Numerical Groundwater Flow Modeling of the Megech River Catchment, Tana Sub Basin, North Western Ethiopia

Amare Getaneh[1] Sileshi Mamo[2]
1. Department of Geology, Faculty of Natural Science, P.O.Box , Woldia , University, Ethiopia
2. School of Earth Sciences, College of Natural Sciences, Bahirdar, University, Ethiopia

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Abstract
The study area is found in Amhara Regional State, North Gondar Administrative Zone, Gondar town and surrounding Keble of river catchment. It's total area coverage is 785 km^2 with main lithologic units of lacustrine deposit, Middle Basalt (Aiba) and Upper basalt (Alajie).Numerical Groundwater Flow Modeling of the Megech River Catchment, Tana Sub Basin is conducted with the objective of simulating the groundwater flow system of the area and to evaluate the response of the hydrogeological system under different stress, so that the resulting consequence on the system can be estimated.The calibrated statistics of the model area with Mean Error (ME) of 4.8, Absolute Mean Error (AME) of 4.9, and Root Mean Square Error value of 6.8 (RMSE), which is an indicator of good calibration. The sensitive parameter of the model was identified during calibration process. Based on this, hydraulic conductivity and recharge is sensitive in RMSE than River Conductance values. The simulated water budget at steady state condition of Megech river catchment is analyzed. The simulated inflow of the model is 1.0703551E+06 m^3/day which is equal to simulated outflow 1.0703559E+06 m^3/day with difference -7.9617882E-01(-0.79617882) m^3/day. The groundwater system of Megech Catchment total withdrawals of the well is 1.78853E+04m3/day. Scenario analysis was conduct in recharge decreasing and increasing of withdrawals rate.
Keywords: calibration, water budget, simulation, Scenario, steady state, numerical groundwater flow modeling, sensitive, Tana sub basin, Megech River, groundwater withdrawal.
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Introduction

Groundwater is an invisible resource, both the dynamic of the resource base and the services it produces are not well known. It is poorly understood resource, yet one that is critical to a wide variety of social, economic and environmental services.

Groundwater development using a numbers of boreholes, shallow wells and hand dug wells have been increasing from time to time in Megech area to satisfy the demand for water for domestic water supply and industry purposes.

In groundwater flow modeling, steady state and two dimensional modeling will be done to better understand the groundwater flow systems and predict the impact of the increased groundwater withdrawal and climate change on the groundwater and surface waters (Ayenew, Demlie and Wohnlich, 2008).

The use of groundwater models is prevalent in the field of hydrogeology. Groundwater flow models have been applied to investigate a wide variety of hydrogeological conditions. Groundwater flow models are used to calculate the direction of movement of groundwater through aquifers in the subsurface. MODFLOW is widely used to predict groundwater flow or head fluctuations (Yang, Lun and Fang, 2011).

MODFLOW allows for the specification of flows associated with wells, areal groundwater recharge, rivers, and other groundwater sources/sinks. When properly conceptualized and constructed, MODFLOW model can simulate groundwater flow with a fast, good convergences and an accurate solution for most complex groundwater flow systems (Gao***, 2011***).

In groundwater flow modeling, boundary conditions influence the extent of flow domain to be analyzed or simulated. The extent of the flow domain is initially determined by the extent of the area of concern. Moreover, it should be noted that correct conceptualization of boundary is important to select an appropriate mathematical representation in the model so that the effect of the boundary on flow can be correctly understood (Ayehu, 2010).

Once the numerical groundwater flow model has been set-up and calibrated, various groundwater impact scenario schemes for the near future will be simulated, in order to understand the aquifer behavior, i.e. the variations of the groundwater levels in the long term. In particular, in order to possibly restore positive conditions of the river catchment water balance and to improve the condition of its depletion, groundwater management scenarios are numerically investigated (Al-Dhuhli, Schmitz and Lennartz, 2013).

Constructing the groundwater model requires inputting a tremendous amount of field data to modify the model. The difficulties in model calibration are caused by the lack of field information, the measurement errors, and natural environmental variables and all the factors affect the uncertainty of the field data which in turn causes the parameter uncertainty and the inaccuracy of the modeling predictions. Under some circumstances, the net change only depends on a few parameters. If we can establish a mathematical modeling to simulate the net change directly, we can reduce the need for field data and the bad effects of the uncertain factors found in the modeling in order to raise the efficiency and accuracy of the modeling process (Xiu-yuan and Wei-shen, 2009).

Increasing size of population and number of industries in the Megech catchment will lead to higher groundwater stress on it in the future. Even if well field is serving as source water supply for domestic and industrial purposes, there is no groundwater modeling and detail hydro geological study taken place to manage the resource. These intensive groundwater use prior to detail hydro geological system analysis and recharge investigation expose the groundwater resource and surface water of the catchment to risk, and ultimately a problem threatening the water supply become inevitable.

In this catchment the peoples are getting their water supply from the boreholes, shallow wells, hand dug wells and springs. But these wells contribute about a minimum amount of water to the community and do not cover the demand of the population. Since, detail studies are lacking to reveal the groundwater potential of the catchment. Therefore, this research is designed to solve these problems. It will help to better understand the aquifer and groundwater flow systems, and evaluate the impact of proposed groundwater development and management alternative scenarios, and anticipated change in increasing groundwater withdrawal.

Materials and methods

Materials used

To accomplish the objectives mentioned above, the following materials and equipment were used 1:50,000 scale topographical map, Land satellite images, Geological and hydrogeological maps, various computer software (MODFLOW 2000, ArcGIS 10.2, Global Mapper 12, and Surfer 8, Cropwat), Compass, Deep meter and Current meter.

Area description

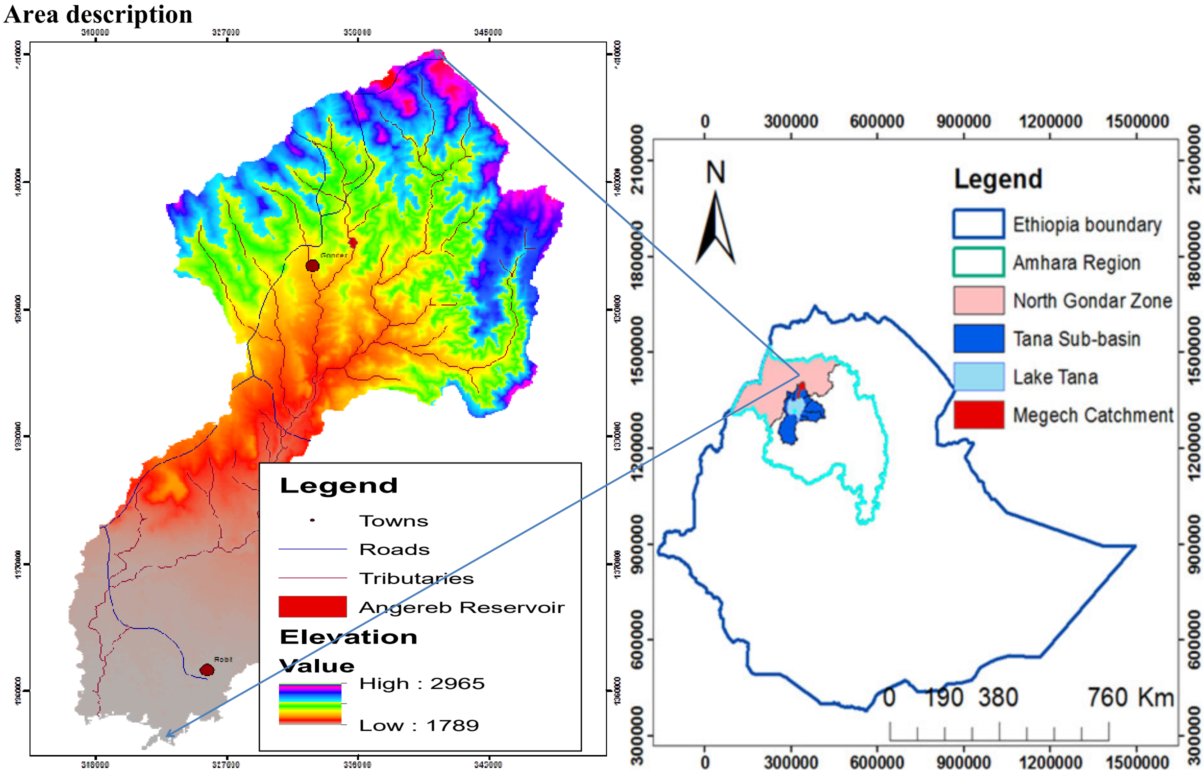


Fig 1-Location of the Study area,Amhara region ,Ethiopia

The study area is found in the North Gondar Zone of the Amhara region. Gondar town, which is found almost at the center of the study area, located about 750km far from Addis Ababa. The area covers a total surface of 785 km^2 (Fig 1). Geographically it lies between UTM coordinates of 12^0 29'07"-$12^0$45'00"N latitudes and $37^0$22'48"-$37^0$37'18"E longitudes. The main roads that connects Addis Ababa city extends from Gondar town and connects to Tikildengay and Rasdashen. Since the area is highly ragged and mountainous, most of the area is not accessible to vehicles especially the north and north east of the catchment.

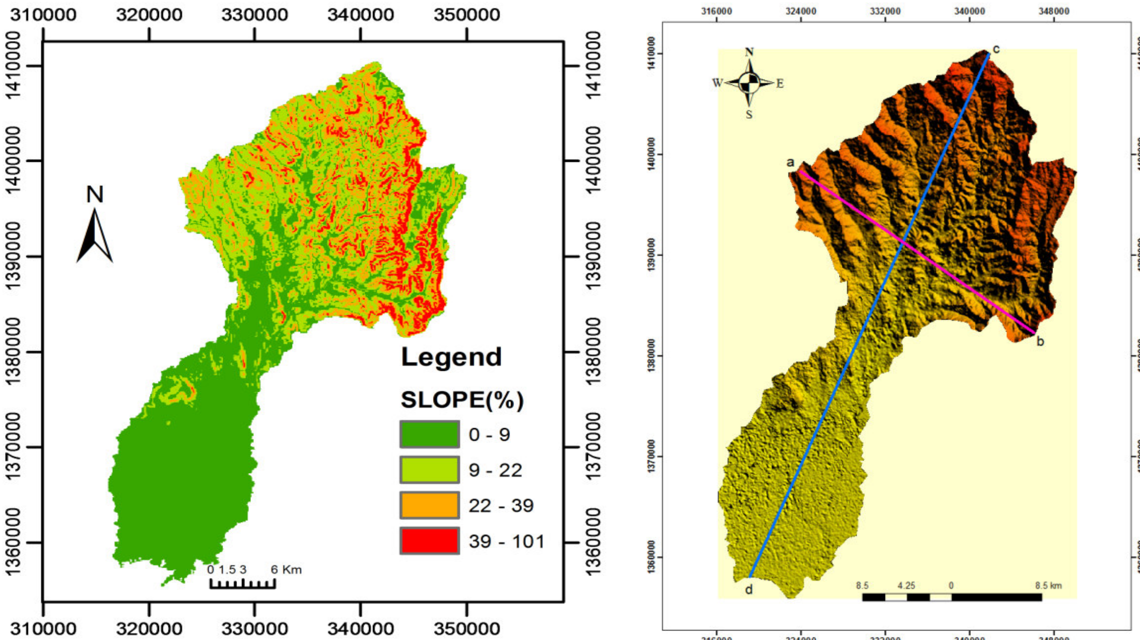


Figure 2.Slope and topography variation map of the study area

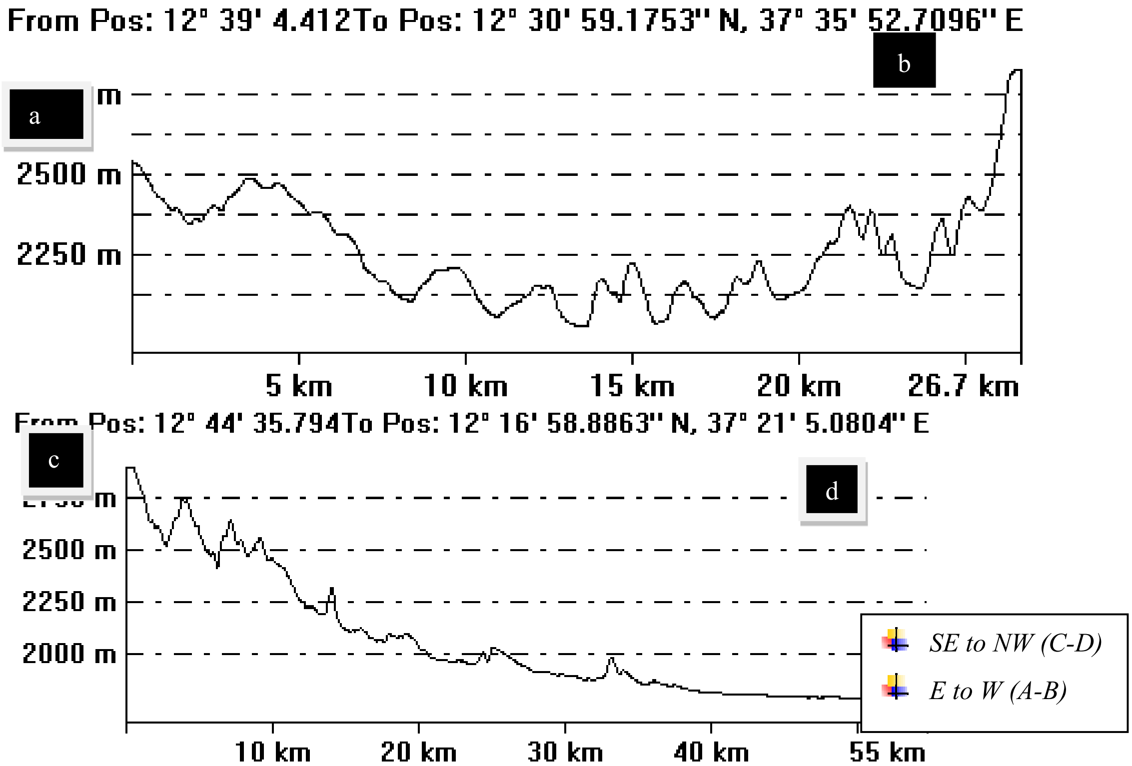


Figure 3.The Topographical section of Megech River catchment

The Morphology of the study area is the direct manifestation of the tectonic activities and the action of erosion. The general inclination of the slope becomes lower towards the flow directions.

The Northern, Northeastern and Northwestern part of the catchment is characterized by rugged topography with chain of ridges bordering sub catchments. Within the area, the southern part is characterized by a gently sloping surface, around lake shore.

The Northern and Eastern part of the catchment has very rugged topography and steep slopes. There is the large elevation difference within the watershed. Elevations ranged from 1789m (at South tip of study area, Lake Tana) to 2965m (North Extreme of the catchment).

Hill slope of surrounding areas are farm lands, permanent plants and grass lands are sparse. Although much have been talked about environmentally friendly land practices for over two decades, terracing and other forms of land use practices which can protect the hill slopes of Gondar area from degradation and erosion are not implemented. As a result the hill slopes are exposed for erosion and rain induced surface run off washes away the soil from steep grounds. As a result flood water of the rivers carry high silt loads during rainy seasons and Angereb Dam could be silted up. The plain drained by the Megech River that forms wide flood plain and water logged area as it approaches its delta. The rugged geomorphology setups, drainage patterns and gradients of the river valleys and geology of the surrounding areas are major factors that control the groundwater recharge of the aquifers in the region.

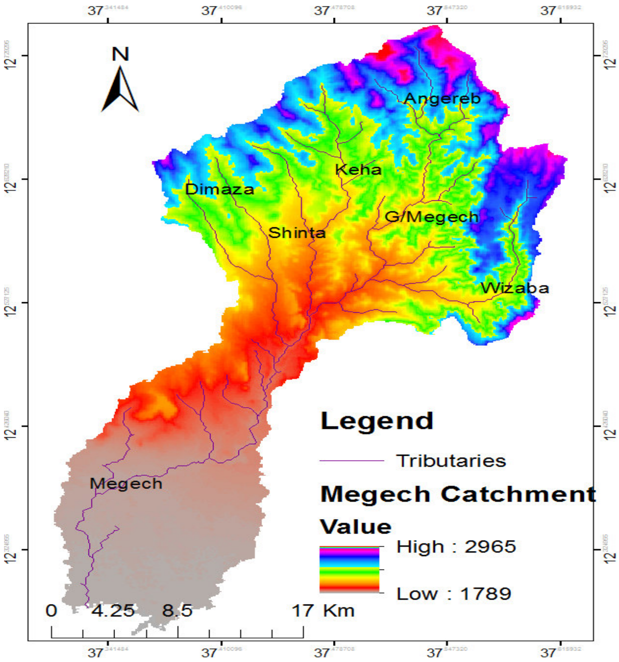


Figure 4. Drainage map of the study area

The drainage pattern of the study area shows dendritic pattern. Megech Rivers that run to the S directions and there is a structural control that is responsible for the present drainage pattern of the area. Megech River catchment of Lake Tana Sub basin comprises of numerous small rivers such as Dimaza, Shinta, Keha, Angereb, Gilgel Megech, Wizaba and other streams and enters into Tana Lake. All streams that drain the area are originated from the surrounding highlands.

Angereb, Keha, Shinta and Demaza are river valleys that drain Gondar and its surroundings. The rivers are emerging from steep and V shaped valleys of the mountain range as they approach the town proper and form wide and relatively gentle slope in the study area. Angereb valley forms the eastern limit of the town and joins with Keha just South of the Gondar. Shinta and Demaza rivers join East of Azezo and they all drain into Megech River north of the Megech river bridge on the road to Bahir Dar.

From general classification the climatic zones of the Lake Tana basin (Mamo, 2015) based on the use of the elevation and precipitation, the Megech River catchment can be categorized in to two broad seasons; Shrub-savannah (Sub-tropical) and Afro-mountain (temperate) zones.

Geology of the area

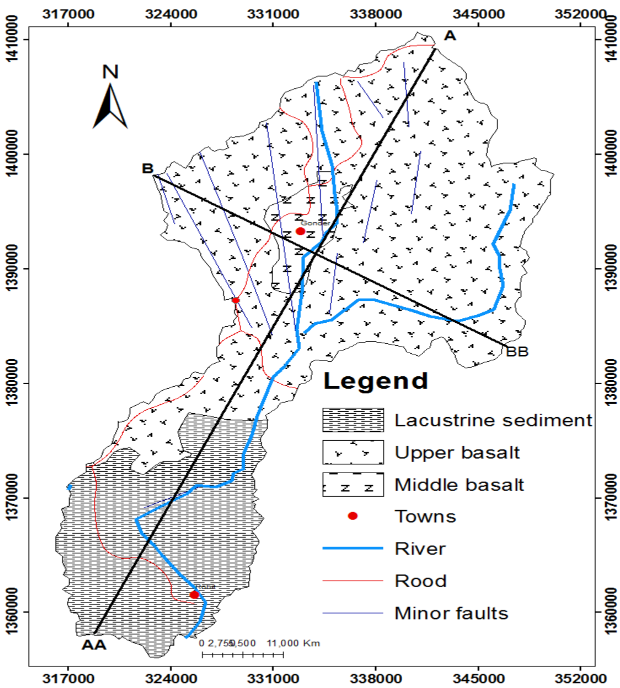


Figure5..Geological map of the study area

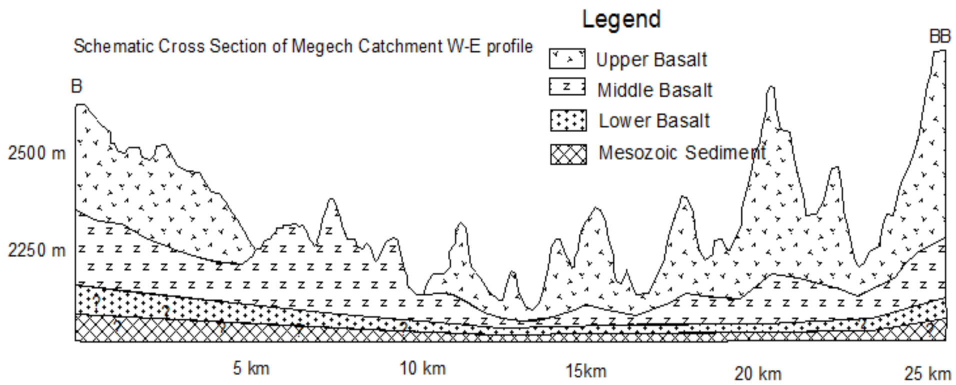


Figure 6.Horizontal geological cross-section of the study area

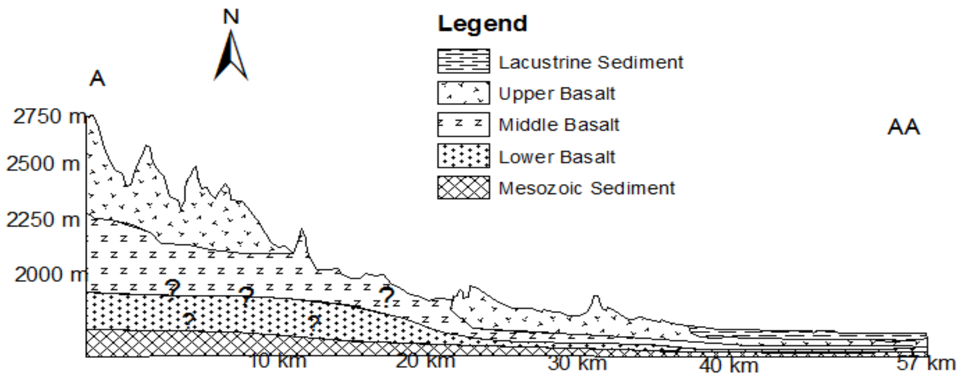


Figure 7 .Vertical geological cross-section of the study area

CONCEPTUAL MODEL DEVELOPMENT

The nature of conceptual model will determine the dimensions of the numerical model and the design of the model. The development of conceptual model is the most important stage in groundwater flow modeling as it simplify the field problems and organize the field as a result the system can be analyzed readily. Hydrologic information on precipitation, evaporation, as well as head data information is used in this analysis. Water level measurement are used to estimate the general direction of groundwater flow, the location of recharge and discharge areas, and the connection between the aquifers and surface water systems (Anderson and Woessner, 1992).

Selecting the appropriate conceptual model for a given problem is one of the most important steps in the modeling process. According to (Bear, Beljin & Ross, 1992) the selection of an appropriate conceptual model and the degree of simplification in any particular case depends on: the objectives of the management problem; the available resources; the available field data.

System Boundary Conceptualization

In Megech River Catchment of Lake Tana basin, the system boundary has carefully delineated based on the DEM data and during field visit.

The Northern, Eastern and Western boundary of the catchment of the model coincide with surface water divide line of the study area which is considered as no flow boundary. It should be remembered that groundwater divide is not a really a boundary in nature, but as groundwater on either side of the divide flows away from the divide and not across it, the divide itself acts as a no flow boundary. In the North, Northwest and Northeast model boundaries of the catchment coincides with the Tekeze basin divide, in the Eastern coincides with the Gemero River catchment, in the western with Dirma River catchment, in South concides with Lake Tana.

The model also consider specified head boundary which is simulated by setting the head at the relevant boundary nodes equal to known values. For lakes the boundary is described by constant head condition i.e. Tana lake.

Hydro-stratigraphic units and aquifer characterization

Hydro stratigraphic units for conceptual model are defined from geologic information combined with information on hydrogeological properties.

The different volcanic rocks and unconsolidated sediments have been classified into different hydrostratigarphic units based on their field hydraulic properties, borehole and spring yields and pumping test data (transmissivity). Furthermore, topographic setting and recharge conditions have been considered to evaluate the productivity of hydrostratigarphic units.

In this study, the aquifer thickness lies within the range 150 m to 360 m in most parts of the catchment except along the boundaries where ridges with high elevation are found. The lithology is dominantly highly weathered and fractured tertiary basalt in elevated areas and alluvial sediments in low lands around the Lake.

According to Mamo, 2015. Hydro stratigraphic units have been grouped based on whether the groundwater flow is in porous or fracture dominated media as intergranular and fracture aquifer categories and aquitards. However, in Megech River catchment the area is dominated by intergranular and fractured aquifer.

Intergranular aquifer: groundwater is stored in and flow through pores of unconsolidated sediments. Lacustrine sediments are categorized to this aquifer group.

Fracture aquifer: groundwater is stored in and flow through the weathered and fractured parts of the volcanic rocks and through primary flow features like vesicles and breccia, etc. The Tertiary volcanic rocks are classified to this aquifer groups. These volcanic rocks formed stratified multi layered aquifer systems, which are confined at depth by massive layers and/or paleosols. Each intergranular and fracture aquifers are ranked based on their productivity using the following criteria (Table 15).

Table 15.Aquifer classification criteria (after Geoffery and Gall,1991:in Mamo, 2015).

Aquifer productivity	Mean Transmissivity (m2/day)	mean yield(l/s)
Very high	>500	>25
High	100-500	5-25
Moderate	50-100	2-5
Low	10-50	0.5-2
Very low	1-10	0.05-0.5
Aquitard	<1	<0.05

Extensive aquifer: when the area is greater than 100 km2.

Transmissivity is deduced using empirical equation, which is

$$T=1.22\times SC \qquad \text{eq4}$$

Where, T is transmissivity and SC is specific capacity.

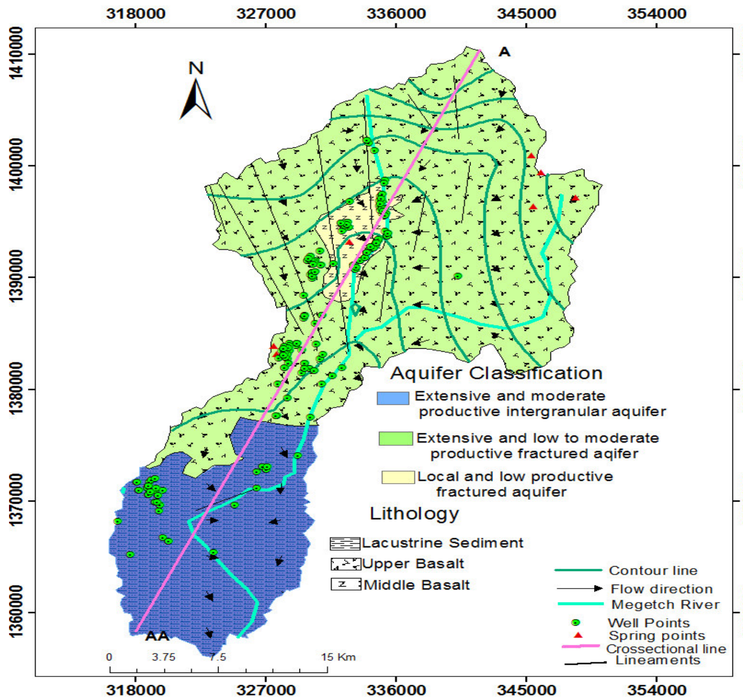


Figure 32. Shows the hydrogeological map of the study area

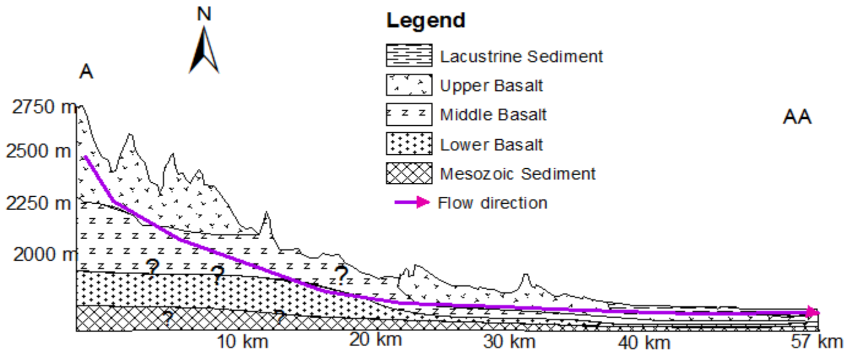


Figure7. Conceptualize groundwater flow from NE-SW (A-AA)

Groundwater flow in the Megech river catchment of Lake Tana basin aquifer system has been simulated using a modular two dimensional finite difference groundwater flow model of the U.S. When the groundwater flow does not vary over time, $\delta h/\delta t$, = 0 states that the system is in a steady or permanent state. To model the study area, Megech river catchment aquifer system the governing equation has been adjusted according to the prevailing field condition. Since the conceptualized model is a two dimensional steady state in a single layer, the equation can be simplified in to the following equation.

$$\frac{d}{dx}.\left(Kx.\frac{dh}{dx}\right)+\frac{d}{dy}.\left(Ky.\frac{dh}{dy}\right)\pm W = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq1}$$

$$K_{xx}\partial^2 h/\partial_x^2 + k_{yy}\partial^2 h/\partial_y^2 \pm W = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq2}$$

Where: Kx and Ky are components of hydraulic conductivity in the x and y directions; h is hydraulic head and W is a general sink/source term that is defined to be intrinsically positive to represent recharge and negative for withdrawals of groundwater.

Model design

Top layer is the top elevation of the aquifer under considerations. The top layer elevation was considered to be the elevation of topography. The nodal values of ground surface elevation were interpolated from DEM data. The interpolation was done at the resolution of 500m X 500m and then loaded in to the MODFLOW top elevation array from the interpolated DEM data with 30X30m resolution but it was sliced by the model area cell size, and then exported as surfer grid format and open in MODFLOW software as gridded file.

Bottom layer is the bottom elevation of the aquifer layer being modeled. In this study, the aquifer thickness lies within the range 150m to 360m in most parts of the catchment except along the boundaries where ridges with high elevation are found. Elevated zones were simulated by giving relatively higher thicknesses at the cells in order to avoid drying of cells during simulations. Hence bottom elevation was obtained by subtracting the aquifer thickness from top elevation in the catchment.

Initial and prescribed hydraulic head

They must be higher than the elevation of the cell bottom and are necessary for the start of model calculations. In this model, the initial hydraulic heads was obtained by subtracting constant number 25 m from top layer elevation throughout the model area, accordingly with the topographic and interpolated water table elevation.

Spatial discretization and Grid lay out

The model grid is set based on aquifer properties, size of the model area, and the availability of hydraulic properties of the aquifer. The extent of Megech river catchment from North-South and East-West is 56000m and 35000m, respectively. The model area is bounded by 315688 West and 1354879 South and 350907 East and 1410867 North, respectively. The model area is divided as uniform rectangular grid system or block centered diagram. The model domain has 70 columns and 112 rows with 500mx500m grid spacing within 7840 total number of cells. The grid system has regular grid system and each cell has a homogenous property. Groundwater flow equation for recharge, hydraulic head and hydraulic conductivity are calculated at the center of the cell.

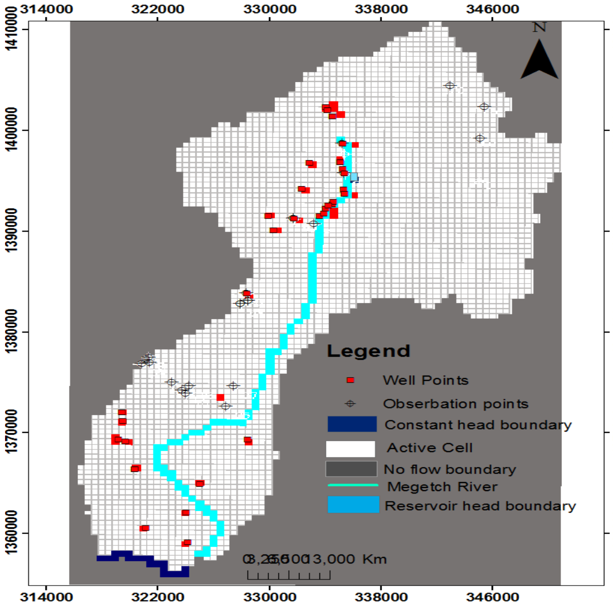
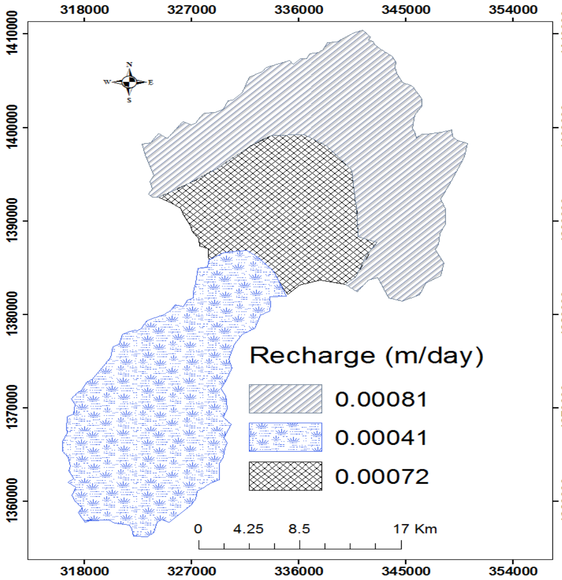


Figure 38. Shows the discretization of the model area

Hydraulic conductivity (K) and Recharge Spatial distribution

The hydraulic conductivity of fractured rocks depends largely on the density of the fractures and width of their apertures. It is obtained through pump test analysis, and lithologic type and literature review. The initial hydraulic conductivity parameter is assigned with an overlay analysis of boreholes conductivity results aerial distribution of the geological map based. The distribution is done by average of conductivity value from pump test data based on their lithology.

The average groundwater recharge of Tana basin has been estimated to be 284.7 mm/year based on the results of soil water balance and chloride mass balance methods(Mamo, 2015),which includes the shallow recharge that feeds the streams and deep recharge to the regional groundwater flow beneath the streams beds.



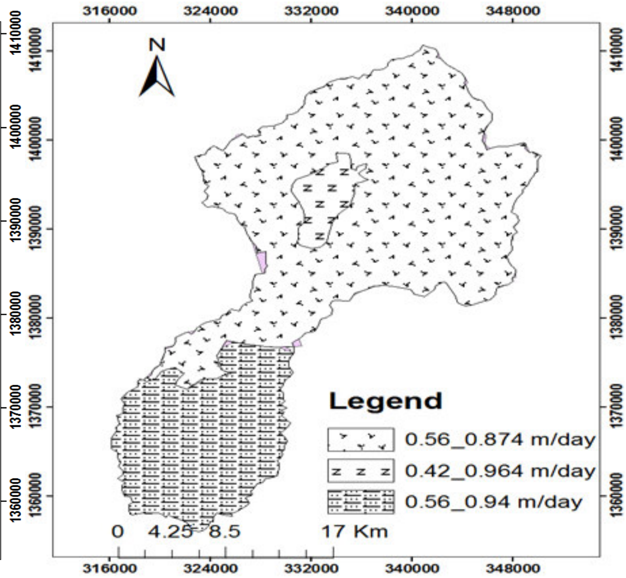


Figure 36. Recharge Distribution Map of the Study Area. Figure 33. Hydraulic conductivity map of the study area.

Groundwater discharge

Aquifer system is not only with an input of a recharge but also releases its resource out of the system. The major removal groundwater from aquifer system of the river catchment is possibly occurred through abstraction of water wells (16132 m3/day), springs (16.6 l/s), Base flow to surface water body (296794m3/day) and Evapotranspiration from marsh land (1634521m3/day).

Calibrated Aquifer and sensitivity analysis

The model calibration accounts the matching of the 19 observation points with simulated head with a permissible residual head of ±10 m. The criteria set is almost 75% of the difference the maximum and minimum measurement water level head in the study area which is about 5 m. It is almost with tolerable difference with respect to the gradient, the objective to understand the groundwater flow pattern and the diversity of hydraulic nature of volcanic aquifer. The model was assumed calibrated when the fit between observed and calibrated heads was within this criteria and calibration evaluated based on final spatial distribution of the difference.

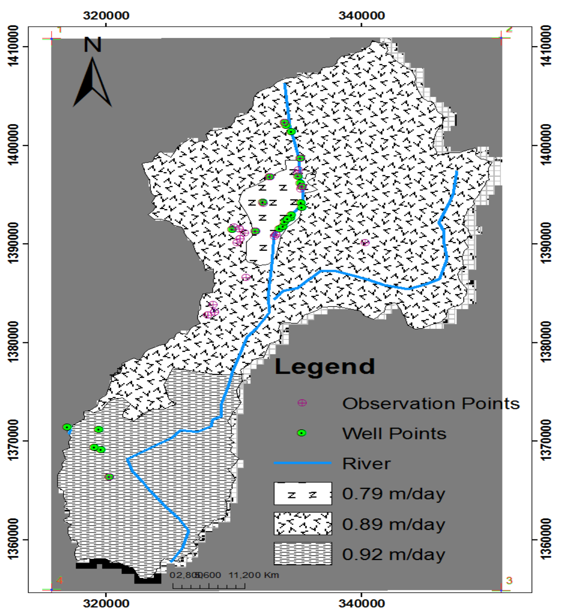


Fig. 9 - Hydraulic conductivity map.

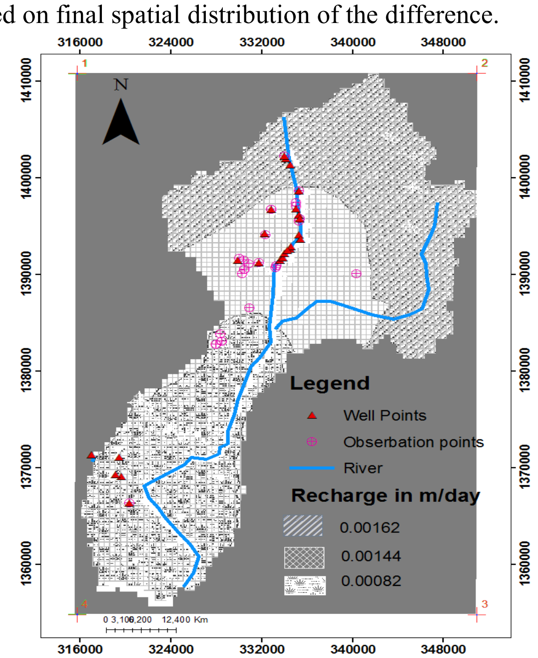


Figure 43. Calibrated Recharge rate of Megech river catchment.

Model Sensitivity Analysis

Model sensitivity was determined for variations in hydraulic conductivity, recharge and River bed conductance.

The results of the sensitivity analysis for this study were evaluated by calculating the sum of square deviation between measured and simulated heads in the modeled area for a decrease or increase in percent, from the calibrated value, of that parameter. The greater the deviations of the water level from its calibrated model value, the greater the sensitivity of the model to an increase (positive percent) or decrease (negative percent) for that parameter. To test the sensitivity of the above parameters, the calibrated values of each parameter were separately increased by 125%, 150% and 175% and decreased by 25%, 50% and 75% percent and then simulated to see the resulting heads.

In the model, simulated water levels were sensitive to both to the decrease and increase in the recharge, river conductance and hydraulic conductivity values. In this case the results of the sensitivity analysis shows that recharge and hydraulic conductivity, will have more significant effect on the model simulation results.

Model result and analysis

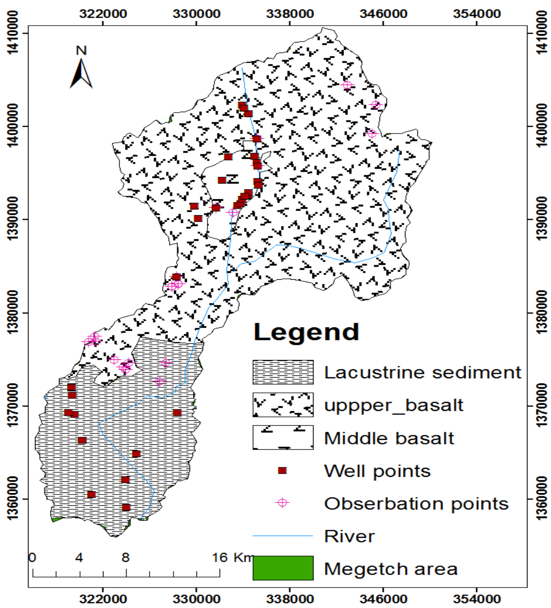


Figure 8. Location of Observation points used for head calibration.

Table 1.Sensitivity analysis by increasing and decreasing of model parameters

percentage		River conductance	Hydraulic conductivity	Recharge
Decreased by:	0.25(75%)	17.4	198.68	58.80
	0.5(50%)	5.92	66.30	55.5
	0.75(25%)	1.97	22.24	18.59
1(100%)		0	0	0
Increased by:	1.25(25%)	1.18	13.58	18.24
	1.5(50%)	1.97	22.8	36.27
	1.75(75%)	2.54	29.56	54.28

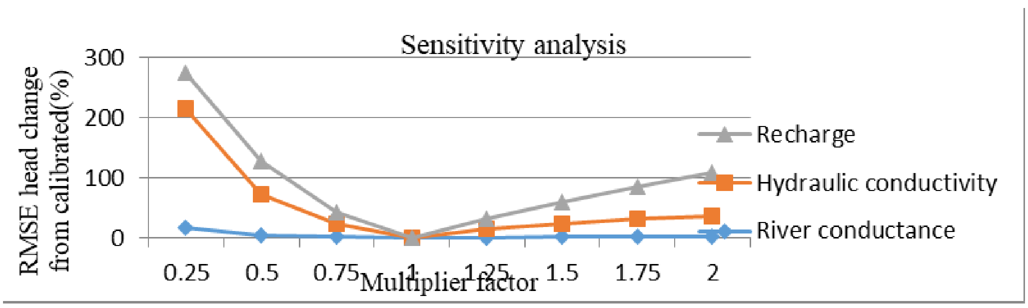


Figure 8. Sensitivity analysis of model parameter

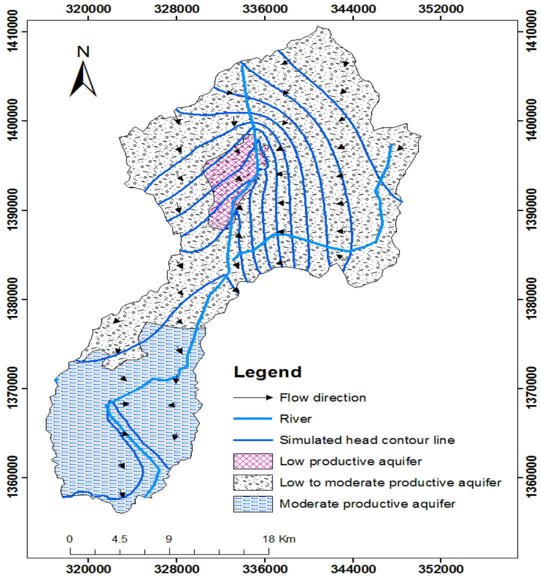


Figure 9. Groundwater level contour and flow direction of the model area

The simulated inflow and outflow of groundwater in the whole model domain is 1070355 m^3/day and 1070356 m^3/day respectively and the difference is-0.799038 m^3/day with discrepancy of 0%. The head distribution shows the groundwater surface follows the topographic contour and it coincides with surface water flow. The study area catchment groundwater flows from the recharge area to discharge area following the morphology. The MODFLOW calculates the hydraulic head distribution of groundwater flow surface.

Histogram of calibrated result

This helps to observe clearly the distribution of the absolute value of the difference between observed and simulated hydraulic heads and the frequency occurrence. Absolute head difference above 10m can be attributed to uncertainty in estimated stresses and hydraulic parameters.

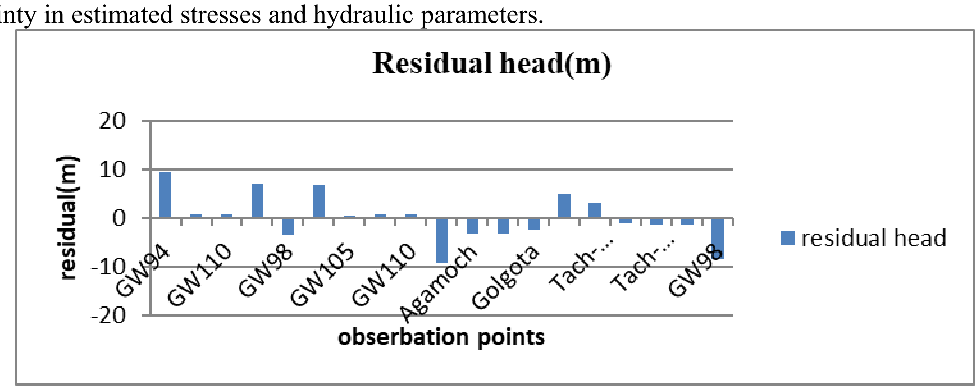


Figure 46. Residual head for showing error distribution

Scatter plot showing error distribution

Plots are useful in assessing the quality of calibration simulations. The scatter plots where observed values are plotted versus the value computed by the model. In an ideal calibration the points will fall on the straight line with a 45 degree slope that means the computed value equals with the measured value. In this model, it was difficult to match the theoretical line with the plot, but follows a straight line with ±10mts. The narrower the area of scatter around this line, the better is the match.

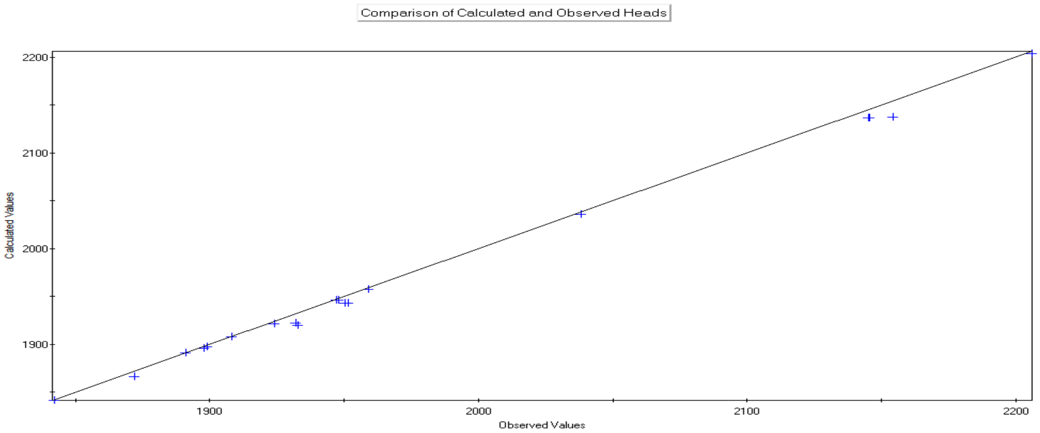


Figure 44. Scatter Plot Head Distribution of Calibrated Model.

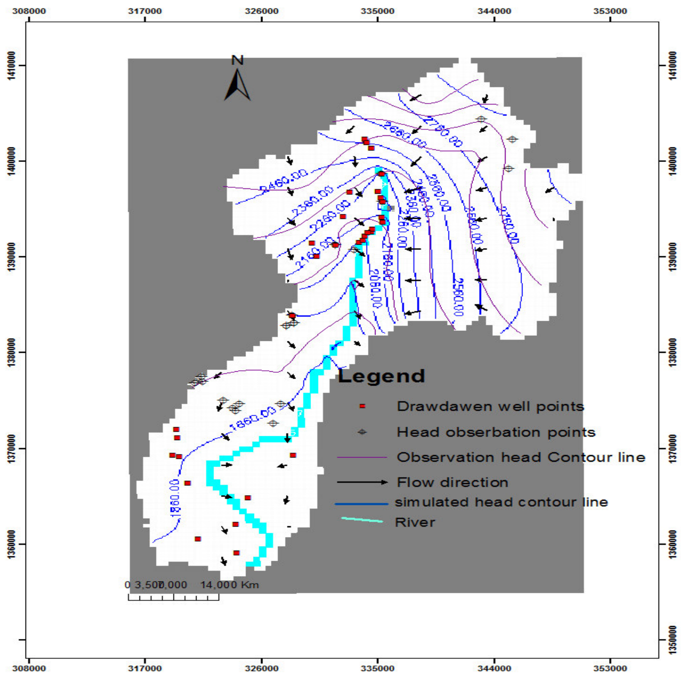


Figure 45. Simulated head vs observed head distribution

Scenario Analysis

The calibrated flow model helps as a tool to evaluate the response of the aquifer system to different stress by different scenario analysis result in a numerical groundwater flow modeling. This paper has tried for the simulation of two scenarios with the increasing abstraction of the groundwater and the decreasing recharge over the aquifer system. This part of model analysis has ability to predict the response of the system to change in the future events. The model is simulated for increasing of pumping of groundwater with 150%, 200%, 250%; and decreasing the recharge 25%, 50%, 75%.

Effects of increased Groundwater withdrawals

Gondar town is expanding and flourishing in different parts of the Megech River Catchment or hence, it is reasonable to assume that the water demand will increase too due to Gondar and Azezo town, Dashen Beer industry, expansion and flourishing in different parts of the Megech River Catchment. To meet this increasing demand, it is must that the existing boreholes should be pumped at greater rates or new boreholes with higher capacity should be drilled in the future. This truth can be seen from large number of wells drilled since recently in the catchment. In the first scenario, 24 increased well withdrawal rates were simulated by considering all active wells in the catchment. The current withdrawal rate estimated under steady state simulation was 16132m^3/day.

Table 25. Minimum and maximum draw down during scenario analysis

		Scenario One	Scenario Two	Scenario Three
Withdrawal Increase (%)		150%	200%	250%
	Q(m3/day)	26827.91	35770.55	44713.18
	Q(l/s)	310.508	414.01	517.5137
Water	Mini.(m)	0.078	0.158	0.238
Level	Maxi.(m)	1.41	3.774	5.36
Decline	Average(m)	0.880	2.076	2.8047

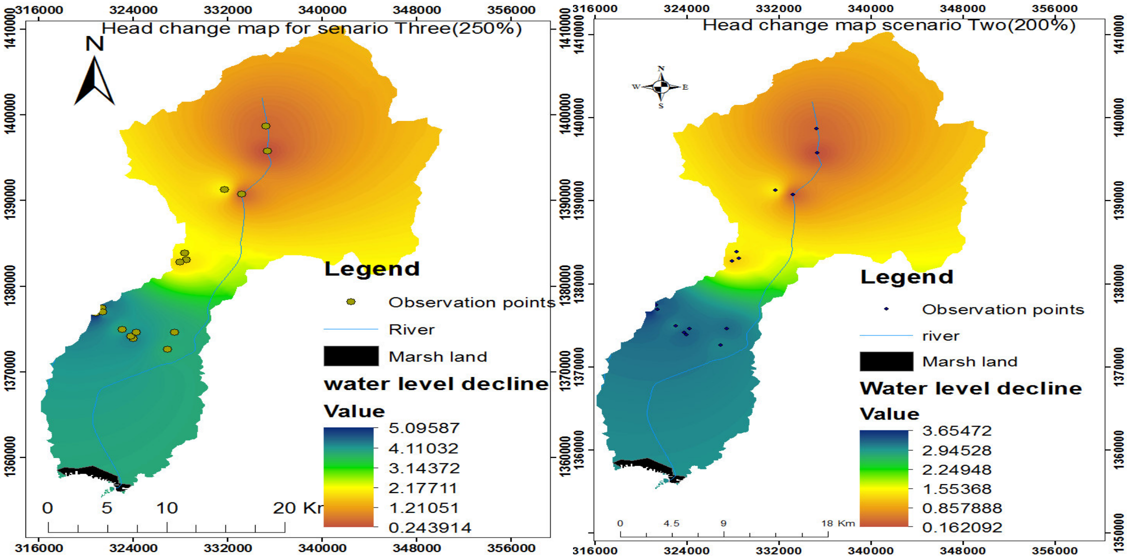


Figure 50. Head change map in three scenarios by increasing well abstraction

Increased well withdrawal by 150% resulted in the reductions of evapotranspiration, out flow to constant head, rive base flow (out flow) and outflow to the Reservoir by -0.39%,-1.97%, -0.87%,-0.28% respectively but the river leakage increased by 0.16%.Increasing well discharge by 200% resulted in the reductions of river base flow (out flow) by-1.74%, evapotranspiration by-0.77% and out flow to constant head by -3.94%,and out flow to the Reservoir by -0.55%. The leakage from the river to the aquifer increased by 0.325%. Similarly, increasing withdrawal by 250% resulted in reduction of groundwater base flow to the river by-2.62%, evapotranspiration by -1.21%, out flow to constant head by-5.85% and out flow to the Reservoir by-0.825% but the aquifer gain from the river leakage by 0.487%. In general, the above mentioned scenarios show that the river leakage to the aquifer increase and the system gain from Lake Tana while the marsh lands decrease and groundwater contribution to the Tana Lake and the streams decrease, which can cause drying of streams and wetlands and diminishing of the lake.

Table 26.Calibrated and increasing groundwater withdrawal water budget (m3/day).

Water budget component	Calibrated		Scenario 150%		Scenario200%		Scenario 250%	
	In flow	Out flow	In flow	Out flow	In flow	Out flow	In flow	Out flow
Constant head	0	23.17	0	22.72	0	22.26	0	21.82
ET	0	17930.76	0	17861.66	0	17792.57	0	17713.64
River Leakage	55045.12	991965.19	55134.62	983299.3	55224.1	974632.9	55313.52	965975.06
Reservoir leakage	0	42551.5	0	42431.76	0	42316	0	42200.24

Table 27.System response in percentage for increasing withdrawal.

$$\frac{\text{SIMULATED} - \text{CALIBRATED}}{\text{CALIBRATED}} * 100\%$$

Water budget component	Scenario by 150%		Scenario by 200%		Scenario by 250%	
	In flow	Out flow	In flow	Out flow	In flow	Out flow
Constant Head		-1.97%		-3.94%		-5.85%
ET		-0.39%		-0.77%		-1.21%
River Leakage	0.16%	-0.87%	0.325%	-1.74%	0.487%	-2.62%
Reservoir leakage		-0.28%		-0.55%		-0.825%

Effects of decreasing Recharge

In this scenario the simulation was done for decreasing recharge to aquifers that may result from environmental changes, expansion of agriculture, deforestation and town expansion. Simulation was done for decreasing of recharge to get the maximum and minimum decline of groundwater level in the model area from observation points. Decreasing of the current recharge by 25%, 50% and 75% of the calibrated model was tested.

Decreasing of recharge by 25% gave the minimum and maximum decline of water level by 3.934m and 20.68m, respectively. While the recharge decreases by 50% the minimum and maximum decline of water level are 6.22 m and 39.411m, respectively, and when the recharge decreased by 75 % in the model area showed 12.46m and 61.80m of minimum and maximum decline of water level, respectively. The average decline of groundwater level or head changes in the model area found to be 51.3m, 29.67and 17.58 for scenario one (75%), two(50%) and three(25%), respectively. The minimum decline of water level is observed on north and northeast of the study of northern side of Gondar city while the maximum decline of water level is observed south, southwest and southeast of the study area in the plain area.

Table 28 .The minimum and maximum drawdown observed from observation points during recharge decreasing

		Scenario one	Scenario two	Scenario three
Recharge decrease (%) by		75%(*0.25)	50%(*0.5)	25%(*0.75)
	Q(m3/day	15524.35	23809.25	47979.648
	Q(l/s)	179.68	275.57	555.32
Water	Mini	12.46	6.228	3.934
Level	Maxi	61.80	39.41	20.68
Decline(m)	Average	51.33	29.67	17.58

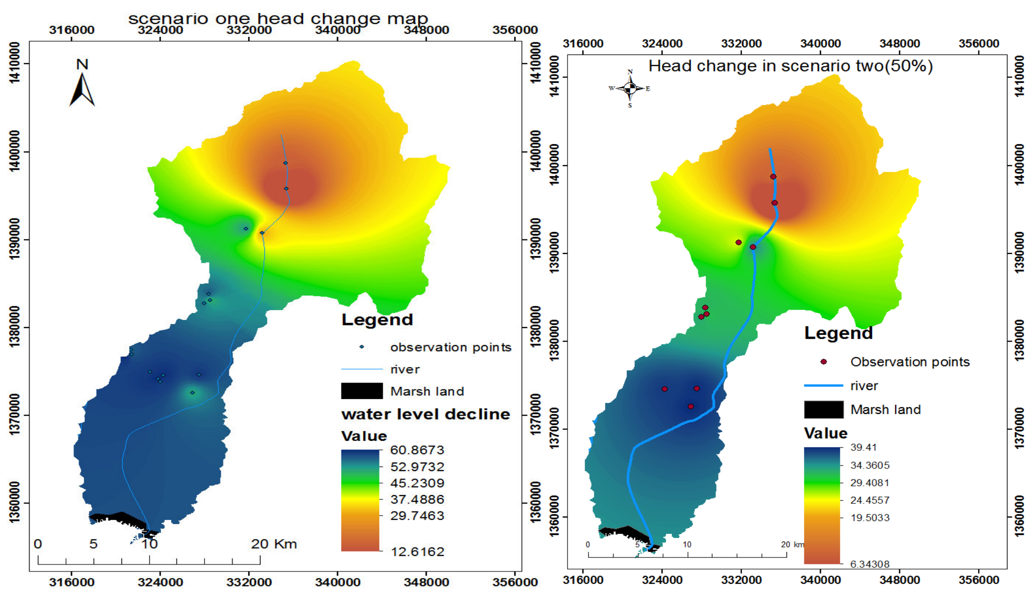


Figure 52. Head change map in three scenarios by decreasing recharge

Conclusion

The model calibration accounts the matching of the 19 observation point of simulated head with a permissible residual head of ±10m. The model was calibrated with mean error 4.85, absolute mean error 4.921m and square root mean error 6.83m. The model was more sensitive in the increasing order from river bed conductance, horizontal hydraulic conductivity and Recharge, respectively. The numerical groundwater flow modeling is empowered with computation of water budget. The simulated out flow of the model is 1070356m3/day which is nearly equal to simulated inflow with difference 0.79618m3/day.

The base flow discharge of simulated model is 991965 m3/day which hold 91.86% of the out flow but still with lower volume than the estimated one. The river recharges the aquifer with 55045.1m3/day which hold 5.15% of the simulated inflow. The river and aquifer interaction implies huge amount discharge of groundwater to the dominantly gaining streams. The groundwater of the catchment is highly depleted with discharge of the groundwater to the stream. The lake Tana is conceptualized CHB with a simulated 23.177 m3/day discharge of Groundwater to the Lake.

The model is simulated for increasing of pumping of groundwater with 150%, 200%, and 250% and decreasing recharge on 25%, 50% and 75%. The model response has been recognized for the average water level, groundwater discharge to the river and CHB. The average water level of the system shows a drawdown starting from 0.88m with 150% increment of pumping to 2.8m with 250% increment of groundwater withdrawal. And the average water level of the system shows a drawdown starting from 17.5 m with 25% increment of pumping to 51.3 m with 75% increment of groundwater withdrawal.

The steady state simulated recharge was decreased by 25% and the simulation results showed on average head decrease of 17.5m over the whole area; with the highest fall 20.68m in wells to north and a minimum of about 3.934m in wells to the south. The 50% decreased recharge simulates the water level decline with 39.4m, 6.2m, 29.6m of maximum, minimum and average water level decline respectively. And the value 61.8m, 12.4m, 51.3m maximum, minimum, mean water level decline in 75% recharge decreasing scenarios. While, the change groundwater well withdrawal on the discharge of groundwater to river with a relative lowering of 0.874% with pumping increment by 150% and lowering of 2.62% by pumping increment 250%. The increment of the groundwater withdrawal will also have an impact of the lake that is represented by the CHB in the model. The groundwater discharge will decrease from 1.97 % with 150% increment to 5.8% with 250% increment of pumping groundwater withdrawal. And the increment of the groundwater withdrawal will have an impact of the reservoir in the model. The groundwater discharge will decrease from 0.28% with 150% increment to 0.82% with 250% increment of pumping groundwater withdrawal. And the change on the discharge of groundwater by evapotranspiration with a relative lowering of 0.39% with pumping increment by 150% and lowering of 1.21% by pumping increment 250%.

The current withdrawal rate estimated under steady state simulation was 17885.27m3/day. Steady state withdrawal rates were increased by 150%, 200% and 250%, to study the response of the system in this scenario, increased are equivalent to withdrawing 26827.9, 35770.5, and 44713.1m3/day over the whole catchment respectively.

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