model is calibrated in order to check the exactness and real representation of the actual filed conditions with this model. The groundwater model is calibrated for steady state condition. The groundwater model developed to solve the identified groundwater problems in the study area and to achieve the research goals were calibrated and gives a well-accepted calibration result in the form of (RMSE, ME, MAE and R^2).The calibration result shows that the groundwater model developed for this research perfectly representing the prototype and the model is enough to respond the problem raised at the beginning of this research work.

This result indicates that there was a monthly groundwater recharge variation in the study area. Since there is a great rainfall difference from month to month across omo gibe river basin, this rainfall difference brings groundwater recharge and hydraulic head variation. The result clearly shows that there was a minimum groundwater recharge in January and a maximum groundwater recharge in August.

The annual groundwater recharge is the total groundwater recharge volume from rainfall to the basin. Annual groundwater recharge is estimated based on the monthly groundwater recharge and found to be 668645.4m^3. The result shows that there was a groundwater level fluctuation from on month to the next month. In the basin, during wet season there is a great rainfall variation and sufficient groundwater recharge amount compared to the dry season. The groundwater table rises in rainy season, because there is sufficient recharge amount from rainfall.

There is a direct relationship between the groundwater recharge and groundwater table variation. When there is a maximum recharge amount in the rainy season the groundwater table rises, and a groundwater table lowers, when there is a minimum groundwater recharge in the dry season.

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5.2 Recommendation

Depending on the established simulated groundwater numerical model developed for this study area and the results of the model, the following recommendations were forwarded:-

The water sector organization should be worried about the increased water demands for water supply and develop sufficient groundwater data base system for the future to address potable drinking water for the nations. Complete recharge estimation has to be carried out by combining methodologies like finite element groundwater modeling technique with predictable methods so as to conduct a comprehensive groundwater model simulation because recharge is the best important groundwater modeling input parameter in the study area. To characterize the system in a more realistic condition, it is important to divide the aquifer system into different layers rather than representing a huge geologic medium with one groundwater model layers for a better estimation of their hydraulic parameters. This research has only one groundwater model layer, or it uses the equivalent porous medium approach so the geologic medium across a model layer have the same hydraulic parameters. The reason is the absence of detailed geological and hydrogeological study and shortage of data to classify the groundwater model layer more than one. The future groundwater research modeling on the study area must consider representing the groundwater aquifer system as two or three groundwater model layers that would permit upward variation in hydraulic properties. There is no sufficient groundwater monitoring wells and pumping test data for a better characterization of the groundwater in the study area.

The present groundwater model assumes that recharge is distributed uniformly throughout the study area and takes the maximum and minimum porosity to characterize and estimate the groundwater potential; but, this is impractical. The upcoming studies must add the updated groundwater modeling input data collected from the site and apply different conceptual model design and other groundwater modeling parameters. There is no site observation for this research, so the future research must include the observed site data for model calibration. The upcoming research must include the direct method of groundwater potential assessment and add water bodies for a detailed groundwater characterization and potential assessment study in the study area.

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Appendix

Appendix A: - Well inventory

The following well and spring data was inventoried. Most of these data are collected within three months (from November to January). All were used for the groundwater model.

UTM EAST (X)	UTM North (Y)	Elevation	Ground Water table	Scheme type
249668	841364	1818	1801.9	borehole
238173	836477	2037	2028.95	borehole
226949	831469	1868	1861.75	borehole
200624	815886	1759	1749.6	borehole
195544	803344	1768	1760.7	borehole
184552	808085	1944	1934	borehole
342710	903933	1592	1588.1	borehole
334211	898466	1953	1939.5	borehole
307408	843461	1859	1850.58	borehole
304496	858342	1582	1572.6	borehole
276948	852443	1693	1687.6	borehole
256890	862252	1544	1541.45	borehole
265405	830283	2222	2206.72	borehole
196038	857507	2033	2026.34	borehole
260651	848497	1697	1686	borehole
357094	781123	1718	1703.55	borehole
352931	795355	1775	1760.55	borehole
349010	797056	1590	1579.4	borehole
365420	796733	1803	1786.3	borehole
378189	800263	2078	2068.9	borehole
351073	746189	1747	1737.8	borehole
297895	780953	2418	2407.1	borehole
348325	762382	2193	2176.4	borehole
353921	765745	2059	2054	borehole
288490	707013	1195	1189.6	borehole
238722	707343	2082	2071.6	borehole
235935	696385	1763	1758.52	borehole
257516	695276	2357	2353.6	borehole
231901	654118	1747	1737	borehole
230487	640387	1547	1534.5	borehole
210934	652553	607	606.22	borehole

172424	531184	399	386.5	borehole
224426	550369	895	891	borehole
228731	572264	1079	1075	borehole
235217	599988	1295	1293	borehole
249668	841364	1818	1801.9	borehole
238173	836477	2037	2028.95	borehole
226949	831469	1868	1861.75	borehole
168184	4 674177	1849	1866	Shallow Well
377932	856372	2677	2665.1	borehole
396998	803844	2780	2762.5	borehole
391269	899457	2263	2258.1	borehole
362403	878191	2058	2047.6	borehole
351131	914224	1592	1589	borehole
381322	933296	1933	1919	borehole
405616	938733	2415	2408.2	borehole
398971	934633	2177	2159.3	borehole
286980	1008967	1602	1601.7	borehole
292948	1005556	1633	1625.5	borehole
315768	993801	1678	1663	borehole
329463	996413	2536	2522	borehole
371843	836672	2270	2150	borehole
365060	916329	1861	1824.75	borehole
372824	836485	2283	2103	borehole
197013	856517	2064	2063	borehole
320618	867247	1784	1777.76	borehole
195070	806175	1547	1542	borehole
333537	898284	1920	1896.7	borehole
307192	843093	1835	1818	borehole
303942	857852	1679	1653	borehole
276857	852720	1752	1747.82	borehole
216306	862513	2003	1997.4	borehole
275615	893437	1732	1715	borehole
261232	848310	1705	1702.8	borehole
259850	847764	1634	1621	borehole
357337	780293	1726	1713.3	borehole
360225	758510	1804	1710.4	borehole
313456	709936	1178	1150	borehole
329667	715352	1420	1413.65	borehole
341793	733469	1252	1194.4	borehole

340655	743331	1515	1452	borehole
272700	701790	1305	1304.47	borehole
288306	707168	1196	1185.1	borehole
229526	638762	1446	1438.74	borehole
392884	870585	2757	2748	borehole
197890	836065	1698	1698	spring
197905	799057	1643	1643	Protected on-spot Spring
198297	857014	1998	1998	Protected on-spot Spring
198578	825463	1417	1417	Protected on-spot Spring
200244	832266	1782	1782	Protected on-spot Spring
201879	816628	1760	1760	Protected on-spot Spring
202021	859133	1340	1340	Protected on-spot Spring
203047	859737	2142	2142	Protected on-spot Spring
203170	859165	1905	1905	Protected on-spot Spring
203988	781973	1743	1743	Protected on-spot Spring
204007	851495	1896	1896	Protected spring
204647	819523	1378	1378	Protected on-spot Spring
205706	860283	1965	1965	Protected on-spot Spring
205820	831776	1908	1908	Spring with Distribution Small
206647	818675	1909	1909	Protected on-spot Spring
206679	832418	1463	1463	Protected on-spot Spring
206799	776934	2019	2019	Protected on-spot Spring
207774	831954	2168	2168	Protected on-spot Spring
208590	779952	1537	1537	spot Spring

208632	856003	1755	1755	Protected on-spot Spring
208750	860630	1387	1387	Protected on-spot Spring
209068	804531	1473	1473	Protected on-spot Spring
209850	831825	1324	1324	Protected on-spot Spring
210816	885479	1479.22	1480	spring
211639	852273	1580	1580	Protected on-spot
212410	852953	2221	2221	Protected on-spot Spring
213161	852029	1972	1972	Protected on-spot Spring
214395	860602	1630	1630	Protected on-spot Spring
214740	853525	2491	2491	Protected on-spot Spring
214850	828312	2143	2143	Protected on-spot Spring
214930	834035	1979	1979	Protected on-spot Spring
215039	791457	2188	2188	Protected on-spot Spring
216436	859143	2120	2120	Protected on-spot Spring
216798	818986	1800	1800	Protected on-spot Spring
217510	819699	2367	2367	Protected on-spot Spring
217911	853156	2274	2274	Protected on-spot Spring
218262	824998	1419	1419	Protected on-spot Spring
219224	834470	1795	1795	Protected on-spot Spring
220900	832270	1443	1443	Protected on-spot Spring
221161	835875	1653	1653	spot Spring
221366	834638	1600	1600	spot Spring

221657	828034	1489	1489	Protected on-spot Spring
222217	831600	1945	1945	Protected on-spot Spring
222448	854885	1613	1613	Protected on-spot Spring
222658	825518	1670	1670	Protected on-spot Spring
223032	657763	1942	1942	Protected on-spot Spring
223161	856970	2084	2084	Protected on-spot Spring
223243	866898	2410	2395	Protected on-spot Spring
223492	835343	1933	1933	Protected on-spot Spring
224065	664198	1924	1924	Protected on-spot Spring
224666	834082	1567	1567	Protected on-spot Spring
225495	830047	2123	2123	Protected on-spot Spring
226292	669260	1884	1884	Protected on-spot Spring
226710	829724	1759	1759	Protected on-spot Spring
226940	876878	1507.75	1514	Hand Dug Well Normal Pump
227329	852795	1739	1739	Protected on-spot Spring
227667	850755	2093	2093	Protected on-spot Spring
228142	573491	1617	1617	Hand Dug Well Normal
228665	572622	2305	2314	Water Point
229046	659979	2372	2372	spot Spring
229890	847822	2442	2442	spot Spring
230064	649250	1973	1973	spot Spring
230472	659558	1631	1631	Protected on-spot Spring

230824	660978	1992.5	2005	Protected on-spot Spring
231705	650934	1890	1890	Protected on-spot Spring
232118	652580	2362	2362	Protected on-spot Spring
232848	852847	2580	2580	Protected on-spot Spring
233196	851229	1580	1580	Protected on-spot Spring
233523	844384	2157	2157	Protected on-spot Spring
233550	850401	2392	2392	Protected on-spot Spring
233743	851752	1744	1744	Protected on-spot Spring
234103	654247	2371	2371	Protected on-spot Spring
234281	853243	2396	2396	Protected on-spot Spring
236053	840265	1832	1832	Protected on-spot Spring
236464	853074	2019	2019	Protected on-spot Spring
237181	852446	1622	1622	Protected on-spot Spring
238172	865419	2487	2487	Protected on-spot Spring
238992	844884	2302.95	2311	Protected on-spot Spring
241278	850671	1967	1967	Protected on-spot Spring
241893	845557	2139	2139	Protected on-spot Spring
241903	1079873	1775	1775	spot Spring
242428	835053	2150	2132	spring
243245	849857	1974	1974	spot Spring
244387	831449	2320	2320	Protected on-spot Spring
244391	843163	1767	1767	spot Spring

244905	846633	1768	1768	Protected on-spot Spring
246542	840038	2170	2170	Protected on-spot Spring
246654	849184	2226	2226	Protected on-spot Spring
247364	845024	2114	2114	Protected on-spot Spring
247544	837522	2112	2112	Protected on-spot Spring
248555	841734	20299	20299	Protected on-spot Spring
248569	829876	1582	1582	Protected on-spot Spring
249217	851981	1931	1931	Protected on-spot Spring
249236	837561	1803	1803	Protected on-spot Spring
249662	1000383	1837	1837	Protected on-spot Spring
250549	834822	1783.9	1800	Protected on-spot Spring
251454	847506	1835	1835	Spring with Distribution Small
251998	853477	2036	2036	Protected on-spot Spring
252754	844890	1779	1779	Spring with Distribution Small
252947	847495	1359	1359	Spring with Distribution Small
253127	838324	1862	1862	spot Spring
253416	850201	2008	2008	Spring with Distribution Small
254035	841082	2119	2119	spot Spring
254081	840141	1766	1766	spot Spring
254351	826595	1618	1618	Protected on-spot Spring
254742	827337	1814	1814	spring
255152	845766	1727	1727	Protected on-spot Spring

256383	842253	2676	2676	Protected on-spot Spring
256483	839396	1777	1777	Protected on-spot Spring
256637	893053	2469	2469	Protected on-spot Spring
256809	850784	1786	1786	Protected on-spot Spring
257396	832020	2762	2762	Protected on-spot Spring
257710	853652	2339	2330	Protected on-spot Spring
258602	829065	1616	1616	Protected on-spot Spring
259010	834889	1746	1746	Protected on-spot Spring
259252	830703	1788	1788	Protected on-spot Spring
259322	820842	2010	2010	Protected on-spot Spring
259372	817115	1677	1677	Spring with Distribution Small
259846	1008331	2363	2363	Protected on-spot Spring
260348	834015	2533	2533	Protected on-spot Spring
260616	895864	1863	1863	Protected on-spot Spring
261223	841322	1394	1407	Protected on-spot Spring
262178	982605	1820	1820	Shallow Well
262293	819352	1720	1731	spot Spring
262553	837545	1864	1864	spot Spring
262669	828070	1968.75	2005	spot Spring
263255	834531	1971	1971	Protected on-spot Spring
264124	826310	2073	2073	Protected on-spot Spring
264164	820773	2476	2476	Protected on-spot Spring

264166	840550	1750	1750	Protected on-spot Spring
265221	1101350	2295	2295	Spring with Distribution Small
265300	696132	1619	1619	Shallow Well
265406	829570	1769	1769	Protected on-spot Spring
266664	817964	1810.2	1827	Protected on-spot Spring
268458	831926	2426.72	2442	Protected on-spot Spring
268577	794914	1642	1642	Spring with Distribution Small
268908	840941	2214	2214	Protected on-spot Spring
269006	835382	1811	1811	Protected on-spot Spring
269185	843607	2540	2540	Protected on-spot Spring
269200	832817	1761	1761	Protected on-spot Spring
269263	851417	1764	1764	Protected on-spot Spring
269915	830619	1705	1705	Protected on-spot Spring
269957	850697	2150	2150	Protected on-spot Spring
270674	878170	1639	1639	spot Spring
270857	882159	1844	1832	Spring
270948	880268	1901	1901	Protected on-spot Spring
271021	853483	1946	1946	spot Spring
271033	826347	2173	2173	spot Spring
271082	828859	1791	1791	Protected on-spot Spring
271133	884565	1728	1728	Protected on-spot Spring
271624	849774	1635	1635	Protected on-spot Spring
271878	900901	1838	1838	spot Spring

272024	835731	1655	1655	Protected on-spot Spring
272194	880361	1868	1868	Protected on-spot Spring
272359	828271	1888	1888	Protected on-spot Spring
272850	887520	1837	1837	Protected on-spot Spring
272866	876727	1774	1774	Protected on-spot Spring
273232	840949	1965	1965	Protected on-spot Spring
273295	831377	1646	1646	Protected on-spot Spring
273415	824281	1969	1969	Protected on-spot Spring
273802	888150	2134	2134	Protected on-spot Spring
273996	853664	1706	1706	Protected on-spot Spring
274185	896815	1779	1779	Protected on-spot Spring
274735	882311	1890	1890	Protected on-spot Spring
274742	910827	2162	2162	Spring
275240	900579	1732	1732	Protected on-spot Spring
275418	855693	1763	1763	spot Spring
275421	856794	1914	1914	Protected on-spot Spring
275489	846845	1806	1806	spot Spring
275780	899662	2266	2266	Protected on-spot Spring
276072	832557	1781	1781	Protected on-spot Spring
276414	846789	1672	1672	Protected on-spot Spring
276444	884317	2295	2295	Protected on-spot Spring
276521	815694	1758	1758	spot Spring

276740	780197	1830	1830	Spring with Distribution Small
276755	913312	1815	1815	Protected on-spot Spring
276852	848841	1789	1789	Spring with Distribution Small
276885	899338	1892	1892	Protected on-spot Spring
277337	907539	1695	1695	Hand Dug Well Normal Pump
277517	918109	1820	1820	Protected on-spot Spring
277610	892509	2195	2195	Protected on-spot Spring
278027	843182	2130	2130	Protected on-spot Spring
278047	914221	2224	2224	Protected on-spot Spring
278113	827691	1719	1719	Spring with Distribution Small
278125	997074	2163	2163	Distribution Small
278141	912281	1782	1782	Protected on-spot Spring
278439	901876	1961	1961	Protected on-spot Spring
278529	896465	1744	1744	Protected on-spot Spring
279286	898898	1795	1795	spot Spring
279314	858516	1858	1858	spot Spring
279403	849955	1995	1995	Protected on-spot Spring
279630	819648	1539	1539	Protected on-spot Spring
279738	771574	1885	1885	Protected on-spot Spring
279836	853697	1661	1661	Protected on-spot Spring
279918	983334	2273	2273	Protected on-spot Spring
280085	988609	1949	1949	spot Spring

280126	837630	1752	1752	Protected on-spot Spring
280143	830316	1938	1938	Protected on-spot Spring
280538	772335	1925	1925	Protected on-spot Spring
280593	917103	2100	2100	Protected on-spot Spring
280797	854349	1968	1968	Protected on-spot Spring
280950	829012	2256	2256	Protected on-spot Spring
280960	819077	1757	1757	Protected on-spot Spring
281187	903387	1908	1908	Protected on-spot Spring
281384	778579	1694	1694	Spring
281477	991339	2065	2065	Protected on-spot Spring
281602	855990	2052	2052	Protected on-spot Spring
281851	902533	1598	1598	spot Spring
282200	838068	1760	1760	Protected on-spot Spring
282251	835299	1807	1807	Protected on-spot Spring
282506	824600	2116	2116	spot Spring
282742	828502	1877	1877	Protected on-spot Spring
283422	988254	1917	1917	Protected on-spot Spring
283828	853247	1743	1743	Protected on-spot Spring
284125	792521	1743	1743	Spring with Distribution Small
284186	772094	1782	1782	Protected on-spot Spring
284240	834152	1735	1735	Protected on-spot Spring
284249	908964	1994	1994	spot Spring

284328	859159	1990	1990	Protected on-spot Spring
284387	862348	1730	1730	Spring with Distribution Small
284691	822250	1798	1798	Protected on-spot Spring
284888	821348	2090	2090	Protected on-spot Spring
284930	850128	2579	2579	Protected on-spot Spring
285168	895330	1499	1499	Protected on-spot Spring
285450	929629	1779	1779	Spring
285630	933726	1756	1756	Protected on-spot Spring
285649	825852	2216	2216	Protected on-spot Spring
285653	856653	1894	1894	Protected on-spot Spring
286173	866506	2097	2097	Protected on-spot Spring
286267	918974	1716	1716	Protected on-spot Spring
286269	917202	1963	1963	spot Spring
286448	914382	2134	2134	spot Spring
286519	910920	2657	2657	Protected on-spot Spring
286610	851449	1965	1965	Protected on-spot Spring
286836	822827	1876	1876	Spring with Distribution Small
287029	818618	1986	1986	Protected on-spot Spring
287623	829060	2141	2141	Protected on-spot Spring
287702	844653	1850	1850	Protected on-spot Spring
288035	920541	1616	1616	Protected on-spot Spring
288240	822034	2107	2107	spot Spring

288480	916499	1637	1637	Protected on-spot Spring
288538	912154	2087	2087	Protected on-spot Spring
288540	915613	2190	2190	Protected on-spot Spring
288910	856371	1960	1960	Protected on-spot Spring
289285	853058	1718	1718	Spring
289315	854872	2404.6	2410	Protected on-spot Spring
289889	791037	1804	1804	Spring with Distribution Small
290453	986720	1597	1597	Protected on-spot Spring
290869	777039	2368	2368	Hand Dug Well
291044	763249	2310	2310	Water Point
291062	916618	1151	1151	Protected on-spot Spring
291173	987352	2766	2766	Protected on-spot Spring
291800	854298	2138	2138	spot Spring
291804	915258	1363	1363	spot Spring
291844	841407	1673	1673	Protected on-spot Spring
291977	968362	1896	1896	Protected on-spot Spring
292046	853406	2154	2154	Protected on-spot Spring
292623	775112	1598	1598	Protected on-spot Spring
292956	921312	1691	1691	Protected on-spot Spring
292961	918751	1997	1997	Protected on-spot Spring
293256	907987	1668	1668	Protected on-spot Spring
294462	947091	1786	1786	Spring with Distribution Small
294789	786295	1838	1838	spot Spring

294924	785231	2467	2467	Protected on-spot Spring
294932	833879	2516	2516	spot Spring
295094	843048	1610	1610	Spring
295425	770078	2406	2406	Protected on-spot Spring
295477	924602	2356	2356	Protected on-spot Spring
295583	968323	2001	2001	Protected on-spot Spring
295715	915940	2483	2483	Protected on-spot Spring
296412	928438	1634	1634	Protected on-spot Spring
296729	939878	1859	1859	Protected on-spot Spring
296847	789380	1773	1773	Protected on-spot Spring
297159	924329	2232	2232	Protected on-spot Spring
297344	834707	1554	1554	spot Spring
297386	829741	1745	1745	Protected on-spot Spring
297645	770930	1806	1806	Protected on-spot Spring
297687	832399	2681	2681	Protected on-spot Spring
297716	778008	1632	1632	Protected on-spot Spring
297859	909879	1652	1652	Protected on-spot Spring
298239	792359	1767	1767	Protected on-spot Spring
298275	980331	2076	2076	Protected on-spot Spring
298359	954038	1660	1660	Protected on-spot Spring
298429	785050	2117	2117	Spring with Distribution Small
298446	826010	2619.1	2630	spot Spring

298617	775618	2327	2327	Spring
298621	776792	2750	2750	Protected on-spot Spring
298915	781042	2197	2197	Protected on-spot Spring
299530	837076	1958	1958	Protected on-spot Spring
299885	774944	1825	1825	Protected on-spot Spring
300513	822162	1738	1738	spot Spring
300644	772524	2712	2712	Protected on-spot Spring
300693	849184	2728	2728	Protected on-spot Spring
300777	784358	2362	2362	Protected on-spot Spring
300921	786302	2302	2302	Protected on-spot Spring
300934	952888	2074	2074	spot Spring
300963	779015	1826	1826	Protected on-spot Spring
301102	788648	2101	2101	Protected on-spot Spring
301409	843084	1970	1970	Protected on-spot Spring
302096	827134	2345	2345	Protected on-spot Spring
302178	828901	1748	1748	Protected on-spot Spring
302412	772612	2119	2119	Protected on-spot Spring
302497	777812	2830	2830	Shallow Well
302713	777532	1832	1832	Protected on-spot Spring
302850	863522	1820	1820	Protected on-spot Spring
302959	826521	1800	1800	spot Spring
303110	781227	2123	2123	Spring
303190	821907	1815	1815	Protected on-spot Spring

304203	777786	2224	2224	Protected on-spot Spring
304271	761771	3183	3183	Protected on-spot Spring
304296	840673	2095	2095	Protected on-spot Spring
304395	765507	1841	1841	Protected on-spot Spring
304439	829440	2112	2112	Protected on-spot Spring
304485	667096	3160	3160	Protected on-spot Spring
304563	765668	2342	2342	Protected on-spot Spring
304604	768898	3113	3113	Protected on-spot Spring
304673	831579	2176	2176	spot Spring
304783	839999	1931	1931	spot Spring
305284	847438	1821	1821	Protected on-spot Spring
305344	866064	2180	2180	Protected on-spot Spring
305526	871371	2030.6	2040	Protected on-spot Spring
305595	770602	1863	1863	Protected on-spot Spring
305686	872708	2350	2350	Protected on-spot Spring
305759	797277	3087	3087	Protected on-spot Spring
306582	784776	2214	2214	Protected on-spot Spring
306971	872700	1864	1864	Protected on-spot Spring
307254	835541	1986	1986	spot Spring
307376	727334	2227	2227	Spring with Distribution Small
307432	869325	1944	1944	Protected on-spot Spring
307788	761949	1973	1973	spot Spring

308104	778348	1755	1755	Protected on-spot Spring
308432	967415	1536	1536	Protected on-spot Spring
308594	870751	2832	2832	spot Spring
308626	666643	1762	1779	Protected on-spot Spring
308758	831816	1992	1992	Protected on-spot Spring
309221	784110	1752.58	1761	Protected on-spot Spring
309525	831757	1978	1978	Protected on-spot Spring
309851	768055	2671	2671	Protected on-spot Spring
309864	833954	1733	1733	spot Spring
309956	967921	1867	1867	Spring with Distribution Small
310213	767139	1960	1960	Protected on-spot Spring
310404	762123	1782	1760	Protected on-spot Spring
311040	766510	1605	1605	Protected on-spot Spring
311212	837551	2844	2844	Protected on-spot Spring
311583	779017	2233	2233	Protected on-spot Spring
311701	837947	1917	1917	Protected on-spot Spring
311712	829304	1588	1588	Protected on-spot Spring
311917	836267	2781	2781	Protected on-spot Spring
312791	870726	2814	2814	Protected on-spot Spring
312811	830624	2184	2184	Protected on-spot Spring
312812	834653	1888	1888	Protected on-spot Spring

313320	767724	1824	1824	Protected on-spot Spring
313335	986075	2491	2491	Spring
313400	833972	1711	1711	Protected on-spot Spring
314555	767286	2082	2082	Protected on-spot Spring
315014	829642	1750	1750	Protected on-spot Spring
315821	832141	2268	2268	Protected on-spot Spring
316579	781924	2348	2348	Protected on-spot Spring
316660	834595	2369	2369	spot Spring
316701	769864	1739	1765	Water Point
316791	769888	2517	2517	Protected on-spot Spring
316816	779232	2715	2715	Protected on-spot Spring
317316	858727	2060	2060	Protected on-spot Spring
317832	779983	2052	2052	Protected on-spot Spring
318032	875305	2070	2070	Protected on-spot Spring
318477	837688	2373	2373	Protected on-spot Spring
318738	863539	1685	1700	spot Spring
320053	870409	1320	1320	Protected on-spot Spring
321601	935972	1972	1972	Spring with Distribution Small
321930	885165	1855	1855	Protected on-spot Spring
322145	980974	1935	1935	Spring with Distribution Small
322233	873632	2476	2465	Protected on-spot Spring
322323	880551	2438	2438	Protected on-spot Spring

329751	767181	2100	2100	Spring
334191	812119	2075	2075	Protected on-spot Spring
334451	749508	1185	1185	Water Point
335024	750284	2108	2108	Water Point
335479	744631	1220	1220	Water Point
335671	808133	1904	1904	Spring with Distribution Small
336040	743921	1576	1561	Water Point
336167	739690	1421	1421	Spring with Distribution Small
336541	986535	1859	1859	Spring with Distribution Small
336776	816543	1808	1808	spot Spring
337687	744925	1377	1377	Spring
338772	820930	2029	2029	Protected on-spot Spring
340264	750574	2475	2475	Spring with Distribution Small
342564	857830	2402	2402	Protected on-spot Spring
344051	786976	1674	1674	Shallow Well
344753	922084	2070	2070	Shallow Well
345378	748534	2359	2359	Water Point
347222	816437	2141	2141	spot Spring
348050	823853	1655.6	1695	Protected on-spot Spring
348454	764899	2322	2322	Protected on-spot Spring
349481	822734	1884	1884	Spring with Distribution Small
349941	816681	1589	1589	Protected on-spot Spring
351915	820552	1391	1391	Protected on-spot Spring
352029	824572	1834	1834	Protected on-spot Spring
352295	842909	2436	2436	spot Spring
352789	836015	2296	2296	spot Spring

352878	846744	1765	1765	Protected on-spot Spring
352920	785425	1543.5	1574	Shallow Well
353353	849127	2265	2300	Protected on-spot Spring
353397	822151	2721	2721	Protected on-spot Spring
353402	818959	2032	2032	Water Point
353634	845050	1747	1747	Protected on-spot Spring
353644	921214	1990.7	2005	Protected on-spot Spring
354234	814260	1853	1853	spot Spring
354290	848136	1639	1639	spot Spring
354383	821360	2469	2469	Protected on-spot Spring
355066	859095	2417.46	2448	Spring with Distribution Small
355149	851339	2030	2030	Protected on-spot Spring
355261	802537	2447	2447	spot Spring
355372	813642	1867	1867	spot Spring
355738	815922	2240	2240	Protected on-spot Spring
356469	850044	1833	1833	Protected on-spot Spring
356864	811496	2100	2100	Protected on-spot Spring
356981	829764	1900.55	1915	Protected on-spot Spring
358545	831870	1916	1916	Protected on-spot Spring
358575	827164	1881	1881	Water Point
358837	816085	2054	2054	Protected on-spot Spring
359391	837748	2317	2317	Protected on-spot Spring
359413	763395	1852	1852	Water Point
359877	819543	1941	1941	Spring with Distribution Small

360024	810940	2354	2354	Protected on-spot Spring
360036	825713	1875	1875	Protected on-spot Spring
360740	816138	217	217	Protected on-spot Spring
360776	828742	1897	1897	Protected on-spot Spring
361414	837500	2464	2464	Protected on-spot Spring
361683	808368	1855	1855	Spring with Distribution Small
361928	817084	1830	1830	spot Spring
362070	922400	2367	2367	Protected on-spot Spring
362311	848282	1973	1973	Protected on-spot Spring
362342	825132	2380	2380	Protected on-spot Spring
362344	889466	1862	1862	Protected on-spot Spring
362668	863670	2041	2041	Protected on-spot Spring
362714	910415	2046	2046	Protected on-spot Spring
362800	879575	2552	2541	Protected on-spot Spring
362988	910127	2523	2523	Protected on-spot Spring
363075	858999	2000	1987	Protected on-spot Spring
363282	838788	1833	1833	Water Point
363403	829678	2262	2262	Protected on-spot Spring
363446	890642	2265	2265	Protected on-spot Spring
363668	886597	2648	2648	Water Point
363704	837575	2477	2477	Spring with Distribution Small
363922	826443	2070	2070	spot Spring

364101	848340	2092	2092	Protected on-spot Spring
364439	827797	2317	2317	Protected on-spot Spring
365281	845230	2437	2437	Protected on-spot Spring
365440	837142	1817	1817	Protected on-spot Spring
365525	858142	2154	2154	Protected on-spot Spring
365770	887442	2108	2108	spot Spring
366079	818898	1917.6	1928	Protected on-spot Spring
366146	857659	2197	2197	Protected on-spot Spring
366297	855570	2050	2050	Protected on-spot Spring
366374	870636	1746	1746	Protected on-spot Spring
367241	887981	2231	2231	Protected on-spot Spring
367280	821692	1753	1753	Protected on-spot Spring
367671	869079	1606	1606	Protected on-spot Spring
367725	825633	2306	2306	Protected on-spot Spring
369046	893746	2094	2094	Protected on-spot Spring
369173	870167	2067	2067	Protected on-spot Spring
369305	882141	2052	2052	spot Spring
369353	852053	2266	2266	Protected on-spot Spring
369510	838997	2122	2122	Protected on-spot Spring
369539	784527	2020	2020	Protected on-spot Spring
369702	865106	2135.75	2172	Protected on-spot Spring

369756	755355	2061	2061	Spring with Distribution Small
369851	864185	2443.3	2460	Protected on-spot Spring
370150	910198	2306	2306	Protected on-spot Spring
370161	899161	2196	2196	Protected on-spot Spring
370210	868900	2320	2320	spot Spring
370213	840225	1811	1811	spot Spring
370418	885385	1811	1811	Water Point
370973	857911	1785	1785	Spring with Distribution Small
371210	884294	2334	2334	Protected on-spot Spring
371499	861663	2542.4	2567	spot Spring
371553	879256	2058	2058	Protected on-spot Spring
372056	866580	2276	2276	Protected on-spot Spring
372145	872156	2222	2239	Protected on-spot Spring
372240	913323	2371	2371	Protected on-spot Spring
372395	790802	2556	2556	Protected on-spot Spring
372396	791623	2524	2512	Protected on-spot Spring
372433	857948	1903	1903	spot Spring
372730	785777	1946	1946	spot Spring
373346	876374	2159	2159	Protected on-spot Spring
373403	914114	2086	2086	Protected on-spot Spring
373721	865671	2512	2512	Protected on-spot Spring
373885	899042	2293	2293	Protected on-spot Spring
374029	900700	1993	1993	Protected on-spot Spring

374082	792401	2194	2194	Protected on-spot Spring
374363	868447	2660	2660	Protected on-spot Spring
374660	826688	2270	2270	Protected on-spot Spring
374688	881882	1867	1867	Protected on-spot Spring
375120	867440	2183	2183	Protected on-spot Spring
375688	861120	2210	2210	spring
376002	894305	1935	1935	Protected on-spot Spring
376211	924310	2092	2092	spot Spring
376388	899329	2453	2453	Water Point
376553	864038	2075	2075	Protected on-spot Spring
376602	884353	2352	2352	Protected on-spot Spring
376633	880554	2187	2187	Protected on-spot Spring
376907	901026	2270	2270	Water Point
377025	878560	2224	2224	Protected on-spot Spring
377079	860431	1801	1801	Protected on-spot Spring
377095	866199	1933	1933	Protected on-spot Spring
377411	804313	1929	1929	Protected on-spot Spring
377551	804273	2184	2184	Protected on-spot Spring
377729	886847	2107	2107	Protected on-spot Spring
379000	866071	2222	2222	Protected on-spot Spring
379930	900133	1901	1901	Water Point
380069	888988	2355	2355	Protected on-spot Spring
380148	897210	1957	1957	spot Spring

380461	912471	1922	1922	Protected on-spot Spring
380781	879942	1924	1924	Protected on-spot Spring
381369	927662	2524	2524	Protected on-spot Spring
381435	883181	2122	2122	spot Spring
383282	891132	2317	2317	spot Spring
383316	888383	2527	2527	Water Point
383489	884471	2533	2533	Protected on-spot Spring
383902	888977	2015	2015	Protected on-spot Spring
384070	893665	1850	1850	Water Point
384092	758138	1967	1967	Water Point
384719	880806	2500	2500	Protected on-spot Spring
384919	877312	2316	2316	Protected spot Spring
385322	896289	2018	2018	Spring with Distribution Small
385755	931652	1927	1927	Spring with Distribution Small
385918	8366416	2545	2545	Protected on-spot Spring
386060	928422	2566	2566	Protected on-spot Spring

Appendix B: - Mean annual areal precipitation in the study area

The rainfall is the main groundwater modeling input parameters to estimate the groundwater recharge and groundwater hydraulic head.

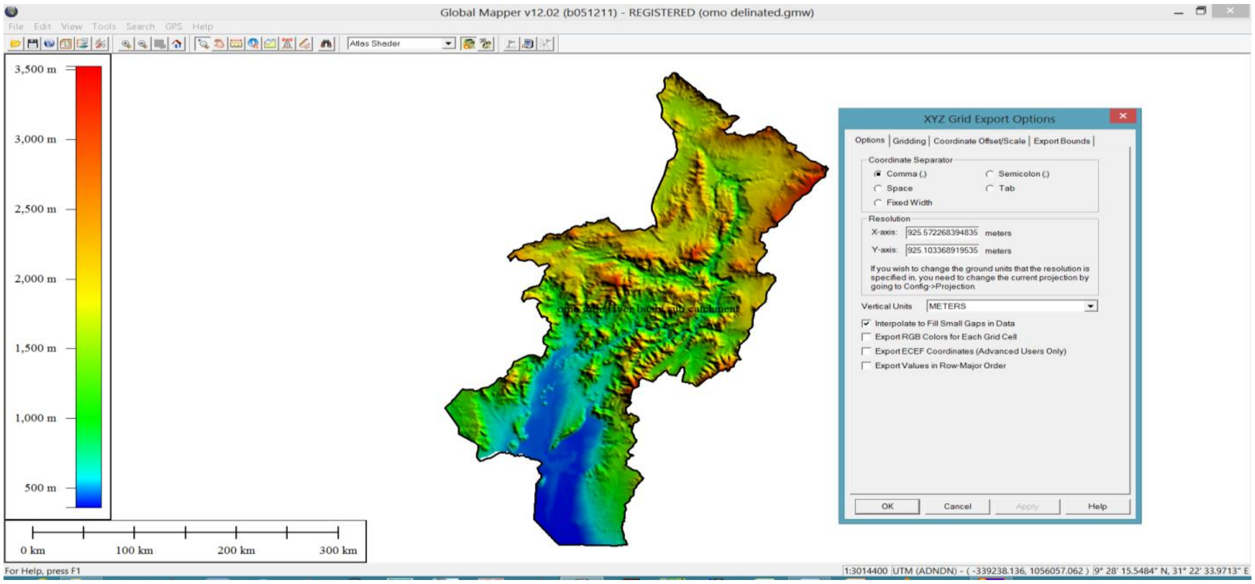
No.	Station name	UTM-E(m)	UTM-N (m)	Mean Annual rainfall(mm)	Enclosed A (sq km)	P*A
1	Ifbia	287917.6794	1013018.162	1417.632	477.74	677259.5117
2	Bako	285665.4349	1003075.17	1718.37	424.43	729327.7791
3	Tibe	294433.3145	997498.7223	1524.2	674.51	1028088.142
4	Seyo	303957.4153	917819.6376	2070.199	2437.1	5045281.983
5	Darian	342533.768	923192.5172	1571.0	913.16	1434532.853
6	Gibe farm	318206.2297	900063.786	979.4	1421.1	1391818.88

7	Limu seka	229966.9683	891659.5488	1664.55	1756.5	2923782.075
8	Limugenet	232199.0015	896071.9046	1841.0205	718.14	1322110.462
9	Busa	283744.3176	837172.1687	1500.4	593.21	890067.8948
10	Dobi	321242.808	893907.735	2320.5	552.37	1281774.585
11	Saja	323641.578	880873.76	1440.8	242.25	349044
12	Kumbi	332890.537	897426.005	1289.5	297.47	383577.6493
13	Abeliti	349439.534	902895.93	1121.7	396.12	444338.5873
14	Gubre	368391.496	905108.531	1762.081818	601.54	1059962.697
15	Chitu	381125.387	939654.322	1318.105	976.96	1287735.861
16	Wolisogyon	388111.767	945163.535	1219.6625	548.73	669265.4036
17	Dilea	394463.928	954636.971	1173.531818	229.18	268950.0221
18	Bantuliben	429244.027	952660.086	1314.514737	374.13	491799.3985
19	Koshe	447685.243	884953.584	824.4454545	71.772	59172.09916
20	Imdibir	382785.541	897451.654	1544.895	1298.6	2006200.647
21	Gunchire	371860.111	887223.63	1348.845833	377.29	508906.0445
22	Kokir	367749.255	884409.937	1364.5	701.21	956801.045
23	Kidamegebaya	334653.175	877146.488	1506.994444	634.86	956730.493
24	Fonko	386175.418	844804.431	1243.4375	165.91	206298.7156
25	Hosana	373559.13	836544.182	1175.004167	1349.8	1586020.624
26	Cheka	323577.994	864286.315	1558.789474	1614.1	2516042.089
27	Dimtu	305210.637	868046.261	1775.734	647.45	1149698.978
28	Serbo	275717.884	851588.306	1406.716667	1306.3	1837593.982
29	Babu	255592.609	871969.363	1854.5665	99.358	184266.0183
30	Chekorsa	249919.279	842499.13	1772.358333	1242.8	2202686.937
31	Gembe	242691.586	866507.99	1500.461111	208.441	312757.6145
32	Boto	239044.699	872060.214	2202.353889	105.02	231291.2054
33	Toba	222573.842	885065.576	1780.322222	272.15	484514.6928
34	Bitawoshi	172405.667	809762.42	1679.679048	1734.7	2913739.244
35	Kemssie	183457.32	809690.676	2117.365	1575.5	3335908.558
36	Shedatura	211050.538	803989.682	2117.781176	3234.4	6849751.437
37	Delbi	264502.335	814770.834	1941.515	2252.7	4373650.841
38	Metso	264330.256	777900.018	1797.805556	3880.7	6976744.019
39	Bele	337128.169	764872.607	1252.77	2430.9	3045358.593
40	Areka	357277.244	780784.482	1433.147826	2089.6	2994705.697
41	Danna	342039.465	733590.876	2353.033333	1078	2536569.933
42	Dinke	325232.379	712232.996	1271.117391	1123.3	1427846.166
43	Daramalo	312375.615	699157.925	910.0782609	705.28	641859.9958
44	Kemba	297086.913	669012.626	1536.120833	131.87	202568.2543
45	Malanaha	288152.511	707290.94	1218.152174	1069.7	1303057.38
46	Lote	238274.28	696927.464	1295.919048	835.72	1083025.466
47	Zenga	273287.771	702678.272	1350.23913	792.93	1070645.114
48	Laska	238274.28	696927.464	1429.721429	5053.6	7225240.211
49	Kulish	151620.374	787762.639	1992.138095	2338.2	4658017.294
50	Chena	148327.929	791475.527	1773.715789	74.854	132769.7217
51	Kibish	142057.307	662447.132	1250.57	9712.2	12145785.95

52	Jinka	228660.445	637936.156	1308.477083	4023.4	5264526.697
53	Turmi	200623.876	564293.764	916.5	1491.5	1366959.75
54	Bakosim	209491.533	562044.263	839.28	4252.2	3568786.416
55	Omo rate	176175.205	556653.312	784.357	5602.2	4394124.785
				Sum	79213.155	114389340.5
				Sum(A*P)/Sum(A)		1444.069997

Appendix c: - Model grid design procedures

The model grid of the study area is used to check the exactness of delineated study area and better to check the fair distribution model calibration well. Different procedures are used for this research to design the model grid for the study area, (a) open the defined study area on global mapper software working window, (b) picking the study area by the digitizing tools,(c)exporting the chosen defined study area in the form of elevation grid format XYZ.



Coordinate Separator
● Comma (,) ○ Semicolon (;)
○ Space ○ Tab
○ Fixed Width

Resolution
X-axis: 925.572268394835 meters
Y-axis: 925.103368919535 meters
If you wish to change the ground units that the resolution is specified in, you need to change the current projection by going to Config->Projection.

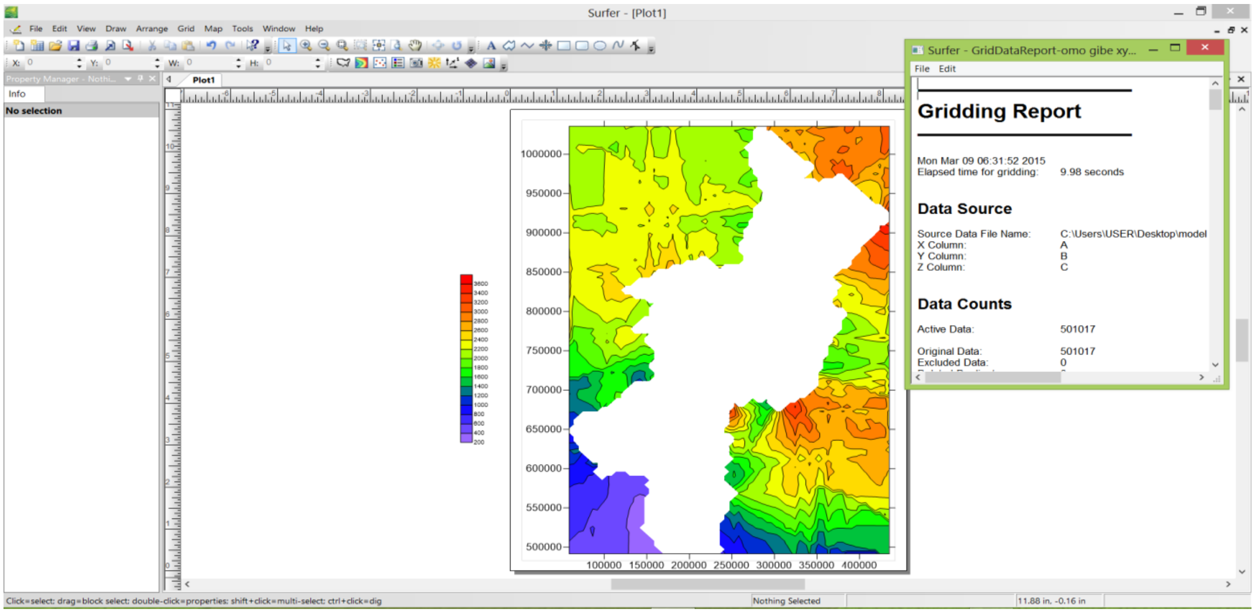
Vertical Units: METERS

☑ Interpolate to Fill Small Gaps in Data
☐ Export RGB Colors for Each Grid Cell
☐ Export ECEF Coordinates (Advanced Users Only)
☐ Export Values in Row-Major Order

1:3014400 | UTM (ADNDN) - (-339238.136, 1056057.062) | 9° 28' 15.5484" N, 31° 22' 33.9713" E

MAP 1 EXPORTING TO ELEVATION GRID FORMAT

The exported elevation grid of the study area continues to check the exact delineated study area are ,(d) rearrange the dialogue box window and obtain the XYZ data,(e) the elevation grid data are arranged in the form of Txt.dat files,(f) generate the path profile for study area,(g)after generating the path profile the data must be in the form of blanked files data and (h)finally the elevation grid data is blanked by the border profile blanked files.



Gridding Report

Mon Mar 09 06:31:52 2015
Elapsed time for gridding: 9.98 seconds

Data Source

Source Data File Name: C:\Users\USER\Desktop\model
X Column: A
Y Column: B
Z Column: C

Data Counts

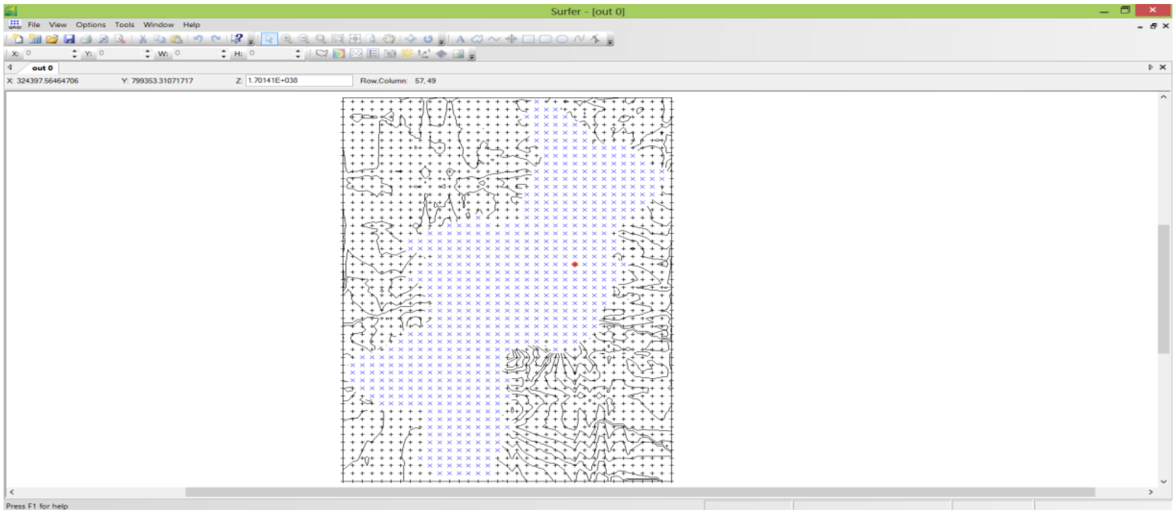
Active Data: 501017

Original Data: 501017
Excluded Data: 0

Click=select: drag=block select: double-click=properties: shift+click=multi-select: ctrl+click=dig
Nothing Selected
11.88 in, -0.16 in

MAP 2 MODEL GRID OF THE STUDY AREA

To check the correctness of the defined study area, there is inner and outer blank of the region. The outer blank is performed by blanking the dot.dat elevation grid files with the blanked files of the border profile element one thousand and two hundred ninety six (1296) with zero (1) value. Look the figure below which shows the outer blanked section of the study area with the cross hatch and the external by the contour line.

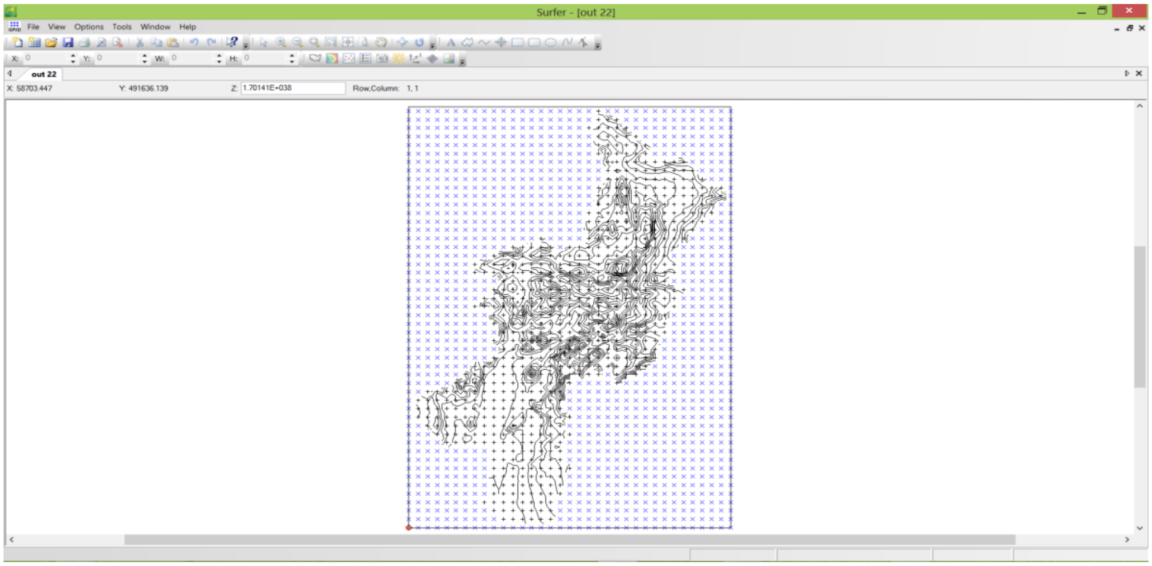


X: 324397.56464706
Y: 799353.31071717
Z: 1.70141E+038
Row,Column: 57, 49

Press F1 for help

MAP 3 OUTER BLANK OF THE STUDY AREA

The inner blank is performed by blanking the dot.dat elevation grid files with the blanked files of the border profile element one thousand and two hundred ninety six (1296) with zero (0) value.



X: 58703.447 Y: 491636.139 Z: 1.70141E+038 Row,Column: 1, 1

MAP 4 INNER BLANK OF THE STUDY AREA