ADDIS ABABA UNIVERSITY

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CHARACTERIZING THE GROUNDWATER POTETIAL OF WABI SHEBELLE RIVER BASIN

BY

TESEMA KEBEDE

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A thesis submitted to school graduate studies, Addis Ababa institute of Technology, in partial fulfillment for the degree of masters of Science in Civil Engineering under Hydraulic Engineering.

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ABSTRACT

Water is one of the limiting factors for development in the Wabi Shebelle basin area. The overall quantity of water available in the basin is very insufficient. In addition, the difficult access of water resources in the basin severely restricts their utilization. With an area of some 191146 km^2, the WSRB basin mainly comprises the south eastern highlands of the Arsi Bale. The basin is endowed with abundant groundwater resources that require proper management if they are to be wisely utilized in a sustainable manner. With the Wabi Shebelle River as the major resource, the WSRB is the most undeveloped. The groundwater potential in the basin is seldom estimated.

The objective of this study is to investigate the regional groundwater characteristics and to assess the groundwater resource potential of Wabi Shebelle river basin. To achieve this objective, a three dimensional groundwater model (TAGSAC) that uses finite element method were applied. Ground water models provide a scientific and predictive tool for determining appropriate solutions to water allocation, surface water – ground water interaction, landscape management or impact of new development scenarios. The model can also be used to simulate possible future changes to hydraulic-head or groundwater-flow rates as a result of future changes in stresses on the aquifer system.

The numerical model was calibrated by trial-and-error methods where by hydrogeological parameters like hydraulic conductivity and the recharge amount are adjusted. The relatively small span of physically possible values of head was not considered sufficient to justify the effort required to implement inverse calibration methods. Calibration results provided the estimate on the regional distribution of hydraulic conductivity values, which range from 8.64×10^{-8} m/s to 7.7×10^{-4} m/s over 36 zones resulting in a greater reliability of the spatial and temporal evolution of state variables for simulations. Best model performance achieved, resulted in a mean absolute error of 8.77 m and a root mean square error of 15.30 m (R2 = 0.9992). From this work the estimated replenish able groundwater potential of the study area is about (8700 MCM). Results show that groundwater head have an immediate effect on hydraulic conductivity of the aquifer. And the amount of recharge also has its own effect on the model simulation.

Keywords: **Numerical Groundwater Flow Models; Finite Element Method, Wabi Shebelle River Basin, Wabi Shebelle River, TAGSAC, Ethiopia**

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DEM-	Digital Elevation Model
BGS-	British Geological Survey
FAO -	Food and Agricultural Organization.
GIS -	Geographical Information System
GPS-	Geographical Positioning System
GSE-	Geological Survey of Ethiopia
FDM-	Finite Difference Method
FEM-	Finite Element Method
ITCZ -	Inter Tropical Convergence Zone
MAE-	Mean Absolute Error
ME -	Mean Error
MoWR-	Ministry of Water Resource
NMA-	National Metrological Agency
P -	Precipitation
PH -	Negative of the logarithm to the base ten of the hydrogen ion concentration.
REV-	Representative Elementary Volume
RMSE	Root Mean Square Error
R^2 -	Correction coefficient
TDS -	Total Dissolved Solids
UNESCO -	United Nations Educational Scientific and Cultural Organization
UTM -	Universal Transverse Mercator
WAPCOS -	Water and Power Consultancy Service (India) Ltd
WHO -	World Health Organization
WMO -	World Meteorological Organization
WSRB-	Wabi Shebelle River Basin
WWDSE -	Water Works Design and Supervision Enterprise

1. INTRODUCTION

Water is the most vital component of all living things; the need for water is strongly ascending, which is not only important for domestic purpose but also vital for the development activities in both agricultural and industrial sectors. Any developmental activity is related, either directly or indirectly with water utilization. Similar to other areas of the world, groundwater is the major source of drinking water in Ethiopia. More than 80% of the country‘s drinking water supply source is from ground water. This includes more than 25 major cities in the country according to Tsehayu et al., (2004).

Ethiopia has 9 major river basins, with a total estimated annual flow of approximately 122 billion cubic meter of water. Though this is a relatively big endowment, the paradoxical situation is that 80% of the country‘s water resources are concentrated in the western part, where only 33% the population reside, while the eastern part with 67% of the population has only 11% of the surface water resources, which means there are less water resources in the area with very big demand and larger amounts of the resource in areas with relatively low population. A total of 70% of Ethiopia‘s river basins are Tran‘s boundary. The climatic conditions of the country are elevation (altitude) dependent, with temperature as high as 47^0C in Danakil depression and as low as 10^0C in the highlands.

Basin studies were first undertaken in the country in the 1950s, and the United States Bureau of Reclamation (USBR) conducted the Abay River basin study in 1964. Subsequently, basin level studies have been carried out in the northern basin (Tekeze, Mereb-Gash and Guang) and the Wabi Shebelle River basin. Basin development studies have been carried out recently in a more comprehensive and integrated manner in five of the twelve major basins in the country, and studies in two more basins are underway. To date, the implementation of these studies has been limited.

Wabi Shebelle River Basin (WSRB) is one of the seven trans-boundary rivers basin in Ethiopia with a total area of about 191146 km^2. WSRB is part of the Oromiya regional state in the north western and Somali regional state in south eastern and in north western margins of the area also extend to adjoining areas of Sidama Zone in South Nation, Nationalities and Peoples Regional State and also the Harari regional state is found there. The Wabe River which is the major tributary to Wabi Shebelle River originates just east of Wetera Resa Village in South Nations, Nationalities and Peoples Regional State. **(**Gizachew, 2009)

Water plays a vital role in the development of agricultural activities in the study area. The surface water resources are inadequate to fulfill the water demand. Productivity through groundwater is quite high as compared to surface water, but groundwater resources have not yet been properly exploited.

Groundwater can be defined as the water stored underground in rock crevices (fractured media) and in the pores of geologic materials (porous media) that make up the earth‘s crust. Nowadays, groundwater is considered as an important life support system, both in terms of human water supply and sustenance of some ecosystems. Wrong decisions about groundwater management can provoke undesired non-reversible effects, concerning quality and quantity. These concepts are strongly linked to groundwater motion.

Groundwater is widely used in national economy of many countries for most different purposes: potable water supply of the population and cattle-breeding farms, industrial water supply, irrigation, biological use (mineral water), as a raw material for extracting valuable components, such as iodine and bromine (industrial water) and for central heating (thermal power water). Fresh groundwater is of particular importance, as in many countries it is the main source of public water supply and its role in domestic and drinking water supply balance is growing every year that is due to continuing contamination of surface water resources. Rapid growth in groundwater use is a central aspect of the world‘s water story, especially since 1950. Shallow wells and muscle-driven lifting devices have been in vogue in many parts of the world for the millennia. Groundwater is of paramount importance for Ethiopia to supplement the available surface water resources in providing drinking water to its population and for economic development (agriculture, livestock, industry, tourism) and in general to mitigate the effects of climate variability. It was acknowledged in World Bank Country Water Assistance Strategy that the groundwater resources should be more fully explored. In the last five years groundwater assessment has accelerated and a number of ambitious projects for groundwater irrigation have been conceptualized.

The occurrence of groundwater in Ethiopia is mainly influenced by the country‘s geology, geomorphology, tectonics and climate. The variability of these factors strongly influences the quantity and quality of groundwater in different parts of the country. There is usable groundwater in many areas, offering good transmission of rainfall to recharge aquifers, sustaining springs and maintaining flows in perennial rivers. In other areas, however, groundwater is only found at depth (e.g. lowland regions such as Somali), in only limited quantities (with limited storage), or quality poses a risk to health (particularly its fluoride content). (Negash, 2012)

As groundwater cannot be seen directly from the earth‘s surface, so a variety of techniques can provide information concerning its potential occurrence. Several studies since early 1960‘s have been attempted to explain spatial variability of groundwater occurrence in different terrain conditions using technologies like aerial photography and geographic information system. (Eshetu, 20087)

Many of the basic principles of the flow of groundwater through aquifers were established by the early 1970s. In addition, numerous analytical solutions were available. At that time, numerical modeling of groundwater flow was also developing although limited computing power restricted applications. (Rushton, 2003)

A groundwater model is a mathematical representation (often computer-based) of a groundwater flow system. While groundwater models are, by definition, a simplification of a more complex reality, they have proven to be useful tools for investigating groundwater problems and have provided valuable support for decision-making in groundwater management. Models provide insight on how a groundwater system behaves. Where it can be demonstrated that a model is able to reasonably reproduce past behavior it can forecast with a degree of confidence a range of responses to changed future conditions (e.g. related to future climatic variations, future changes in land use or future changes in groundwater extraction (Knight, 2013)

Groundwater-flow models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface, and the exchange of groundwater between aquifers and sources and sinks, where groundwater is added or removed from the aquifer. These calculations are referred to as ―simulations." The simulation of groundwater-flow depends upon a thorough understanding of the hydro geologic characteristics of the facility and the surrounding area.

According to Michigan Department of Environmental Quality Remediation and Redevelopment Division, Model calibration consists of changing the values of model input parameters, within a reasonable range, in an attempt to match a given aquifer hydraulic state or solute behavior within some acceptable criteria. This necessitates that field conditions at a facility be properly characterized. Lack of proper characterization may result in a model that is ―calibrated" to a set of conditions which is not representative of actual field conditions.

To identify and understand the behavior of the aquifer system in the basin, the properties of materials found from borehole log, literature works done – on the hydrogeological behavior of the aquifer. The present study deals a model a complex real life situation. The domain of the model is based on the geometry and topography of the WSRB. The domain is three- dimensional type. In this study finite element method is used to approximate the governing equations. The output of this study will pave different scenarios of study results which describes detail groundwater flow system of the basin. It also develops ideas for sustainable utilization and better managements to plan multipurpose projects for the basin. This study in WSRB is therefore; contribute some points as an input for water resource management of the basin to provide sustainable and equitable supplies for communities in and around the south eastern Ethiopia.

1.2 Statement of the Problems

Water plays a major role in virtually every aspect of human life. The objective of managing water resources is beyond reduction of hunger and poverty through its effects on increasing agricultural production (Feletcher, 1995)

Ethiopia is one of the most drought prone countries in the world, with a significant proportion of the net gross domestic product dependent on rain fed agricultural practices. The intensity and duration of rainfall is highly erratic and variable, resulting in significant reductions in agricultural production and in some cases total crop failure.

The dominant agricultural system in Ethiopia is small-holder production of cereals under rain feed conditions, leaving the population and economy extremely vulnerable to hydrology. Ethiopia has the largest livestock population in Africa. Livestock is an integral part of nearly all the mixed type highland farming systems and the principal store of farmer wealth.

Lack of proper estimation of groundwater is the main reason why groundwater exploitation and management have serious problems compared to surface water in the country. For proper estimation of recharge time series data of rainfall, runoff, evaporation, ground water level and hydrodynamic parameters of the aquifers (transimissivity and storativity) are required (WWDSE, 2004). The study area of this research is wabi Shebelle river basin, situated south eastern part of Ethiopia. The Wabi Shebelle river basin is one of the water scarce basins in the country. While having the largest area coverage, its annual runoff and water availability are one of the lowest among the major river basins. This is one of the more reasons for the selection of the basin as the study region. The annual amount of rainfall is relatively small and erratic as compared to other parts of the country.

Ground water is the safest and most reliable water source, use in domestic, irrigation, industries, and municipality purposes. Also the mechanisms of groundwater recharge are not known, but infiltrations associated to the river flows are considered the main component of inflows. There are rough maps estimating zones of high groundwater potential. Together with local population densities these provide an indication for quantity and quality of groundwater resources.

1.3 Research Questions

This research has planned to answer the following questions:

- Can we study the regional groundwater characteristics of Wabi- Shebelle river basin using finite element numerical ground water model?
- What is the relevant hydro geological, water well and selected land use information in the study area?
- Can hydrological, metrological, geological, well inventory data used to estimate the groundwater potential of the basin?
- Can numerical groundwater model establish the groundwater flow direction of the area?
- How can we simulate the model with field data (metrological data, geological data, and well inventory data)?
- Can we describe the hydrogeology of the area from the known hydraulic conductivity distribution?
- What mean by accessible depth of groundwater and what are the factors that affect it?

1.4 Objective of the study

1.4.1 General objective

The general objective of the study is to investigate the regional groundwater characteristics and to assess the groundwater resource potential of Wabi- Shebelle river basin using finite element numerical ground water model. This makes an interest from the groundwater potential point of view to evaluate its water resource potential on the basis of aquifer characterization, recharge mechanism, groundwater flow conditions and the hydrochemistry of the groundwater.

1.4.2 Specific objectives

Within these broad objectives, some of the specific objectives that need to be met include;

- Compile and review relevant hydro geological, water well and selected land use information
- To assemble relevant data and information that can be used to develop a long term plan to manage the quantity and quality of groundwater resource within Wabi- Shebelle river basin.
- Identifying of existing water point data‘s in WSRB.
- To develop the groundwater flow direction of the basin.
- To determine the accessible groundwater depth in the study area.
- Describe the hydrogeology of the area.
- To develop three dimensional numerical groundwater model using finite element method.
- To provide additional input to other researchers in the area.

1.5 Significance of the study

Area wise, Wabi Shebelle river basin is one of the largest river basins among nine river basins in Ethiopia, but it the lowest on water resource point of view. It accounts for about 17% of the country_s land area and 11 % of the country_s population. (WWDES, 2004) The irrigation potential of this basin as estimated by WAPCOS, 1990 was at 204,000 ha, whereas its hydropower potential was estimated at 6143 GWh/year. (WWDSE, 2004) There are two major distinct settlements in this basin and these are the highlands and lowlands exhibiting sedentary and pastoral ways of life respectively. This basin is known generally for its wide range of variation of climate and primarily because of climatic factors most of the crop production in the basin is in the highland areas. Drought has been a common recurring phenomenon every year in one or other part of the basin. The result of this research could be an input for the limited fresh water resource development and management of the basins.

1.6 Purpose and Scope of the study

The purpose of this report is to present the results obtained from the application of a finite-element three dimensional groundwater model. In doing so the study simulates steady state three dimensional groundwater flow model of WSRB. This regional model was developed in part to gain a better understanding of the ground-water flow system beneath the study area, as well as for later use in simulating the change in position of the water table resulting from a change in future climatic conditions leading to increased precipitation and increased recharge. Model results also can be used as a basis for assessing the effect of future ground-water withdrawal for irrigation.

Results from the present modeling effort may be used in modeling the potential of groundwater in the basin in more detail manner. The results may be useful in siting additional boreholes that could be used to characterize the flow system further.

The report includes a discussion of the assumptions and values of variables used in the model and estimates of hydraulic conductivity determined by the trial and error calibration procedures. The purpose of modeling Models are typically used to: Evaluate the interaction between hydrology and geologic systems.

Three-dimensional models have been used extensively in groundwater study and are generally adequate for predicting aquifer head changes and groundwater flow paths and travel times. The three-dimensional model described in this report was developed

1) To assist the potential of Groundwater in WSRB

2) To investigate hydraulic conductivity variation to a geologic; and

The scope of this study was to develop a three dimensional groundwater model of the aquifers in the WSRB. Three-dimensional models have been used extensively for groundwater modeling in Ethiopia and are generally adequate for predicting aquifer head changes. The model was developed using the following steps:

- Create the three-dimensional conceptual model of the Site
- Numerical model implementation;
- Development and calibration of a regional steady state model;
- To estimate the groundwater potential of WSRB
- To identify the major groundwater sources of recharge over the WSRB;
- To identify the importance of geological parameters.
- To investigate the groundwater-surface water interaction.

1.7 Modeling Approach

The finite element is a numerical method like finite difference method but it is more general and powerful in its application to real-world problems that involve complicated physical geometry and boundary conditions.

In FEM, a given domain is viewed as a collection of sub-domains, and over each sub-domain the governing equation is approximated by any of the traditional variational methods.

The main reason behind taking approximate solution on a collection of sub-domains is the fact that it is easier to represent a complicated function as a collection of simple polynomials. (Mardal, 2011)

The design of the finite-element mesh allowed for complex geometries in the modeled area, including barriers, aquifers, and recharge and discharge areas. An automated mesh-generation program was used to construct the initial mesh. Different terrains missive zones were considered in the selection of control blocks used by the mesh-generation program. Triangular elements were generated because they could be easily rearranged manually and still maintain a proper element-aspect. (Brownbill, 2011)

The research mainly relies on meteorological, hydrological, geological data‘s. This study focuses on equivalent porous medium approach. The equivalent continuum approach uses equivalent properties of rock mass as the input data for a continuum analysis. This is a common modeling method used in the field of rock mechanics and hydrogeology.

1.8 Thesis Organization

This report is organized as follows; the thesis is divided into five chapters. Chapter one provides introduction, objective, background and problem of the study area. Chapter two presents the literature review and previous study of the area. The general procedure and methodology of the research is included in chapter three. A more detail description of the study area is also presented in this chapter. Chapter four deals with the data analysis and discussion part of the study. The last chapter five draws conclusion and expresses the modeler‘s idea about the basin study. Finally the reference material and the data used by the model are presented in the reference and appendix respectively.

2. LITERATURE REVIEW

Previous chapters provided background information about the importance of this study and the primary objectives of this project. This chapter provides a review of previous groundwater study of the basin.

2.1 Previous studies

Researches have worked in the study area at regional levels in the past. Most of previous works focused on the hydrogeology, hydrology, humanitarian action and land use changes. Most of the hydrogeological studies are carried out by the governments and by the non-governmental organizations (NGOs).

In 1961 there was preliminary study Wabi Shebelle river basin by Electoproject, Zagreb-Yugoslavia. The main purposes of the report was: the preliminary report of Wabi Shebelle watershed, the scheme for water economy over the whole watershed, to carry out work suggested in the preliminary report provided that this works are included also in the water economy schemes, to design and give priority to those projects which is proved indispensable for the cultural and economic developments of the country.

In 1972 a detail study was conducted by National Water Resource Commission which studies the Geological Survey of the Wabi Shebelle Basin. The content of this study includes explicative note of the geological map of the basin, the geological map of Ogaden, geological map of wabi Shebelle basin in scale of 1/1000000. This study gives clues for general overview the basin geology, stratigraphy, structural patterns, hydrology, geological and geomorphological studies.

The first groundwater resource assessment was attempted over the whole basin has been made by WAPCOS 1990, by using the sub-surface drainage and recharge approach which are very crude approximation (WWDSE, 2004).

The most important works in relation to groundwater system analysis were done by (WWDSE, 2004). The main objectives of the Master plan study were to assess the groundwater resources of the area by determining the hydrogeological conditions such as recharge and discharge conditions, spatial distribution of different aquifers, hydraulic parameters and water quality of the aquifers and by giving recommendations on the strategy of groundwater resources development. The activities conducted to achieve the objectives include review of previous studies, inventory of water points, and analysis of water quality, geological mapping and hydro meteorological studies. These studies demonstrated preliminary estimation of groundwater recharges of the Wabi Shebelle river basin the following methods of estimation are applied i.e. Safe yield method, Recharge Assessment based on Rainfall Infiltration and Hydrograph separation.

Accordingly the estimated values are;

- Safe yield estimation 2294.7 MCM
- Recharge assessment from rainfall infiltration 2228.0MCM
- Hydrograph separation 1128.6 MCM

According to the report, from these methods, the hydrograph method estimation of 1128 MCM/year uses more available data for estimation than the other methods.

In 2006, Catchment Characteristics as predictors of Base Flow Index (BFI) in Wabi Shebelle river basin, east Africa by Adane Abebe and Gerd Foerch. This paper seeks to establish a relationship between the climatic, morphologic and geologic features of a catchment to its base flow in the Wabi Shebelle river basin. It employs the parameters catchment size, stream density, climate index, hypsometric integral, normalized digital vegetation index (NDVI) extracted from satellite images and geologic features to derive the base flow index of a catchment. Values of base flow index determined for a network of stream flow gauges are matched to the composite morphometric and climatic data using spatial and regression analyses.

In 2009, Hydrological Drought Analysis-occurrence, severity, risks: of Wabi Shebelle River Basin, is undertaken by Adane Abebe, This study analyses hydrological drought with due emphasis to ungagged catchments. Identification of hydrological drought and methods of unveiling its intrinsic multi-variate characteristics are investigated. The severity of drought has been examined using a multitude of methodologies.

So from the above information the base flow separation method was the one that the researches recommended. But base flow separation method is indirect approach of groundwater potential assessment. It estimates the amount of stream flow of Wabi Shebelle River that is contributed by groundwater. In addition it uses only hydrological data. Finite element method of numerical groundwater modeling (using TAGSAC) is better method to study the groundwater potential of the study area. Rather than base flow separation method, this method uses more input data‘s like geological, metrological, water point data, stream flow data, etc. for groundwater potential assessment. There is no groundwater model that studies groundwater potential of the basin before. Therefore, this study is proposed to address some ideas about groundwater modeling and other related aspects regarding the basin groundwater resource potential and sustainable management.

2.2 Groundwater Resources

Groundwater is the major source of water across much of the world, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential. Aquifers generally are replenished by effective rainfall, rivers, and lakes. This water may reach the aquifer rapidly, through macro-pores or fissures, or more slowly by infiltrating through soils and permeable rocks overlying the aquifer.

Many parts of Ethiopia have limited supplies of groundwater because of the poor permeability of the crystalline rocks and variable water-table depths. Groundwater is an important source of water and is the dominant source for domestic supply in many areas, especially the dry areas where surface waters are scarce and seasonal (e.g. Somali region in the east). Much of the remaining water supply is from rivers, although these often only supply water for parts of the year. (BGS, 2001)

Groundwater in the area is exploited in the basin in three forms,

- Capping of springs in the upper basin emerging from basalts, sandstones and limestone and metamorphic rocks,
- Hand dug wells in the weathered part of the metamorphic rocks (Harar area) and alluvial and alluvial fans of intermittent rivers and streams in the Ogaden area,
- Deep wells in the limestone and volcanic rocks

Groundwater occurrence in the basin is extensive; the problems are low permeability of the sedimentary formation and salinity. The salinity of the groundwater is caused by two factors i.e. salinity by evaporation (secondary salinity) i.e. salinity of the alluvial aquifer and salinity caused by geological formation due to gypsum (primary salinity) or a combined cause. There could be a possibility of the occurrence of deep groundwater in Hamanlei series and Antalo limestone in the central part of the basin underlain by younger and thick sedimentary formation, which outcrops at the upper basin (WWDSE, 2004).

The groundwater of Wabi Shebelle can be generally categorized into three parts i.e. the alluvial, volcanic and the sedimentary formation aquifers (WWDSE, 2004).

The hydro geological conditions of the country are linked with the occurrence and distribution of the various hydro stratigraphic units, the topography, the recharge and discharge conditions which, in turn are related to the spatial and temporal variation of rainfall. These hydro stratigraphic units include the Precambrian basement, Paleozoic rocks and Mesozoic sediments (Tertiary and Quaternary volcanic and the Tertiary and Quaternary sedimentary rocks and sediments).In most cases, the groundwater/aquifer systems of Ethiopia are discontinuous and isolated. There are confined, unconfined and semi-confined aquifer systems with local artesian conditions. The temporal and spatial variation of groundwater occurrence is very high. This is owing to differences in structural setting and local litho logical variations; the former being the main cause for the drastic variability. (Mawatha, 2012)

Many arid and semi-arid regions in Ethiopia rely on groundwater resources for their domestic supply and agricultural production. Therefore, a better understanding of the groundwater systems is important to manage these resources for sustainable urban development. Increasing water demands due to an increase in population and land use change will further increase dependence on groundwater in this region. (Adane, 2014)

The existence of numerous perennial springs, out cropping along faults and fractures from upper part forms substantial part of the base flow Wabi Shebelle river flow ascertains the presence of groundwater resources in the part of the Basin.

The 2011 report from Somali regional state shows, the low annual rainfall and its uneven distribution, together with the frequent recurrence of drought, have made water the single most important element that determines the living style of the population in south eastern part of the basin.

Consolidated Sedimentary Aquifers sandstones or limestone‘s with consolidation and fracturing increasing with depth/age; variable, but can form thick aquifers, which have moderate to very high groundwater storage.

According to Wabi Shebelle River Basin Integrated Development Master Plan Study Project, the groundwater occurrence, potential and quality decrease from northwest to southeast direction in the river basin. The total estimated recharge for the Basin works out to 2315 Mm^3 (1385 Mm^3 in Oromiya region and 930 Mm3 in Somali region), the utilizable being 1737 Mm3 after deducting poor quality groundwater. Generally 80% of the available ground water can be exploited without any adverse impact on the ground water regime. Thus about 1360 MCM of ground water is available for use. (WWDSE, 2005)

Previously there are studies that discuss the groundwater potential WSRB. But this study put the estimation to the groundwater potential using three dimensional finite element models. Therefore this work will bring new insight concerning modeling groundwater in WSRB.
Thus, as a part of filling the gap, the present study, numerical groundwater model was used to systematically assess the importance of each input parameters in the evaluation of groundwater occurrence and potential zone in the area.

2.3 Conceptual Modeling Approach to the study

Usually three vertical zones are distinguished in a hard rock environment. An upper or weathered zone characterized by regolith, colluvium and talus, side by side with alluvial, fluvial, glacial and lacustrine deposits with intergranular porosity prevailing. A middle fractured zone with depth between tens to hundreds of meters. Here permeability‘s generally decreasing with depth, due to the dependence of fracture aperture on exogenous geologic processes. At lasts a deep or massive zone with relatively scarce fracture and fault zones. In homogeneities in the deep or massive zone, in general due to light fracture apertures may form interconnected networks facilitating enhanced regional to continental groundwater flow (Krasny & Sharp, 2007).

In practice hydraulic parameters are usually derived from aquifer pumping tests but in fractured media it is very difficult to extrapolate them to the scale of the grid size of the regional model. Therefore recharge, rather than transmissivity/hydraulic conductivity is used as an independent variable during regional steady-state model calibration and in transient model, temporal distribution of recharge (if available) in place of storage coefficient and porosity (Lubcynski, 1997).Effective porosity is defined as the ratio of void space that is available for groundwater flow, i.e. void spaces used by adhesive and capillary water excluded. In fractured medium effective porosity depends in part on fracture frequencies, orientations and apertures. Also it was found that effective porosity is a dynamic parameter that depends on fluid velocity and fluid or tracer molecular size. Furthermore, a fractured material can have a lower effective porosity than unfractured one of the same material. This arises from the dominant effect that even small fractures can have on groundwater flow. The continuity of fractures profoundly affects the effective porosity. Is the fractured material treated as a porous continuum, the equivalent continuum effective porosity is estimated as the volumetric fraction of fracture void space contributing to flow per bulk volume of rock, i.e. interconnected matrix void space is neglected. Due to the low matrix permeability compared to the fractured permeability, matrix void space may not substantially contribute to groundwater flow and advective contaminants transport (Gordon, 1986).

In principle the EPM has some limitations, only a cell size much bigger than the fracture spacing should be used. **(**Weiler, 2010**)** Besides, the fracture network must be interconnected and rather uniformly distributed within zones of equal density, when dealing with contaminant fate and transport analysis where all field scales are equally important (Kresic, 2006).

Several conceptual models exist to represent groundwater flow and solute transport in fractured geological systems.

The most commonly used are

- the equivalent porous medium (EPM) model,
- the dual-continuum model and
- The discrete fracture model.

The differences between each model reside in their mathematical complexity, data requirement and also on their ability to accurately represent observations.

2.3.1 Equivalent Continuum Model

The equivalent continuum models are based on the concept of the representative elementary volume introduced by Bear. The heterogeneous system is modeled by a single continuum which is divided into sub-volumes with uniform properties. These hydraulic properties are obtained by averaging over each sub-volume. Hence, the sub-volumes must be sufficiently large such that the average value will be representative for the whole sub-volume. In this way, there is no explicit distinction made between the matrix and the fractures, and flow occurs throughout the system.

An equivalent continuum model is a model which we will also refer to as the single model (as opposed to the dual model). In this model we deal with a single continuum, and we have no knowledge of the location of the fractures. Local thermal equilibrium is assumed, and we cannot discern between fluid and solid.

The volume of interest is considered to be large enough that, on average, permeability is a sum of fracture and porous media permeability. This approximation substantially simplifies the flow problem. In broad terms, where the scales of integration are sufficiently large, the single equivalent continuum approximation will do a fair job of conserving fluid mass. It may, however, be a poor predictor of spatial and temporal distributions of contaminant fluxes. (Diodato , 1994)

Fractured material represented as an equivalent porous medium (EPM) by replacing the porosity and hydraulic conductivity distributions with continuous porous medium having so-called equivalent or effective hydraulic properties. An EPM approach assumes that the fractured material can be treated as a continuum and that a representative elementary volume (REV) of a material characterized by effective values of hydraulic parameters can be defined. The EPM approach treats the porous medium and fractures as a single domain, with a single set of hydraulic and transport properties.

2.3.2 Dual-porosity Model

The second approach is the dual-continuum model. In this approach, the porous medium and fractures form two separate domains that are both represented by their own REV. In the mathematical formulation, both domains are coupled with a fluid or mass exchange term. For large-scale domains, this approach can also be inaccurate if discrete fractures are present in the porous medium.

In the early 1960s, Barenblatt et al. and Warren and Root introduced the concept of dual-porosity models for fractured porous media. The idea is to divide the system into two parts: the fractures and the matrix. All flow occurs in the fractures, while the matrix merely acts as source or sinks for the flow system. To characterize the porous media, we associate a primary porosity with the pore system, and a secondary porosity with the fracture system. We can also define two pressures, volume fluxes, etc., for each point; one primary and one secondary. The fractures are assumed to be uniform and oriented parallel to the principal axes of permeability. The two systems are then superimposed, and the equations are modified to include a coupling term that describes the communication between the two regions. (MeKay, 1997)

2.3.3 Discrete Fracture Model

The third conceptual model is based on a discrete representation of individual fractures. Each fracture is located in the simulation domain and assigned hydraulic and transport properties. In discrete fracture models, each fracture is modeled explicitly. In field scale there is usually a very large number of fractures, and it is impossible to model all of them explicitly. In addition, there is no detailed information about the field geometry and fracture characteristic available. Hence, for the model to be useful, fracture networks containing the significant fractures impacting the flow are generated based on observations and measurements. These models are suitable if the complex fracture network can be approximated by only several fractures of significance. The system is then treated as any other non-homogeneous medium.

2.4 Groundwater flow Model formulation

Models use a single equation or a set of governing equations that represent the process (es) occurring (e.g., ground water flow, solute transport, etc.). They can be analytical or numerical; deterministic or stochastic; or steady state or transient. In addition, models can be one-, two-, or three-dimensional.

Numerical models (e.g., finite difference or finite element) solve the partial differential flow or solute transport equations through numerical approximations using matrix algebra and discretization of the modeled domain. In discretization, the model domain is represented by a network of grid cells or elements and the time of the simulation is presented by time steps. The accuracy of numerical models depends on the model input data, the size of the space and time discretization‘s, and the numerical method used to solve the model equations. (Strickland, 2007)

Groundwater flow models are based on the differential equations for groundwater flow. Ground water flow and contaminant fate and transport models are used to help understand and evaluate hydrogeological systems. Models are simplified representations or approximations of real hydro geologic systems and may incorporate a number of processes operating within ground water and/or unsaturated zones.

The derivation of equation used in groundwater applications are based on the conservation principles dealing with mass, momentum and energy. This principles require that the net quantity (mass, momentum, and energy) leaving or entering a specific volume of aquifer during a given interval be equal to the change in the amount of that quantity stored in the volume.

Use of Groundwater models: To describe the system in order to analyses various assumptions. To generate a hypothetical system that will be used to study principles of groundwater flow associated with various general or specific problems.

Mathematical model: simulates ground-water 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 and Woessner, 1992).

The code can simulate three-dimensional, transient flow of groundwater of constant density through porous material using a partial differential equation derived using Darcy‘s law and a mass-balance equation:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) + W = S_s \frac{\partial h}{\partial t}$$

where Kx, Ky and Kz are values of hydraulic conductivity (m/s) in the x, y and z coordinate directions, *h,* is head (m), W is a volume flux per unit volume where negative values are extractions and positive values are injections, or recharge (s–1), S_s is the specific storage of the porous medium (m^{-1}) and t is time (s).

2.5 Groundwater Flow Equation

Numerical solutions to the equation governing variably saturated flow are usually obtained using either the finite difference (FD) method or the finite element (FE) method. A detailed comparison of these methods shows that the main difference between them is in how the numerical schemes spatially average the variation of material properties. Further differences are also observed in the way that flux boundaries are represented in FE and FD methods. A modified finite element (MFE) algorithm is used to explore the significance of these differences. (Simpsona, 2012)

The finite element is a numerical method like finite difference method but it is more general and powerful in its application to real-world problems that involve complicated physical geometry and boundary conditions. In FEM, a given domain is viewed as a collection of sub-domains, and over each sub-domain the governing equation is approximated by any of the traditional variational methods. The main reason behind taking approximate solution on a collection of sub-domains is the fact that it is easier to represent a complicated function as a collection of simple polynomials. (Mardal, 2011)

Finite difference method approximates differential equation by differential approach, whereas finite element method approximates differential equation by an integral approach.

Advantages of finite element method: Can readily handle very complex geometry, Can handle a wide variety of engineering problems, Can handle complex restraints, Can handle complex loading, High accuracy easily included., Evaluates cross-product terms better. (Olivier, 2004)

2.6 Basics of Finite-Element Methods

The basic idea in the finite element method is to find the solution of a complicated problem by replacing it by a simpler one. Since the actual problem is replaced by a simpler one in finding the solution, we will be able to find only an approximate solution rather than the exact solution. The existing mathematical tools will not be sufficient to find the exact solution (and sometimes, even an approximate solution) of most of the practical problems. Thus, in the absence of any other convenient method to find even the approximate solution of a given problem, we have to prefer the finite element method. Moreover, in the finite element method, it will often be possible to improve or refine the approximate solution by spending more computational effort. (Rao, 2005)
The introduction of finite element method to groundwater is relatively recent development compared to finite difference method. Unlike finite difference method, which is usually implemented with rectangular cells, finite element method can be implemented with variety of

element types. Triangular elements are probably the most commonly used, being defined by three nodes one at each corner.

The finite-element method (FEM) is a numerical analysis technique for obtaining approximate solutions to a wide variety of problems in physics and engineering. The method was originally applied to structural mechanics but is now used in all fields of continuum mechanics. Huebner (1975) describes four different approaches to formulate the finite-element method for a problem, which are: the direct approach, the variational approach, the weighted residual approach, and the energy balance approach (Huebner 1975). In groundwater problems, the approach frequently used is either the weighted residual or variational approach.

The finite-element method (FEM) uses a concept of "piecewise approximation". The domain of the problem, that is the extent of the aquifer to be simulated, is divided into a set of elements or pieces. In theory, the elements can be of different shapes and sizes. Most FEM computer programs use one shape element, most commonly either triangular or quadrilateral elements. In the groundwater model MODFE (Torak 1993; Cooley 1992) triangular elements are used, whereas in the groundwater model SUTRA (Voss 1984) quadrilateral elements are used. Point values of the dependent variable (for example, head) are calculated at nodes, which are the corners or vertices of the elements, and a simple equation is used to describe the value of the dependent variable within the element. This simple equation is called a basis function and each node that is part of an element has an associated basis function. The simplest basis functions that are usually used are linear functions. The solution to the differential equation for flow is approximated by a set of elements in which the dependent variable only varies linearly within the element, but the entire set of elements approximates the complex distribution of head or concentration. Huyakorn and Pinder (1983), Huebner (1975), Zienkiewicz (1971), Wang and Anderson (1982), and Cooley (1992) provide more comprehensive explanations of the method.

Although the method has been extensively used in the field of structural mechanics, it has been successfully applied to solve several other types of engineering problems, such as heat conduction, fluid dynamics, seepage flow, and electric and magnetic fields. These applications prompted mathematicians to use this technique for the solution of complicated boundary value and other problems. In fact, it has been established that the method can be used for the numerical solution of ordinary and partial differential equations. The general applicability of the finite element method can be seen by observing the strong similarities that exist between various types of engineering problems. (Rao, 2005)

The use of triangular element gives finite element methods a significance advantage over finite difference methods. Irregular shape boundaries and heterogeneities can be much more accurately simulated without excessively increasing the number of elements.

2.7 Governing Equations for Saturated Groundwater Flow

In the previous section I tried to describe all the governing equation used in the study; equation groundwater flow. The governing equation for water flow in saturated medium can be obtained by combining a special form of Darcy‘s law (derived from the water phase momentum balance) and the continuity equation written for the water phase. The derivation is traditionally done by referring to a cube of porous material (Fig. 1) that is large enough to be representative of the properties of the porous medium and yet small enough so that the change of head within the volume is relatively small (Anderson and Woessner, 1992).

The process of groundwater flow is generally assumed to be governed by the relations expressed in Darcy's law and the conservation of mass. Darcy's law does have limits on its range of applicability, however, and these limits must be evaluated in any application.

The development of mathematical equations that describe the groundwater flow processes may be developed from the fundamental principle of conservation of mass of fluid.

The mathematical treatment of the groundwater flow equation through a porous medium depends upon an equation that captures the essence of the physics of flow. The basis for developing such an equation is a conservation statement that balances the inflow, outflow and change in water mass within a representative volume of porous medium.

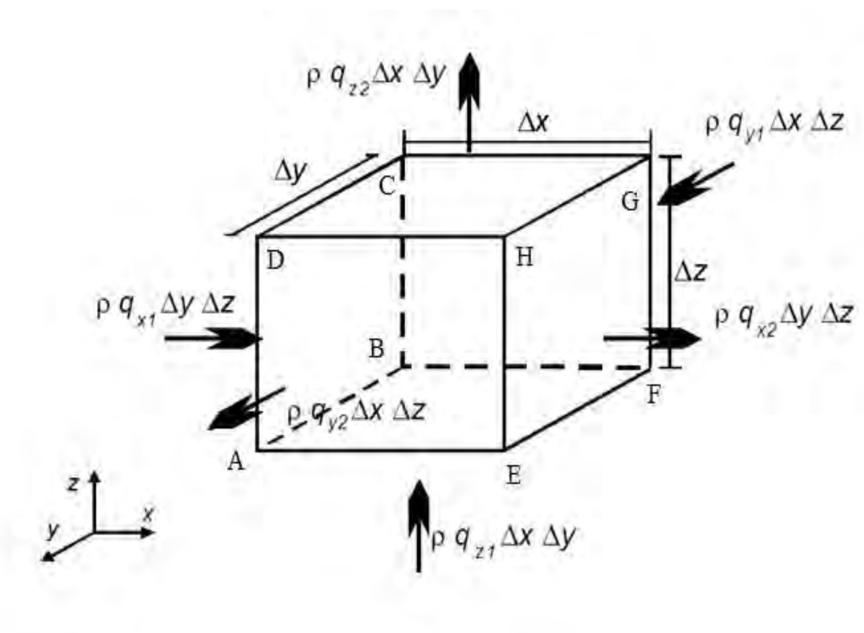

Figure 1 the representative elementary volume (REV)

The flow of water through the REV is expressed in terms of the discharge rate (**q**), whose magnitude in the three coordinates will be $\mathbf{q_x}$, $\mathbf{q_y}$, and $\mathbf{q_z}$.

Statement of Mass Conservation (or Continuity)

(For Transient, Saturated Flow)

Volume in – Volume out = Change in storage

Volume into face x **= $q_x A_x$ = q_x d_y d_z**

Volume into face y = **q_y d_x d_z**

Volume into face z = **q_z d_x d_y**

Total volume inflow = **q_x d_y d_z + q_y d_x d_z + q_z d_x d_y**

The governing equation of flow in porous medium is derived from mass conservation law applied to a control volume. Given a representative volume of porous medium, a general equation for conservation of mass for the volume may be expressed as:

(Rate of mass inflow) – (rate of mass outflow) + (rate of mass production/consumption) = (rate of mass accumulation)

$$\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial z})=S_s\frac{\partial h}{\partial t}-W$$

Where K is hydraulic conductivity (LT^{-1}); h is peziometric head (L); W volumetric source flux (L^3T^{-1}); Ss is specific storage (L^{-1}); A is cross sectional area of aquifer in each direction (L^2)

Consider a unit volume filled with water saturated porous medium with unit length Δx, Δy en Δz (figure 1). Mass inflow rate through side **ABCD** is

$$\boldsymbol{\rho_w q_x \Delta y \Delta z}$$

Where, $\boldsymbol{\rho_w}$ is the water density (kg/m3) and $\mathbf{q_x}$ is the Darcy velocity in the x-direction (m/d).

Mass outflow through the side **EFGH** is;

$$\boldsymbol{(\rho_w q_x + \frac{\partial(\rho_w q_x)\Delta x}{\partial x})\Delta y \Delta z}$$

Mass inflow and outflow respectively through the sides **CDHG** and **BAEF** are;

$$\boldsymbol{\rho_w q_y \Delta x \Delta z}$$

$$(\rho_w q_y + \frac{\partial(\rho_w q_y)\Delta y}{\partial y})\Delta x \Delta z$$

Where, q_y is the Darcy velocity in the y-direction (m/d).

Mass inflow and outflow respectively through the sides **ADHE** and **BCGF** is:

$$\rho_w q_z \Delta x \Delta y$$

$$(\rho_w q_z + \frac{\partial(\rho_w q_z)\Delta y}{\partial z})\Delta x \Delta y$$

Where, q_z is the Darcy velocity in the z-direction (m/d).

Adding these results gives the net outflow rate (inflow minus outflow rate) through all the faces:

$$-\left(\frac{\partial(\rho_w q_x)}{\partial x} + \frac{\partial(\rho_w q_y)}{\partial y} + \frac{\partial(\rho_w q_z)}{\partial z}\right)\Delta x \Delta y \Delta z$$

Inflow – Outflow = rate of change of storage

(Minus because outflow is greater than inflow)

Taking density as constant, the total change in flow rate is equal to the change in storage and is expressed as:

$$\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right)\Delta x \Delta y \Delta y = \boldsymbol{change\ in\ storage}$$

The solution to this equation describes the value of the hydraulic head at any point in a three-dimensional-flow field at any given time or, more precisely, how the head is changing with time at any place.

So, groundwater flow is governed by Laplace‘s equation in the case of steady state flow. The existence of sink (e.g. a pumping well) or source of water (e.g. injection well or some other source of recharge) within the REV is unquestionable. The volumetric inflow rate of such sources is represented by R*dxdydz. Here the R* is defined to be intrinsically positive when it is a source of water; therefore it is added to the right hand side of the above equation. Therefore the equation becomes:

$$\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}-R^*\right)\Delta x\Delta y\Delta y = change\ in\ storage$$

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

$$S_S = -\frac{\Delta V}{\Delta h\Delta_x\Delta_y\Delta_z}$$

The sign convention is that the V is intrinsically positive when the □h is negative, or in other words, water is released from the REV when head decreases.

The rate of change in storage in REV will be:

$$\frac{\Delta V}{\Delta t} = -s_s\frac{\Delta h}{\Delta t}\Delta_x\Delta_y\Delta_z$$

$$\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z} = -s_s\frac{\partial h}{\partial t}+R^*$$

Apply Darcy‘s Law: (for case where hydraulic conductivity tensor axes are aligned with **x,y,z** axes)

$q_x = -K_x\frac{\partial h}{\partial x}$ $q_y = -K_y\frac{\partial h}{\partial y}$ $q_z = -K_z\frac{\partial h}{\partial z}$

Where $\mathbf{k}_{x,y,z}$ are directional hydraulic conductivities.

Substituting these expressions in Eq. A.4 the desired groundwater flow equation is formulated: The three-dimensional movement of ground water of constant density through porous earth material may be described by the partial-differential equation:

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right) = s_s\frac{\partial h}{\partial t}-R^*$$

Coordinate system must be selected so that axes are collinear with principal axes of hydraulic Conductivity. Kx, Ky, and Kz are components of the hydraulic conductivity values along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T); h is the potentiometric head (L); W is a volumetric flux per unit volume representing sources and/or sinks of water, with $W<0.0$ for flow out of the ground-water system, and $W>0.0$ for flow into the system (T-1); S_S is the specific storage of the porous material (L^{-1}); and t is time (T).

In the above derivation it is assumed that Kx, Ky, and Kz are collinear to the X, Y- and Z- Axes. If the geology is such that it is not possible to align the principal direction of the hydraulic conductivity tensor with the rectilinear coordinate system, a modified form of equation that utilizes the hydraulic conductivity tensor is required. For three dimensional spaces of hydraulic conductivity tensor;

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

The hydraulic conductivity tensor is symmetric, that is Kxy = Kyx; Kxz = Kzx and Kyz = Kzy . This means that actually only six distinct components in three dimensional flows, and three such components in two-dimensional flow, are needed for fully defining the hydraulic conductivity.

It is always possible to find three mutually orthogonal directions in space such that when these directions are chosen as the coordinate system for expressing the components K_{ij}' we find that K_{ij} == 0 for all i = j and $K'_i = 0$ for i = j. These directions in space are called the principal directions of the anisotropic porous medium (actually of the permeability of the medium).When the principal directions are used as the coordinate system, the above equation becomes; (Bear, 1987)

$$K = \begin{bmatrix} K_x & 0 & 0 \\ 0 & K_y & 0 \\ 0 & 0 & K_z \end{bmatrix}$$

2.8 Assumptions

The numerical model of ground-water flow described in this report simulates transient flow of ground water in which the flow field is three dimensional. The numerical technique used to solve the transient radial flow equations is called the Galerkin finite-element method. Use of the model requires certain assumptions, or simplifications. These assumptions are

1. The saturated thickness of an aquifer does not change significantly
2. The aquifer is finite in extent. (A constant-potential boundary far from the well or basin is generally established in the model.)
3. Medium is non-deformable (i.e., no inelastic deformation)
4. Fluid is of nearly constant density
5. Darcy‘s Law applies

Linear triangular elements are used to represent the flow field. The section to be simulated is represented as a net, or grid, of connected elements. The model program allows each element to be assigned a value of the hydraulic conductivity in the X, Y, and Z-directions.

2.9 Model Limitations

• Scarcity of data outside of the axis

• Model cells are larger than hypothetical release areas

• Limited information regarding fractures and faults

The main limitations of the equivalent porous media models is that they cannot accurately simulate the direction or rate of water flow in the aquifer, which precludes them from simulating point source contamination or delineating aquifer protection zones. It is questionable whether any model can simulate these processes because of the complexity of karst systems.

The model covers a largest river basin, which discretize element size of 5 x 5 x 5 km triangular element due to unavailability of the computing device. So this is one of the limitation, the finnier the element the more accuracy of estimation.

The results of this study show the ability of equivalent porous media distributed and lumped parameter models to simulate regional groundwater flow, which is critical for managing water resources in aquifers and predicting the impact of future pumping and potential future drought conditions on spring flow. (Scanlon, 2013)

3. METHODOLOGY

The previous chapters give background information about the objective of the research and discussed previous water resource studies done in WSRB. This chapter discusses details of data used for applying numerical groundwater model using finite element method for WSRB.

The objective of this study is determining the groundwater resources potentials of WSRB. So to implement this objective the method used is three dimensional numerical groundwater modeling. In doing so the study works on reviewing different literatures, collection and assessing previous researches done in the study area.

3.1 Description of the study area

3.1.1 Location and Convenience

The study area is found in south eastern Ethiopia covering a large part of the country's land mass. The basin is found in the two largest regional state of the country; the Oromiya regional state in the North West and the Somali Regional State in the South East. There are also two regions that contribute their part for the basin (i.e. north eastern part of the SNNP and the whole Harari regional state). The higher elevation area is found in Oromiya regional state which is the major contributor of the surface water of the basin. On the other hand the lowest elevation part is found in Somali regional state, which is south and south eastern part of the basin. Geographically, the study area is bounded between latitudes 4° 55' 31" N and 9° 34' 59" N; and longitudes 38° 41' 38" E and 45° 28' 11" E with north to south average length of 530 km and east to west average width of 450 km having areal extent of about 191146 sq. km out of 1127261 sq. km (the country landmass). It covers about 17% of the country landmass.

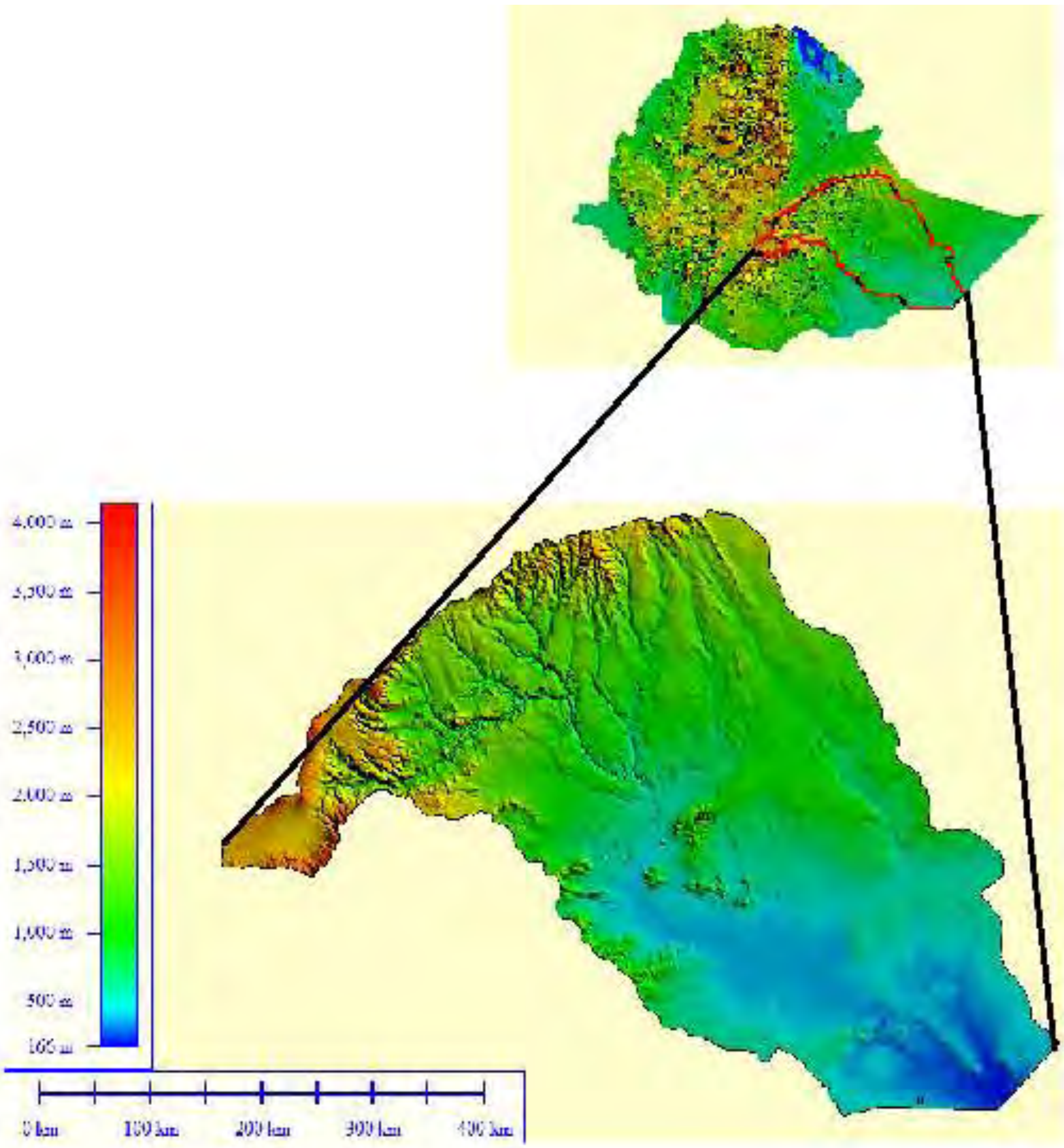

Figure 2 Location map of basin

In this study the area of the basin delineated by the researcher due to some added areas in the previous studies as a part of the basin. So that the area covered by WSRB is about 191146 sq.km out of 1127261 sq.km (the country landmass), which covers about 17% of the country.

The WSRB can be accessed by the Addis Ababa - Dire Dawa main asphalt road and Ethio-Djibouti railway. There is also a flight from Addis Ababa to Dire dawa and Jijiga towns. Additionally, it can also be reached by Addis Ababa – Adama- Assela, all weather roads, Addis Abeba – Shashemene- Kofele-Dodola-Adaba-Robe all weathered roads and a number of dry weather road like (Babile- Fik- Hamere- Imi- Gode) networked starting from the main road Addis Ababa- Harar.

3.1.2 Topography and Drainage

Ethiopia can be divided into four major physiographic regions; the north western plateau, the south eastern plateau, the Main Ethiopian Rift and the Afar depression. The study area found maintains originating from one of this physiographic region which is south eastern plateau. The Arsi and Bale highlands, western and eastern Hararghe plateaus are the margin that forms the north and northwestern water-shed divide of the basin. It is bounded to north by the Awash River basin and the Rift valley lake basin, to the east by Genale River basin, to the west by Ogaden dry basin and in the southern to Ethio-Somali political boundary. The basin has great geographical diversity with high and rugged mountains, flat topped plateaus including river valleys and rolling plains. These major physical features are the result of uplift of the land mass and the emission of huge quantity of lava along extension and spectacular faulting. The basin consists of lowlands and highlands. The physical condition and variation in altitude have resulted in great diversity of climate, soil and vegetation. (WWDSE, 2005)

The basin is divided by eastern Oromiya region and western Somali region. There are four zones in the as a part of WSRB in eastern Oromiya region ; Arsi- bale zones, Bale zone, West Hararghe zone ,East Hararghe zone. In Somali region also there are four zones as a part of the basin; Jijiga zone, Korahe zone, Afder zone, Fike zone and Gode zone. Harari regional state is bounded by the basin and in northwestern margin Sidama zone of SNNP regional state found to be as the part of the basin.

This basin is one of the largest river basins in the country. The basin is very relief-outstanding area; elevations range between 1500 to 4250 meters above sea level in higher parts to 150-300 meters above sea level in the lower part of the basin. The maximum elevation belongs to the highlands of the Escarpment while the minimum elevation belongs to the national boundary in south most part. About 11% of the total basin area is highland. The Wabi Shebelle River emerges from the mountainous areas of the north western borders of the river basin near a place called Hebeno. It springs from the Bale mountain ranges of the Galama and the Ahmar about 4000 m above mean sea level and drains into Indian Ocean crossing Somalia. The Wabi Shebelle River is 1297 km long in the country from the starting to the end at Somali border. (Abebe, 2009)

Initially the river flows in the southern and then in the eastern direction and subsequently changes its course towards northeastern direction to East Hararghe Zone of Oromiya region. Thereafter the river course finds its path towards south and flows into the limestone tablelands situated in the central areas of the basin. These land mass has been deeply eroded by the river waters. The erosion, however, decreases progressively at the beginning of the Somali region. At this stage, the river takes a turn towards south – easterly direction from slightly upstream of Imi and continues flowing towards Somalia via Gode, Mustahil and Ferfer. (WWDSE, 2005)

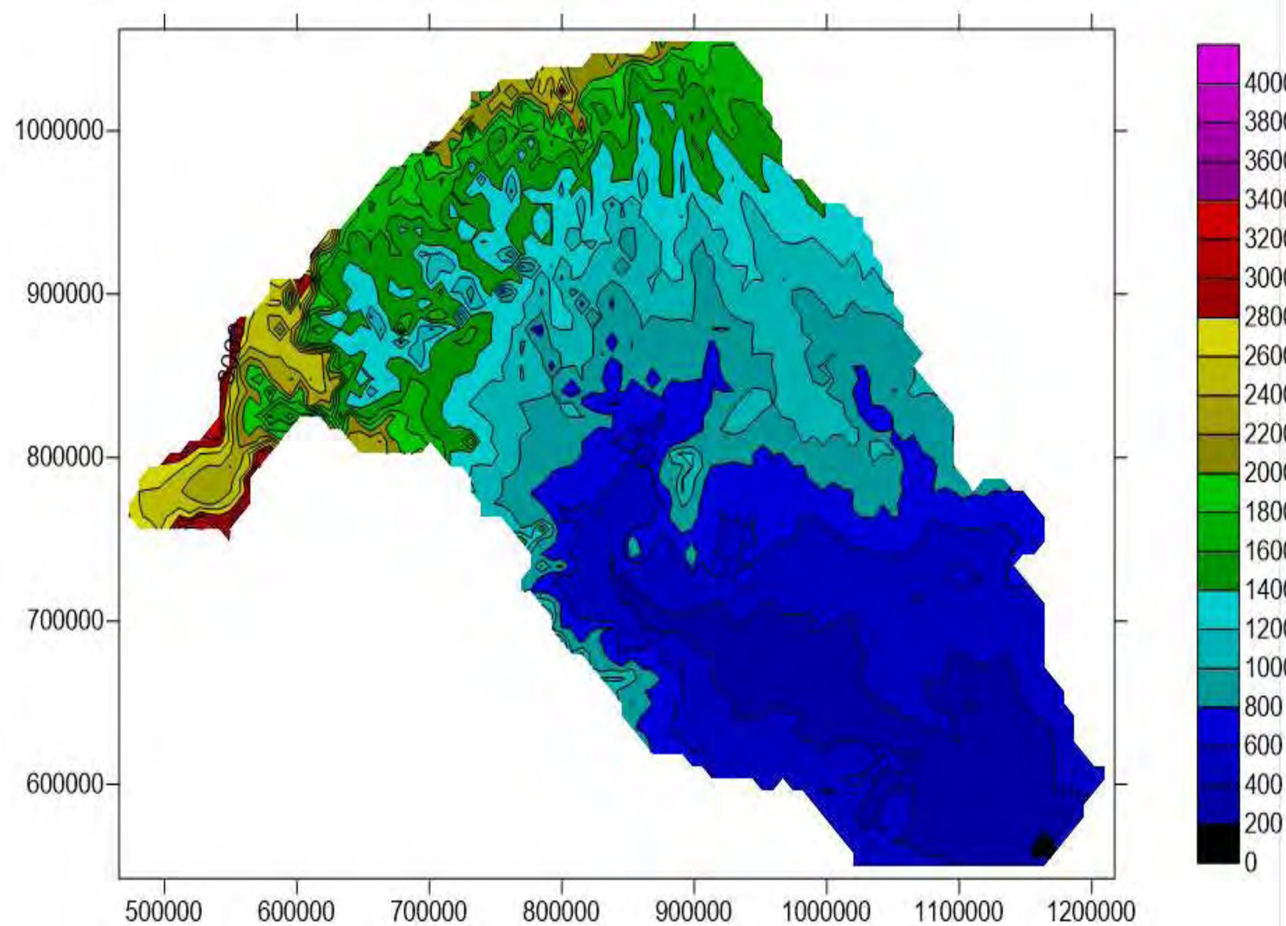

Figure 3 Surface topography of WSRB

The basin within Ethiopia is divided into three portions: the upper valley where the river is intermixed between steep slopes, plains and meanders in deep valleys; the middle valley where the river is suddenly deeply embedded in limestone plateaus; and a lower valley where the river flows in a vast alluvial plain with a very gentle slope of 0.25 to 0.35 m/km. Among the significant tributaries to the river within Ethiopia are the Maribo, Ulul, Hadida, Siyanan, Ungwata, Ramis, Errer and Daketa Rivers.

The Wabi Shebelle is a permanent river mainly supplied by the tributary flow from the high plateau of Arsi and Bale zones, but the tributary on the downstream part are all temporary rivers except Erer River from Hararghe highland. The Wabi Shebelle flows across the frontier into Somalia and disappears by evaporation in a vast water spreading zone.

Integrated flood management case study in Ethiopia shows that the Wabi-Shebelle River is one of the rivers that have significant floods occur in south eastern Ethiopia near the Somali border. The Lower Part of Wabi-Shebelle from Kelafo on to the Somali border is frequently flooded during the rainy season.

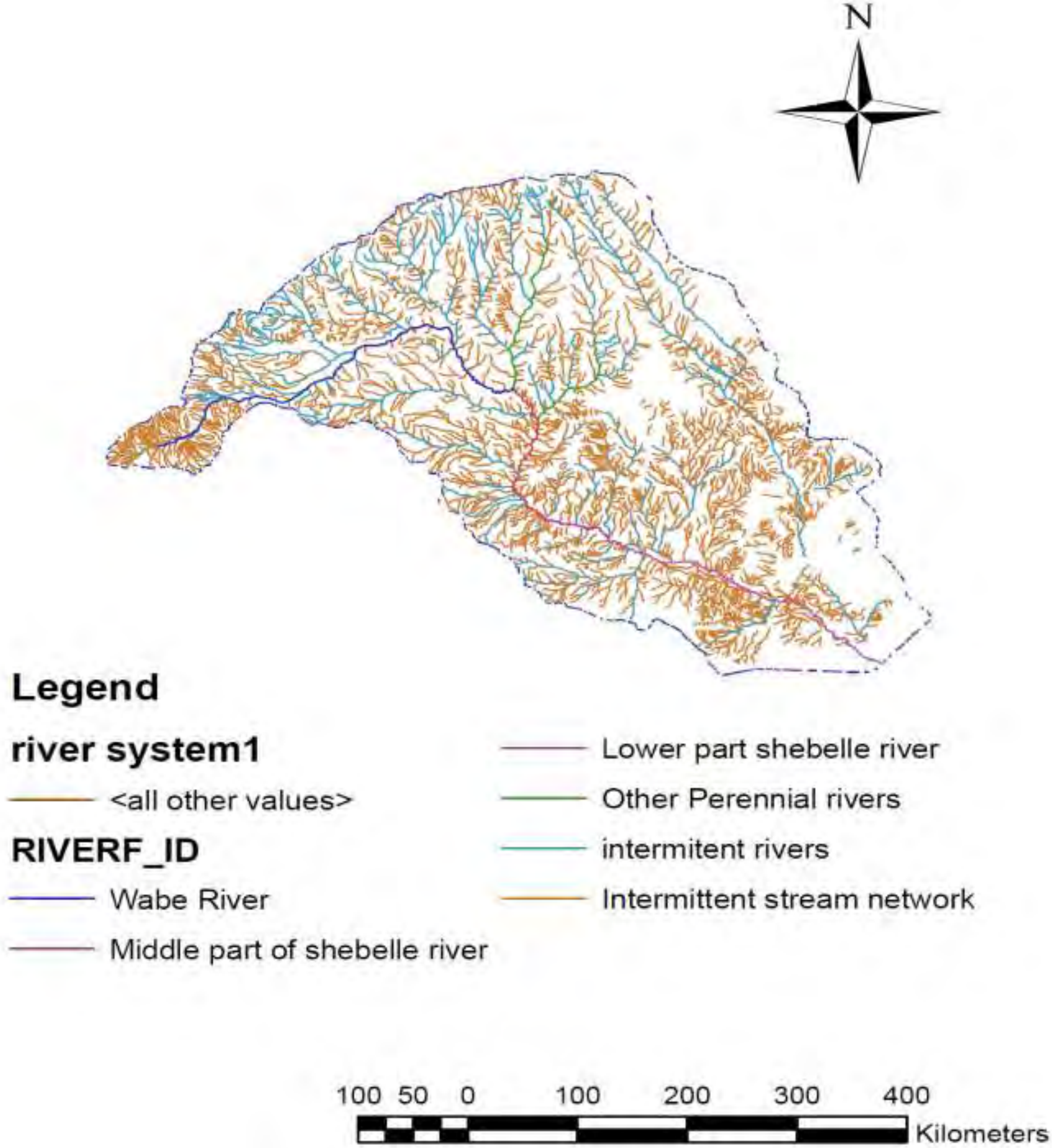

Figure 4 Drainage Network of the basin

3.1.3 Climate

Water is indispensable for life, but its availability at a sustainable quality and quantity is threatened by many factors, of which climate plays a leading role. Climatic elements such as precipitation, temperature, humidity, sunshine and wind are affected by geographic location and altitude. Ethiopia in general, and the basin in particular being near the equator and with an extensive altitude range, has a wide range of climatic features suitable for different agricultural production systems. Climatic heterogeneity is a general characteristic of the country as well the basin. (FAO, 2006)

A change in the amount of effective rainfall will alter recharge, but so will a change in the duration of the recharge season. Increased winter rainfall, generally is likely to result in increased groundwater recharge. This basin is known generally for its wide range of variation of climate and primarily because of climatic factors most of the crop production in the basin is in the highland areas. Drought has been a common recurring phenomenon every year in one or other part of the basin (i.e. south eastern part).

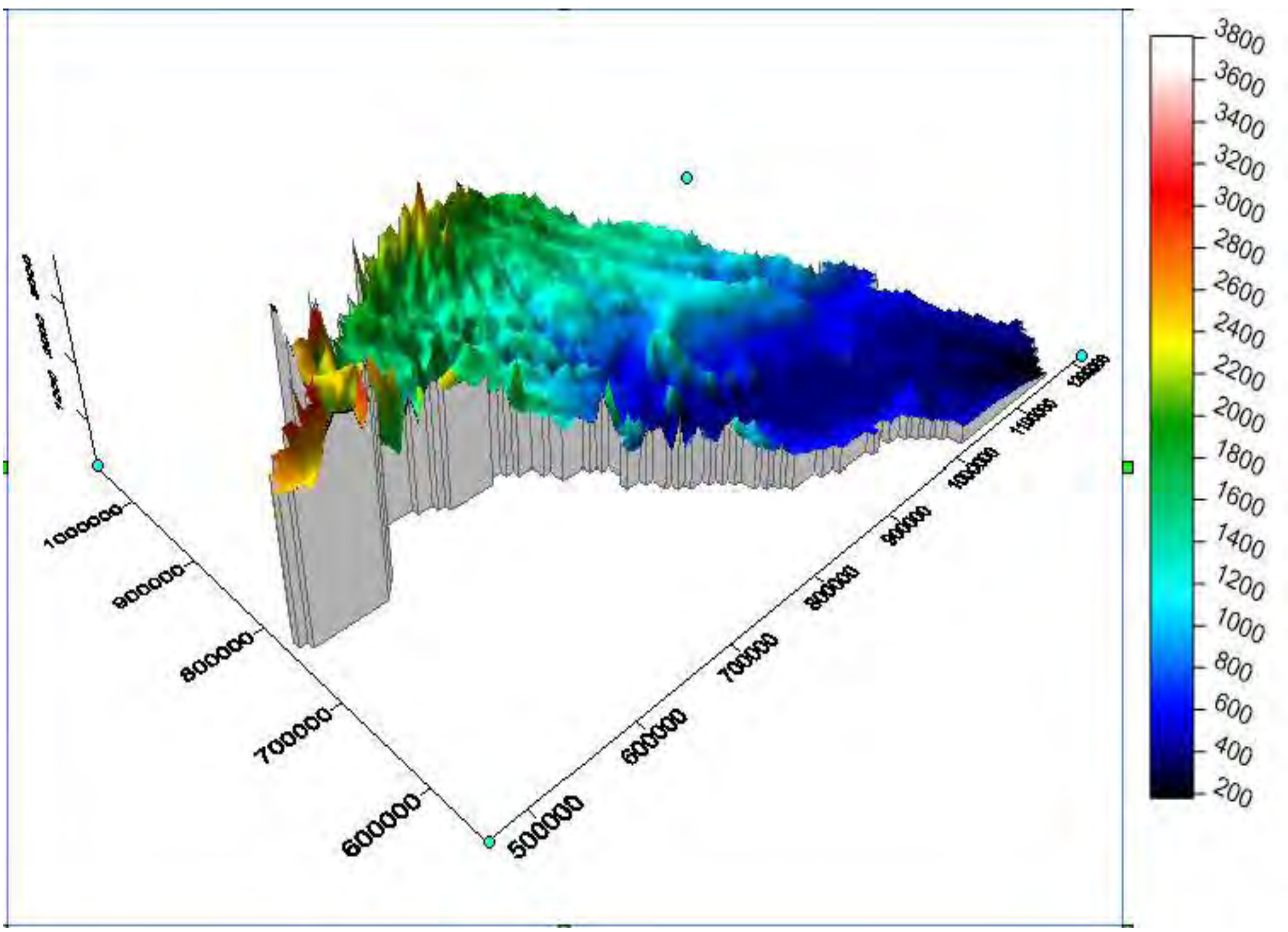

Figure 5 Three Dimensional relief map of WSRB

The basin relief slops from north western to south eastern part, altitude is the main determinant of rainfall volume, and both increase towards the northwest of the Region. The highlands are cool and densely populated while the lowlands are arid and sparsely populated. Due to the north and south movement of the Inter-Tropical Convergence Zone (ITCZ), the Region has two distinct rainy seasons. The report from Somali Regional State reflected that, most of the pastoralists and agro-pastoralists depend heavily on these rains for their livelihood. Local groundwater recharge is possible due to the rains in different seasons. There are also dry seasons, which extend to very long dry months when the rain becomes erratic and unpredictable. Long and extended dry seasons are responsible for livelihood loss, including loss of a huge number of animals.

The spatial distribution of mean annual rainfall in the area generally decreases from the north western escarpment toward the Somali border. In general the spatial and temporal distribution of rainfall tends to decrease with decreasing altitude.

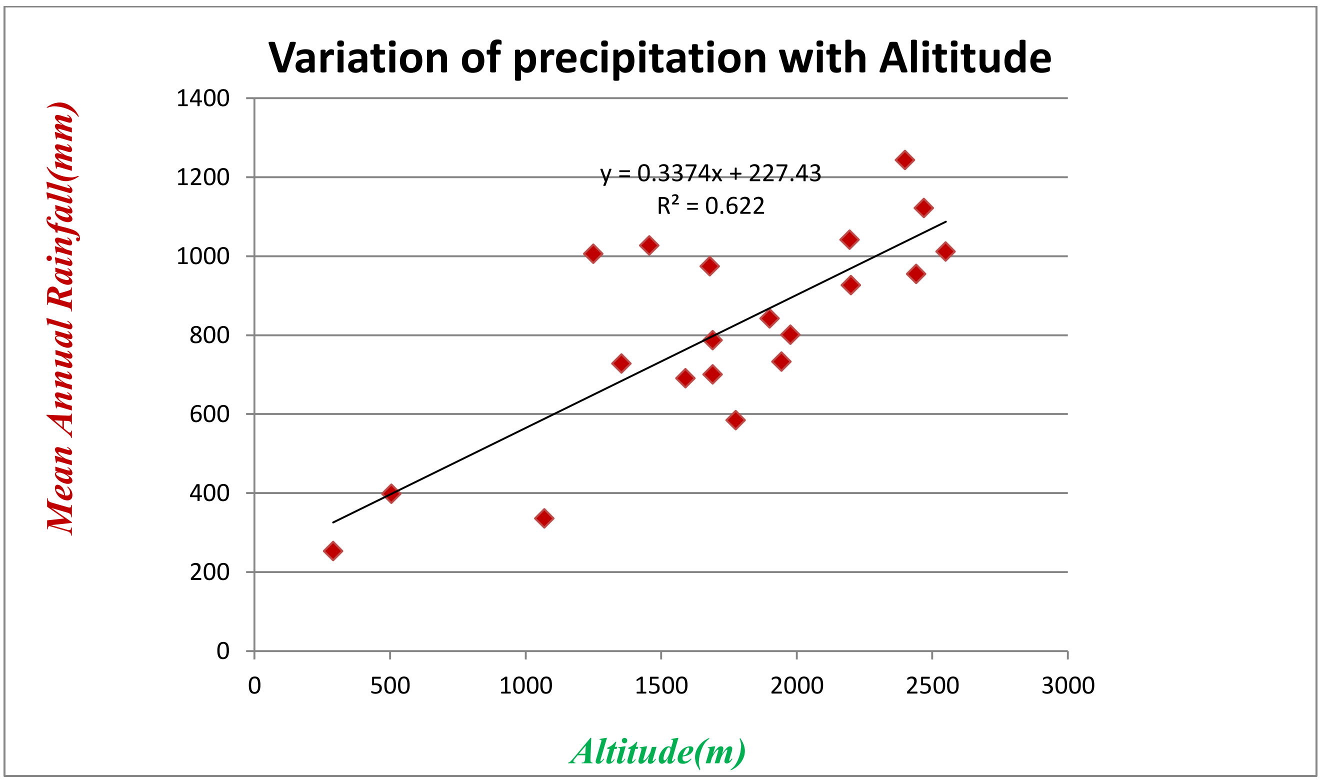

Figure 6 Variation of Precipitation with Altitude

The rainy season is bimodal from March to May and from September to October for the upper catchments north western part; the annual mean rainfall was adopted as being 650 -1250mm/year for this area. In the south eastern part, ~~t~~There are two primary rainy seasons throughout most of the region, the long rainy season from March to May, and the dry short rainy season from October to December

Four seasons are found in this region; this comprises of the south and southeastern part of Ethiopia with two rainy seasons (very rainy-March - June and small rains-September - November) and two distinct dry seasons (July - August and December - February).

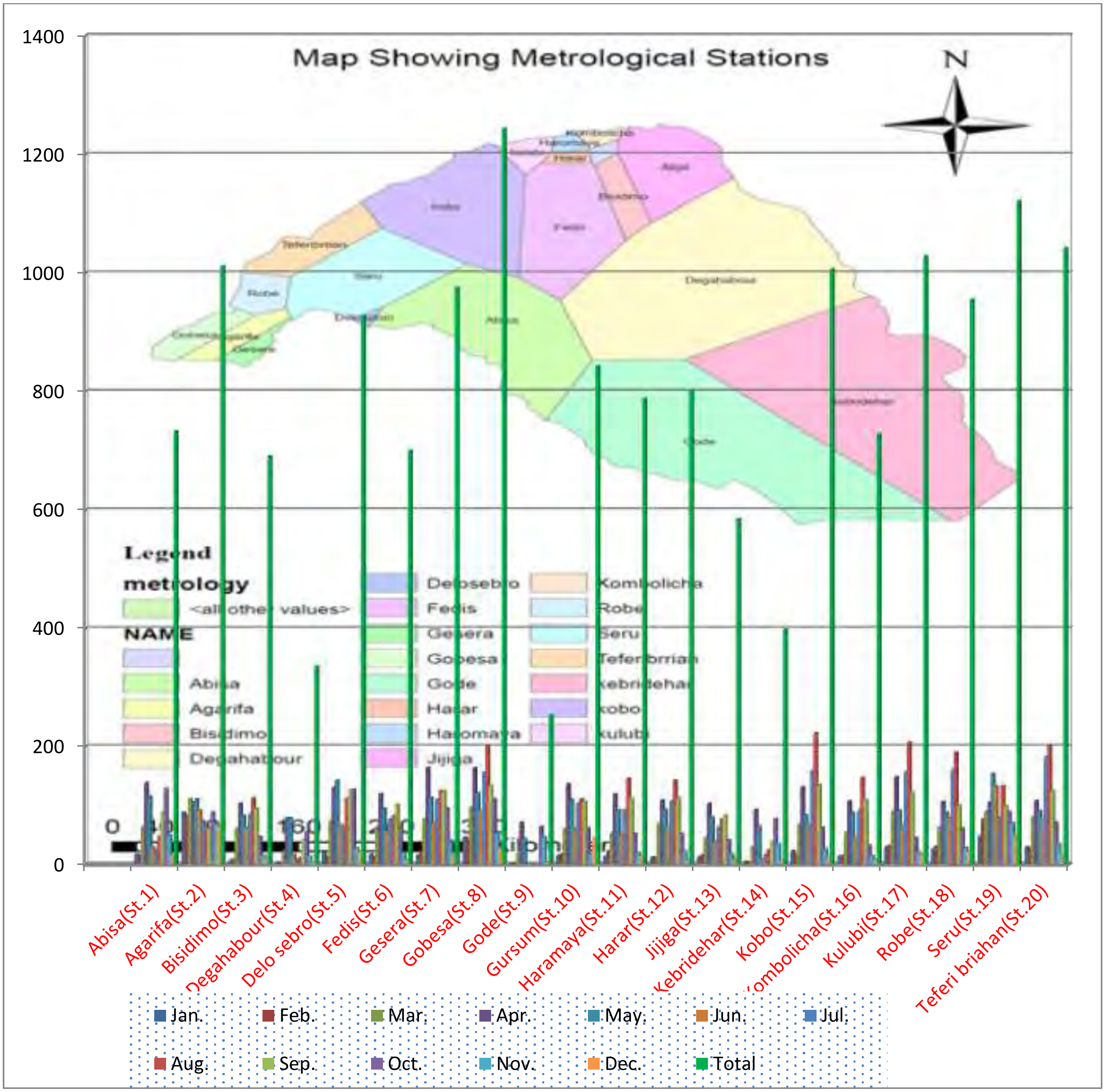

Figure 7 Average Monthly total rainfall observed at the twenty stations

3.1.4 Hydrometeorology

3.1.4.1 Hydrology

Hydrologic time series almost always exhibit seasonality due to the periodicity of the weather. This arises greatly from seasonal variations in precipitation volume, as well as the rate of evapotranspiration.

The majority of the stream flow contributions are from the northern and north western catchments having greater elevation difference from the southern and south eastern part which have elevation range from 600 m to 166 m above sea level.

The region has significant stream flow in two major river systems as well as numerous ephemeral rivers. Moreover, in some parts of the Basin, although surface water may not be available, substantial shallow and/or deep groundwater exists, though, depending on depth, at sometimes prohibitive cost. Economic rather than absolute scarcity of water is the greater determinant of access to the resource across the region. This has significant implications for how and where the region decides to invest in resource access improvements.

It is also important to note that water availability in the basin is part of a wider resource picture in which stream flow across the area derives from rainfall in the upper catchments of the basin and flows to adjacent countries, including Somalia, where significant use of water is made in irrigation and for livestock watering and other activities.

The volume of water discharge of surface drainage of basin is determined by climatic condition, while its relief controls the flow pattern of rivers. High seasonal fluctuation and variation of climatic condition characterize precipitation of the basin. So, the volume of discharge is subjected to high fluctuation, sporadic flash of flood as a result of torrential tropical rains in summer and dry channels for some rivers and streams in dry season.

In general, the regional has a total of more than five major rivers (Wabe, Ramis, Geletti, Erer, Deceta, and Fafen) and many minor tributaries which form one of the largest basins and draining a total of 191146 square km of land.

Lakes/Reservoirs: Lake Haromaya and Adele, which are completely dried out recently, were the major natural lakes in the basin. Originally three lakes were located at a short distance from Harrar, (Lake Haromaya, Lake Adele, and Lake Lange) but the largest one, Lake Haromaya, has completely dried up, as it supposedly supplies the drinking water for the town and as it is used for irrigation by local farmers. Lake Adele is an adjoining lake to Haromaya. There had been a steady decline over the past decade in both the quality and quantity of water being delivered from this lake to the residents of Harar. Large deposits of silt have compounded the problem reducing the lake's water capacity greatly. The fresh-water lake that once provided recreation for swimmers, boaters and Shermen, slowly choked and diminished.

At present there is one large man made reservoir by Melkawakena dam that is commissioned in 1988 for hydropower generation. The river assumes a ravine character above the site and carries water through a vast trench suitable for creation of the reservoir. A rather large-capacity regulating reservoir with a volume of 763 million m^3 was created by the construction of a relatively low dam with a maximum height of 38 m. Below the cataracts, which have a drop of the order of 80 m, the river flows into a deep and narrow canyon having significant slopes. The magnitude of the head at the hydroelectric plant is 300 m. Its rated capacity is 153 Mw. The mean annual electric-power generation at the plant is 543 million Kwh (Cheryachukin and Sitnin, 2000).

The basin is predominantly rural in character with an economy dominated by rain-fed subsistence agriculture. Within the basin, the current water use in Ethiopia is confined to one major dam and irrigation scheme. (Mohamed, 2014)

Most of the rivers in the study area gain water from the highly fractured and Karsted aquifer. According to wash report in the upper part of Wabi Shebelle basin (i.e. Arsi Bale zones and Hararghe zones), a number of springs emerge from the volcanic rocks and sedimentary formations. The volcanic rocks of Arsi-Bale basalt bordering the rift valley are highly fractured. Numerous springs outcrops along faults and fractures in this area and form substantial part of the base flow of Wabi Shebelle River. (Abebe, 2009)

Unregulated irrigation with farmers pumping water to reach ends up to 12 km away, has depleted already strained resources even further. In 2004 it is completely exhausted, no longer able to supply the pipes with even ration levels. This is one of the recent painful lessons of inappropriate water management in the area.

Hydrological setting

Most of the rivers in the area arise along the northern and north western margins of the basin (Arsi Bale and Hararghe Plateau) and descend with a steep gradient into the eastern and south eastern direction and joining to the Wabi Shebelle river which flow first to eastern direction and then south eastern and finally to Somalia territory.

Currently some areas in the upper catchments have gauging station. According to MoWIE, the lower catchments are remote areas and not accessible to have gauging station. In the upper catchment there are more than 15 stations, among these Lelisso, Hararo, Assassa, Weyib at Agarifa, Ukuma, Maribo near Adaba, Jewis near Bedesa, Wabi at bridge and Wabi at Melkawakena, Robe station at Robe town, Jijiga River at Jijiga and Lake Adelle at Adelle are operational stations. But all the data in these stations are not complete to define the hydrograph separation of the area.

3.1.4.2 Meteorology

Rainfall is the most important part of the atmospheric precipitation in the hydrologic cycle that falls on the earth surface in the form of water droplets and its amount is one of the most fundamental factors to determine the density and distribution of vegetation. The rainfall in WSRB varies from less than 200 mm in arid zones (the south east part) to 1250mm in upper catchment. This is due to altitude variations over the basin from about 166m above sea level in the south east border up to 4250m above mean sea level in the Arsi- Bale Mountain Massif.

Meteorological setting

The distribution of the meteorological stations is not well integrated reducing the credibility of such data. There are about 48 meteorological stations in the basin. Most of them are clustered in or near urban centers of the upper portion of the basin. Meteorological data are taken from the station based on their availability within the recording year. The stations are not evenly distributed and sometime lack continuous meteorological records. However, long term records of values of meteorological parameters are enough for the purpose of this study.

As mentioned before the study area is an area of various hydro meteorological characteristics it needs as many station as that of topographic variation. So there are meteorological stations that measures different meteorological parameters in the basins. According to national meteorological agency of Ethiopia there are four class of station in the country. These are First class (synoptic station), second class (principal station), third class (ordinary station), and fourth class (rainfall recording stations). The distribution of these stations depends on the topographical point and accessibility. On the study area the meteorological station distribution are parallel with the population distribution and are condensed upper catchments.

3.1.5 Land Use/land Cover

Poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role in causing land degradation problems in the country. Because of the rugged terrain, the rates of soil erosion and land degradation in Ethiopia are high.

In WSRB, only a small percentage of the north western area is intensively and moderately cultivated land. Large parts of the area are bush, wooded or open grasslands. The northeastern part of the lowlands is covered by shrubs and bush and is used mainly for pasture; crop cultivation is not common in this area. (Mulugeta, 2011)

A small dense forest is found at the North Western portion of the basin. Dense shrubland is the predominant land cover in the basin. The shrubland occurs mainly on the semiarid parts and often consists of patches of shrubs interspersing grasslands with some scattered low trees. Patches of exposed rock or sand surface are found in parts of Bale and Hararghe lowlands in the southeast. Parts of central Arsi and northern Bale has afro-alpine and sub-afroalpine vegetation.

These consist mostly of short shrub and heath vegetation used partly for sedentary grazing and browsing; and, where the terrain permits, for some cultivation of barley. Riparian woodland and bushland occur along the river banks and on floodplains and are important in the semi-arid and arid parts of the basin where they are used for grazing and browsing and scattered seasonal crop cultivation on some of the flood plains. The land use consists of a large part of silvipastoral type. Areas of intensively cultivated land are found on the highlands of Arsi and parts of highland Hararghe, and northern Bale. The major seasonal crops in the basin include maize, barley, wheat and sorghum while the perennial crops include coffee, chat and fruit trees.

3.1.5.1 Cultivation

According the different studies the basin is divided in to different farming system; upper parts (north western side the Arsi-Bale zones) have High potential cereal (HPC), north eastern part of the basin east Hararghe have Low potential cereal (LPC), southern and south eastern part is the area they have Livestock population, pastoral and agro-pastoral lowland areas with low and variable rainfall includes Somali Regional States.

People in the highlands in the northwestern parts of the basin are engaged in agricultural practice, cultivating different kinds of crops: wheat, teff, maize, sorghum etc. In addition to agriculture most of the farmers raise domestic animals. Lowland inhabitants live in scattered villages and are semi pastoralists. (Mulugeta, 2011)

Pastoralism and agro-pastoralism are the main activities and the area is characterized by desert with high temperatures and low precipitation. In many areas there are an increasing number of rural families with few livestock assets who mainly rely on rain fed cultivation. The rural population density is 11 persons per $km^{2.}$

According to MoWIE report; south central part of there is cropping scanty crops while the border to Wabi Shebelle River is covered with irrigated crop. But larger portion of central part is having pastoral farming life style. The higher elevation part is covered with crop like barely, wheat, sorghum, maize; with lower part is covered by other cultivation.

National Meteorology Agency Jijiga Branch Office reported, in the southern and south eastern parts, because of insufficient watering and grazing resources people in the area are forced to move from one place to place. This, of course, means that the people are not sedentary, but neither is they nomads in the strict sense of the term. They move in such a way that they match their needs to the periodic supplies of nature. These areas are pastoral areas having an altitude from 1000 m to 166 m from sea level. Annual precipitation less than 700mm and the area are dominated by Somali peoples.

The Gode irrigation project with a 17 km long canal has the capacity to irrigate 17 000 ha and diverge 46 m3/s of water in the semi-desert Ethiopian province of Ogaden. (Mohamed, 2014)

The total area suitable for irrigation in the Wabi Shebelle basin is estimated 345,000 ha. This consists of about 12% of the total irrigable land in the country (Imperial Ethiopian Government 1973). From this 265,000 ha is classified as class 1 that is described as very suitable for irrigation. The remaining 90,000 ha are classified as moderately suitable for irrigation, according to Somali regional state report.

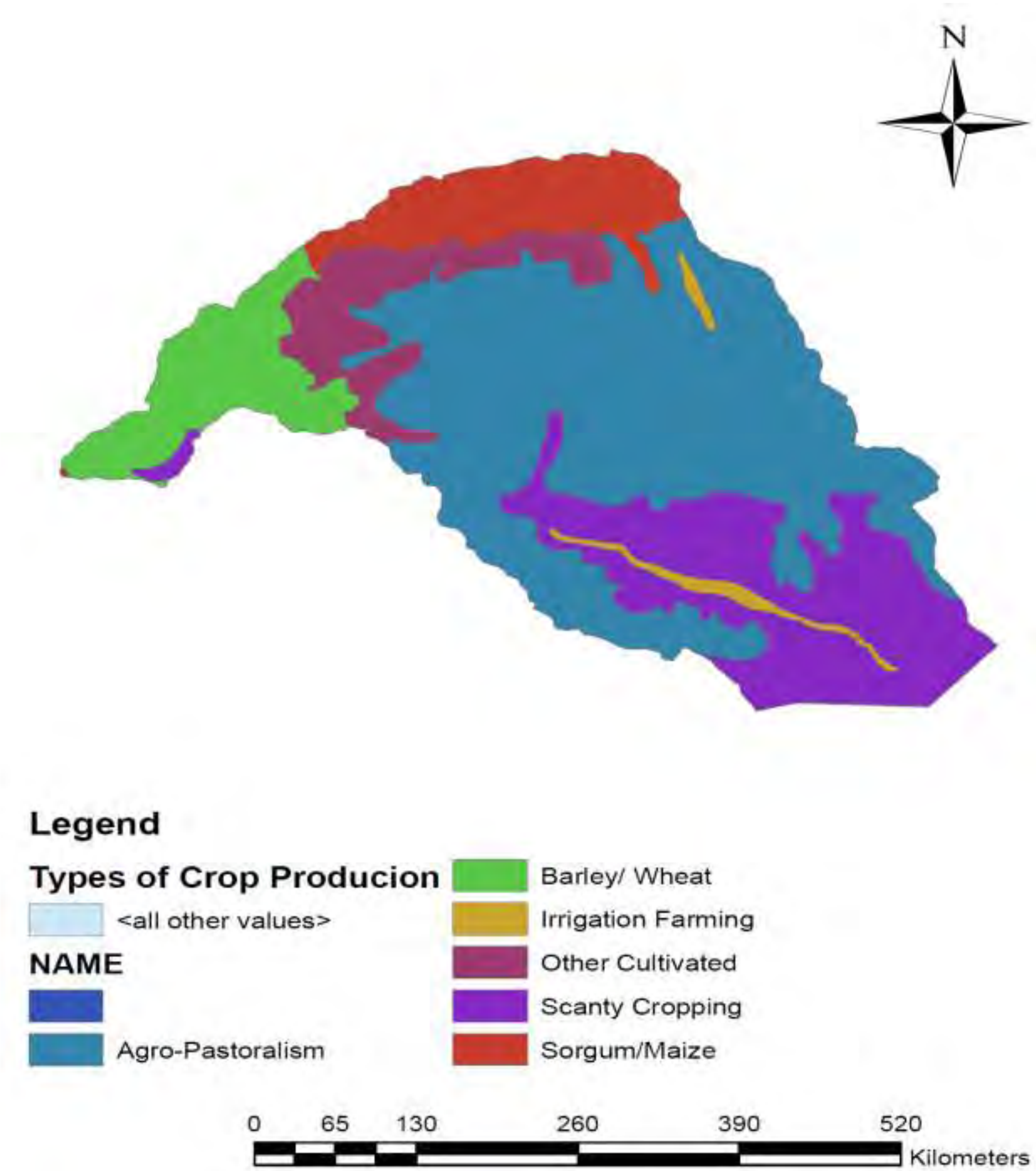

Figure 8 Types of crop production in WSRB (source; MoWIE)

3.1.5.2 Soil Types

The wide ranges of topographic and climatic factors, parent material and land use have resulted in extreme variability of soils (FAO, 1984). In different parts of the country, different soil forming factors have taken precedence. According to the Ministry of Agriculture about 19 soil types are identified throughout the country. (FAO, 2006)

Soils About 50% of the soils in the basin are soils of calcarious or gypseous di erentiation types. Vertisols comprise 12% of the basin covering significant areas at the middle Study Area belt. The soils with calcarious di erentiation are characterized by the redistribution of lime in the profile while the soils with gypseous dierentiation are characterized by the redistribution of gypsum in the profile. The latter predominantly occurs in the southern arid part of the basin. The water-holding capacity of the soils is subdivided into nine classes, from wetlands (which are given a water-holding capacity of 1000 mm) to soils with a water-holding capacity of < 20 mm. (Abebe, 2009)

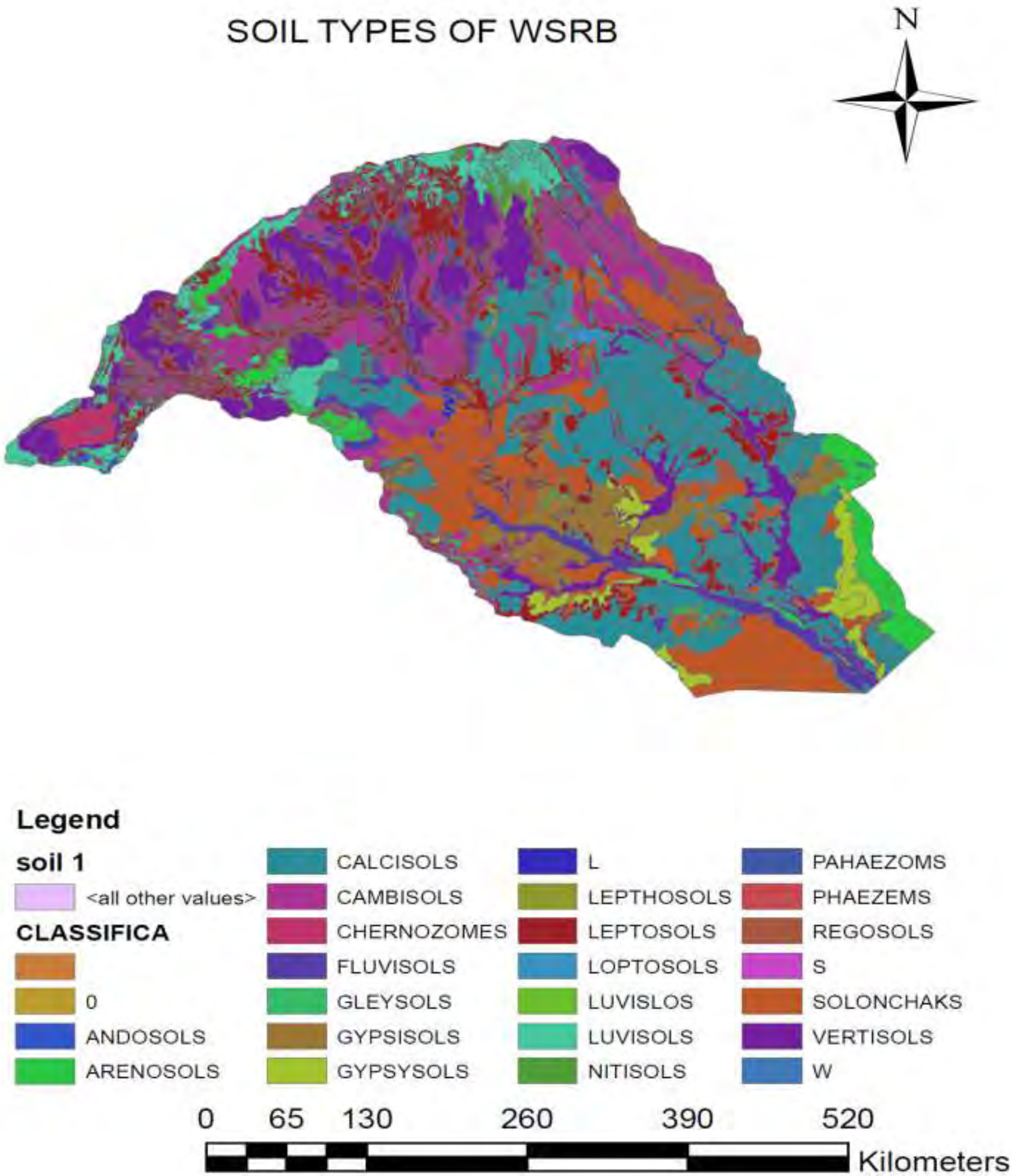

Figure 9 Soil types of WSRB (source; MoWIE)

3.1.6 Geology

Groundwater inevitably occurs in geological formations. Knowledge of how these earth materials formed and the changes they have undergone is vital to hydrologist. The earth is basically heterogeneous, geological training is prerequisite to understanding the distribution of geological materials of varying hydraulic conductivity and porosity.

The geology of Ethiopia broadly comprises:

- Precambrian basement,
- Paleozoic-Mesozoic sediments and
- Cenozoic volcanic rocks.

The Precambrian basement rocks are mainly exposed in northern, southern, western, and eastern part of the country and have covered about 20% of the landmass. The Paleozoic-Mesozoic sedimentary rocks cover about 25% of the country and are exposed mainly in eastern, central and southern Ethiopia. The Cenozoic volcanic rocks with sediments cover about 55% of the country landmass and form the spectacular Ethiopian highlands and the Main Ethiopian Rift. (Selassie, 2012)

In Ethiopia, there are a number of lithological units of varying age and composition including metamorphic, sedimentary and igneous rocks. In many parts of the country, groundwater is an important source of potable water, especially in rural areas, where perhaps 90% of rural water supplies are groundwater-dependent, but also for towns. Annual groundwater recharge in the five basins where studies have been conducted is estimated at 18BCM, and total annual recharge can reach 36bcm. The total stored potential of groundwater is estimated at one TCM. (Negash, 2012)

The lowlands of south-eastern Ethiopia (east of Goba,) as well as parts of the north are composed of sedimentary rocks of various ages. (BGS, 2001)

According to studies, the major types of rocks of the basin are illustrated as follows;

Rocks of the Precambrian Era: In WSRB, the Precambrian rocks, occur in smaller portion of eastern East Hararghe Zone. The oldest rock group is that of the archaean sub-era which is the geologic time of over 1500 million years in age. This earliest rock group includes basically gneisses and schists of relatively advanced metamorphism. Coarse-grained biotite, biotite amphibol gneisses, quartizo-feldspathic, iron stones, calcareous silicates, foliated biotite gneisses and schists, granitoids and other undifferentiated complexes characterize the types of rocks of this era.

Rocks of the Paleozoic Era: The Paleozoic era was characterized by long geologic time of 375 million years (600 ton 225 million years ago). It was time of persistent denudation accounting for the gradual penalization of the Afro-Arabian region. Identified rock formation of this era is limited to a small cover (about 0.1 percent) along the Blue Nile bed in East Wellega and in East Hararghe.

Rocks of the Mesozoic Era: Mesozoic rocks are found areas like East Hararghe, southern part of West Hararghe, Eastern Bale.

Rocks of the Cenozoic Era: Cenozoic era lasts from about 65 years ago up to recent. Extensive fracturing and subsequent faulting created in the tertiary period induced wide spread volcanism. Great outpour of lava flows along fissures covered much of the present highland formed thick basalt lava rocks of the Trap series. The Trap series consist of rocks of both the Ashange and the Shield groups. Rocks of this group cover northeastern part of West Hararghe and Arsi zones. (Bekele, 2010)

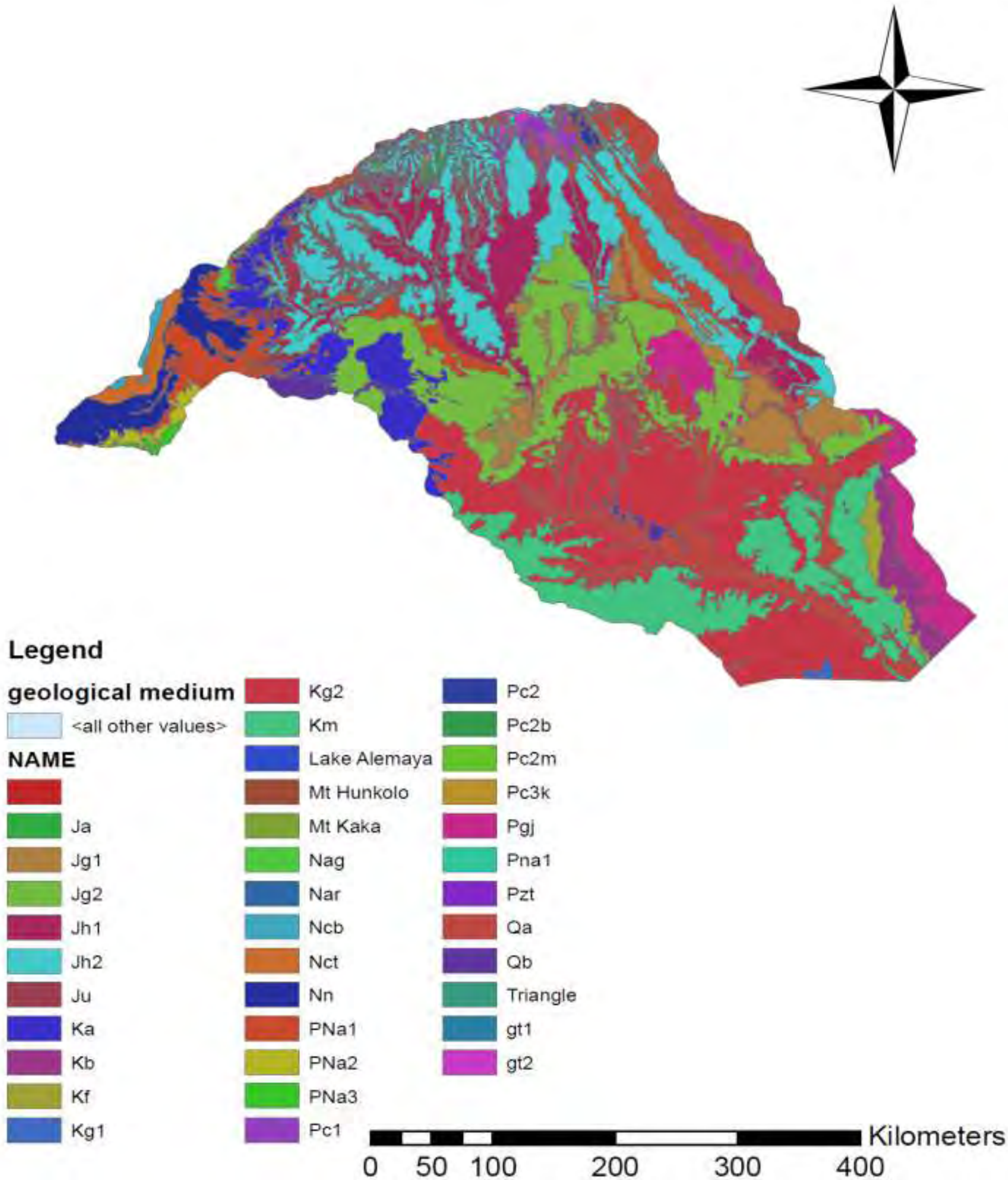

Figure 10 Geological parameters of the basin (source; MoWIE)

3.1.6.1 Regional Geological Setting

The study area is dominated by Mesozoic sedimentary formations, to some extent there are also volcanic rocks at the North West of the basin and isolated ridges and hills within the sedimentary basin. Metamorphic rocks outcrops in a small extent at the northern part of the study area. Alluvial deposits are also distributed linearly along the Wabi Shebelle, Jerer, and Fafen rivers and fan deposits of seasonal floods and stream beds. The volcanic rocks of Arsi-Bale basalt bordering the rift valley are highly fractured. Numerous springs outcrops along faults and fractures in this area and form substantial part of the base flow of Wabi Shebelle River. The Southern part of the basin is overlain by thick gypsum and limestone. The water level monitoring for one hydrologic cycle on two wells at Gode showed that the water level is deep always lower than the river bed and the phreatic water level is practically the same during the hydrologic cycle and no interaction with Wabi Shebelle river water indicating the permeability is very low. On the other hand at Kelafo there is interaction of the alluvial ground water with Wabi Shebelle River. At Mustahil there is infiltration of the river flood waters into the alluvial ground water (MoWIE, 2003).

Wabi Shebelle river basin is found in the southern-eastern Ethiopian plateau. It is the only river basin in Ethiopia where about 90% of the basin is composed of sedimentary rocks and about 10% volcanic rocks. The geological and structural condition has formed an extensive sedimentary groundwater basin. The volcanic rocks of Arsi-Bale basalt bordering the rift valley are highly fractured. Numerous springs outcrops along faults and fractures and forms substantial part of the base flow Wabi Shebelle river flow. The Hamanlei series and Antalo limestone also forms an extensive aquifer of fresh groundwater at the upper part of the basin in Bale at Shek Hussien area, at western and eastern Hararghe. South of the basin, this series is overlain by thick sedimentary formation. The overlying sedimentary formation is dominated by intercalation of gypsum and gypsum formation with low recharge condition due to low rainfall in the area have made the groundwater of this formations to be saline except at some localities (such as Kebridahar) where the salinity is reduced due to runoff recharge form Fafen intermittent river (WWDSE, 2004).

3.1.6.2 Aquifer system

The aquifer in the study area is Sedimentary rocks (Mesozoic sand stone, karstic limestone,) etc. to tap water average depth; 200-300m, average specific yield (2-5 lit/sec). These are thick layers of Mesozoic sedimentary rocks (only in some areas Palaeozoic rocks exist) that have different layers of sand stone, marl, limestone, shale and conglomerate. The primary porosity developed is very poor for some of the layers (limestone) while secondary porosity and karistification is very common in the limestone. Therefore, good yield of water is extracted from the karstified limestone and the sand stone. However, due to the location of these layers deep underground, wells striking these aquifers are very deep to as much as 400 meters while the average depth being 250 meters.

Ancient (Precambrian) rocks outcrop in four main regions: Bale regions in the south and Hararghe region in the east (Tefera et al., 1996).

According to Wabi Shebelle river basin integrated master plan, July 2004, Addis Ababa, volume VII water resources. There 36 types of geologic unit in the basin. In the north eastern part or most of Arsi area dominated by Nazareth group (Nn) which cover most of these areas. Urandab formation (Ju) is the other formation found in eastern Arsi areas having moderate hydraulic conductivity. Amba Aradom formation (ka) is the other major formation in western Arsi area. The north and north eastern Arsi is dominated by Arba Gugu basalts (Nag), Arba Gugu silicics (Nar), Chilalo alkaline basalts (Ncb), chilalo trachy basalts (Nct). Alkali trachyte and basalt flows (PNa3), Alkali trachytes flows (PNa2), Alaji basalts (PNa1) are also distributed in southern and south western part of Arsi area.

Western and eastern Hararghe highlands cover with; Adigrat formation (Ja), Hamanlei formation upper unit (Jh2), Hamanlei formation lower unit (Jh1). Soka groups (Pc3k), Marbles (Pc2m), Boye group (Pc2), Mafic gneisisses (Pc1) are the other formation in Hararghe highlands. Late to post tectonic granites (gt2), Pre to syn-tectonic granites (gt1), and Wayu sandstone (Pzt) are other part of formation that are found in Hararghe highlands.

The central part of the basin is dominated by Gebredarre formation upper unit (Jg2), Gebredarre formation lower unit(Jg1). The southern parts have Mustahil formation (Km), Korahe upper formation (Kg2), Korahe lower formation (Kg1), and Ferfer formation (Kf).

Alluvial sediments (river sediments and alluvial sediments)(Qa) is a geologic formation that are widely distribute following the (valley) gorges of north western, central and southern part of study area. Alaji basalts (PNa1) is also one the geologic formations that widely distributed over the northern and central part of the basin. (sources; wabi Shebelle river basin integrated master plan, July 2004, Addis Ababa , volume VII water resources)

A geologic formation that will yield significant quantity of water has been defined as aquifer. Many types of formation serve as aquifer. A key requirement is their ability to store water in the rocks pores. (Todd, 2005)

Ancient (Precambrian) rocks outcrop in regions: Bale regions in the south and Hararghe region in the east (Tefera et al., 1996). These rocks are usually highly metamorphosed and include some granite. Some have zones of associated sulphide minerals bearing gold, copper and other metals. (BGS, 2001)

According to ministry of water & energy research & development directorate report the WSRB the hydrogeological map of the basin shows that most northern and north eastern parts of the basin comprise of highly productive aquifers (loose sand, limestone and sandstone). Some of the central northern and most southern parts of the basin are covered by low productivity aquifers (shale, rhyolitic, and Meta rocks). The most central part covered by moderate productivity aquifers (old and young basalts) which extended to north- south and west- east directions.

3.2 Materials used for the study

- Digital Elevation Map (30m resolution)
- Geological and hydrogeological maps, reports and raw data from various sectors
- Meteorological data records from National Meteorological Agency
- Arc GIS software version 10.1, Global Mapper 12 & 15, Surfer 32, Microsoft Excel and Access 2010
- TAGSAC-software

Before starting the model works archive data such as geologic data, metrological data, drilling reports (i.e. bore holes, dug wells) and springs data were collected from different Organizations. Several offices were visited to collect data; the visited organization for data is listed in table below.

Table 1 the name of organization visited in time of data collection

Location	Data Source
Addis Ababa	Ethiopian Geological Survey
Addis Ababa	National Metrological Agency
Addis Ababa	Ministry of Water, Irrigation and Energy
Addis Ababa	Addis Ababa University
Addis Ababa	Water works design and supervision
Addis Ababa	Oromiya water works

For this study, well point data, spring data, shape files of the basin that contain boundary, streams ,land use, geology of the basin, were collected from Ministry of Water Energy and Irrigation. In addition to these a digital elevation model (DEM), Soil map and land use map were collected from MoWIE. Metrological data (daily rainfall data for the past 20-30 years for 20 stations) were collected from National Metrological Agency (NMA). Other well point data‘s from water works design and supervision office. Geological data from Ethiopia geological survey (GSE).

3.2.1 TAGSAC software

There are a variety of factors involved in choosing a suitable approach to simulate groundwater flow and transport in an aquifer. Among these factors that is important in choosing a particular modeling approach include (1) the type of aquifer, (2) the objective of the modeling study, (3) availability of different types of data, and (4) availability of codes.

TAGSAC A three dimensional FEM code, developed in Geosphere research Institute of Saitama University is adopted for the analysis. The code is developed based on Galerkin FEM. The Galerkin solution technique assumes a trial solution to the partial differential equation. The

residual error produced by the trial solution weighted by each shape function is then minimized at each computational node to form an algebraic analogue to the partial differential equation. (Simpson, 2003) Groundwater flow in heterogeneous porous media is carried out in using continuum analysis model: 'TAGSAC' solves three-dimensional saturated/unsaturated groundwater flow equation in heterogeneous porous media using finite element method (FEM). In the TAGSAC approximation procedure, the flow region is first discretized into a network of finite elements, and an interpolating trial function is used to represent the unknown dependent variable (hydraulic head) over the discretized region.
The advantages of using TAGSAC models are that data requirements are minimal and the simulations are rapid. Additionally the selection of TAGSAC model for this study is related to data availability and the type of conceptual model used.

3.2.2 DEM digital elevation model

A digital elevation model (DEM) is a digital model or three dimensional representation of a terrain‘s surface of earth. Digital elevation data can now be obtained for any place on the Earth, at several resolutions. There are other terms related to DEM, digital surface model (DSM), digital terrain model (DTM) in literature. In most case digital surface model represent the earth surface including the entire object on it. But digital terrain model represent the bare ground surface without any objects like plants and building. DEMs are commonly built using data collected from remote sensing techniques, and the may also built from land surveying. DEMs are used often in geographic information systems and are most common basis for digital produced relief maps. DSM may be useful for land scale modeling, city modeling and visualization application. DTM used for flood and drainage modeling, land use study, and geological applications. Here digital terrain model (DTM) is used for delineation of watershed for this study. The SRTM high resolution DEM with 3 arc-seconds (30 m resolution) mosaicked of 1 degree by 1 degree tiles that was used in the topographical mapping is composed of several tiles (which cover the study area).

Watershed delineation in Global Mapper

Mappers may prepare digital terrain model in number of ways, but they frequently use remote sensing data rather than direct survey data. We can automatically determine stream flow and delineate the watersheds for those stream based on any loaded terrain surface DTM data. The generated line and area features can be exported to any support vector format, such as shapefiles. The generated watershed command allows performing watershed analysis on the loaded terrain data to find stream path as well as delineate the watershed areas that drain in to given stream section. The resolution section controls the resolution at which the loaded terrain data is sampled to perform the watershed analysis. The resolution section controls the resolution at which the loaded terrain data is sampled to perform the watershed analysis. Here I used the default values that capture the full resolution of the loaded terrain data.

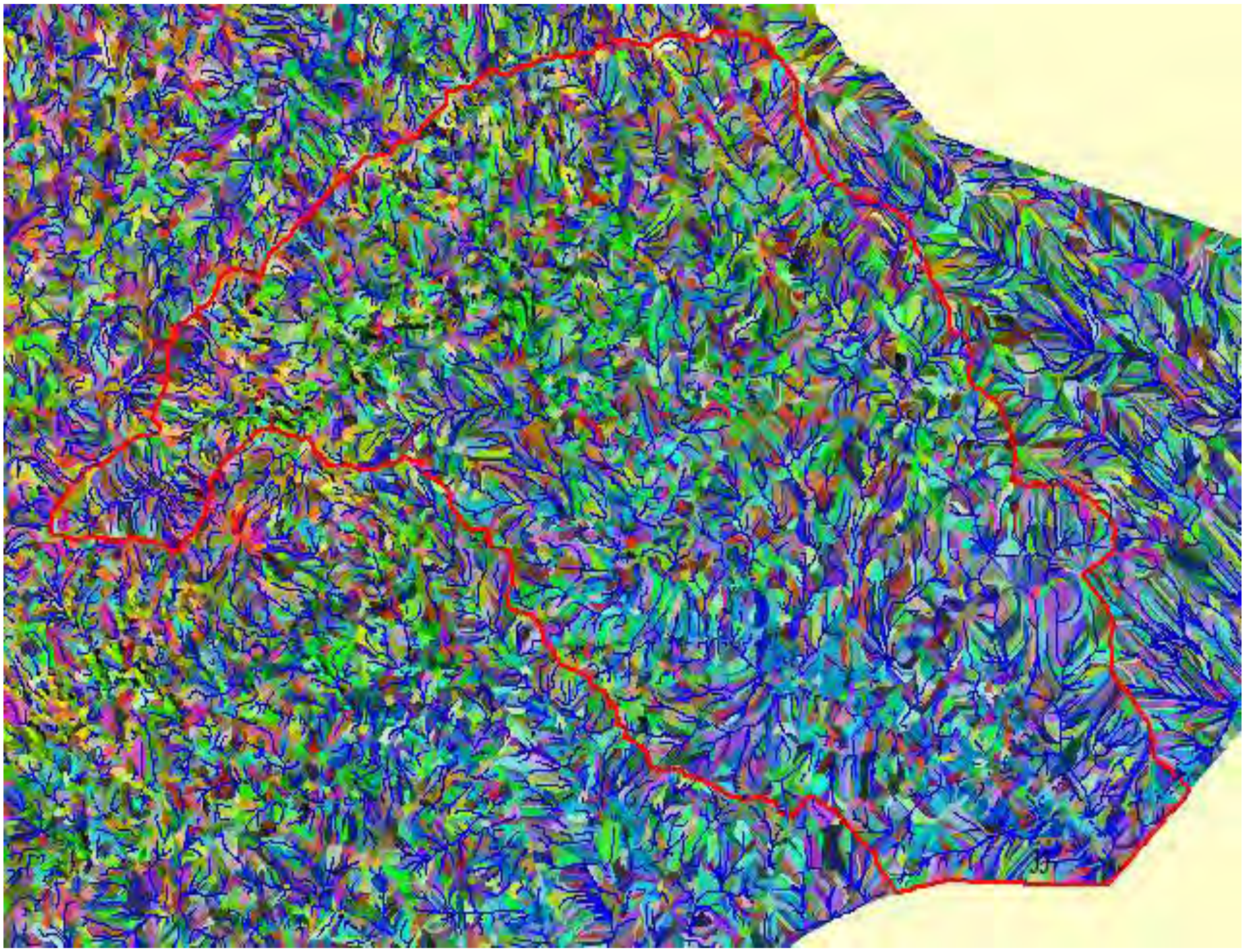

Figure 11 Watershed Delineated shape of the basin

3.2.3 Data management

Data quality refers to a level of quality of data. Data is considered as high quality if, they are fit for their intended purpose in operation, decision making and planning. In other word data is thought to high quality if it correctly represents the real world cases.

As stated earlier there three types of basic data are used for the study; meteorological data, historical well inventory data, and geological data.

Reliable data and information are key inputs to the sound and wise management of water resources and are critical to decision making. Managing data is an integral part of research process. In order to improve the quality of the data first detecting the outliers of the hydrological times series data should be performed. Outliers are data points that depart significantly from the trend of the remaining data. The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples. Procedures for treating outliers require judgment involving both mathematical and hydrologic

considerations. Daily rainfall in the Wabi Shebelle river basin is analyzed for a time period of 33 years (1980- 2013).
According to the Water Resources Council (1981), if the station skew is greater than +0.4, tests for high outliers are considered first; if the station skew is less than —0.4, tests for low outliers are considered first. Where the station skew is between ±0.4, tests for both high and low outliers should be applied before eliminating any outliers from the data set.
The following frequency equation can be used to detect high outliers:

$$\boldsymbol{y_H = \bar{y} + K_{nS_y}}$$

Where; $\boldsymbol{y_H}$ is the high outlier threshold in log units, and $\boldsymbol{K_n}$ is as given calculated for sample size *n*. The $\boldsymbol{K_n}$ values are used in *one-sided tests* that detect outliers at the 10-percent level of significance in normally distributed data. If the logarithms of the values in a sample are greater than $\boldsymbol{y_H}$ in the above equation, then they are considered high outliers.
A similar equation can be used to detect low outliers:

$$\boldsymbol{y_L = \bar{y} - K_{nS_y}}$$

Where; $\boldsymbol{y_L}$ is the low outlier threshold in log units
$\boldsymbol{S_y}$ Standard deviation of the time series Y
$\boldsymbol{K_n}$ Frequency factor (critical value) for the risk coefficient
So I tried to check these data in accordance with their relative benchmarks.

Continuous rainfall data is validated by comparison to one or more nearby rainfall gauges. The meteorological data is checked and is corrected in accordance with the literatures previous works done in the study area. The data is daily data of more than 30 stations but the study uses only 20 of them due to incomplete data problems. In fulfilling some gaps in the data inverse distance method of data filling is undertake by writing Matlab command in order to fill the data using Matlab. The basic idea of this method is that, for each gap of a station the solver check the three nearest neighboring stations and calculates the average of these three stations values and takes it as the value of missing station.
The same thing is seen in the borehole and spring data, these data are already collected by different researcher and governmental offices like WWDSE and MoWIR and used previously for many related research in the area. These data are present in the study area from 1960 until 2014 and used by many researches in groundwater and related study of the basin. It was checked many times their quality and get acceptance.

3.3 Groundwater Modeling Approach

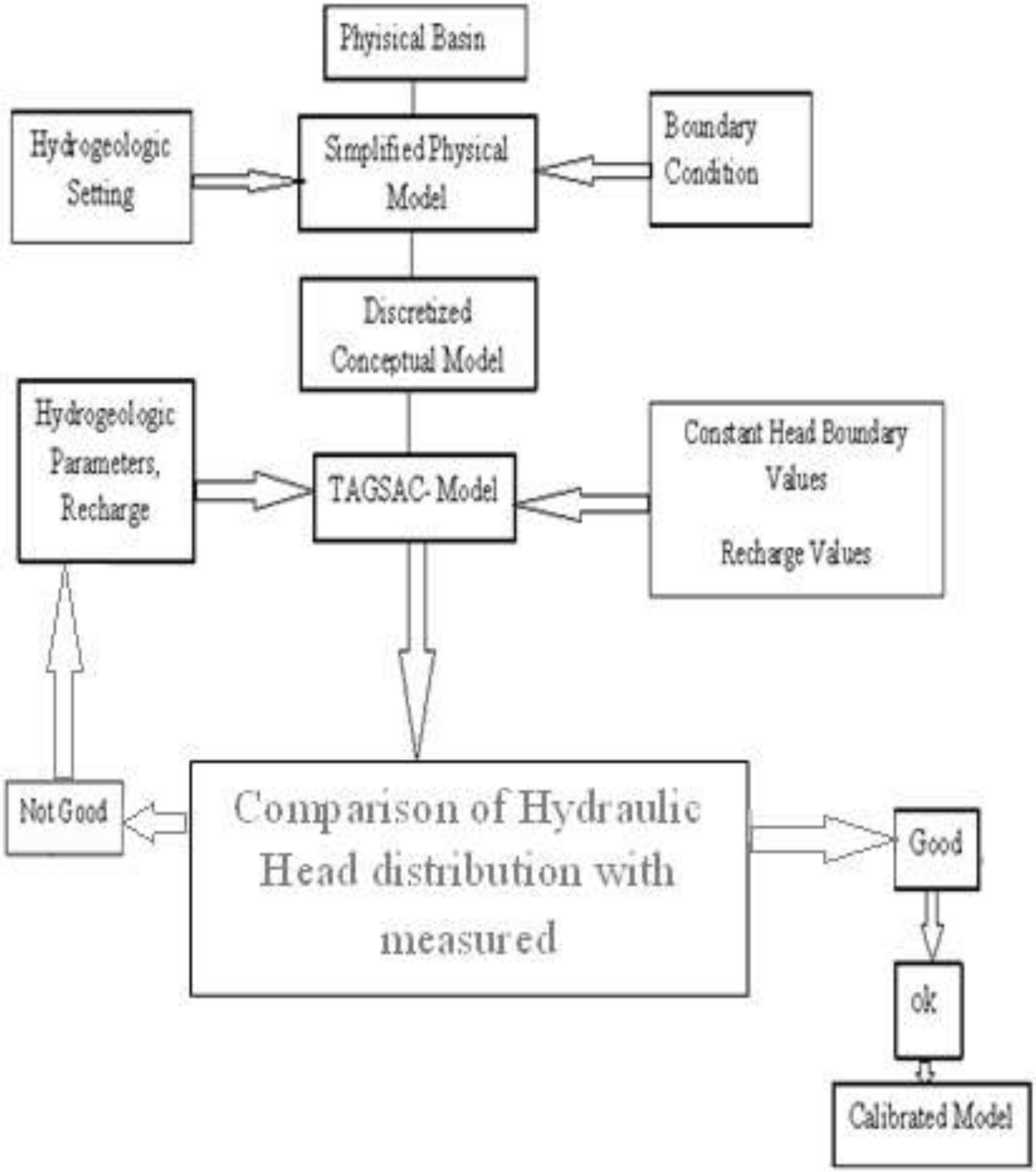

Figure 12 Groundwater Modeling Approach

3.4 Physical basin and Input data

The shape of the basin was delineated using DEM of the country as mentioned above. As stated earlier a new physical shape of the basin was delineated for this work. Accordingly, the area of the basin lowers than that of the previous studies.

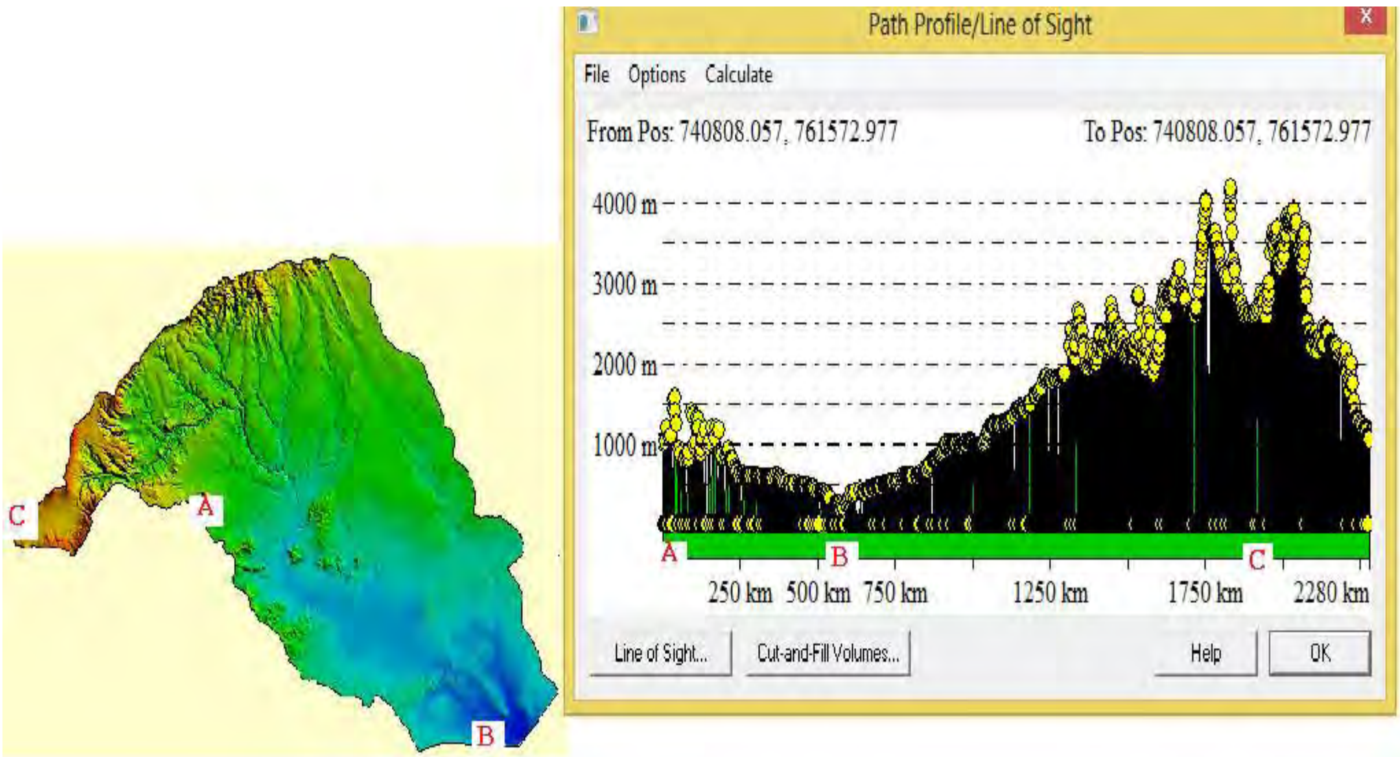

Figure 13 Border profile of the basin

Data required for the groundwater flow simulation include values of the saturated hydraulic conductivity and specific storage of each aquifer and aquitard material, the geometry and configuration of the flow region, as well as, initial and boundary conditions associated with the flow equation. So the values of hydraulic conductivity for each geologic unit are given to the model.

Input data of the flow model include the following;

(1) System Geometry(x-y coordinates)

- Horizontal and vertical dimensions including layering and other heterogeneity (L)

(2) Porous Medium Properties (Hydraulic properties of the basin geology)

- Horizontal Saturated hydraulic conductivity component, KHx (LT^{-1})
- Saturated hydraulic conductivity component in the other derection, KHy (LT^{-1})

- Vertical Saturated hydraulic conductivity component, KHz (LT^{-1})
- Effective porosity, Φ

(3) **Recharge from precipitations**

- From average annual precipitation for each station 10% value is taken as the amount that contributes for groundwater.

3.4.1 Well Inventory used

In the study area more than **1500** boreholes (springs, deep wells and shallow wells) have been collected, however due to incomplete data problems, 112 boreholes (are shallow boreholes having 200 meters or less length along the borehole length) and 845 springs have been selected in this research. But calibration result uses only 357 data of spring and well that are exist in the study area from 1960 until 2014. Their location in the study area can be seen in Figure 15. (See Appendix A for well inventory).

Since the study focuses on collecting already existing wells and springs, the distribution seems concentrated towards the location of upper catchments (northern and northwestern part), the catchment in Oromiya, and Harari regional states while sparsely distributed in Somali regional state. But the results that would be obtained from this research are then more representative of the groundwater surface water interaction of WSRB.

3.4.2 Rainfall data

The precipitation process is essentially random in nature. We cannot predict with certainty what would be the rainfall for any given period of time. The rainfall magnitude can be estimated only with some probability attached to it. Therefore the analysis of the rainfall data obtained over a long period in the past would help to make reasonable probabilistic estimates of rainfall to be used in various development activities.

The study uses about 20-30 year daily rainfall data depending on its availability from 20 metrological stations. Daily rainfall for 20 stations has been collected from the National Meteorological Service Agency (NMSA). The metrological station distribution is not even in the study area. Among the 20 station 3 stations are outside the study area border 17 stations are found inside the basin. The stations from outside the catchment are used due to unavailability of the required data inside the basin.

Thiessen Polygon Method

This is the weighted mean method. The rainfall is never uniform over the entire area of the basin or catchment, but varies in intensity and duration from place to place. Thus the rainfall recorded by each rain gauge station should be weighted according to the area, it represents. Thiessen polygon is one of the methods to determine the areal depth of precipitation for the catchment under consideration from several point rainfall data records. This method involves determining the area of influence for each station after locating all available rainfall stations and amount within and surrounding the catchment on a base map. This method is more suitable under the following conditions:

- When rainfall stations are few compared to the size of the basin.
- In moderate rugged areas.

The catchment area is drawn to scale and these 20 stations are pointed on it. These stations are joined so as to get a network of triangles. Perpendicular bisectors are drawn to each of the side of the triangles. These bisectors form a polygon around each station. If the boundary of catchment cuts the bisectors then the boundary is taken as the outer limit of the polygon. The bounding polygon are called Thiessen polygon.

3.5 Conceptual Model

This section briefly describes the conceptual model of the WSRB aquifer system. The conceptual model was developed from information on the geologic structure of the aquifer, spatial distributions of hydraulic and transport properties and boundary conditions.

Conceptual models describe how water enters an aquifer system, flows through the aquifer system and leaves the aquifer system. Conceptual models start with simple sketches although in their final form they may be detailed three-dimensional diagrams. (Rushton 2003)

The conceptual model is an idealized representation (usually graphical) of one‘s hydrogeological understanding of the essential flow processes of the system. (Shiferaw, 2006)

Major components of the conceptual model of the ground-water flow system are recharge/discharge fluxes, boundary fluxes, and distribution of hydrologic properties of geohydrologic units within a three-dimensional framework.

The conceptual model used in this study is based largely on the model proposed previously. It has been refined by data that are available at the study area. The types of data used in developing the conceptual model include: (1) Geologic information; (2) water-level information (obtained from drill holes and spring altitudes); (3) precipitation data; (4) hydrological data like river profile and reservoir points and (5) porosity of geologic medium

3.5.1 Physical model

Groundwater models are used to represent the natural groundwater flow in the environment. The mathematical or numerical models are usually based on the real physics of the groundwater flow follows. Three dimensional models require discretization of the entire flow domain. To that end the flow region must be subdivided in to smaller elements (or cells), in both horizontal and vertical sense.

The WSRB Basin is a broad triangular basin oriented north west / south east 740 km, in the south/north direction it is 520 km. The modeled area is about 191146 km^2 and extends from Arsi- Bale Mountain in the north western to discharge areas at the Somalia in the south and Ogaden arid area at south east.

The boundaries for this basin are not well delineated before; there are different boundary shapes in different basin study. To this end I tried to modify the boundary shape of the basin by using Global mapper 12 software.

First discretize the model domain in to element; next to this a matrix expression is developed to relate the nodal variable of each element. The resulting matrix is called ‗element matrix'. The element matrix is then combined to form ‗global matrix'. Prescribed boundary conditions are incorporated into the assembled global matrix equation. The resulting set of equation is solved using TAGSAC. A three dimensional FEM code, called TAGSAC, developed in Geosphere research institute of Saitama university is adopted for the analysis. The code is developed based on Galerkin FEM. (Mebruk, 2009) TAGSAC has proofed to be applicable in a number of researches done all over the globe.

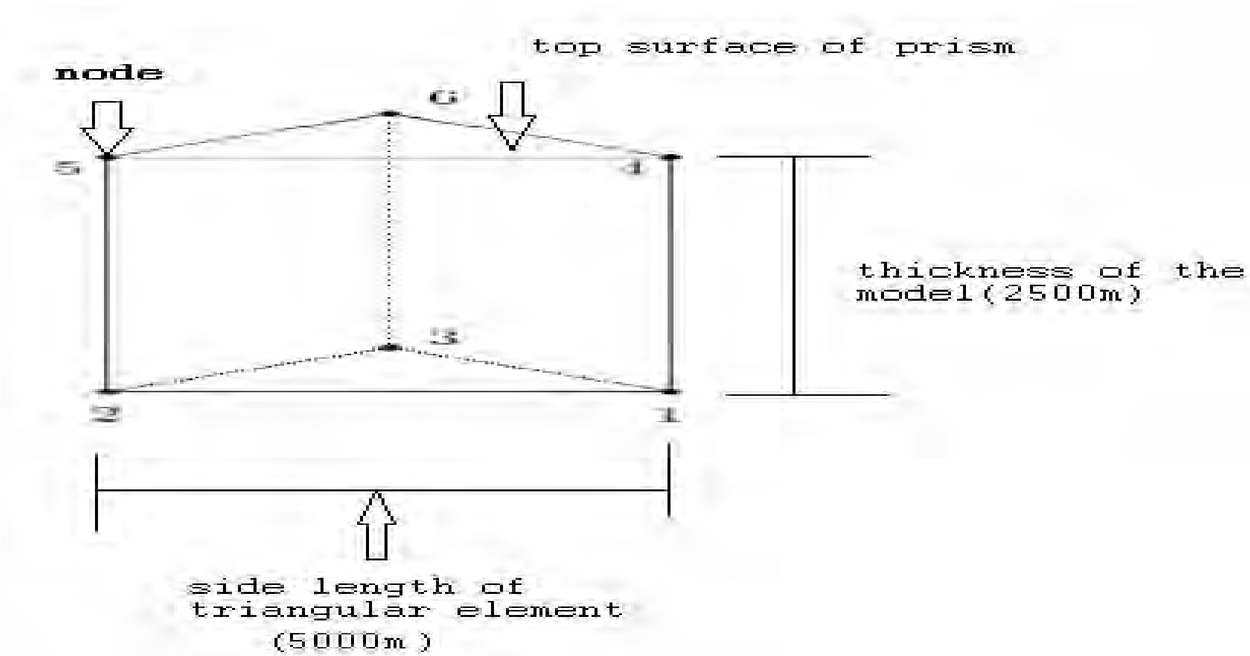

Figure 14 Prisma elements of Three Dimensional meshes for Finite Element Method with six vertices

 The geology, and hence the hydrogeology, of the region is complex, and the model approximate this complexity by the principle of equivalent porous medium.

Simulation of groundwater system to the construction and operation of a model, whose behavior assume the appearance of actual aquifer behavior. A mathematical model is simply a set of equations which subject to a certain assumptions describe the physical process active in aquifer.

Several conceptual models have been developed for describing fluid flow in fractured porous media. Fundamentally, each method can be distinguished on the basis of the storage and flow capabilities of the porous medium and the fracture. The storage characteristics are associated with porosity, and the flow characteristics are associated with permeability. Four conceptual models have dominated the research: 1) explicit discrete fracture, 2) dual continuum, 3) discrete fracture network, and 4) single equivalent continuum. (Diodato, 1994)

This study focuses on equivalent porous medium ideologies, in which fractured material is represented as an equivalent porous medium (EPM) by replacing the primary and secondary porosity and hydraulic conductivity distributions with a continuous porous medium having the so called equivalent or effective hydraulic properties. The parameters are selected so that the flow pattern in the EPM is similar to the flow pattern in the fractured system

The study area has been characterized to achieve the most representative conceptual model. Lithology was grouped into three main units, namely, sand, gravelly sand, and clay. Based on the characterization, it is concluded that the sand/gravelly sand and the clay layers are hydraulically connected. The three layers were then merged to constitute a single equivalent layer with an equivalent hydraulic conductivity and a thickness equal to the sum of their thicknesses. This approach of an equivalent single monolayer model is, however, consistent with hydraulic head measurements which did not show any significant difference for the different layers. This is necessary as a multilayer model will be difficult and unrealistic due to limited data to calibrate such a model**.**

Groundwater flow in the aquifer is governed by the conditions at the boundary of the regional system. The boundary conditions for the area are approximated as constant head with the rivers in the basin. The borders of the WSRB were taken as no-flow boundary. The thickness of the model is 2.5km and the lower/bottom is taken as no flow boundary.

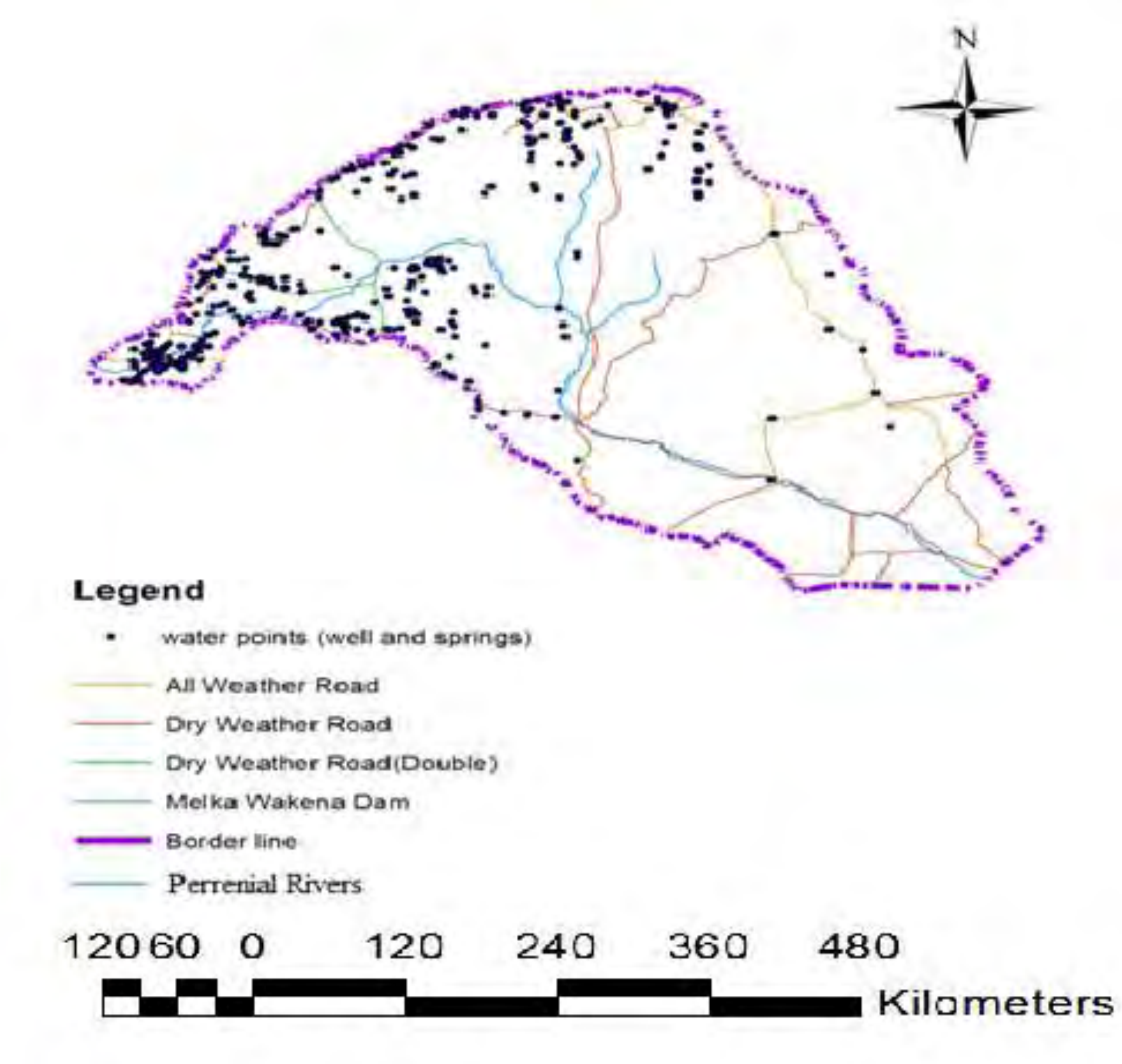

Figure 15 Boundary and parameters of the basin

The Figure above shows the distributions of water point data, the conveyance system of the basin, the perennial river profile and border of the study area. Accordingly the well inventory data are concentrated on the northern and northwestern catchment area of the basin. The lower catchment has only a few number of water point data that are sparsely distributed like one data in one zonal administration. The figure also shows how much the road is distribute with one or a maximum of two all-weather road in the largest basin. One all-weather road from Addis Ababa to Jijiga two in the upper most border of the basin and one from Jijiga to Gode in the most eastern border area. Additional the figure shows the longest river of the country flow starting from most western extreme of the basin to the south eastern and cross the nationally Ethio-Somali border and goes to Indian Ocean.

3.5.2 Hydrogeology

According to WWDSE, (2004) the Hydrogeological map of Wabi Shebelle river basin was constructed at scale of 1:250000. The hydrogeological map of Wabi Shebelle river basin is prepared based on hydrodynamics properties of the geological formation, their geomorphology and topological relationship and water quality.

The hydrogeological map legend classification follows the recommendation included in hydrogeological maps, 1995. Based on the recommendation the geological formations of the Wabi Shebelle river basin are categorized into three groups.

- Group I: Granular aquifer of primary porosity
- Group II: Fractured aquifers where the water resource is mainly linked to fractures
- Group III: Granular or fractured rocks bearing very limited localized water or practically no groundwater

Groundwater resource potential assessment in WSRB and adjoining areas by MoWIE classified aquifer productivity of the area in to low, moderate and high productive aquifers.

Nazareth group (Nn) in the north eastern part or most of Arsi area having high hydraulic conductivity. Urandab formation (Ju) in eastern Arsi areas and Amba Aradom formation (ka) in western Arsi area have moderate hydraulic conductivity. The north and north eastern Arsi is dominated by Arba Gugu basalts(Nag), Arba Gugu silicics(Nar), Chilalo alkaline basalts(Ncb), chilalo trachy basalts(Nct) are also formation which have high conductivity . On the other part the formation like Alkali trachyte and basalt flows (PNa3), Alkali trachytes flows (PNa2), Alaji basalts(PNa1) distributed in southern and south western part of Arsi area have low conductivity.

Western and eastern Hararghe highlands the formation likes; Adigrat formation (Ja), Hamanlei formation upper unit (Jh2), Hamanlei formation lower unit (Jh1) are formation that have moderate hydraulic conductivities. On the other hand; Soka groups (Pc3k), Marbles (Pc2m), Boye group (Pc2), Mafic gneisisses (Pc1), Late to post tectonic granites (gt2), Pre to syn-tectonic granites (gt1), and Wayu sandstone (Pzt) are geologic formation in these areas with low conductivity.

The central part; Gebredarre formation upper unit (Jg2), Gebredarre formation lower unit(Jg1) are formations having moderate hydraulic conductivities..

The southern are low hydraulic conductivity due to Mustahil formation (Km), Korahe upper formation (Kg2), Korahe lower formation (Kg1), and Ferfer formation (Kf).

The valleys and gorge in north western, central and southern part of study area have moderate conductivity due to, Alluvial sediments (river sediments and alluvial sediments) (Qa). High hydraulic conductivity is also due to Alaji basalts (PNa1); geologic formations that widely distributed over the same area in the Northern and central part of the basin, Generally speaking most of the northern and north western parts have high hydraulic conductivity, most of central area of the basin has moderate hydraulic conductivity and the southern part suspected to low conductivity.

3.6 Boundary Conditions

3.6.1 Recharge and Flow System Boundaries

The recharge to the groundwater system is also variable as the rainfall over Ethiopia is extremely variable in both space and time. (Alemayehu, 2006) The main source of recharge for the vast groundwater system is the rainfall on the highlands.

Rainfall is the principal source for replenishment of moisture in the soil water system and recharge to groundwater. Moisture movement in the unsaturated zone is controlled by suction pressure, moisture content and hydraulic conductivity relationships. The amount of moisture that will eventually reach the water table is defined as natural groundwater recharge. The amount of this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type.

Rainfall is the major source of recharge to groundwater. Part of the rain that falls on the ground is infiltrated into the soil. Part of this infiltrated water is utilized in filling the soil moisture deficiency while the remaining portion percolates down to reach the water table, which is termed as rainfall recharge to the aquifer. The amount of rainfall recharge depends on various hydro meteorological and topographic factors, soil characteristics and the depth to the water table. (Shiferaw, 2006)

The amount of water that may be extracted from an aquifer without causing depletion is primarily, dependent upon groundwater recharge. The primary sources of recharge to the study area are from rainfall on the outcrop and seepage from lakes and streams. Natural recharge to the aquifer system occurs from infiltration of 1) runoff from elevated regions along the north western boundary of the site, 2) spring discharges originating from the upper catchment, and 3) precipitation falling across the Site. Some recharge also occurs along the Wabi Shebelle River in the southern portion of the Site. The other source of recharge to the aquifer is recharge from Melkawakena reservoir and the lakes from north eastern part of the basin.

Inflow from surface water and lateral subsurface inflow: This is considered to be the major inflow component of the WSRB ground water system. The main source of recharge to the groundwater system is the intermittent streams originating from the western and north western mountains that flow to the plain in south eastern direction. Almost all of the streams are carrying water during the rainy season and their beds get dry during the dry season except for perennial rivers.

3.6.2 Flow system Boundary

Quantitative modeling of a ground-water system entails the solution of a boundary-value problem-a type of mathematical problem that has been extensively studied and has applications in many areas of science and technology. The flow of ground water is described in the general case by partial differential equations. A groundwater problem is “defined” by establishing the appropriate boundary-value problem; solving the problem involves solving the governing partial differential equation in the flow domain while at the same time satisfying the specified boundary and initial conditions. In ground-water problems, the solution is usually expressed in terms of head (h); that is, head is usually the dependent variable in the governing partial differential equation. **(**Zailin Huo, 2010**)**

The boundary condition on the ground surface is set as a free seepage face. Recharge rate at the ground surface is employed as the top boundary condition, taking precipitation into consideration. Constant head equal to the average water level in dry season of the Wabi Shebelle and Erer Rivers is given for the nodes representing the rivers. Bottom boundary assumed at 2500 m below the surface was set as a no-flow boundary. This thickness is half of the side of the triangular element. This large element size is selected due to the problem of computing device for fine arrangement.

A no flow boundary may also represent a groundwater divide or a streamline. Therefore the side of the model domain in the upper catchment (north and north western part) can be assumed as no flow boundary to represent a streamline created by the groundwater divide along the rivers and ridges. The side boundary generally depends on the border of the basin. The side boundaries on upper catchment are represented by mountain ridges (the north eastern, northern and north western boundaries) and the national boundary (the southern boundary). The ridges could be considered as watersheds of groundwater, however, some studies point that these ridges are not always coincident with watershed because of local geological structures.

- Constant head boundary at river Boundary condition of the first type (DIRICHLET-type)
- No flow boundary at the lower limit of the model z, Boundary condition of the second type (NEUMANN-type)
- Boundary condition of the third type (CAUCHY-type) Specifies semi pervious boundaries, e.g. leakage from a surface.
- Known flux
- Stream
- Well

Initial condition

- Values of the hydraulic head for each active and constant-head cell in the model. They must be higher than the elevation of the cell bottom.

- For transient simulation, heads to resemble closely actual heads (realistic).
- For steady state, only hydraulic heads in constant head-cell must be realistic.

In the FEM analysis, at first, arbitrary combinations of vertical (KV) and horizontal (KH) hydraulic conductivities were given in the two layer hydrogeological model. (Mebruk, 2009)

3.7 Discretized Conceptual model

The physical systems we are considering are mathematically described by partial differential equations (PDE), together with boundary and initial conditions.

Except in some simple and idealized cases, the equations cannot be solved analytically, and so various numerical methods have been developed to approximate the solutions. Some of the most popular methods for the type of problems we are considering are the finite difference method (FDM), the finite element method (FEM) and the finite volume method (FVM). Every method has its pros and cons, and which method to use must be chosen after considering the particular problem. The FEM is widely used in these kinds of problems, and this is the method we will make use of here.

The initial phase of any numerical simulation begins with the generation of a suitable mesh. Discretization is modeling a body by dividing it into an equivalent system of finite elements interconnected at a finite number of points on each element called nodes. Now we go for partitions of the domain into triangles. A triangulation of domain is a subdivision of this domain into triangles. Triangles must cover all domains but no more and must fulfill the following rule:

If two triangles have some intersection, it is either on common vertex or a common full edge. In particular, two different triangles do not overlap. The triangulation must respect the partition of the boundary into Dirichlet and Neumann boundaries.

The basic concept in the physical FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called finite elements or elements for short.

For three-dimensional grid generation, a surface grid is first constructed by generating a two-dimensional triangular mesh on the surface boundaries of the domain. This triangular mesh forms the initial front, which is then advanced into the flow-field by placing new points ahead of the front and forming tetrahedral elements. The required intersection checking now involves triangular front faces rather than edges as in the two-dimensional case. (Mavriplis, 1997)

The spatial discretization is based on a hierarchy of prism grids. These grids are constructed in such a way that they are consistent (no hanging nodes) and that the hierarchy of triangulations is stable.

This study employs a right-handed Cartesian coordinate system (x, y, z) to generate a three dimensional triangular grid for finite element analysis. The grid is oriented such that the z-axis points in the vertical upward direction (the elevation of the nodes above sea level). In the areal extent the grid is confined to be comprised of triangular elements, while in the vertical direction distorted elements are handled. Based on the formulation chosen and accuracy considerations, the level of horizontal and vertical elemental distortion from a triangular shape should be kept to a minimum.

Varying levels of spatial discretization of the solution domain are performed prior to the main model execution. In the aerial view a triangular grid is used to represent three dimensional model domains. The vertical planes (i.e., the x-z and y-z planes) are constrained to be flat surfaces that are perpendicular to each other; therefore, the resulting elements are also triangular in shape and their shape remains invariant in the vertical direction. The overall three dimensional mesh is unstructured.

Each element possesses a set of distinguishing points called nodal points or nodes for short. Nodes serve a dual purpose: definition of element geometry, and home for degrees of freedom. When a distinction is necessary we call the former geometric nodes and the latter connection nodes.

The size of elements influences the convergence of the solution directly and hence it has to be chosen with care. If the size of the elements is small, the final solution is expected to be more accurate. However, we have to remember that the use of elements of smaller size will also mean more computational time. The number of elements to be chosen for idealization is related to the accuracy desired, size of elements, and the number of degrees of freedom involved. Although an increase in the number of elements generally means more accurate results, for any given problem, there will be a certain number of elements beyond which the accuracy cannot be improved by any significant amount. (Rao, 2005)

Each element is represented by a linear (6- nodded) finite element that is triangular in the horizontal direction. The vertical coordinate (z-axis) is in the opposite direction relative to the gravity vector.

The geometry of the element is defined by the placement of the geometric nodal points. Most elements used in practice have fairly simple geometries. In three dimensions the most common shapes are tetrahedra, pentahedra (also called wedges or prisms), and hexahedra (also called cuboids or ―bricks

The surface of about 191146 km2 study area was divided into a grid on a two dimensional plane so that, the boreholes and the springs in the water shed are represented. Elevations of the individual nodes are calculated from the digital elevation model (DEM) in 90 m-interval to express the topography of the study area. The ground surface elevation ranges from 166 to 4250 m a.m.s.l.

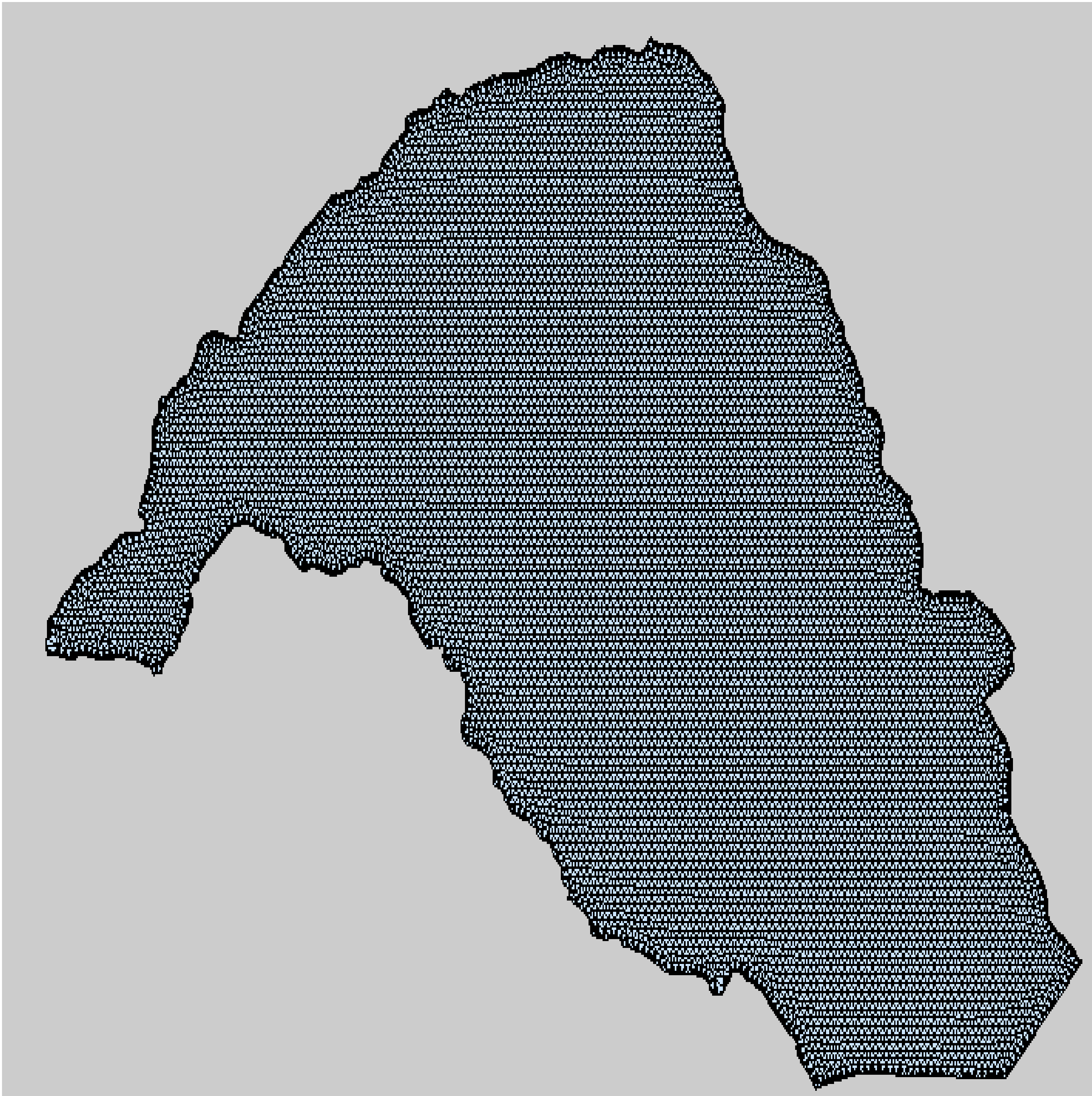

Figure 16 Finite elements discretization for the WSRB

An aerial depiction of the surface finite-element grid and boundary conditions used in the three-dimensional models of the aquifer is illustrated in Figure 16. It demonstrates the grid chosen for current study area simulations. The mesh is composed of the nearly same dimensioned elements. The average planar size 5000 * 5000 *5000 meters of triangular elements, smaller sized elements occurs towards the boundary of the model area. The entire study area from surface to the bottom of has been divided into a horizontal layer having dimension of 2500 meters height. A total of

13028 triangular prism elements are formed from 10,826 nodes distributed all over the study area. The mesh is non-uniform, hence needs more refinement near the boundary, because sharp changes are expected there.

The perennial rivers in the basin treated as constant head boundary and represented by nodes. These nodes are the nodes nearest to the river following the path. Each node has its own XYZ coordinates. There are also well inventory data which also represented by using nodes. Boreholes and spring are represented by three nearest nodes with their respective coordinates.

3.8 Equivalent Porous Medium model

Since it is very difficult to account for all properties of faulted, weathered and fractured rocks (e.g. fracture network geometry) especially in large scale models the subsurface is often assumed to be an equivalent porous media. This approach is known as the Equivalent Porous Medium approach (EPM).

This study is based on equivalent porous medium (EPM) approaches. Single continuum approaches are commonly used for simulating groundwater flow. These approaches are conceptually simpler than discrete fracture network approaches and require much less data and few fitting parameters. Theoretical modeling studies comparing flow and transport in simulated networks of discrete fractures (Long et al., 1982; Berkowitz et al., 1988) show that in general EPM behavior is more likely for materials with high fracture density, random fracture orientation, numerous fracture interconnections, and uniform aperture distribution, and for cases at larger physical scales or greater transport distances. (MeKay, 1997)

The equivalent continuum models are based on the concept of the representative elementary volume introduced by Bear. The heterogeneous system is modeled by a single continuum which is divided into sub-volumes with uniform properties. These hydraulic properties are obtained by averaging over each sub-volume. Hence, the sub-volumes must be sufficiently large such that the average value will be representative for the whole sub-volume. In this way, there is no explicit distinction made between the matrix and the fractures, and flow occurs throughout the system.

3.9 Model Calibration Techniques

A number of calibration simulations were performed to evaluate the appropriate hydraulic conductivity value to achieve the best overall match. Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. Model calibration requires that field conditions at a site be properly characterized.

3.9.1 Manual Trial and Error Calibration

The comparison of simulated heads and fluxes with field measured values during the repeated adjustment of aquifer parameters and stresses is the heart of the calibration process.

There are basically two ways of finding model parameters to achieve calibrations. (1) Manual trial and error adjustment of parameters and (2) automated parameter estimation. The calibration of a deterministic groundwater model is often accomplished through a trial and error adjustment of the model's input data (aquifer properties, sources and sinks, and boundary and initial conditions) to modify the model's output.

In the trial-and-error calibration of groundwater models, the model parameters such as hydraulic conductivity and specific storage are assigned to each node and the model calculates values of piezometric heads. The calculated heads are then compared with measured values and the model parameters are adjusted according to a modeler‘s judgment, in order to provide a better match. The calibration is repeated until an adequate match (with acceptable error) is obtained.

Model calibration is the process of adjusting the input parameters (hydraulic conductivity, porosity, specific storage, well or natural recharge/discharge rate) and boundary conditions (head or Darcy flux along sections of the boundary) of a model to achieve a close to observed data (e.g., hydraulic head, flow rate) in a real groundwater system. In flow model calibration, simulated heads and Darcy fluxes are typically compared to their observed counterparts. If a model is well calibrated, there will be some random deviations between simulated and observed data, but there will not be systematic deviations. If there are systematic deviations such as if most of the simulated heads exceed the observed heads, the calibration is poor and adjustments should be made. (Zhang, 2011)

3.9.2 Calibration Evaluation

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.

3.10 Model Validation

Before the numerical model is applied to solve engineering problems, it is used to simulate some small scale problems and simple cases for which the results are known or can be easily obtained, for verification. Validation is the process of determining the degrees to which a simulation model and is associated data are accurate representation of the real world from the perspective of intended uses of the model. Model validation is possibly the most important step in the model

building sequences. There are a variety of method are used to validate models, ranging from comparison to other models to the use data generated by the actual system (i.e., predictive validation). Here we use historical data validation method for this study. Historical validation method is used if historical data exist (e.g. data collected on a system specifically for building and testing model), part of the data are used to build the model and the remaining data are used to determine(test) whether the model behaves as the system does.
The goal of validation is

- To produce a model that represents the true behavior close enough for decision making purpose.
- To increase the model‘s credibility to an acceptable level.

4. RESULT AND DISCUSSION

4.1 Rainfall data analysis

The next figure shows Thiessen polygon classification of the station coverage area. As we see from the figure the contiguous of the station and the coverage area are not even. There are smaller divisions in the upper catchment due to station concentration and whereas large coverage is represented by fewer number of stations in southern catchment.

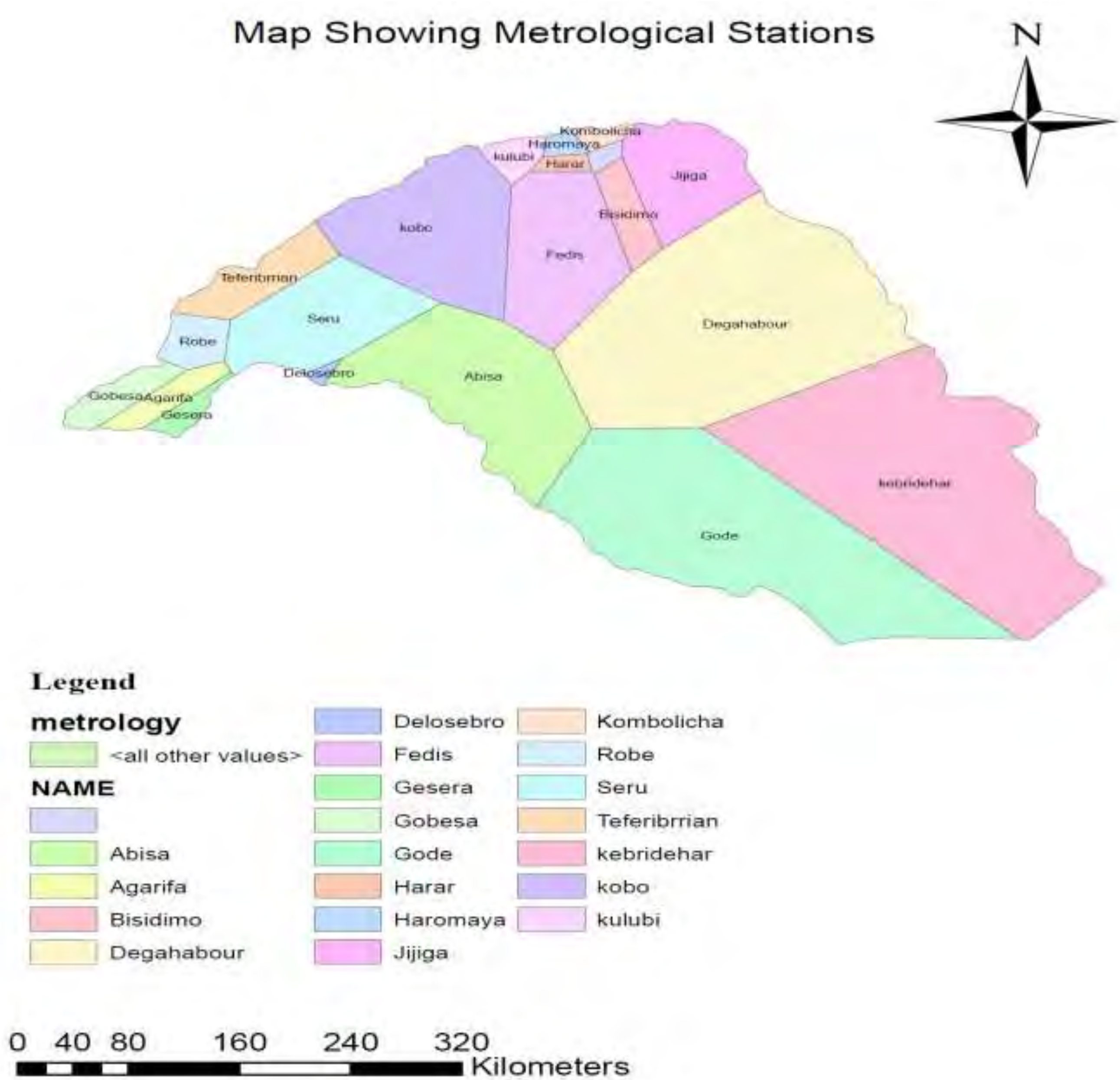

Figure 17 Rain gauge stations area coverage of WSRB by Thiessen polygon

Rainfall recorded at each station is given weightage based on the area closest to the station. The above figure shows that a Thiessen polygon constructed a set 20 meteorology station points (precipitation measurements). Each point gets its own polygon and the point value is distributed throughout the entire polygon. So the rainfall value, initially measured at the station point, expands to become the value of the entire polygon.

Rainfall characteristics

The next table shows annual rainfall values of each meteorological station, the area enclosed by each and their geographical locations. We can see from the table the maximum annual rainfalls are recorded on the upper catchment and the minimum record is found the lower catchment. The rainfall distribution in the study area ranges from 252 mm to 1243 mm. The highest rainfall is recorded in Gobesa highland area and the lowest rainfall is from Gode.

Table 2 Rainfall Data Availability for WSRB

		Thiessen Polygon Method of Rainfall Calculation				
	Metro station	Location (UTM)		Altitude	Annual rainfall	Enclosed area
	(symboling)	*Latitude N*	*Longitude E*	*(m)*	*(mm)*	*(sq.km)*
1	Abisa(St.1)	70952	403855	1944	732.53	17600
2	Agarifa(St.2)	71600	394900	2550	1011.58	2096.9
3	Bisidimo(St.3)	91430	422867	1590	690.56	2538.6
4	Degahabour(St.4)	81300	433300	1070	336.01	37432
5	Delo sebro(St.5)	71500	402800	2200	926.54	**284.01**
6	Fedis(St.6)	90800	420500	1690	700.19	11716
7	Gesera(St.7)	70800	395600	1680	974.76	1141.3
8	Gobesa(St.8)	73800	393000	2400	**1243.35**	2427.7
9	Gode(St.9)	55400	433448	290	**252.91**	33828
10	Gursum(St.10)	92100	422300	1900	842.70	494.19
11	Haramaya(St.11)	93795	420310	1690	787.49	594.04
12	Harar(St.12)	91800	420500	1977	801.23	606.35
13	Jijiga(St.13)	92000	424700	1775	584.89	7985.9
14	Kebridehar(St.14)	64400	441800	505	398.19	**38402**
15	Kobo(St.15)	91200	412100	1250	1006.13	14735
16	Kombolicha(St.16)	94337	421185	1354	728.11	657.26
17	Kulubi(St.17)	94300	416760	1456	1027.21	1390.3
18	Robe(St.18)	75233	393720	2441	955.24	2170
19	Seru(St.19)	74409	401209	2469	1121.67	10077
20	Teferi briahan(St.20)	82200	394900	2196	1042.10	4348.1

Average precipitation of stations is calculated by:

$$\boldsymbol{P_A = \frac{\sum_{i=1}^{n} p_i a_i}{A_t}}$$

Where $\boldsymbol{P_A}$ is average precipitation (mm), $\boldsymbol{P_i}$ is observed precipitation (mm), $\boldsymbol{a_i}$ is area of influence of a station (km^2), $\boldsymbol{A_t}$ is total area of the catchment under consideration (km^2). The area of each station and the total area of the catchment are calculated using global mapper 15.

For example using Thiessen polygon, let us calculate the annual weighted precipitation of Abisa station (St.1):

$$P_1 = 732.53mm\ , a_1 = 17600km^2\ , A_t = 190524.65km^2$$

$$\boldsymbol{P_A} = \frac{\sum_{i=1}^{n} \mathbf{732.53 * 17600}}{\mathbf{190524.65}} = \mathbf{67.7mm}$$

Similarly the annual weighted precipitation for the other stations are calculated and presented in the table below. The annual average depth of precipitation estimated for the catchment under consideration by using Thiessen polygon method is **558.8** mm/year.

Table 3 Weighted Annual Rainfall of the research area using Thiessen polygon method

		Thiessen Polygon Method of Rainfall Calculation			
	Metro station	Annual rainfall	Enclosed area	Weighed Area	Annual Weighted Rainfall
	(symboling)	(mm)	(km2)	(%)	(mm)
1	Abisa(ST.1)	732.53	17600.00	9.24	67.67
2	Agarifa(St.2)	1011.58	2096.90	1.10	11.13
3	Bisidimo(St.3)	690.56	2538.60	1.33	9.20
4	Degahabour(St.4)	336.01	37432.00	19.65	66.01
5	Delo sebro(St.5)	926.54	284.01	0.15	1.38
6	Fedis(St.6)	700.19	11716.00	6.15	43.06
7	Gesera(St.7)	974.76	1141.30	0.60	5.84
8	Gobesa(St.8)	1243.35	2427.70	1.27	15.84
9	Gode(St.9)	252.91	33828.00	17.76	44.90
10	Gursum(St.10)	842.70	494.19	0.26	2.19
11	Haramaya(St.11)	787.49	594.04	0.31	2.46
12	Harar(St.12)	801.23	606.35	0.32	2.55
13	Jijiga(St.13)	584.89	7985.90	4.19	24.52
14	Kebridehar(St.14)	398.19	38402.00	20.16	80.26
15	Kobo(St.15)	1006.13	14735.00	7.73	77.81
16	Kombolicha(St.16)	728.11	657.26	0.34	2.51
17	Kulubi(St.17)	1027.21	1390.30	0.73	7.50
18	Robe(St.18)	955.24	2170.00	1.14	10.88
19	Seru(St.19)	1121.67	10077.00	5.29	59.33
20	Teferi briahan(St.20)	1042.10	4348.10	2.28	23.78
			190524.65	**100.00**	**558.82**

Additionally, the maximum rainfall is recorded is in the month of April and August the minimum in the month of December. The majority of rainfall in the catchment is concentrated during March to May and July to September season and the rain fall is of bimodal in nature. 72% of the total annual rainfall is covered in the bimodal season. The table below shows the monthly and annual average rainfall data used for the model for calibration. The last column of the table contains annual average rainfall of each station.

Table 4 Long terms mean monthly rainfall (mm) of all stations

	Long term mean Monthly Ranifall(mm)												
Metro Station	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Abisa(St.1)	16.9	15.1	64.2	138.9	115.2	28.7	22.2	47.8	89.4	128.8	49.5	15.8	732.5
Agarifa(St.2)	88.2	81.7	111.3	105.5	110.3	91.4	74.3	63.0	61.8	88.8	69.4	65.8	1011.6
Bisidimo(St.3)	6.5	9.0	60.5	103.3	83.0	62.8	85.0	112.6	94.5	46.9	15.5	11.0	690.6
Degahabour(St.	3.5	1.8	22.4	78.6	78.8	16.4	7.2	11.2	42.4	56.0	13.6	4.1	336.0
Delo sebro(St.5	20.5	12.8	74.1	130.5	142.6	66.8	64.0	112.0	125.7	127.3	27.6	22.7	926.5
Fedis(St.6)	16.5	13.0	59.7	120.1	94.6	55.0	76.6	82.7	101.1	54.2	19.2	7.6	700.2
Gesera(St.7)	15.0	22.3	77.1	164.0	113.6	71.8	109.9	124.3	124.8	95.3	40.6	16.2	974.8
Gobesa(St.8)	46.0	43.1	96.8	163.2	120.8	91.4	155.9	201.1	133.9	110.9	52.5	27.8	1243.4
Gode(St.9)	1.2	0.7	18.2	71.1	43.6	0.2	1.4	0.1	2.4	64.1	45.8	4.1	252.9
Gursum(St.10)	15.3	17.1	59.9	136.5	110.0	60.4	102.9	110.7	106.6	62.2	17.3	44.0	842.7
Haramaya(St.11)	13.4	22.9	53.3	119.2	92.2	50.9	92.8	145.2	111.0	52.3	19.6	14.6	787.5
Harar(St.12)	11.9	11.5	69.6	108.9	92.8	64.0	107.5	142.5	112.7	51.7	21.1	7.0	801.2
Jijiga(St.13)	11.9	15.8	44.5	103.1	80.2	38.9	63.3	76.9	83.4	41.3	17.6	8.2	584.9
Kebridehar(St.1	4.4	3.2	28.5	92.4	64.0	8.6	16.2	24.3	37.9	77.1	35.0	6.6	398.2
Kobo(St.15)	22.5	16.7	68.2	131.0	84.3	67.0	159.2	222.4	134.5	62.6	26.1	11.7	1006.1
Kombolicha(St.1	13.8	15.4	53.9	107.2	87.6	45.6	91.3	147.5	109.4	32.8	14.8	8.9	728.1
Kulubi(St.17)	29.6	32.1	89.8	148.4	91.1	66.8	156.4	206.9	122.9	44.5	20.5	18.2	1027.2
Robe(St.18)	26.6	30.9	63.3	105.9	88.0	78.5	160.2	189.9	100.3	61.4	28.3	21.9	955.2
Seru(St.19)	47.6	76.5	89.1	105.2	153.6	132.9	78.0	132.3	98.6	89.0	70.1	49.0	1121.7
Teferi briahan(S	28.9	27.0	80.5	108.0	90.6	75.1	182.3	202.7	124.8	71.2	34.8	16.1	1042.1

The groundwater recharge was calculated with three dimensional finite element (TAGSAC) groundwater models which use 10% of annual rainfall serves as input for the model calibration. The model worked on both annual and monthly rainfall of each station. The table 4 above shows average monthly and annual rainfall for each station in the study area. Thus data‘s are used directly for the model by taking 10% recharge to the groundwater.

4.2 Flow systems

The basin has limited surface water resources compared with other river basin of the country. The major surface water is the Wabi Shebelle River which flow more than 1297 km distance from north western border to south eastern extreme point. The other river like Erer River and a number of streams from the upper catchment contribute the surface water resources of the basin

Additionally the most eastern lakes in the country are parts of the WSRB, Lake Haromaya, Lake Adele and Lake Lange. But the largest one, Lake Haromaya, has completely dried up, as it supposedly supplies the drinking water for the town and as it is used for irrigation by local farmers.

There is one man made reservoir in the basin; Melkawakena dam in North West part of bale zone. The surface area is about 82 km^2. These surface waters are a contributor for the aquifer in the basin.

In this three-dimensional modeling effort, the surface nodes at the river edge and Lakes were simulated as constant-head boundary conditions reflective of the assumed river stage or Lake water level. The nodes below the surface and along the center of the river were simulated as no-flow boundaries. This design leads to a more accurate approximation of the upward movement of groundwater as the groundwater flow is controlled by the hydraulic gradient between the aquifer and the river/Lakes.

The ground surface is set as a free seepage face. Recharge at the top surface boundary takes precipitation into consideration. Recharge rate of 10 % is given to the model for proper estimation of the water levels measured in the wells. Simulated hydraulic-head altitudes range from 4191.6 m near Mountain to 156.6 m at the south gorge of the river Valley.

4.3 Model Calibration

The objective of model calibration in this study is to minimize the difference between calculated and measured of hydraulic head. The model was calibrated by varying the aquifer‘s hydraulic conductivity (K) and aquifer‘s recharge (R).

The parameters Hydraulic conductivity (K) and recharge (R) were initially assumed to be unknown. In this study the manual trial and error adjustment of parameters is used. The model calibration is performed to data observed at wells points (*Black dotes in Figure 15*).

From trial and error analysis the recharge taken in the model is 10 % of the annual rainfall received at the same point. For the hydraulic conductivity and recharge values the modeled and the measured values comparison can be seen in Figure 18. In the figure the best fit equation obtained between the modeled and Measured (well inventory data) is made by making the intercept at the origin (0, 0). The average indicators between modeled and calibrated results are shown in the following table.

Table 5 Error calculated for measured and modeled head of the study

No of Wells and springs	ME(m)	MAE(m)	RMSE(m)	r2
205	7.77	8.77	15.30	0.9992

The mean error is the mean difference between measured heads (h_m) and simulated heads (h_s).

$$a_{\boldsymbol{mean\ error}} ME = \frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i = 7.77$$

The mean absolute error (MAE) is the mean of the absolute value of the differences in the measured and simulated heads.

$$b_{Mean\ Absolute\ Error}\ MAE = \frac{1}{n}\sum_{i=1}^{n}|(h_m - h_s)_i| = 8.77$$

The root mean squared error (RMS) is the average of the squared differences in measured and simulated heads.

$$c_{Root\ Mean\ Squareed\ Error}\ RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i{}^2\right]^{0.5} = 15.30$$

Where h_m and h_s are measured and simulated results and **n** is the number of data. The coefficient of determination, $\mathbf{r^2}$, compares estimated and actual groundwater level -values, and ranges in value from 0 to 1. If it is 1, there is a perfect correlation between the modeled and measured values — there is no difference between the estimated and measured values. At the other extreme, if the coefficient of determination is 0, the regression equation is not helpful in predicting the groundwater level-value. The correlation coefficient between measured and simulated heads for the final simulation is 0.9992, indicating an acceptable representation of the hydrologic system by the model.

Results obtained from model simulations of the ground-water flow system in the vicinity of WSRB provide a good match of simulated-to measured hydraulic-head values throughout most of the modeled area, in spite of hydro geologic complexities and lack of data in several areas.

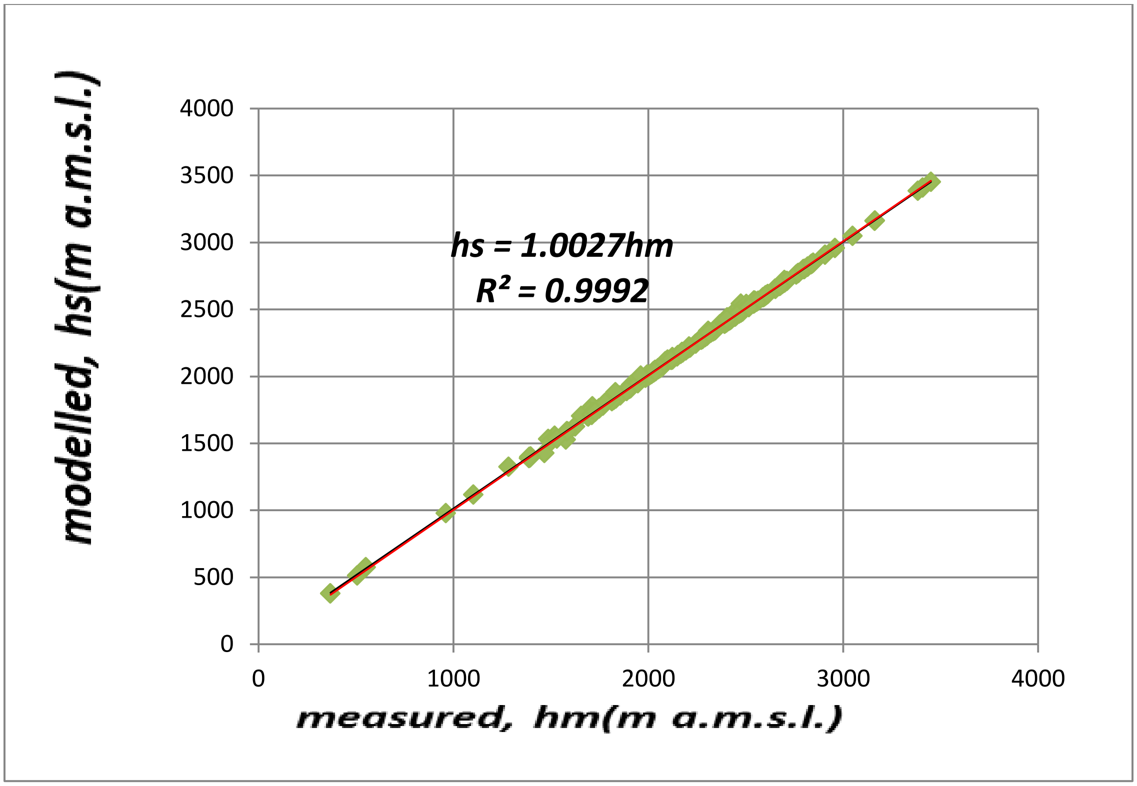

Figure 18 Measured vs. Modeled Groundwater level for water point data

4.4 Validation Result

We validate the model by the method called historical validation**,** so we divide the data in to two parts for calibration and validation. The data for validation are taken as that of the calibration data reserved. From the total data majority of the data are used for calibration and about 15 data are taken for validation. The result shows that with minimum number of data the relatively similar results are obtained from the analysis.

Table 6 Error calculated for validation result

No of Wells and springs	ME(m)	MAE(m)	RMSE(m)	r2
15	4.74	10.4	19.37	0.9988

The mean error is the mean difference between measured heads (h_m) and simulated heads (h_s).

$$a_{\boldsymbol{mean\ error}}ME = \frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i = 4.74$$

The mean absolute error (MAE) is the mean of the absolute value of the differences in the measured and simulated heads.

$$b_{Mean\ Absolute\ Error}\ MAE = \frac{1}{n}\sum_{i=1}^{n}|(h_m - h_s)_i| = 10.40$$

The root mean squared error (RMS) is the average of the squared differences in measured and simulated heads.

$$c_{Root\ Mean\ Squareed\ Error}\ RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i{}^2\right]^{0.5} = 19.37$$

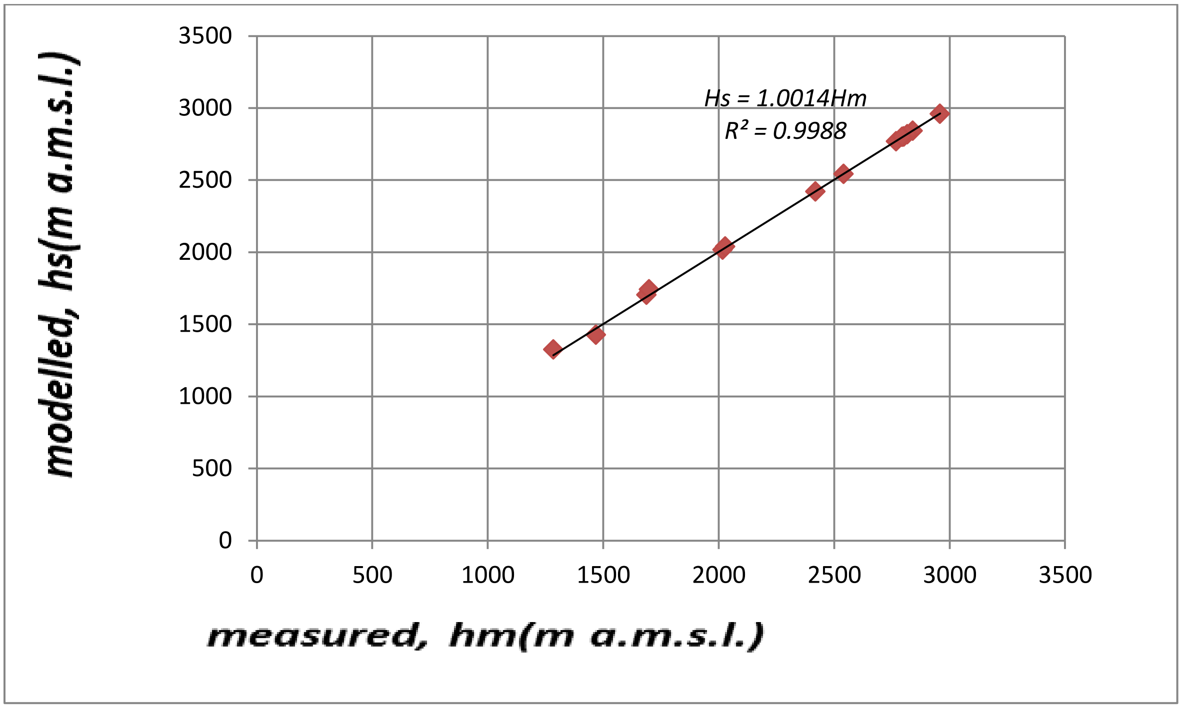

Figure 19 Validation result of the model.

4.5 Hydraulic Conductivity for the Calibrated model

The geological condition of the area is complex and the model is assumed as a single layer in all over the thickness, which ignores the natural heterogeneity of the vertical direction. Therefore, further refinement of the model would be possible with additional data which improve the accuracy of model prediction parameter to apply it for a detail analysis.

There are 36 types geologic medium in the basin. These mediums have different hydraulic conductivity. The developed model is computed by varying the hydraulic conductivity and the recharge. After a number of trial and error procedures, selection of a set of hydraulic parameters for geologic units in Figure 10. The following parameter values are selected as the best among other combinations.

In order to determine the volume of groundwater the hydraulic conductivity and porosity of the each geologic unit should be known. From trial and error procedure the hydraulic conductivity values for the different zones that provide the best fit are presented in the table below. The last Column of table 7 shows hydrogeological classification of the study is based on hydraulic conductivity values after acceptable calibration error of 15.30 meter.

The simulated hydraulic conductivity value varies from 8.64×10^{-8} m/s to 7.7×10^{-4} m/s which is within the range of the conceptual model assigned value taken from WWDSE, 2004 report.

Table 7 Calibrated Geological parameters and their Hydrogeological zones

	Geologic medium	K_x (m/s)	K_y (m/s)	K_z (m/s)	Hydrogeologic zones
1	Ja	1.73×10^{-7}	8.64×10^{-7}	8.64×10^{-7}	HGz-1
2	Jg1	1.73×10^{-7}	8.64×10^{-7}	8.64×10^{-7}	
3	Jg2	1.73×10^{-7}	8.64×10^{-7}	8.64×10^{-7}	
4	Jh1	4.32×10^{-6}	4.32×10^{-6}	4.32×10^{-6}	HGz-2
5	Jh2	4.32×10^{-6}	4.32×10^{-6}	4.32×10^{-6}	
6	Ju	8.64×10^{-7}	8.64×10^{-7}	8.64×10^{-7}	HGz-3
7	Ka	8.64×10^{-7}	8.64×10^{-7}	8.64×10^{-7}	
8	Kb	8.64×10^{-6}	6.9×10^{-6}	8.64×10^{-7}	HGz-4
9	Kf	8.64×10^{-6}	6.9×10^{-6}	8.64×10^{-7}	
10	Kg1	7.7×10^{-5}	8.64×10^{-7}	7.7×10^{-5}	HGz-5
11	Kg2	7.7×10^{-6}	8.64×10^{-7}	7.7×10^{-5}	HGz-6
12	Km	7.7×10^{-6}	8.64×10^{-7}	7.7×10^{-5}	
13	Lake Haromaya	7.7×10^{-6}	8.64×10^{-7}	7.7×10^{-5}	
14	Mt Hunkobo	7.7×10^{-5}	7.7×10^{-5}	7.7×10^{-5}	HGz-5
15	Mt Kala	7.7×10^{-5}	7.7×10^{-5}	7.7×10^{-5}	
16	Nag	7.7×10^{-6}	2.6×10^{-6}	8.64×10^{-7}	HGz-7
17	Nar	7.7×10^{-6}	2.6×10^{-6}	8.64×10^{-7}	
18	Ncb	8.64×10^{-6}	8.64×10^{-8}	8.64×10^{-6}	HGz-4
19	Nct	8.64×10^{-6}	8.64×10^{-8}	8.64×10^{-6}	
20	Nn	8.64×10^{-7}	4.32×10^{-7}	8.64×10^{-8}	HGz-3
21	PNa1	8.64×10^{-7}	4.32×10^{-7}	8.64×10^{-8}	
22	PNa2	7.7×10^{-5}	7.7×10^{-5}	7.7×10^{-6}	HGz-5
23	PNa3	7.7×10^{-5}	7.7×10^{-5}	7.7×10^{-6}	
24	Pc1	8.64×10^{-7}	4.32×10^{-7}	8.64×10^{-7}	HGz-8
25	Pc2	8.64×10^{-7}	4.32×10^{-7}	8.64×10^{-7}	
26	Pc2b	7.7×10^{-4}	7.7×10^{-4}	7.7×10^{-4}	HGz-9
27	Pc2m	7.7×10^{-4}	7.7×10^{-4}	7.7×10^{-4}	
28	Pc3k	8.64×10^{-7}	8.64×10^{-8}	8.64×10^{-7}	HGz-3
29	Pgj	8.64×10^{-7}	8.64×10^{-8}	8.64×10^{-7}	
30	Pna1	8.64×10^{-8}	8.64×10^{-8}	8.64×10^{-8}	HGz-10
31	Pzt	8.64×10^{-8}	8.64×10^{-8}	8.64×10^{-8}	
32	Qa	8.64×10^{-8}	8.64×10^{-8}	8.64×10^{-8}	
33	Qb	8.64×10^{-8}	8.64×10^{-8}	8.64×10^{-8}	
34	Triangle	8.64×10^{-8}	8.64×10^{-8}	8.64×10^{-8}	
35	gt1	8.64×10^{-8}	8.64×10^{-8}	8.64×10^{-8}	
36	gt2	8.64×10^{-8}	8.64×10^{-8}	8.64×10^{-8}	

From the table above we can see that medium1-medium 3 (Ja, Jg1, and Jg2) have the same hydraulic conductivity. Medium 4 and medium 5(Jh1 and Jh2), medium 6 and medium 7(Ju and Ka), Medium 30 - medium 36(Pna1, Pzt, Qa, Qb, triangle, gt1, and gt2) have the same hydraulic conductivity and so on. As expressed previously and from the table we deduce that the medium that have the same hydraulic conductivity are same hydrogeological character.

From the calibration analysis we can comprehend that, the geologic unit's labeled by green (in figure 20) have lower response on RMS value when the hydraulic conductivity value change. The geologic medium labeled by blue color on the other hand has a greater response to hydraulic conductivity change. In addition the medium in yellow color are found as the border and gorge area of the basin, also have almost no response.

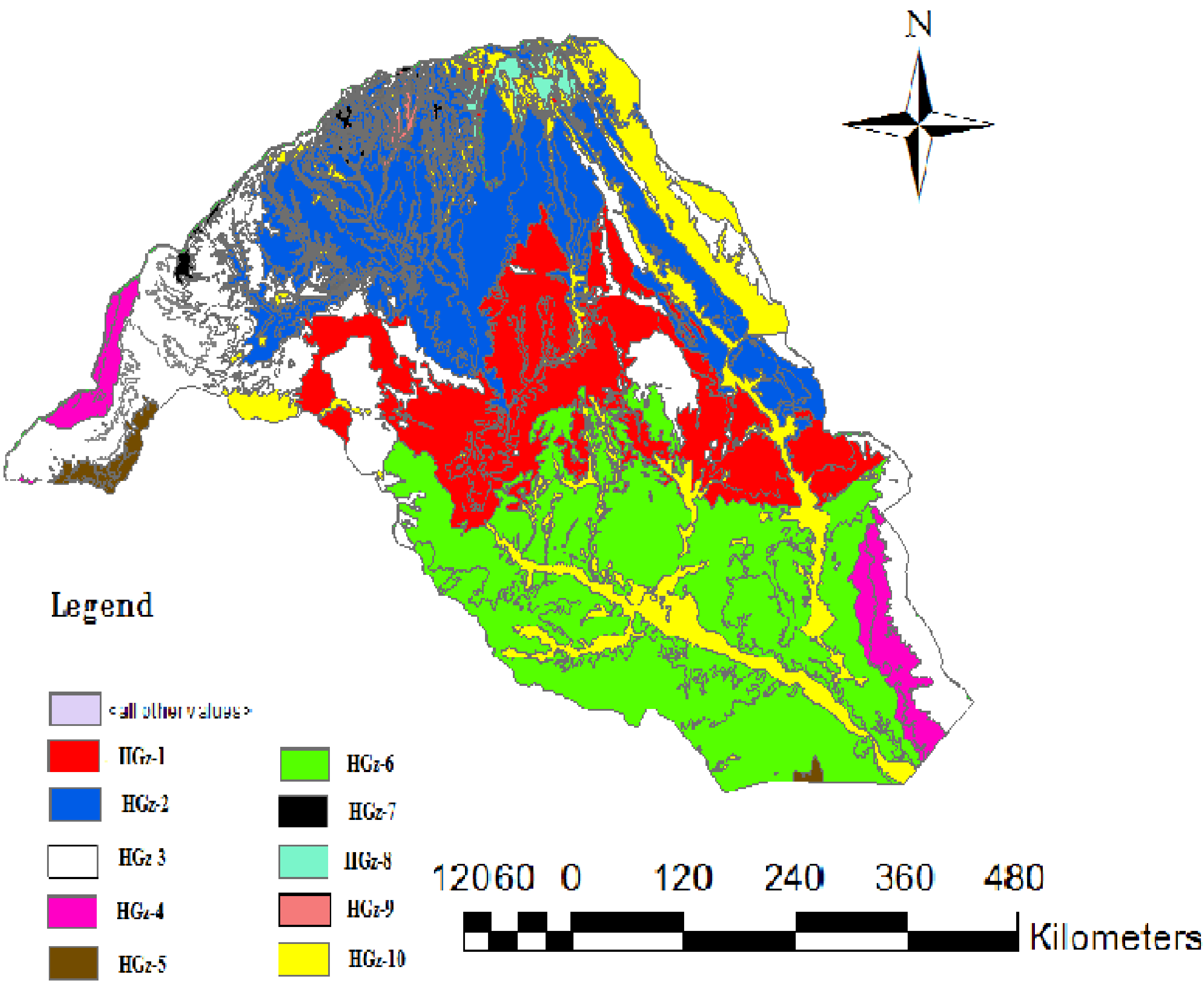

Figure 20 Hydrogeological map of the basin. (*The code of geologic units in each zone are presented in table 7*)

4.6 Estimated Groundwater Potential of the basin

The rechargeable groundwater potential of the basin is calculated for each number of elements by using TAGSAC in the analysis. For calculating the volume of groundwater the maximum and minimum porosity of each geologic medium are used as input parameters. These porosity values are taken from material written as a standard values for different types of geologic unit. The volume of groundwater is calculated by multiplying the saturated recharge groundwater with the porosity of the geologic unit in the triangular prismatic element that discretized by TAGSAC.

$$\boldsymbol{V_T = H_e * \sum A_i}$$

$$V_T = \text{total saturated volume}$$

$$H_e = \text{average hydraulic head}$$

$$A_i = \text{area of each triangular element}$$

The actual groundwater volume is determined by introducing porosity to the total groundwater volume. This is calculated as:

$$\boldsymbol{V_W = V_T} * \eta$$

V_w =actual volume groundwater

V_T =total volume groundwater

η=porosity of geologic material in the study area

The porosity values are taking in two forms the maximum and minimum porosity values. From these two values the average is taken for groundwater volume.

The table below shows the monthly volume of groundwater in column 3. Among these values the minimum is found in the driest month of the year which December. At the month of December the volume of groundwater is about $2.19* 10^{10}$ m^3, which is non replenishable. By taking this value as the base (i.e. the values lower than this value are non-replenishable component) the replenishable component has been estimated in column 5. The maximum value is found in the month of April. This shows as that the recharge amount high in this month. From the rainfall analysis the upper catchment receive maximum rainfall in months from July to September. In the lower catchment this is reversed, the amount of rainfall is lower in these months than in the month of March to May of the bimodal character of the rainfall. From this we can grasp that even if higher amount of rainfall is scored there should be topographical parameters (like slope) to recharge these amount to the underground. That is what we see from the Wabi Shebelle basin study, the upper catchments are hilly and the lower catchments are flat. In flat areas the amount of rainfall that dropped are more effective to join the underground water than hilly areas. The analysis shows the replenishable volume of groundwater is about 8.7 x 10^9 m^3. This value is more than that estimated previously by WWDSE, 2004. This is because of the method of estimation and data unavailability in time of estimation. The methods of estimation used previously are the hydrograph method estimation (1128 MCM/year=1.128 x 10^9 m^3). The table below shows computations of monthly replenishable groundwater in study area.

Table 8 Monthly Replenishable Groundwater volume

	Month	*Total Volume*	*Minimum Volme*	*Replenishable volume*
1	September	23044614587	21929410114	1115204473
2	October	22926927616	21929410114	997517501.5
3	November	22469164300	21929410114	539754185.8
4	December	21929410114	21929410114	0
5	January	21951963955	21929410114	22553841.11
6	February	21929674210	21929410114	264095.7713
7	March	22775022669	21929410114	845612554.8
8	April	23271883092	21929410114	1342472977
9	May	23096785584	21929410114	1167375470
10	June	22505754473	21929410114	576344358.3
11	July	22874236840	21929410114	944826725.3
12	Augest	23086257813	21929410114	1156847699
	Total	2.71862E+11		8708773882

The amount of groundwater recharge different from one month to the other, this is due to the difference in the amount of precipitation in months. The figure below shows the monthly replenish able amount of groundwater of the study area.

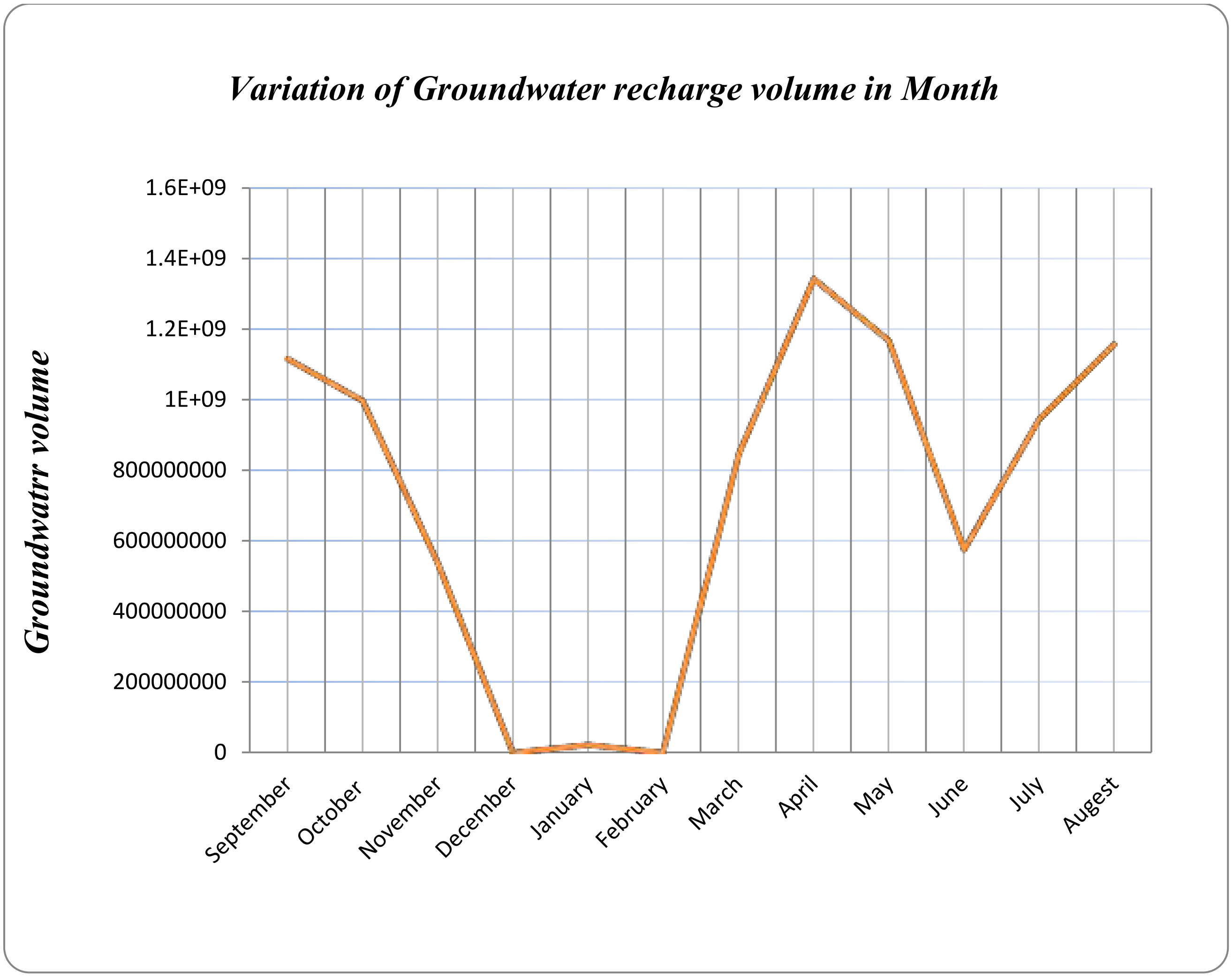

Figure 21 Monthly average Groundwater recharge volume in the basin

4.6.1 Drawback of the previous study

It is important to remember that the assumption that base flow equates to groundwater discharge is not always valid. Water can be released into streams over different timeframes from different storages such as connected lakes or wetlands, snow or stream banks. As the hydrographic record represents a net water balance, base flow is also influenced by any water losses from the stream such as direct evaporation, transpiration from riparian vegetation, or seepage into aquifers along specific reaches. Water use or management activities such as stream regulation, direct water extraction, or nearby groundwater pumping can significantly alter the base flow component. Hence, careful consideration of the overall water budget and management regime for the stream is required.

Another complication is that base flow is also influenced by any water losses from the stream. The hydrographic record essentially represents the net balance between gains to and losses from the stream. These losses include direct evaporation from the stream channel or from any connected surface water features such as lakes and wetlands, transpiration from riparian vegetation, evapotranspiration from source groundwater seepages, leakage to the underlying aquifer, or rewetting of stream bank and alluvial deposits (Smakhtin, 2001). These processes are often aggregated into a transmission loss for the reach of the stream.

The previous works have their own limitations and mayn‘t provide any comprehensible ideas with respect to the current major groundwater management constraints and future groundwater management prospects, estimation of the current and projected domestic water demand and irrigation water requirements, and the sustainability of groundwater reserve of the catchment. Almost all of the rivers gauging stations are found at the Northwest upper catchment of the Wabi Shebelle river basin. Preliminary analysis of the recharge estimation based on hydrograph separation method questioned due to uneven distribution of the station as well as the number of perennial rivers in the biggest watershed basin of the country. The three gaging stations Wabi at Dodola, wabi at Melkawakena, Wabi at Gode are found in one river system, this affects the estimation of recharge using hydrograph separation. Additionally these stations area also found in three geologic unit that relatively covers very small areas; the Nazarerth group (Nn), Volcanic rocks of the pre-rift succession (PNa1, PNa2 and PNa3), Chilalo Volcanics (Ncb and Nct) which are not representative for the whole basin geological units.

The estimation is made on considering the following conditions: similarity in topography, climate patterns, soil characteristics, land-use and land cover so these parameters are varies for the station mentioned above. All the above mentioned points are the challenge to accept the previous study the accurate estimation of groundwater in the basin. The model does not conclude this study the final and correct estimation, but understand as a better estimation of groundwater potential in one of the largest basin. So this is a starting issue to study further on the area to modify.

4.6.2 Change in groundwater volume

The result shows that the replenishable volume of groundwater is larger than the previous study estimated. The quantity and quality of groundwater are changing positively or negatively due to human activity. Assessing the impact on the groundwater system and predicting the magnitude of change in the future is therefore a major scientific challenge.
Land use change is also one of the parameters that affect groundwater volume of an area. Land-use and land-cover changes are one of the main human induced activities altering the groundwater system.

The volume of water contained in the rock depends on the percentage of these openings or pores in a given volume of the rock, which is termed the porosity of the rock. More pore spaces result in higher porosity and more stored water.
An essential feature of groundwater movement is the phenomenon of change in groundwater storage. Storage change is governed by three fundamental processes

- Change in void volume of skeleton
- Change in fluid saturation
- Change in fluid density

Natural sources of freshwater that become groundwater are;

1) Areal recharge from precipitation that percolate through the unsaturated zone to the water table. Because areal recharge occurs over broad areas, even small average rates of recharge (for example few inches per year) represent significant volumes of inflow to the groundwater.
2) Losses of water from streams and other bodies of surface water such as lakes and wetlands. Streams commonly are significant sources of recharge to groundwater downstream from mountain forms and steep hill slops in arid and semiarid areas.

Therefore, the main point here is not how the replenishable groundwater volume increases but it is the way of determination of the rechargeable groundwater. The previous study shows only the starting point of groundwater replenishable volume, it is not an end. The next researchers may modify the study with finer information‘s on the study area.

4.7 Groundwater Flow Direction

Groundwater is not ―held" in one place, it flows through the aquifer. Groundwater is transported through the aquifer because of the reason; gravity and pressure. In an aquifer water flows from one point to another due to gravity. Groundwater moves from areas of higher elevation or high pressure to areas of lower elevation or low pressure. The groundwater gradient is pretty low. The gradient (hydraulic conductivity and effective porosity) are quantities that are to be measured or estimated in order to calculate the speed of ground water flow.

In order to define groundwater flow directions and rates through aquifer systems, individual measurement of hydraulic head are combine to generate contour map of water level. Each contour represents a line of equal hydraulic head.

The figure below shows the direction of subsurface water flow in the study area, the figure also shows the location of ridges, high potential zones and lower potential areas in the basin.

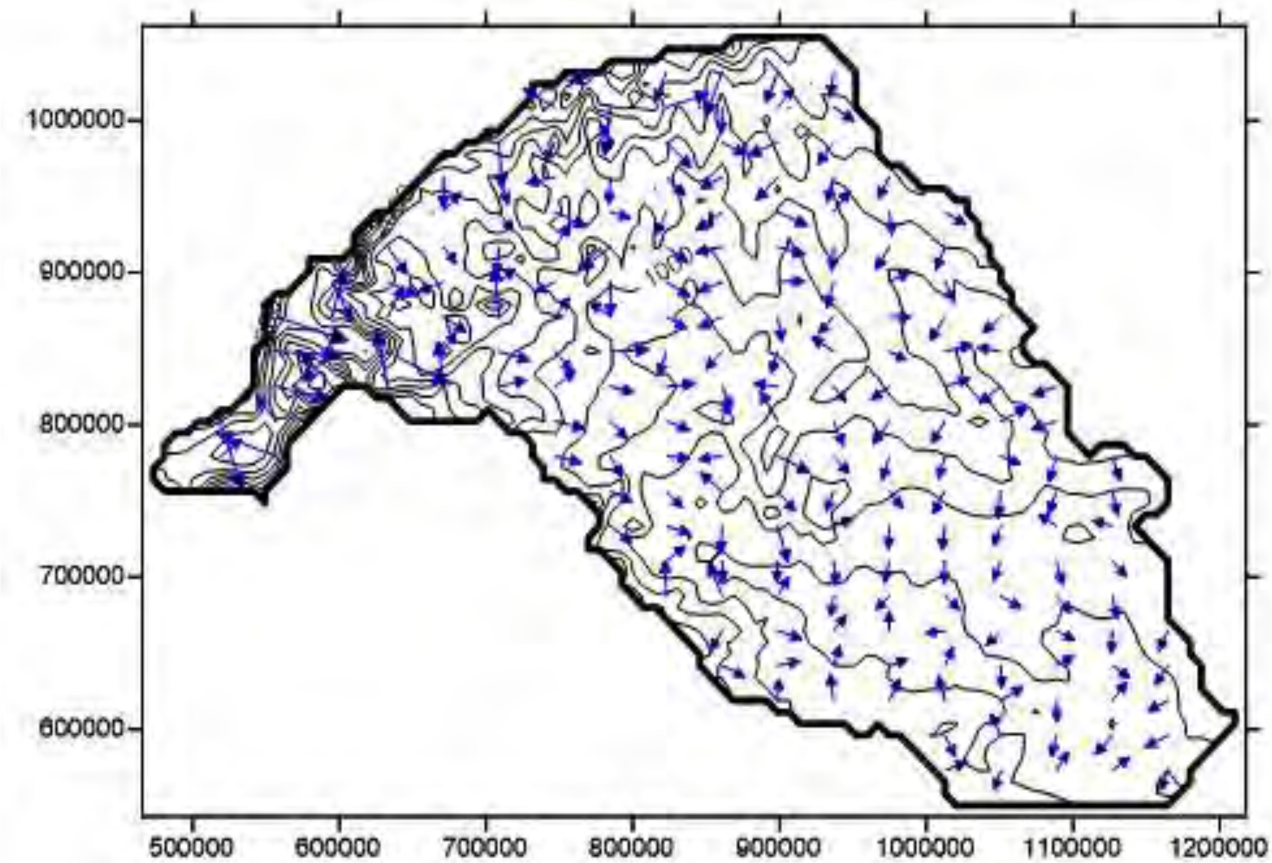

Figure 22 Groundwater flow direction of the basin

4.8 Accessible Groundwater Depth

Accessibility is a function of saturated thickness, depth of water, and hydraulic conductivity, which is a measure of how easily water flows through or can be pumped from an aquifer. Accessibility is zero if hydraulic conductivity or saturated thickness is zero, and increases as these values increases. However, accessibility decreases as the depth to water increases. Underground water occurs in two different zones. One zone, which occurs immediately below the land surface in most areas, contains both water and air and referred to as unsaturated zone. Unsaturated zone is a zone between land surface and a deepest water table. The other portion of underground water is saturated zone (phreatic zone), is the area in an aquifer below water table, in which relatively all pores and fractures are saturated with water. The phreatic zone size and depth may fluctuate with change of season, and during wet and dry periods.

When we go on the study area the depth that has available water differs from place to place. We can see some of this variation in three cases. The cases are based on the seasonality of the rainfall. The basin is bimodal in nature which has two major season having maximum precipitations. This are March to May and June to August, and one dry season from November to January. From this season two extreme points are selected to show the ground water accessibility.

- At the driest month of the year(December is the driest month in the basin)
- At the wettest month of the year (August is the wettest month). For each case there are also three specific conditions stated.

The thickness of unsaturated zone depends on factors like; climate, elevation, season of the year and area wide-groundwater withdrawals through pumping. In rainy season of humid areas, the unsaturated zone become thin layer extending from land surface to only a few meters below the surface. But in drier month of the year, the unsaturated zone may extend deeper as recharge to the aquifer declines and withdrawals increases. The next cases show this difference between the driest and wettest month of the year in accessible groundwater of the basin.

Three situations which are based on depth are considered in each seasonal condition (for the two cases):

- Depth at 50 meters
- Depth at 150 meters and
- Depth at 300 meters

1. **At the most driest season(December)**

In December the amount of rainfall is the lowest in the study area. So the recharge in this season is also the lowest one. This gives deepest accessible groundwater depth or thicker unsaturated zone. The accessibility at this month at three situations is shown below.

a. **At 50 meter depth**

The figure shows that the shaded area is an area which gives groundwater at 50 meters depth. We can see from the figure that the shaded area cover the part of the basin area that drainage network found. That means the shaded region follows the paths of perennial rivers (Wabi Shebelle and Erer rivers) and major streams of the basin. In the area like the above the physical boundary of the aquifer may closely coincide with the surface stream watershed. That means the shaded area is an area at which the soil is saturated with water. In other word the white area is an area needs greater depth than 50 meters to access groundwater.

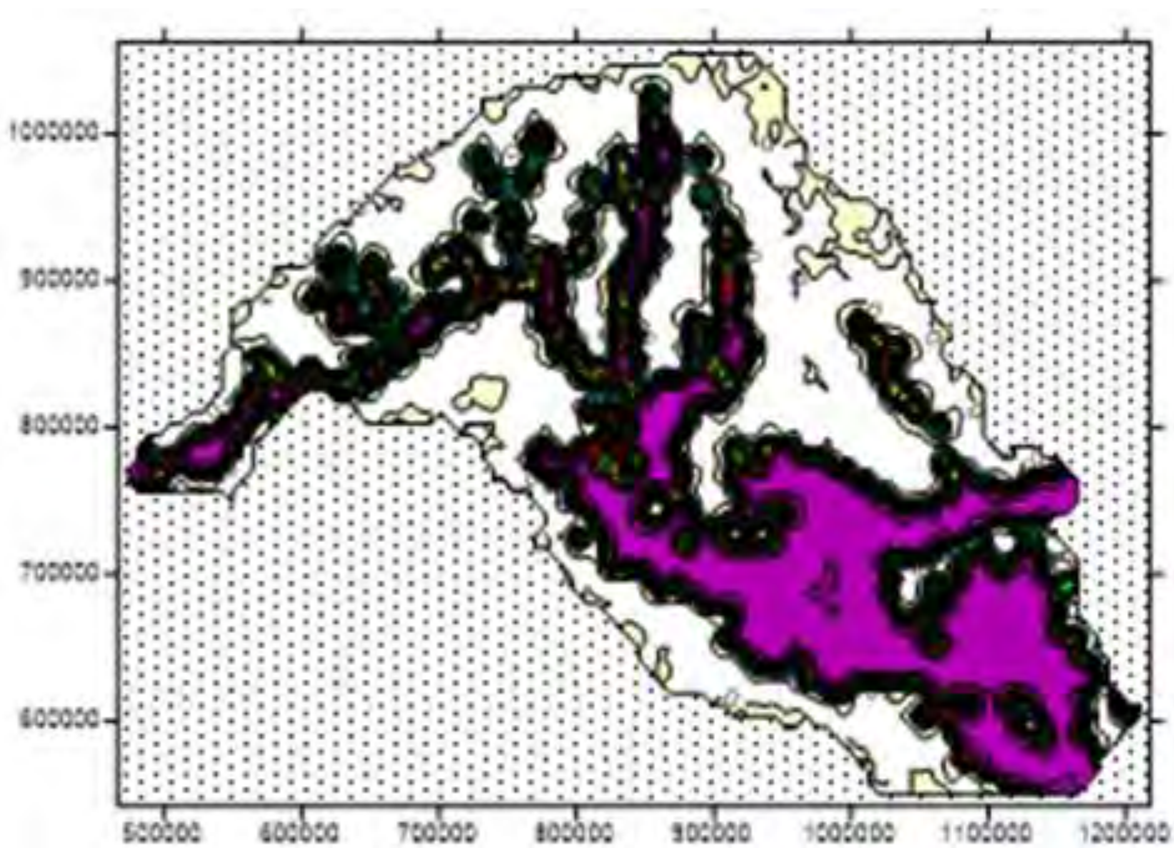

Figure 23 Accessible groundwater levels in driest month (at 50 meter depth)

b. At 150m depth

In this case the area coverage is broader than that of the first case due to increasing the depth. This the area covers starting from the gorge of the rivers and become to cover the neighbor areas of the gorge and in the lower catchment it cover all surface area that have an elevation below 800 m .a. s. l.

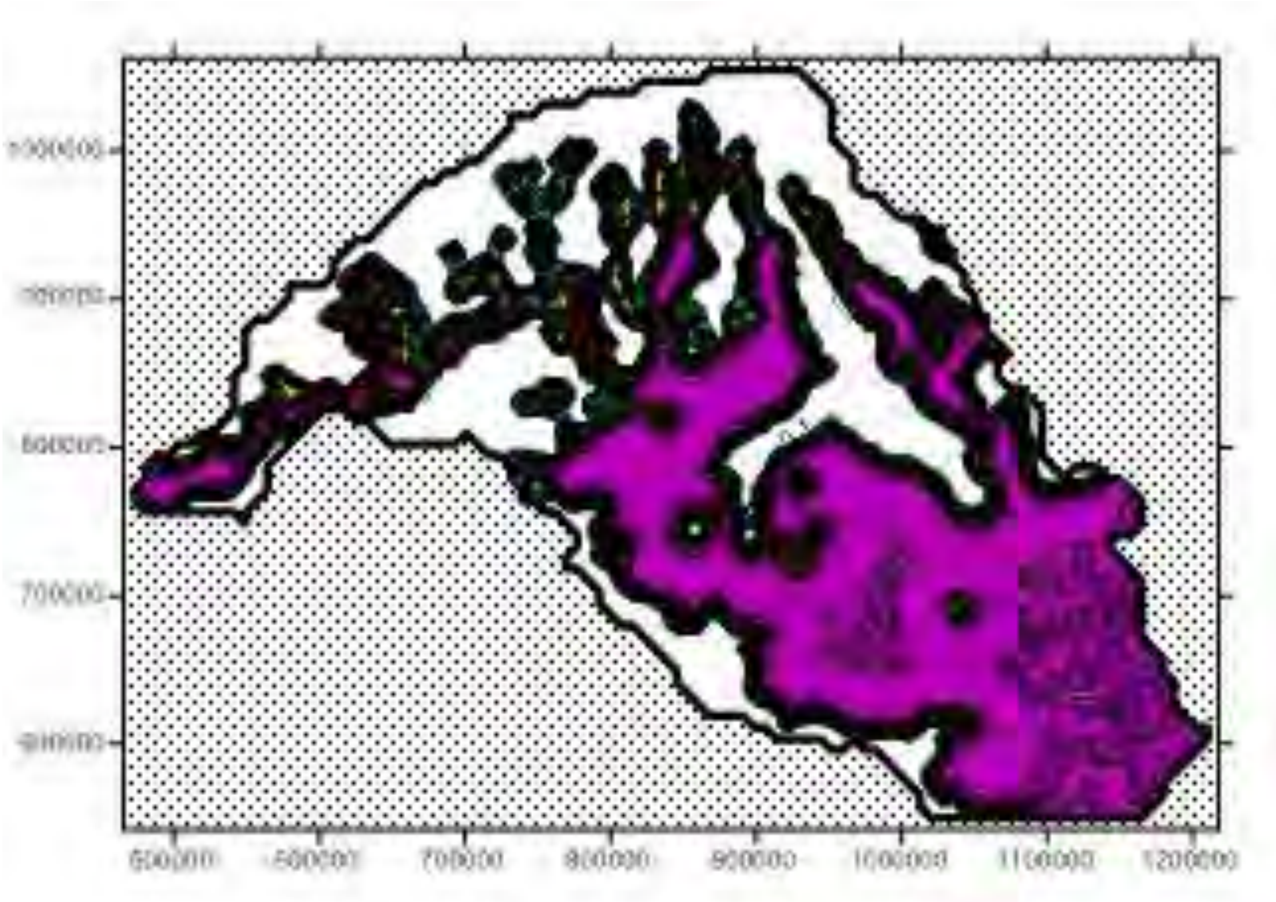

Figure 24 Accessible groundwater levels in driest month (at 150 meter depth)

From the figure above we can see that, the water table (or potentiometric surface) is not flat surface; rather, there are high areas and low areas just like the hill and valley found on the land surface. Just as surface water tends to flow downhill, groundwater tends to move down gradient from water table areas of higher elevation to water table areas of lower elevation. The areas that are shaded as red in the figure is an area of lower elevation compared to the white part. The red shaded area is an area of gorge and valley in the northern and north western catchment of the basin of which are the path of river flow and the areas in the lower catchment are an areas lower elevation in the basin that are flooded in the wettest season of the year.

The general flow of groundwater is downstream and there is a close relationship between stream flow and groundwater depth as we can see from the two figures above. This is due to the types of aquifers which is alluvial aquifers.

c. At 300 meter depth

In this situation most of the basin have accessible groundwater at 300meters depth, except some border area of northern and north western mountain areas and some parts of south western catchment. We can see from topographic map of the basin that these areas are an area of higher elevation, elevation range from 2000- 4000meters above sea level.

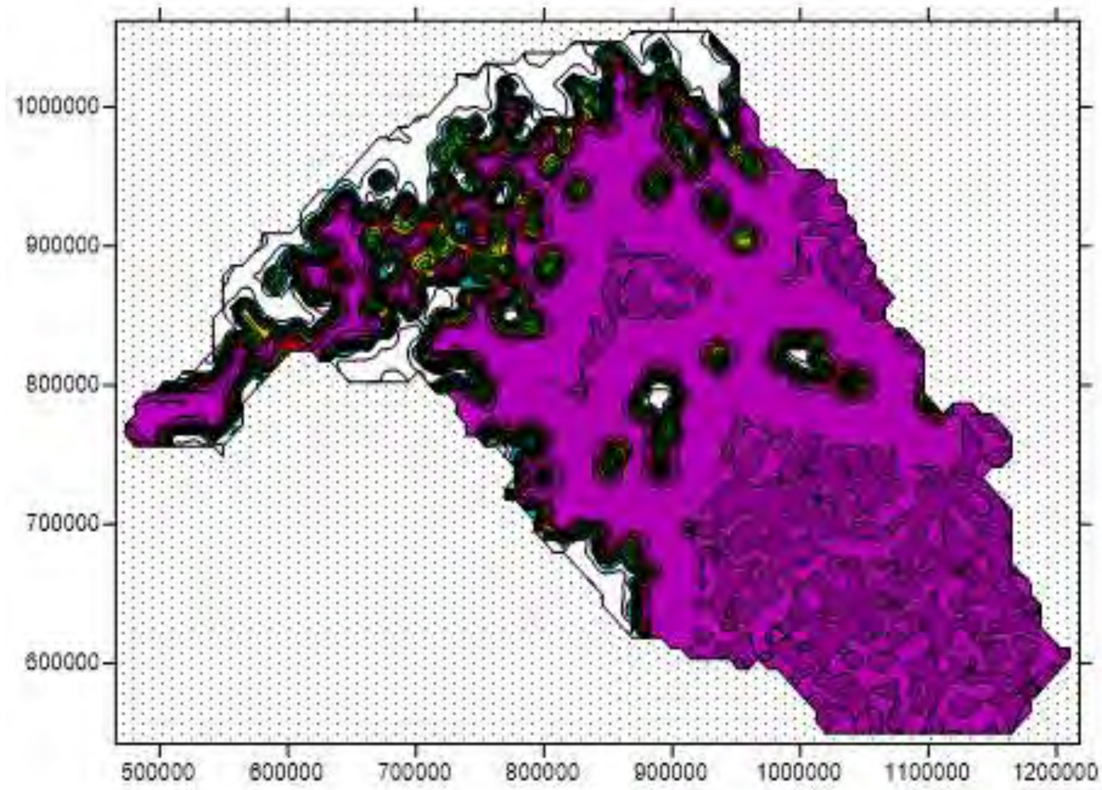

Figure 25 Accessible groundwater levels in driest month (at 300 meter depth)

The figure shows that in shaded area are areas we can access groundwater in this month. In other word the white areas needs depths greater than 300 meters to access groundwater in this month. The regions manifest one the physiographic region of the country as stated earlier. Beside the surface water topography of the land surface also determines the general direction of groundwater flow and it influence groundwater recharge and discharge. The high topographic areas are recharge areas, groundwater flows from the recharge area to discharge area. These area may take as groundwater dived, which we cannot access the groundwater with 300 meters depth.

At month of August (the wettest month)

The most general regional laws of groundwater resource generation are governed by the effect of climate, geomorphological, geological, structural, and hydrogeological conditions of individual regions. The influence of some factors can be more clearly established by studying in detail conditions of groundwater generation in an individual region.

As pointed out by researchers, the quantity of infiltrating water ranges widely and depends on the permeability and thickness of deposits through which percolation occurs, the difference in head between recharge sources and aquifers, and the extent of the area through which infiltration occurs. The amount of precipitation reaching the saturated zone depends on several factors. Among them the main factors are the nature and thickness of soil and rocks of the vadose zone, topography, vegetation cover, land use, soil moisture content, depth to water, the intensity, duration and seasonal distribution of rainfall, solid or liquid precipitation (snow or rain), meteorological factors, air temperature, moisture content and wind.

I. At 50 meter depth from the surface

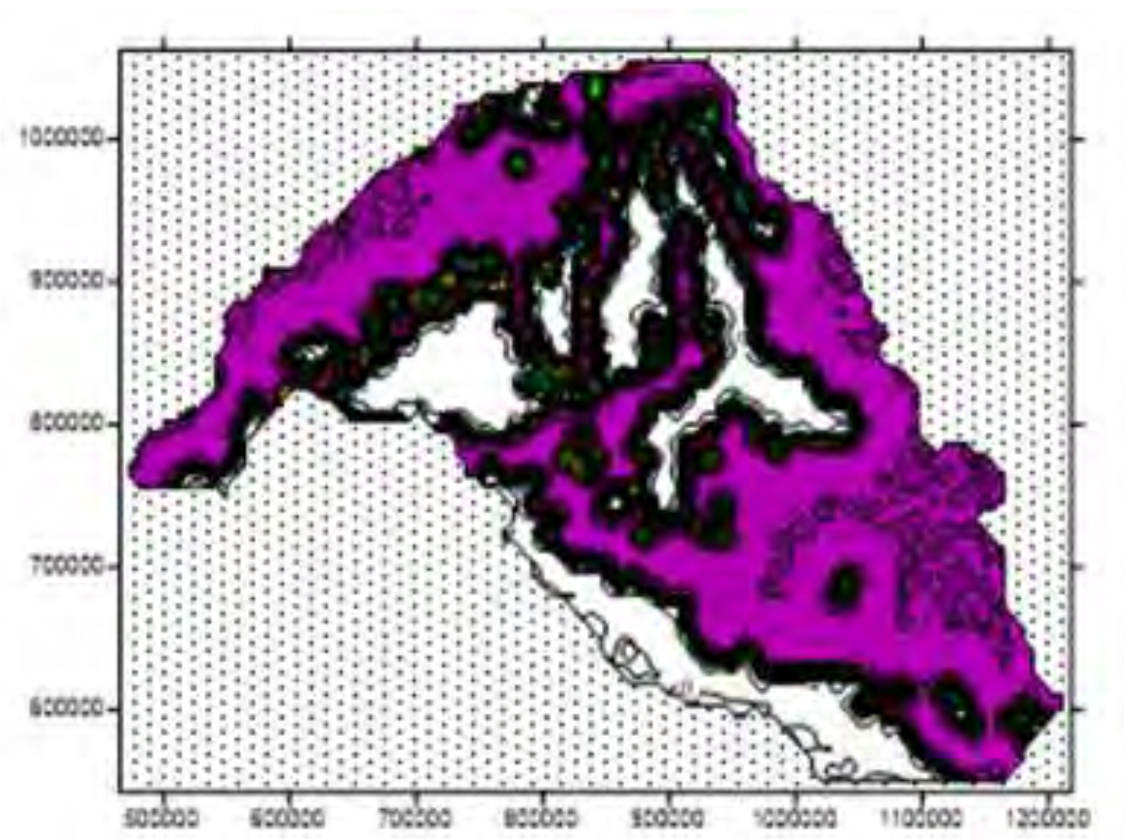

Figure 26 shows the groundwater level in wettest month (August) (at 50 meter depth)

Let us compare this figure with that of the same situation but for the driest month condition. In both situations the similar region are found in south-western border and central area between perennial rivers gorge of Wabi- Shebelle, Erer, and Deceta with only some different in broadness, which we cannot access groundwater. But there is major difference in the water accessibility in the given depth (50m) on northern and north eastern, and major eastern border region, that the wettest season have accessible groundwater in these area, in driest not at all. So we can deduce from this condition that their similarity is due to topography and their difference is due to precipitation. But we can also understand here, in wet season the topographic parameter may not be an obstacle to access groundwater in a given point. Therefore the white area in both situations are an area that needs greater depth to access groundwater due to other factors like; geology, soil types and moisture content, land use etc.

II. At 150 meter depth from the surface

In this situation, there are catchments that are still no accessible groundwater at the given depth in the south western border and central part of the basin. As we compare this situation to that of the first case in second situation (at driest month of 150m depth) there difference is only on the upper catchment border areas and broadness of the condition the first case. They are similar in the south western border and central part of the basin, the inaccessibility is not solved by seasonal variation.

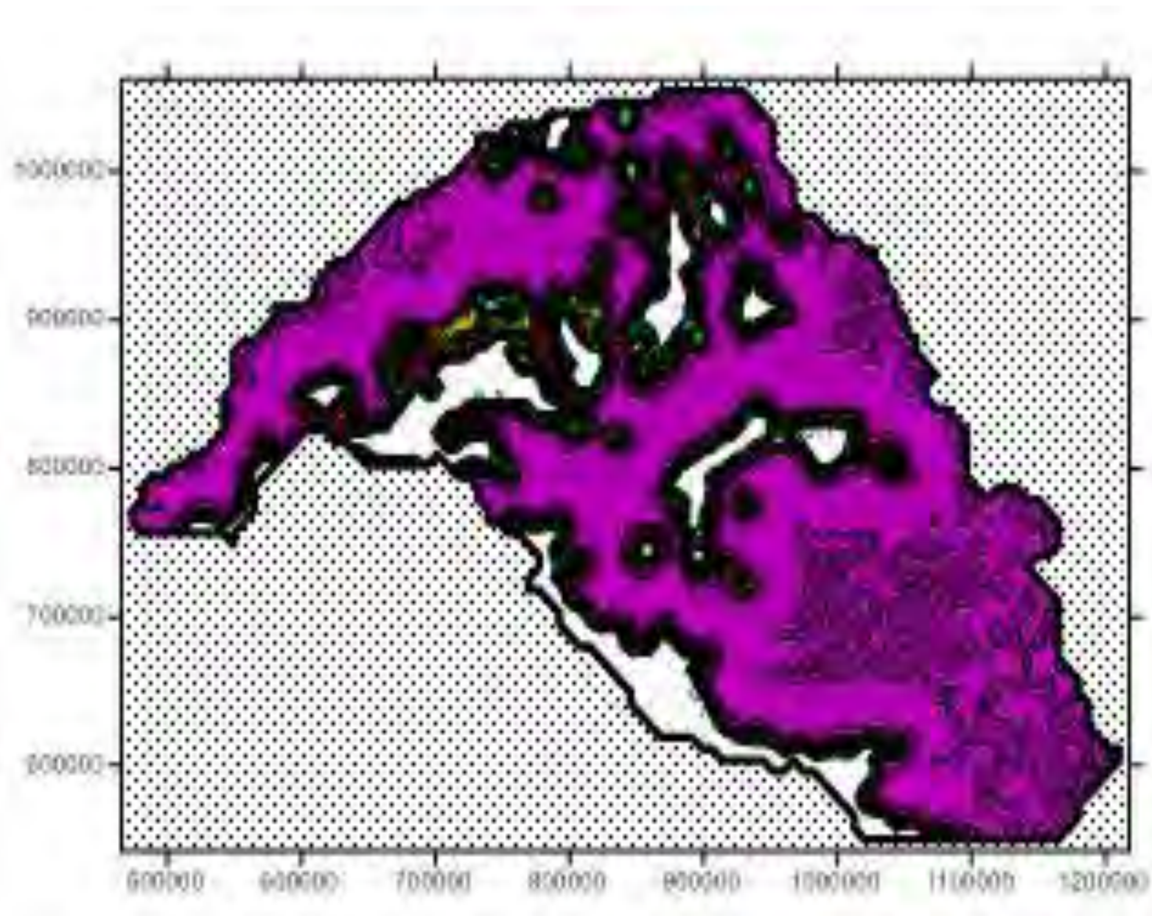

Figure 27 Accessible groundwater levels in wettest month (at 150 meter depth)

III. At 300 meter depth from surface

The area in white in the above figure shows no groundwater at 300 meters depth even if the season is wet. But here we can understand that almost all part of the basin has accessible groundwater at 300meters depth from the surface. Additional the analysis shows as that there are areas that are not accessible in groundwater point of view even if the season is wet and with greater depth trial.

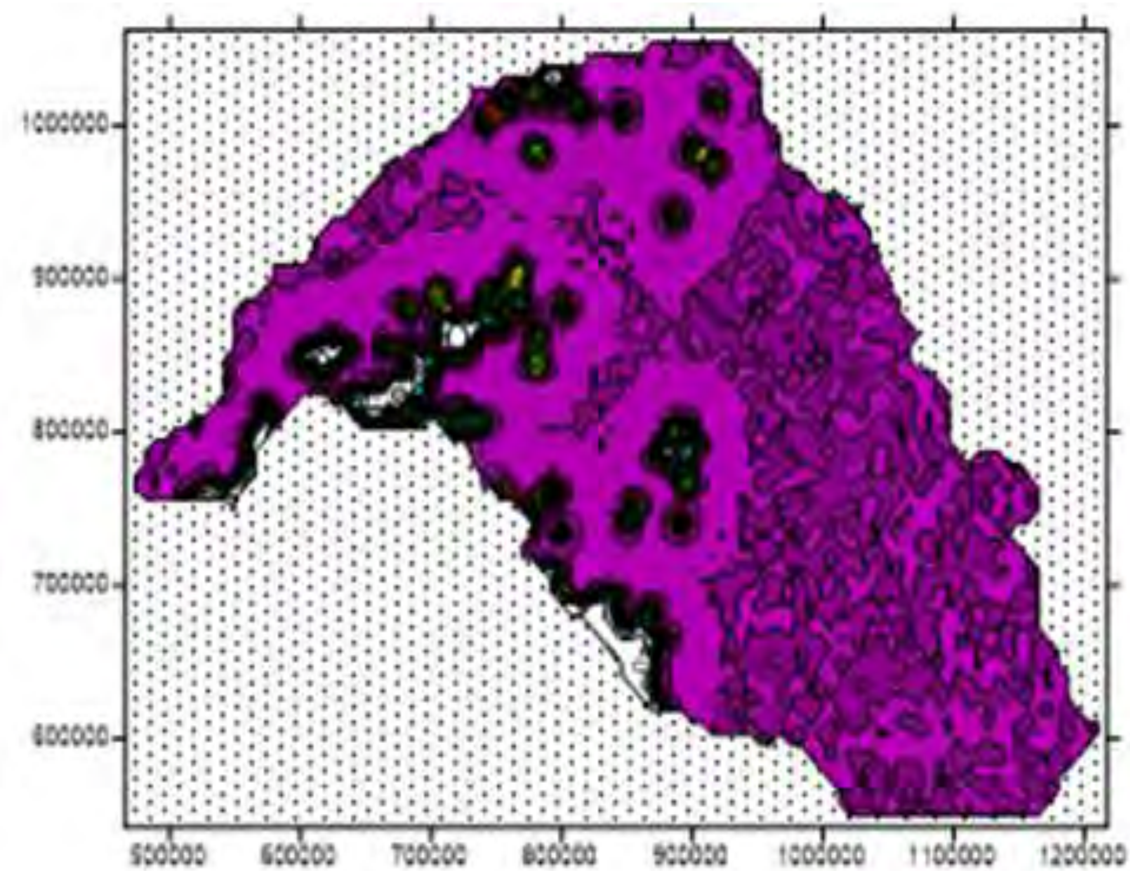

Figure 28 Accessible groundwater levels in wettest month (at 300 meter depth)

The amount of water that may be extracted from an aquifer without causing depletion is primarily, dependent upon groundwater recharge. The primary sources of recharge to the study area are from rainfall on the outcrop and seepage from lakes and streams. The amount of this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This work describes a conceptual model of groundwater flow in the aquifer and documents the development and calibration of a numerical model to simulate groundwater flow. The objectives of developing three dimensional groundwater models and calibrating this model by comparing the simulated measured groundwater heads have been achieved.

Groundwater potential characterization means determining the groundwater resource in the study area in depth, location and groundwater direction and estimates some hydraulic parameters like (hydraulic conductivity and porosity). This study worked on characterizing the groundwater potential of the basin by determining, the amount of replenishable groundwater volume, the new hydrogeological maps, the groundwater flow direction and its accessibility in the study area.

The computer model is developed in the framework of finite element method with standard Galerkin approach. The geometry of the domain is discretized into simple triangular elements of uniform size central areas and non-uniform sizes in the border with nodal points at their vertices. The model simulates groundwater flow under steady state conditions. The modeling effort was first started by defining of the conceptual model. To decrease the uncertainties in the conceptual model, field data related to wells and springs were collected. These data were used to calibrate the model. With the calibrated model, it is possible to realize the behavior of the aquifer system of the basin.

From North west to South east along the Wabi Shebelle River course, the rainfall highly decreases and the interaction of surface water and groundwater is highly reduced due to the low permeability of the gypsferous formation that dominate large part of the lower catchment.

The ground water recharge and discharge condition of the WSRB is controlled by the topography, the prevailing geologic set up especially the existence of weathered and fractured geologic materials, the associated geological structures and rainfall amount. The main recharge of study area is from the highlands of northern and north western part and surrounding areas which slopes towards south eastern part of the basin.

Three-dimensional models have been used extensively for groundwater modeling in Ethiopia and are generally adequate for predicting aquifer head changes. However, the three dimensional model described in this report was developed to identify the potential of groundwater over the WSRB.

The flow packages treated in the model are recharging, well, springs, and river package. In recharge package recharge from direct precipitation is specified to each cell. In springs package 845 springs are treated. There are 94 well (deep well, hand dug well) used for the model. The coordinates of perennial rivers are also used as an input parameter.

Model calibration was completed by varying the model parameters within acceptable ranges to produce the best fit between simulated and observed hydraulic heads in the modeled area. Summary of statistics on the difference between simulated and observed water levels indicates that the calibrated model has RMS of 15.30 meter, MAE of 8.77 meter and ME of 7.77 meter. The scatter plot shows a correlation coefficient of 0.9992.

The simulated hydraulic conductivity value varies from 8.64 x 10^{-8} m/s to 7.7 x $10^{-4\ m}$/s which is within the range of initially assigned value taken by WWDSE, 2004. The value showed that there is a large variation of hydraulic conductivity in geologic medium.

This study showed that equivalent porous media models could be used to simulate regional groundwater flow in the aquifer. Modeling of aquifer systems as equivalent porous media has been found to be suitable in simulating regional groundwater flow using regional aquifer parameters adequately reproducing the regional groundwater levels and observed discharge to the rivers.

This study was accomplished by applying finite element numerical groundwater flow modeling software called TAGSAC. The interaction characteristics of these water sources were mainly targeted on the comparison surface water and simulated groundwater head in response to the surface water availability within the years 1980 – 2013.

The model result has clearly showed that the groundwater level is affected more in its western part than other parts of the basin. The basin water level variation has significant effect on the groundwater on its western part than locations in the other directions. Efficiency of the model, evaluated is on the basis of simulated and observed head data at the water point site, is 99.9 %., which is good sign to grade the model very acceptable. The model is adaptable in nature such that it can be implemented for a choice of several types of elements and solves other problems of similar nature with slight alterations.

As final say, for any groundwater and/or surface water planning work, the model created should be applied with caution, considering all drawback and limitations related to model input parameters.

5.2. Recommendation

Future studies should consider a variety of improvements to the existing models that should include additional data collection, different conceptual model design, and other factors. The current study depends on the sparse data collected on the basin; this is one of the limitations so it is recommended to go through a detail study on the data availability in the area to have a realistic modeling of groundwater in the area.

The current study considers few gauging stations; the stations are only 20 but the study cover a very large area (191146 sq.km). It is suggested using more number of gauging station for metrological data accuracy in the basin. The meteorological setting concentrate on the upper catchment, so this also a problem uneven distribution of data‘s, which affect the accuracy of the model.

Future modeling should consider focusing recharge at different points on the basis of the field data and sensitivity of model output to various distributions should be examined. Future studies should improve the reliability of the head data by accurately locating wells and measuring the surface elevation.

The model was discretized using a grid cell size of 5000 x5000 x 5000 meter triangular mesh with 2500 meter thickness due to unavailability of computing device for large area. Accordingly it is recommended for the next study to use more finite discretization. The model is not suitable for analysis of site-specific problems or issues.

The geological condition of the area is complex and the model is assumed as a single layer in all over the thickness, which ignores the natural heterogeneity of the vertically. Therefore, further refinement of the model would be possible with additional data which improve the accuracy of model prediction parameter to apply it for a detail analysis.

It is recommended that Groundwater model should be simulated by a detail and representative hydrological, geological and metrological data‘s of the area modeled for better calibrating the model and to understand the aquifer response to abstraction and recharge. However, in the WSRB the hydrological and well inventory data‘s are not evenly distributed in all part of the basin. It is necessary to distribute the well inventory, hydrological and metrological data‘s in the area to get better understanding of groundwater and surface water resources of the basin. There exist few and unevenly distributed boreholes even in a ground water potential zone (upper catchment) and there concentration are around the towns. The rural people will benefit more if additional boreholes are drilled in rural areas which in turn help for further quantitative characterization of the aquifer system. Therefore the user of the model should consider the deficiency of the data that encountered the modeler.

Soil and water conservation has to be implemented to reduce runoff and enhance the recharge capacity of the upper Wabi Shebelle River catchment. To prevent the flooding of lower catchment it is recommended to use artificial recharge to the groundwater in doing so the groundwater potential will be increased.

Many springs in the basin are not simulated clearly because of the regional nature of data in performing the model in the basin. Thus, the relation of the springs to the groundwater flow system is poorly understood. An understanding of the spatial and temporal sources of water to springs could be gained by additional field investigation and modeling.

Also further study is suggested in the wetland areas of the basin because the Lakes in the eastern part of the country suspected to dried out, replenishment of these water resources improve the groundwater recharge of the area.

Different governmental and nongovernmental organizations that entail in the preliminary and detail study of the water resources as well as construction of water wells should develop the habit of data base management system.

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APPENDIX

well Inventory Data's

The following well and spring data was collected from MoWIE and Water Works design and Supervision office. The study used 357 data's for calibration of the model.

WATER POINT index	Locality name	REGION	UTM_N	UTM_E	ELEVATION	Depth of well	Depth of water level
BH-1	Woter BH-2	Oromiya	1035489	804501	2047	61	
BH-2	Lange	Oromiya	1043705	807063	2006	40	
BH-3	Kersa-2	Oromiya	1045879	815324	2005		
BH-4	Gelemso#2	Oromiya	973728	666517	1753	89	
BH-5	Wachu	Oromiya	978637	679061	1762		
BH-6	Medega	Oromiya	981360	844295	1533	254	209.15
BH-7	Fedis	Oromiya	1011772	837941	1800	86	
BH-8	Hasene	Oromiya	1006745	838692	1688	290	
BH-9	Gale Bob	Somali	1056482	932455	1834	180	128.45
BH-10	Lefe Issa(BH-2)	Somali	1065394	937182	1736	90	72.6
BH-11	Hadew(BH-2)	Somali	1036791	902627	1774	74	
BH-12	Fechatu	Oromiya	997249	843638	1688	150	78.14
HD-1	Erer#1	Harari	1023272	856406	1340		
HD-2	Soula	Harari	1034490	838660	1984		
HD-3	Aweday	Oromiya	1036061	834143	2080	16	
HD-4	Sigicha	Harari	1034571	844298	2100		23
HD-5	Kura	Oromiya	1047359	817164	2020		
HD-6	Erer#2	Harari	1034259	852857	1401		
HD-7	Befetu	Oromia	1042735	842105	2128	8	3.5
SP-1	Medisa	Oromia	1037732	765726	2084		0
SP-2	Gendemaota	Oromia	1041369	802434	2113		0
SP-3	Grawa	Oromia	1010800	813268	2448		0
SP-4	Gotu	Oromia	1027854	815443	1729		0
SP-5	Awe lemay	Oromia	1034102	819492	2000		0
SP-6	Inchini	Oromia	1008100	788942	2320		0
SP-7	Kurfa chole	Oromia	1020145	808836	2483		0
SP-8	Geru belena	Oromia	1020711	808497	2510		0

SP-9	Boreda	Oromia	1031888	749855	2345		0
SP-10	Habru	Oromia	1038409	775658	2103		0
SP-11	Burka Jalala	Oromia	1040682	793618	2079		0
SP-12	Deder	Oromia	1029605	768014	2247		0
SP-13	Kinchero	Oromia	1040543	802966	2138		0
SP-14	Harawacha	Oromia	1015498	756755	2777		0
SP-15	Mesela	Oromia	1004384	738980	2521		0
SP-16	Tero	Oromia	1005477	734753	1837		0
SP-17	Debeso	Oromia	1010553	720486	2133		0
SP-18	Chancho(Met akesha)	Oromia	1014123	724498	2245		0
SP-19	Medegedu(Be dessa)	Oromia	981401	696578	1670		0
SP-20	Kenso	Oromia	995522	707188	2491		0
SP-21	Lukanda	Oromia	997919	708880	2297		0
HD-8	Hassenge	Harari	1035847	840637	2034		
HD-9	Alishan beker	Harari	1035708	840728	2029	4	
SP-22	Queleta	Oromia	1047527	849806	2139		0
SP-23	Keto	Oromia	1027044	863354	1711		0
SP-24	Burka	Harari	1027693	839987	1892		0
SP-25	Jarso spring	Oromia	1050175	854886	2554		0
SP-26	Lege hida	Oromia	1050023	852719	2493		0
SP-27	Hakim gara	Harari	1029330	843576	1919		0
SP-28	Kora multi	Oromia	909359	602663	3386		0
SP-29	Koro-Multi	Oromia	907077	600869	2944		0
SP-30	Mine-River	Oromia	911996	624525	1540		0
SP-31	Bololcha-spring	Oromia	911613	624442	1490		0
SP-32	Hora-Burka	Oromia	911824	625023	1480		0
HD-10	El-Tokey	Oromia	912025	627963	1430		0.5
SP-33	Biro-Coffee Plantation	Oromia	903924	618177	1730		0
SP-34	Jinga sokoru	Oromia	905750	614373	1900		0
SP-35	Damu-Burkitu	Oromia	899735	616006	1860		0
SP-36	Chole	Oromia	897998	614292	2730		0
SP-37	Chinchero-spring	Oromia	898136	611956	2780		0
SP-38	Burra Kele	Oromia	897825	612117	1600		0
SP-39	Sinkele spring	Oromia	898380	608978	2800		0
SP-40	Jawi - Spring	Oromia	897806	607176	2700		0
SP-41	Chole-2	Oromia	898442	602431	2800		0

SP-42	Loga Soka	Oromia	898052	604721	2800		0
SP-43	Chole Town W.S.	Oromia	903982	603424	3100		0
SP-44	Gara	Oromia	904384	599900	3010		0
SP-45	Bila	Oromia	904915	600571	3100		0
SP-46	Sekora	Oromia	905465	600542	2962		
BH-165	Watera Gola	Oromia	896063	564681	2840	190	92
SP-47	Balambaras	Oromia	853892	610141	2600		
BH-13	Balambaras BH	Oromia	853939	610159	2600	92	65
SP-48	Koso	Oromia	849154	632237	2448		0
HD-11	Seru Town	Oromia	848630	632490	2446	11	9.9
SP-49	Seru Town Ejersa Spring	Oromia	848520	631944	2455		0
SP-50	Gedajiru	Oromia	851940	624374	2438		0
SP-51	Allela-Zenbaba	Oromia	851663	623702	2432		0
SP-52	Jida Guberba	Oromia	852201	618962	2630		0
BH-14	Jida-Guberba	Oromia	852567	618887	2620	200	
HD-12	Jida Town	Oromia	853090	619011	2445	11	10.6
HD-13	Jida Town	Oromia	852843	619371	2440	21.9	21.2
BH-15	Bele 01	Oromia	854566	610166	2570	45	36
SP-53	Tujja-Sp	Oromia	860483	607908	2411		0
BH-16	Addele - 03	Oromia	861892	600434	2457	90	
BH-17	Addelle - Dirre Jarti	Oromia	861896	599632	2630	160	
BH-18	Bamo-Chaffa	Oromia	861665	601223	2456	78	
BH-19	Cheleleka	Oromia	858505	600142	2600		
HD-14	Sheleleka	Oromia	858834	599697	2580	9.75	9.05
BH-20	Merfogera	Oromia	862087	591893	2590	53	
BH-21	Habi-01	Oromia	864686	586956	2550	38	0
HD-15	Habe-El.school	Oromia	864810	586297	2550		
BH-22	Habe Dangazda	Oromia	864145	584930	2550		
BH-23	Balla Kassa Gado	Oromia	866135	581861	2580	72	
SP-54	Georgis Tebel	Oromia	862326	556956	2600		0
SP-55	Altimeraba	Oromia	865977	557574	2700		0
SP-56	Tileku Wolkesa	Oromia	864202	556538	2700		0
SP-57	Robe spring	Oromia	868259	562521	2530		0

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SP-58	Robe spring#2	Oromia	869257	562789	2550		0
HD-16	Kersa-Sedika	Oromia	839783	593295	2510	3	1.9
BH-24	sedika-01	Oromia	843800	590150	2550	80	
SP-59	Telela	Oromia	844850	589941	2510		0
HD-17	jeyina - Holala	Oromia	855073	577456	2540	9.5	8.9
HD-18	Jeyina -Town	Oromia	855232	577535	2530	4	2.8
BH-25	Kula Town	Oromia	881002	576111	2650	77	73
HD-19	Dereba HDW	Oromia	889410	576079	2660	4.1	3.5
BH-26	Dereba BH	Oromia	889425	576149	2670	45	26.6
BH-27	Elandode BH	Oromia	890570	563052	2830	178	122
BH-28	Didai -H. School	Oromia	870581	568821	2560		
BH-29	Robe - Didea Town BH	Oromia	869793	569314	2560	60	30
BH-30	Old wealth center BH (Robe)	Oromia	869882	569278	2560		
SP-60	Burka/Uduga spring	Oromia	872468	568648	2570		0
SP-61	Tena Kara spring	Oromia	882882	558624	2930		0
SP-62	Sure-chole spring /Chole Burkitu spring	Oromia	833823	568590	2400		0
SP-63	Jawi spring /Choncho Jawi spring	Oromia	840449	552908	2570		0
SP-64	Tijo Yaya spring/Gobesa town	Oromia	840035	552320	2600		0
SP-65	Guna spring	Oromia	834842	542856	3180		0
BH-31	Melka Wakena BH2	Oromia	791525	549086	2520	106	
SP-66	Dabara 1&2 spring	Oromia	804068	515228	3160		0
SP-67	Walamid spring No 1&2	Oromia	804642	515282	3180		0
SP-68	Gorgis spring	Oromia	804310	516606	3100		0
BH-32	Tedacha Bulura BH	Oromia	792266	525559	2600	80	66

BH-33	Kakawa BH	Oromia	794777	528420	2590		
BH-34	Dabara waltahi BH	Oromia	790482	525428	2580		
BH-35	DebaraDA BH	Oromia	790405	523396	2570	62	
BH-36	Ardu BH	Oromia	786568	521909	2570	60	
HD-20	Ela No 3	Oromia	788725	500625	2730	6.85	375
HD-21	Ela 1&2 HDW	Oromia	788764	500584	2770	5.75	3.65
BH-37	Ardayita BH2	Oromia	784701	509383	2620	150	137
BH-38	Ardayita BH1	Oromia	784647	509614	2600	150	118
BH-39	Ardayita BH3	Oromia	784843	508476	2630	180	
BH-40	Wakachila BH	Oromia	778653	509808	2580		
BH-41	Huruba walkite BH	Oromia	778588	515612	2550	68	32
BH-42	Huruba Hunta	Oromia	780283	520370	2530	80	20
SP-69	Hinja spring	Oromia	791636	538009	2500		0
BH-43	Watentera Edo BH	Oromia	790314	513589	2650	117	
BH-44	Bucho No1 BH	Oromia	786692	518766	2550	80	
BH-45	Bucho No2 BH	Oromia	785382	517102	2580		
BH-46	Oboltо BH	Oromia	784553	514899	2580	94	90
SP-70	Assasa spring	Oromia	785702	521822	2510		0
BH-47	Chere BH	Oromia	776676	517008	2540		
BH-48	Kachemol BH	Oromia	771114	514728	2570		
BH-49	Geneta BH	Oromia	767902	509695	2750	105	
BH-50	Berisa BH	Oromia	772443	525855	2600	192	
SP-71	Ashelecho spring	Oromia	770110	524796	2650		0
BH-51	Wabe Birkitu BH	Oromia	780070	528375	2530		
BH-52	Tulu Alwanso BH	Oromia	777963	520840	2550		
BH-166	Alentu	Oromia	764165	505698	2780	60	
HD-22	Serofita tulu	Oromia	757706	504520	2930	10	
BH-167	Sefofita School	Oromia	759591	501861	2800	45	
BH-53	Serofita Town BH	Oromia	759057	500869	2750	75	

HD-23	Serafita town HDW	Oromia	758880	500909	2750		
HD-24	Negele Metema HDW1	Oromia	757849	493401	2730	26.5	
HD-25	Negele Metema HDW2	Oromia	757748	493472	2740	19	17
HD-26	Negele Metema HDW3	Oromia	757769	493557	2730	23	
HD-27	Gare Husta HDW1&2	Oromia	756157	497641	2745		
HD-28	Gara Husta HDW3,4&5	Oromia	755813	497800	2740		
HD-29	Gara Husta HDW 6&7	Oromia	754689	497092	2750		
SP-72	Gare Husta School spring	Oromia	755052	497503	2740		0
BH-54	Serafta state farm BH	Oromia	770950	501973	2535	103	
BH-55	Edo Town BH	Oromia	771478	501233	2500		
SP-73	Ejakelo spring	Oromia	766515	519622	2720		
BH-56	Deneba BH	Oromia	768687	519368	2650		
BH-57	Dodola Town BH	Oromia	772034	519834	2590	138	
BH-58	Herero St. Farm BH	Oromia	775215	530306	2360	66	30
BH-59	Herero Town BH	Oromia	773363	536057	2540	60	35
HD-30	Herero Town HDW1	Oromia	773002	535775	2540	36	29
HD-31	Herero town HDW2	Oromia	773112	535108	2530		
HD-32	Burachele HDW1	Oromia	770935	533391	2590	26.3	1
HD-33	Bura chele HDW2	Oromia	770034	533850	2600		
HD-34	Keta HDW1	Oromia	772555	536878	2560		
HD-35	Keta HDW2	Oromia	771643	537038	2600		
BH-168	Wesha tullu	Oromia	777597	553113	2610	60	15
BH-169	Wesha tulu HDW2	Oromia	778752	552963	2530	60	19.9
SP-74	Wesha Tulu Spring	Oromia	777265	552593	2630		0

BH-60	Halola Hunte BH	Oromia	782736	543437	2510	96	
HD-36	Halola Hunte HDW1	Oromia	782535	543104	2510	16	10.5
BH-61	Gudedo Genet BH	Oromia	787418	552706	2570	96	
BH-170	Gededo Genet HDW1	Oromia	787118	552869	2570	30	
BH-171	Gededo Genet HDW2,3,4	Oromia	787557	552190	2560		
SP-75	Kinsho spring	Oromia	793616	553836	2570		0
HD-37	Konsho HDW	Oromia	793647	553995	2570	6	1.5
HD-38	Lajo Birbirsa HDW1	Oromia	806363	563541	2515	14	11
BH-172	Lajo Birbirsa HDW2	Oromia	806672	563448	2520	30	25
BH-173	Fonsho HDW1	Oromia	803884	558996	2530	36	24
BH-174	Geredilo HDW1	Oromia	798648	555132	2570	54	
HD-39	Ejersa Mudemtu HDW 1,2,3&4	Oromia	774314	539863	2520		
SP-76	Ejersa Mudemtu spring	Oromia	774411	539803	2520		0
SP-77	Bucha Rouye spring	Oromia	766752	547476	2875		0
HD-40	Haro Hunte HDW1&2	Oromia	779156	539464	2515		
BH-62	Hunte state Farm BH	Oromia	784680	547851	2530	60	2.5
SP-78	Wesha tulu Gora spring	Oromia	778380	556508	2585		0
SP-79	Beneba spring	Oromia	818372	638313	2360		0
HD-41	Deneba HDW1	Oromia	817946	637859	2357	6	2
SP-80	Wariyo spring	Oromia	810579	640397	2380		0
HD-42	Birbirta HDW1	Oromia	816919	645799	2400	6	2
SP-81	Bereket spring1	Oromia	817193	662102	2080		0
HD-43	Bereket HDW1	Oromia	815993	664190	2010	5	3.5

HD-44	Bereket HDW2 & 3	Oromia	816227	663583	2010		
BH-63	Jara Town BH	Oromia	815012	664830	2040	130	
BH-64	Tagay BH	Oromia	813044	668387	2000		
BH-65	Dirusa BH	Oromia	825034	676631	1940	54	48
BH-66	Dobi BH1	Oromia	821566	668628	1950		
SP-82	Borati spring 1&2	Oromia	812037	664710	2020		
SP-83	Legehida spring	Oromia	870858	718459	1635		0
BH-67	Gora raya BH	Oromia	870627	718297	2610	210	119.74
BH-68	Doyo Abo BH(Aregu)	Oromia	863529	725231	1500	161	34.75
BH-69	Legehida BH	Oromia	871741	720963	1665	214.5	53
BH-70	Micha BH	Oromia	824998	718650	1330	96	40.5
BH-71	Adele BH	Oromia	811268	709835	1670	148	62
BH-72	Arda Gelma BH	Oromia	800974	703024	1710		
BH-73	Kokosa Town BH	Oromia	745061	477152	2580	95	
SP-84	Kokosa Town spring	Oromia	745050	477417	2590		0
HD-45	Kokosa town HDW	Oromia	744850	476749	2590	6	5
BH-74	Jijiga(J1)	Somali	1033340	916795	1628	62.1	15.42
BH-75	Jijiga(J-6)	Somali	1032422	917141	1630	73	42.78
BH-76	Jijiga(J-7)	Somali	1036741	918225	1654	30	7.52
BH-77	Jijiga(J-8)	Somali	1036920	918003	1655	36	
BH-78	Jijiga(J-10)	Somali	1043057	915549	1700	30	11.22
BH-79	Jijiga(J-9)	Somali	1042457	915523	1703	36	12.34
BH-80	Jijiga(JU-1)	Somali	1042057	915280	1700		
BH-81	Jijiga(JU-2)	Somali	1039850	915444	1699		
BH-82	Jijiga(JU-3)	Somali	1039520	915668	1679		
BH-83	Jijiga (J-11)	Somali	1039039	915885	1675	42	
BH-84	Jijiga (J-3)	Somali	1038880	916001	1668	32	15.42
BH-85	Jijiga(J-2)	Somali	1038627	916265	1672		
BH-86	Elbayeh BH	Somali	1039832	920869	1685	29.5	1.2
BH-87	Elyere BH	Somali	1038772	920084	1678	24	
BH-88	Jijiga (J-4)	Somali	1032884	916893	1628	70	47.8
BH-89	Jijiga(J-5)	Somali	1032635	917016	1629	56.4	
BH-90	Lefe Issa(BH-	Somali	1065365	937218	1746	99.7	65.3

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BH-91	Leffe Issa (BH-3)	Somali	1065273	937491	1751	155	
BH-92	Chinaksen (BH-1)	Somali	1053662	896736	1976	52	8
HD-46	Chinaksen(old well)	Somali	1053688	896780	1978	14.4	
HD-47	Chinaksen (HD)	Somali	1053616	896586	1996	5	
BH-93	Chinaksen (new)	Somali	1053170	895723	1996	60	
HD-48	Gebigebo(HD -1)	Somali	1035029	891931	1515	15	8
HD-49	Gebigebo (HD-2)	Somali	1034963	891915	1512	8	5.7
BH-94	Hare (BH-3)	Somali	1022065	945261	1640	228	218
BH-95	Hare(BH-2)	Somali	1014307	941262	1559	250	214
BH-96	Kebribeyah-EB2	Somali	997990	941729	1422	170	
BH-97	Kebri Bayeh (PB2)	Somali	998595	941269	1425	205	
BH-98	Kebribeyah (NW-2)	Somali	1000163	940271	1430	208	
BH-99	Kebribeyah (NW-1)	Somali	999693	940470	1428	210	
BH-100	PB1(BH6)	Somali	996643	941898	1424	168	
BH-101	EB1(BH5)	Somali	997430	941822	1422		
BH-102	Hadew BH-3	Somali	1036630	902539	1770	45	
BH-103	Hadew BH-1	Somali	1036929	902663	1769		
BH-104	Haroresa(BH-5)	Somali	1045300	950024	1809	235	
BH-105	Haroresa(BH4)	Somali	1045317	950029	1810		
BH-106	Haroresa (BH-1)	Somali	1045357	949925	1811	252	
BH-107	Tuluguled	Somali	1064414	912480	1911	91	77.7
BH-108	Turanod(BH-2)	Somali	1064479	915590	1894	102	
BH-109	Biyo	Somali	1048910	908892	1780	90	13.2
BH-110	Elyere(BH-2)	Somali	1038758	920077	1678	12	6
BH-111	Degeh Bur(BH1)	Somali	909177	1001667	1025	54	
BH-112	Degeh bur(BH-2)	Somali	909153	1001416	1025	54	12

BH-113	Kebridehar BH3	Somali	746827	1082965	525	59	23.5
BH-114	Geladid	Somali	791391	1072644	650	185	
BH-115	Lasole	Somali	712725	1095018	420	131	
BH-116	Shekosh	Somali	813422	1045594	750	180	
BH-117	Shilabo	Somali	676250	1137640	410	131	103
BH-118	Berdhale	Somali	890590	992664	950	94	16
BH-119	Deghamedo	Somali	884848	943610	1020	230	
BH-120	Meskar	Somali	815224	989578	1025	183	76.92
BH-121	Brmil	Somali	803445	909178	900		
BH-122	Ferfer	Somali	565254	1181605	300		
BH-123	Danan(old well)	Somali	720628	998040	425	111.25	
BH-124	sheder	Somali	1071377	9511756	1680	26	
BH-125	Galalcha	Somali	982041	906179	1500	162.8	45
BH-126	Micheta	Oromia	945998	644923	1743	102	12
BH-127	Sororo	Oromia	948208	649466	1740	67	
BH-128	Mechara	Oromia	951363	645377	1776	68	
BH-129	Belebelti	Oromia	963357	655476	1744	75	
BH-130	Defo	Oromia	965878	658349	1740	130	
BH-131	Hardim	Oromia	975718	655718	1605	78	18
BH-132	Mekerech	Oromia	974460	672192	1696	72	23.75
BH-133	Duso	Oromia	977042	671146	1752	80	17.7
HD-50	Ature selale	Oromia	975057	672103	1693	30	4.2
HD-51	Dalo	Oromia	975414	670403	1752	38.5	11.85
BH-134	Melino Zewde	Oromia	975753	673143	1706	73	6
BH-135	Soro	Oromia	961458	686685	1735	96	22.6
BH-136	Boke tiko	Oromia	963588	681992	1864	153	
BH-137	Karakurkura	Oromia	980785	686096	1843	224	
BH-138	Wolargi	Oromia	989438	703266	1916	53	1.6
SP-85	Soloro	Oromia	992966	703507	2223		
SP-86	Kuni town	Oromia	995085	707008	2415		
BH-139	Asbeteferi town	Oromia	1003093	705069	2446	19	
BH-163	Lange BH-1	Oromia	1043896	807110	2000	17.8	

SP-87	Hirna	Oromia	1019614	730141	1844		0
BH-140	Oda belina	Oromia	1020389	732326	1885	90	25.3
HD-52	Harar Police Hospital	Harari	102992	852224	1860	12	4
BH-141	Bati town	Oromia	1041783	834705	2019	53	3.7
HD-53	Adele	Oromia	1041183	824573	2045	9	8
HD-54	Ras hotel	Harari	1030548	844156	2046		5.1
SP-88	kobo (Erer)	Oromia	1041474	773766	1756		0
SP-89	Karamile	Oromia	1035429	759438	2388		0
SP-90	Chilalo	Oromia	1036338	786107	2020		0
SP-91	Chelenko	Oromia	1030705	780066	2260		0
BH-142	Erer (Kile)	Harari	1023128	856646	1333		
BH-143	Fafen	Somali	1023476	895105	1449	44	11.57
HD-55	Bombas	Oromia	1019924	880308	1592	8	
SP-92	Gursum	Oromia	1040998	870316	2200		0
HD-56	Bisidimo	Oromia	1020297	853562	1360	12	
SP-93	Kulubi	Oromia	1042594	793753	2427		0
HD-57	Kore	Oromia	1021931	878088	1615	10	3
BH-144	Bale woraba	Oromia	987647	849039	1603	174	95.3
BH-145	Terkanfenta bh-1	Oromia	991443	847064	1655	150	
BH-146	Terkanfenta bh-2	Oromia	991437	847090	1655	228	
BH-147	Agdora	Oromia	1005313	837405	1670	105	
BH-148	Umer kule	Oromia	1015868	838712	1782	270	
BH-149	Kernesa(HBF BH OO1)	Oromia	1048013	832232	2032	51	0.84
BH-150	Finkile(HBF BH 002/96)	Oromia	1048031	831691	2014	80	
BH-151	Finkile(BH 003/96)	Oromia	1047473	831588	2032	85	1.45
BH-152	Tinike(BH-1)	Oromia	1045904	832391	2030	59	2.6
BH-153	Tinike(BH-2)	Oromia	1045905	832524	2030	64	1.92
BH-154	Alemaya University(BH-8)	Oromia	1041651	834017	2015	56.35	8.12
BH-155	Alemaya university(BH-9)	Oromia	1041206	833620	2011	66	9.3
BH-156	Alemaya university (BH-10)	Oromia	1041649	833633	2012	63	11.18

BH-157	Alemaya university(BH -11)	Oromia	1041681	833395	2007	63	
BH-158	Alemaya university(BH -12)	Oromia	1041654	833261	2005	66	
SP-94	Mitao	Oromia	1044363	838109	2182		0
HD-58	Elan (HD-1)	Somali	654967	1015285	276	8.5	8
HD-59	Elan(HD-2)	Somali	654960	1015282	276	9	8
BH-159	Shekosh	Somali	831831	1028337	775	140	
HD-60	Bargun	Somali	603802	1164019	325	10	
HD-61	Lammabar	Somali	618582	1160158	375	4.22	
HD-62	Dambar	Somali	664664	1139277	400	4.33	
HD-63	Shilavo	Somali	673900	1137325	400	11.7	
HD-64	Aptol	Somali	664586	1131862	370	11	
HD-65	Iglole-1	Somali	683158	1137227	410	9.73	
HD-66	Iglole-2	Somali	638523	1117294	360	10.3	
HD-67	Bellekoschi	Somali	679435	1135413	400	9.15	
HD-68	Lazolale	Somali	697928	1133360	460	12.39	
HD-69	Deghabour	Somali	909172	1001667	1025	8.61	
HD-70	Kebri dehar	Somali	747370	1084686	525	15	
HD-71	Degah Medo	Somali	882688	943018	1000	14.38	
HD-72	Segeg	Somali	849261	923069	780	0.9	
HD-73	Dadin	Somali	739852	1073667	530		
HD-74	Dalad	Somali	734207	1064477	525	8.25	
HD-75	El har	Somali	751274	1103143	600	13.91	
HD-76	Mererale	Somali	732851	1110751	500	8.46	

HD-77	Danan	Somali	720612	996191	425	2.9	
HD-78	Duhun	Somali	799288	908750	750	6.38	
HD-79	Bube	Somali	738487	1118092	500	15.23	
HD-80	Dourre	Somali	738571	1125496	530	19.68	
HD-81	Ferfer	Somali	565011	1175538	300		
BH-160	Kebridhar	Somali	747370	1084686	525	212	
BH-161	Danan(Old well #1)	Somali	720612	996191	425	112.8	
BH-162	Gode	Somali	656347	1044865	500	250.3	
BH-164	Aware	Somali	915579	1068531	1130	262	
BH-175	Kito well	Oromiya	1025000	863450	1600	51	3.8
BH-176	Milkaye	Oromiya	950000	675000	1650	350	154
BH-177	Arsi Robe	Oromiya	868550	568500	2500	114	87.15
BH-178	Melka wakena BH-1	Oromiya	792450	549000	2520	120	13.6
BH-179	Woter BH-1	Oromiya	1035400	804025	2040	84.5	7.5
BH-180	Burka ella	Oromiya	1030000	757500	2000	120	21.4
BH-181	Setewa kenisa	Oromiya	949598	775181	1400	221	6
BH-182	Sede Fentia no-1	Oromiya	795390	687000	1355	60	42.4