Ground water - surface water interaction and impact assessment, in the case of western Ziway catchment, in Ethiopia

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Abstract

The goal of this research was to enhance the current understanding of the interaction of surface water-ground water and impact assessment using a numerical model. Initially, to measure the natural recharge of the aquifer and to model streamflow, the surface water hydrology of the sub basin was researched using the HEC-HMS (SMA) model. The ground flow mechanism was analyzed by using 3D numerical groundwater flow model (Processing Modflow Pro (Version 5.3.0.1)). The HEC-HMS (SMA) model was used to measure the recharge rate for the sub-basin in order to achieve a recharge. Model calibration was subsequently carried out using the process of trial-and-error calibration using groundwater contours formed from heads collected at 56 observation points. Therefore, the average RMSE for simulated hydraulic heads was approximately 20.65 m. Simulated water levels in the model were more sensitive to decreases in recharge values and sensitive to decreases in hydraulic conductivity values. However, relative to recharge and hydraulic conductivity, the model is not as sensitive to decreases or increases in pump age. According to the simulation Lakes and rivers are significant sources of aquifer recharge. Finally, the model's water budget results showed that groundwater recharge comprised 81.48%, through river leakage 3.28% and constant head was 15.24% of the total water input for the entire study region. Because of this, it can be noted that the surface water impacts to the water budget of the sub-basin.

I. Introduction

Surface water and groundwater interaction is a natural phenomenon dictated by the fact that the two-water media are critical components of one system intimately linked by hydrologic cycle (Hamilton, 2005). Surface and groundwater processes are in continuous complex interaction and They are the two elements of hydrological cycle that are not separated from the interaction. However, Surface water and groundwater supplies are typically managed as separate structures. Therefore, this can contribute to resource over/under-allocation and detrimental impacts on the climate. Production of land and water supplies affects the quantity and quality; thus, understanding the connectivity between surface water and groundwater systems is required to plan and manage surface water and groundwater resources accordingly.

Groundwater is discharged to the surface through natural springs, transpiration by plants, seepage under rivers and streams. On the other hand, groundwater is recharged by surface water from direct precipitation and indirectly from losing rivers and streams. This is due to the fact that surface and groundwater flow systems, in many cases, interact with each other. Krause et al. (2007) found out that there is high spatial and temporal variability in interactions between surface and groundwater and the exchange of fluxes between them. In that respect, the direction of the flux exchange determines the type of interaction. Whereas, Groundwater recharge is a function of the volume of residual rainfall, surface infiltration, and geological percolation rates (Hamilton, 2005).

In Ethiopia currently, water supply and small-scale irrigation schemes have been implemented in the area and water abstraction from surface water and groundwater resources puts an increasing claim on scarce
water resources in the area understanding of the existing and future water demand with negative impact on economic development and environment of the basin enables to identify and design hearty development options. This was creating shortage of water resources for irrigation and water supply purposes. In addition, the increasing pressure on land and water resources intensifies conflicts between various stakeholders.

Among the rift valley basin western Ziway-Meki River catchment has an abundance surface and groundwater resources. However, due to climatic change, high population growth, the amount of water available is decreasing. In order to access both surface and groundwater appear to be more feasible and consistence as demand can be met from several sources instead of using one source. Therefore, initial assessment of (SW-GW) interaction and their effects were imperative, in order to use surface and ground water supplies in conjunctively. To use Modeling software is critical because it can simulate a time period very quickly which saves time and money over an experimental monitoring study. Therefore, for this study used modeling software to investigate aquifer interactions with surface water components by combines two important modeling software's: HEC-HMS for surface water modeling and processing MODFLOW for groundwater modeling. Finally, the aim of this research is to improve understanding of the relationships between surface and ground water and to investigate the effect of one over the other for sustainable use and to influence future elective decision making in water resource management in the catchment. Moreover, it aims to improve more societal benefits by ensuring availability of water for agricultural activities and sustenance of ecological systems in the study area.

I I. Materials And Methods

Study Area and Data Used

Western Ziway- Meki River catchment is located in the central main Ethiopian rift valley and originate in the highlands of Gurage and travels a distance of about 100 Km from the highlands at altitude of 3,500 m to 1, 636 m at point draining into Lake Ziway. As well as, its geographical location approximately between 7051E and 8027E longitude 38015N and 38051N latitude (UTM: 415131-489329E and 865165-935680N, zone 37, northern hemisphere) respectively. Additionally, the total area of western Ziway- Meki River catchment is about 2318. 6km².

**Modeling materials for groundwater and surface water**

Global Mapper (18), GIS (10.4.1), and surfer (12) were used depending on the purpose and form of data to be simulated to GW-SW interaction and their effect assessment in the research topic. In order to understand the nature of catchments Topography data of 30 m resolution was used for catchment delineation and catchment characteristics using Arc GIS software, soil, land use and geological data used. As well as, Stream flow from 1998–2008 collected for calibration and validation. Source of data collected from Ethiopian Ministry of Water, irrigation & Energy. Meteorological data also collected from Ethiopian Meteorological Station Agency (NMSA).
Methods

Arc GIS 10.4.1 was used to delineate the catchment area. The watershed and sub basins delineation were carried out based on an automatic delineation procedure using a Digital Elevation Model (DEM) and digitized stream networks. GIS is critical for this analysis because it is used to analyze climate data, previous groundwater borehole data, topographic data, land use and land cover data, and it is used to coordinate and handle data from the Ministry of Water, Irrigation, and Energy (MoWIE).

Surfer can be used to preprocess groundwater modeling data, and it was (a) used to generate model data that met the groundwater model's requirements. Surfer preprocesses all of the groundwater simulation input parameters, (b) to check the uniform distribution of the terrain profile in the basin, the global mapper path profile documents can be modified to model input and blanked file formats, respectively, to outright the XYZ grid global mapper information, (c) to plot the river basin's topography uniformity map (d) to convert excel files to surfer model input files (e) to construct the study area's model grid

Global mapper software can discretize the groundwater problem in the study area. By discretizing the groundwater issue and delineating the study area, the global mapper can be used. Since the global mapper program is stress-free when it comes to DEM delineation and interpretation. The study area must be described through a series of procedures, (a) The first step is to open the country's digital elevation model (Ethiopian DEM) in the global mapper software working window. The Ethiopian mapping agency provided the digital elevation model (DEM) with a resolution of 30m*30m. (b) after placing the DEM on the global mapper working space, selecting the file menu from the global mapper toolbar and exporting the file in global mapper package format, (c) On the global mapper working space, after exporting the file, a dialogue box appears, from which we can pick export bounds. (d) finally, from the dialogue box, pick the box delineation instruction menu and delineate our study area in box size, saving the values anywhere you want.

HEC-HMS and soil moisture accounting method (SMA).

(USACE, 2016) The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) is software developed by the U.S. Army Corps of Engineers and has a tool bar extension in the ArcMap GIS program. The HEC-HMS model is therefore used for the surface water simulation of the Meki- River flows in this analysis. As part of this surface water simulation, the volume of water percolated from the Meki River and surrounding watershed rainfall-runoff in HEC-HMS known as Soil Moisture Accounting (SMA) was used to assess the quantity of water percolated to the groundwater. This package was chosen because, rather than an event model, a continuous hydrological model was needed. A continuous model accounts for the long-term balance of soil moisture in a watershed as is appropriate for the simulation of daily, monthly, and seasonal streamflow (W. Scharffenberg, 2016). For full simulation of the eleven-year study period, the SMA package allows moisture accounting. Therefore, the parameter of interest is the percolation of groundwater from the soil profile. Instead of the soil infiltration data, the percolation results are chosen because soil storage and evapotranspiration are also accounted for by the SMA process. SMA has parameters that need to be determined for the sub-watersheds before simulating the watershed rainfall-
runoff relationship, according to the soil moisture accounting algorithm schematic (W. Scharffenberg, 2016). The selected parameters for this model represent: storage of canopy interception, storage of surface depression, maximum infiltration rate, maximum soil storage, storage of tension zone, percolation rate of soil zone, percolation of groundwater 1 and storage depth of groundwater 1 due to unconfined depths. The surface water model can be adapted to the parameters using these tools to better fit the wet or dry periods that occur throughout the year. Instead of creating an annual average that is a fit for both wet and dry periods, these modifications help minimize model error by fitting the parameters to a shorter time period. The Lag Routing Method for the river reach segments was selected for the estimation of flow in the Meki River. This is a method that represents flood wave translation and does not include any representation of processes of attenuation or diffusion (W. Scharffenberg, 2016). The method was adequate for the purposes of this study and this assumption is confirmed through the calibration process shown in the following sections. The lag time in minutes is the only parameter. The inflow in a range is delayed by HEC-HMS by the time specified for lag in the river range and then the flow becomes outflow (W. Scharffenberg, 2016).

**HEC-HMS model setup**

Basin model manager, meteorological model manager, control specifications manager, input data manager are four key components produced for the HEC-HMS project development (time series, paired data and gridded data). For example, the Basin model manager involves the hydrological elements (sub-basin, reach, intersection, reservoir, diversion, source and sink) and their connectivity, which reflects the flow of water through the drainage system (W. A. Scharffenberg, 2013). One of the project’s key components is the Control Requirements Manager, which is primarily used to control simulation time intervals. The meteorological component is also the first computational component in which the input of precipitation is distributed spatially and temporally across the river basin. The spatiotemporal distribution of precipitation is achieved by the inverse distance method and for estimating basin-average rainfall, the hydrological model also needs time-series precipitation data. A time series, often referred to as observed flow or observed discharge, of flow data. Both meteorological data such as rainfall, observed discharge, were entered into this main component. By forming and recreating the sub-watersheds and the Meki River using the HEC-Geo HMS in ARC GIS, the HEC-HMS model was developed. The HEC-Geo HMS information was imported into the HEC-HMS model and receives sub-watershed characteristics such as location, slope, infiltration parameters, river routing parameters, and connectivity of the sub-watershed-stream network. Additional watershed data necessary for the creation of the HECHMS model were then defined after exporting HEC-geo HMS data. That includes, for the upper Meki, precipitation and historical streamflow. This data is then entered as time-series data controls. Time-series data is used to specify time-dependent data from various methods of measurement. Start and stop times and dates, the interval of time between readings, and the data values are the necessary information for time series input. The interval of time will vary from one minute to one day, with many alternatives in between (W. A. Scharffenberg, 2013). For this study, both precipitation and flow time series data were entered from
midnight (00:00) January 1, 1998 to midnight January 1, 2008 as daily data and HEC-HMS also has meteorological controls. This control enables various methods to evaluate and apply precipitation to a watershed and also shows the basin model in the HEC-HMS projection.

**HEC-HMS calibration and Validation**

The Control Specification for this model therefore extends from 1 January 1998 to 31 December 2005 with a time increase of one day and the Control Specifications for the calibration attempts have also been established. Calibration is an iterative process for minimizing an objective function (USACE, 2016). The model was simulated again for the entire period after the calibration was completed and the flows used to derive the river boundary inputs to the MODFLOW model were derived. To calibrate models, HEC-HMS has an integrated optimization tool (W. A. Scharffenberg, 2013). In addition, to calibrate, an optimization test is generated by choosing a previous simulation trial to be calibrated and attempting to fit the observed dataset. Several parameters can be chosen for the program to use during the calibration process once the optimization trial is developed. To calibrate the HEC-HMS model, the twelve parameters of the SMA and river lag times were used. The purpose of the calibration is to evaluate the optimum value (i.e., non-measurable inputs) of model parameters. In this case, for the Eight-year period from January 1998 through December 2005, two types of calibration runs were completed, with a time interval set at one hour for better resolution of the daily data. Therefore, the first calibration attempt was aimed at reducing the difference between the streamflow volume simulated by HEC-HMS and the streamflow volume observed.

The objective function was set to Percent Error in Volume for the volume calibration. This objective feature ignores timing factors to decrease the overall volume difference over the calibration duration. (W. A. Scharffenberg, 2013) The Sum of Absolute Residuals was the objective function for the calibration of peak flow. In addition to improving the model’s peak flow prediction capability, calibration for peak flow was carried out, which also yielded very good results. The resulting percent difference was 0.1% for the objective function of the Total of Absolute Residuals. The SMA parameters recognized by the first calibration attempt were used in this calibration, and the model was calibrated by changing the lag times in each of the river reaches. It takes runoff to flow through the river as flow gets to junctions to mix with flows from other reaches to adjust the length of time. Instead of many flows merging to form a very large peak flow, changing lag times to offset the flows may result in a smaller peak flow. In addition, the table of sensitivity analysis indicates that none of the river reaches is significantly sensitive to the simulated streamflow, even with drastic adjustments between initial and optimized values of up to (50%) modification. It can

be pointed out that the model produced relatively reasonable results taking into consideration average (time invariant) parameters were used for the whole calibrated period (8 years) and lumped parameters values for the whole area of the Meki- watershed. The Nash-Sutcliffe (1970) coefficient of efficiency ($D^2$) was used to judge the model performance. The estimated $D^2$ value for the calibration period is 0.535
which will be moderate to judge on the similarity and consistency between the observed and estimated hydrograph shape.

\[
D^2 = \frac{\sum (Y - Y_m)^2 - \sum (Y - Y_{sf})^2}{\sum (Y - Y_m)^2} (1)
\]

\[
D^2 = 0.535 = 53.58\% \text{ Where: } Y_{sf} : \text{estimated flow discharges by the model, } Y: \text{observed flow discharges, } Y_m: \text{mean of } y \text{ in the calibration period as depicted from Fig. 1 the model produced moderate estimated results.}
\]

**Overview of the ground water model**

Through the MODFLOW model software processing (version 5.2.0.1), which is based on the finite-difference method, the three-dimensional groundwater flow equations that form the groundwater flow model of this study were solved. As a one-layered and steady-state condition, the groundwater flow model was set up. In general, the purpose of the model was to simulate the groundwater flow of the unconfined aquifer and thus analyze the distribution of water table elevations and groundwater, The flow in the upper-Meki catchment was simulated by a modular three-dimensional finite-difference groundwater flow model geological survey and The model was carried out to handle the input and output environment in the code supplied using the Processing Modow Pro interface (Version 5.2.0.1.) (Kinzelbach, 2014). It is also essentially based on the physical theory of groundwater flow, Darcy's law and the equation of continuity. The steady-state groundwater flow is typically simulated in a three-dimensional aerial view based on the following governing differential equation (McDonald & Harbaugh, 1984)

\[
\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 (2)
\]

Where: \(K_x, K_y \text{ and } K_z\) are hydraulic conductivity terms along the three axes and the units are \(m/\text{s}\) also \(h\) indicates the hydraulic head (m).

**model characteristics and structure**

**model grid size**

There are 240 columns, 230 rows, and one layer for a total of 55,200 cell nodes in the finite difference grid, and each cell size has a uniform grid size of 300 m by 300 m. The size of the model is high, but it serves the purpose of understanding the regional groundwater flow mechanism. The model grid, boundary conditions, flow package (rivers and well packages) are shown in Fig. 3.19; active, inactive and constant head.

Top of layer
It is the top elevation of the confined aquifer layer under consideration and drawn from the ASTER digital elevation model of 30m-by-30m resolution. The aquifer was considered to be a single layer and unconfined in this study. The top layer elevation was therefore deemed to be the ground surface elevation. In this case, the DEM data is interpolated using global mapper 18 as field data to generate a grid file in a format compatible with the Processing Modflow Pro (Version 5.2.0.1.) and imported into the elevation model referenced by its geographical position.

Bottom of layer

It is modelled on the bottom elevation of the aquifer layer. The aquifer thickness, which lies within the (80–265) m interval, is very rough in this study. But, except for the central part of the Inseno-Kosh-Dugda and cindare cones areas where high elevation ridges are found, in most parts of the watershed. Because of this, higher altitude zones have been simulated by assigning relatively higher cell depths in order to avoid cell drying during simulations. In most parts of the sub-basin, the bottom layer was therefore removed by subtracting a range of (80–265 m) from the top elevation. The thicknesses of the aquifers are generally very irregular as they have not yet been determined precisely for the aquifers boundary conditions

The major part of the boundary is flux boundary inflow in western and northern direction as well as at lake- Ziway out let direction and the western and northeaster escarpment areas of Meki catchment which are out of the model boundary the recharge computed as flow rate based on the area covered by them and assigned in the model as flux. But, the remaining part of the boundary taken as no flow boundary. The recharge and well discharge within the actual model boundary in the catchment are provided by specified flux boundaries in the model. Ziway lake is at the catchment outlet under the model boundary and is regarded as the internal specified head boundary.

The following hydrological process is included within the model boundary: recharge, groundwater flow to and from streams, well withdrawal and groundwater outflow to Lake Ziway. In addition, the surface water simulation outcome of precipitation recharge is represented as a specified-flux boundary condition. Recharge to the groundwater system was provided through consideration of groundwater sources from precipitation infiltration and is simulated as a specified flux to the top layer of the model river package

under the consideration of the conceptual model the perennial river is also important boundary condition and used to simulate the flow of water between aquifer and river.as well as, the package of the code described by(Kinzelbach, 2014).therefore, It allows water to flow from the aquifer to river, thereby removing water from the model by seepage to gaining stream reaches. In addition to this, Water can also flow out of the stream into the aquifer. however, the seepage out of the stream is independent of the
stream discharge. Thus, a losing reach of stream could recharge the aquifer with higher elevation is being carried in the stream.

The river package takes the river bed conductance by considering the following variables; Length(m), width of river channel(m), river bed sediment thickness (m) and vertical hydraulic conductivity (Kr). That means, \( C_{riv} = \frac{KrLW}{M} \) (3a).

then, the leakage rate between the aquifer and the river is calculated as follow;

\[ Q_{riv} = C_{riv} (H_{riv} - h), \] when \( h > R_{bot} \) (3b).

Whereas, \( H_{riv} \); the head in source reservoir and \( h; \) is the head in aquifer below the source reservoir; at the time the water table decline below the bottom of the stream bed (\( R_{bot} \)), leakage stabilizes as well as, \( Q_{riv} \) is determined from the following equation: \( Q_{riv} = C_{riv}(H_{riv} - R_{bot}), h < R_{bot} \) (3c).

Western Ziway catchment include Meki river, Lebu, Irenzaf, Weja and Akamuja perennial tributaries. The movement of ground water to or from streams is a function of the head in the stream, \( H_{riv} \), also known as stream stage. Stream stages used in this simulation were determined by taking an approximate average stream elevation within the cell based on the observed eld value, and ASTER DEM derived from a 30m-by-30m resolution. The rate of water movement to and from a stream in response to a given head gradient is controlled by streambed conductance.

The final boundary condition is groundwater withdrawal, which is simulated as a specified flux. In the study area there are irrigation, public water supply and individual domestic wells pumping from the aquifer. Specified fluxes are removed from cells corresponding to the geographic locations of the wells

**Initial and prescribed hydraulic head**

MODFLOW processing requires initial heads to begin the simulation. It was then obtained by subtracting a constant value of 30 m from the top elevation of the sheet, based on aquifer topography and conceptual hydrogeological map, over a wide area. After that as initial heads in active cells, the real value of water level elevation was given.

**Hydraulic conductivity**

The number of layers is one in this model since flow inside the layer was considered to be horizontal. Hydraulic conductivity is the amount of water that flows under a unit hydraulic gradient through a unit area calculated at right angles to the flow direction through a porous medium in a unit time. Both the medium and the fluid are a function of hydraulic conductivity. The hydraulic conductivity that determines the flow rate of the groundwater in the aquifer system is the required parameter in the aquifer system. The model used a hydraulic conductivity of 0.0. About 1 m/day and 20 m/day (taken from professor Tenalem, 1998).
Groundwater recharge

The groundwater recharge per day is simulated from surface water model of river flow in sub-basin total area of 1824 km\(^2\). Assign the total daily spatial distribution of groundwater recharge to the whole sub-basin. That means, Recharge to the model is applied by computed result from HEC-GEO HMS (SMA) In this model Recharge was applied to the active model area as a spatially varying, specified flux to the highest active cell. Generally, precipitation recharge changes spatially with land surface permeability, which is a function of soil characteristics and land use, and spatial distribution and intensity of rainfall. since model predicts the amount of recharge in Meki-river catchment with limited data and time referred in appendix 6. Therefore, from the surface water simulation result the amount of annual recharge to western Ziway-Meki River catchment applied in this model is 64.6 mm/year or \((1.769 \times 10^{-4})\) m/day.

Discharge

In the model area, discharge from groundwater systems includes groundwater withdrawal, groundwater outflow to Lake Ziway and discharge to stream and different MODFLOW packages were used to simulate these discharge components.

Discharge to streams were modeled using the river package and was used to simulate the hydraulic connection between groundwater and surface water by allowing streams to gain or lose water, based on the difference between the surrounding hydraulic head and stream stage, through riverbed material of a specified hydraulic conductance (McDonald & Harbaugh, 1984). Estimated riverbed conductance was based on model calibration. Model cells were designated as river cells along major streams and tributaries where the ground water table intersected the land surface.

In the model, pumping wells were simulated with the well package and by assigning the recharge rate of the well negative values are used to assign pumping wells, then positive cell values indicate injection wells. The injection or pumping rate of a well is independent of both the cell area and the hydraulic head in the cell. MODFLOW assumes that a well penetrates the full thickness of the cell. In case of, shortage of well-construction data available, all wells were assumed to be fully penetrating in the layer.

Model interpretation and calibration

(McDonald & Harbaugh, 1984) has investigated that calibration clarify the simulation is reproducing field measured heads and flow. The following parameters are basic for the model calibration; boundary condition, hydraulic conductivity, recharge and discharge stress condition. Under this study, Steady-state calibration was made using static water level of 56 wells. In order to get the best match between simulated and observed hydraulic heads and flow-controlled modification of parameter and values were imperative.

The calibration of the model can be done by the hand operated trial and error modification of aquifer parameters or inverse solving method. The later one method approaches a problem to get a set of
hydrogeological parameters to meet observed value and the forward solving method use an aquifer system parameter to calculate the head. In spite of this, in this model the calibration target is taken with observed hydraulic head measured on the selected production well. As well as, the model applies the trial-and-error method which gives good results for the steady state calibration and satisfy the objective of the study.

The model is calibrated to steady state condition with observed head measured at the available production well. As well as, the water balance is checked every time corresponding to input values of recharge and outputs from wells. The groundwater level measurement is taken during the construction and inventory time of the borehole. Because, there is lack of monitoring the existing well standing water level and no accessing like an observation pipe installation to easily measure the water level. The model uses 56 wells for calibration targets distributed within the basin. Prior to calibration assessing simulated result with observed data means that the hydraulic gradient and the simulated head roughly match those of the estimated one. As well as, the calibration process keeps the base flow of upper-Meki catchment.

Then after, the Western Ziway-Meki River catchment is calibrated with manual trial and error adjustment as follow:

**trial and error calibration**

This calibration method relies on prior information and expertise about the region from the modeler. In order to determine the response of the aquifer parameter or boundary changes on the simulated head to match the observed head, the modeler uses his expertise. With data on the head distribution over the aquifer system, the model tries to determine the aquifer parameter. It results in a set of parameters of the aquifer system that minimize the difference between the head being simulated and observed.

In trial-and-error calibration, the aquifer parameter will be modified or adjusted until the sequential model run match simulated head to calibration target. Accordingly, the model use adjustment, dominantly, in the hydraulic conductivity and minor adjustment on the recharge and river conductance. In model calibration process, a satisfactory result for the steady state calibration is found which meet the overall goals of the study.

**Evaluation of the calibration process**

The calibration outcome is determined both quantitatively and qualitatively and aims to use the recommendation of the protocol (McDonald & Harbaugh, 1984) to test the calibration that involves matching the contour map of the measured and virtual head, calibration statistics used to evaluate the model outcome.

Two calibration parameters were used in this model: visual correspondence of the simulated contours with those of the observed contours and correspondence of the simulated hydraulic heads at 75% of the points within 25 m of the observed hydraulic heads. After that when the fit between observed and
calibrated heads was within this criterion and simulated groundwater contours, the model was presumed to be calibrated.

**Contour map comparison**

Visual judgment of the simulated and observed heads of the region is carried out to evaluate the calibration of the model using contour map comparison. Upper-Meki River catchment modeling could be categorized as regional studies and one way to calibrate the model is to match the simulated and measured map trend. Therefore, the simulated contour model of the hydraulic head approaches the measured contour one. It is found that the simulated heads follow almost the same trend as that of the ground water contour observed. That means, with reasonable accuracy, approximating the observed contour. However, in the context of complex aquifers with an inherited nature of head difference in small distances and poor groundwater data management of the country, it will be very unusable to achieve identical simulated and measured contours.

**Root Mean Squared Error (RMSE)**

Observed from the field data that is modelled or measured using The Root Mean Square Error to measure the difference between values predicted by a model and the values actually (RMSE). The typical deviation of the residuals (prediction errors). Residuals are a measure of how far data points are from the regression line and RMSE is a measure of how these residuals are spread out. Furthermore, it tells you how focused the data is around the best fit line. In accordance with (McDonald & Harbaugh, 1984). Mean error (ME), mean absolute error (MAE) and root mean squared error are the usual ways to define the average difference between simulated and observed hydraulic heads (RMSE). However, the use of RMSE is very common and makes numerical predictions an excellent general-purpose error metric. RMSE amplifies and severely punishes large errors, as compared to the comparable Mean Absolute Error. The RMSE values can be used to distinguish model performance from that of a validation period during a calibration period, as well as to compare the performance of the individual model with that of other predictive models. A direct relationship with the correlation coefficient exists when standardized observations and forecasts are used as RMSE inputs.

The RMSE of a model prediction is defined with respect to the estimated $X_{\text{model}}$ variable as the square root of the mean squared error:

$$\text{RMSE} = \sqrt{\frac{\sum (X_{\text{obs}, i} - X_{\text{model}, J})^2}{n}}.$$
Where \(X_{\text{observed}}\) is observed values and \(X_{\text{model}}\) is modeled values at time/place Correlation coefficient\((R^2)\) was found to be 0.823 after calibration below Fig. 3

<table>
<thead>
<tr>
<th>Measures</th>
<th>calibrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual mean((m))</td>
<td>19.079</td>
</tr>
<tr>
<td>Root mean square error ((\text{RMSE}))</td>
<td>20.65</td>
</tr>
<tr>
<td>sum of residual squares((M^2))</td>
<td>23902.5264</td>
</tr>
<tr>
<td>minimum residual((M))</td>
<td>0.364</td>
</tr>
<tr>
<td>Maximum residual((m))</td>
<td>29.475</td>
</tr>
<tr>
<td>Range in target value((m))</td>
<td>29.111</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>29.98</td>
</tr>
<tr>
<td>Standard dev./range of observed values%</td>
<td>14.19</td>
</tr>
</tbody>
</table>

According to this study, in the subsurface of the groundwater reservoirs (Aquifers), the groundwater potential is stored, recharged from rainfall, the internal groundwater flow from one aquifer with a better hydraulic head to another aquifer with a lower hydraulic head.

### III. Result And Discussion

#### Evaluation of the HEC-HMS results

As the simulated results match the observed data moderately well the HEC-HMS model simulation has been successful. According to the model results Fig. 5 below, both simulated and observed peak and low flows occur at about the same moment. During the rainy winter from 1998 to 2008, the highest flow occurs, while the low flows occur in every dry season because there is no flow for most of the summer months in the Meki-catchment. After that, according to Fig. 5 below, the model parameters discovered by the calibration procedure were determined acceptable to use for the whole simulation period and, based on the validation results, are suitable to use for further analysis. the above Fig. 5 indicates SMA model runoff effects the model therefore predicts lower runoff during the peak observation periods; however, during the low observed runoff, the simulated runoff was higher and the SMA approach in the HEC-HMS model can correctly predict the peak runoff timing. The SMA method has been able to produce useful knowledge about groundwater percolation. The amount of groundwater percolated was dependent on the type of water year (wet or dry). As expected, wet years produced more groundwater percolation, while dry years produced less percolation. The interesting outcome was the volume of water that was transferred to groundwater. The total amount of groundwater water percolated was just above 64.6 mm per year and
the amount of run-off was 162.5 mm per year. The outcome suggests that the rainfall in this area is delivered almost different to the groundwater and surface run off.

**PMWIN modflow results evaluation**

**Water budget of the domain of the ground water model**

The water budget is balanced with a percentage discrepancy of 0.03% for steady-state simulation. The model's water budget includes the terms of inflow; the boundary of recharge, river and constant head, and the outflow term; the boundary of wells, river and constant head. Both inflow and outflow are in balance according to the model outcome, which is compatible with the steady-state theory. A strong inflow of groundwater towards the watershed was observed at the foothills of the eastern escarpment in the northwest of the study area based on the modeling results. In fact, the flow directions towards the river varied considerably, primarily affected by stream-aquifer relationships and groundwater withdrawals. Results of the model's water budget, showed that groundwater recharge represented about 81.48% of the total water input for the entries as well as, leakage from the river into the subsurface and constant head was 3.28%, 15.24% respectively under input water budget. It is also observed that when ground water flow directions are examined in the surrounding area of the river, there is a significant amount of ground water influx towards the river. To quantify and identify all flows in and out of the aquifer structure, the water budget of the model domain is used. Through an aquifer system, this water budget of the model area quantitatively evaluates the amount of groundwater. Although the in-flow and outflow components of the groundwater system are the most difficult to directly calculate, the model has computed both components. By trial-and-error approach, model calibration was performed until the simulated head matched the observed head values to a satisfactory degree. A reasonable match between simulated and observed heads with an RMSE error of 20.65 m was indicated by the calibration result. Therefore, the calibrated groundwater flow for this study area was able to simulate the measured head, especially the sub-basin. The main purpose of these hydraulic conductivity calculation values was to determine the properties of the aquifer. The hydraulic conductivity obtained in this model varies from 0.1 to 21 m/d and on the other hand, the calibrated values mostly range from 0.1 In general, by using the calibrated model with a percentage difference of 0.03, the water budget of the whole model domain was simulated. It includes the following groundwater flow system inflow components: first, constant head boundary recharge, with a value of \((9.85981 \times 10^4)\) m3/day. Second, precipitation groundwater recharge, which is \((5.270846 \times 10^5)\) m3/day and river leakage groundwater inflow, with a value equal to \((2.1141334 \times 10^4)\) m3/day. It includes the simulated outflow of groundwater from the system. Discharge to the constant head boundary, which is \((6.3129125 \times 10^5)\) m3/day, groundwater outflow with a value equal to \((1.5121273 \times 10^4)\) m3/day through river leakage and groundwater outflow with well withdrawal a value equal to \((2.2708463 \times 10^2)\) m3/day. Finally, Table 4.2 shows the inflow and outflow components of the water balance and the steady-state hydrologic budget of the model-calculated study area.

**V. Conclusion**
This research demonstrates progress in integrating a surface water model with a groundwater model to achieve an analysis of groundwater pumping near & away from a river. In evaluating this result, surface and groundwater models were combined to address the goals. First, HEC-HMS 4.2.1 simulated the daily runoff and compared to measured daily records and important data for the hydrological simulation methods considered are: catchment area, land use patterns, daily rainfall, daily river discharge, base flow, catchment soil types, and impermeable areal coverage. As well as, for the ground water model: layer top elevation taken from ASTER DEM, layer bottom elevation is based on the aquifer thickness (85–260), boundary conditions assigned to active cell 1 (model area), assigned to inactive cell 0 for north western % south western area and assigned to Lake constant-head cell with a value of -1. The other parametric input is the initial hydraulic head defined for each cell, by subtracting (20–30) m from DEM. The next parameter is horizontal hydraulic conductivity a value of 0.1 m/day to 15 m/day is used. In addition, Direct precipitation recharge package is \((1.769 \times 10^{-4})\ m/day\), defined for each cell and 103 abstraction wells are handled in well package. After that, in order to calibrate the hydraulic head, the (SWL) measurements for 56 wells used for steady state model calibration with manual testing and error adjustments. According to statistics the optimized model has an RMSE of 20.65 meters and a correlation coefficient of 0.823 after calibration. With a percentage difference of 0.03. Furthermore, a sensitivity analysis was performed to analyze the response to changes in model parameters including horizontal hydraulic conductivity, recharge rate, and pumping for an increase and decrease of the numerical model adjusted to steady state conditions. Simulated water levels in the model were more sensitive to decreases in recharge values and sensitive to decreases in hydraulic conductivity values. However, relative to recharge and hydraulic conductivity, the model is not as sensitive to decreases or increases in pumpage. Finally, for pumping scenarios, including increased pumping based on water supply demand for the years 2010, 2015 and 2020, the model is also simulated. The result shows that the maximum drawdown is 9.714 m in the Cinder cone areas and the least drawdown is in the Kuntane-Inseno-Kela plain, which is only about 1.003 m for the maximum pumping quantity of 325 l/s in 2020. But this is actually the maximum that can be reached in 10 pumping wells for each hydrological zone. However, the drawdown would be less when the number of wells were increased and distributed over the whole area. Finally, the result shows that the community's water supply demand can be covered by fewer declines in Kuntane-Inseno-Kela plain. Whereas, more decline in the Cinder cone areas.

V. Future Scope

Future analysis is still recommended for the western Ziway-Meki Sub basin, given the conclusions of this models, and this model had acceptable fits to the observed data, several assumptions were made and there is a lack of available data for the entire Sub basin. First of all, as the population grows and new and larger water supply wells and irrigation wells are installed and brought into operation, this analysis should be repeated every few years as a check on the sustainable status of the Sub Basin. The main issue is that there is a lack of data on coordinates, aquifer information, static water level and test pumping, and so on. It would therefore help to improve the calibration process by finding more monitoring well data, as the model would have a better understanding of the current conditions it is trying to match. In addition, the
river simulation would assist with additional stream monitoring by building new stream gages. Having data to calibrate the HEC-HMS generated flows would create more reliability in the generated runoff flows.

**Declarations**

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**Conflict of interest**

We here submitted the manuscript entitled “GROUND WATER - SURFACE WATER INTERACTION AND IMPACT ASSESSMENT, IN THE CASE OF WESTERN ZIWAY CATCHMENT, IN ETHIOPIA” to be considered for publication. We declare that this is our original research work. There is no conflict of interest between the authors.

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**Ethical statement:**
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study.

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**Data Availability**

The required data collected for analysis are included in the manuscript. The corresponding author is ready to clarify the data and provides all the necessary data set as per the request

**References**


**Figures**
Figure 1

Scatter diagram of Observed versus estimated discharge for the calibration period (1/1/1998 - 31/12/2005)
Figure 2

observed vs simulated hydraulic heads overlay contour map
Figure 3

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Figure 4

calibrated ground water hydraulic head of western Ziway-Meki watershed
Figure 5

comparisons of observed and simulated stream flow.