Adama Science & Technology University

School of Applied Natural Science

Applied Geology Program

Simulation-Optimization Modeling for the Management of Groundwater Resources in Modjo River Catchment, Main Ethiopia rift

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Abstract

In this study, steady state groundwater flow model was constructed and calibrated to analyze groundwater budget and ground flow system. Pumping scenarios were done to investigate the response of the system under increased groundwater pumping rates. The main inflows are inflow from lakes and recharge from precipitation. An outflow from the system is through pumping well, subsurface outflow from the catchment, groundwater flow to lakes and base flow. The response of the system under increased groundwater pumping rates and decreased recharges rate were investigated using calibrated groundwater heads and fluxes as a base line. Increasing the pumping rate considerably changed the groundwater dynamics and fluxes. Increasing groundwater pumping rate by 10% resulted in a slight decline in groundwater levels and base flow. However, 50% increase in pumping rate causes groundwater level decline, reduction of groundwater subsurface out flow from the catchment and base flow by 6.37 m, 5.6 % and 27 % respectively compared to calibrated steady pumping model value. The decrease in groundwater recharge by 25 % result in maximum decline of the water level by 24.18 m and minimum water level decline by 1.57 m at around vicinity of lakes, decrease of subsurface groundwater outflow by 7.21% and base flow by 22.99%. Under optimum steady pumping condition, the total abstraction rate is reduced to 200,093 m^3/day. In conclusion, the excessive groundwater pumping rate to meet growing water demand and altered recharge due land use and climate changes is expected to disrupt hydrological system and groundwater budgets in study area.

The physico–chemical results were compared with the Ethiopian and World Health Organization (WHO) standards for drinking and public health, in order to have an overview of the groundwater quality in study area. According to the overall assessment of the area, almost all the parameters analyzed are below the desirable limits of WHO except Katila and Mudasenkele.. Using GIS interpolation methods with Arc GIS 10.3.1, spatial distribution maps of pH, TDS, EC, HCO_3, F, Ca, Na, and K, RSC, SAR, TH, Na% were produced. Most of the groundwater samples' fall within excellent and good water class and suitable for irrigation purpose. However, different industries exist in study area used chemicals different from major cations and anions. Thus, these chemicals need to be investigated in future.

Key words: Optimization, Groundwater recharge, groundwater flow modeling, Modjo River basin, Main Ethiopian rift

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1. INTRODUCTION

1.1 Background

In many areas of the world, groundwater is a source of domestic and potable water supply. Groundwater is also used for irrigation purpose and accounts 43% of the global consumptive use in irrigation (Siebert et al., 2010). In addition, groundwater discharge maintains and sustains river flows, springs, and wetlands (Morris et al., 2003). The exploitation of groundwater resources for a national economic development of many countries dates from the earliest civilizations, but massive resource development has been largely restricted to the past 50 years (Foster et al., 2003). In recent years, unsustainable development pathways and governance failures have generated immense pressures on groundwater resources, affecting its quality and availability, and in turn compromising its ability to generate social and economic benefits (UN Water report, 2015). Nowadays, the abstraction of groundwater resources continues to grow due to the increasing demand for the drinking purposes as well as for the industrial purposes (Ayvaz and Karahan, 2008).

To meet the increasing demand of water due to rapid growth of population, urbanization and industrialization especially in developing countries, it is very important to evaluate groundwater resources quality and quantity. Urbanization is a challenging issue particularly in developing country like Ethiopia due to groundwater pollution and aquifer vulnerability. The human intervention in the natural system has a significant effect on the quality of natural waters. Human activities like disposal of untreated toxic chemical and industrial waste into streams, unplanned urban development, lack of sewerage system, over pumping of aquifers, contamination of water bodies with substances that promote algal growth (possibly leading to eutrophication) and global warming are some of the prevailing causes of water quality degradation. This draws an attention to develop a groundwater management plan in the world. For instance, according to the European Water Framework Directive (WFD 2000/60/ EC) to achieve a good groundwater status, member states shall ensure a balance between abstraction and recharge of groundwater.

In Ethiopia, there is a lack of proper water resources management and development to sustainably meet current and future demands, because the lack a comprehensive assessment of the quality and availability of the resources. For instance, in Modjo River catchment, unsustainable groundwater is causing groundwater depletion and quality deterioration. In this catchment, groundwater resources are poorly managed and abstracting without understanding the groundwater potentials and the consequences of over abstraction. Groundwater and surface water are in a continuous dynamic interaction and the imbalance on ground recharge-discharge processes disturbs water system of a basin (Winter et al., 1998; Sophocleous, 2002). The over abstraction of groundwater disrupts hydrologic cycle and affects availability of groundwater to is its dependent ecosystem (Alemayehu et al., 2007). For instance, Climate change in conjunction with human activities triggered by climate related disasters have killed Lake Haromaya (Tamiru et al, 2006). The Rift Valley Lakes are sensitive to changes in the water use regime and most lakes particularly those located in a terminal position have undergone significant lake level changes since the 1970s due to climate change and excessive abstraction of water (Legesse and Ayenew, 2006). To achieve a good groundwater status, it is essential to balance between abstraction and recharge of groundwater. GTP 2 plan is from 2015/16 to 2019/20 and it will focus on sustained human development with a clear target of achieving universal coverage for water supply and sanitation by the end of the period. As a result, there is a significant emphasis on exploitation of groundwater in study area to increase water supply coverage. Groundwater flow models have played an increasingly important role in the evaluation groundwater development and management. The objectives of this study are to compute groundwater recharge, simulate groundwater flow system and to analysis surface-groundwater interaction in study area. Effect of groundwater withdrawal on surface water in study area will investigated

1.2 Problem Identification

Many arid and semi-arid regions in Ethiopia rely on groundwater resources for their domestic supply and agricultural production. Currently, more than 80% of Ethiopia's drinking water supply comes from groundwater (Awulachew et al., 2007). Increasing demand due to an increase in population and climate variability will further increase dependence on groundwater in future. Moreover, despite the increase in water access, water quantity, quality and sustainability of urban water service are a huge concern.

The upper part of Awash River basin in Ethiopia, which includes the study area, is the most developed region of the country and groundwater is widely used for different purposes. In the Modjo River catchment groundwater is exploited by different industries and institutions for different purposes. In this catchment, there is a lack of proper groundwater resource management and development to sustainably meet current and future demands. The uncontrolled withdrawal may result in water level declines, which causes imbalance among hydrologic stresses. In addition, rate of groundwater recharge and the effect of land use change on groundwater system and contamination are largely unknown. On top of that, the groundwater resources of the study area are increasingly exposed to anthropogenic activities due to urbanization and industrialization, but there is no groundwater protection measure of any significance in the area so far. There are uncontrolled discharges of effluents from urban area (solid waste and untreated waste water) and industries. The aquifers and the shallow aquifer systems in the urban area are severely contaminated by these discharges. The intensification of agriculture can further result in an increase in groundwater demand and pollution risk. Thus, this study focuses on Spatial variation of groundwater quality parameter invitation, groundwater flow modeling, capture zone analysis and ground water recharge estimation to enhance sustainable development of the groundwater resources.

1.3 Objectives

1.3.1 General objective:

- To simulate groundwater flow in Modjo River catchment and to optimize Ada'a well field pumping rates

1.3.2 Specific Objective:

- To estimate groundwater recharge
- To analysis groundwater flow system
- To assess the surface-groundwater interaction within the catchment
- To determine the impact of different pumping scenarios on the Modjo River and the lakes in the area
- To optimize pumping rates of Ada'a wells
- To analysis water quality

1.4 Significance of the Research

The study significantly contributes to the understanding of the groundwater system of the study area. In research area, the groundwater is a major source of water for domestic, industrial and agricultural purposes. Sustainable groundwater management requires knowledge of groundwater recharge and groundwater budget under future stress scenarios. Therefore, the output of this study plays an important role for sustainable utilization and effective management of the groundwater resources in the area. Surface water- groundwater hydraulically interconnected and intensive ground water pumping affect surface water and disrupts hydrological system. The output of this study helps to develop an integrated water management plan for the study area.

2. DESCRIPTION OF STUDY AREA

2.1 Location and Accessibility

Modjo River catchment is located in the main Ethiopian rift, in upper Awash basin. Access to the area is possible in, through Addis Ababa-Dukam-Modjo asphalt road which is about 70 km. The other access to the study area is through the Addis Ababa-Modjo-Adama express road which is about 50 km. The location map of study area is shown in Fig. 1.

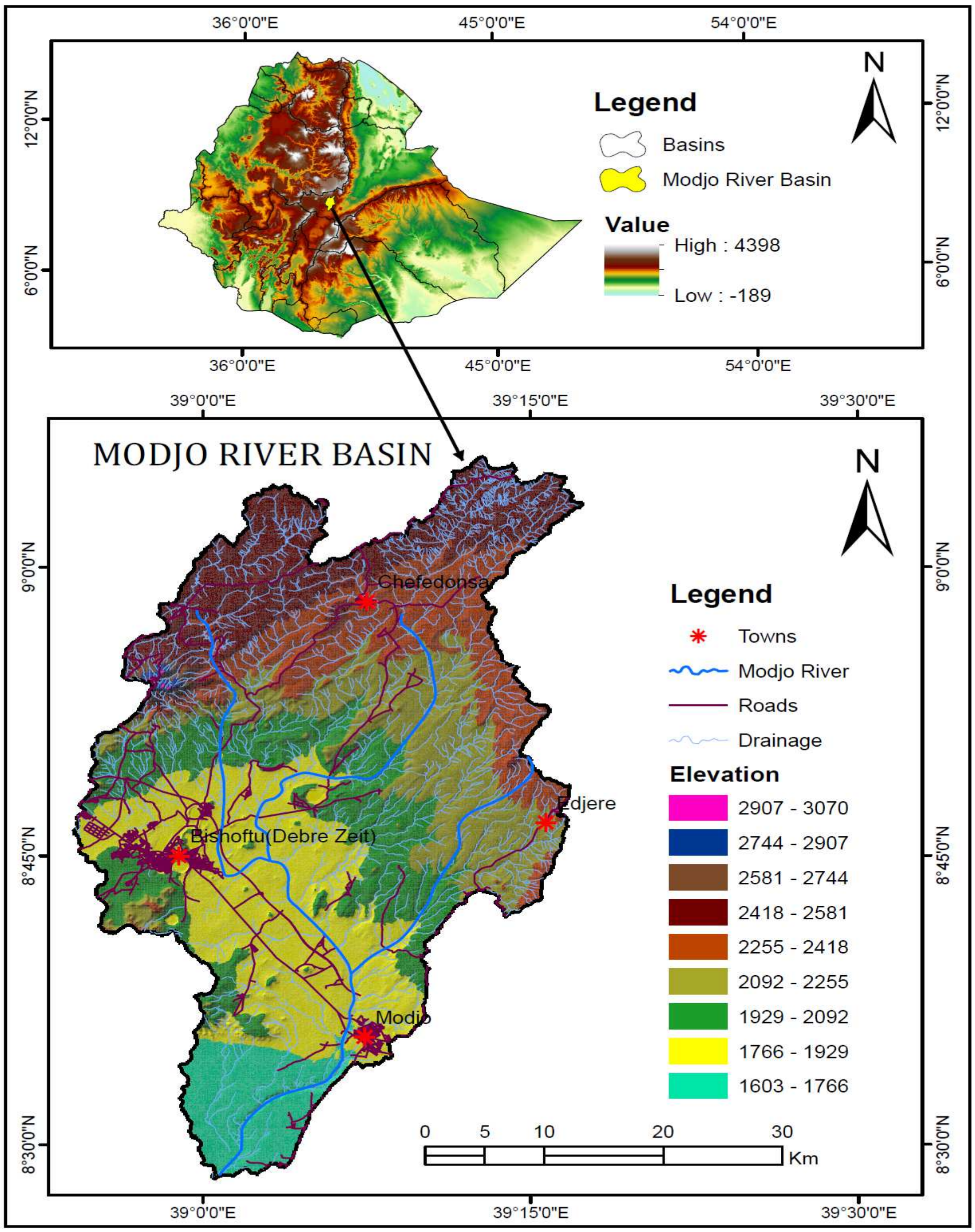

Fig. 1 Location Map of the Modjo River Catchment

2.2 Geology

Various lithologic units ranging from Tertiary to Quaternary age groups of acidic and basic volcanic rocks and Quaternary lacustrine deposit are mapped in the study area (Fig.2). These rock units are summarized in the following section.

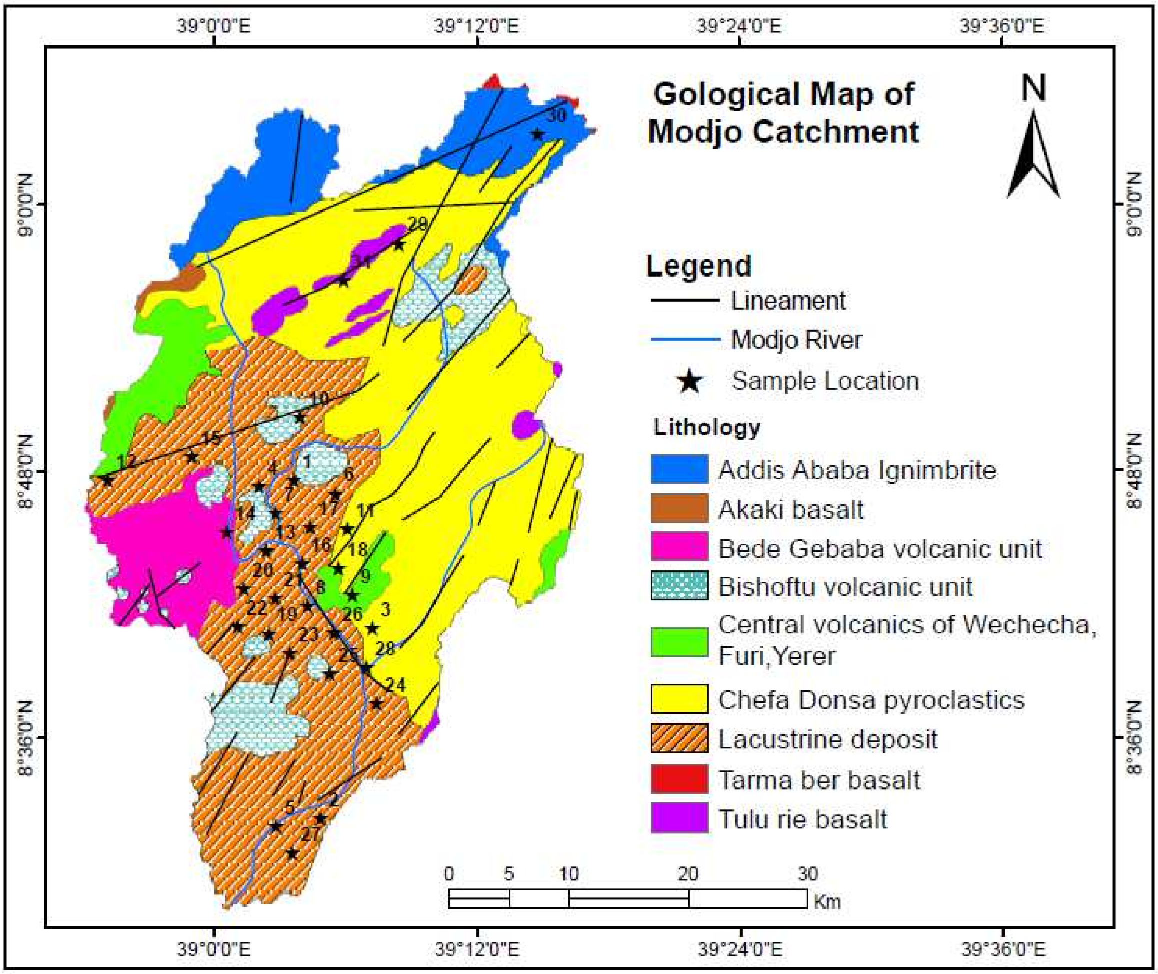

Fig. 2 Geological Map of Modjo River Catchment

2.2.1 Tertiary Volcanic Rocks

Tarmaber Basalt

The Tarma Ber Basalt which is the minor unit exposed in the northern part of the study area. It is consisting of mainly Scoriaceous lava flows. It is columnar olivine bearing basalt as pockets within the Scoriaceous components. It is highly weathered, fractured and pinkish to grayish in color. The age of this unit is Miocene, 27-5Ma (Morton et al 1979).

Addis Ababa Ignimbrite

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

Central volcano

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

Akaki Basalt

This unit is outcropped at Dukem area. It is coarse grained porphyritic olivine basalt. It is highly vesicular basalt and at places the vesicles were filled by carbonate minerals. It is consisting of scoria and spatter cones with associated lava flows. Both the basalt and scoria is quarried for construction around Dukem area. The age of the Akaki basalt is 2.9-2.0 Ma (Chernet et al 1998 and Morton et al 1979).

Tulu Rie Basalt

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

Chefe Donsa Unit

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

2.2.2 Quaternary Volcanic Rocks

Bede Gababa Volcanic Unit

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

Bishoftu Volcanics

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

2.2.3 Quaternary Lacustrine Deposit

Lacustrine Deposits

The deposits are exposed in NE elongated depression in the central section of the area. Lacustrine environment started after the Bede Gebaba volcano unit and continued during the eruptive activity of Bishoftu (Abebe, 1999). The lacustrine sedimentations are the results of deposition in this large ancestral lake (Mohr, 1967 and Abebe, et al., 1999) and they are interbedded with Pliocene-Pleistocene ignimbrite in lakes region and on the rift shoulders in general, and within Modjo and the surrounding areas in particular (Mohr, 1966). These fine-grained deposits are generally brown-yellowish, thinly stratified and often contain abundant volcanic matrix.

2.3 Hydrogeology of the area

Modjo River catchment is covered with volcanic rocks of diverse and variable hydraulic characteristics. Fig. 3 shows categories of hydrogeological unit based on their permeability (WWDSE, 2008). The major aquifers in study area are highly permeable Quaternary scoriaceous basalts with high primary permeability; in deep wells ignimbrites and poorly fractured basalts can be encountered (Kebede, 1987; Alem, 2004; Kebede et al., 2007). The alluvial and lacustrine deposits at Ada'a plain especially around the Bishoftu lakes and Modjo area have thickness up to 80 meters and composed of course sediments (WWDSE, 2008). Chefe Donsa Pyroclastics, Nazaret unit (Welded ignimbrites) have poor permeability except at the weathered and fractured zones. The localized acidic volcanic units of Quaternary Bede Gebaba volcanic unit have low permeability, except along weathered and fractured zones. These formations are less fractured and faulted (WWDSE, 2008).

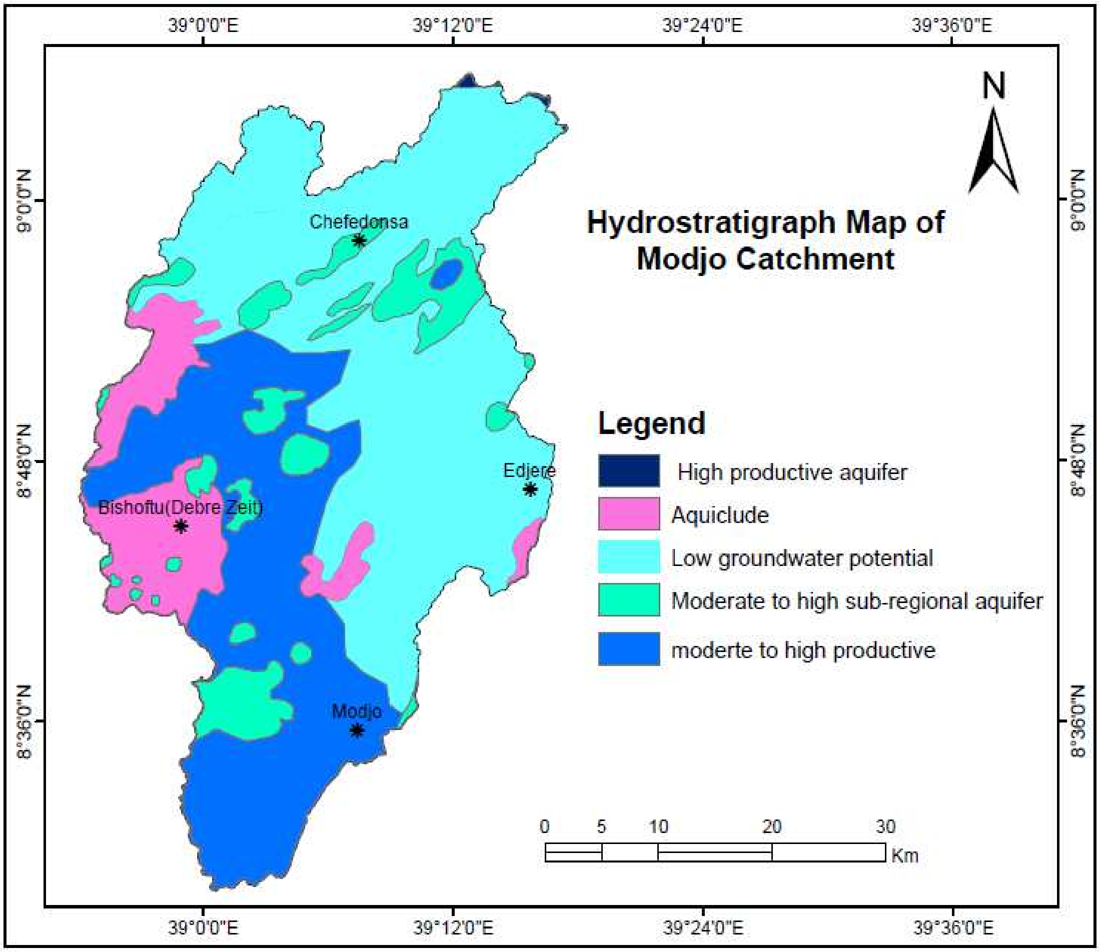

Fig. 3 Hydrogeological Map of Modjo River Catchment (Modified from WWDSE-2008)

3. METHODOLOGY

To simulate the ground water flow system of the catchment; various approaches and methodologies were applied. The analysis and interpretation of data were carried out by using different softwares Such as, MODFLOW, Groundwater management Model, Arcgis 9.1, surfer 8, and Microsoft Excel.

3.1 Groundwater recharge Estimation using WetSpass

WetSpass model is widely used for estimating spatially distributed, long-term average recharge (Batelaan, O. and De Smedt, F.,2001: 2007). It uses long-term average climatic data together with elevation, land use and soil map of an area to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area. This model is fully integrated or embedded in the Arc View (version 3.2) as raster model. Inputs for this model include grids of land-use, groundwater depth, precipitation, potential evapotranspiration, wind speed, temperature, soil and slope, where by parameters such as land-use and soil types are connected to the model as attribute tables of their respective grids (Batelaan, O and Woldeamlak, 2007).

3.2 WetSpass input data

Two types of inputs are required so as to run the WetSpass model: Parameter tables (dbf data) and grid map using ArcView.

Parameter table (dbf data)

Inputs of land-use, soil and runoff characteristics parameter table were required. Then, these tables were added/joined to the maps as attribute.

Land use parameter table

Summer and winter land-use, parameter tables were prepared as; either crop, forest, grass, bare soil and open water. The table has also values for rooting depth, leaf area index, minimum stomata opening, interception Percentage and vegetation height.

Soil attribute table

The soil attribute table contains soil type of the area, field capacity, permanent wilting pointand residual water content of these soils.

Runoff characteristics parameter table

The runoff characteristics parameter table contains runoff coefficient, slope and soil type for each corresponding land-use. Values in these tables are considered to be universal; no modifications are required for parameters of these tables.

Grid maps

Topography, slope, land-use, soil, evapotranspiration and groundwater level maps were prepared. Hence, the topographic grid map, which is used to characterize hydrological characteristics of the land surface and the slope data layer, describes the maximum change in elevations were derived from SRTM using Global Mapper 15. Temperature, precipitation, and wind speed parameters were prepared using the available meteorological data from National Meteorological Agency (NMA). The meteorological data are converted to special grid maps by grouping the data into winter and summer seasons for WetSpass modeling.

Potential evapotranspiration (PET) is among the important input parameters of WetSpass model and were calculated using the Penman combination method. The monthly estimated PET values were used to prepare the summer and winter PET grid map.

Topography and Slope

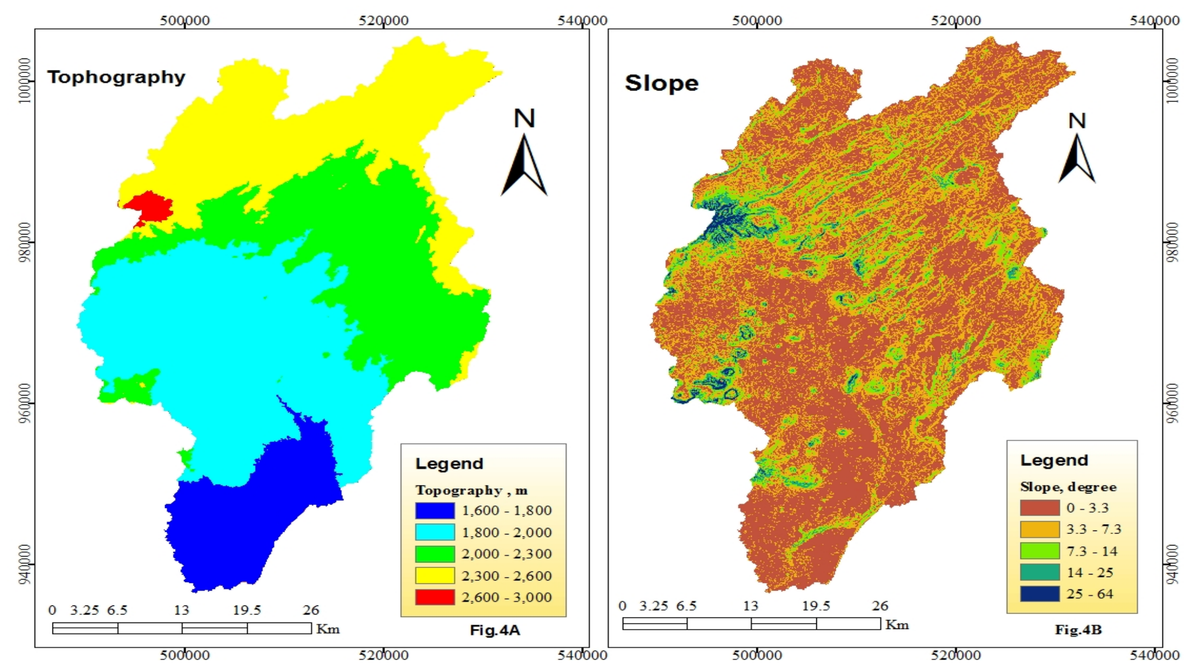

Fig. 4 Topography and Slope of study area

Two major types of land forms generally characterize the study area: volcanic ridges and hills surrounding the catchment at its northern and eastern, with flat land forms in central and southern part. Modjo river catchment has an elevation range of 1600m.a.s.l. to 3000m.a.s.l. (figure 4A).The general slope of the area is towards the south and ranges between 0 to 64 degre(Figure 4B).

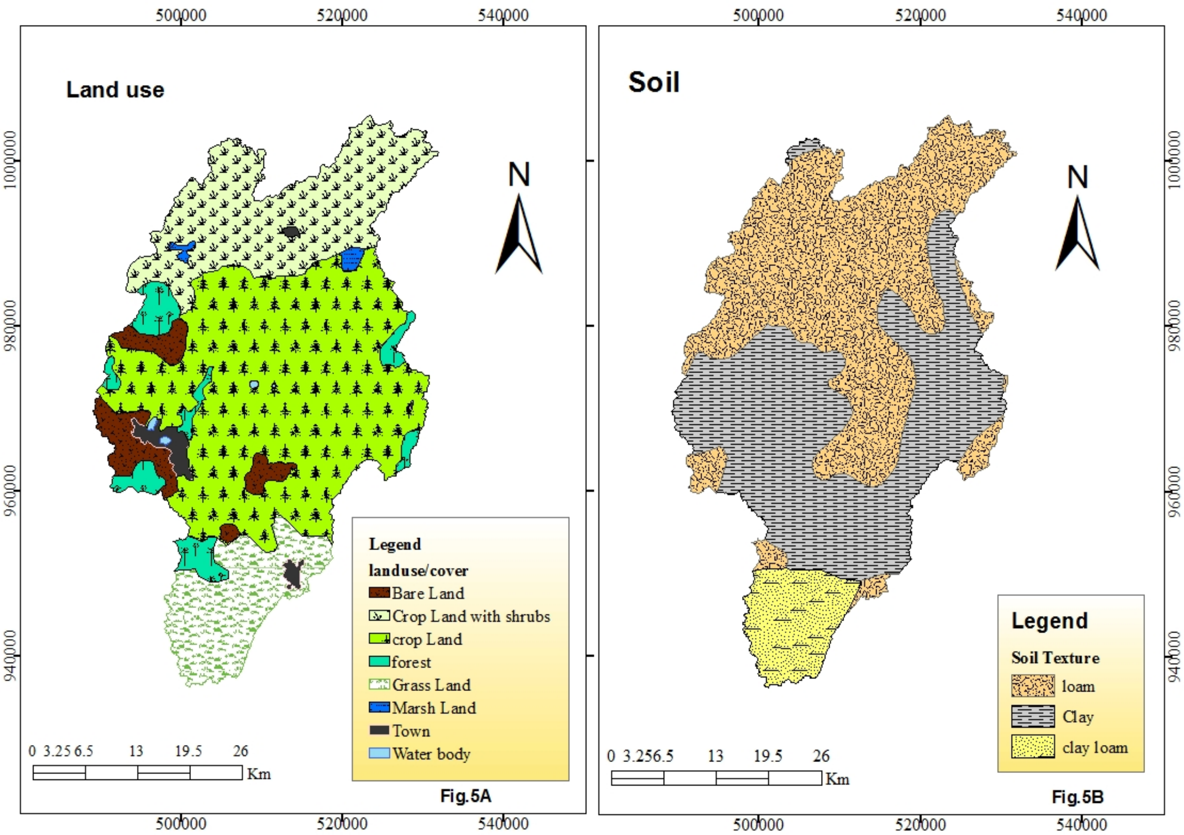

Fig. 5 Land Use Land Cover (Adapted from Sisay, 2007) & Soil Texture (FAO, 1997) & (Ethiopian Road Authority, Drainage Design manual-2002)

Potential Evapotranspiration

Evapotranspiration is an important parameter in water budget which abstracts water from the system and controls the soil moisture content, groundwater recharge and stream flow components of any basin. Penman combination formula has been used widely and helps to provide a more realistic evaluation of moisture content of catchment (Shaw, 1994). Accordingly, the monthly PET of Modjo river catchment is calculated using the Penman formula and the Seasonal potential Evapotranspiration grid map displayed (Fig.6 and Fig.6B). The monthly results are subdivided in to two main seasons (4 months of summer and 8 months of winter). Finally the summed PET values of each season, which is prepared in the form of dbf, are converted to spatially distributed grid maps. The grid maps of PET for both seasons are incorporated with other input parameters in WetSpass model to estimate the recharge as well as actual evapotranspiration (AET).

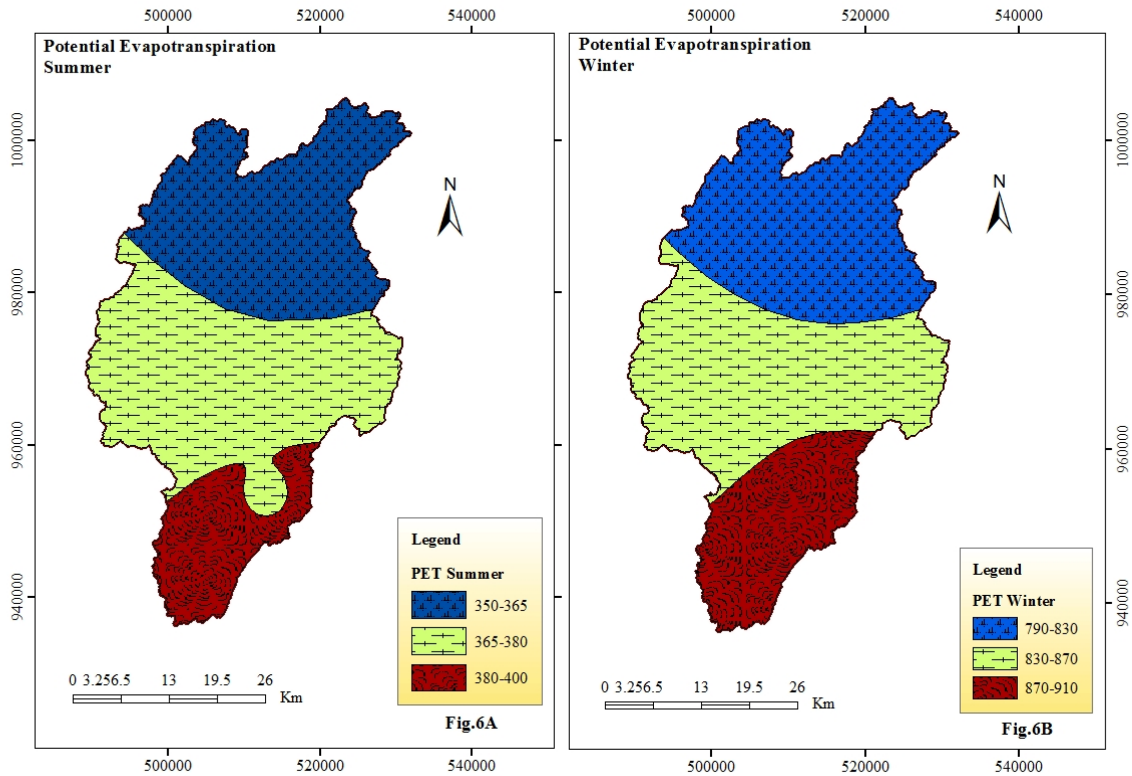

Fig. 6 Seasonal Potential Evapotranspiration distribution map of Modjo River catchment

Rainfall

In order to analyze the rainfall condition of the area nineteen years data were collected in and nearer the catchment metrological stations from eleven meteorological stations (1995 – 2014). According to this, the study areas is characterized by three distinct seasons and are locally known as "Bega" (October-January), "Belg" (February-May), and "Kiremt" (June-September).Therefore, the rainfall pattern in the area has two distinct peaks during a year that is a short rainy seasons in months of February / March-May and long Rainy Seasons in moths of June/ July-September. The mean annual rainfall of the study area is 862.36 mm. The seasonal grid map of the study area is displayed in (Fig.7A and 7B).

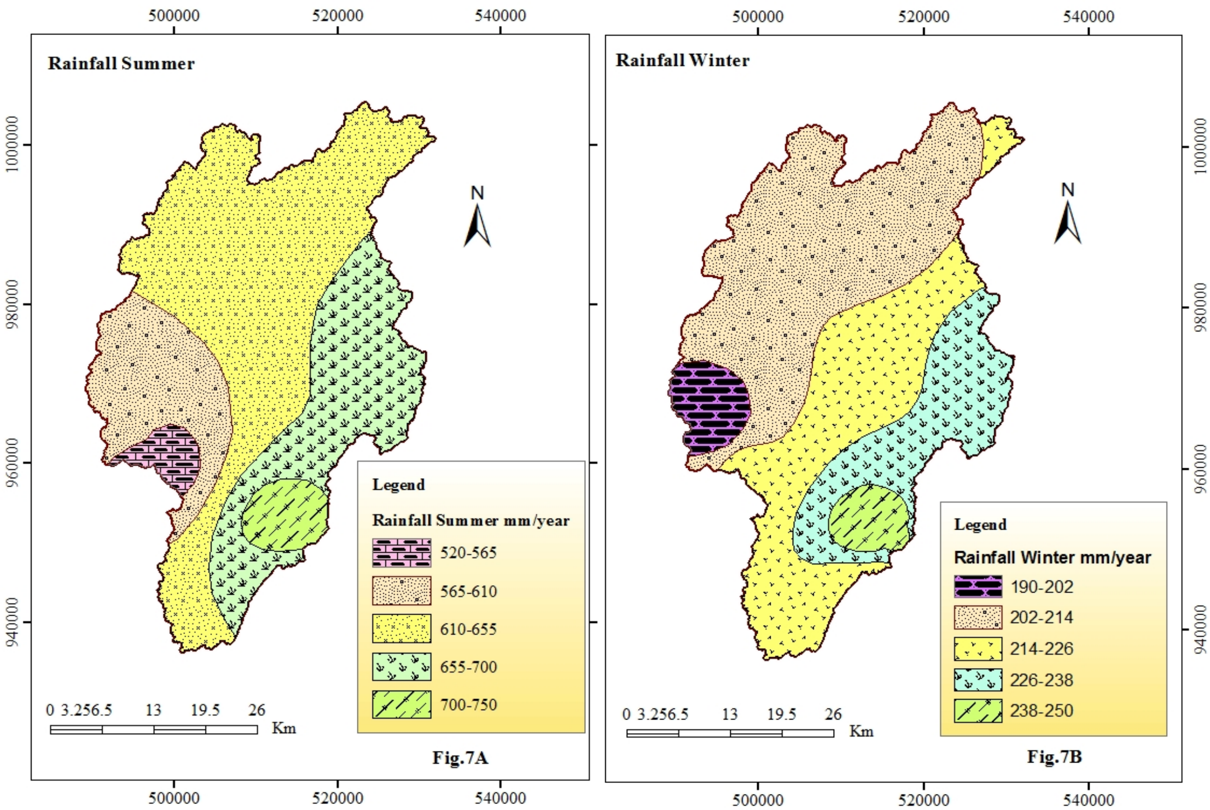

Fig. 7 Seasonal Rain fall distribution map of Modjo river catchment

Land use / Land cover and Soil

Land use is an important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration. The existing land use patterns in the catchment have been broadly divided in to eight groups based on area of coverage: Crop land with shrubs; crop land, grass land, forest, plantation, urban area with its associated different uses; bare land, water bodies and Marsh Land (Fig. 8).The areal extent and proportions of each land use/land cover is given in table 1 and Fig. 8.

Table 1 Land use/Land cover of Modjo River Catchment

No.	Land Use Land Cover	Area(km^2)	Area (%)
1	Bare land	95.95	5.65
2	Crop land with shrubs	394.66	23.23
3	Crop land	859.12	50.58
4	Forest	99.06	5.83
5	Grass land	205.55	12.1
6	Towns	31.39	1.85
7	Water body	3.08	.18
8	Marsh land	9.8	0.58
	Total	1698.7	100

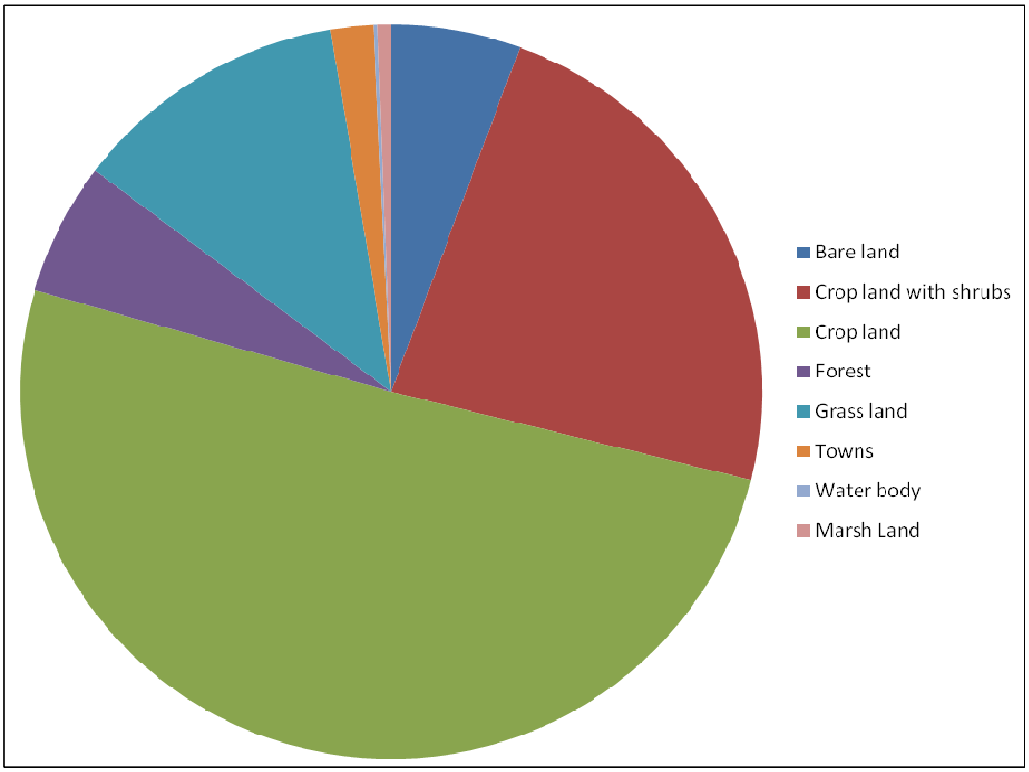

Fig. 8 Land use and land cover of study area

Soil

Land use/land cover, soil texture and precipitation are the three controlling factors affecting the water balance of Watershed hydrology (Fetter, 2001). Soil map is shown in figure 6. In this study, a soil Textural classification is used to estimate spatially distributed groundwater recharge. Permeability and infiltration are the principal data required to classify soils into Hydrologic Soils Groups (HSG) (Ethiopian roads Authority drainage design manual -2002). Based on infiltration rates, the Soil Conservation Service (SCS) soil of the study area divided in to three hydrologic soil groups as follows:

Group B: loam soils having a moderately low runoff potential due to moderate infiltration rates.

Group C: Clay loam soils having a moderately high runoff potential due to slow infiltration rates.

Group D: Clay soils having a high runoff potential due to very slow infiltration rates. These soils primarily consist of clays with high swelling potential, soils with permanently – high water tables, and soils with a claypan or clay layer at or near the surface, and shallow soils over near the surface, and shallow soils over nearly impervious parent material. Based on soil groups and the digital soil and terrain database of east Africa (1997) and ERA (2002) soil of study area were classified in to three soil texture classes (Table 2) and (Fig. 9).

Table 2 Texture class of soils (Adapted from ERA drainage design manual, 2002)

S/N	Soil Types	Hydrologic Soil Group	Soil texture
1	Lithic Leptosols	B	Loam
2	Eutric Vertisols	D	Clay
3	Vertic Cambisols	B	Loam
4	chromic Luvisos	B	Loam
5	Mollic Andosols	B	Loam
6	luvic Phaeozems	C	clay loam
7	Haplic luv sols	B	Loam

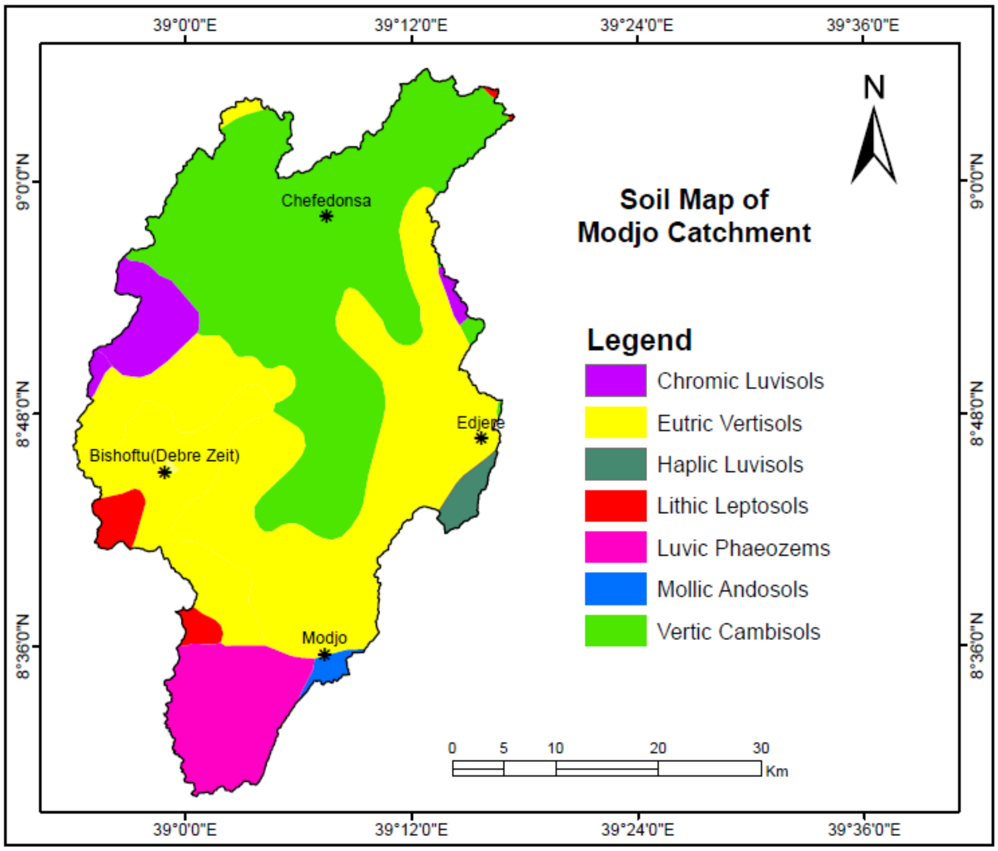

Fig. 9 Soil map of Modjo River basin

3.3 Construction of a steady natural model

Under the natural conditions, groundwater is usually in a steady state. The long-term average recharge equals the long-term average discharge (Zhou, 2009). The obtained groundwater levels were used as initial conditions for pumping groundwater modeling. Groundwater flow model was developed using MODFLOW-2000. This model is used to simulate groundwater abstractions from pumping wells, interactions between groundwater and river. Natural model was used to assess the impact of groundwater abstraction. Water balance under natural model was used to evaluate influences of abstraction on groundwater system.

Spatial discretization

In a numerical model, the continuous problem domain is replaced by a discretized domain consisting of an array of nodes and associated finite difference blocks (cells). The nodal grid forms the framework of the numerical model (Anderson and Woessner, 1992). A critical step in grid design is the selection of the size of the nodal spacing as the horizontal dimension depends on the expected curvature in the potentiometric surface and the change in head in the vertical direction influences the vertical nodal spacing. Other factors that influence the size of nodal spacing are the availability of data, variability of aquifer properties and the size of the area to be modeled.

The extent of the Modjo River Catchment in the north-south and east-west is 73,000 m and 50,000 m, respectively. The modeled catchment has an area of about 1,698.7 km^2. The array of cells arranged in 365 rows and 250 columns. The lateral dimension of the cells is 200 m by 200 m on each side. A regular grid has been adopted for the entire catchment and each cell has homogeneous property. Flow area and gradient used to determine flow through the cell are determined at the center of each cell and represent the average area and gradient through the cell. A single aquifer of one layer system was considered for the purpose of groundwater flow simulation in this study.

Top and Bottom of layer

Layer top or surface elevations were extracted from DEM of 30 m spatial resolution. Layer bottom elevations were obtained by subtracting aquifer thickness from layer top elevations. Elevated zones were simulated by giving relatively higher thicknesses at the cells in order to avoid drying of cells during simulations.

Initial and Prescribed Hydraulic Head

Processing MODFLOW needs this initial heads to start simulation. For this simulation, it was obtained by subtracting static water levels from the layer top elevation. Water level elevation was given as initial heads in cells represented by constant heads.

Boundary Conditions

Boundary conditions are mathematical statements specifying the dependent variable (head) or the derivative of the dependent variable (flux) at the boundaries of the problem domain

(Anderson and Woessner, 1992). The boundaries chosen for the model describe mathematically how the simulated groundwater system interacts with the surrounding hydrologic system. In mathematical analyses of groundwater flow system, three common mathematical boundary conditions are specified (Anderson and Woessner, 1992). These are: Specified head, Specified flow, Head dependent flows. In the Modjo River catchment, there are five crater lakes.The lakes were represented as specified head in the model. The water surface elevations of Bishoftu Guda (1864m), Hora (1860m), Bishoftu (1856),Hado (1870m) and Chelelka (1890) were given as initial heads to cells representing such constant head nodes.

The flux across head dependent boundary depends on the difference between user supplied head on one side of the boundary and model output head on the other side. In this study, groundwater flow system and system boundary is conceptualized and the inflow and outflow component of water budget is quantified based on groundwater contours constructed from borehole data collected in and near the study area, field visit made and existing work of WWDSE, 2008. Southern, Southeastern and Western parts that found between Bede Gebaba and Yerer Mountain boundaries was simulated by using the General Head Boundary Package of MODFLOW based on (WWDSE, 2008) and other areas are considered as no flow boundary (Fig.10) . The flux across this boundary was calculated using the conductance of the interface (C_b), head in the aquifer (h) and head in the external source (h_{source}). The flux Q_b is given as:

$$\mathbf{Q_b = C_b (h_{source} - h)} \ldots\ldots\ldots\ldots (1)$$

The hydraulic conductance of the GHB has been calculated using the relation:

$$\mathbf{C_b = K.L} \ldots\ldots\ldots\ldots (2)$$

Where: C_b is interface conductance (m^2/d), K is hydraulic conductivity of GHB (m/d)

L is length of the GHB (m)

Only C_b and h_{source} were estimated and MODFLOW calculated the fluxes based on the head in the aquifer using these estimates.

The River package was used to simulate the flow between groundwater and Modjo River. It simulates the water exchange between aquifer and river (Harbaugh et al., 2000).

Groundwater Recharge

Recharge to the aquifers in the catchment is directly from precipitation during intensive rainy seasons. The catchment was subdivided in to different zones of recharge and it was obtained from WetSpass model (Fig.16). The recharge was simulated as specified flux by using the

Recharge package of MODFLOW with the option recharge is applied to the top grid layer and is not expected to change with water level changes.

3.4 Construction of a steady Pumping model

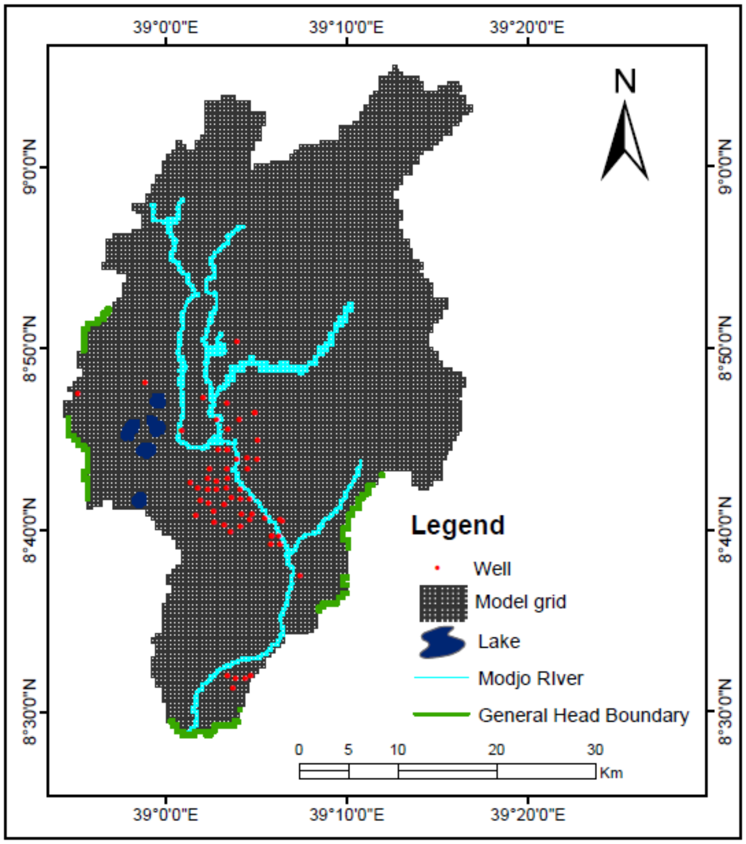

Fig. 10 Boundary conditions and location of pumping wells

The aim of this model is to assess the response of the groundwater system to abstraction. A pumping well is defined by using the Cell-by-Cell input methods of assigning negative sign to model cells. MODFLOW assumes that a well penetrates the full thickness of the cell. Data from 123 wells were used to quantify daily and annual abstraction from the aquifer (Fig. 10). Total daily abstraction based on 18 hours pumping from the aquifer of the Modjo River catchment is 374,029m^3/d.

Initial groundwater levels

In order to assess the changes of the groundwater levels caused by abstraction, the calculated Natural groundwater levels are used as initial heads in the development model.

Pumping wells

The well package of MODFLOW is used to simulate pumping wells. Pumping rate shown in Fig. 11 was specified for each abstraction wells

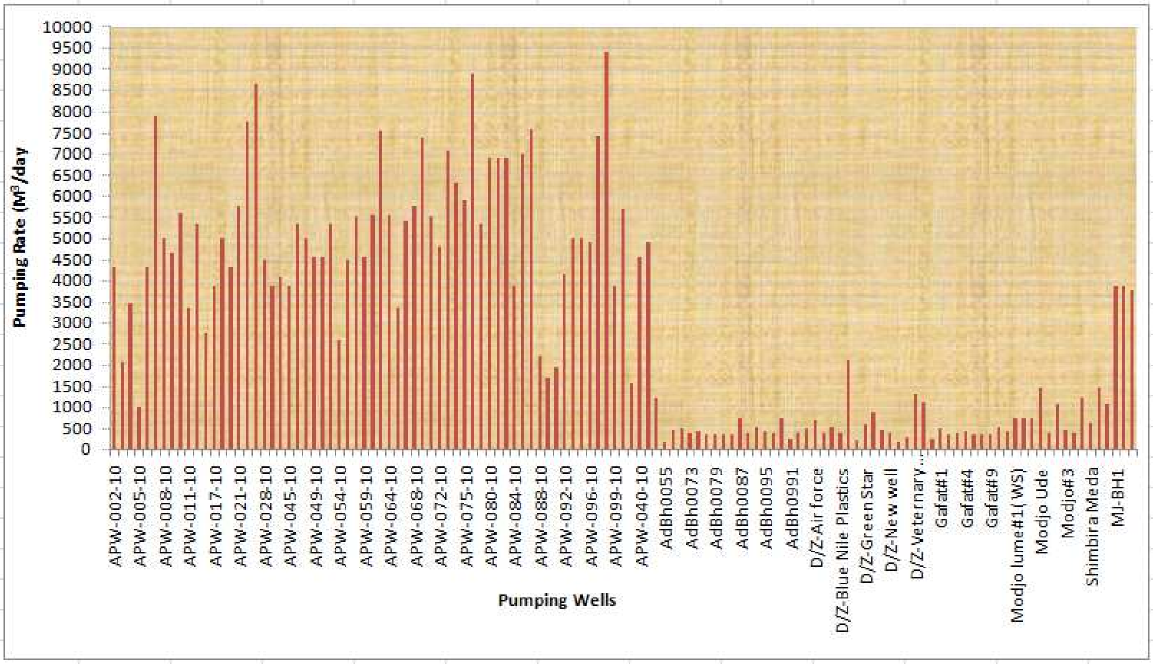

Fig. 11 Daily pumping wells rates of study area

3.5 Coupled simulation-optimization model

GWM formulation consists of decision variables, state variables, objective function, and constraints. Groundwater management model uses the MODFLOW file name (NAM) and GWM file name to solve formulated optimization problem. MODFLOW file name contains input and output data such as a recharge data, a river data, a DIS package file, a BAS6 package file, a PCG solution package, BCF6, a general head boundary package and output control data. The GWM data contains head constraints (HEDCON), decision variable (DECVAR), objective function (OBGFNC), variable constraints (VARCON) and solution method (SOLN). The decision variable used to specify information such as type of wells (abstraction), location in the model (row and column), and stress periods. Steady state optimization

3.5.1 Steady state Optimization

Objective function

The objective function was formulated as to optimize pumping rate from the Maghaway valley production wells. The objective function of the steady pumping model was expressed as:

$$Maximize\ Z = \sum_{i=1}^{M} q(i) \tag{3}$$

Where Z is the objective function, M is the number of pumping wells and $q(i)$ is the pumping rate of well i (m^3/day).

The functional relationship between the pumping rates and groundwater level decline under the steady state optimization was formulated with the response matrix approach as:

$$s(j) = \sum_{i=1}^{M} q(i)\beta(j,i) \tag{4}$$

Where $s(j)$is the total drawdown at the well location j caused by M pumping wells; $\beta(j,i)$ is the coefficient of the response matrix, which is the drawdown at the well location j caused by a unit rate at the well i.

Hydraulic head constraint

Hydraulic head constraint was used to prevent excessive groundwater level dropping resulted from pumping. According WWDSE, (2008) static water level in Ada'a well field is 1750-1800 m above sea level and depths of pumping wells are between 300 to 350 m below ground level. Fig. 12 shows the wells near lakes and river. Therefore, 1600 m of hydraulic head was imposed as minimum hydraulic head at wells far from lakes and rivers (Eq. 5a) and 1800 m was used for pumping well placed near lakes to avoid excessive lake inflow and 1650 m for wells near river water (Eq. 5b and Eq. 5c):

$$h(j) = H_0(j) - s(j) \geq 1600\, m \tag{5a}$$

$$h(j) = H_0(j) - s(j) \geq 1800\, m \tag{5b}$$

$$h(j) = H_0(j) - s(j) \geq 1650\, m \tag{5c}$$

Where $h(j)$is the hydraulic head (m) at the well location j; $H_0(j)$is the natural groundwater level before the abstraction at the well location j.

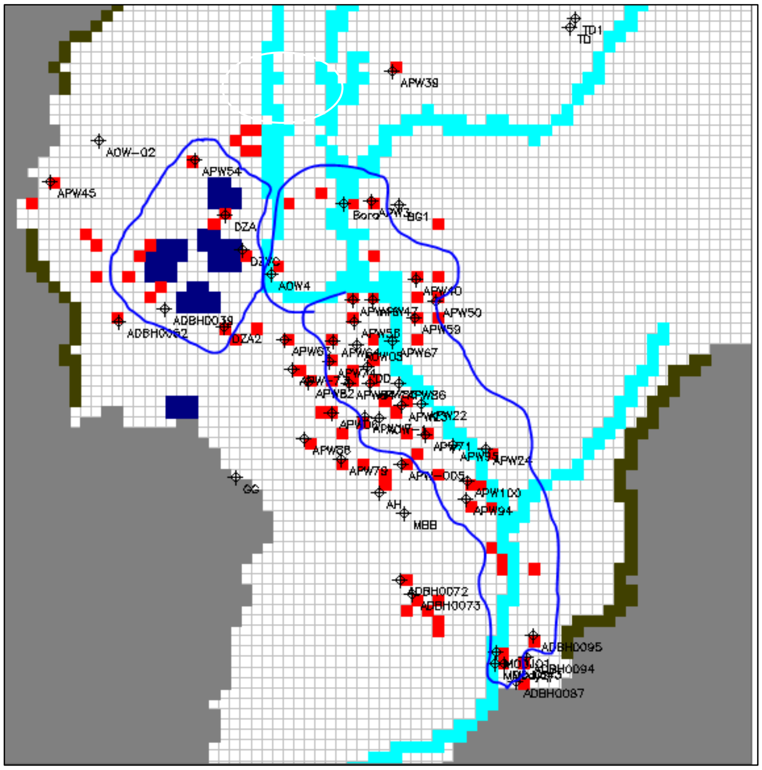

Fig. 12 Head constrains for well near lakes and Rivers

Decision variable constraint

Restrictions to pumping rate from each abstraction well were imposed by the upper limit constraints. The pumping rate at each pumping well should not exceed pump capacity and the pump capacity for each wells are shown in Table 1 (Anex1). For each pumping wells a minimum and maximum pumping rates were set equal to zero and $q_u(i)$(m^3/day).

$$0 \leq q(i) \leq q_u(i) \tag{6}$$

Where $q_u(i)$ is the upper bounds on pumping rate (pump capacity of wells in Table 1 at annex).

In this study, data of designed pump capacity is not available. Thus, current pumping rate was used as upper bounds on pumping rate.

Solution method (SOLN)

Unlike the confined aquifer, saturated thickness is not constant in the unconfined aquifer and variability of saturated thickness results in nonlinearity of groundwater system. Therefore, the formulated groundwater optimization problem (Equations 3 to 6) of Ada'a well field was solved using SLP method implemented in GWM-2005.

3.6 Water Samples collection and Analysis

Hydrogeochemical research requires proper site selection for collection of water samples and appropriate method for analysis. Sampling sites were located taking several factors into considerations like lithology, structure, geomorphology, river influence, industry, urban, agricultural activity and availability of wells. Groundwater sampling is an important tool of hydrochemical studies of a particular area. In the present study groundwater samples were collected from Modjo River catchment, Modjo, Ethiopia. The concentration of ions in groundwater was often expressed in two different units. (a) parts per million (ppm) or mg/l and (b) equivalents per million (epm) or meg/l.

3.6.1 Field methods (Ground water sampling)

A total of 30 groundwater samples were collected (Fig.2) and analyzed to understand the physico-chemical variations of water quality parameters in study area. The water sample bottles were thoroughly washed with acid and then with distilled water in the laboratory before filling the bottle with the sample in the field and then labeled with an identification number. The location of the sampling area was registered using GPS. Prior to collection, the bottles were thoroughly washed with dilute HNO_3 acid and then with distilled water in the laboratory before sample filling. The bottles were immediately sealed after collecting the sample to avoid reaction with the atmosphere. The sample bottles were labeled systematically. The collected samples were analyzed in the laboratory for various physico- chemical parameters..

3.6.2 Laboratory methods

Water analyses were carried out by using standard procedures (APHA 1995). The parameters such as pH and electrical conductivity (EC) were measured in the field while the concentration of chemical constituents such as Ca, Mg, Na, K, Cl, HCO_3, and SO_4 in groundwater samples was determined in the laboratory at Water Works Design and supervision Enterprise (WWDSE). Total dissolved solids (TDS) were calculated from Electrical conductivity (EC) and multiplied by 0.64 (Brown et al., 1970). The sampling preservation and analysis were carried out as per the standard methods (Table.3) prescribed by American Public Health Association (APHA 1995). The results of analysis are presented in Table.3.

Table 3 Analytical techniques adopted

Parameter	Method	Instruments
pH	In situ	Field kit
EC	Digital Conductivity Meter	Field Kit
TDS	Indirect method (Raghunath, 2003)	0.64 x EC µS/m
Sodium &Pottasium	Flame photometry	Flame Photometer
Calcium & Magnesium	Spectrometry	Spectrophotometer
Chloride	Volumetric	Titration
Bi- carbonate	Volumetric	Titration
Sulphate	Turbidity	Nephelometer

3.6.3 Softwares Used

The location of each wells were taken in to the GIS environment and the results of each parameters analyses were added to the concerned wells. Spatial Analyst, an extended module of ARC / GIS 10.3.1 was used to find out the spatial behavior of the groundwater quality parameters. The geochemical characterization was done by using AqQA software. Simplified methodology adopted is shown as a data flow in Fig.13.

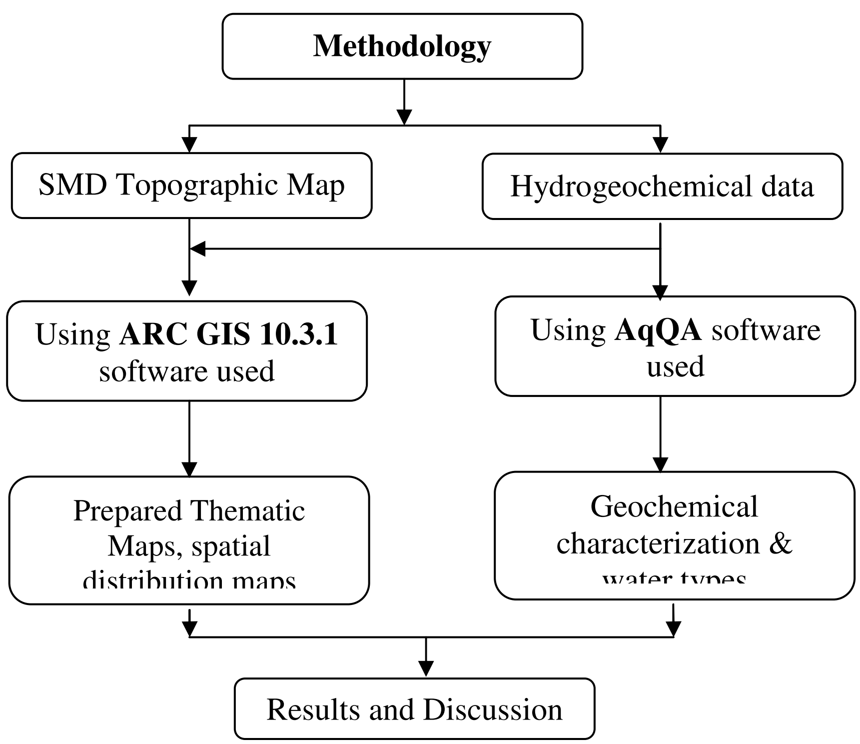

Fig.13 Data Flow of water quality analysis Methodology

4. RESULT AND DISCUSSION

4.1 Analysis of Water Balance Modjo River Catchment

The WetSpass model produces seasonal and annual hydrological parameters like grid maps of groundwater recharge, actual evapotranspiration, surface runoff, interception loss, evaporation, etc. Annual groundwater recharge, annual actual evapotranspiration and annual surface runoff are the main outputs of the WetSpass model.

4.1.1. Annual evapotranspiration

The annual evapotranspiration is calculated by WetSpass as a sum of evaporation from bare soil, transpiration of the vegetated cover, interception loss by vegetation and evaporations of open water body. According to the WetSpass simulated results of annual evapotranspiration, its value ranges from 412.26 to 595.21 mm in the catchment. The output of annual evapotranspiration grid map is shown in Fig.14.

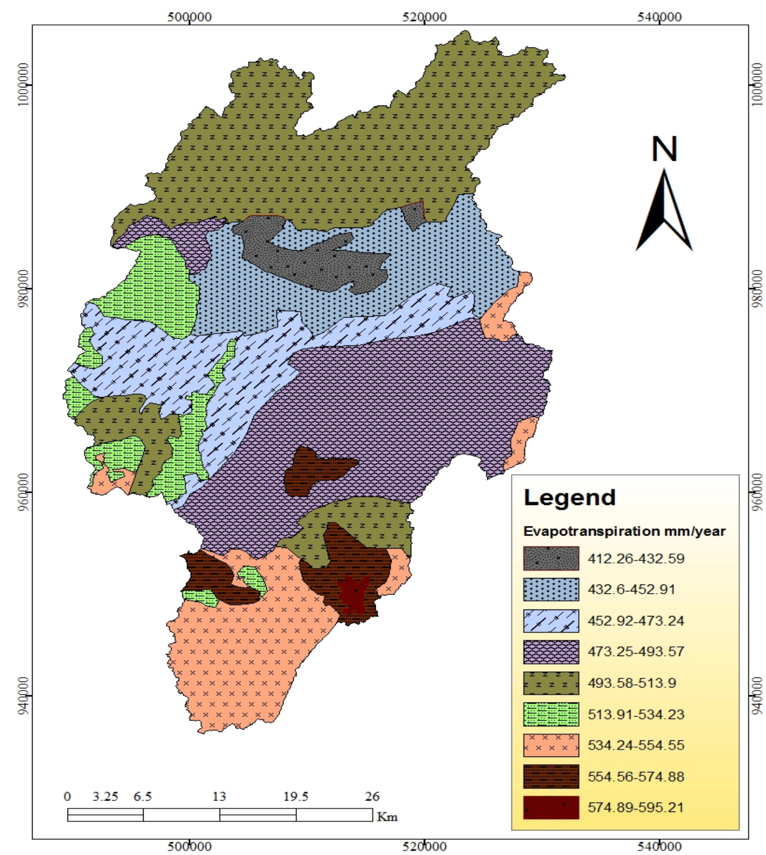

Fig. 14 Annual evapotranspiration map of Modjo river catchment

Generally the value of annual evapotranspiration of Modjo River catchment varies with precipitation and land-use/land-cover. Hence, precipitation and land-use/land-cover are the main controlling factors of evapotranspiration in the catchment.

4.1.2. Surface runoff

The surface runoff of Modjo river catchment shows variation with land-use, soil type, slope, topography, precipitation and the other meteorological parameters (Fig.15). The amount of Surface runoff in the Modjo river basin ranges from 40.96 to 322.71 mm with 172.91 mm of mean. The mean value represents 20% of the total annual precipitations of Modjo river basin.

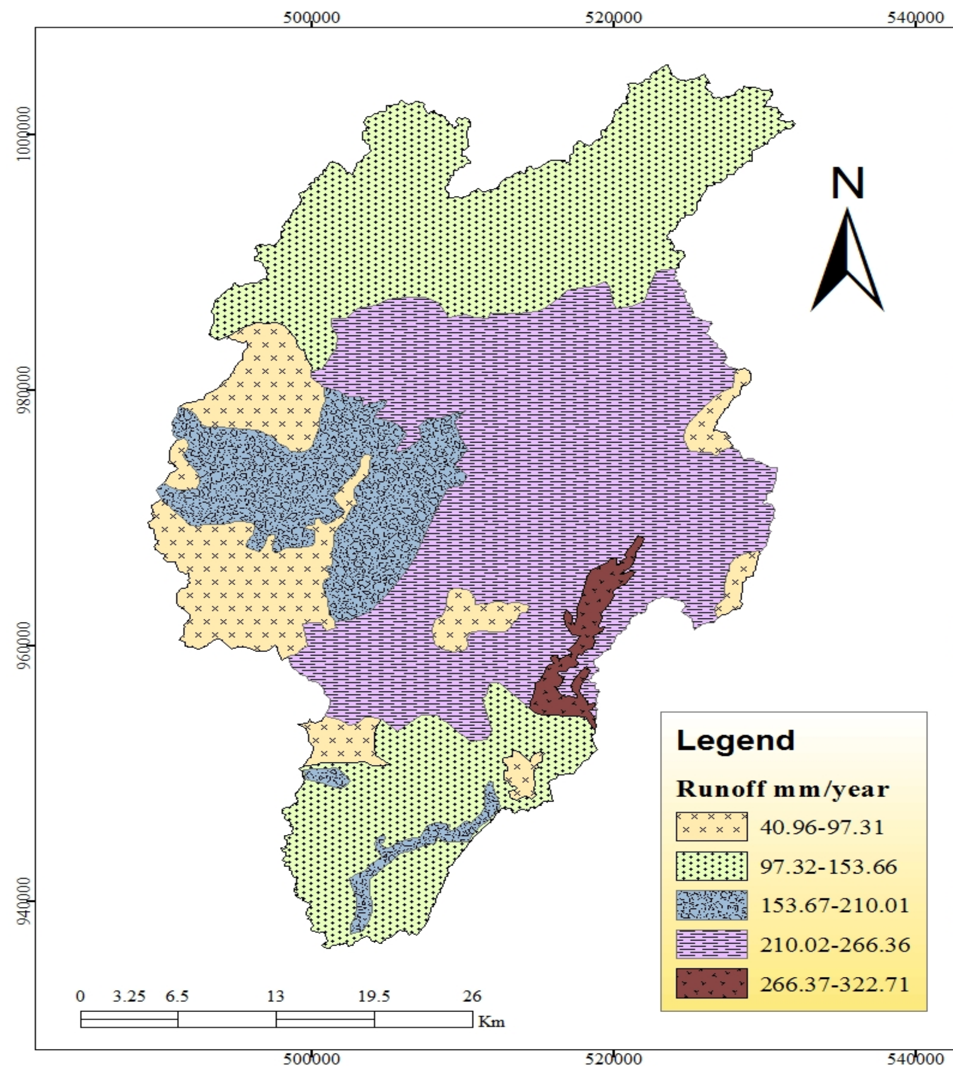

Fig. 15 Annual surface runoff map of Modjo river catchment

4.1.3 Groundwater Recharge

WetSpass model was applied to determine the mean annual recharge of Modjo river catchment. WetSpass model estimates seasonal and annual long term spatial distribution of groundwater recharge by subtracting the seasonal and annual surface runoff and evapotranspiration from the seasonal and annual precipitation respectively. The WetSpass simulated recharge to the Modjo river basin is presented in Fig. 16. Spatial variation of groundwater recharge resulted due to distributed land-use, soil texture, topography, groundwater level, and hydrometeorological conditions in study area. In study area, the annual groundwater recharge varies between 56.55 to 347.19 mm. The average annual recharge in the modjo river basin is 197.94 mm. This is 23 % of the average annual precipitation over the catchment mm. However the result obtained shows a slight different compared to groundwater recharge estimated by (Berehanu, 2007) and (Zelelam 2011) for Modjo river catchment which accounts 19.4% and 17.8 % of the annual precipitation respectively.

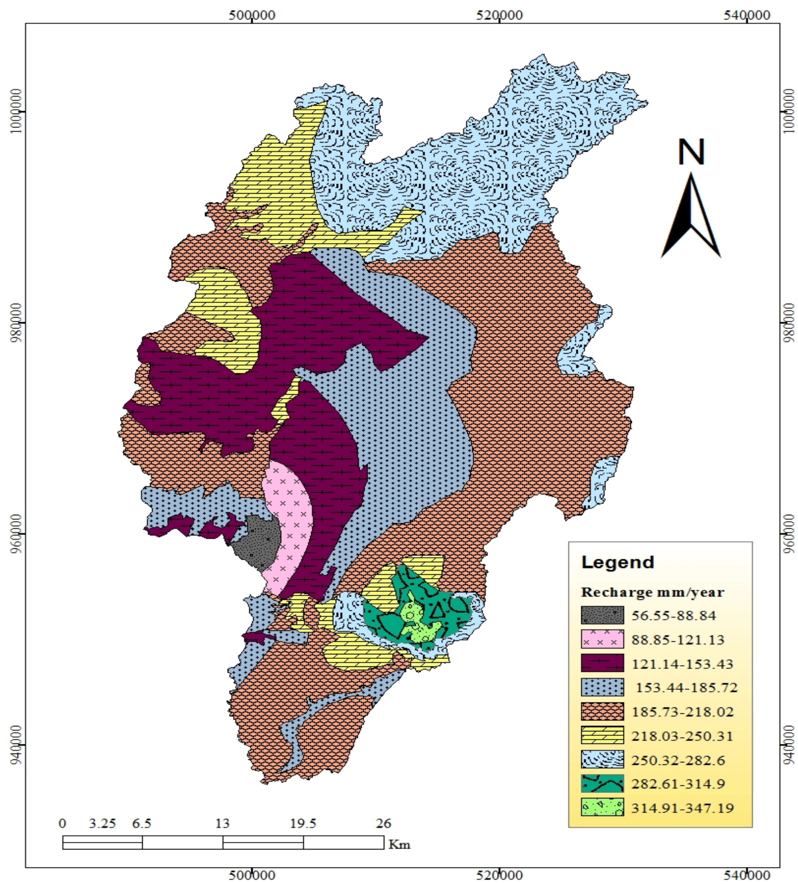

Fig. 16 Annual groundwater recharge map of Modjo river catchment

From the groundwater water recharge of the catchment (Fig. 16), it can be seen that high recharge occurs in the northern, northeastern and southeastern parts around Chefe Donsa and Modjo parts of the area and it ranges between 250.32-347.19mm. This is due to the presence of permeable soils, high precipitation, deeply weathered and fractured volcanic in this part. On the contrary, the some areas of the basin the groundwater recharge ranges between 56.55-153.43mm due to low precipitation, impermeable soils, bare land and overcrowded settlements (Fig. 16). Moderate groundwater recharge ranges between 153.44-250.31mm in middle, eastern, northwestern and southern parts around Ejere and Bishoftu areas due to high precipitation, Highly fractured Scoriaceous Basalt and favorable flat land topographic setup.

4.2 Groundwater flow Model Results

4.2.1 Steady Pumping model

The steady state pumping model was calibrated by the trial and error method. Field measured water levels at 99 wells were used during calibration. Hydraulic conductivities zones (Fig. 18) were adjusted until a good agreement between computed and observed heads were obtained (Fig. 17). The correlation coefficient was found to be 0.99. Vertical hydraulic conductivity is about 1/10th of the horizontal hydraulic conductivity (Waterloo Hydrogeology 2006).

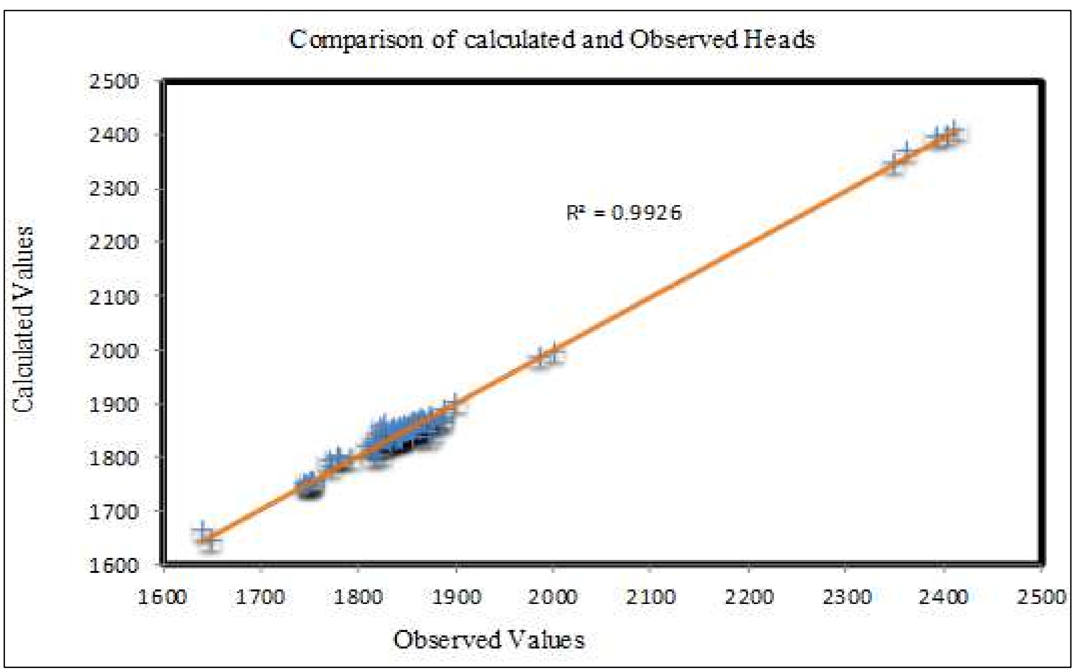

Fig .17 Comparison of observed and computed heads for steady pumping model

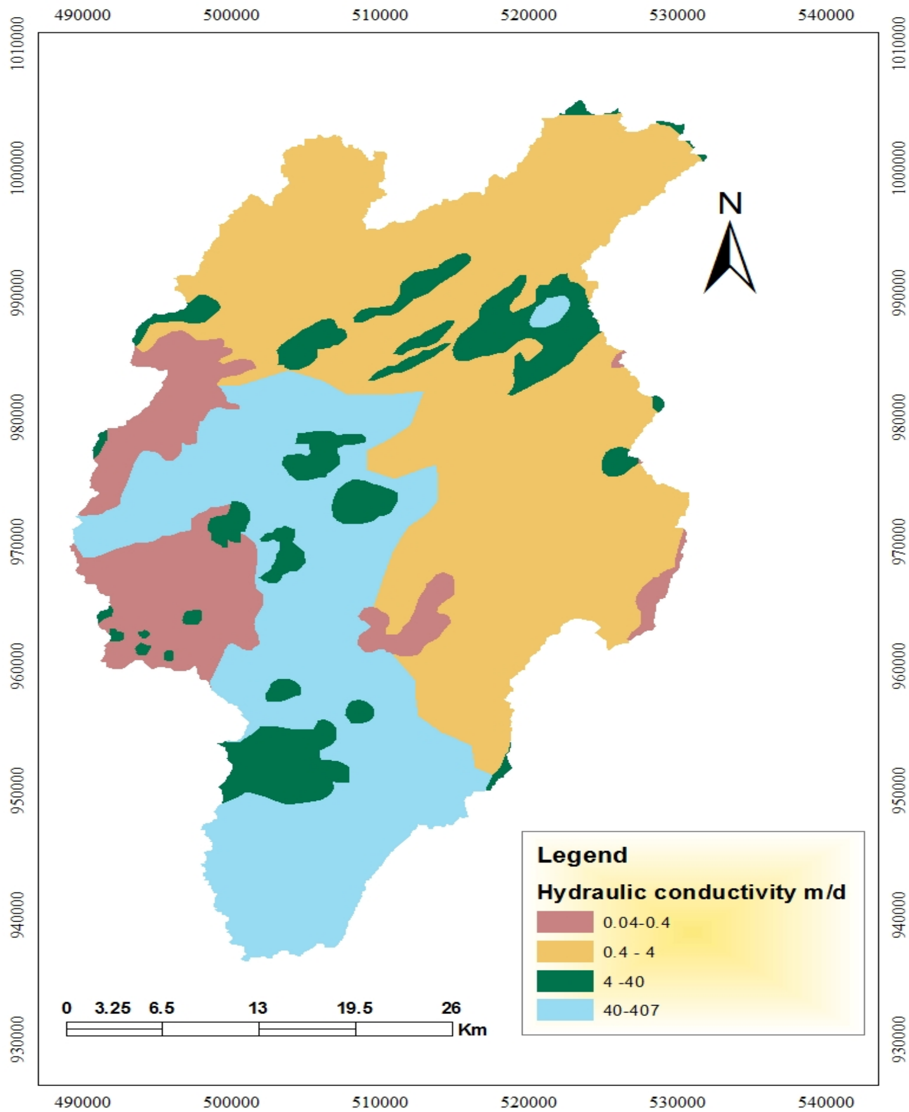

Fig. 18 Horizontal hydraulic conductivity zones

4.2.1.1 Groundwater flow system

The contour map of groundwater levels is shown in Fig.19. Groundwater flows from north towards Bishoftu crater lakes and finally leaves the catchment through south direction. It shows that water level contour is the subdued replica of the topographic surface. Groundwater flows from high topographic area towards the Ada'a well field and crater lakes and finally leaves the catchment.

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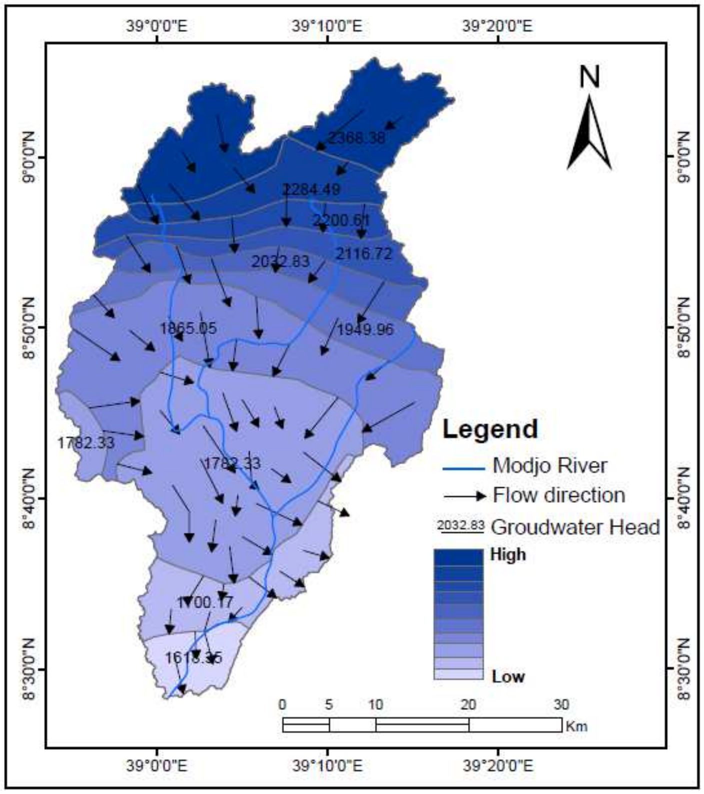


Fig. 19 Groundwater head distribution under steady pumping model

4.2.1.1 Groundwater Budget

Water budget of steady pumping model shows that, the inflow from the five crater lakes accounts for 51.30% of total inflow (Table1). The recharge from precipitation accounts for 46.46 % of total inflow. The groundwater outflow to river and groundwater outflow to lakes are accounts for 11% and 48%, respectively. Groundwater abstraction and downstream subsurface outflow are accounts for 20% and 21% outflow component, respectively.

Table 4 Water budget of steady pumping model

Inflow component	**m^3/day**	**Percentage (%)**
Subsurface boundary inflow	26220.89	1.42
Recharge	860,595	46.46
Constant head in (Lake Inflow)	950,254	51.30
River Leakage	15,344	0.83
Sum	1,852,414	100
Outflow component		
Outflow to downstream area	387,628	21.0
Abstraction	374,093	20.0
Discharge to river	197,392	11.0
Discharge to lakes	892,789	48.0
Sum	1,851,901	100.0
In - Out	513	
Discrepancy [%]	0.030	

4.2.2 Particle Tracking Analysis

Particle tracking is a method used in conjunction with numerical simulation of groundwater flow to delineate flow paths and evaluate advective contaminant transport. Particle tracking can be used also to determine recharge and discharge areas. PMPATH is an advective solute transport model and is used to compute forward and backward particle tracked path lines. In particle tracking simulations effective porosity, horizontal hydraulic conductivity and pumping rates were considered. In this study backward particle tracking were used. The particles were assigned at each the well and backward particle tracking was used which is an effective and powerful tool that can be used to delineate groundwater protection zones (Moutsopoulos et al., 2008). Backward tracking was used to delineate capture zone for well fields. Fig. 20 shows the capture zone of the selected abstraction wells. It is clear that water comes from a high elevated areas, rivers and lakes to the abstraction wells. The water balance analysis (Table 4) confirms that inflow from lakes, river and subsurface inflow flow from outside of study area. According to Jonoski et al (1998) the minimum travel time of the infiltrated water to reach pumping wells abstraction wells should be at least 60 days. This is sufficient for removal of microorganisms and virus, which have a limited lifetime. In study area, water travels more than 60 days to reach pumping wells, however in wells places near wells the water travels less than 60 days. Abstracted water treated before directly distributed for water supply and this kill’s different disease causing organisms that found in abstracted water.

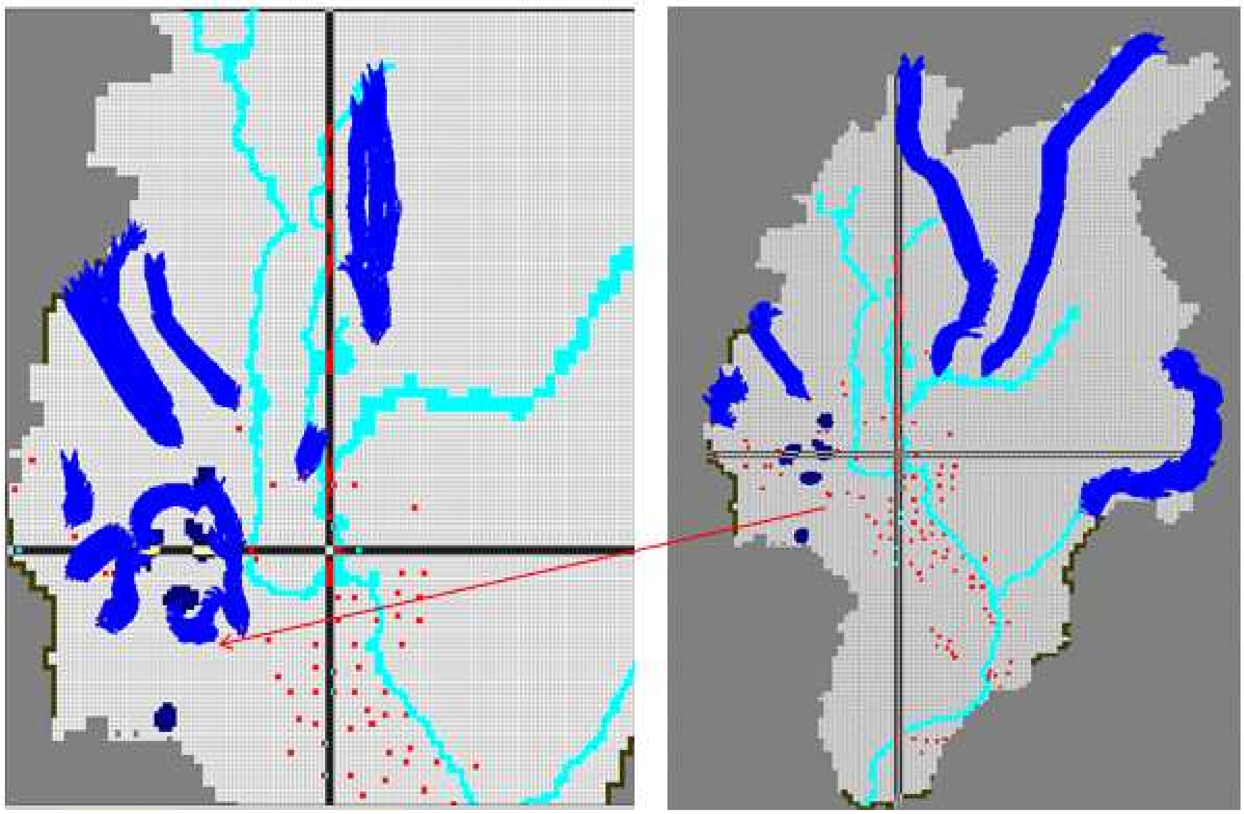


Fig. 20 Particle track analysis

4.2.3 Scenario analysis

In study area, groundwater is pumped by different industries, institutions and water demand is increasing from time to time. Thus, scenarios of increased groundwater pumping rates were simulated to evaluate the responses of an aquifer system to a future stresses (Fig. 13). The groundwater pumping rate was increased by 10%, 20%, 40% and 50% and aquifer response to increased pumping rates were assessed by using water budget and groundwater heads of the calibrated steady state model as a baseline. The resulting changes in river-aquifer interaction, changes in ground heads and subsurface groundwater outflow from the catchment were analyzed.

Increasing the pumping rate by 10% resulted in reductions of base flow by 5.6%, subsurface outflow from the catchment by 1.1% and average ground water level by 1.61 m compared to the steady state model. Scenario of increasing the pumping rate by 20% resulted in reductions of base flow by 11.1%, subsurface outflow by 2.2% and average water level by 2.78 m (with a maximum of 21.1 m and a minimum value of 0.2 m around vicinity of lakes at air force well and increased groundwater inflow from lakes). Increasing the pumping rate by 40% resulted in reductions of base by 21.7%, subsurface outflow by 4.54% and average water level by 5.16 m (with a maximum of 24.24 m and a minimum value of 1.13 m at Debre Zeit air force well that found around vicinity of lakes). Similarly, increasing the steady state withdrawal by 50% resulted in reduction of base flow by 53,359 m^3/day, which is 27% of the calibrated steady state model value. The average groundwater level decline in this scenario was about 6.37 m with minimum of 1.56 m at Debre Zeit air force well that found around vicinity of lakes and maximum of 25.8 m. Scenario analysis shows that, the excessive groundwater pumping and groundwater heads decline in the study area is expected to bring polluted Modjo river water and Crater lakes into the aquifers and affects grounds water system in future. Furthermore, lakes level and Modjo river discharge is expected to decline by excessive groundwater pumping.

The scenario decreased recharge by 25% was investigated which may result from land use change and climate change. The heads calculated for this scenario shows a maximum decline of the water level by 24.18 m and a minimum of 1.57 m (around vicinity of lake in Debre Zeit Air force well). In addition, decreases in recharge caused decreases of subsurface groundwater outflow and base flow by 7.21% and 22.99% respectively compared to steady state model water budget.

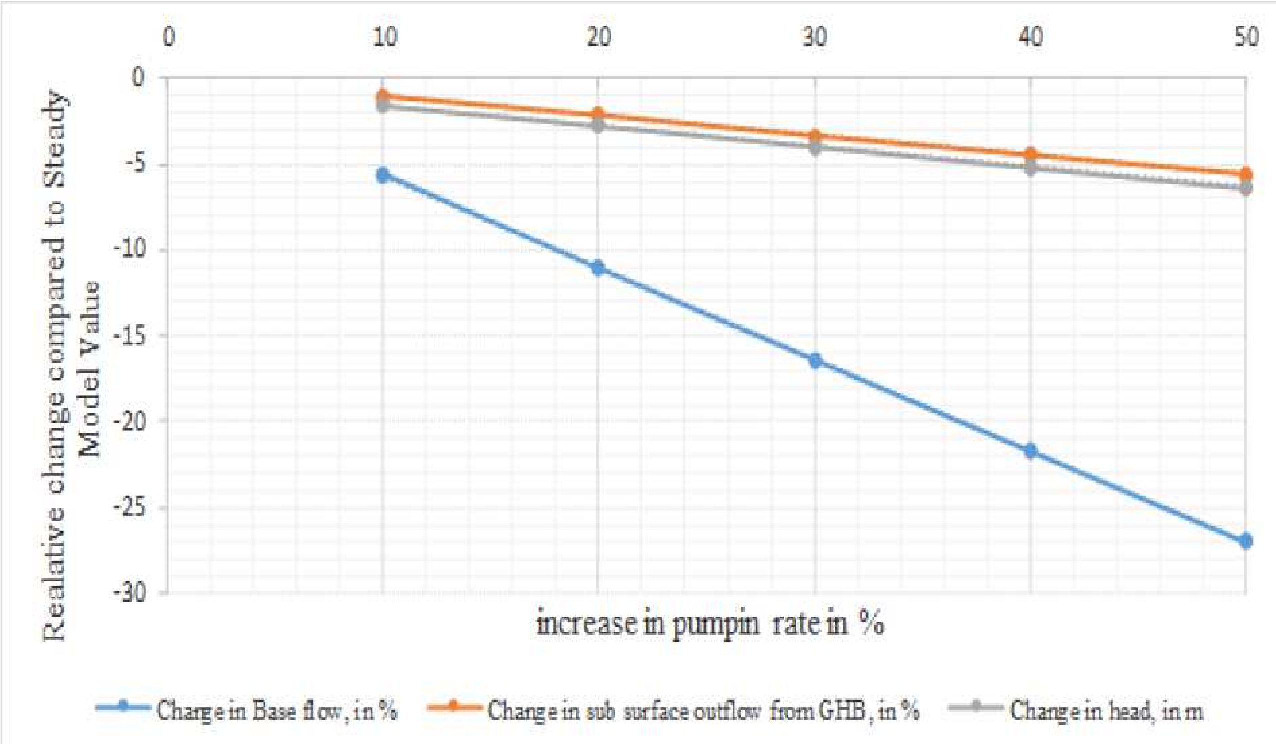


Fig.20 pumping scenario analysis

4.3 Steady state optimization

Table 5 presents the results of water budget from the steady state optimization model. Under optimum steady pumping condition, the total abstraction rate is reduced to 200,093 m^3/day.

Table 5 Water budget from the steady state optimization model

Inflow components	**IN(m^3/day)**	**IN (%)**
Subsurface boundary inflow	40894.47	2.44
Recharge	860,595	51.36
Constant head in (Lake inflow)	756,941	45.17
River leakage	17,344	1.04
SUM	1,675,775	100
Outflow components	**OUT(m^3/day)**	**OUT (%)**
Outflow to downstream area	364,366	21.46
Abstractions	210,093	12.46
Discharge to river	210,392	42.48
Discharge to lake	900,789	53.44
Sum	1,675,640	100
In_Out	135	
Discrepancy [%]	0.030	

This is resulted due to head bound constraints imposed at each pumping wells, especially current head of lakes used to as head constraints to avoid lake level decline. The significant inflow comes from natural recharge and lake inflow which accounts for 51.36% and 45.17% of the total inflow respectively. The subsurface inflow and river leakage account for 2.44% and 1.04% of the total inflow, respectively. The main outflow from study area consist discharge to lakes, subsurface outflow and abstractions wells.

4.4 Water quality analysis results

The water never occurs in its pure state in nature, all ground water contains minerals carried in solution, the type and concentration of which depend upon the surface and subsurface environment, rate of groundwater movement and source of groundwater. Precipitation is relatively free of minerals until it comes into contact with the various constituents present in the soils, which are carried as solution when the water moves through the aquifer. The cation and anion concentration depends upon the solubility product of the minerals present in the formation and of time duration of water is in contact with the rocks, the amount of dissolved carbon dioxide present in the water. In addition to the natural mineralisation, human activities can adversely alter the chemical quality of groundwater through disposal of animal wastes and sewages or various industrial wastes. The suitability of groundwater for various uses is determined by its chemical, physical and bacteriological properties. Water to be used for drinking purposes must meet very high standards of physical, chemical and biological purity. Certain minimum quality parameter for this requirement has been suggested by World Health Organization (WHO, 2008). Hydrogeochemical processes that are responsible for altering the chemical composition of groundwater vary with respect to space and time. The study of geochemistry of groundwaters is an important aspect for its suitability towards drinking, irrigation and industrial purposes.

Groundwater samples were collected in space and time and analyzed for major ions using standard procedures. The results of Statistics analysis are presented in Table.6. The results of sample analyses shows the charge balance error percentage in the total cations (TZ^+) and total anion (TZ^-) balance (Freeze and Cherry 1979). The error percentage is observed in the samples between ±1% to ± 10% with few exceptions as certain ions show abnormally higher concentration occurring. Occurrence of errors in chemical analysis of groundwater may also be due to the reagents employed, limitations of the methods and the instruments used presence of impurities in distilled water etc.

Table 6 Comparison of seasonal water chemistry with WHO and Ethiopian standards

Descriptive Statistics of Hydrochemical Parameters					WHO 2011	Ethiopian limit (mg/l)
Ions	**Min**	**Max**	**Average**	**STD**		
PH	6.4	8.4	7.1	0.42	6.5-8.5	6.5-8.5
EC	366	1554	740	205.47	1000	-
TDS	230	1060	470.51	144.44	500	1776
Ca	3.20	174.80	53.44	25.78	75	200
Mg	0.48	33.60	16.35	8.09	50	150
Na	26.50	276.00	86.69	46.50	200	358
K	3.60	36.00	15.82	8.29	-	-
Cl	3.64	50.10	18.51	7.72	250	533
HCo_3	224.48	1000.40	434.73	136.51	200	-
So_4	0.00	114.14	24.04	22.57	200	483
No_3	0.29	85.50	7.59	11.97	50	-
F	0.07	3.69	0.88	0.66	1.5	3

Note: Max - Maximum; Min – Minimum; (All Values in mgl^{-1} *except EC in µS/cm and pH)*

4.4.1 Physiochemical characteristics of ground water

pH is a term used universally to express the intensity of the acid or alkaline condition of a solution. Results of chemical analysis of groundwater were compared with the domestic water standards of WHO (2011) to arrive at conclusions. According to WHO (2011) standard the PH of the water should ranges between 6.5-8.5 (Table 6). In the study area pH ranges from 6.4 to 8.4 with an average 7.1 respectively. The lowest PH is recognized in NW and the highest PH is observed in South. This shows that the groundwater of the study area was mainly of slightly acidic to alkaline in nature. Study area is dominated by the alkaline water (Fig . 22a) due to the presence of alkalies in carbonate ions present Davis (1966). If $pH < 8.2$, it is a measure of bicarbonate ions. From the Fig. 22 (a) most of the samples PH are in the range of 6.5- 8.5 which fulfill the WHO requirement.

The optimum values are much higher than the maximum permissible range of the standard EC value set by World Health Organization (WHO, 2011) for drinking water, which is 1,000 µs/cm. The Electrical Conductivity (EC) of rain water is 0.05 µs/cm (Hem 1991). EC of groundwater was found to be in the ranges from 366 to 1554 µS/cm, respectively (Table 6 & 7; Fig. 22b). According to Wilcox (1955) most of the groundwater samples are found to be within the Good for drinking and Katila is permissible limit. The occurrence of high EC values in the study area might be due to addition of some salts through the prevailing agricultural activities.

Table 7. Classification of groundwater based on different parameters for different purposes

Parameters	Range	Classification
pH	< 6.5	Acidic non-desirable
	6.5-8.5	Desirable
	> 8.5	Alkaline non- desirable
EC (μs/cm) Wilcox (1955)	250-750	Good
	750-2250	Permissible
	2250-5000	Doubtful
	>5000	Unsuitable
TDS (mg/l) Wilcox (1955)	< 500	Desirable
	500-2000	Permissible
	> 2000	Non-Permissible
TDS (mg/l) (Davis and De Wiest 1966)	< 500	Desirable for drinking
	500–1,000	Permissible for drinking
	< 3,000	Useful for irrigation
	>3,000	Unfit for drinking and irrigation

TDS values are considered as important values in determining the usage of water. The groundwater with high TDS values is not suitable for both irrigation and drinking purposes. The concentration of total dissolved solids (TDS) ranges from 230 and 1060 mg/l (Fig. 22c). Based on TDS classification (Wilcox 1955), almost majority of the samples are classified under permissible for drinking and useful for irrigation category. According to the Davis and De Wiest (1966) (Table.7) classification of groundwater based on TDS, 72 % of the total groundwater samples are desirable for drinking (TDS\500 mg/l), 25 % permissible for drinking (500–1,000 mg/l) and 3 % is suitable for irrigation purposes. High concentration of TDS in the groundwater sample is due to leaching of salts from soil and also domestic sewage may percolate into the groundwater, which may lead to increase in TDS values. Higher content of TDS can be attributed due to the contribution of salts from the thick mantle of soil and the weathered media of the rock and further due to longer residence time of groundwater in contact with the aquifer.

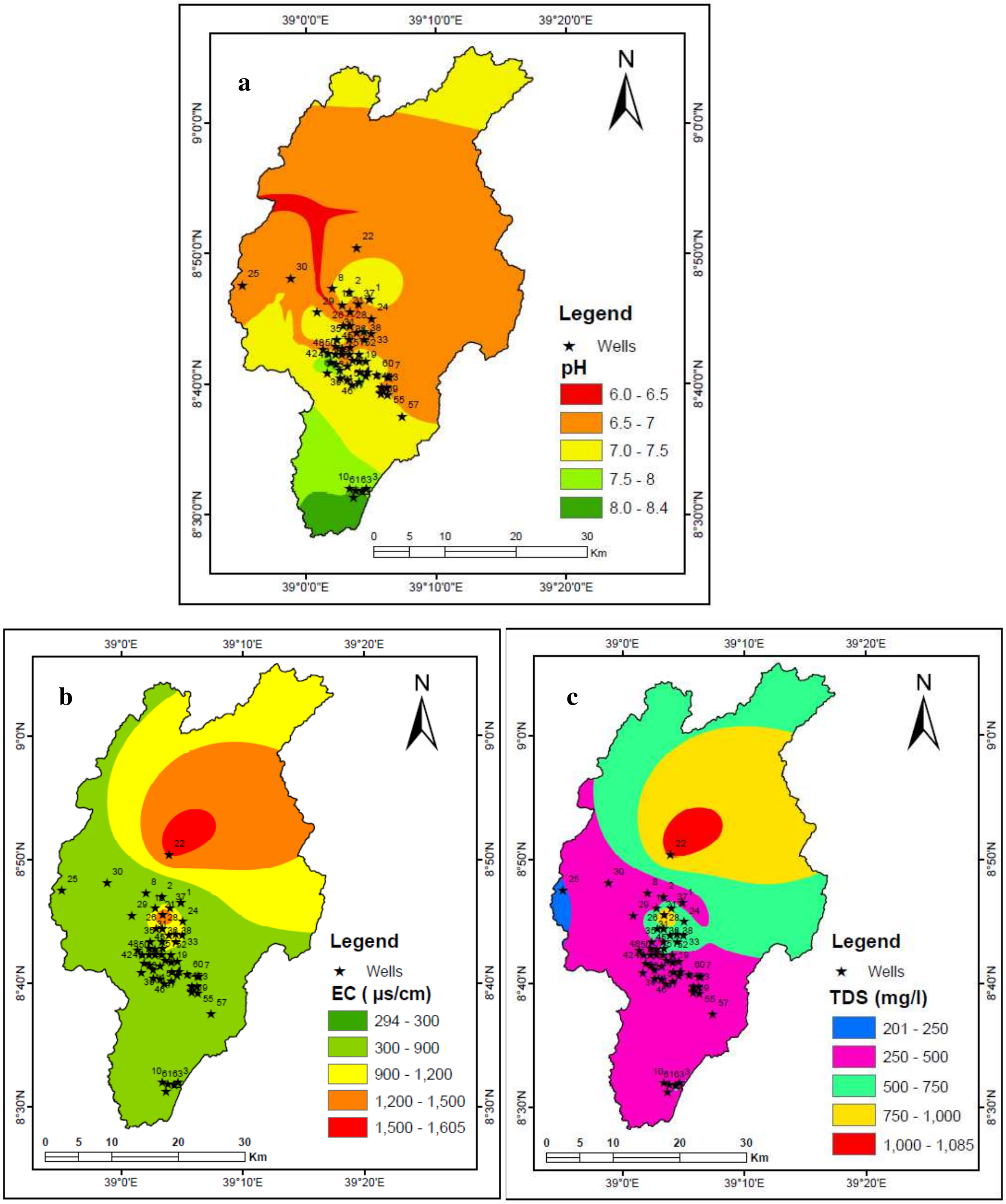


Fig. 22 a) Distribution of pH level in the study area, b) distribution of electrical conductivity (EC) in the study area, c) distribution of total dissolved solids (TDS) in the study area

4.4.2 Chemical characteristics of ground water
4.4.2.1 Major Cations

Calcium (Ca)

Calcium is an element that is found naturally and in abundance in the earth crust, it is present in groundwater due to its easy solubility and abundance in most rock types (Ezeh, et al., 2016). In the study area Calcium concentration is ranging from 3.2 mg/L to 174.8 mg/L with an average of 53.4.9 mg/L. As per WHO (2011), the allowable limit for Ca is 75 mg/L. (Table. 6) So most the groundwater samples are found to be within the Permissible limit of drinking and good groundwater quality zones except Katila (Fig.23a) due to irrigated drained water. Acidic rain water can increase the leaching of calcium from soils.

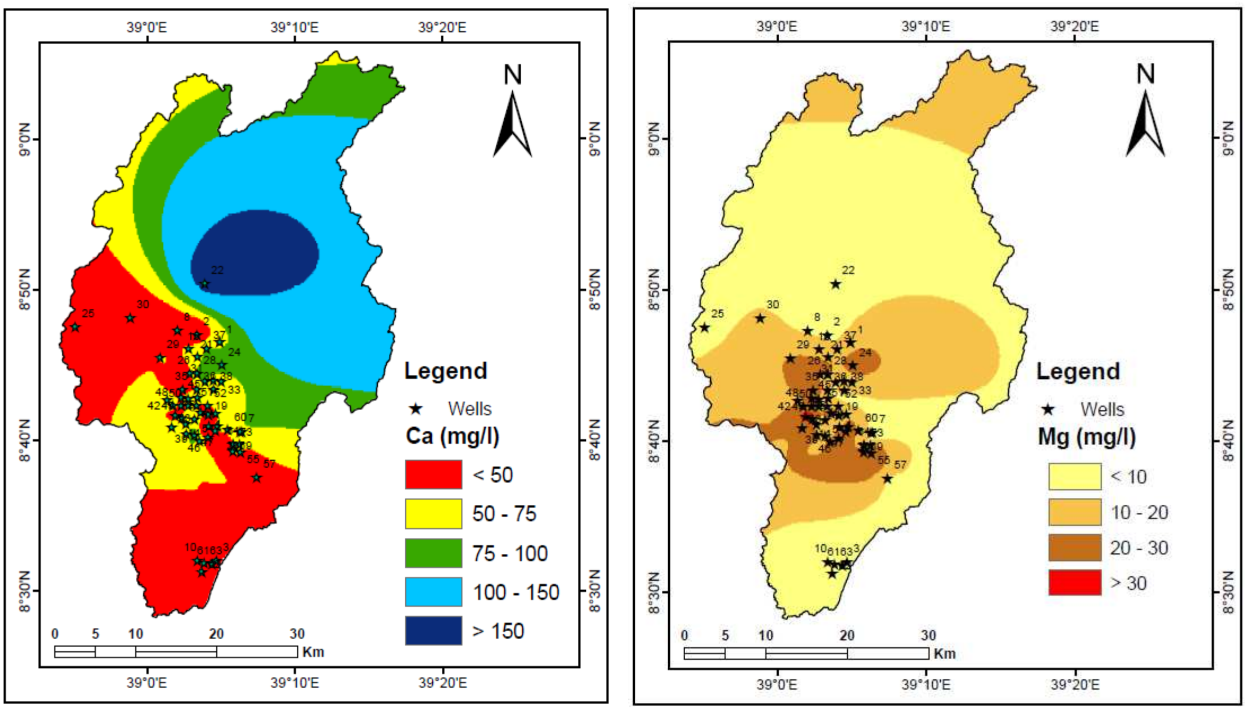


Fig. 23 Spatial distributions of Ca (a) and Mg in the Study area (b)

a **b**

Magnesium (Mg)

Magnesium is an alkaline-earth metal and has only one oxidation state of significance in water chemistry. It is a common element in occurrence and is essential for plant and animal nutrition. The value of magnesium ranges from 0.48 to 33.6 mg/L with an average of 16.35 mg/L. (Fig.

23b and Table 6). The concentrations of magnesium were below WHO, (2011) maximum permissible limit. Magnesium concentration is classified with less than 30 mg /L as a safer zone for drinking. Magnesium concentration in groundwater was found to occur above 30 mg/L in Adaa (Fig. 23b). Source of Mg is generally from SiO_4 and feldspathic rocks (Hem, 1970). Ezeh, et al., (2016) stated that magnesium can penetrate into the environment from discharge and emissions from industries that use or manufacture magnesium.

Sodium (Na)

Sodium is generally highly soluble in water and is leached from the terrestrial environment to groundwater (WHO, 1996). The concentration of Sodium in ground water samples of the study area varies from 26.50 to 276 mg/L, with an average of 86.69 mg/L. Sodium concentration is higher in Katila to indicate its contribution due to contamination by urban and agriculture. Human activities can also have a significant influence on the concentrations of sodium in ground water (Hem, 1985). The possible source of sodium might be from deep percolating water from the top soil layers due to atmospheric precipitation that has been subjected to such concentration effects (Herman Bower, 1978). Spatially Katila in an around of the study area has Poor groundwater quality zone (Fig. 24a).

Potassium (K)

Potassium is essential for both human and plants. WHO, (2011) stated that very high concentration of potassium can be dangerous to human to digestive and human nervous. Potassium in groundwater is generally lesser due to its lesser mobility (Herman Bouwer, 1978). It may be released due to weathering of Mica and Orthoclase Feldspars. Potassium in groundwater samples of the study area ranges from 3.6 to 36 mg/L with an average of 15.8 mg/L. It has been categorized based on WHO'S standards of < 50 mg/L as good zone suitable for drinking, 50-100 mg/ L as moderate zone suitable for drinking and 100 mg/ L is the standard fixed for domestic consumption. Above 200 mg / L zones were classified as a poor groundwater quality zones. The concentrations of potassium were below WHO, (2011) maximum permissible limit. So all the groundwater samples are found to be within the Permissible limit of drinking (Fig. 24b).

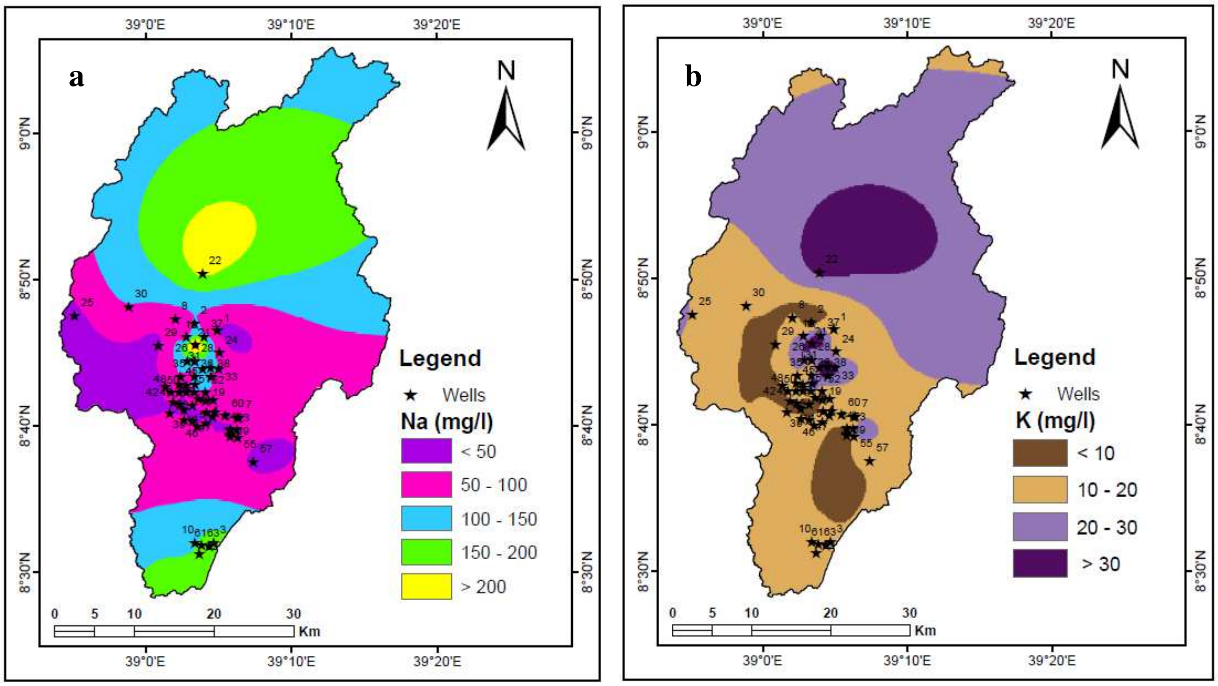


Fig. 24 Spatial distribution of Na (a) and K in the study area (b)

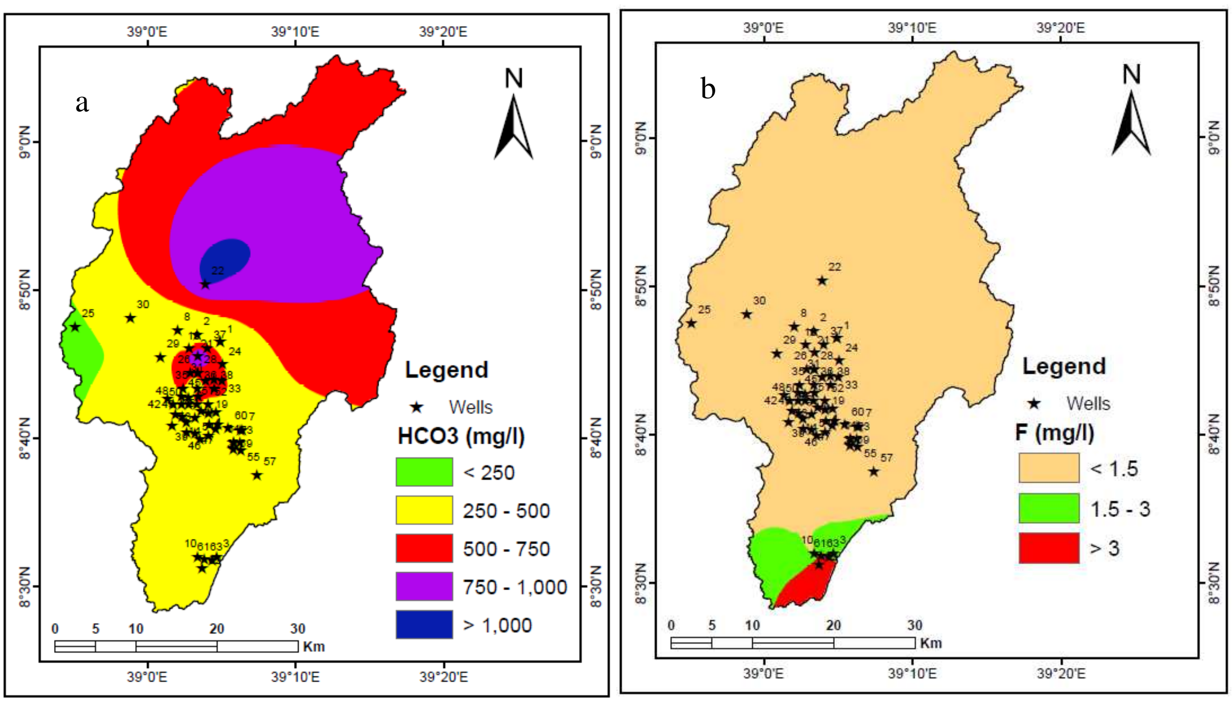


Fig.25 Spatial distribution of HCO_3 (a) and F in the study area (b)

4.4.2.2 Major Anions

Bicarbonate (HCO_3)

Bicarbonate represents the major sum of alkalinity in water. In the study area bicarbonate ranges from 224.4 to 1000.4 mg/L with an average of 434.7 mg/L. The concentration of HCO_3 is higher to indicate the contribution from silicate and carbonate weathering process (Mondal et al, 2004). HCO_3 concentration is classified based on WHO'S standard with < 100 ppm was categorized under good zone which is suitable only for industrial activity (Fig. 25a). Poor zones occur in 100% of the study area (Fig. 25a) by considering the concentration greater than 250 mg/L.

Chloride (Cl)

Chlorides in water are more of a taste than a health concern, although high concentrations may be harmful to people with heart or kidney problems (Weiner, 2000). Chloride concentrations ranges from 3.64 to 50.10 mg/l have been found in shallow groundwater, and its possible source is tanneries where sodium chloride is used as a raw material. The concentrations of calcium were below WHO, (2011) maximum permissible limit.

Sulphate (SO_4)

Sulphate minerals are widely distributed in nature, and the sulphate anion (SO_4) is a common constituent of unpolluted water. Sulphate may be leached from most sedimentary rocks, with appreciable contributions from such sulphate deposits as gypsum (Obasi, et al., 2015). Sulphate may also occur as leachates from their ores and other minerals. Sulphate is commonly less than 300mg/l in natural waters except in well influenced by acid mines (Todd, 1980). The highest desirable limit of Sulphate in groundwater is 200 mg/L and the maximum permissible limit is 400 mg/L(WHO, 2008). Concentration of SO_4 in the study area ranges from 0 mg/L to 114.1 mg/L. In the study area most of the samples are found to be within the prescribed limit for drinking purpose. (Table.6). The low value signifies that the study is free solid waste dump which could have it way into groundwater through leaching (Moses, et al., 2016). The result were below (WHO, 2011) permissible limit.

Nitrate (NO_3)

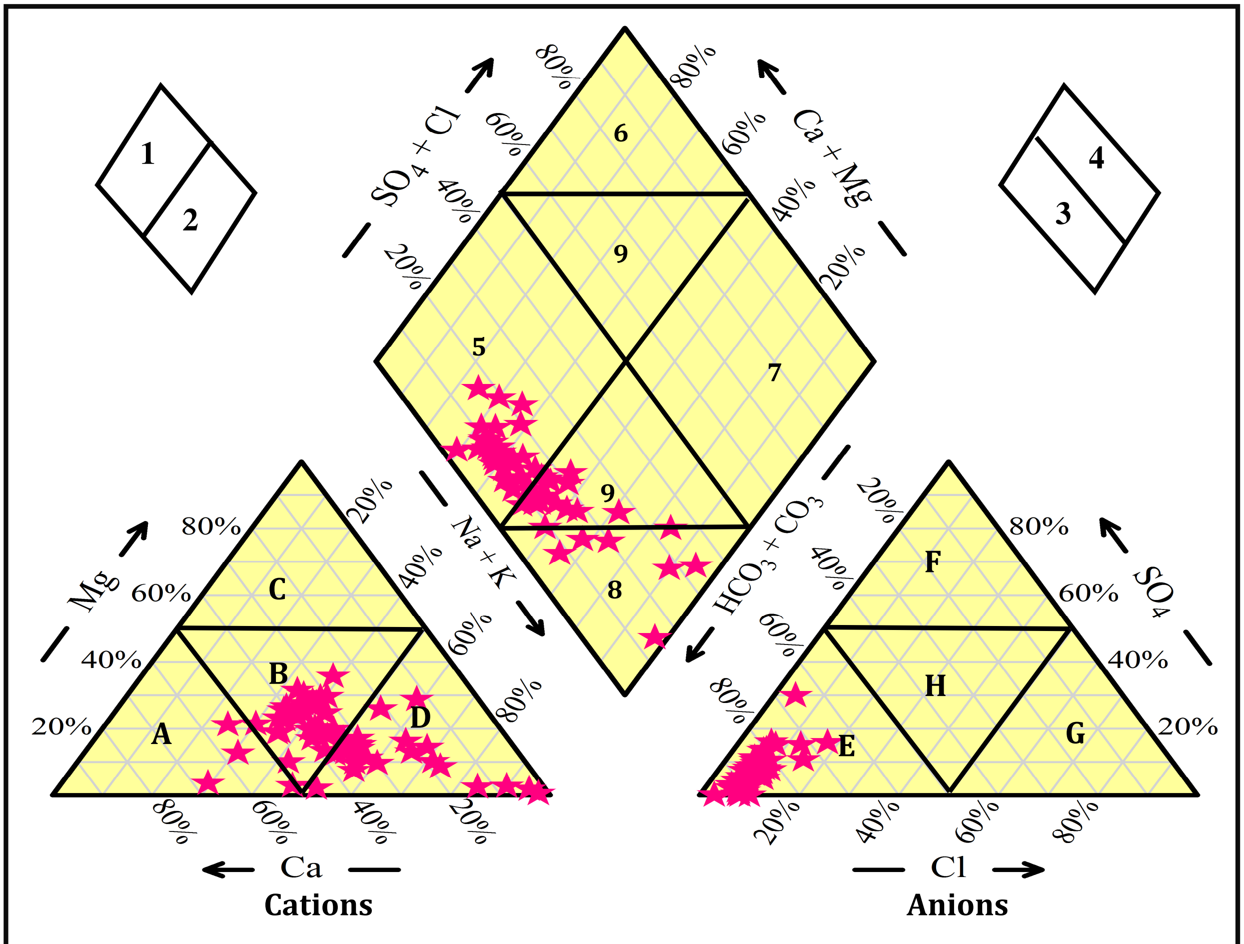
Hydrogeochemical data reveals that nitrite is the major artificial pollutant present in quantities that exceed the maximum contamination level (0.1 mg/l) at several wells. The value of nitrate ranges from 0.29 to 85.5 mg/L with mean value 7.59 mg/L (Table .6). This was far below the stipulated value of 50mg/L by WHO (2011) standard for drinking water, hence, the water is recommended for irrigation purposes. The value of nitrate were above (WHO, 2011) permissible limit at Hidi. One of the major source of nitrate in groundwater as a result of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures),from wastewater treatment and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks (WHO, 1996). Nitrate–N and nitrite–N are hazardous to human health (USEPA 2002). The nitrogen compounds cause the methemoglobinemia, hypertension, diabetes, spontaneous abortions, respiratory tract infections and changes in immune system. Methemoglobinemia (blue baby syndrome) is produced when nitrite oxidizes the ferrous iron in hemoglobin to its ferric form (Fewtrell 2004).

Fluoride (F)

The safe limit of fluoride from 0.5 to 1.0 mg/ L is essential for normal growth of bones, in potable water. Less than 0.6 mg/L of fluoride causes dental caries, while more than 1.0 of fluoride results in fluorosis. Fluoride concentration of ground water samples in the study area is ranging from 0.07 mg/L to 3.69 mg/L with an average of 0.83 mg/L. The most of the study area is showing under the permissible limits of WHO (2011), drinking water standards of 1.5 mg/L (Table. 6 and Fig.25b) in the study area, except Mudasenkele. In volcanic or igneous rocks such as the rift valley in Africa ground water contain up to 20mg/l of fluoride naturally.

4.5 Hydrogeochemical facies

As water flows through an aquifer, it assumes a characteristic chemical composition as a result of interaction with the lithologic framework. The term “hydrochemical facies” is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition. The facies are function of the lithology, solution kinetics, and flow patterns of the aquifer. Hydrochemical facies can be classified on the basis of dominant ions using the Piper’s trilinear diagram.



LEGEND

A: Calcium type;
B: No dominant (Mixed type);
C: Magnesium type;
D: Sodium and potassium type;
E: Bicarbonate type;
F: Sulphate type;
G: Chloride type;
H: No dominant (Mixed type)

1: Alkaline earths exceed alkalies;
2: Alkalies exceed alkaline earths;
3: Weak acids exceed strong acids;
4: Strong acids exceed weak acids;
5: Calcium (Magnesium) bicarbonate type;
6: Calcium chloride type;
7: Sodium chloride type;
8: Sodium bicarbonate type;
9: Mixed type

Fig.26 Hill piper plot for the groundwater

The concentrations of major ionic constituents and water types of groundwater samples were plotted in the Piper trilinear diagram (Piper 1954, 1994) using AqQA software. The classification for cation and anion facies, in terms of major-ion percentages and water types, is according to the domain in which they occur in the diagram segments (Back and Hanshaw 1965; Back 1966). The diamond-shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions. The points for both the cations and anions are plotted in the appropriate triangle diagrams. The positions of the points are projected parallel to the magnesium and sulphate axes, respectively, until they intersect in the center field.

This diagram is an effective tool in suggesting analytical data with respect to sources of the dissolved constituents in groundwater modifications based on the character of water as it pass through an area and related geochemical problems. It consists of two lower triangular fields and a central diamond shaped field. All the three fields have incorporation of major ions only. The Triangular fields are plotted separately with epm values of cations (Ca, Mg) alkaline earth, (Na+ K) alkali, (HCO_3) weak acid and (SO_4 and Cl) strong acid. Water facies can be identified by projection of plots in the central diamond shaped field (Fig.26).

Applications of the diagram pointed out by Piper include testing groups of water analyses to determine whether particular water may be a simple mixture of others for which analyses are available or whether it is affected by solution or precipitation of a single salt. It can be shown easily that the analysis of any mixture of waters. The composition of water in the study area reflects of chemical processes occurring between the minerals and flowing waters. The Diagnostic chemical aspects of the well water of the study area can be described in terms of hydrogeochemical facies (Back, 1966). Hydrogeochemical facies interpretation is a useful tool for determining the flow pattern, origin and evaluation of chemical history of groundwater.

The cations plotted in the diagram are showing the dominance of Mixed; Na or K type in maximum number of samples. In anion plot it is clearly seen that $HCO_3 + CO_3$ is dominant. The salt combinations of aquifers (90%) are dominated by Ca-Mg-HCO_3; Mixed Ca–Na–HCO_3 type facies type and few samples represented Na-K-HCO_3 (Fig. 26). Groundwater from the highlands (Ayenew 2008), typically show Ca (Mg)–HCO_3 hydrochemical facies similar to that of rivers and cold springs where the sum of Ca and Mg exceeds Na and K. On the contrary hot springs and most groundwater in the rift display a Na–HCO_3 fingerprint, with Na and HCO_3 proportions constituting more than 10% of all the ionic species in the solution. Often the high fluoride concentration is associated with Na–HCO_3 type of waters. From the plot, alkaline earths (Ca_2 and Mg_2) significantly exceed the alkalis (Na and K) and weak acids (HCO_3 and CO_3) exceed the strong acids (Cl and SO_4).

4.5 Suitability of groundwater for irrigation purposes

To ascertain the suitability of groundwater for drinking, irrigation, and public health purposes, hydrochemical parameters of the study area were compared (Table. 6) with the guideline limits recommended by the World Health Organization (WHO 2011) and the Ethiopian limit standards. Chemically, the water should be soft with less dissolved solids and free from poisonous constituents. Water quality, soil types and cropping practices play an important role for a suitable irrigation practice because excessive amounts of dissolved ions in irrigation water affect plants and agricultural soil physically and chemically and thereby to reduce the productivity. The physical effects of these ions are to lower the osmotic pressure in the plant structural cells, thus preventing water from reaching the branches and leaves, while the chemical effects disrupt plant metabolism.

Total hardness (TH)

The temporary and permanent hardness of water are due to the action of soap in water due to the precipitation of Ca and Mg ions. Temporary hardness is mainly due to calcium carbonate in water that gets removed during heating. Permanent hardness is due to Ca and Mg ions that get removed by ion-exchange processes. Hardness of water limits its use for industrial purposes; causing scaling of pots, boilers and irrigation pipes. In some studies, a significant correlation was observed between hardness and heart diseases, in contrast a number of epidemiological studies suggest that water hardness protects against diseases (WHO, 1996). The total hardness (TH) expressed in mg/L is determined by Todd (1980) as.

$$\mathbf{TH\ (CaCO_3)mg/l = (2.497)\ Ca + (4.115)\ Mg}$$

The average TH was found to be 200.73 mg/l with a variation ranging from 9.97 to 456.93 mg/l. In general, the groundwater in the study area was soft to very hard (Table. 8) and within desirable range and can be utilized for domestic use. The World Health Organization (2008) suggested an upper limit of 500 mg/L. All the groundwater samples TH is within the tolerable limit. The spatial distribution of hardness in most of the study area falls in soft to hard zone (Fig.27a; Table .8).

Table 8 Classification of groundwater quality based on suitability of water for irrigation purposes

Parameters	Range	Classification
TH	< 75	Soft
	75 - 150	Moderately Hard
	150 - 300	Hard
	> 300	Very Hard
SAR	< 20	Excellent
	20 – 40	Good
	40 – 60	Permissible
	60 – 80	Doubtful
	> 80	Bad
Na%	< 20	Excellent
	20 – 40	Good
	40 – 60	Permissible
	60 – 80	Doubtful
	> 80	Bad
RSC	< 1.25	Good
	1.25 - 2.5	Doubtful
	> 2.5	Unsuitable

Sodium Adsorption Ratio (SAR)

Sodium absorption ratio SAR as considered a better measure of sodium (alkali) hazard in irrigation as it is directly related to the adsorption of sodium by soil and inhibits the supply of water needed for the crops by reducing soil permeability. SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali. The SAR measures the relative proportion of sodium ions in a water sample to those of calcium and magnesium (Kalra and Maynard 1991) and is calculated using the equation:

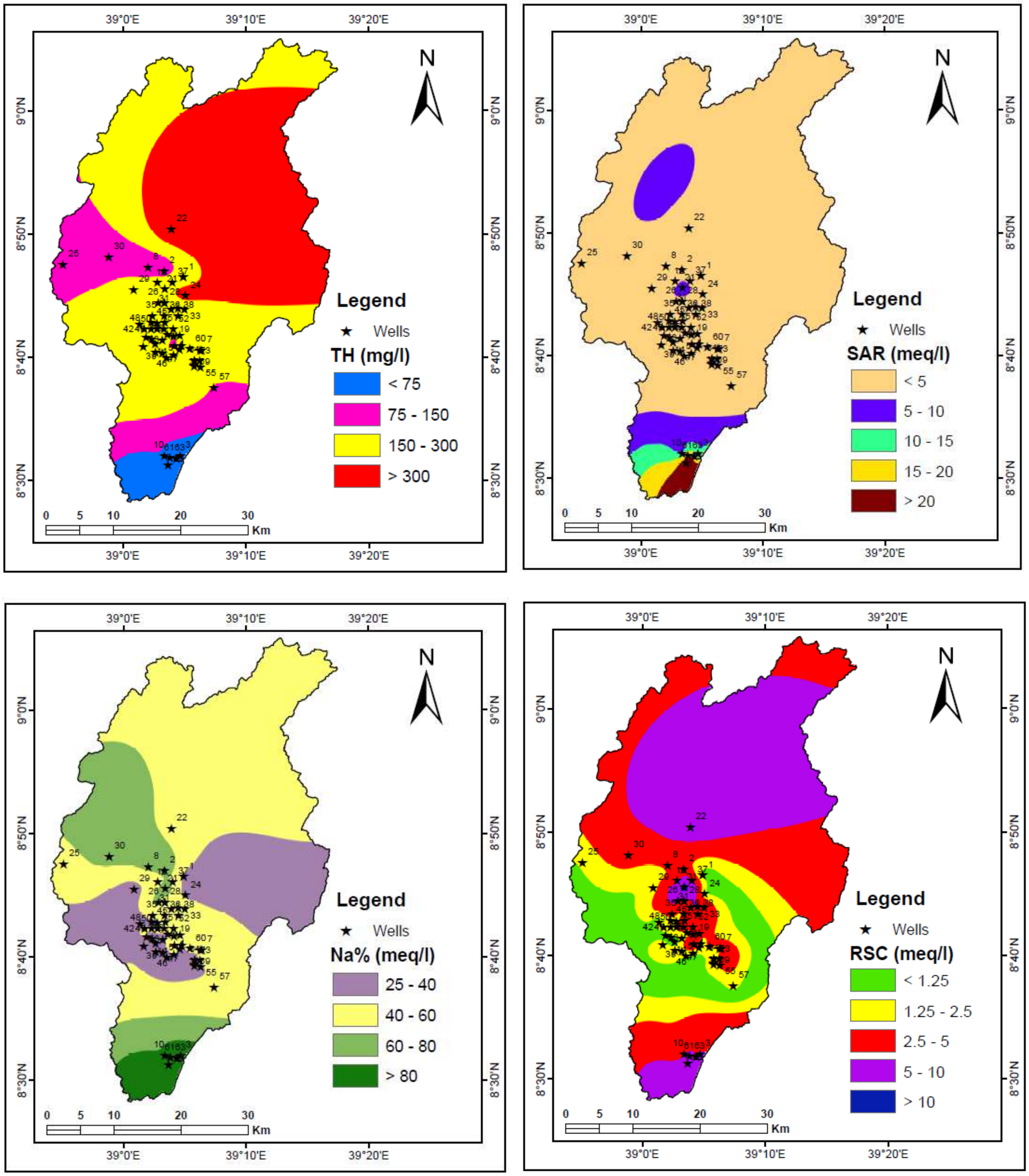


Fig. 27 Spatial distribution of TH (a), SAR (b), Na % (c), RSC (d) in the study area

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Where all cationic concentrations are expressed in epm or meq/l. It is evident from the classification of groundwater samples based on SAR (Todd 1959) that most of the samples belong to S1 category (SAR <10), considered excellent for irrigation (Table.8 and Fig.27b) except Mudasenkele. The calculated value of SAR in this area ranges from 0.92 to 22.61 and has been classified as suitable for irrigation. Based on the Richards (Richards, 1954) classification, all the groundwater samples' have excellent and good (Table .8) water class indicates that the samples are suitable for irrigation purpose.

Sodium Percentage (Na %)

The suitability of the groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg and Ca ions, thus reducing soil permeability and eventually results in soil with poor internal drainage. Thus, air and water circulation is restricted during wet conditions and such soils become usually hard when dry (Saleh et al. 1999). This condition can be analyzed by estimating sodium percentage using the equation:

$$Na\,\% = \frac{Na + K}{Ca + Mg + Na + K} X\,100 \;\; meq/l$$

It is widely agreed that the high percentage of sodium in irrigation water degrades the soil conditions. In the study area, Na% for groundwater in the range of 24.66 -97.41 respectively. The Na% indicates that around 90 % of samples fall in the field of permissible limit. It was revealed from the analysis that the groundwater of doubtful and bad quality (Mudasenkele and Katila) was found less than 10 % of the area (Fig.27c). Irrigation water with high Na% may cause sodium accumulation and calcium deficiency in the soil leading to a breakdown of its physical properties. Therefore, good drainage, high leaching and use of organic matter are required for its management in the study area tolerate the soil to increase the crustal conductive property of the soil.

Residual sodium carbonate (RSC)

The excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the suitability of groundwater for irrigation. If the waters have high concentrations of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. An excess quantity of sodium bicarbonate and carbonate is considered to be detrimental to the physical properties of soils as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. Hence, the relative proportion of sodium in the water is increased in the form of sodium carbonate, denoted as residual sodium carbonate (RSC) (Eaton 1950; Ragunath 1987) can be calculated as:

$$\mathbf{RSC = \{(HCO_3 + CO_3) - (Ca + Mg)\}}$$

where all ionic concentrations are expressed in epm or meq/l.

According to the US Department of Agriculture, water having more than 2.50 epm of RSC is unsuitable for irrigation purposes. Based on RSC values, most of the samples were considered doubtful and Unsuitable (Table 8; Fig.27c) for irrigation purpose. In Spatial distribution of RSC indicate 40 % of the samples falls in good quality and the remaining 60 % of samples fall in the category of Doubtful to unsuitable quality (Fig.27c) especially in most of the study area, due to the occurrence of carbonate residue in the soil.

5. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

Groundwater modeling approach was used to investigate groundwater flow system and water budget in Modjo river catchment. First, a steady model was constructed and calibrated, then scenarios of increased pumping rate and altered recharge were done to predict groundwater change under future imposed stress. Results of groundwater flow model led to a better understanding of the Modjo river basin groundwater budget and groundwater flow system under different conditions. Simulation model shows that main inflow comes from lakes, Precipitation and River whereas outflow includes subsurface flow to downstream area. Simulations made under different pumping rate indicate that an increase in pumping rate results in, increasing of inflow form lakes area and decreasing of the downstream subsurface outflow and groundwater flow to lakes and rivers. The Modjo River and lakes are polluted by the nearby industrial discharge. The scenario analysis shows that, flow from contaminated rivers and lakes into productive aquifers close to main river courses and lakes. Thus, the sources of potential threats need to be properly investigated in selecting the appropriate position of groundwater pumping well for water supply purpose in future. In conclusion, excessive groundwater pumping is expected to decline Bishoftu lakes level, Modjo River discharge and resulted in hydrologic imbalance between groundwater inflow and outflow conditions that may affect ecological system in study area.

The observed pH range of groundwater samples indicate slightly acidic to alkaline in nature due to the presence of alkalies in carbonate ions. EC of groundwater was found to be within the good for drinking and Katila is permissible limit. The occurrence of high EC values in the study area might be due to addition of some salts through the prevailing agricultural activities. The TDS concentration almost majority of the samples will come under permissible for drinking and useful for irrigation category. High concentration of TDS in the groundwater sample is due to leaching of salts from soil and also domestic sewage may percolate into the groundwater, which may lead to increase in TDS values. The concentrations of cations and anions are found to be within the Permissible limit of drinking and good groundwater quality zones except Katila (northern part of study area) and due to irrigated drained water and contamination by urban and agriculture. The groundwater nature is explained by the Piper Trilinear diagram which indicates that most of the groundwater samples fall in in Ca-Mg-HCO_3; Mixed Ca–Na–HCO_3 type and few samples represented Na-K-HCO_3 type. In general, the groundwater in the study area was soft to very hard and within desirable range and can be utilized for domestic use. No SAR problem was observed in the sampling well during the study. It is observed that all the groundwater samples' have excellent to good water class indicates that the samples are suitable for irrigation purpose. The suitable to moderate-suitable irrigation water is mainly found in the western and central parts of the study area. Northern, southern and north eastern is unsuitable quality in the study area, due to the occurrence of carbonate residue in the soil.

5.2 Recommendation

Detailed geophysical survey to characterize aquifer system and more than one layer Transient Groundwater modeling studies should be conducted to predict the effects of different stress conditions on the groundwater resource. Time series groundwater head monitoring should be needed to develop transient ground water flow modeling and to analysis the groundwater fluctuation of the area as well as to conduct further detail groundwater storage change with time.

The study area is highly industrialized and high agricultural practice. Thus, integrated water quality modeling and nitrate leaching modeling is necessary to develop aquifer protection and well field protection development.

The result of Wet Spass model can improve further if more seasonal groundwater depth data and new meteorological stations become available. Effort should be made to analysis mothly groundwater recharge rate of study area to develop transient groundwater modeling dividing into recharge period and dry period. In order to avoid surface runoff effect and to enhance ground use in study area different artificial recharge mechanisms needed by further investigating ground level dropping and storage change.

The optimal abstraction rate results that obtained by GWM-2005 depends on the accuracy of simulation model results. The accuracy of simulation model depends on accuracy of data input. Unmanaged current abstraction rate are different than obtained optimal values. Some aspects of further studies are needed to properly manage groundwater resources in study area. Besides, in GWM-2005, only single objective is supported. Further research needed to be conducted using multiple objective optimization techniques to properly mange groundwater and surface water resources of study area.

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Annex- 1 Current pumping rate and location of pumping wells

No	Well ID	Location		Abstraction in m^3/day
		X	Y	
1	APW-002-10	505166	970960	4320
2	APW-003-10	506138	970846	2073.6
3	APW-004-10	508552	943199	3456
4	APW-005-10	507556	958248	998.784
5	APW-006-10	504300	960685	4320
6	APW-007-10	503475	960957	7920.288
7	APW-008-10	511723	958922	5011.2
8	APW-009-10	503717	971356	4665.6
9	APW-010-10	509308	957888	5616
10	APW-011-10	506187	943199	3352.32
11	APW-012-10	511430	957367	5369.76
12	APW-014-10	508991	969895	2769.984
13	APW-017-10	505863	960482	3888
14	APW-019-10	505116	969081	5011.2
15	APW-020-10	508432	959037	4326.912
16	APW-021-10	506615	961264	5788.8
17	APW-022-10	508471	961147	7776
18	APW-023-10	507557	961072	8640
19	APW-028-10	506220	968104	4492.8
20	APW-039-10	507157	977107	3888
21	APW-041-10	509241	967123	4093.632
22	APW-045-10	491050	971817	3888
23	APW-046-10	505273	966105	5356.8
24	APW-047-10	506187	966105	5011.2
25	APW-049-10	508137	966205	4579.2
26	APW-050-10	509163	966079	4579.2
27	APW-053-10	501573	967638	5356.8
28	APW-054-10	497866	972874	2592
29	APW-056-10	505332	965079	4492.8
30	APW-058-10	507153	965139	5529.6
31	APW-059-10	508185	965261	4579.2
32	APW-060-10	509189	965087	5572.8
33	APW-063-10	502085	964206	7575.552
34	APW-064-10	504379	964125	5555.52
35	APW-066-10	506154	964148	3352.32
36	APW-067-10	507127	964121	5443.2
37	APW-068-10	508223	964173	5788.8
38	APW-069-10	504784	959857	7418.304
39	APW-071-10	508697	959616	5529.6
40	APW-072-10	507630	959592	4795.2
41	APW-073-10	502454	962792	7097.76
42	APW-074-10	504203	963155	6337.44
43	APW-075-10	505095	962950	5927.04
44	APW-076-10	506213	963103	8899.2

45	APW-079-10	504753	958477	5356.8
46	APW-080-10	505855	958505	6912
47	APW-082-10	503185	962173	6912
48	APW-083-10	504203	962102	6912
49	APW-084-10	505077	962102	3888
50	APW-085-10	506109	962140	7007.04
51	APW-086-10	507472	962097	7603.2
52	APW-088-10	503018	959480	2203.2
53	APW-089-10	506490	957774	1681.344
54	APW-090-10	511524	956435	1933.632
55	APW-092-10	513546	953365	4147.2
56	APW-094-10	510602	956528	5011.2
57	APW-095-10	509971	959175	5011.2
58	APW-096-10	506989	960627	4924.8
59	APW-097-10	507034	942864	7430.4
60	APW-098-10	506734	941867	9417.6
61	APW-099-10	507999	942824	3888
62	APW-100-10	510664	957391	5702.4
63	Sululta WSW	507556	958248	1555.2
64	APW-040-10	508223	967097	4579.2
65	APW-096-10	506989	960627	4924.8
66	AdBh0052	494320	965101	1209.6
67	AdBh0055	493179	968613	172.8
68	AdBh0060	492987	967055	440.64
69	AdBh0072	507491	952694	483.84
70	AdBh0073	508079	952013	388.8
71	AdBh0075	508995	951614	432
72	AdBh0078	509385	950325	345.6
73	AdBh0079	509020	950736	345.6
74	AdBh0080	508684	951058	345.6
75	AdBh0081	507950	951364	345.6
76	AdBh0087	512957	947774	734.4
77	AdBh0090	511927	948292	388.8
78	AdBh0094	513423	948940	535.68
79	AdBh0095	513773	949998	406.08
80	AdBh0295B	492803	969204	388.8
81	AdBh0352	512282	951356	717.12
82	AdBh0991	490000	968000	259.2
83	AdBh1024	495765	966397	388.8
84	D/Z-Air force	500909	964676	483.84
85	D/Z-Air force	499228	964796	691.2
86	D/Z-Air force No.2	499500	964500	388.8
87	D/Z-Almaz Ayele poultry Farm	499320	970175	518.4
88	D/Z-Blue Nile Plastics	495765	966397	388.8
89	D/Z-Dugda PLC	502364	970907	2108.16
90	D/Z-Girma Gebre Kidan	495561	968574	209.952
91	D/Z-Green Star	494598	967157	578.88
92	D/Z-Hora Tannery	498633	970028	864
93	D/Z-Hospital	492987	967055	440.64
94	D/Z-New well	492803	969204	388.8
95	D/Z-Oxford	493179	968613	172.8
96	D/Z-Sahilu	494829	967088	291.168

97	D/Z-Veternary College BH2	500078	968505	1330.56
98	Dukem	490336	970789	1123.2
99	Dukem-Industrial Park	490000	968000	259.2
100	Gafat#1	507491	952694	483.84
101	Gafat#10	507950	951364	345.6
102	Gafat#2	508079	952013	388.8
103	Gafat#4	508995	951614	432
104	Gafat#7	509385	950325	345.6
105	Gafat#8	509020	950736	345.6
106	Gafat#9	508684	951058	345.6
107	Modjo Bekele Mola	513423	948940	535.68
108	Modjo Ethio Japan Nylon	513773	949998	406.08
109	Modjo lume#1(WS)	512282	951356	717.12
110	Modjo Lume#2(New TWS)	512355	951516	717.12
111	Modjo Lume#3	512957	947774	734.4
112	Modjo Ude	506765	957179	1442.88
113	Modjo#1	512011	949196	388.8
114	Modjo#2	511976	948671	1069
115	Modjo#3	512408	948682	432.59
116	Modjo#4	511927	948292	388.8
117	RMI Steel factory	494320	965101	1209.6
118	Shimbira Meda	500766	973335	613.44
119	Shimbira Meda	500494	974376	1442.88
120	Shimbra Meda	501422	973727	1076.544
121	MJ-BH1	512300	953358	3888
122	MJ-BH2	511747	954502	3888
123	MJ-BH3	512200	953889	3786.912
Total Abstraction				**374,029.88**

Annex- 2 Hydrochemical data

Well No.	Ca	Mg	Na	K	HCO_3	SO_4	Cl	TDS	EC	PH	NO_3	F	PO_4
1.	24.76	8.8	106	5.1	308.4	31.89	34.58	392	651	7.38	0.6	0.6	0.2
2.	13.46	2.7	164	11.1	361.6	57.22	35.49	468	739	7.63	0.4	2.1	0.4
3.	71.4	2.5	65	19	424.6	3.24	12.3	452	693	6.63	2.66	0.5	0.4
4.	24.56	8.7	76	12.3	283.0	0.19	11.83	320	487	7	0.32	0.8	0.3
5.	21.16	2.3	140	11	327.0	114.14	12.3	480	685	7.85	9.87	1.3	0.4
6.	76.6	20.3	45	15.5	351.6	30.7	19.1	476	700	7.1	85.5	0.8	0.3
7.	53.48	16.87	70	21	422.73	13.3	15.47	428	684	7.01	4.35	0.71	0.22
8.	56.6	24.96	56	11.8	405.04	14.21	12.74	390	662	7.26	11.09	0.71	0.24
9.	49.8	16.8	92	10.6	409.92	11.33	19.88	412	716	7.35	2.47	0.78	0.3
10.	178.8	4.97	208	32.5	1000.40	78.64	28.39	1030	1528	6.78	10.00	0.81	0.63
11.	96.92	23.69	76	17	512.40	52.54	19.99	590	910	6.63	28.81	0.53	0.23
12.	36.76	6.55	40	19.5	224.48	0.34	7.54	240	366	6.73	2.15	0.56	0.23
13.	46.56	20.06	130	29.5	567.91	35.32	35.49	610	994	7.09	3.95	0.8	0.37
14.	49.56	20.06	43	8.8	358.68	5.92	10.41	374	580	7.17	5.52	0.72	0.15
15.	23.2	11.56	97	11.4	342.00	14.25	17.29	360	623	6.95	1.26	0.82	1.5
16.	64.28	13.92	116	35	578.28	40.77	20.93	640	965	7.16	1.05	0.94	0.79
17.	66.88	15.05	97	33	561.2	34.46	17.98	620	946	6.63	2.3	0.91	0.24
18.	69.86	16.32	33	5	329.4	31.21	13.52	380	562	7.72	25.74	0.71	0.19
19.	59	18.7	49	10.7	384.3	11.04	14.56	370	633	6.95	16.19	0.69	0.51
20.	53.8	17.76	67	11.1	402	13.97	20.93	440	638	6.8	24.3	0.6	0.25
21.	60.88	22.34	60	12.5	426.76	6.7	19.11	432	706	7.38	3.89	0.74	0.46
22.	64.36	24.48	52	15	394.06	0	22.71	454	721	7.24	6.2	0.63	0.21
23.	40.8	10.49	44	12.5	292.8	6.57	7.57	306	475	7.05	1.2	0.83	0.79
24.	56.4	22.8	65	3.6	414.8	13.94	16.36	402	704	7.16	4.56	0.72	0.2
25.	52.49	18.7	73	18	424.56	11.14	19.88	460	713	7.1	4.43	0.44	0.53
26.	3.56	0.48	164	13.6	412.36	23.63	23.66	468	786	8.21	0.29	3.69	0.16
27.	46	22.08	61	18.5	390.4	22.3	11.83	390	676	7.1	3.25	0.78	0.23
28.	32.6	16.2	32.6	9.3	293.5	5.6	8.56	285	427	8	4.5	0.66	0.56
29.	53.6	18.9	38.5	4.5	312.4	1.3	7.4	265	449	7.5	3.2	0.8	0.45
30.	54	17.5	43.5	6.7	398.6	2.8	11.3	302	486	7.1	2.5	0.54	0.78