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Multi Model Approach to Study the Effect of Conceptualization and Discretization on Groundwater Model

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Abstract*— The objective of the study is to develop multiple steady state conceptual and numerical groundwater flow models for Bhiwadi region of Alwar district of Rajasthan, India. Automated parameter estimation tool (PEST) is used for the calibration of the models. To evaluate and select the best suited conceptual flow model, several statistical criteria such as RMSE (Root Mean Square Error), R-squared (R^2), Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), multi model information criteria: Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are used. The result of the study indicates that value R2, NSE and Pbias are almost similar for all the models, hence are insufficient to evaluate the models. Therefore, AIC and BIC statistical criteria are used for accurate evaluation. The result also indicates that grid size and orientation have immense impact on modeling output. For the study area coarse grid size has given better results as compared to finer grid size.

Index Terms*— AIC, Conceptual flow model, NSE, PBIAS.

I. INTRODUCTION

Groundwater is valuable and essential source of water for domestic as well as industrial purpose. Climate change, industrialization, increasing population and socio-economic changes have amplified the stress on groundwater resources, causing a continuous decline in water levels. If current trend of overexploitation of groundwater continues in future, then in 20 years, 60% of all India's aquifers will be in a critical condition (World Bank, 2010).

Rajasthan state occupies a unique geographic position in northwest India with adverse climatic conditions varying from arid to semi-arid, low to scanty and erratic rainfall and lack of perennial water sources (CGWB 2017). Rapid industrialization in few districts has further affected the quality and quantity of groundwater in the state. Industrial clusters have been developed at Bhiwadi, Alsar, Neemrana and Behror in Alwar district of Rajasthan. Pollution study carried out by CGWB (2017) at Bhiwadi industrial cluster, has indicated the contamination of ground water with presence of high concentration of toxic substances such as cadmium, lead and nickel more than the acceptable limit of drinking water specification.

Rajput et al., (2020a) carried out a study in Bhiwadi region to assess the impact of increased industrialization on groundwater quality using remote sensing and geospatial tools. The result of the study indicated that the number of wastewater bodies, due to effluent water discharge from industrial clusters, has increased in the study area and are the potential source of groundwater contamination the region. Groundwater vulnerability assessment of Bhiwadi and nearby region was carried out by Rajput et al., (2020b) using modified and optimized DRASTIC model for anthropogenic source. The study clearly indicated that the groundwater resources in and around the industrial clusters are under highly vulnerable zone.

In recent years, numerical modeling has become an important tool for groundwater studies. Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions (Anderson and Woessner, 1992). There is a need for simplification of real-world systems (Zhou and Herath, 2017) and organize the associated data so that the system can be analysed more readily. Conceptualization is an important factor in groundwater modeling. Extensive studies by various researchers discuss the importance of development of conceptual model (Singhal and Goyal, 2011; Rojas et al., 2010; Bredehoeft, 2005). Due to complexity and inherent uncertainty of the knowledge about the real system, multiple conceptual models are possible for the same system based on different set of simplified assumptions (Hojberg and Refsgaard, 2005; Poeter and Anderson, 2005). Around 5% to 30% of predictive uncertainty is derived from model conceptualization and ignoring the conceptual model uncertainty may result in biased predictions (Rojas et al., 2008). A poor developed conceptual model generates biased results; thus, development of conceptualization serves as a basis of groundwater modeling (Yang et al., 2010). Several conceptual models can be built based on different set of assumptions and can be evaluated to select the most suitable model for the system (Hojberg and Refsgaard, 2005; Poeter and Anderson, 2005).

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Evaluation and comparison of alternative conceptual models using certain statistical criteria is an important step for selecting the best model for the system (Poeter and Anderson, 2005). Root Mean Square Error (RMSE) and R-square are most commonly used statistical criteria to evaluate and compare the alternative conceptual models but may not be adequate as the alternative models can have similar RMSE and R-square values. Hence use of several statistical criterion such as Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), Akaike's Information Criteria (AIC) and Bayesian Information Criteria (BIC) are very important for accurate evaluation and selection of best model (Poeter and Hill, 2007). In present study an attempt has been made to develop multiple conceptual and numerical models for the Bhiwadi region of Alwar, district of Rajasthan. The multiple steady state models thus developed are evaluated and compared using various statistical criteria to find the best model for the study area.

II. STUDY AREA

The study area Bhiwadi is situated in Tijara block of Alwar district of Rajasthan (Fig. 1). The geographical location of Bhiwadi lies between 28°710" N – 28013'40" N latitude and 76045'E – 76055'50" E longitude. Climate can be classified as semi-arid with normal annual rainfall of 645.6 mm during southwest monsoon period (CGWB 2017). A well-drained alluvial sandy soil is found in the region. The aquifers are found primarily in older alluvium and quartzite where alluvium occupies 67% and quartzite forms about 22% of the area. The maximum thickness of alluvium has been noticed in Tijara block. Bhiwadi is a fast-developing industrial township. Industries in Bhiwadi region are of varied nature such as electroplating, rolling and pickling, pharmaceuticals, textiles, paints and inks, automobile parts, foods and beverages etc. and is considered as most polluted industrial area (CPCB 2011).

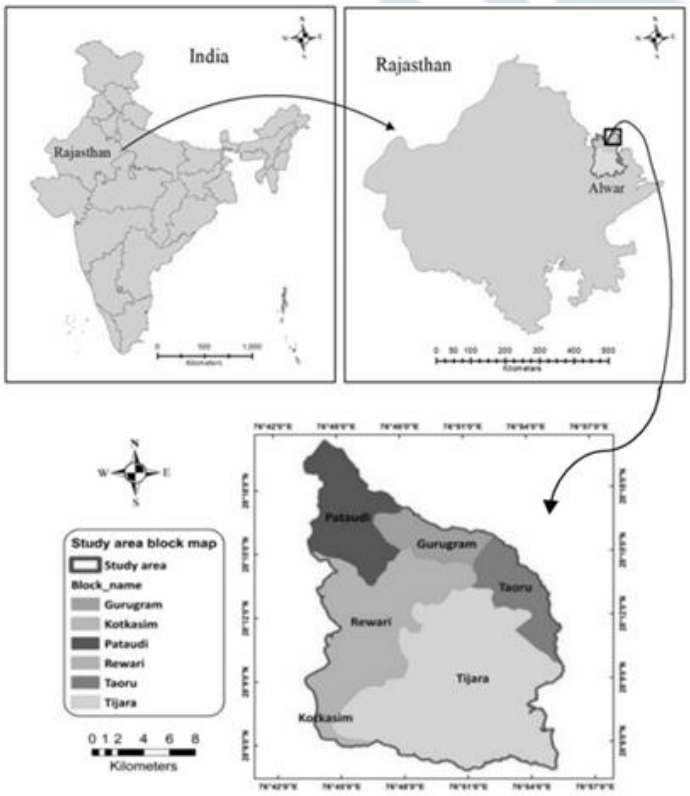

Figure 1. Location map of study area

III. METHODOLOGY

Multiple conceptual models of study area are created using Geographic Information System (GIS). The data obtained from various sources such as Central Groundwater Board (CGWB), State Groundwater Department (SGWD) and Survey of India was utilized to create separate GIS layers. The data obtained from various sources such as Central Groundwater Board (CGWB), State Groundwater Department (SGWD) and Survey of India was utilized to create separate GIS layers. These layers were imported into the GMS (Ground Water Modeling System) software to develop the conceptual model through various coverages and packages (Kushwaha et al., 2009). Groundwater flux across boundaries is calculated using methodology developed by Kushwaha and Goyal (2015). These models are then converted 3-D modular finite difference based MODFLOW numerical models (McDonald and Harbaugh,1988; Harbaugh and McDonald, 1996).

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The observation well coverage was created for the calibration targets for which 12 observation wells are selected with a threshold value of ±3m observed head intervals. Groundwaters heads are computed at location of observation wells and are used to compare the model results for better judgement.

80 steady state conceptual models have been developed for the same system by variation in the parameters like boundary conditions, model layers, grid spacing and grid orientation.

Calibration is the process in which certain parameters like recharge, hydraulic conductivity etc. are altered in systematic way and the model runs repeatedly until the residual errors are reduced by matching the computed head to the observed head. In present study models are calibrated using automated parameter estimation tool PEST. Zone-based parameterization approach is used in PEST.

Several statistical criteria such as RMSE (Root Mean Square Error), R-squared (R^2), Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and multi model information criteria: Akaike Information Criterion (AIC) (Akaike, 1973, 1974) and Bayesian Information Criterion (BIC) were computed for each model in order to compare different models.

IV. RESULTS AND DISCUSSIONS

Most of the models indicated good values of R2, NSE and Pbias, hence these criteria are insufficient for evaluation and comparison. Therefore, the models are evaluated and compared on the basis of AIC and BIC. The statistical analysis of five best models out of total 80 steady state conceptual models is given in Table 1. The comparison of AIC/BIC values and RMSE values of five best models are shown in Fig, 2 and Fig. 3 respectively.

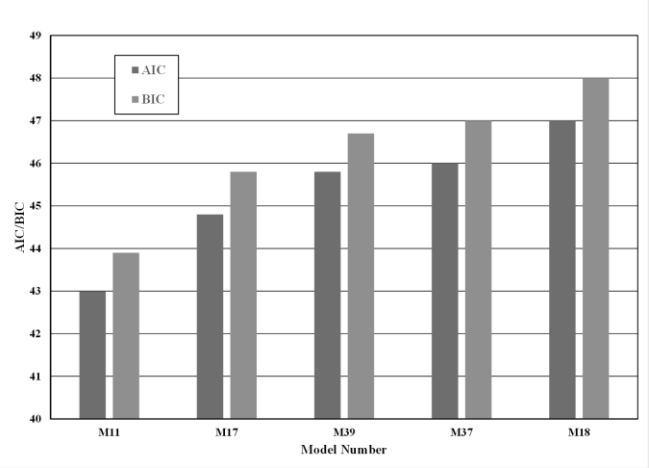

Figure 2. Comparison of AIC and BIC values

Table 1. Statistical analysis of numerical model simulation for different grid size and angle

Model name	Grid size (m)	Grid angle (degree)	Layers	R^2	RMSE	NSE	PBIAS	AIC	BIC
M11	300x300	15	2	1	1.23	0.99	0	42.97	43.94
M17	400x400	25	2	1	1.32	0.99	0	44.8	45.77
M39	400x400	40	2	1	1.38	0.99	0	45.77	46.74
M37	400x400	25	2	1	1.39	0.99	0	46.02	46.99
M18	400x400	30	2	1	1.45	0.99	0	46.99	47.96

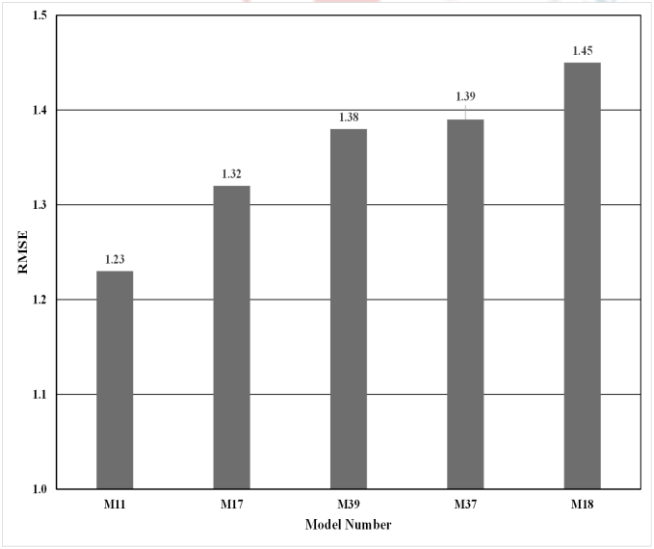

Figure 3. Effect of grid on RMSE values

The result of the study also indicates that the coarse grid size models performed better than finer grid size models for the available data and conditions. However no significant impact of grid orientation was observed on the model output for the study area.

The sensitivity analysis indicated that horizontal hydraulic conductivity of Manesar, Rewari and Tijara zone for layer 1 is the most sensitive parameter whereas horizontal hydraulic conductivity of Kotkasim zone for layer 1 is the least sensitive parameter.

V. CONCLUSION

Development of conceptual flow model depends prima facie on availability of data followed by modelers judgement and understanding of the real system. Hence, multiple conceptual models for the same system are possible due to complexity and inherent uncertainty of the knowledge about the area.

It is found that traditional method of evaluating the models based on comparison of observed heads with the computed heads alone is not adequate to identify the optimum model. Criteria such as AIC and BIC must be used for the evaluation.

Grid size and orientation has immense impact on modeling result. Grid size indicates the extent to which the hydraulic properties and stresses can vary in the study region. For the present study area coarse grid size mainly 300x300m and 400x400m has given better results as compared to finer grid size for the available data and conditions. However, no significant impact of grid orientation was observed on the model output for the study area. Thus, it is also important to account for the uncertainties related to model discretization in groundwater modeling.

Development of multiple conceptual models for the same system and their evaluation using appropriate statistical criteria helps to overcome the uncertainties related to model conceptualization and discretization, which can be useful for transient simulation for reducing errors and predicting the future scenario of groundwater system.

VI. ACKNOWLEDGEMENT

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