NUMERICAL MODELING OF A PHREATIC AQUIFER FLOW IN WESTERN BURSA

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Abstract: The aim of this study is to develop a numerical model of groundwater flow in the lower part of Susurluk Basin located within the boundaries of Karacabey and Mustafakemalpaşa districts of Bursa, Turkey. For this purpose, daily groundwater levels from 5 observation wells were acquired for years between 2013 and 2015. Daily precipitation and evapotranspiration values of several stations in the region were obtained from the General Directorate of Meteorology. In GIS environment, the wells were marked as points and boundaries of the basin were determined using a topographic map and a Digital Elevation Model. Shapefiles containing aquifer boundaries and well locations were transferred to MODFLOW interface. The groundwater flow simulations were performed for years between 2013- 2015 and the groundwater level distribution was obtained. Hydrologic parameters were also estimated.
Keywords: Groundwater, MODFLOW, Numerical Model

Introduction

Various software are available in the field of groundwater modeling. MODFLOW (McDonald and Harbaugh 1988), MIKE-SHE (Refsgaard and Storm 1995) and MODHMS (Panday and Huyakorn 2004) can be given as example. MODFLOW is the most widely used model. For example, Gaur et al. (2011) used Geographic Information Systems (GIS) for watershed management and MODFLOW for groundwater modeling in the study of the Banganga River basin. Wang et al. (2015) modeled the effect of precipitation density on groundwater levels with MODFLOW. Korkmaz et al. (2016) modeled the underground and surface water flow of Eskişehir basin with MODFLOW for transient conditions. Nkhonjera et al. (2017) investigated the importance of direct and indirect effects of climate change on groundwater of the Olifants River basin by basin modeling. Boughariou et al. (2018) modeled the aquifer behavior in the Sfax region of Tunisia by using GIS and MODFLOW 2000 under climate change and high consumption conditions. Liu et al. (2018) conducted basin modeling with MODLFOW in order to investigate the effects of intensive agricultural activities on the groundwater dynamics in the oasis regions of the arid inland river basins in northwestern China.

MODFLOW is a 3D, cell-centered, finite difference, saturated flow model developed by the United States Geological Survey (McDonald and Harbaugh, 1988). MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. MODFLOW uses a combination of three-dimensional water balance equation and Darcy's law as the governing equation:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \tag{1}$$

where K_{xx}, K_{yy} ve K_{zz} are the hydraulic conductivity values along the x, y and z coordinate axes, h is the potentiometric aquifer head, S_s represents the specific storage, W is the source/sink term (per unit volume) and t represents the time. In the steady state conditions, the right-hand side of Eq. (1) equals zero.

In this study PEST was used for parameter estimation. PEST is a general purpose parameter estimation utility developed by Doherty (2013). The purpose of PEST is to assist in data interpretation, model calibration, and predictive analysis. GMS provides a custom interface to the PEST utility offering a simple way to set model parameters and a graphical user interface to run the model and visualize the results.

The aim of this study is to develop a numerical model of groundwater distribution in the part of Susurluk Basin located within the boundaries of Karacabey and Mustafakemalpaşa districts of Bursa, Turkey. Within this scope, daily water levels of 5 observation wells between 2013 and 2015 were acquired. Daily precipitation and evapotranspiration values of the stations in the region were obtained from the General Directorate of Meteorology. In GIS environment, the wells were marked as points and boundaries of the basin were determined using a

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topographic map and Digital Elevation Model. Maps of aquifer boundaries and well locations were transferred to MODFLOW and a grid with a resolution of 150 m x 150 m was generated. By entering precipitation and evapotranspiration values of the years between 2013 and 2015, the groundwater level distribution of the basin was computed. Hydrologic parameters were estimated.

Materials and Methods

The basin used in the study is the part of the Susurluk basin within Karacabey and Mustafakemalpaşa districts of Bursa, Turkey. Uluabat Lake to the east of the basin, Mustafakemalpaşa Stream to the southeast, Mount Çataldağı to the south, Manyas Lake to the west, Marmara Sea to the north. Susurluk River passes through the basin and continues towards north and flows into the Sea of Marmara. However, the modeled basin is bounded by Susurluk River in the north and west and Mustafakemalpaşa Stream in the southeast (Figure 1). The geology of the study area is mainly composed of alluvial plains and river sediments. In general, the topography consists of low plains in the north and the height increases to the south.

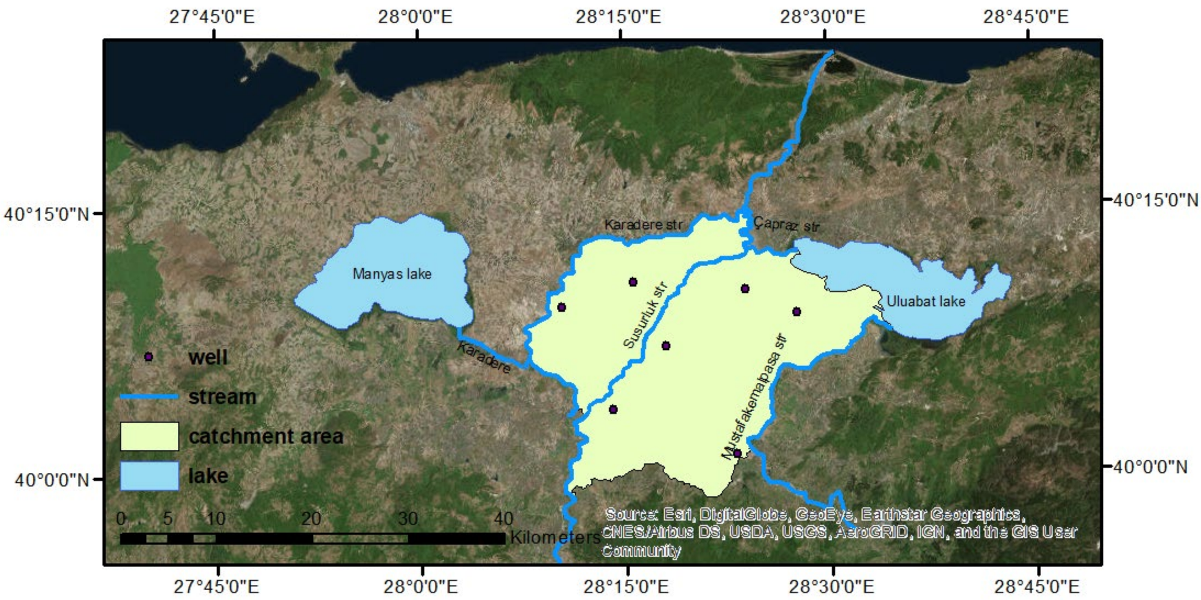

Figure 1. Study Area

Initially, the data of 5 observation wells were acquired from State Hydraulic Works. 3 of these wells are located in Karacabey and 2 in Mustafakemalpaşa districts in Bursa. The data includes hourly water and barometric pressures recorded between 2013-2015. The external parameters that affect the groundwater level of the basin are precipitation and evapotranspiration. Daily precipitation and evapotranspiration values measured between 2013-2015 at observation stations in Karacabey and Mustafakemalpaşa were obtained from the General Directorate of Meteorology.

Basin delineation was done in GIS environment. Aster GDEM raster files with a resolution of 30 m x 30 m were used to determine the basin area. The raster file was converted to point heights for use in MODFLOW. Hydrological analysis of the basin was performed using the ArcHydro toolbar. Shape files were created and the wells, rivers, lakes and meteorological stations in the basin are plotted on the map.

A diagram for modeling process is given in Figure 2:

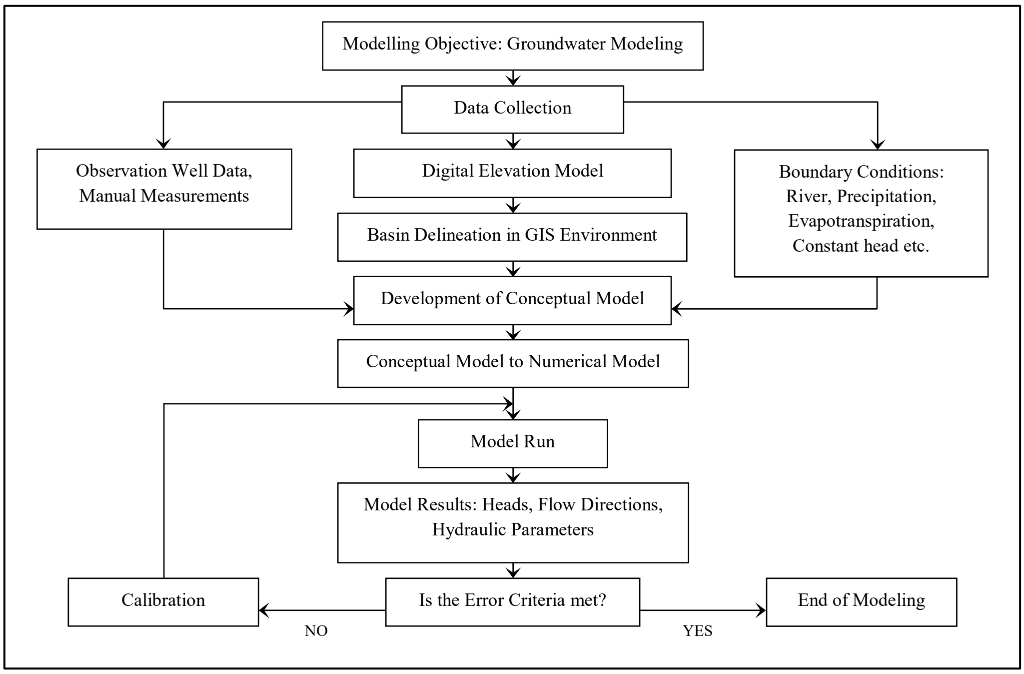

Figure 2. Work flow diagram of modeling

Numerical modeling was done in GMS program. GMS is a program that provides graphical interface for MODFLOW. GMS generates and records input data for and visualizes the output from MODFLOW. Files transferred from the GIS environment to the GMS appear as shape files. These files were transferred to the newly created conceptual model in order to transfer the spatial data to MODFLOW grid. In the generated grid cell size was 150 m x 150 m on x-y plane, and it composed of 1 layer in z direction.

MODFLOW 2005 was selected as version and model type was selected as steady state. LPF (Layer Property Flow) was selected as the flow package and PCGN was selected as the solver. Point elevations were used as surface elevations in MODFLOW. The rivers in the basin were modeled with the RIV1 package. In order to use the RIV1 package, the conductivity value (C, m^2/day) must be entered. In addition, water surface elevation and river bottom elevation should be entered for the river. The water surface elevation of the lake in the northeast of basin was entered as specified head using the CHD1 package. DRN1 package is used to model the drains in the basin. In DRN1 package, the conductivity value (C) of the channel and the bottom elevation of the drain must be specified. RCH1 package was used for precipitation in the basin and EVT1 package was used for evapotranspiration (ET). EVT1 package requires the maximum ET rate and the extinction depth to which the evapotranspiration will be applied.

The constant head boundary condition was used for rivers along the eastern, northern, and southeastern boundaries of the basin. Other boundaries were specified as impermeable boundary. Hydraulic conductivity was determined by calibration using the PEST (Parameter Estimation) model within the range of 5 to 500 m/day. In PEST simulations, the observed groundwater levels were compared with the values calculated by MODFLOW. After the calibration was completed, the groundwater distribution of the basin was determined for all years.

Results and Discussion

Groundwater distribution of study area for years 2013, 2014 and 2015 are given in Figures 3, 4 and 5 respectively. The calculated heads of each well were compared with the observed heads are also given for years 2013, 2014 and 2015 in Table 1, 2 and 3 respectively.

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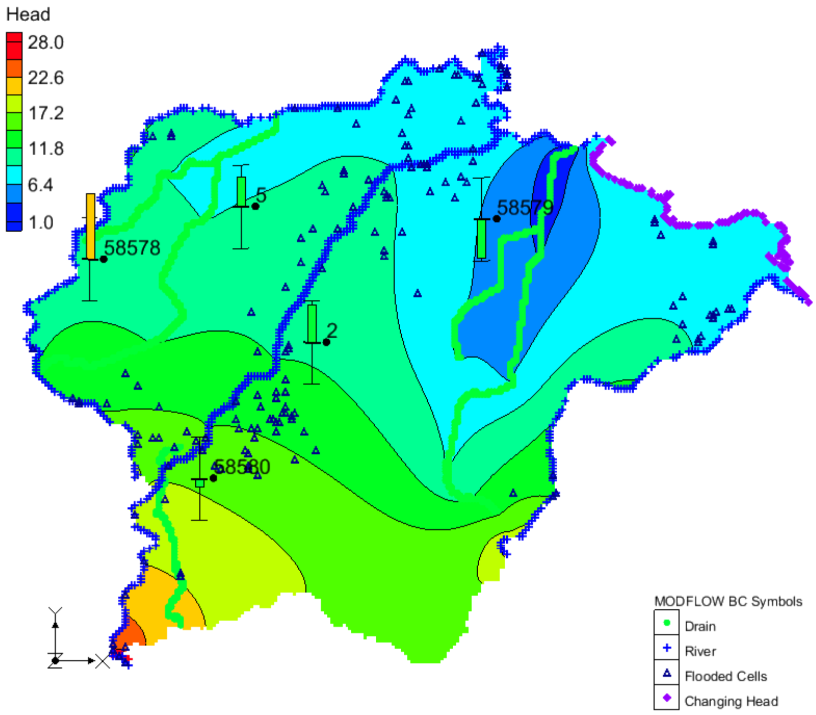

Figure 3. Groundwater level distribution of the basin for 2013

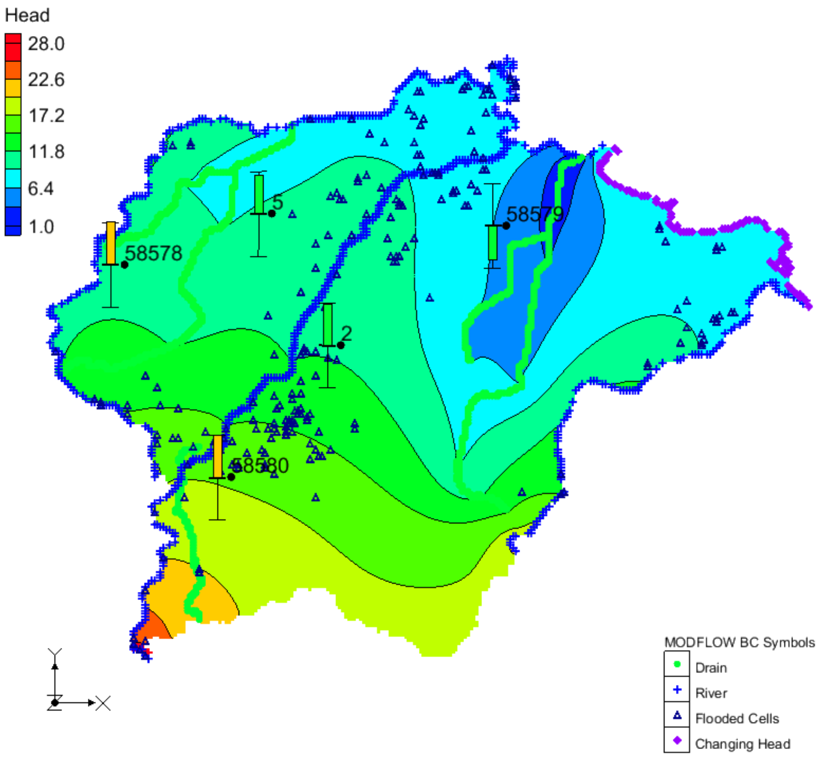

Figure 4. Groundwater level distribution of the basin for 2014

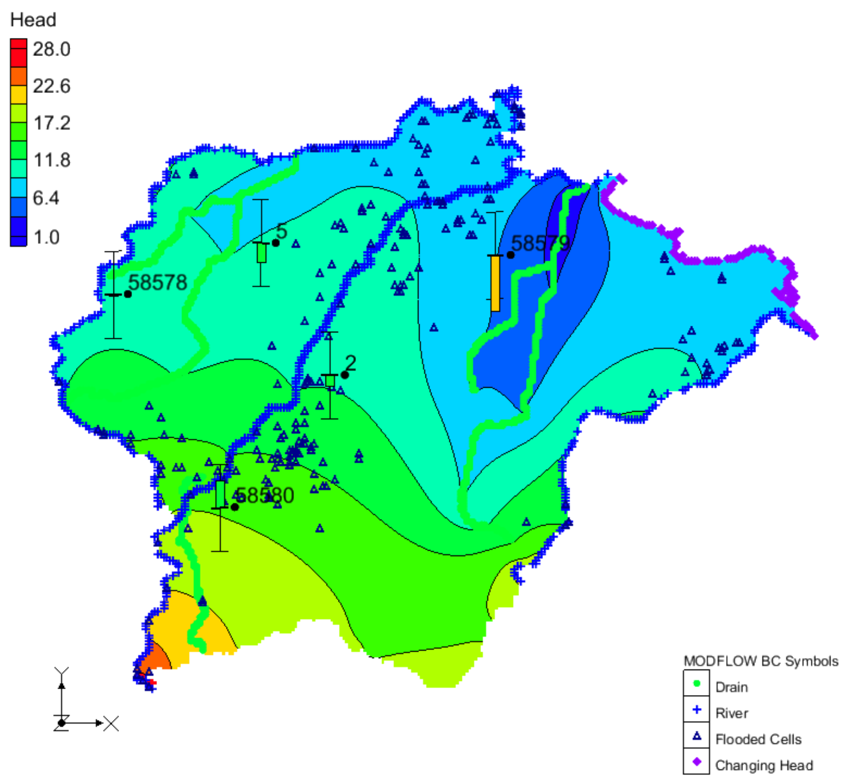

Figure 5. Groundwater level distribution of the basin for 2015

After PEST run and calibration hydraulic conductivity is found 50 m/day. From the residuals it can be seen that the accuracy of the model is high. In the year 2014, when the rainfall was higher and the evapotranspiration was lower, it is observed that the water level is slightly higher compared to the year 2013.

In 2013 it is observed that the highest errors were detected in the northwest of the basin, while the lowest error occurred in the southern part with high elevations. In 2014, the errors are higher in the eastern part of the basin and the calculated values are generally higher than the measured ones. In the year 2014, when the rainfall is highest and the evapotranspiration is lowest, it is seen that the water level is slightly higher compared to other years, as expected. In 2015, when the evapotranspiration value increased compared to the previous year, it is observed that the errors are high in the northeastern part with the lowest elevations in the basin. The water levels obtained for 2015 are generally lower than those observed.

Table 1. Residual errors of each well in the basin for simulation year 2013

Well code	Observed Data (m)	Computed Data (m)	Residual (m)
5	7.8891	9.3256	-1.44
58578	7.8243	10.9697	-3.15
58579	7.4748	5.6273	1.85
58580	16.9079	16.5209	0.39
2	9.3069	11.1109	-1.80

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Table 2. Residual errors of each well in the basin for simulation year 2014

Well code	Observed Data (m)	Computed Data (m)	Residual (m)
5	7.6238	9.4706	-1.85
58578	8.9973	11.0282	-2.03
58579	7.3584	5.7836	1.57
58580	14.7926	16.7947	-2.00
2	9.4538	11.3974	-1.94

Table 3. Residual errors of each well in the basin for simulation year 2015

Well code	Observed Data (m)	Computed Data (m)	Residual (m)
5	10.3528	9.4611	0.89
58578	11.1206	11.0257	0.09
58579	8.3511	5.7725	2.58
58580	15.4729	16.7174	-1.24
2	11.8770	11.3577	0.52

Conclusion

In this study, a numerical model of groundwater distribution in the Susurluk basin within the boundaries of Karacabey and Mustafakemalpaşa districts of Bursa province was developed. The basin hydrological features were drawn as shape files in GIS environment and then they were transferred to the MODFLOW interface, namely, GMS. The necessary data was mapped to MODFLOW grid. Modeling of the basin was made in steady state. Hydraulic conductivity values were determined using the PEST model. Generally, an agreeable fit was observed between simulated and observed hydraulic heads. In days of excessive precipitation and low evapotranspiration groundwater levels increased. An important part of the basin is composed of alluvial lands and hence the high hydraulic conductivity caused the water to spread more easily in the aquifer resulting in a very slight annual fluctuation. Model errors may decrease further by calibrating the hydraulic conductivity regionally considering the geological structure. It is believed that more realistic results can be obtained if modeling is done in transient state conditions. It would be advantageous to include these results in the planning of the water supply in the study area.

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