

Report No. -----

GROUNDWATER FLOW MODELING IN LOWER BINA BASIN

(Final Report)



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PREFACE

Groundwater model has become a commonly used tool for hydrogeologists to perform various tasks. The rapid increase of computing power of PCs and availability of user friendly modeling systems has made it possible to simulate large scale regional groundwater systems. A three dimensional finite difference model is developed for groundwater flow analysis of Lower Bina river basin lying partly in Bina and Khurai block. The conceptual model is calibrated for steady state condition and validated for steady state through USGS 3D Finite Difference code, Visual Modflow. Various analyses were tried out on the calibrated model such as recharge to the aquifer, reasons for water logging, river- drain influencing the aquifer. This study outcome is helpful for groundwater development activity in Lower Bina river basin in Bina block.

The study entitled, "Groundwater Flow Modelling in Lower Bina Basin", has been carried out by Er. Ms Shashi Poonam Indwar, Scientist C as the Principal Investigator along with, Dr. Tejram Nayak, Scientist F, Dr. T.Thomas, Scientist D, Er Ravi Galkate, Scientist E, Er Rahul Jaiswal, Scientist D. The study has been carried under the guidance of Dr. N.C.Ghosh Scientist G and Head GWHD and support from Dr. Sharad Jain, Director and Scientist G. The study has been carried out under the work programme for the year 2016-2018.

(Sharad Jain)

Director, NIH

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ABSTRACT

A finite difference model would be developed for groundwater flow analysis of Lower Bina river basin lying partly in Bina and Khurai block. The conceptual model would be calibrated for steady state condition and validated for steady state through USGS 3D Finite Difference code, Visual Modflow. Various analyses were tried out on the calibrated model such as recharge to the aquifer, reasons for water logging, river- drain influencing the aquifer. This study outcome is helpful for groundwater development activity in Lower Bina river basin in Bina block.

On the backdrop of this, the report entails the data collection and database generation in the framework of ArcGIS, study area description, component of groundwater flow analysis, groundwater recharge to the aquifer and water demand. Conceptualisation of the real scenario of Lower Bina Basin in model domain is presented using Visual Modflow with steady- state calibration and validation of the groundwater flow model. Conceptualization of the model has been done by design of grid, selecting time steps, setting boundary and initial condition, preliminary selection of values for the aquifer parameters and hydrologic stresses such as recharge, pumping rates etc. The 3D finite-difference groundwater model Visual MODFLOW was used for modelling groundwater flow in lower bina basin in steady state condition for monsoon and non-monsoon period during the year 2016. In this model, quasi-steady state calibration comprised the matching of observed heads in the aquifer with hydraulic heads simulated by MODFLOW during monsoon (August) and non-monsoon (May) period for the year 2016 considering recharge and pumping draft. The calibrated steady-state model show observed and computed head of August 2016) which is validated using a steady state modelling according to the water levels of the pre-monsoon season January 2017 which indicated prevailing trend of groundwater flow in lower bina basin. The computed water level accuracy was judged by comparing the mean error with mean absolute and RMS error (Anderson and Woessner, 1992). Residual Mean error is -0.905m (monsoon 2016). RMS error is square root of the sum of the square of the differences between calculated and observed heads, divided by the number of observation wells, which in the present simulation is 3.863 m. The absolute residual mean is 2.325m. Validation result for water levels measured at pre-monsoon (January 2017) during steady state modelling shows residual mean error of 4.079 m, RMS error 6.338 m and absolute residual mean 5.792 m respectively. Ground water modelling involves voluminous data on various input parameter. With the available data the simulated hydraulic heads using MODFLOW and observed hydraulic heads were shown better correlation as shown in (i.e 0.93

and 0.96 for monsoon 2016 and pre-monsoon 2017 respectively). Variations in the observed and simulated water levels were noticed for the wells that are near the river and it is due to the lack of sufficient river flow data for this area.

In the present study, a Modflow model is developed to estimate head calibration of Lower Bina basin a part of Bina River with known boundary conditions and field observations. The best method of reducing modelling errors is to apply good hydrogeological judgment. The model calibration has been performed based on the available data. The model results show that computed values are in good-fitness of the measure data, which indicate the model is reliable. Similar studies can be undertaken for other water stressed areas for reliable water resources estimation adopted in better and efficient water resources planning and management. From the flow budget simulation it was determined that for stationary condition, river is not predominantly recharging the aquifers (Table 10). The total input to the aquifer is 246.179 MCM and the total output is 246.181 MCM during monsoon period 2016. This indicates deficiency of recharge of -0.002 MCM which is responsible for decline of the water table in the region (Table 9). Continuous measurements of water budget components and groundwater levels will build up databases required for analysis of regional flow systems and construction of regional transient groundwater models. The results of calibration showed that the predicted results matched well with the observed data. The model could be used to predict the groundwater levels variation under different hypothesis conditions in lower bina basin, which would provide the effective reference to the rational use and management of the groundwater.

The report also deals with the Spatio – Temporal variation and trend analysis of groundwater level in Lower Bina basin as it provides principal source of information regarding groundwater recharge, storage and discharge. Result and discussion, conclusion is based on the assessment of Spatio- temporal variation and trend analysis of groundwater level using statistical and graphical methods. (Mann- Kendall test and Sen's slope estimator.

INTRODUCTION

Groundwater water systems are affected by natural processes and human activity, and require targeted and on-going management to maintain the condition of groundwater resources within acceptable limits, while providing desired economics and social benefits. Groundwater management and policy decision must be based on knowledge of the past and present behaviour of the groundwater system, the likely response to future changes and the understanding of the uncertainty in those responses.

The location, timing and magnitude of hydrologic responses to natural and human-induced events depend on a wide range of factors- for example, the nature and duration of the event that is impacting groundwater, the subsurface properties and the connection with surface water features such as rivers and oceans. Through observation of these characteristics, a conceptual understanding of the system can be developed, but often observational data is scarce (both in space and time), so our understanding of the system remains limited and uncertain.

Groundwater models provide additional insight into the complex system behaviour and (when appropriately designed) can assist in developing conceptual understanding. Furthermore, once they have been demonstrated to reasonably reproduce past behaviour, they can forecast the outcome of future groundwater behaviour, support decision- making and allow the exploration of alternative management approaches. However, there should be no expectation of a single ‘true’ model, and model outputs will always be uncertain. As such, all model outputs presented to decision- makers benefit from the inclusion of some estimate of how good or uncertain the modeller considers the results. (C.P. Kumar, 2013).

Water demand for industrial, agricultural and domestic uses is continuously increasing and freshwater resources are shrinking. Against this backdrop, groundwater management has become critical issue for current and future generations. Groundwater models play an important role in the development and management of groundwater resources and in predicting effects of management measures. With rapid increases in computational ability and wide availability of computers and models software, groundwater modelling has become a standard tool for effective groundwater management. The study proceeded with development of the conceptual model of regional groundwater flow in lower Bina basin. The study presented here in using processing Visual MODFLOW to construct a groundwater flow model in the

basin. The calibration of the model parameters has been conducted under steady-state flow conditions and various analyses were tried out on the calibrated model such as recharge to the aquifer, reasons for water logging, river- drain influencing the aquifer. This study outcome is helpful for groundwater development activity Lower Bina river basin in Bina and Khurai block.

REVIEW LITRETURE

Groundwater is of fundamental importance in water resources planning as it serves both as a storage and a release entity. Groundwater flow has many applications, among which are agricultural developments, domestic use such as supply of drinking water, irrigation, and a variety of water quality applications.

In this study, groundwater level trends have been evaluated using the non-parametric methods i.e., Modified Mann-Kendall (MMK) and Sen's slope estimator during the period 1998 to 2012 at 13 locations in 4 districts of Lucknow division namely Hardoi, Laxmipur, Lucknow and Sitapur of Uttar Pradesh, India. The entire trend analysis has been verified at a significance level of 5 percent. The groundwater level trend analysis has shown negative values for 7 locations covering 54 percent area and positive values for 6 locations covering 46 percent area in pre-monsoon season. However, in post monsoon season, 4 locations covering 31 percent area exhibited negative and 9 locations covering 69 percent area revealed positive trends. The difference in the water level trends in two different seasons may be attributed to the recharge by rainfall in post-monsoon season. *(Krishan, et al.2018)*

The management of groundwater resources is now a great challenge for many countries of the world at present times groundwater modelling has been an effective way to address this challenge .presently for Groundwater modelling there are number of modeling software are available to simulate groundwater flow among them modeling software MODFLOW is used to determine the interaction between the surface water and groundwater and to develop a model for the study area. *(Moeeni, et al. 2017)*

The present study investigates the application of various methods for identification of trends in groundwater levels in few blocks of Sagar district, which faces severe water scarcity owing to the declining groundwater levels. The non-parametric Kendal rank correlation test as well as the parametric linear regression test has been used for trend detection based on the analysis of the seasonal groundwater levels. Kendal's rank correlation test, has been applied to identify the trend persisting in the data and the linear regression test is used to

identify the significance of the slope. The analysis indicates that the time series of groundwater levels are cyclical with characteristics of seasonal variation in all the blocks coupled with a declining trend at Sagar, Khurai and Bina. (*Thakur, et al. 2011*)

The present study is mainly concerned with the changing trend of rainfall of a river basin of Orissa near the coastal region. It is facing adverse effects of flood almost every year. This is an effort to analyse one of the most important climatic variable i.e. precipitation, for analysing the rainfall trend in the area. Daily rainfall data of 40 years from 1971 to 2010 has been processed in the study to find out the monthly variability of rainfall for which Mann-Kendall (MK) Test, Modified Mann-Kendall Test have been used together with the Sen's Slope Estimator for the determination of trend and slope magnitude. Monthly precipitation trend has been identified here to achieve the objective which has been shown with 40 years of data. There are rising rates of precipitation in some months and decreasing trend in some other months obtained by these statistical tests suggesting overall insignificant changes in the area. (*Mondal, et al. 2012*)

The non-parametric Mann-Kendall and Sen's methods were used to determine whether there was a positive or negative trend in weather data with their statistical significance. The occurrence of abrupt changes was detected using cumulative sum charts and bootstrapping. In the present study, the increasing trends were indicated in both annual and seasonal minimum and maximum air temperatures' series. The relative humidity decreased significantly in summer and autumn, while the vapor pressure had a significant increasing trend in spring, summer and autumn. Besides, no significant trends were detected in summer and winter precipitation series. In general, the results of using the Mann-Kendall and Sen's tests demonstrated the good agreement of performance in detection of the trend for meteorological variables. (*Gocic, et al. 2012*)

The main objective of this research is Simulation of Gotvand Plain aquifer using MODFLOW code of GMS software is the primary objective of this research. The other objective is assessing the artificial recharge project of Abbid-Sarbishe located in north of Gotvand. For this purpose, the study area was discretized in GMS software and the initial and boundary conditions were specified. Then, the model was calibrated from September 2009 to August 2010 in an unsteady state during 12 stress periods. After the optimization of hydrogeologic parameters, the model was validated from September 2009 to August 2010 and then it was used to assess the artificial recharge. By analyzing the water budget model, the

behaviour of piezometers and the observed data, the hydraulic of groundwater was evaluated. The results indicate that artificial recharge has been effective in the western parts of the project and the most effective recharge has occurred during 2005-2006 and 2006-2007 around the piezometer G19. This project has a positive effect on the aquifer, but due to seasonal water-flood spreading, sedimentation and drought in the past years, its effect is not sufficient. (*Movahedian, et al. 2015*)

This study aims to reveals that the suitability of modflow software under various hydrogeologic conditions. The hydrogeologic system may be disturbed by some natural or manmade processes. To predict the system behaviour, visual modflow is the easy to use modeling environment for two dimensional and three dimensional groundwater flow and contaminant transport simulations. (*Laxmi,et al. 2015*)

In this study surrounded villages of mining region of Korba district, India. *The* data on topographical and hydrological data pertaining to the study area were collected from various government departments and organization of Chhattisgarh. The modelling has been done for 240 days (2012-2013). For the calibration, hydraulic conductivity, ground water head, specific yield, recharge are used as input parameters for the model calibration. The model performance has been evaluated by graph between observed head and calculated head, zone budget, mass balance, drawdown contour, depth to water table contour and ground water flow contour computed by the software for three layers. Based on the results obtained for layer 1, it is seen that drawdown is more towards mining area and groundwater velocity is also high compared to layer 2 and layer 3. (*Singha, et. al.2015*)

This paper presents the results of a mathematical groundwater model developed for the Mahesh River basin in the Akola and Buldhana districts, employing conceptual groundwater modelling approach. For this purpose, groundwater modelling software (GMS) was used which supports the Visual Modular three Dimensional Flow-20011 code. For the purpose of modelling the source/sink coverage, recharge coverage, extraction coverage, return flow coverage and soil coverage were considered. The model was calibrated against the historical and observed water level data for the period of 2013 and 2014. *Khadri1 and Pande(2016)*

The present study area is primarily underlain by granites, basalts, and a little bit of laterites. Groundwater occurs under unconfined to semi confined conditions, in weathered and fractured formations, respectively. A three-dimensional groundwater flow model for the

Osmansagar and Himayathsagar catchments—a semiarid hard rock area in India with two conceptual layers—is developed under transient conditions using visual MODFLOW software for the period 2005 to 2009. The 15–20 m top layer is a weathered zone, followed by second 20–25 m-layer fractured zone based on hydro geophysical studies and borehole lithologs. The groundwater recharge estimation is achieved with the help of geographical information system (GIS) and the water table fluctuation method that is well fitted into the flow model with an average recharge value of 21% of the average annual rainfall. The results derived from modelling indicate that the average input to the aquifer system is 321.96 million cubic meters (mcm), and the output is 322.14 mcm. If the same withdrawal is continued up until the year 2020, the water level is believed to decline more than 45 m over the entire study area. *(Varalakshmi, et al. 2014)*

The study focused on groundwater recourse assessment through steady-state flow modelling in Bina River basin. Bina River is a tributary of Betwa River and is the main source of water for domestic water supply and irrigation supply. Despite its importance for the people in the region, the hydrogeological system of the Bina River basin is not well understood. This study reports a simulation study for better understanding of the groundwater balance at Bina River Basin using Visual MODFLOW. The model involved a steady-state hydrogeological simulation of the two-layered aquifer. The groundwater modelling approach was found to be efficient in identifying the dominant hydrological processes in Bina River basin including evapotranspiration and recharge. The aquifer system was modelled numerically by Visual MODFLOW (flex). The model domain was delineated based on field traverses, topographic maps and digital elevation model extracted from Survey of India toposheet contour lines in ILWIS platform. *(Kumar, et al. 2017)*

In this study, a three-dimensional finite difference modelling program namely Visual MODFLOW was used for the study and prediction of aquifer system in a drought prone study area. The base map of the study area, various layers of the geological strata and their geological properties, boundary conditions, well data and recharge conditions were fed in to the model as inputs. The model was then calibrated and validated, after which future groundwater conditions were predicted. *(Namitha, et al. 2018)*

The sustainable use and management of groundwater resources is now a great challenge for many countries of the world. Recently groundwater modelling has been an effective way to address this challenge. There are a number of modelling software exist to simulate groundwater

flow. Among them modelling software MODFLOW is used to determine the interactions between the surface water and groundwater and to develop a model for the study area. (*Lasya and Dr. M. Inayathulla, 2015*)

In this study, the Visual MODFLOW is used to simulate the flow of groundwater through aquifers in Lower Ponnaiyar watershed, Tamilnadu, India. The three-layer model is run with four phases that are model design, calibration, validation and prediction. The model is calibrated in two stages, which is involved a steady state calibration and transient state calibration using observed groundwater levels from 2005 - 2014. The validation is done by using observed groundwater levels from 2014 - 2016. The spatial distribution of hydraulic conductivity and storage properties are optimized using a combination of trial and error method. The simulation results showed that the fluctuations of hydraulic heads are dependent on seasonal variation in recharge from natural infiltration of precipitation and irrigation. The different scenarios are developed to predict aquifer system response under different conditions of the study area. The calibrated parameters are very useful to identify the aquifer properties and to analyze the groundwater flow dynamics and the changes of groundwater levels in the study area. The study suggests that from the prediction the recharge rate must be improved in the villages like Tiruppanambakkam, Karaimedu, Agaram, Kavanippakam, Anangur, Pillur, Tiruppachanur, Pedagam and Perangiyur which are located nearer to the river course. Also, this study concluded that the water level is high in central western part and declining towards the south Ponnaiyar River. (*Sridhar, et al. 2018*)

This paper presents groundwater modelling process, basic data requirements for groundwater modelling and commonly used groundwater modelling software. Groundwater is used for a variety of purposes, including irrigation, drinking and manufacturing. Groundwater is also the source of a large percentage of surface water. Accurate and reliable groundwater resource

information (including quality) is critical to planners and decision-makers. Huge investment in the areas of groundwater exploration, development and management at state and national levels aims to meet the groundwater requirement for drinking and irrigation and generates enormous amount of data. We need to focus on improved data management, precise analysis and effective dissemination of data. Numerical models are capable of solving large and complex groundwater problems varying widely in size, nature and real life situations.

(*C.P Kumar, 2015*)

Visual MODFLOW is a Graphical User Interface for the USGS MODFLOW. It is a commercial software that is popular among the hydrogeologists for its user-friendly features. The software is mainly used for Groundwater flow and contaminant transport models under different conditions. This article is intended to review the versatility of its applications in groundwater modelling for the last 22 years. Agriculture, airfields, constructed wetlands, climate change, drought studies, Environmental Impact Assessment (EIA), landfills, mining operations, river and flood plain monitoring, salt water intrusion, soil profile surveys, watershed analyses, etc., are the areas where the software has been reportedly used till the current date. The review will provide clarity on the scope of the software in groundwater modelling and research. (*Hariharan V, 2017*)

3. STUDY AREA

The study area covers Bina and Khurai blocks in Sagar district located at latitude of 24⁰02'37" to 24⁰10'35" N and longitude of 78⁰11'47" E to 78⁰19'50" and its comes under the UTM zone 43N. Sagar district of Bundelkhand region is situated in midst of India. Bina River is a major tributary of River Betwa in Bundelkhand region of Madhya Pradesh, which originate from Begumganj block of Raisen district and enters Sagar district at Rahatgarh block and traverse through Khurai and Bina tehsil before confluence with river Betwa near Basoda town in Vidisha district.

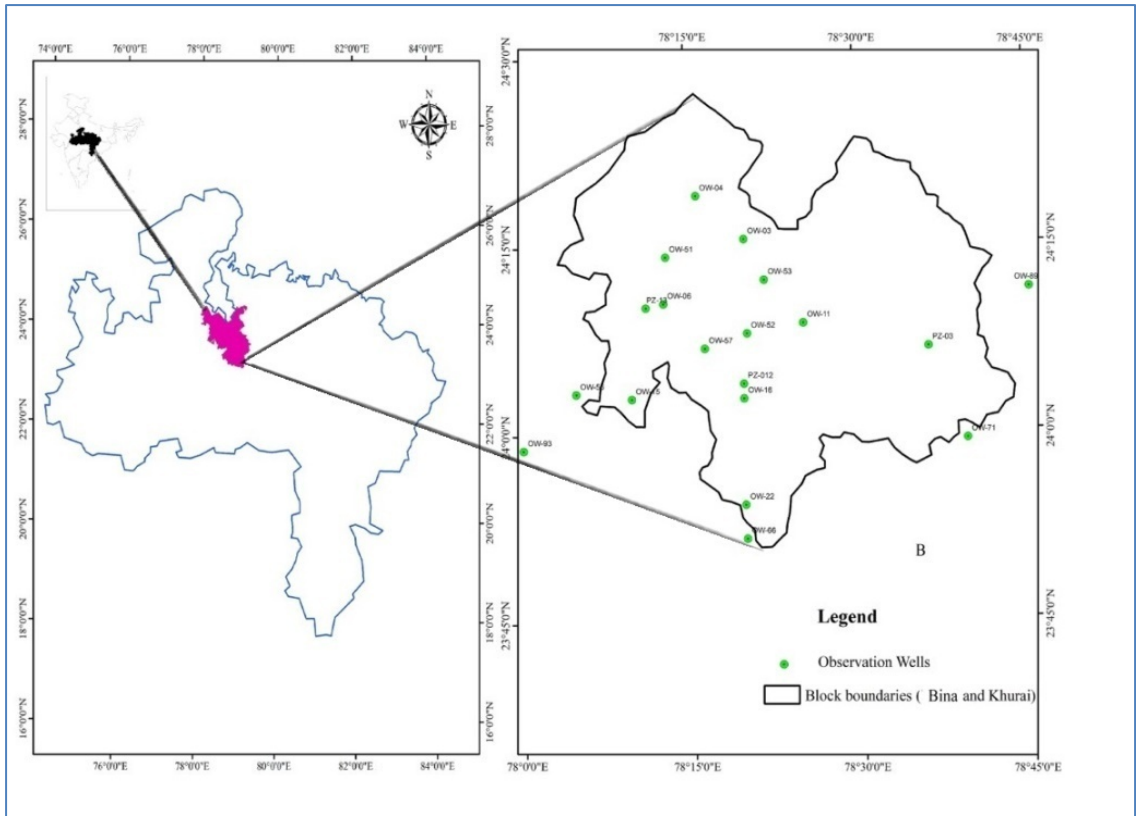


Fig 1.1 Location Map of Study Area.

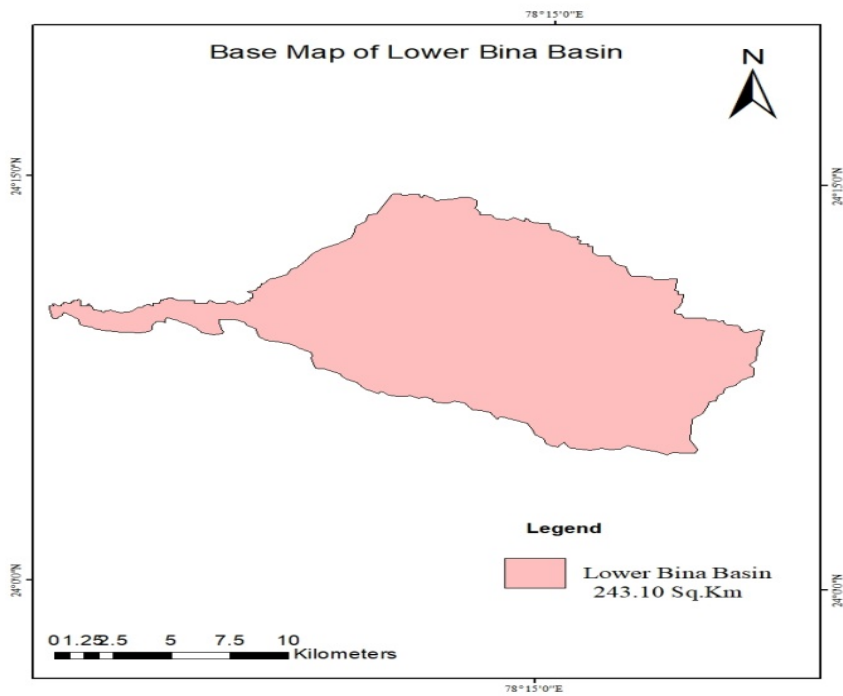


Fig 1.2 Base Map of Lower Bina Basin

The map shown lower Bina Basin which area is found 243.10 Sq.Km.

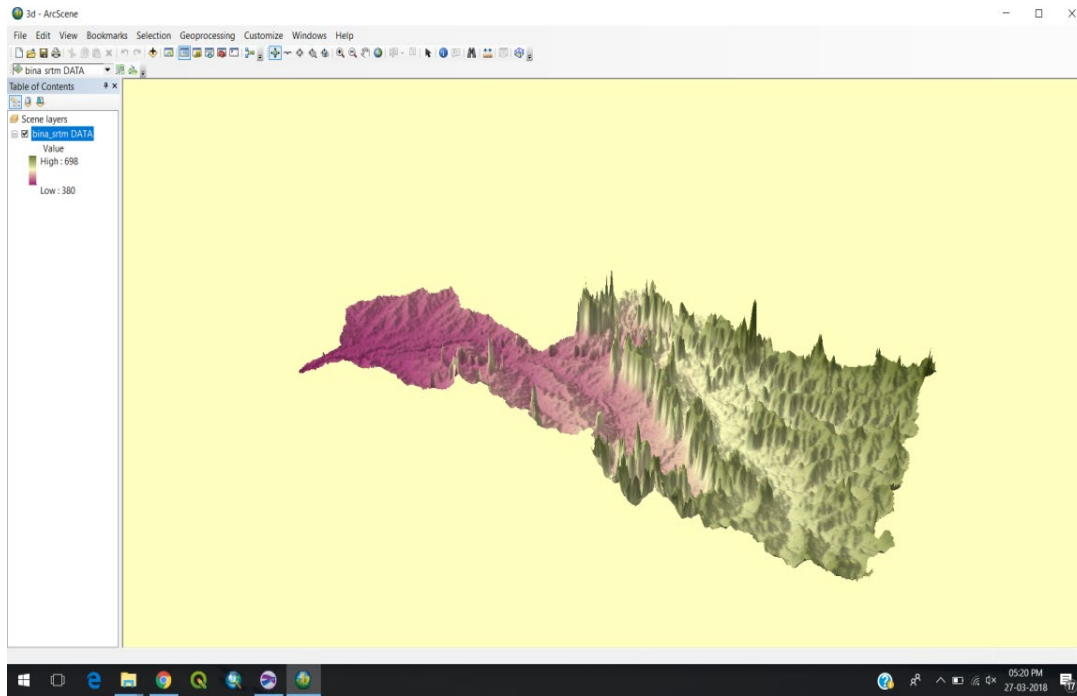


Fig.1.3 Three-Dimensional Digital Elevation Model of Lower Bina Basin.

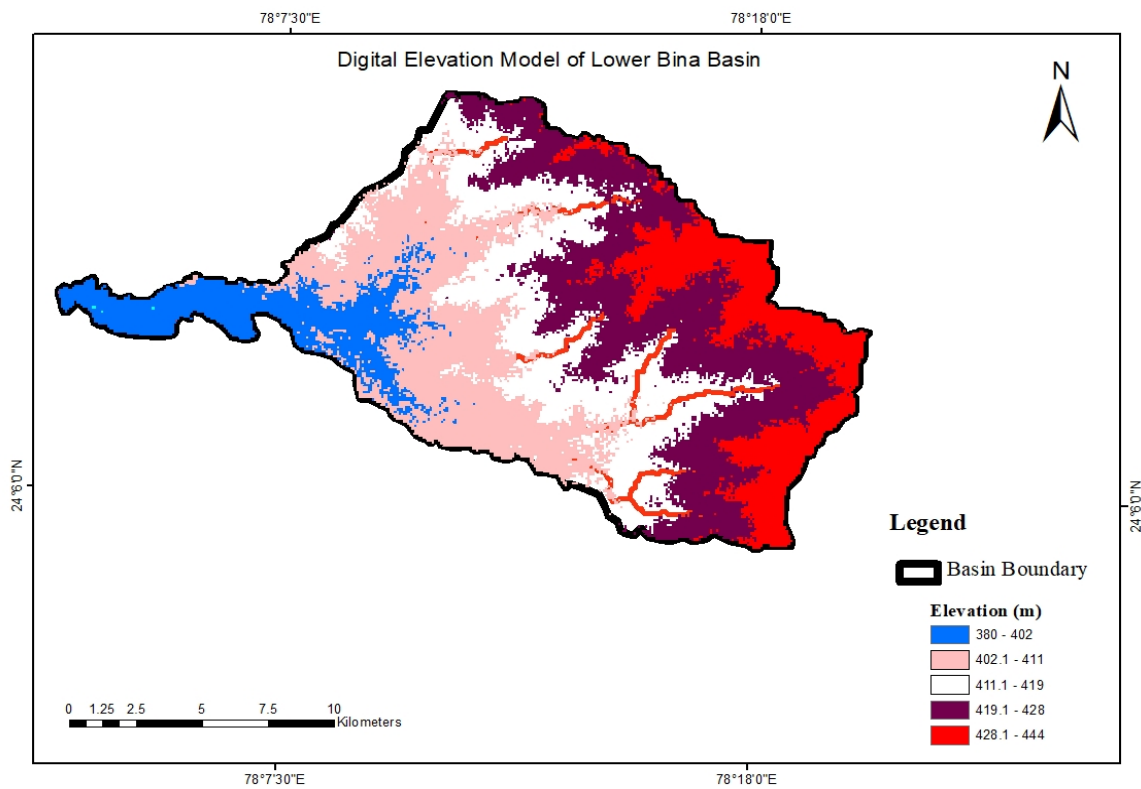


Fig.1.4 Digital Elevation Model of Lower Bina Basin

In the Lower Bina Basin highest elevation shows 444m and lowest elevation shows 380m.

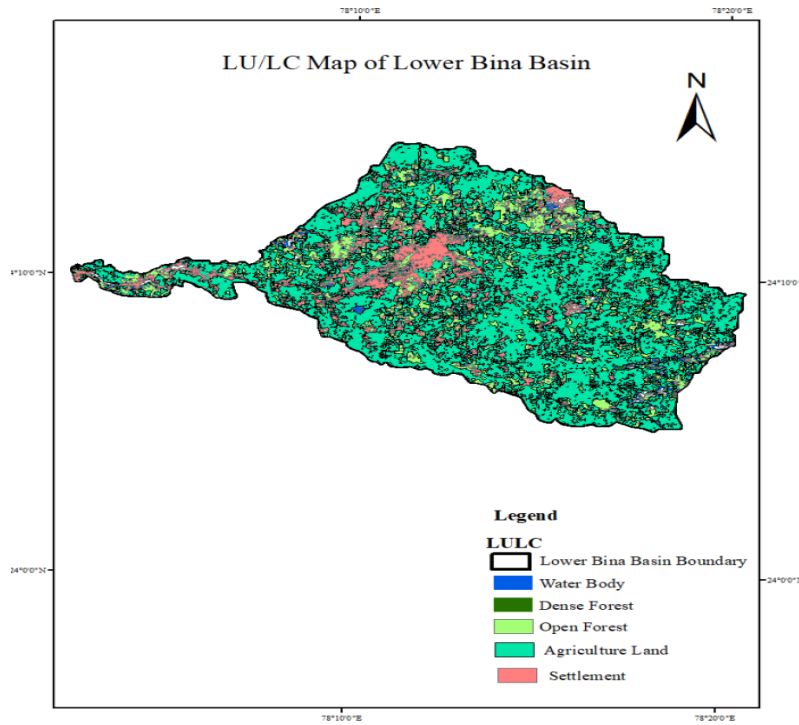


Fig.1.5 Land Use/Land Cover of Lower Bina Basin

The major Land Use/Land Cover Classes in Lower Bina Basin are Water body, dense forest, open forest, Agriculture Land and Settlement. The maximum area of Lower Bina Basin is covered by dense forest.

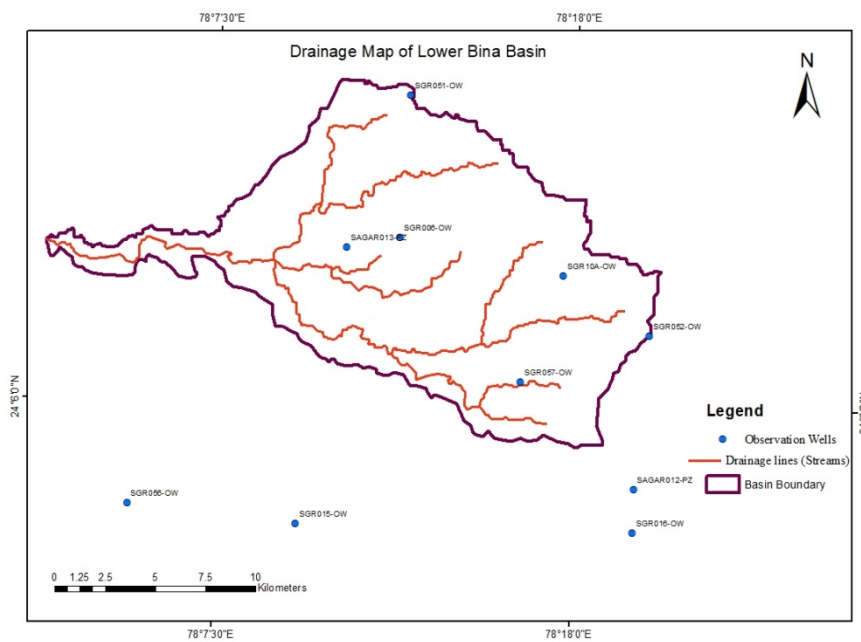


Fig.1.6 Drainage Map of Lower Bina Basin

The map shows drainage network of Lower Bina Basin. The drainage Area (Catchment area) of Lower Bina Basin is 243.10 Sq. Km.

3.1 Climate

The climate of the district is sub-tropical and the climate of study area can be classified mainly into three seasons: Winter season starting from middle of November to end of February; March to May constitutes the summer season whereas the monsoon season starts from second week of June to end of September. During winter season the January is the coldest month with the average minimum temperature of 11.5°C whereas the hottest month is May with average maximum temperature up to 40.9°C. The area is influenced by southwest monsoon and average rainfall is around 1235/mm annually.

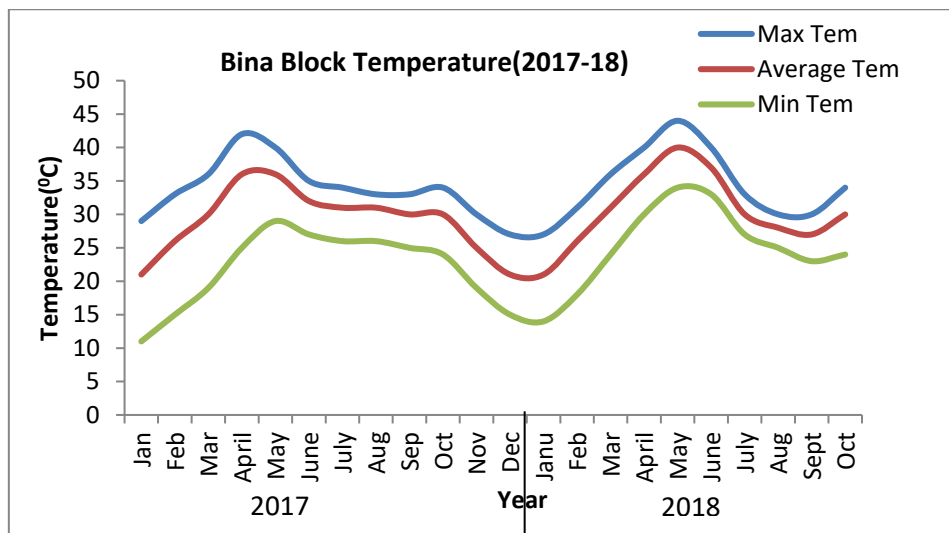


Fig. 1.7 Temperature Graph 2017-2018 of Bina Block

The Highest temperature recorded in 2017-18 in month of June, 2018 is 44°C and the lowest temperature recorded in 2017-18 in January 2018 is 11°C

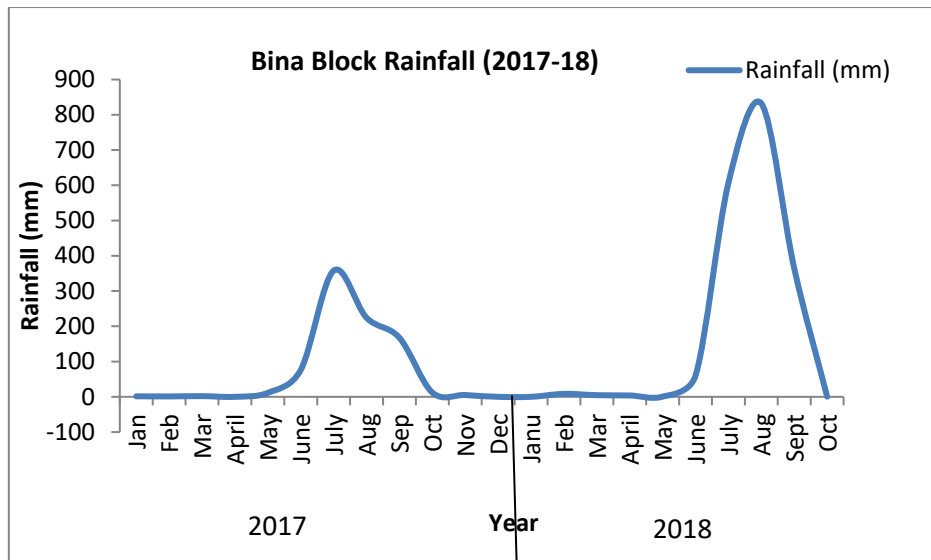


Fig. 1.8 Rainfall Graph 2017-2018 of Bina Block

The Maximum rainfall recorded in 2017-18 is 832 mm in September, 2018.

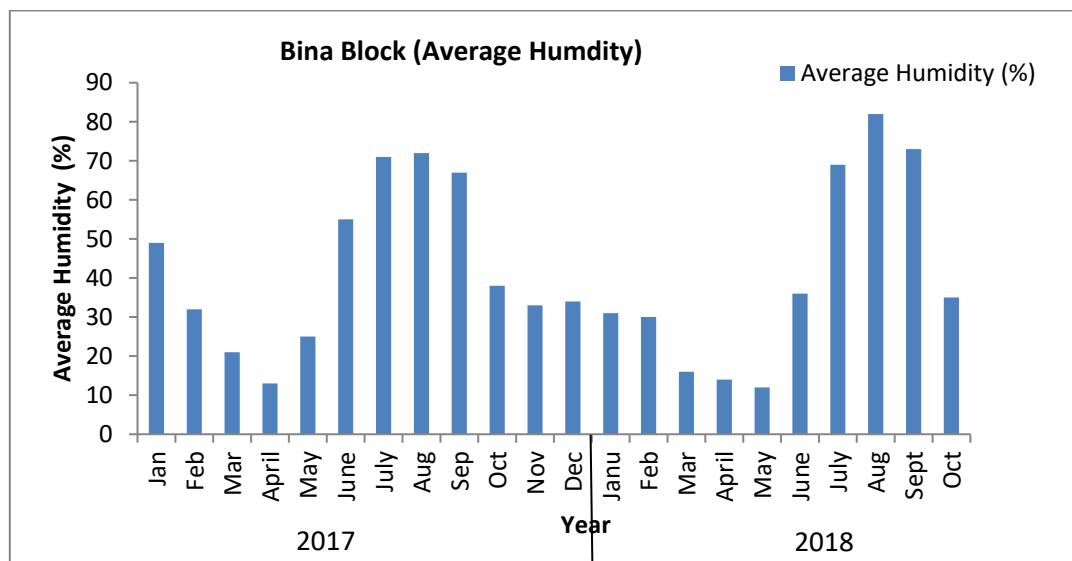


Fig. 1.9 Humidity Graph 2017-2018 of Bina Block

The Maximum Humidity recorded in 2017-18 is 82% in August, 2018.

3.2 Soils

The agricultural land is primarily black soil in Bina and Khurai block. The Bina (river) is the major sources of water Bina and Khurai blocks.

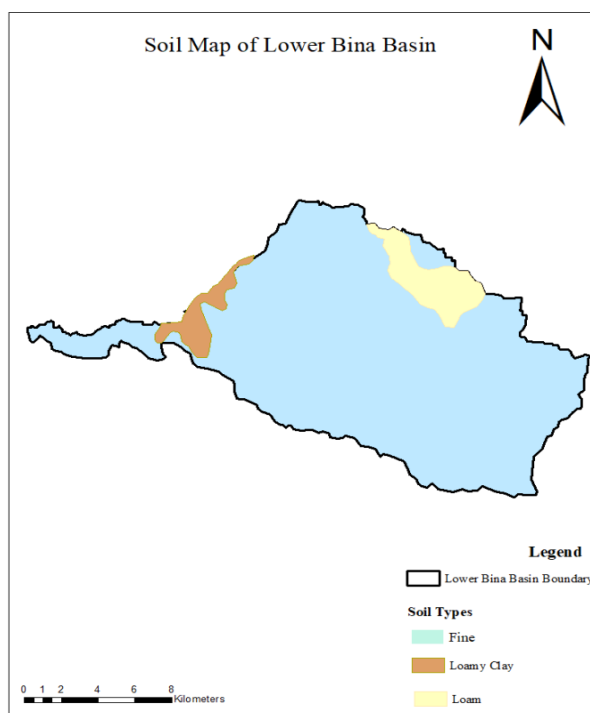


Fig. 2. Soil Map of Lower Bina Basin

The Major Soil types found in Lower Bina Basin is Fine, Loamy Clay and Loam Soil type. Major area of Basin is covered by Fine Soil.

3.3 Crops

The District of Sagar is predominantly a Rabi area. Wheat crop is the agricultural staple. Other staple crops are gram, linseed and jowar. Mixed cropping is resorted to as a measure of insurance against the vagaries of nature. Rabi is the main cropping season, though the proportion of Rabi to kharif has varied from time to time. Occasionally, the Kharif crop exceeded the Rabi when wheat crop was badly affected by rust or frost or when bad season hampered rabi sowing. When the season conditions came to normality the Rabi crops were gradually restored to their original position of prominence. Conversely whenever there are heavy and continuous rains through July and August which prevent the ploughs from getting to work, or Kharif crops get rotten particularly in low-lying and water-logged areas, they are ploughed and diverted to Rabi sowings. The climatic conditions thus largely determine the relative weightage given to Kharif and Rabi crops in a particular year.

4.0 Spatio-temporal Variation and Trend Analysis of Groundwater Level in Bina and Khurai Blocks of Sagar District, Madhya Pradesh.

In this study firstly the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and secondly the slope of a linear trend is estimated with the nonparametric Sen's method (Gilbert 1987). These methods are here used in their basic forms; the Mann-Kendall test is suitable for cases where the trend may be assumed to be monotonic and thus no seasonal or other cycle is present in the data. The Sen's method uses a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time. These methods offer many advantages that have made them useful in analysing groundwater trends.

The study used Mann-Kendall t-test to analyze the data collected from the eight hydrological stations located in Bina and Khurai blocks in Sagar district. The monthly GWL data of fifteen observation wells in which twelve wells are dug well and three wells are Piezometric wells of Bina and Khurai blocks for the period 2000-2016 have been used for the study. The minimum and maximum GWL has been found out to be 0.10 m below ground level (bgl) which is 420.6m above mean sea level (amsl) and 27.60 m bgl (429.50m amsl). Contour map shows that average GWL vary between 4.07 m to 18.75 m bgl (i.e., 401.18 m to 438.35 (amsl)) during pre-monsoon and 0.51 m to 16.18 m bgl (i.e., 404.71 m to 440.92 m above amsl) during post-monsoon. This analysis investigated the pattern and trends of the daily groundwater level data using Mann-Kendall t-test as means of non parametric test and parametric Sen's Slope test on seasonal basis. Pre-monsoon and Post monsoon variations in groundwater trend of Bina and Khurai blocks of Sagar district for 16 years (2000-2016) were analysed using statistical non-parametric tests-the Mann-Kendall (MK) test and Sen's slope estimator. The Mann-Kendall test indicated falling trends at most wells and rising trends at some wells and at few wells there were no significant trends. Mann-Kendall test showed falling trend is observed in most wells during pre-monsoon and post-monsoon in both blocks signifying overexploitation of groundwater whereas no trend is observed in few wells. Sen's Slope test is used to identify the significance of the slope and it is seen that declining trend was observed at 95% confidence interval. An average temporal variation of groundwater shows declining trend in Bina and Khurai blocks.

4.1 Mann-Kendall test

The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i$$

Where $f(t)$ is a continuous monotonic increasing or decreasing function of time and the Residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. We want to test the null hypothesis of no trend, H_0 , i.e. the observations x_i are randomly Ordered in time, against the alternative hypothesis, H_1 , where there is an increasing or decreasing monotonic trend.

In the computation of this statistical test MAKESENS is used which exploits both the so called S statistics given in Gilbert (1987) and the normal approximation (Z statistics). For time series with less than 10 data points the S test is used. (a) Number of data values less than 10. The numbers of annual values in the studied data series is denoted by n . Missing values are allowed and n can thus be smaller than the number of years in the studied time series. The Mann-Kendall test statistic S is calculated using the formula

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k)$$

Where x_j and x_k are the annual values in years j and $k, j > k$, respectively, and

$$\text{Sgn}(x_j - x_k) = \begin{matrix} 1 & \text{if} & x_j - x_k > 0 \\ 0 & \text{if} & x_j - x_k = 0 \\ -1 & \text{if} & x_j - x_k < 0 \end{matrix}$$

If n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1987). In MAKESENS the two-tailed test is used for four different significance levels α : 0.1, 0.05, 0.01 and 0.001. At certain probability level H_0 is rejected in favour of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend. The minimum values of n with which these four significance levels can be reached are derived from the probability table for S as follows

Significance level α	Required n
0.1	≥ 4

0.05	≥ 5
0.01	≥ 6
0.001	≥ 7

The significance level 0.001 means that there is a 0.1% probability that the values x_i are from a random distribution and with that probability we make a mistake when rejecting H_0 of no trend. Thus the significance level 0.001 means that the existence of a monotonic trend is very probable. Respectively the significance level 0.1 means that there is a 10% Probability that we make a mistake when rejecting H_0 .

2.1.2 Number of data values 10 or more if n is at least 10 the normal approximation test is used. However, if there are several tied values (i.e. equal values) in the time series, it may reduce the validity of the normal Approximation when the number of data values is close to 10. First the variance of S is computed by the following equation which takes into account that ties may be present:

$$VAR(S) = 1/18 \left[n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5) \right]$$

q- No: of tied groups

t_p -no: of data values in the p^{th} group

The values of S and $VAR(S)$ are used to compute the test statistic Z as follows

$$Z = \begin{cases} S - 1/\sqrt{VAR(S)} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ S + 1/\sqrt{VAR(S)} & \text{if } S < 0 \end{cases}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. The statistic Z has a normal distribution. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In MAKESENS the tested significance levels α are 0.001, 0.01, 0.05 and 0.1.

4.2 Sen's method

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used. The Sen's method can be used in cases where the trend can be assumed to be linear. This means that $f(t)$ in equation (1) is equal to

$$f(t) = Qt + B$$

Where Q is the slope and B is a constant.

To get the slope estimate Q in equation (6) we first calculate the slopes of all data value Pairs

$$Q_i = x_j - x_k / j - k$$

Where $j > k$

If there are n values x_j in the time series we get as many as $N = n(n-1)/2$ slope estimates Q_i . The Sen's estimator of slope is the median of these N values of Q_i . The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is

$$Q = Q_{\left[\frac{N+1}{2}\right]} \text{ if } N \text{ is odd}$$

$$Q = \frac{1}{2 \left(Q_{\left[\frac{N}{2}\right]} + Q_{\left[\frac{N+2}{2}\right]} \right)} \text{ if } N \text{ is even}$$

A $100(1-\alpha)\%$ two-sided confidence interval about the slope estimate is obtained by the Nonparametric technique based on the normal distribution. The method is valid for n as small as 10 unless there are many ties.

The procedure in MAKESENS computes the confidence interval at two different confidence levels; $\alpha = 0.01$ and $\alpha = 0.05$, resulting in two different confidence intervals.

At first we compute

$$C_\alpha = Z_{1-\alpha/2} \sqrt{\text{VAR}(S)},$$

where $\text{VAR}(S)$ has been defined in equation (4) and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution.

Next $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, Q_{min} and Q_{max} , are the M_1 th largest and the $(M_2 + 1)$ th largest of the N ordered slope estimates Q_i . If M_1 is not a whole number the lower limit is interpolated.

Correspondingly, if M_2 is not a whole number the upper limit is interpolated.

To obtain an estimate of B in equation (6) the n values of differences $x_i - Q_{ti}$ are calculated.

The median of these values gives an estimate of B (Sirois 1998). The estimates for the

Constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure.

Wells	Location name	Latitude	Longitude	Minimum GWL m bgl	Maximum GWL m bgl	Average GWL
PZ-12	Khurai	24°03'54"	78°19'50"	1.80	27.60	17.90
PZ-13	Bina	24°10'06"	78°11'17"	3.1	23.25	13.39
PZ-03	Pali	24°06'41"	78°36'14"	0.20	27.00	4.85
OW-03	Niwari	24°15'27"	78°20'03"	0.42	7.85	3.83
OW-04	Bhangarh	24°18'57"	78°15'54"	0.65	7.10	4.06
OW-06	Bina	24°10'23"	78°12'50"	0.20	16.00	8.33
OW-11	Dugaha kalan	24°08'43"	78°25'12"	5.38	20.60	13.35
OW-15	Dhansara	24°02'50"	78°09'55"	0.70	10.75	6.03
OW-16	Khurai	24°02'45"	78°19'49"	0.20	12.75	8.50
OW-22	nonagir	23°54'15"	78°19'48"	0.65	9.15	6.33
OW-51	Agasod	24°14'07"	78°13'05"	0.43	10.80	5.90
OW-52	Talapar	24°07'56"	78°20'13"	0.60	11.47	7.03
OW-53	Khimlasa	24°12'11"	78°21'50"	0.05	7.50	2.79
OW-56	Mandi bamora	24°03'17"	78°04'58"	0.80	16.30	7.97
OW-57	Kulwai	24°06'39"	78°16'27"	0.10	8.70	4.13

OW-93	Patauwa	23°58'51"	78°00'04"	0.45	11.30	6.07
OW-66	Jhila	23°51'32"	78°19'58"	1.00	10.80	6.29
OW-89	Dhamoni	24°11'16"	78°45'13"	0.10	6.50	3.18
OW-71	Mehar	23°59'17"	78°39'30"	0.26	9.30	4.73

Table 1. Location and Minimum, Maximum and average Groundwater levels of wells during 2000-2016.

5.0 Result and Discussion

The minimum depth to water (0.05 m bgl) has been observed in August, 2015 at Khimlasa whereas maximum value (27.60 m bgl) observed in June, 2015 at Khurai, based on 17 years GWL monthly data. The pre and post monsoon groundwater contours maps (Figure 2(a) & 2(b)) depict the spatial variation of average groundwater level. The average groundwater level in pre monsoon (month-may) varies from 4.96 to 24.22 m bgl (i.e., 431.14 m to 432.22 m above msl) whereas during post monsoon (month-November) groundwater level varies from 2.92 to 14.72 m bgl (i.e. 474.73 m to 442.38 m). GWL is shallower in northern, eastern and southern part of the city whereas deeper GWL can be observed in central and western part of the blocks boundary. Groundwater flow direction in the area helps us decide the location of abstraction wells and pollutant transport path. The directions of the groundwater flow are found similar for the pre- and post-monsoon period (Figure 3). The direction of groundwater flow is towards Southwards and eastwards. The trend analysis was performed by using Mann Kendal at (95% confidence interval) & Sen's slope estimator method for monthly groundwater level. The Trend analysis summarised in Table 2. The negative S-statistics indicate a falling trend and positive indicates rising trend. A positive (negative) value of Z indicates an upward (downward) trend. The statistic Z has a normal distribution. The absolute value of Z is compared to the standard normal cumulative distribution to define if there is a trend or not at the selected level α of significance. The smallest significance level α with which the test shows that the null hypothesis of no trend should be rejected. The computed z-statistics less than the z-value corresponding to 5% significance level (1.96) indicate no significant trend. It can be observed from Table 2 that groundwater level is showing falling and rising trend, which are not significant except few locations. These few locations are viz., Bina , Dhansara and Dugahakalan where groundwater level shows significant rising trend whereas Khurai, Kulwai showing significant falling trend.

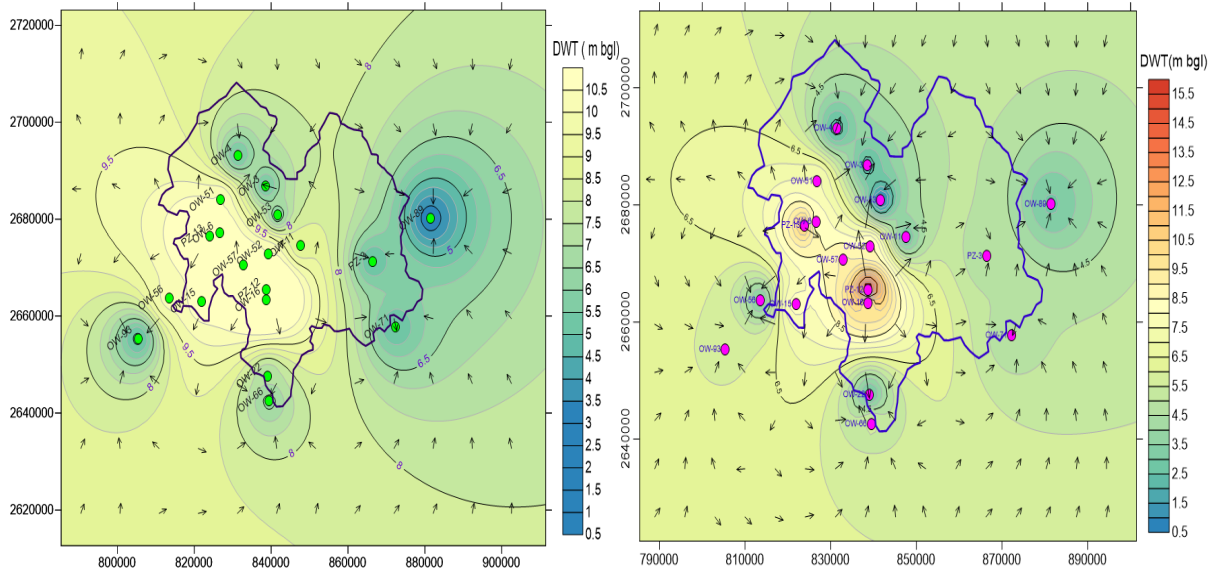


Figure 2.1 Depth to water tables map for (a): Pre-monsoon (b) Post-monsoon for the year 2016

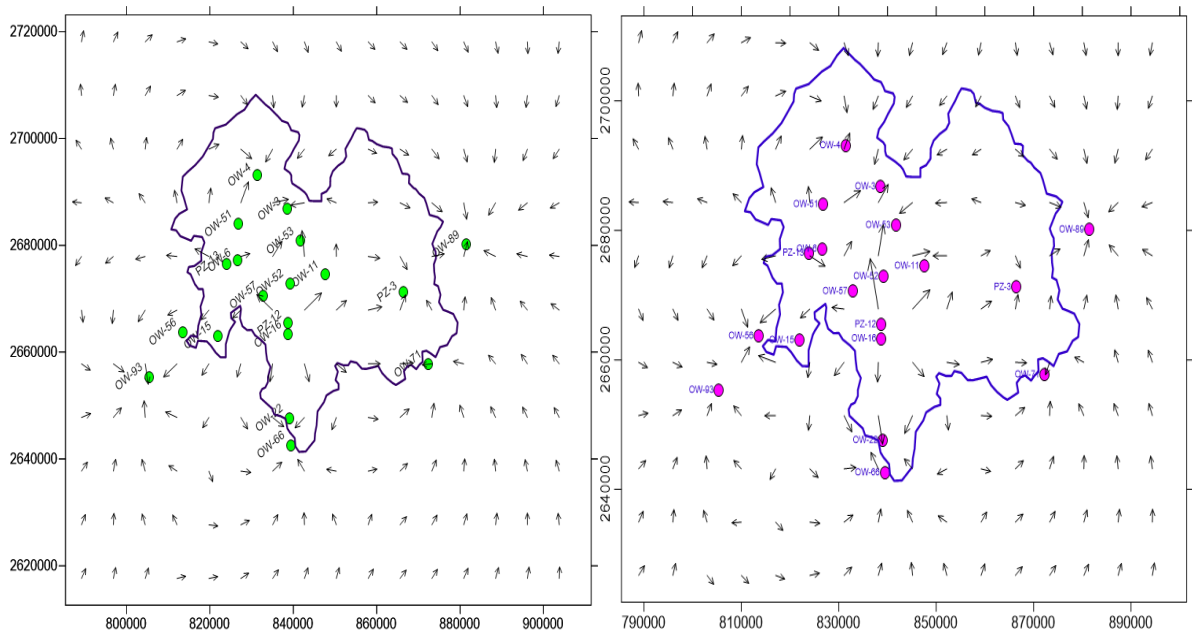


Figure 2.2 Groundwater Flow direction during Pre-Monsoon and Post-Monsoon period for the year 2016

WELLS	Test Z	Trend	Significant	Slope (Q)	Intercept (B)
OW-51	0.34	Rising	Slope not significant	0.017	-5.02
OW-52	0.38	Rising	Slope not significant	0.050	-6.78
PZ-12	-0.49	Falling	Slope not significant	-0.163	-13.55
PZ-13	-0.91	Falling	Slope not significant	-0.122	-10.63

PZ-03	2.39	Rising	*(Significant)	0.147	-4.65
OW-06	3.55	Rising	*(Significant)	0.370	-10.84
OW-15	-0.04	Falling	Slope not significant	0.000	-4.20
OW-16	-1.06	Falling	Slope not significant	-0.115	-8.45
OW-57	-1.40	Falling	Slope not significant	-0.078	-3.29
OW-03	0.00	No change	Slope not significant	0.003	-3.34
OW-04	-1.10	Falling	Slope not significant	-0.050	-4.325
OW-11	-1.03	Falling	Slope not significant	-0.100	-4.7
OW-22	0.25	Rising	Slope not significant	0.026	-5.555
OW-53	-0.95	Falling	Slope not significant	-0.041	-0.859
OW-56	0.25	Rising	Slope not significant	0.019	-6.7

Table 2. Summarized results of trend analyses for each observation wells for Pre-Monsoon.

WELLS	Test Z	Trend	Significant	Slope (Q)	Intercept (B)
OW-51	1.15	Rising	Slope not significant	0.007	-10.44
OW-52	0.73	Rising	Slope not significant	0.000	-11.44
PZ-12	-3.13	Falling	** (Significant)	-0.302	-21.27
PZ-13	-0.45	Falling	Slope not significant	-0.070	-16.66
PZ-03	1.14	Rising	Slope not significant	0.079	-7.49
OW-06	4.06	Rising	*** (significant)	0.480	-16.24
OW-15	2.92	Rising	** (significant)	0.045	-10.55
OW-16	-3.21	Falling	** (significant)	0.000	-12.75
OW-57	-3.00	Falling	** (significant)	-0.125	-6.12
OW-03	-1.41	Falling	Slope not significant	0.000	-7.30
OW-04	-0.05	Falling	Slope not significant	0.000	-6.2
OW-11	2.15	Rising	* (significant)	0.070	-12.44
OW-22	0.33	Rising	Slope not significant	0.000	-8.7
OW-53	-0.78	Falling	Slope not significant	-0.055	-4.4
OW-56	1.08	Rising	Slope not significant	0.033	-15.83

Table 3. Summarized results of trend analyses for each observation wells for Post-Monsoon.

5.1 Results of Man Kendall Test

In the present study the results are shown in two different scenario i.e Pre-monsoon and Post Monsoon. In the Pre-monsoon period out of 15 Observation wells (OW), 8 are showing rising trend whereas 7 OW are showing falling trend. However the magnitude of GWL varies from -0.055 m/yr (Kimlasa in Khurai block) to 0.480 m/yr at Bina in Bina block. Whereas in Post-Monsoon period out of 15 observation wells, 8 stations are showing falling trend, 6 are showing rising trend and 1 well there is no change and the magnitude of GWL varies from -0.041 m/yr (Kimlasa in Khurai block) to 0.370 m/yr at Bina in Bina block. The Z-statistics of whole 15 OW in pre-monsoon varies from -0.45 to 4.06. In pre-monsoon, out of 15 OW those 7 wells showing declining trends significant declining trend (falling) are observed at PZ-12, OW-16(Wells at Khurai), OW-57(Kulwai) (-3.13, -3.21, -3.00 respectively). However out of them Khurai and Kulwai are showing significant declining trends at 1% and 5 % level of significance and Bina, Dhansara and Dugahakalan are showing significant rising trend at 0.1% , 1 % and 5% level of significance respectively. In Post-monsoon, out of 15 OW those 8 wells shows declining trends with not much significance and 6 wells are showing rising trends with significant rising trends at Bina and Pali with 5 % and 0.1% level of significance respectively. The overall result of Man kendall and Sen's Slope is summarised in Table 2a and 2b. The time series plot of GWL with linear trend for the locations showing significant rising or falling trend has been shown in Figure 4 and Figure 5. The rising trend of some wells may be due to recharge from water bodies and less or no abstraction of groundwater from phreatic aquifer. Pre-monsoon and post-monsoon mean groundwater level fluctuations varied from 3.08 to 18.749 and 0.567 to 16.179, respectively. OW-53 location of Khurai block had maximum groundwater extraction in both per and post monsoon periods. Hence, it varies from 1.47 to 4.54 and 0.05 to 3 in pre and post monsoon seasons, respectively.

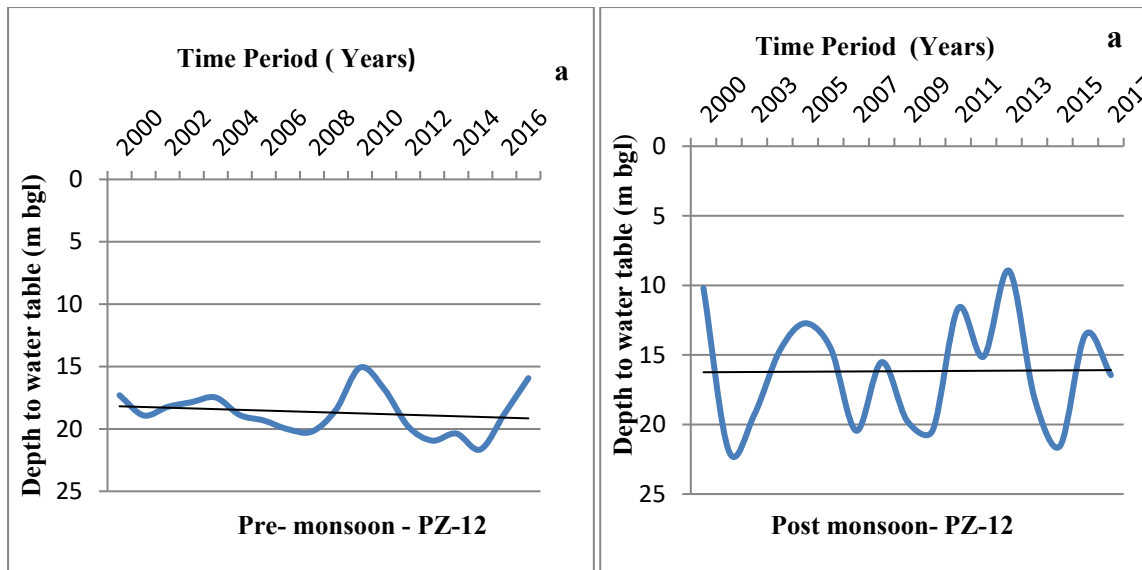


Fig. 2.3(a) Depth to water table (m bgl) Pre and Post Monsoon of PZ-12 Well.

Time Series plot for depth to water for Khurai showing falling Trend.

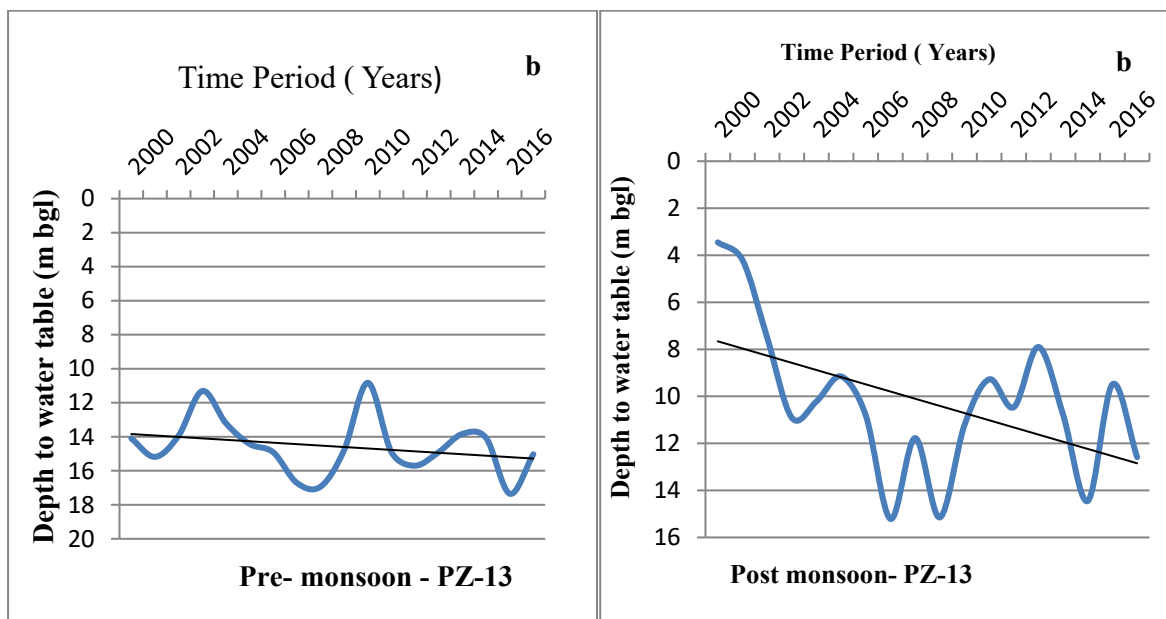


Fig. 2.3(b) Depth to water table (m bgl) Pre and Post Monsoon of PZ-13 Well.

Time Series plot for depth to water for Bina showing falling Trend.

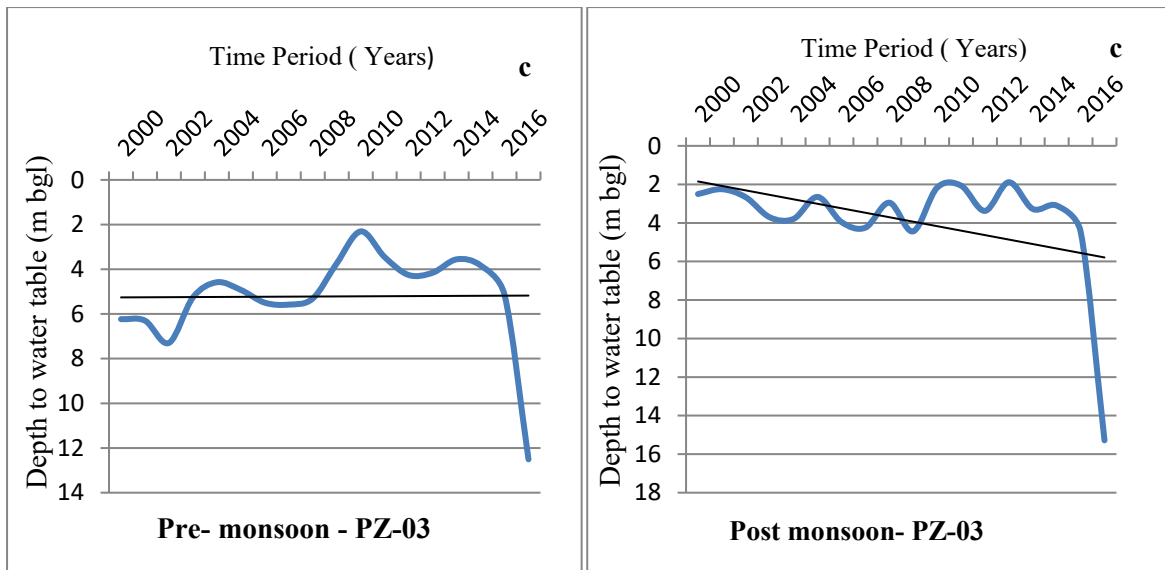


Fig. 2.3(c) Depth to water table (m bgl) Pre and Post Monsoon of PZ-03 Well.

Time Series plot for depth to water for Pali showing falling Trend.

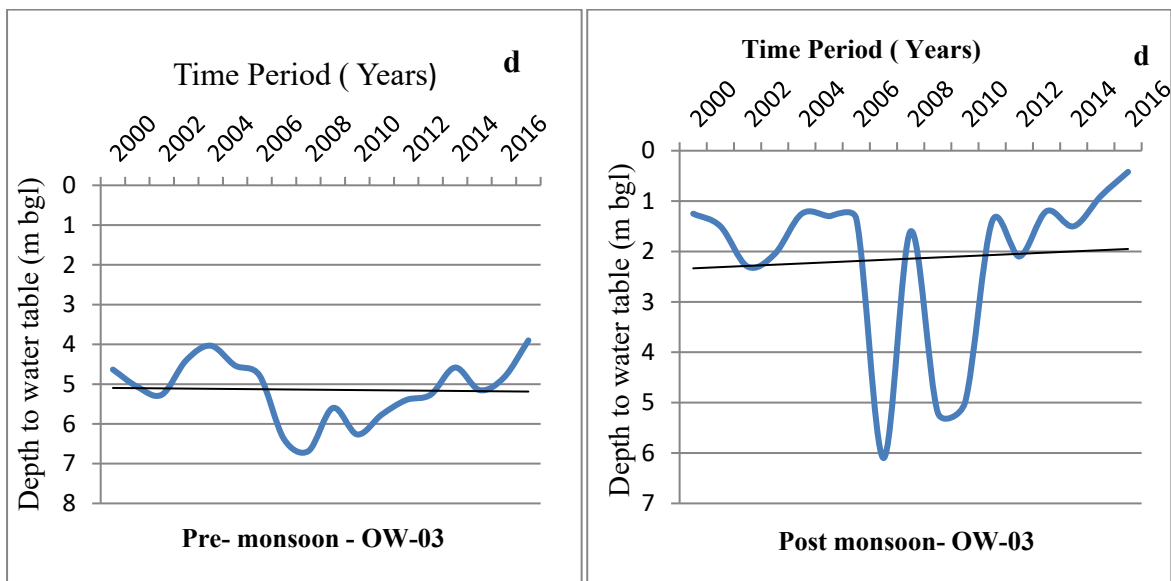


Fig. 2.3(d) Depth to water table (m bgl) Pre and Post Monsoon of OW-03 Well.

Time Series plot for depth to water for Niwari showing falling Trend.

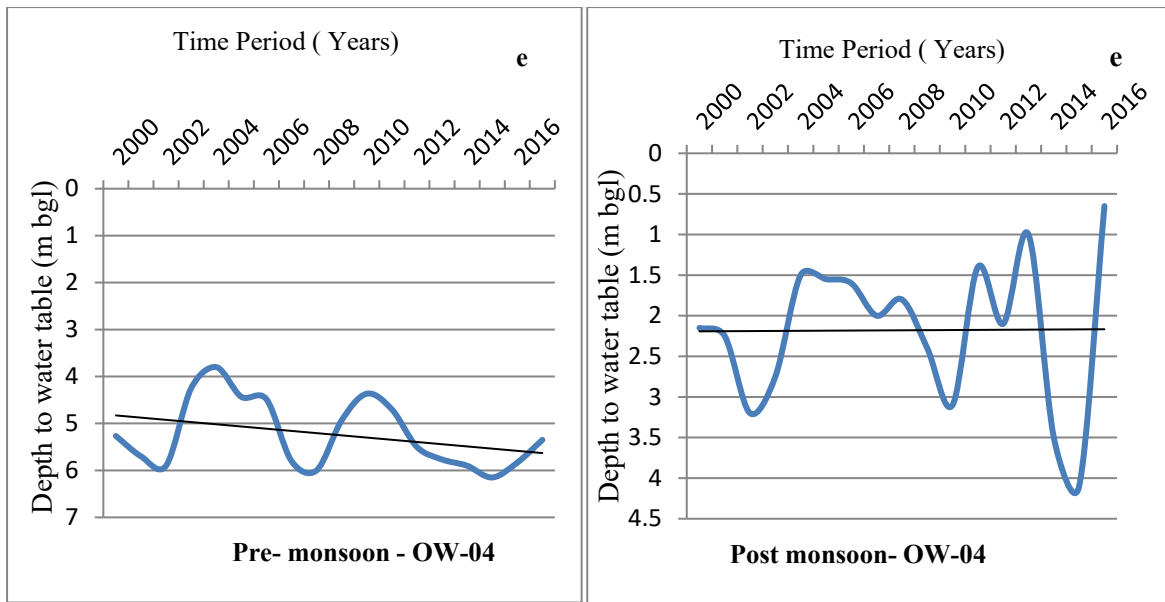


Fig. 2.3(e) Depth to water table (m bgl) Pre and Post Monsoon of OW-04 Well.

Time Series plot for depth to water for Bhangarh showing Raising Trend.

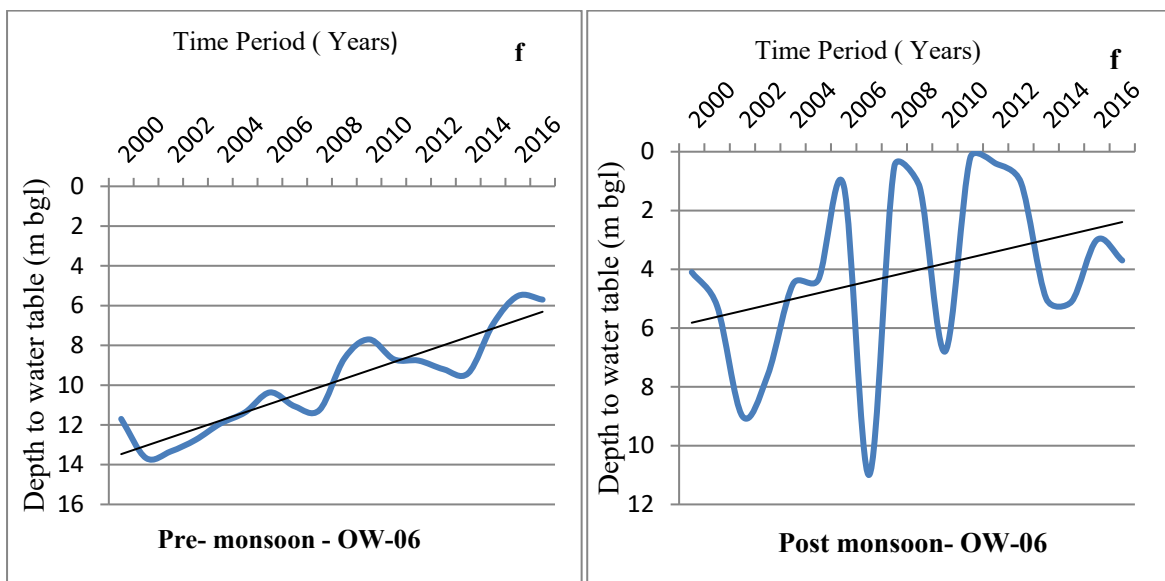


Fig. 2.3 (f) Depth to water table (m bgl) Pre and Post Monsoon of OW-06 Well.

Time Series plot for depth to water for Bina showing Raising Trend.

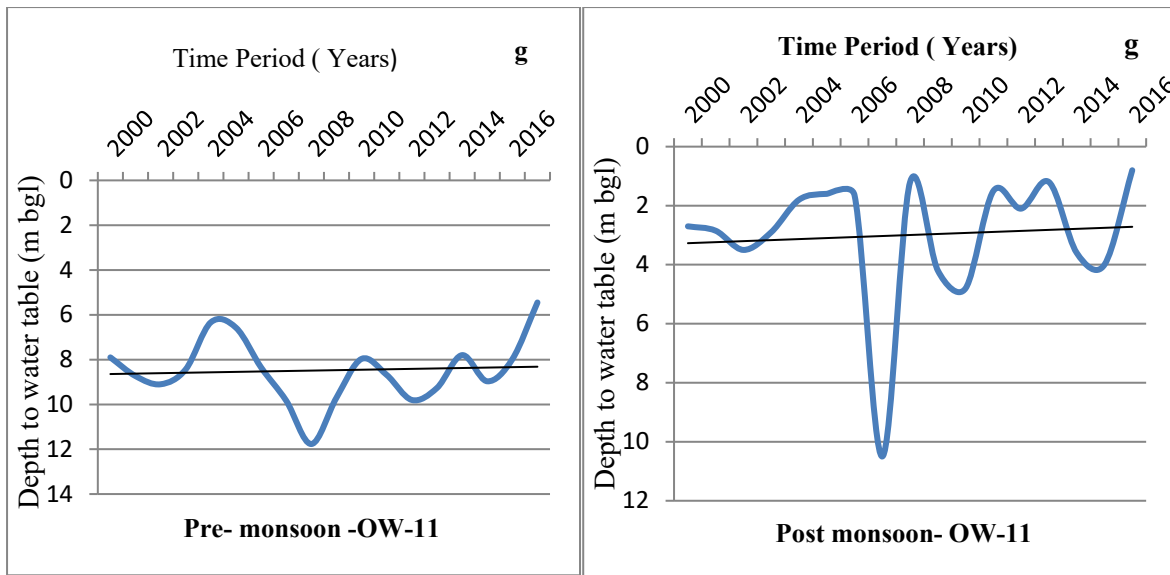


Fig. 2.3 (g) Depth to water table (m bgl) Pre and Post Monsoon of OW-11 Well.

Time Series plot for depth to water for Dugaha Kalan showing Raising Trend.

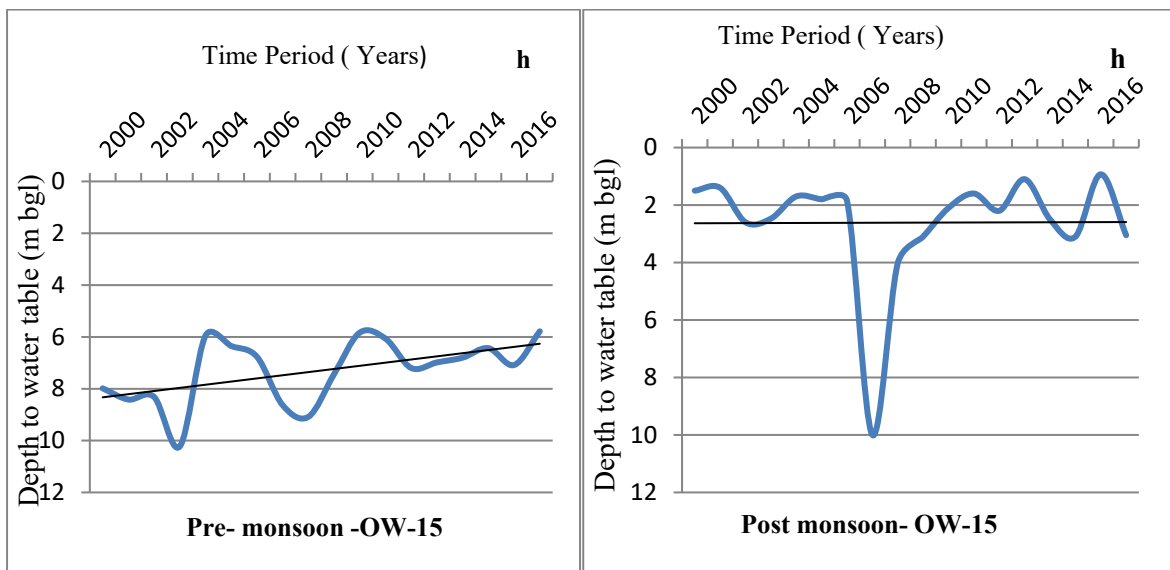


Fig. 2.3 (h) Depth to water table (m bgl) Pre and Post Monsoon of OW-15 Well.

Time Series plot for depth to water for Dhansara showing Raising Trend.

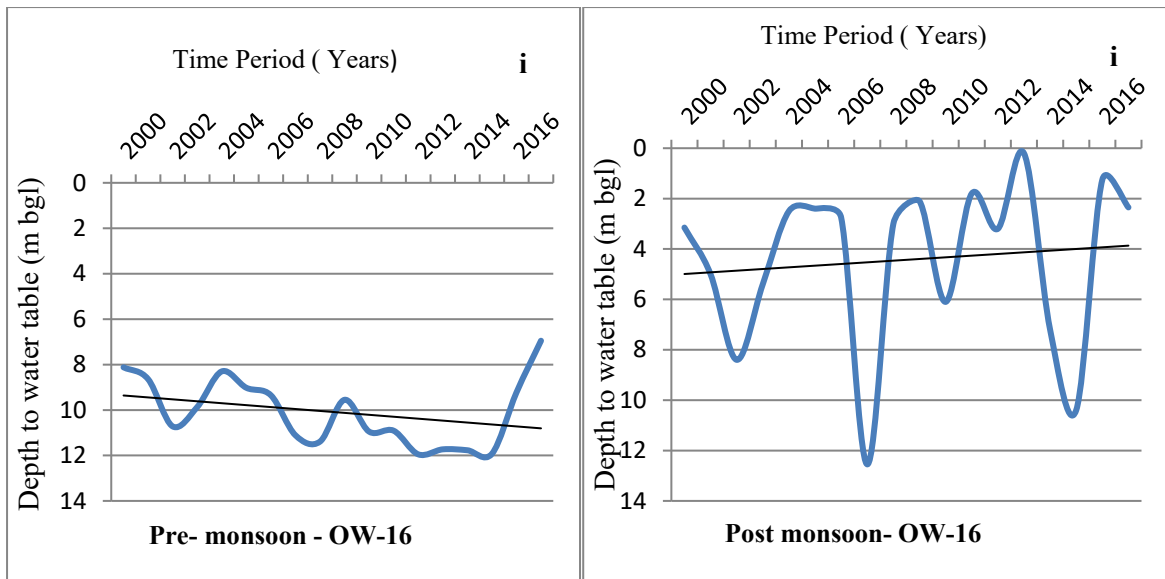


Fig. 2.3 (i) Depth to water table (m bgl) Pre and Post Monsoon of OW-16 Well.

Time Series plot for depth to water for Dugaha Kalan showing Falling Trend.

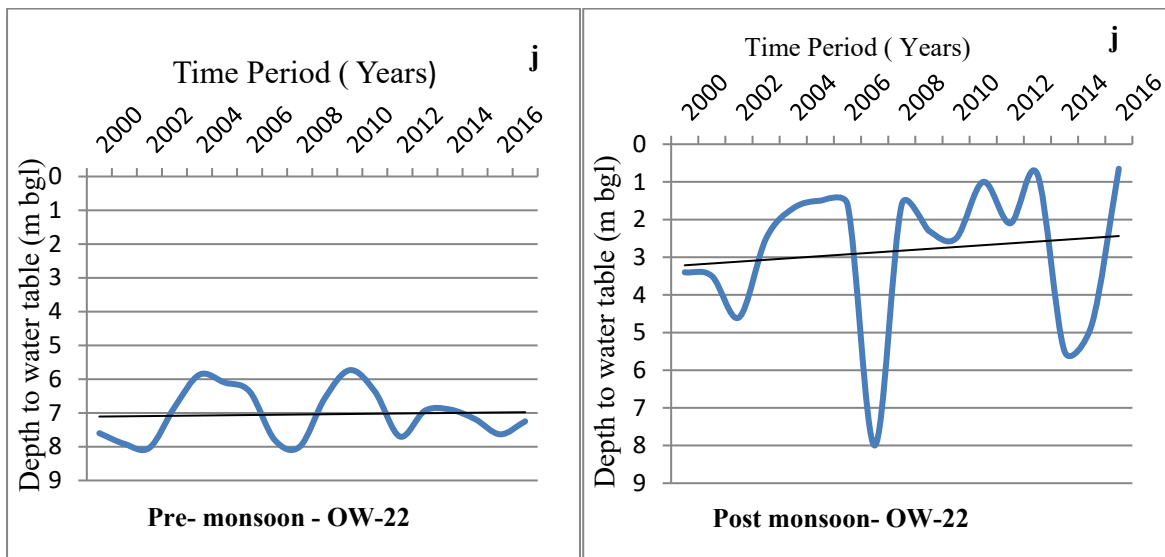


Fig. 2.3 (j) Depth to water table (m bgl) Pre and Post Monsoon of OW-22 Well.

Time Series plot for depth to water for Nonagir showing Raising Trend.

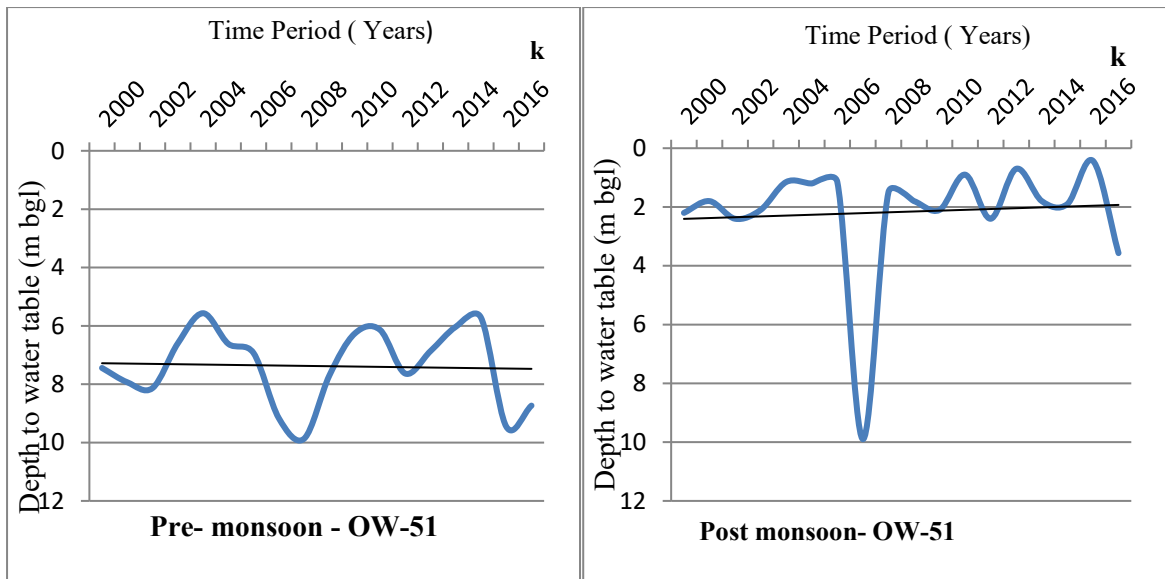


Fig. 2.3 (k) Depth to water table (m bgl) Pre and Post Monsoon of OW-51 Well.

Time Series plot for depth to water for Agasod showing Raising Trend.

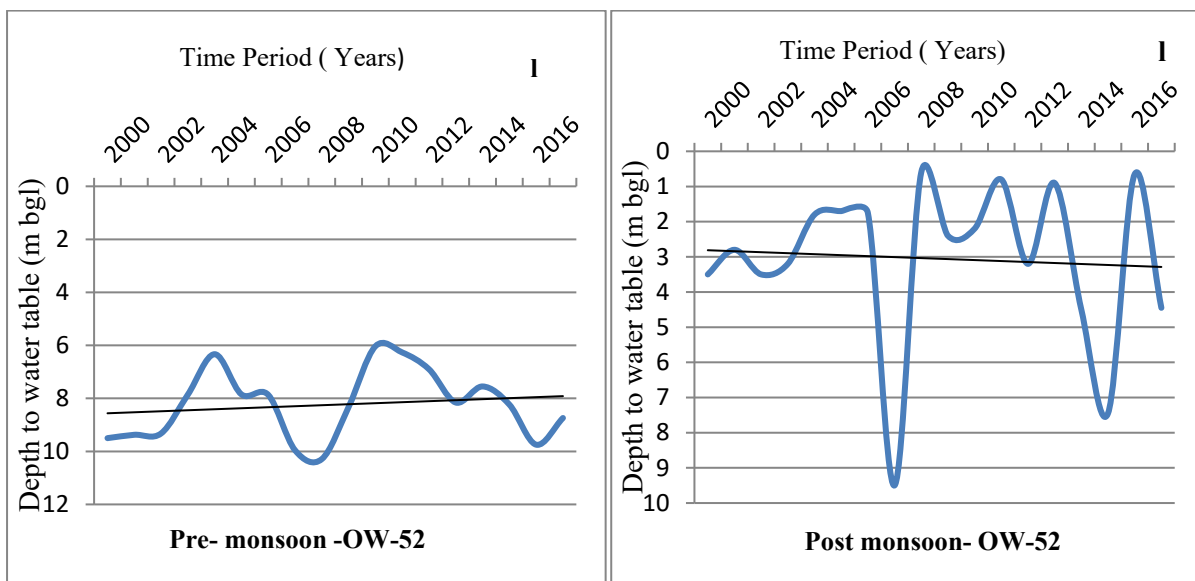


Fig. 2.3 (l) Depth to water table (m bgl) Pre and Post Monsoon of OW-52 Well.

Time Series plot for depth to water for Talapur showing Falling Trend in pre monsoon and Raising trend in Post Monsoon.

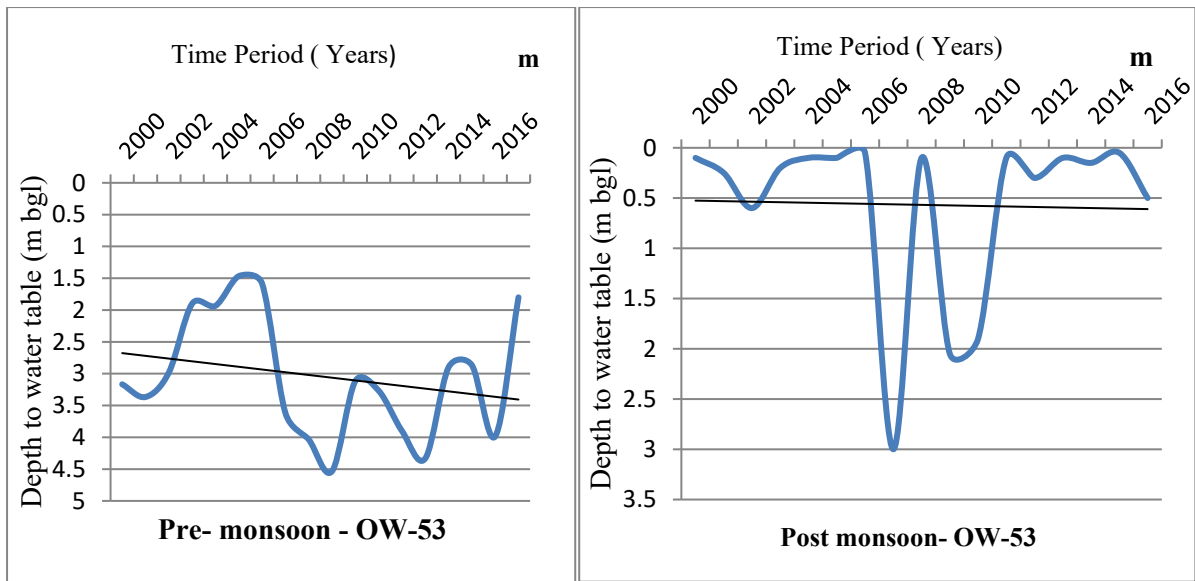


Fig. 2.3 (m) Depth to water table (m bgl) Pre and Post Monsoon of OW-53 Well.

Time Series plot for depth to water for Khimlasa showing Raising Trend.

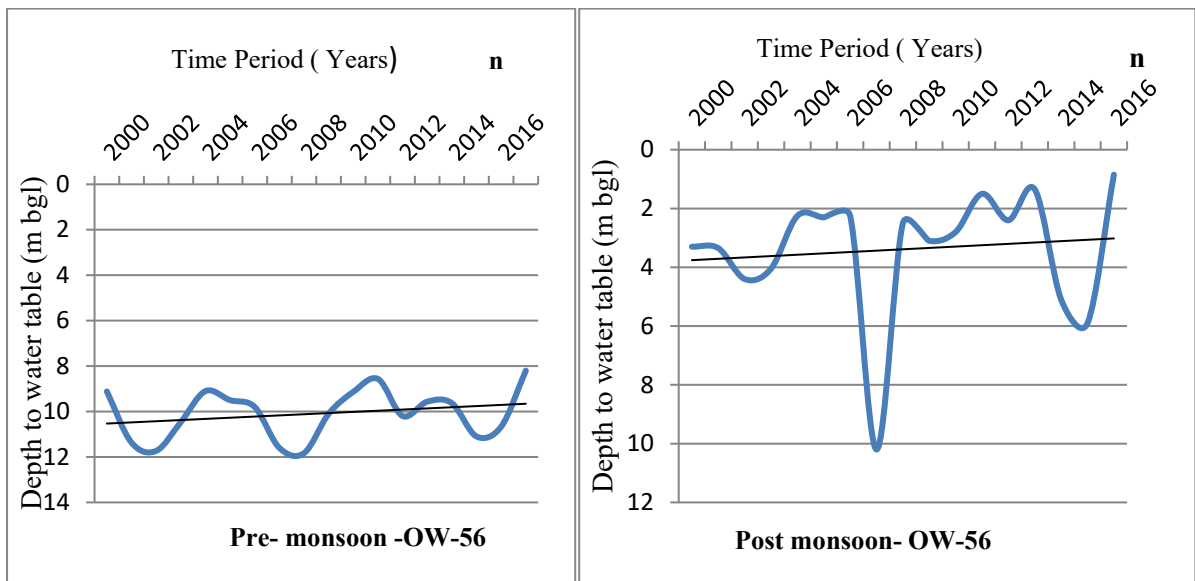


Fig. 2.3 (n) Depth to water table (m bgl) Pre and Post Monsoon of OW-56 Well.

Time Series plot for depth to water for Dugaha Mandi Bamara showing Falling Trend.

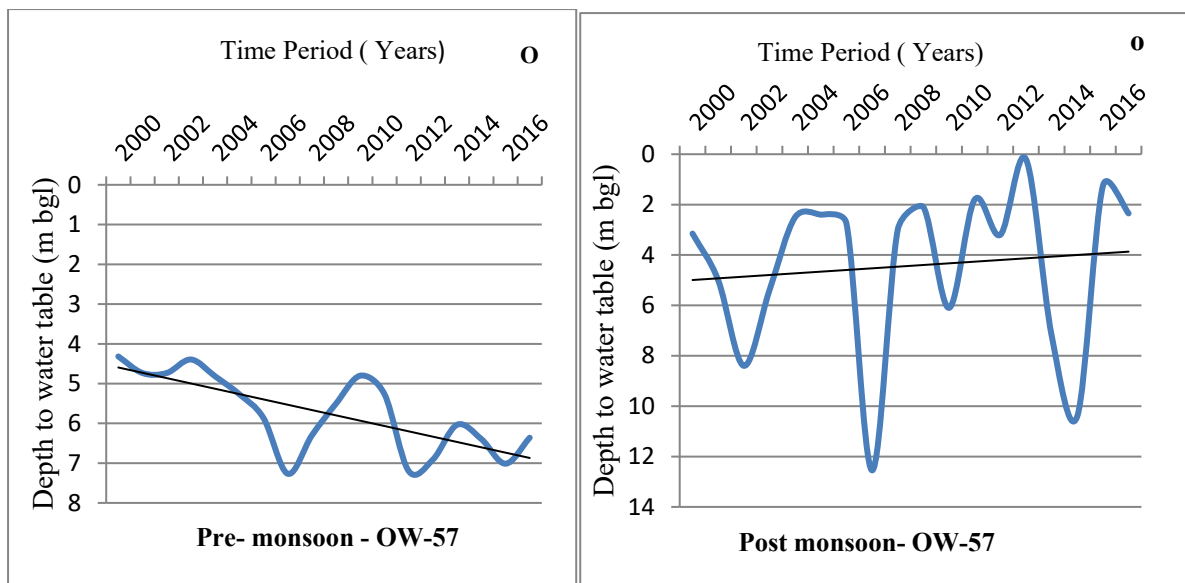


Fig. 2.3 (o) Depth to water table (m bgl) Pre and Post Monsoon of OW-57 Well.

Time Series plot for depth to water for Kulwai showing Falling Trend.

6.0 Conclusion

Groundwater level fluctuations and trends can be used to estimate changes in aquifer storage resulting from the effects of groundwater withdrawal and recharge useful in assessment of the groundwater potential available for utilization. These information can be used for groundwater management needs and evaluate its conservation practices. Mann-Kendall test performed on time series data of pre-monsoon groundwater levels in two blocks Sagar district showed significantly declining trend (increasing depth of water level from ground surface) in pre - monsoon groundwater levels during 2000-2017 and post-monsoon ground water levels showed declining trend (increasing depth of water level from ground surface) in post- monsoon during 2000-2017 with slope not significant. The magnitude of GWL varies from -0.055 m/yr (Kimlasa in Khurai block) to 0.480 m/yr at Bina in Bina block, whereas in Post-Monsoon period the magnitude of GWL varies from -0.041 m/yr (Kimlasa in Khurai block) to 0.370 m/yr at Bina in Bina block. These few locations viz., Bina, Dhansara and Dugahakalan where groundwater level shows significant rising trend may be due to recharge from water bodies and less or no abstraction of groundwater from phreatic aquifer whereas Khurai, Kulwai showing significant falling trend are due to over extraction of ground water. It is to be mentioned here that there are no large surface water irrigation schemes in these blocks during the period under study and as such the effect of return flow from field irrigation is minimal. (Thakur & T.Thomas, 2011).In

view of this it is imperative to arrest the rapidly falling groundwater levels at these locations for its sustainable use. Needful directives should be initiated towards identifying suitable artificial recharge zones in these blocks, so as to recharge the depleted aquifers and the exploitation should be limited within the dynamic recharge zone.

7. Groundwater Flow Modelling of Lower Bina basin

7.1 Simulation Software Visual MODFLOW

To setup these numerical models and visualize the consequences and results of the above mentioned computations, the software package Visual Modflow™ v.9.1. by Waterloo Hydrogeologic, Inc. was utilized. Visual Modflow™ (in the following sections referred to as VM) is a modelling environment for applications in groundwater flow and contaminant transport simulations.

(i) Basic principles

Numerical groundwater-flow models provide a solution to a governing groundwater flow equation which is subject to initial and boundary conditions. A general form of such an equation looks like as follows

$$\frac{\partial}{\partial x} \left(k_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_{zz} \frac{\partial h}{\partial z} \right) - W = S_s \frac{\partial h}{\partial t} \quad Eq1$$

K_{xx} , K_{yy} , K_{zz}hydraulic conductivity along the x-, y- and z-coordinate axes,
which are assumed to be parallel to the major axes of hydraulic conductivity [L/T]

hhydraulic head [L]

Wsource/sink term (e.g. pumping, recharge) [1/T]

S_sspecific storage [1/L]

t time [T]

x, y, zspace coordinates [L]

The solution to Eq. 1 provides a transient prediction of hydraulic head in a three dimensional domain for an anisotropic hydraulic-conductivity field. Among the main numerical approaches for solving such equations are the finite-difference methods (FDM) that replace the governing differential equation by a system of algebraic equations. For that purpose the model domain is subdivided into a three-dimensional rectangular grid of cells which yields to a system of

columns, rows and layers with cell-centered nodes. These nodes represent the points where the unknown hydraulic heads are calculated and one algebraic equation is solved for each node in the model grid.

The finite-difference form of the flow equation can be derived in several different ways. One method is to directly apply the governing flow equation, expressing the derivatives in difference form. In VM, the numerical approach is based on the equation of continuity which states that the sum of flows into and out of any cell is equal to the time rate of storage plus or minus additions of water from sources or sinks. It can be written as

$$\sum Q_i = S_s \cdot \frac{\Delta h}{\Delta t} \cdot \Delta V \quad Eq2$$

with

Q_iGW-flow into the cell from adjacent cells and through addition or withdrawal of water (e.g. through pumping, recharge) [L^3/T]

S_sspecific storage [1/L]

Δhchange in head over a time interval [L]

Δttime interval [T]

ΔVvolume of the cell [L^3]

Q_i in Eq. 2 can be expanded using the Darcy equation, written in terms of the gradients between nodes. Doing this substitution and rearranging terms leads to a system of equations

$$[A] \times \{h\} = \{q\} \quad Eq.3$$

where $[A]$ is the coefficient matrix, $\{h\}$ is the vector of unknown head values and $\{q\}$ is a vector of constant head terms.

VM approaches the solution of this system of equations through iteration which involves making some initial guess at the unknowns (“initial hydraulic head” in the VM terminology) and refining these guesses through a series of repeated calculations until an accurate solution is obtained.

Additionally, in order to solve the system of equations, it is necessary to specify boundary conditions. Boundary conditions for groundwater-flow problems can be classified into three types:

Type	Explanation	Example
1 st „Dirichlet“	provides a value of hydraulic head at a boundary, H	Edge 3-4
2 nd „Neumann“	provides the water flux at a boundary (including no-flow), Q	Edge 1-2, 2-3, 1-5
3 rd „Cauchy“	relates hydraulic head to the water flux, Q = f(H)	Edge 4-5

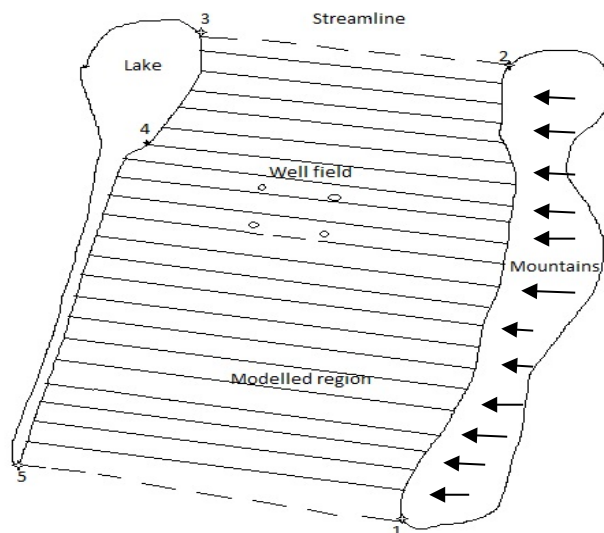


Fig 3.1- Example of boundary conditions

As it will be revealed in section 6.3, it is necessary to conduct simulations of contaminant transport with VM when dealing with RBF calculations. The way VM handles such computations is similar to that which groundwater-flow problems are treated.

The partial differential equation describing the fate and transport of contaminants of species k in 3-D, transient groundwater flow systems can be written as follows:

$$\frac{\partial(\theta C^k)}{\partial t} = \frac{\partial}{\partial k_i} \left(\theta D_{ij} \frac{\partial C^k}{\partial k_j} \right) - \frac{\partial}{\partial X_i} (\theta V_i C^k) + q_s C_s^k + \sum R_n \quad \text{Eq. 4}$$

with

q.....porosity of the subsurface medium [-]

Ckdissolved concentration of species k [M/L3]

- ttime [T]
- $x_{i,j}$ distance along the respective Cartesian coordinate axis [L]
- $D_{i,j}$hydrodynamic dispersion coefficient tensor [L²/T]
- V_i seepage velocity [L/T]
- q_s volumetric flow rate per unit volume of aquifer representing fluid sources (positive) and sinks (negative) [1/T]
- C_s^kconcentration of the source or sink flux for species k [M/L³]
- $\sum R_n$chemical reaction term [M/L³/T]

The first term on the right-hand side of Eq. 4 accounts for dispersion caused by mechanical dispersion, a result of deviations of actual velocity on a micro scale from the average groundwater velocity, and by molecular diffusion driven by concentration gradients.

The advection term of the transport equation, $\partial(\theta V_i C_s^k)/\partial k$ describes the transport of miscible contaminants at the same velocity as the groundwater.

The fluid sink/source term of the governing equation, $q_s C_s^k$ represents solute mass entering the model domain through sources or leaving the model domain through sinks.

The chemical reaction term in Eq. 4 can be used to include the effect of general biochemical and geochemical reactions on contaminant fate and transport.

Eq. 4 is essentially a mass balance statement, i.e., the change in the mass storage at any given time is equal to the difference in the mass inflow and outflow due to dispersion, advection, sink/source, and chemical reactions (Zheng and Wang, 1999).

VM obtains the solution to Eq. 4 by substituting it by a system of algebraic equations which is solved iteratively for each node in the model grid:

$$[A]. \{C\} = \{b\} \quad Eq. 5$$

where [A] is the coefficient matrix, {c} is the vector of unknown concentration values and {b} is a vector containing all the known quantities.

Just like for groundwater flow calculations, specification of initial and boundary condition is required in order to solve the system of equations. Three general types of boundary condition are considered in the transport model:

- concentration known along a boundary (Dirichlet Condition)
- concentration gradient known across a boundary (Neumann Condition)

- a combination of both (Cauchy Condition)

A Dirichlet boundary in a transport model acts as a source providing solute mass to the model domain or as a sink taking solute mass out of the model domain. A special case of a Neumann condition is a no -dispersive-mass-flux boundary. For the Cauchy boundary condition, both the concentration value and the concentration gradient are specified.

7.2 Setup of MODFLOW (numerical model)

For constructing and running a numerical groundwater model, a variety of different tasks have to be done. The main steps include:

- collection and evaluation of available data and information
- conceptualization of this hydrogeological setting in a model framework
- setup and running of the model
- model calibration: modification of model parameters until a good match between measured and calculated values is achieved
- either re-evaluation and collection of new data or model verification: to check that the model is a valid representation of the hydrogeologic system by using the calibrated model to simulate a hydrologic response that is known

Once a model is successfully verified, it can be used as a predictive instrument. This means that it will be much easier to forecast the consequences of future scenarios (e.g. changing water tables, pumping rates and schedules) to drinking water supply through RBF wells.

For model setup and calibration in VM, extensive collection of hydrogeological and hydraulic data is necessary:

Aquifer properties:

- hydraulic conductivity: knowledge of soil structure and soil properties for an adequate number of points within the model domain (preferably with a uniform distribution of the points throughout the model domain)
- storage coefficient and specific yield
- horizontal flow barriers

Aquifer geometry:

- Model Grid
- Model perimeter and extent (active and inactive cells)

- Pumping well and observation well locations and attributes
- Top elevations of layers: surveyed locations of an adequate number of points within the model domain
- Bottom elevations of layers: knowledge of soil structure for an adequate number of points within the model domain for determining different stratigraphical units
- Water levels: hydrographical and geometrical data for pumping wells, observation wells, rivers and other surface water bodies

Boundary conditions and fluxes:

- Pumping: pumping schedules and pump test data (if available)
- Surface water interaction: rivers and other surface water bodies
- Recharge
- Groundwater evapotranspiration
- Top, bottom and lateral boundaries

To take account for the model's relationship with surrounding systems the user can assign different boundary conditions. Within VM, boundary conditions are divided into two sections: flow boundary conditions (e.g. constant head, recharge) and transport boundary conditions (e.g. constant concentration, point source).

Minimum requirements for setting up a groundwater-model would include:

- model perimeter and extent (area of interest)
- pumping well and observation well locations
- rivers and other surface water bodies
- water levels: hydrographical and geometrical data for pumping wells, observation wells, rivers and other surface water bodies
- hydraulic conductivity: at least a coarse clue of soil structure and soil properties for a few number of points within the model domain; a more detailed knowledge can be gained through calibration processes

7.3 Data Collection

In Lower Bina basin there has been no proper record of well data, pumping hours etc , despite the lack of recorded data of long term water level and quality investigations and information on spatial aquifer properties an effort has been made to model groundwater flow using visual mudflow with available data . To describe and conceptualize the study area, data of different categories has been collected. Information about well and aquifer characteristics

was collected from published and unpublished sources through review of literature. Groundwater and river water levels were taken from available sources groundwater survey of WRD, In Table 5 the collected information used for the preparation of a groundwater flow model for Lower Bina basin is summarized. Additionally, the locations of open/dug wells, gauging stations and borehole-logs are summarized in a map in Fig 3.2

Category	Information about
Well data	Location, diameter, depth, groundwater levels and discharge, running hours
River data	water levels, cross-sections, discharge (Bina River)
Borehole-log data	Large-diameter caisson well 6 (Bina and Khurai), vertical filter well Nirtala, Shabda, PZ-13 Bina
GIS data	well, river and borehole-log locations, digital elevation model
Literature data	Range for hydraulic conductivity of the riverbed (Bina river), monthly rainfall and temperature

Table 4. Data used to prepare the groundwater flow model for Lower Bina basin

Water levels

To develop the groundwater flow model and perform simulations, different categories of data are required. Beside the invariant hydro-geologic and topographic characteristics of the study area, which are required to conceptualize the model, the spatial- and time-variant groundwater and river-water levels are relevant to set the boundary conditions and to evaluate the model performance. Thus, the groundwater level data has been collected for monsoon (August) and non-monsoon (May and January) for the year 2016 and 2017 respectively. To determine the river water levels, one existing gauging station (Central Water Commission), have been read out in the mentioned time intervals of monsoon months as during non-monsoon period there is no discharge.

7.4 MODFLOW Model Development

7.4.1 Model Configuration: Model Domain

In GIS framework using Arcgis pumping wells, lower bina river and its respective lower bina basin study area were digitised to the extent of 33265m×23572m in X-Y direction, hence 80 columns and 80 rows defined the study area in model domain of visual modflow, each grid

being 415.81m × 294.65 m. Grid is refined by 2 four times to represent the wells, lower bina river basin which being the study area of 243.10 square kilometers, channels i.e. 25.98m × 18.41m for detailed simulation especially in those areas that represent steep hydraulic gradient (i.e. drawdown near wells). To avoid numerical instability the size difference between adjacent cell is not more than factor of 2. The final spatial resolution for horizontal grid ranges from 25.98m to 415.81m (Fig.3.3). Borelog data from Sabda implies that aquifer is 30 m deep for the entire modelled area. The aquifer comprises of three layers, upper layer consists of yellow clay soil up to a depth of 4 m and below it is second layer to a stretch of 16 m depth imbibing partially penetrating large diameter bottom entry caisson well and consists of weathered basalt (most dug wells or open wells lies in zone as unconfined aquifer and the third layer extends up to a depth of 30 m below ground surface entailing jointed basalt (Fig 3.5). To input the three layers, input file consisting wells locations, their surface elevation, elevation of wells bottom, and bottom of 30 m deep aquifer is created having unconfined aquifer to a depth of 16 m and semi confined to confined aquifer below it till 30 m depth with variable T and S, whereby the uppermost layer is having clay soil up to a depth of 4 metre. Inverse distance approach of Visual MODFLOW is used to interpolate the elevation between each point.

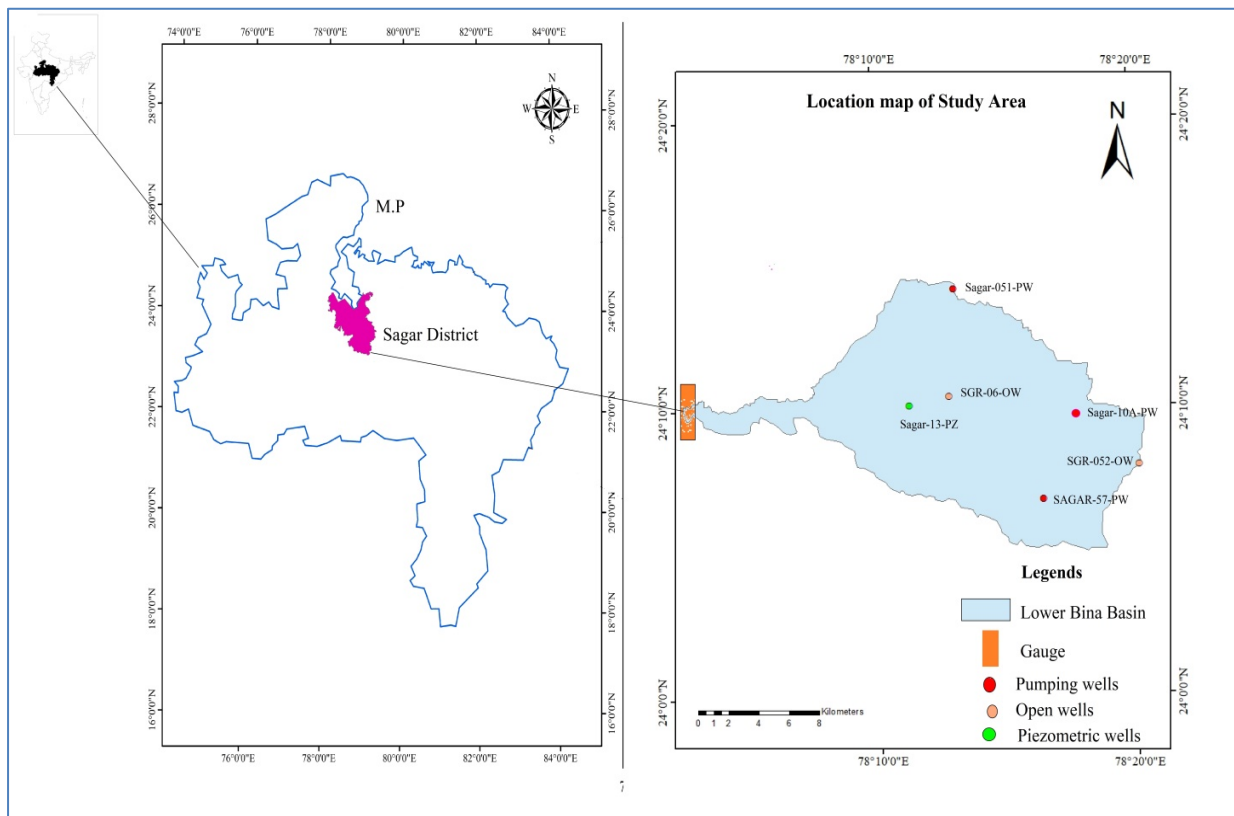


Fig 3.2. Study area of Lower Bina Basin.

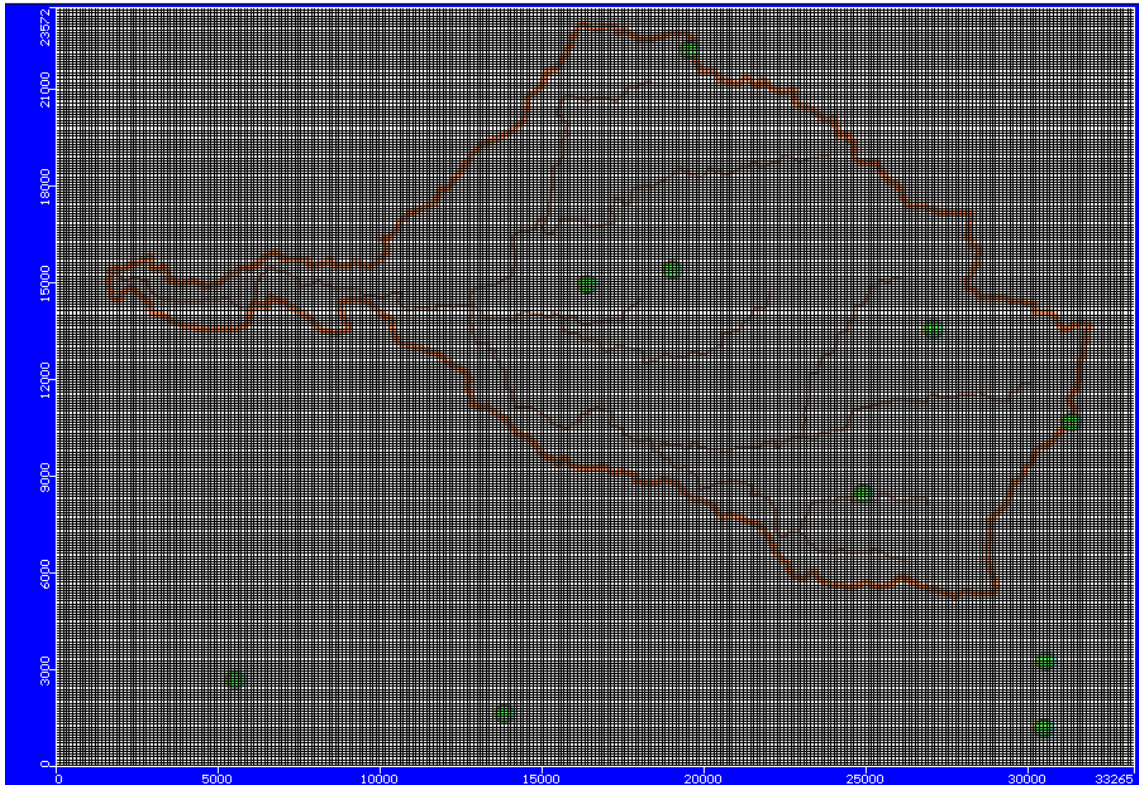


Fig. 3.3- Discretized model domain of Lower Bina Basin and Bina River.

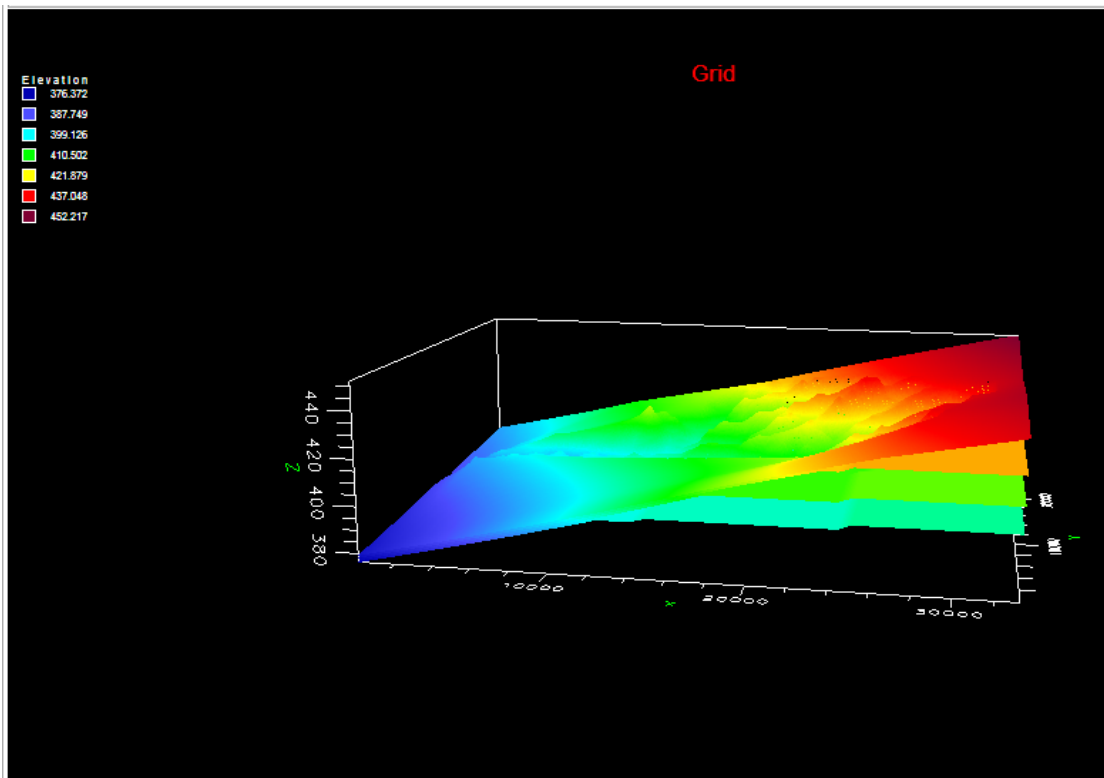


Fig.3. 4- DEM (SRTM data) generated for Lower Bina basin study area and interpolated in model domain using nearest neighbourhood technique of Visual MODFLOW.

7.4.2 Hydrogeological setup and Aquifer Characteristics

The detailed hydrogeological formations of the study area are delineated from the borelogs data of two exploratory wells (data source CGWB) located along NE-SW direction extending almost the entire length of the study area (Figure 3.5 and 3.6). The sectional view of the sub-surface formations along X-X'' (Figure 3.5) showed that the uppermost layer comprising thickness of about 4 m has surface soil (Yellow Clay Soil), which is underlain by the formations represented by weathered basalt upto a depth of 16m which represent the aquifer hydraulically connected to the Bina River under the unconfined condition. The hydrogeological setup of all the observation wells and pumping wells represents an unconfined aquifer of depth varies between 4 m at the upper reaches and about 16 m at the lower reaches below the ground surface except for wells lying below 16 m -30 m depth are in semi-confined to confined aquifer state .

The depth to groundwater level varies from location to location as the area has a varying topography; during non-monsoon months groundwater level occurs at a depth below 21.40 m from the lowest ground level (near to SGR PZ-13) and 11.47 m below from the highest ground level (near to SGR 052 OW) that gives an average depth of 10.45 m below the normal ground surface level. In terms of elevation, the groundwater table during non-monsoon months occurs at 414.21m above msl. During monsoon months, the groundwater level goes up by an average height of 1.467 m and reaches to the average level of 423.21 m. The normal groundwater flow direction along the left bank of the river Bina is from the north-westerly towards the south-westerly, and along the right bank is from south westerly.



Fig 3.5: Hydrogeological setup of the study area, section along X-X''.

The tapping zone of all the observation and pumping wells lies within the unconfined aquifer between depth of 4 m and 16 m below the ground surface. Most of the wells have penetrated the aquifer partially, and maintain a considerable gap between the well-bottom and the underneath impervious strata of jointed/amygdaloidal basalt. The yield of the third zone i.e 16m to 30m tested together was only 3.2 lps. The tranmissivity was 36.3 m²/day (CGWB report).

Fig: 3.6- Stratigraphy of borewell (sabda) and open/dug wells located in Lower Bina Basin.

7.4.3 Model properties and boundary conditions

For groundwater flow modelling purposes information on filter screen depth, pumping rate of each well, aquifer characterization as well as storage of the large diameter well based on hydraulic conductivities of the model layers is necessary. In present scenario the dug well do not have vertical filter installed in them, rather the water is entering from the bottom of the well. Such well has good storage capacity allowing the Groundwater flow from aquifer to store in well storage and water being extracted to the whole saturated depth of the open well. Therefore, the required screen in Visual MODFLOW is defined from the top up to the well bottom. The rated discharge Q_p , the daily duration of operation and the daily abstracted amount Q_{ex} for each well are summarized. The required amount of extracted water Q_{ex} depends upon the daily running hours of the pumps. The duration of operation (in hours) for some wells varies between monsoon and non-monsoon season, as a result of higher surface water levels (in monsoon) and the seasonal variation in demand for water. A higher well yield during monsoon season allows a longer operation of the pumps to cater the increased demand for water. During the non-monsoon season, the operating hours of some wells are increased due to more demand, as the onset of the hot dry weather season (April-June) (Table 6) and water is used for increased irrigation requirement.

Table 5 Rated discharge, operating hours and the daily discharge of water (Q_{ex}) abstracted during monsoon and non-monsoon season for each dug/open wells (listed from north to south)

Well ID	Q_p [L/min]	Monsoon		Non-Monsoon	
		Duration of operation [h]	Q_{ex} [m ³ /d]	Duration of operation [h]	Q_{ex} [m ³ /d]
SGR-13-PZ	347	10-12	500	10-12	435
SGR051-PW	180	8-9	180	9-10	260
SGR057-PW	159	4-5	45	8-9	230
SGR10A-PW	125	9-10	250	8-9	180

According to lithologs of bore well and hydraulic data collected from CGWB report on Bina basin the initial horizontal hydraulic conductivity k_x and k_y of the aquifer was assigned within a range of 1.15m/day to 0.006 m/day. The k-value in Z-direction was set to 4m/day to 30m per day, while the

final hydraulic conductivity in X- and Y-direction was determined during the model calibration (sec. 7.4.4).

To solve the groundwater flow equations, boundary and initial conditions are required. The boundary condition in the west of the study area has been assigned constant head boundary condition to account for water levels of Bina River at confluence point of Bina and Betwa. The boundary condition in the central part of the study area where the Bina River is flowing has been interpolated using the triangulation method for undisturbed groundwater levels and river water levels. The hydraulic connection between the river Bina, its drainage and the aquifer is represented by the river boundary conditions. To assign river boundary condition, stage of river, riverbed bottom, riverbed thickness and hydraulic conductivity of the riverbed are required. Consequently, the conductance value for each grid cell, which changes due to different cell sizes within the model, is calculated automatically. The river level is assigned at particular points where the stage has been measured. Riverbed elevation and width have been determined using cross-sections constructed from field measurements. Between those points, the required physical dimensions of the river are interpolated automatically by Visual MODFLOW. The hydraulic conductivity of the riverbed is finally set during the calibration.

7.4.4 Steady-state model calibration and validation

The model is calibrated for steady state conditions. The PEST programme of the model looks for the difference between the models calculated values (determined with the initial values) and the observed field values. PEST runs the model MODFLOW as many times as may be necessary and searches for an optimal parameter set for which the sum of squared deviations (objective function) between model – computed and the experimental observation is reduced to a minimum. In order to optimize the number of iterations, the default values of coefficients were used. Accordingly, head observation wells are required to compare calculated and measured heads. Since the groundwater levels were directly measured in the dug/open wells, imaginary observation wells have been assigned for each dug/open well in the model.

The following dug wells are pumping wells namely, SGR013-PZ, SGR057-PW, SGR051-PW, SGR10A-PW and observation wells are SGR 006-OW and SGR 052-PW. The calibration has been performed for two different steady state scenarios, using the observed groundwater levels on August,2016 and May 2016, which represent the monsoon and the non-monsoon (post-monsoon) season, respectively (Fig 3.8, 3.10, 3.11). A flow chart, summarizing the calibration procedure of the groundwater flow model, path lines is given in Fig 3.7. The adjustable modelling parameters are the hydraulic conductivity of the aquifer and the riverbed (sec.

7.4.3). Table 6 summarizes the adjusted hydraulic conductivities after the completed calibration process. Here the conductance of the riverbed/river is calculated automatically after assigning the riverbed thickness, river width and river hydraulic conductivity which here range from range 450-500m²/ day.

The riverbed material of the Bina River contains of fine material mostly sand and silt content of 40% as a result of low surface flow velocities, which results in increased deposition and limits the hydraulic connection with the aquifer to an assumed k-value of 0.15 m/d, 1.14m/d, and 0.001m/d. The k-values of the remaining riverbeds are constant over the whole channel-length. The hydraulic conductivity values of the upper and bottom aquifers are varied iteratively so that root mean square (RMS) error could be kept below 10 m.

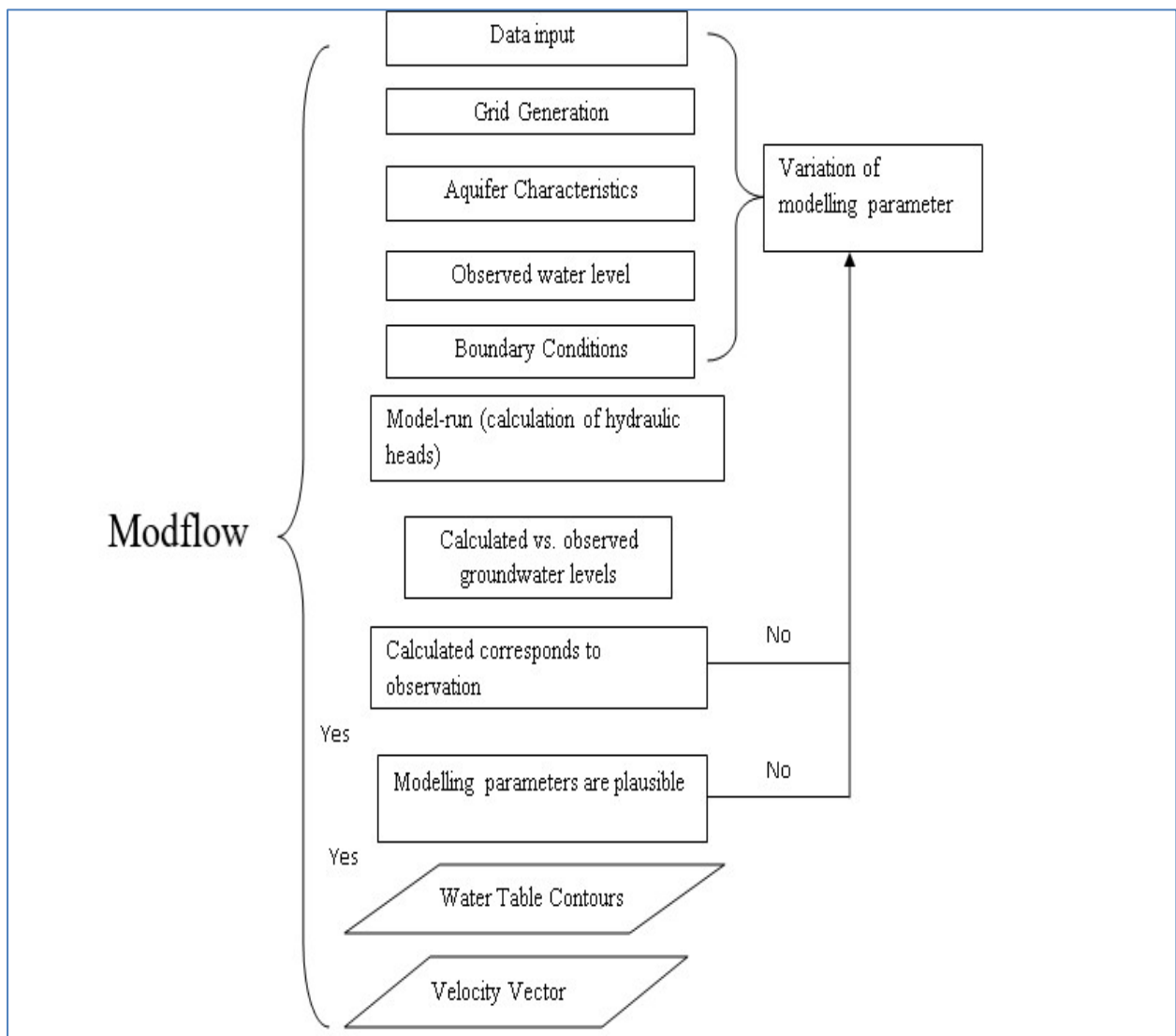


Fig. 3.7- Flow Chart of the methods involved in calibration of the groundwater flow model, path lines and portion of extracted bank filtrate from each well.

Hydro-geological unit	Calibrated hydraulic conductivity [m/s]
Aquifer	K _x =1.31E-5 m/sec K _y = 1.6E-6 m/sec K _z =1.6E-6 m/sec
Bina River	K _z =5E-5m/sec,4.62E-6 m/s

Table 6: Calibrated Hydraulic conductivities for the hydro geological set-up of the model.

Statistical evaluation	Monsoon	Non-Monsoon
Residual Max [m]	6.87	17.08
Residual Min [m]	-0.061	7.60
Residual Mean [m]	0.107	12.35
Standard error [m]	1.86	1.33
RMS [m]	4.17	12.71
Norm. RMS [%]	13.28	34.89
Correl.-Coeff. [-]	0.95	0.971

Table 7. Statistical Evaluation of the calibrated model.

The calibration has been evaluated by comparing the measured and calculated groundwater levels (Fig 3.8, 3.10 and 3.11). The measured groundwater levels from dug/open wells which show maximum drawdown were considered while the pump was in operation during the model calculation.

Table 7 shows the evaluation of the final results for monsoon and Pre- monsoon period (2016). The difference between the calculated and the observed groundwater levels mainly varies within a range of -0.061m to 6.87 m, which was taken as threshold for a good calibration result for monsoon period. This is shown by the residual minimum and residual mean in Table 7 with a value range of -0.061m to 0.107m. For non-monsoon period head difference between calculated and observed head varies from 7.6m to 17.08m which was taken as threshold for a calibration result for non-monsoon period. This is shown by the residual minimum and residual mean in Table 7 with a value range of 7.6m to 12.35m. However, it was not possible to fit the simulated and observed water level for each well within this threshold. For some wells, where it was not possible to interpolate the undisturbed groundwater level and where the simulated heads were calibrated to the maximum observed drawdown, the difference between calculated and observed heads exceeds the value of 12.35 m. This is emphasized by the residual maximum in Table 7. For those wells with significantly overestimated groundwater levels, the plausibility of the calibration result has been validated by modelling the steady state groundwater level without pumping. Here, each modelled groundwater level has been compared with the corresponding surface elevation level. The result was proven reliable; when the elevation of the modelled groundwater levels is lower than the elevation of the surface level (when the

groundwater is not passing out of the aquifer). The minimum and maximum deviation between the observed and simulated water levels varies between -0.061m to 17.08m, and the RMS error is at minimum (4.17m) in monsoon and at maximum (12.35m) in pre monsoon during the study period.

In order to analyse flow direction a comparison between the wettest and driest periods of the year is of particular interest. Therefore, a steady state modelling according to the water levels of the pre-monsoon season (January, 2017) was realized with the calibrated model. This model output validates the parameterised model by comparing the observed and calculated heads. Here, again measured draw-downs within the wells were taken. The result is similar to the calibration under monsoon and post-monsoon conditions as indicated by the statistical parameters in Table 8. Considering the mentioned problems in detecting the maximum draw-downs of the well and the missing undisturbed observation wells, the quality criteria in Table 8 emphasize an adequate validation output (Fig 3.9 and 3.12). As a consequence, the following model study is realized for the monsoon and pre-monsoon period under steady state conditions.

Table 8: Validation result for the measured and interpolated water levels in pre-monsoon period (January 2017)

Residual Max [m]	Residual Min [m]	Residual Mean [m]	Standard error [m]	RMS [m]	Norm. RMS [%]	Correl.- Coeff. [-]
-27.546	1.59	0.369	5.72	12.80	36.68	0.89

8.0 Statistical Analysis

8.1 Mean error

The mean error (ME) is defined by the equation

$$\text{Mean Error} = \frac{1}{n} \sum_{i=1}^n (X_{calc} - X_{obs}) \quad \text{Eq.13}$$

Where X_{obs} is observed value and X_{calc} is the calculated value for a data series.

It is to be noted that there may be cases where over-calculated and under calculated values will negate each other and produce a mean error value close to zero. This can lead to false interpretation of model calibration.

8.2 Mean absolute

The mean absolute error is the same as the mean error except the absolute values of each calculated and observed head difference, are summed. In other words,

$$\text{Mean Absolute Error} = 1/n \sum_{i=1}^n |X_{calc} - X_{obs}|_i \quad \text{Eq.14}$$

This measures the magnitude of the calibration residuals and therefore provides a better indication of calibration than the mean error.

8.3 Standard error of the estimate

The standard error of the estimate is expressed by the equation,

$$S.E.E = \frac{\sqrt{\sum_{i=1}^n (X_{calc} - X_{obs})^2_i - (\sum_{i=1}^n (X_{calc} - X_{obs})_i)^2}}{N-1} \quad \text{Eq.15}$$

The error of the estimate is also commonly referred to as the calibration residual.

8.4 Root mean squared

The root mean squared error (RMS) is defined by the equation,

$$RMS = 1/n \sqrt{\sum_{i=1}^n (X_{calc} - X_{obs})^2_i} \quad \text{Eq.16}$$

8.5 Normalized RMS

The normalized root mean squared error is the RMS divided by the maximum difference in the observed values. In other words

$$\text{Normalized RMS} = \frac{RMS}{(X_{obs})_{max} - (X_{calc})_{max}} \quad \text{Eq.17}$$

If there is one data value, then this denominator will be 100.

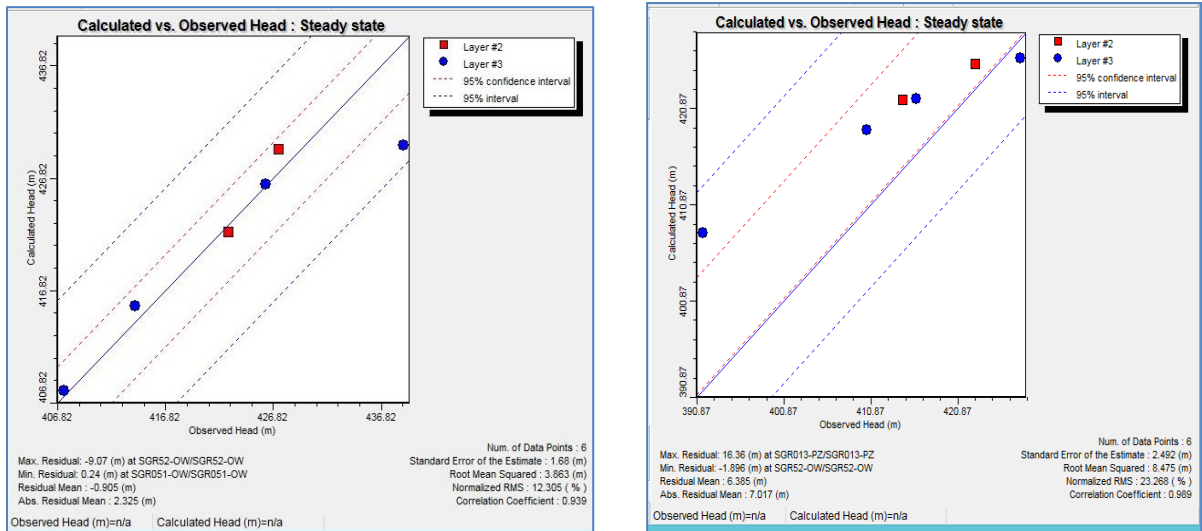


Fig 3.8- Calibration result for water-levels measured at monsoon: August 2016 (left) and pre-monsoon: May 2016 (right) during steady state modelling.

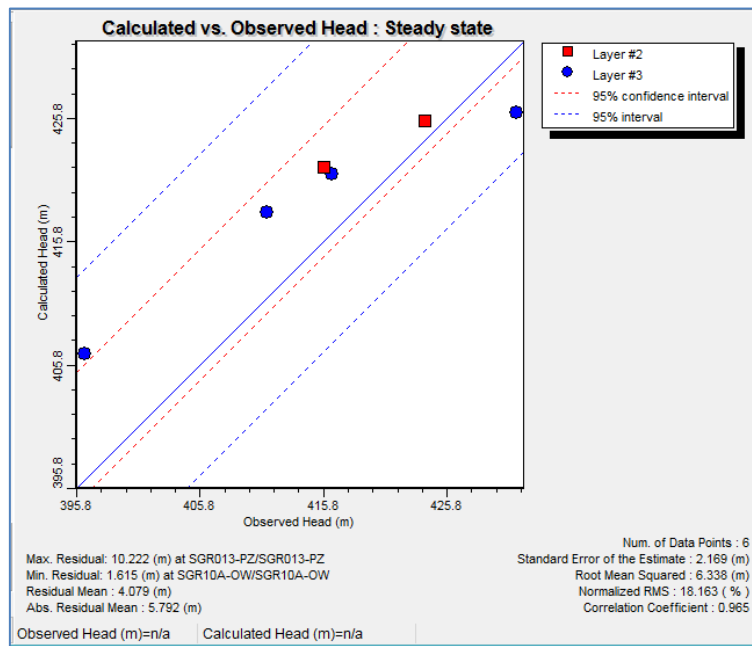


Fig 3.9- Validation result for water levels measured during non-monsoon (January, 2017) during steady state modelling.

Equipotential lines and flow paths of groundwater flow domain of Observation/Pumping wells and Piezometer in Lower Bina Basin for steady-state condition in monsoon season (August, 2016)

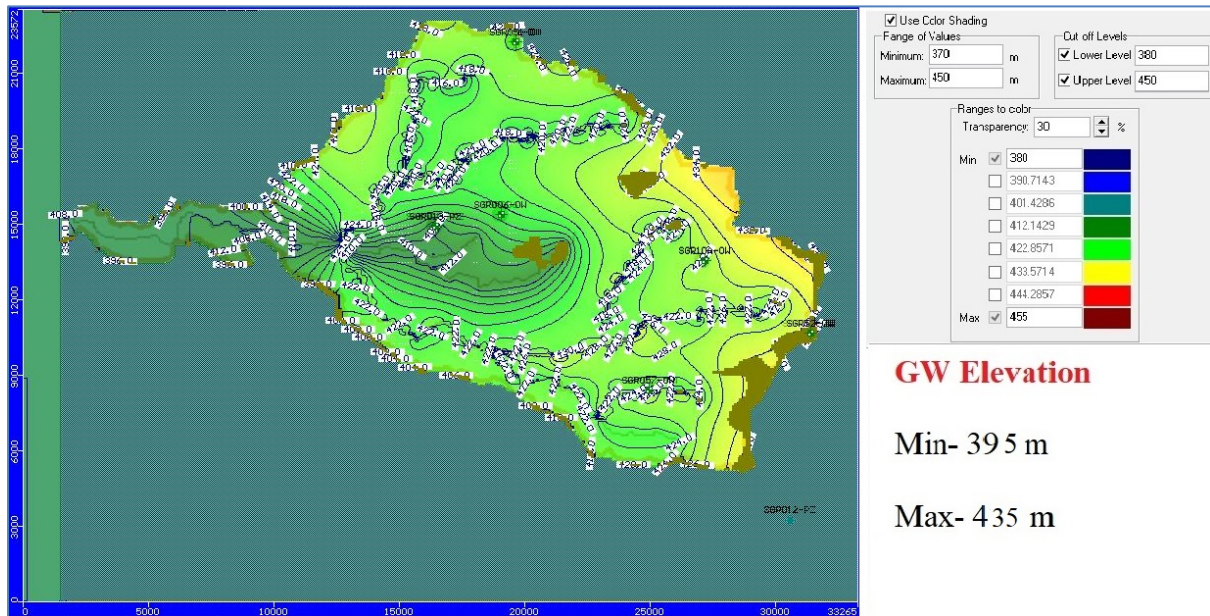


Fig 3.10- Calibration plot of Observation/Pumping Wells and Piezometers located in Lower Bina Basin during Monsoon Season (2016) in Steady State condition

Equipotential lines and flow paths of groundwater flow domain of Observation/Pumping wells and Piezometer in Lower Bina Basin for steady-state condition in Non-monsoon season

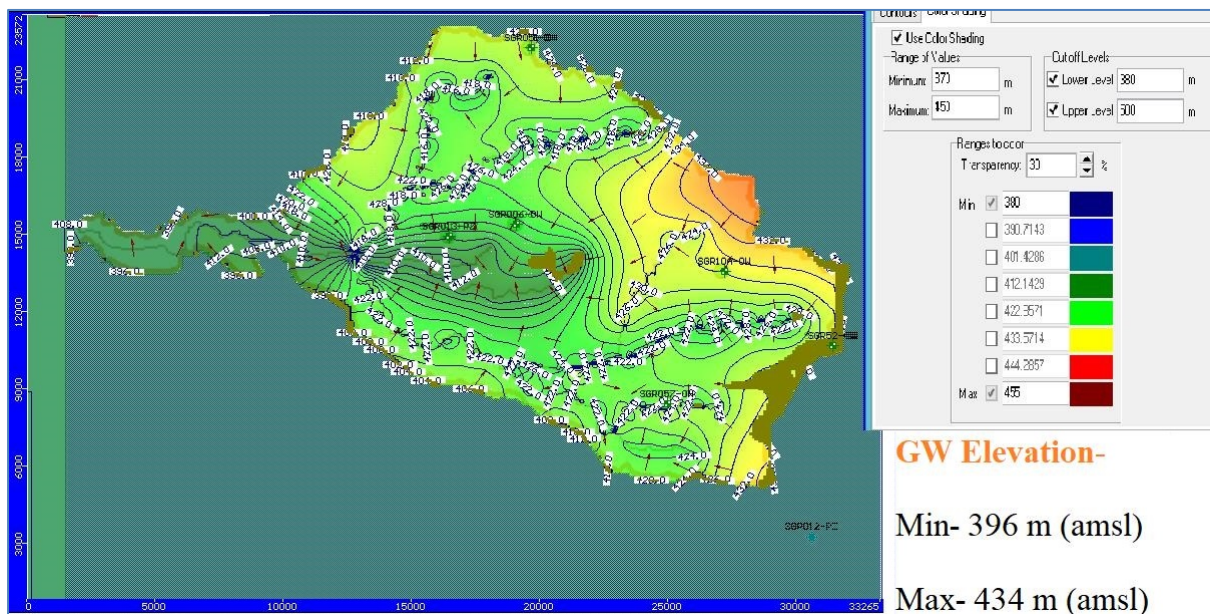


Fig 3.11- Calibration plot of Observation/Pumping Wells and Piezometer located in Lower Bina Basin during Pre- Monsoon period (2016) in Steady State condition

Equipotential lines and flow paths of groundwater flow domain of Observation/Pumping wells and Piezometer in Lower Bina Basin for steady-state condition in Non-monsoon season (January 2017)

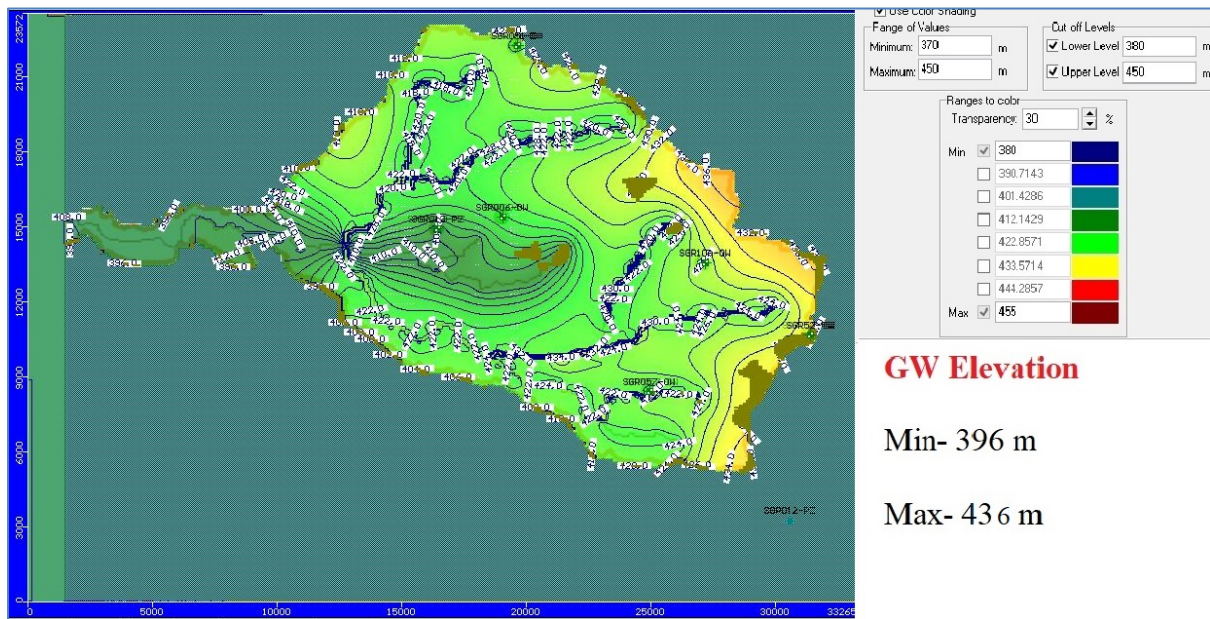


Fig 3.12- Validation plot of Observation/Pumping Wells and Piezometers located in Lower Bina Basin during Non- Monsoon period in Steady State condition (January, 2017).

Groundwater balance using MODFLOW

Groundwater balance under steady-state condition is given in Table9 below:

Year	Input	Output	Balance
2017(Pre-Monsoon)	184.28MCM	184.28MCM	-1712 m ³ /day or -0.001MCM
2016(Monsoon)	246.17MCM	246.18MCM	-2016 m ³ /day or -0.002MCM
2016(Pre-Monsoon)	185.779MCM	185.735MCM	-43552 m ³ /day or -0.043MCM
Average(Pre-Monsoon2016 and 17)	185.02MCM	185.00MCM	-0.022MCM

A Steady-state calibration is accomplished for the year 2016 monsoon. The general groundwater flow is from east to west. The total input to the aquifer is 246.179MCM and the total output is 246.181 MCM .This indicates deficiency of recharge of -0.002 MCM, which does not indicate significant decline in Water table.

Table 10.Components of Groundwater balance using MODFLOW for the year 2016

Sub-surface inflow	$5.0 \times 10^5 \text{ m}^3/\text{day}$	Sub-surface outflow	$9.2 \times 10^5 \text{ m}^3/\text{day}$	
River Leakage (river infiltration)	$1.7 \times 10^8 \text{ m}^3/\text{day}$	River Leakage (river exfiltration)	$1.8 \times 10^8 \text{ m}^3/\text{day}$	$-0.1 \times 10^8 \text{ m}^3/\text{day}$
Direct Recharge	$8.3 \times 10^6 \text{ m}^3/\text{day}$	Draft through Pumpage	$1.8 \times 10^5 \text{ m}^3/\text{day}$	

7.4.5. Result and Discussion

The 3D finite-difference groundwater model Visual MODFLOW was used for modelling groundwater flow in lower bina basin in steady state condition for monsoon and non-monsoon period during the year 2016. In this model, quasi- steady state calibration comprised the matching of observed heads in the aquifer with hydraulic heads simulated by MODFLOW during monsoon (August) and non-monsoon (May) period for the year 2016 considering recharge and pumping draft. The calibrated steady-state model show observed and computed head of August 2016) which is validated using a steady state modelling according to the water levels of the pre-monsoon season January 2017 which indicated prevailing trend of groundwater flow in lower bina basin. The computed water level accuracy was judged by comparing the mean error with mean absolute and RMS error (Anderson and Woessner, 1992). Residual Mean error is 0.107m (monsoon2016). RMS error is square root of the sum of the square of the differences between calculated and observed heads, divided by the number of observation wells, which in the present simulation is 4.17m. The absolute residual mean is 3.17m. Validation result for water levels measured at pre-monsoon (January 2017) during steady state modelling shows residual mean error of 0.369 m, RMS error 12.80 m and absolute

residual mean 9.55 m respectively. Ground water modelling involves voluminous data on various input parameter. With the available data the simulated hydraulic heads using MODFLOW and observed hydraulic heads were shown better correlation as shown in (i.e 0.95, 0.97 and 0.89 for monsoon, pre-monsoon 2016 and pre-monsoon 2017 respectively). Variations in the observed and simulated water levels were noticed for the wells that are near the river and it is due to the lack of sufficient river flow data for this area. The model indicates that average input to the aquifer is 185.02MCM and output from the aquifer is 185.00 MCM.

Flow budget

The stationary flow budget includes two major inputs (direct groundwater recharge from precipitation and rivers infiltration) and two major outputs (pumpage and river exfiltration). The direct recharge is estimated to be $\sim 8.3 \times 10^6$ m³/day mostly recharging the vesicular/jointed basalt zone underlying at a depth from 16 mbgl (Table 10). The total river infiltration (downward leakage) is 1.7×10^8 m³/day (i.e 170 MCM) which contributes to subsurface recharge. In terms of outflows from the flow domain, river exfiltration (upward river leakage) represents the most important budget component (-1.8×10^8 m³/day) followed by the pumping draft (-1.8×10^5 m³/day) and the outflows through the western limit of top aquifer (-9.2×10^5 m³/day, termed as “constant head”) (Table 7). For the semi-confined to confined vesicular/jointed basalt aquifer 1.7×10^8 m³/day gets recharged from the river but -0.1×10^8 m³/day exfiltrate to the surface water. In addition, river exfiltration (upward river leakage) is more than river infiltration (downward infiltration) by -0.1×10^8 m³/day for both unconfined (weathered basalt) and semi-confined to confined (vesicular/jointed basalt) aquifers meaning that river remain overall gaining in the flow domain (Table 7). This means that for the stationary condition, river is not predominantly recharging the aquifers.

In the present study, a Modflow model is developed to estimate head calibration of Lower Bina basin a part of Bina River with known boundary conditions and field observations. The best method of reducing modelling errors is to apply good hydrogeological judgment. The model calibration has been performed based on the available data. The model results show that computed values are in good-fitness of the measure data, which indicate the model is reliable. Similar studies can be undertaken for other water stressed areas for reliable water resources estimation adopted in better and efficient water resources planning and management. Continuous measurements of water budget components and groundwater levels will build up databases required for analysis of regional flow systems and construction of regional transient

groundwater models. The results of calibration showed that the predicted results matched well with the observed data. The model could be used to predict the groundwater levels variation under different hypothesis conditions in lower bina basin, which would provide the effective reference to the rational use and management of the groundwater.

7.4.6. Summary and Conclusion

Groundwater model has become a commonly used tool for hydrogeologists to perform various tasks. The rapid increase of computing power of PCs and availability of user friendly modeling systems has made it possible to simulate large scale regional groundwater systems. The present modeling study is very preliminary and subject to many assumptions and assumed hydraulic parameters. Groundwater models are tools which are frequently used in studying groundwater flow systems. A ground water model is a simplified representation of a more complex reality. They have proven to be useful tools over several decades for addressing a range of ground water problems and supporting the decision-making process. Ground water modeling involves voluminous data; accuracy of result depends on the availability of data on various input parameter. With the available data the simulated hydraulic heads using MODFLOW and observed hydraulic heads were shown better correlation. Variations in the observed and simulated water levels were noticed for the wells that are near the river and it is due to the lack of insufficient river flow data for this area. In the present study, a MODFLOW model is developed to estimate head calibration of a part of Bina River basin with the known boundary conditions and field observations. The field monitoring is incorporated to verify model predictions. The best method of reducing modeling errors is to apply good hydrogeological judgement. The model calibration has been performed based on the available data. The model results show that computed values are in good-fitness of the measure data, which indicate the model is reliable. Similar studies can be undertaken for other water stressed areas for reliable water resources estimation adopted in better and efficient water resources planning and management. From the flow budget simulation it was determined that for stationary condition, river is not predominantly recharging the aquifers (Table10). The total input to the aquifer is 246.179MCM and the total output is 246.181 MCM during monsoon period 2016. This indicates deficiency of recharge of -0.002 MCM which is responsible for decline of the water table in the region (Table 9). The model indicates that average input to the aquifer is 185.02MCM and output from the aquifer is 185.00 MCM. Continuous measurements

of water budget components and groundwater levels will build up databases required for analysis of regional flow systems and construction of regional transient groundwater models.

The model should be used to simulate impacts of human activities on groundwater flow systems, to formulate sustainable groundwater resources development scenarios, and to communicate the results to public and decision-makers. The results of calibration showed that the predicted results matched well with the observed data. The model could be used to predict the groundwater levels variation under different hypothesis conditions in lower bina basin, which would provide the effective reference to the rational use and management of the groundwater.

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