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Modeling of groundwater heads for the climate change scenarios

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Abstract - *Groundwater is the most critical wellspring of water all through the world. But now a days the groundwater resources of the world have been facing a big problem due to the urbanization, industrialization, population growth and also due to climate changes especially, in the Asian countries. India is one among those countries which is facing the problems of groundwater due to its low capacity to adapt. Karnataka is facing severe groundwater problems from the past few years due to the uneven rainfall, climate change, cropping pattern and also by the over exploitation of the groundwater. For this purpose an attempt has been made to measure the water resources. This study mainly focuses on modeling the groundwater flow process respectively, for the Hiranyakeshi watershed of the Ghataprabha sub-basin. The groundwater modelling is carried out by using modelling software. There are wide number of programming's to mimic the groundwater, out of those Visual MODFLOW (Modular Finite Difference Groundwater flow Model) Flex v 14.2 has been chosen due to its accuracy and popularity The A1B climate change scenario for the mid scenario period 2021-2050 was used to study the effect of climate change on the hydrologic process of the study area assuming that the landuse remains same. The mid scenario data was derived from HadRM3 (Hadley Regional Model 3) model.Groundwater models are utilized to reenact and foresee aquifer conditions.*

Key Words: Groundwater, MODFLOW modeling, simulation, calibration, validation

1. INTRODUCTION

With the increasing population and globalization, there is an increase in water demand. Both surface water and groundwater are the valuable resources to sustain the human life. As humans have direct access to the surface water, it has been extensively exploited, degrading its quality and quantity, making it a scarce source. However, advancement in the technology made it easy to abstract water from subsurface. In the recent years, use of water resource is being dependent on the dominating source availability, either groundwater or surface water. Apart from human pressure on water resources, climate change driven by anthropogenic activities possesses severe threat on these scarce resources. There are uncertainties associated with climate change, however, they possess severe threat across low latitude and developing countries like India because of its low capacity to adapt. Furthermore, climate change has direct impact on surface water resources. In contrast to surface water relationship with climate change, the relationship between the climate change and groundwater is quite complicated and is difficult to quantify. Groundwater is finite yet most valuable natural resources for human survival, economic development, and ecological diversity. Due to its several inherent qualities such as consistent temperature, widespread and continuous availability, excellent natural quality, limited vulnerability, low development cost and drought reliability), it has become an important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries. The net annual ground water availability of the country has been assessed as 396 bcm with the annual ground water draft of 243 bcm as on March, 2009 irrigation sector (about 91%) being the largest user. The stage of ground water development for the entire country has been computed as 61%, which was only 32% with the annual draft of 115 bcm in the year 1991 (CGWB, 2011). Further, the irrigated area has increased by five folds since 1960 ignited by the advancement in the technology, increasing availability of drilling equipment, pumps, and the government subsidies.

2. STUDY AREA

The Hiranyakeshi watershed of the Ghataprabha sub-basin falls between the latitude 15° 56' N to 16° 21' N latitude and longitude 74° 00' E to 74° 35’ E longitude in Hukkeri taluk of western part of Karnataka and the remaining portion in Ajara and Gadhinglaz taluk of southern Maharashtra. The maximum and minimum elevation of the Hiranyakeshi watershed varies from 619 meter to 1029 meter respectively. The area of the Hiranyakeshi watershed is about 1078sqkm. The Ghataprabha River rises from the Western Ghats at an altitude of 884 meters. The river flows eastwards for a distance of 60km through Sindhudurg and Kolhapur district in Maharashtra. The river borders the two states i.e. Maharashtra and Karnataka about 8km before flowing into Karnataka. Sahyadri ranges lies in the western part of the basin and the slope of the domain decreases from west to east. The river Hiranyakeshi flows from south west to north east direction and meets Ghataprabha River in Karnataka before joining to the river Krishna. Rainfall is unevenly distributed over the basin and it decreases from the west to the east, greater than 3000mm/years to less than

1000mm/year respectively. The figure 1 shows the location map of the study area.

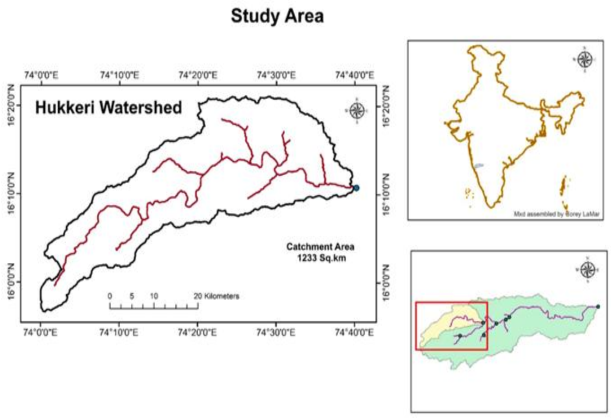

Fig -1: Location map of the study area

3. METHODOLOGY

Methodology is the major/vital part of the modeling. The methodology adopted here, in this modeling depends on the objectives defined. Here Visual MODFLOW has been used for the groundwater modeling and the figure 2 represents the workflow process for the MODFLOW. The first step in every modeling is to collect the data's such as lithology, river data, observation well and pumping well data and recharge data. The modeling was carried out in three steps, the first step is to develop the conceptual model, the so developed conceptual model is converted to numerical model/MODFLOW model and the numerical model was translated and simulated. The figure 2 shows the workflow process of groundwater modeling. The observation and pumping well data were collected from the Central Groundwater Board, Bengaluru. The rainfall data for the period 2021-2050 was obtained from Hadley Regional Model 3 (HadRM3).

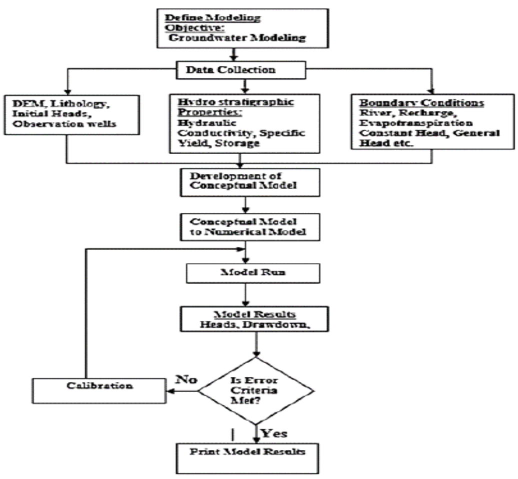

Fig -2: Workflow process for groundwater modeling using MODFLOW

4. CLIMATE CHANGE SCENARIOS

Climate change scenarios are the alternate image of how future climate might unfold, based on the current emission range of greenhouse gas (GHG). Various organizations have been involved in developing the global climate models (GCMs). Limitation of the GCMs future climate variables to model hydrologic processes in regional scale due to their coarser resolution and failure in accounting influence of monsoon rainfall pattern in Indian context, led to the development of regional climate models (RCMs). RCMs downscale the GCMs simulation to a regional scale after incorporating the topographic details of the area of interest. In this case, Hadley Regional Model 3 (HadRM3) data was used to study the climate change scenarios. The climate characteristics of the model simulations used by the Hadley Centre models are based on a set of emission storylines created by the Intergovernmental Panel on Climate Change. The design of the models was based on the UK climate impact program, which has been linked to the IPCC story lines. The four UKCIP02 scenarios represent a climate forced by: low emissions, medium-low emissions, medium-high emissions and high emissions. Data from Hadley Regional Model 3 (HadRM3) are of a smaller scale, with grid resolution of 50km by 50km. The daily weather parameters are generated for two extreme periods: 1960-1990 and 2021-2050.

4. RAINFALL AND RECHARGE DATA

The rainfall data was obtained from the Hadley Regional Model 3 (HadRM3), the recharge for the Hiranyakeshi watershed was calculated from the formulae given by the Groundwater Estimation Committee (GEC). The rainfall and recharge values for the mid scenarios (2021-2050) is shown in the table 1. These recharge values were inputted into the MODFLOW and the model was simulated for 30 years.

Table-1: Rainfall and Recharge values for the mid scenarios

Year	Precipitation (mm)	Recharge (mm)
2021	2206.8	742/748
2022	1587.1	550.090
2023	1743.5	633.976
2024	2247.9	769.717
2025	1970.7	699.7461
2026	1944.9	618.996
2027	1908.3	622.659

2028	2175.7	721.1715
2029	1568.1	583.144
2030	1171.5	348.677
2031	1841.5	695.024
2032	2021.7	694.446
2033	1446.2	550.840
2034	2094.3	710.1614
2035	2227.1	724.1002
2036	1652.1	552.167
2037	1939.3	611.279
2038	1735.7	650.324
2039	1446.4	499.841
2040	1975.3	631.7541
2041	1788.2	583.219
2042	2015.6	691.5301
2043	1382.5	464.6203
2044	2290.5	711.4684
2045	1490.6	571.6962
2046	1494.9	538.5126
2047	1876.2	663.5368
2048	1351.5	436.7939
2049	1452.9	570.2938
2050	1874.8	667.907

5 .CALIBRATION AND VALIDATION

Calibration refers to the fine tuning of the model parameters such that model simulated results properly matches the field conditions. So, for this purpose, it is necessary that field conditions should be properly characterized. Improper characterization may results in a model, subjected to a set of boundary conditions, which is not representative of real field conditions. Parameter ESTimation (PEST) has been used to calibrate the model in the current study. Doherty and Johnston in 2003 developed the PEST, which is a non-linear parameter estimation and optimization package. It offers model independent optimization routines. PEST uses Levenberg-Marquardt algorithm (i.e. gradient-based methodology) to search for the optimal solution. The objective in case of groundwater model calibration is to minimize the sum of squared residuals. Residual are differences between observed and simulated groundwater heads. Visual MODFLOW FLEX has a PEST serving as a GUI for calibration purpose. Initially, observation heads with initial weights are assigned. Then, next step is to assign the pilot points. Pilot points are the user defined points where PEST algorithm optimizes the parameters. Once the pilot points are assigned, next step is to define the range for the parameters to be optimized. Now next step is to perform sensitivity analysis and then go for parameter optimization. Once done with sensitivity analysis and parameter optimization, a new sets of calibrated parameters are obtained for which model is run once again.

6. RESULTS AND CONCLUSIONS

The major outcomes of the modeling are heads, drawdown and water table. Groundwater modeling showed an increase in groundwater level in the study area supported by the long term groundwater level analysis. Groundwater model was calibrated and validated. R^2, NRMSE and RMSE have been used to evaluate the model performance. Model behaved well with R^2, RMS and NRMS for 0.99, 1.68m and 3.41% respectively .Increase in groundwater level possess a severe threat of creating water logging condition and groundwater flooding in low lying areas. Further, the climate change scenarios revealed the increased groundwater recharge in the study area. Incorporating these results in planning the water resource in the study area would be advantageous.

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