# Automatic Calibration of Groundwater Simulation Model (MODFLOW) by Indeterministic SUFI-II Algorithm

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## ABSTRACT

**Mathematical simulation of groundwater resource systems is one of the essential tools in managing these valuable resources and calibration of the groundwater simulation models is the time-consuming, and complicated step of these systems. Automated calibration, developed in recent years by researchers with different algorithms, is one of the effective methods to overcome these computational problems. On the other hand, lack of field data in terms of time and space and the hydrological and hydrogeological complexities leads to many uncertainties in the calibration results. The SUFI-II algorithm is an uncertainty-based automatic calibration method that is capable of calibration and uncertainty analysis of numerical simulation models. In this paper, for the first time, this algorithm is used to calibrate and analyze the uncertainty of hydrodynamic parameters (hydraulic conductivity and specific yield) of the MODFLOW model. The results of model implementation for the Ardabil plain groundwater model (Northwestern Iran), indicate an average of 62 percent of the observation data within the 95 percent confidence interval. Finally, the best intervals of parameters are determined for the hydraulic conductivity and specific yield by the proposed approach. Also, the calibration of the groundwater model has been carried out using PEST. According to the results, the root-mean-squared error (RMSE) value in this case (RMSE = 3.37) is higher than the SUFI-II method (RMSE = 1.86), which indicates better performance of the SUFI-II algorithm than the PEST model.**

## KEYWORDS

**Automatic calibration, MODFLOW, uncertainty analysis, SUFI-II algorithm, Ardabil plain aquifer.**

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## 1. Introduction

The main challenge that researchers deal with numerical simulation models is the calibration of these models. PEST [1], UCODE [2], etc. some of the famous ways to calibration these models. Although these methods speed up the calibration process, they may obtain irrational values for the parameters because their purpose is to match observational and computational values regardless of physical reality [3].

In this study, we used an uncertainty-based automatic calibration method for auto-calibration of the Ardabil groundwater model. The MODFLOW model developed for groundwater modeling and the SUFI-II algorithm used for automatic calibration and uncertainty analysis of the hydraulic conductivity and specific yield of the aquifer. Although a lot of methods are developed for groundwater calibration, this method has not been used in the groundwater model. Unlike other optimization methods, SUFI-II can consider the uncertainty of the input parameters in output results. Also, the calibration of this model performed by PEST and compared with the SUFI-II method.

## 2. Methodology

The general framework used in this study is shown in Figure 1, According to this figure, the SUFI-II algorithm, by changing the values of parameters (which used as input to the groundwater simulation model), repeatedly invokes the groundwater simulation model and sampling Depending on the objective function of the evaluation. Then, calculate the uncertainty criteria and finally determine the optimal values for each of the parameters.

The 3D governing equation for transient groundwater flow used in MODFLOW can be expressed in equation (1):

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

Where, $K_{xx}$, $K_{yy}$ and $K_{zz}$ are hydraulic conduction values in the x, y, and z directions. h is The hydraulic head, $W$ is the recharge term (in this case, $W$ is negative) or the discharge term (in this case, $W$ is positive), $S_s = S_y / b$ is the specific storage that here $S_y$ is the specific yield coefficient and $b$ is the aquifer thicknesses [4].

SUFI-II algorithm is the second version of the SUFI algorithm SUFI-II finds the best range of parameters

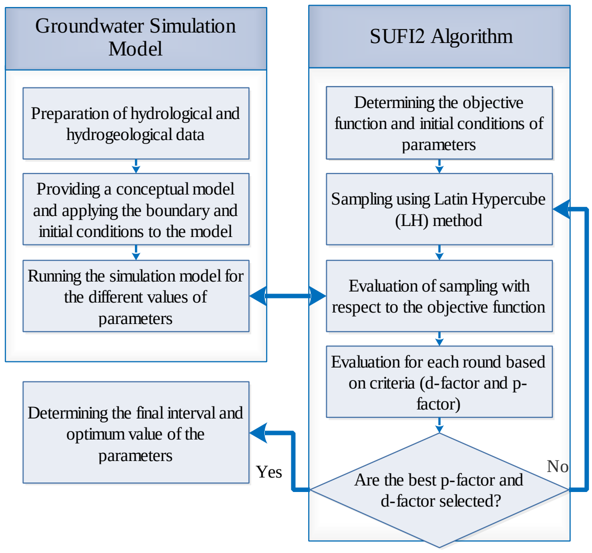


Figure 1. MODFLOW-SUFI2 linked model

with the minimum number of iterations. The initial uncertainty intervals of each parameter determined by Latin Hypercube Sampling (LHS) with uniform distributions. Sampling is evaluated based on the objective function. The uncertainty of the model output is represented within 95 percent prediction uncertainty (95PPU). This algorithm minimizes the uncertainty range of parameter in a way that, the number of observation points located in the region of 95PPU is reasonable. The quality of the calibration and uncertainty analysis is evaluated based on the p-factor and d-factor indexes. The p-factor index is expressed in terms of the ratio of the number of observations in the 95PPU region to the total observations also, the d-factor is the average width of 95PPU divided by the standard deviation of the observation data [5].

## 3. Discussion and Results

The groundwater model of the Ardabil aquifer is developed for 12 monthly time steps (from October 2007 to September 2008) in transient conditions. the groundwater level of September 2007 that obtained from 12 observation wells distributed in the model domain, is considered as the initial groundwater level. Based on SUFI-II, the optimum p-factor and d-factor are obtained in round 5 with 0.62 and 1.77 values respectively. In Figure 2, unsteady conditions of the 95% confidence interval for observation wells Number 2, along with observational data from the Ardabil aquifer is calculated as a time series for the duration of the modeling period. As shown in this figure, it seems that the SUFI-II algorithm has been able to predict the range of calibration values correctly. The observed values are within the range of values predicted by the MODFLOW-SUFI-II model.

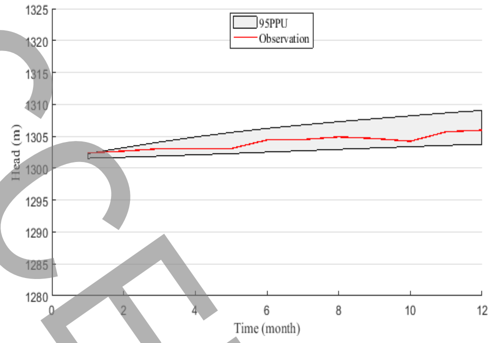


**Figure 2. Comparing monthly simulation head with observation head in observation well No.2**

Based on optimal values of the parameters obtained from SUFI-II method, the distribution of hydraulic conductivity and specific yield in the aquifer domain is shown in Figure 3 and Figure 4.

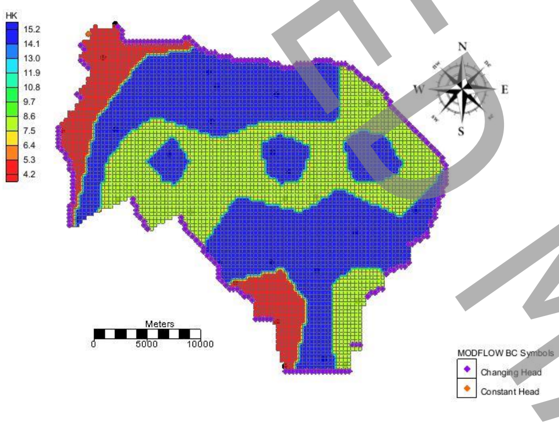


**Figure 3. Hydraulic conductivity of Ardabil aquifer after calibration with SUFI-II (m/day)**

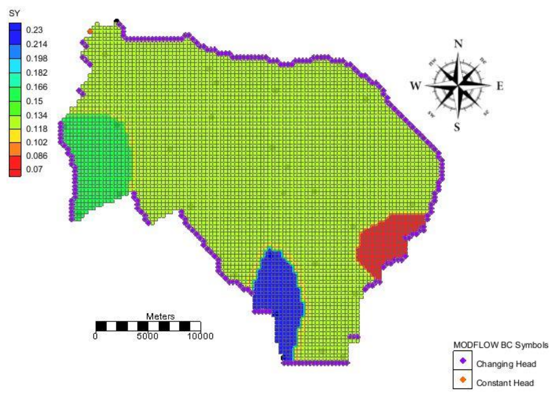


**Figure 4. Specific yield of Ardabil aquifer after calibration with SUFI-II**

Also, Figure 5, represent the groundwater level of Ardabil aquifer after calibration with the SUFI-II method for September 2007. The calibration targets are shown for the observation point in this figure that the colored bar shows the error. If the error, less than 1 unit the color will be green and if it is between 1 and 2 unit the color will be yellow.

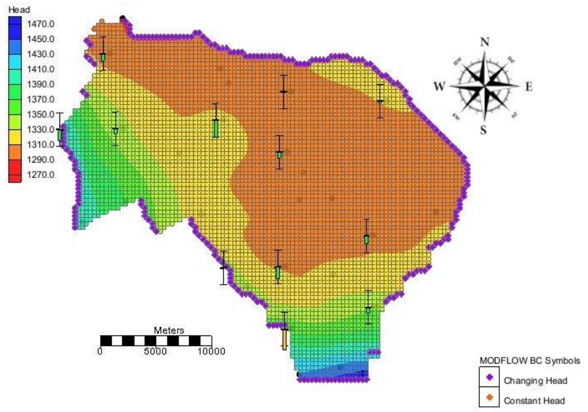


**Figure 5. Groundwater level of Ardabil aquifer after calibration with SUFI-II algorithm (September 2007)**

## 4. Conclusions

In this study, we developed the MODFLOW-SUFI-II model for uncertainty-based automatic calibration of the Ardabil groundwater model. Results of SUFI-II in comparing with PEST for calibration of hydraulic conductivity and specific yield showed that the p-factor and d-factor values were calculated as 62% and 1.77, which resulted in a value of 1.86 m for the RMSE. Also, the RMSE in the model run using PEST was 3.37 m. Finally, by comparing the SUFI-II algorithm with PEST it can be said that this algorithm performs well in the calibration of the Ardabil aquifer model. Also, there are various sources of uncertainty in modeling input parameters that can be considered separately.

## 5. References


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