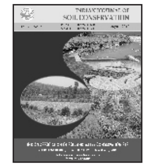
Vol. 47, No. 1, pp 21-29, 2019
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home



Studies on groundwater resources using visual MODFLOW – A case study of Kadalundi river basin, Malappuram, Kerala

S. Sajeena[1,*] and E.K. Kurien[2]

[1]*ICAR-Krishi Vigyan Kendra, Malappuram, Tavanur, Kerala;* [2]*Kerala Agricultural University, Vellanikkara, Thrissur, Kerala.*

**Corresponding author:*
E-mail: sajeenahakkim@gmail.com (S. Sajeena)

ARTICLE INFO

Article history:
Received : August, 2018
Revised : March, 2019
Accepted : April, 2019

Key words:
Hydro-geological properties,
Kadalundi river basin,
Visual MODFLOW

ABSTRACT

Groundwater models describe the ground water flow and transport processes using mathematical equations based on certain assumptions. Visual MODFLOW is a complete and user-friendly, modelling environment for three dimensional ground water flow and contaminant transport simulation. In this study, Visual MODFLOW software version 2.8.1 developed by Waterloo Hydrogeologic Inc. was used for the flow modelling of Kadalundi river basin, which covers major geographical area of Malappuram district. This river basin can be considered as a general representation of the district. Base map was prepared using Arc GIS (Arc Map10.1) and imported into the model. The conceptual model for the study area was developed using the toposheet of the area, well logs at 30 sites and the data obtained from the geophysical studies conducted in the study area. The model was developed and calibrated with four years data (2008 to 2011) and validated with two years data (2012 and 2013). The validated model was used to predict the flow head for the next 15 years assuming 5% decrease in recharge for every year and also to predict the ground water condition by increasing the pumping rate by 10, 25 and 50% of pumping rate of the validation period (2013). From the modelling studies, it could be noted that the Kadalundi river basin may remain safe for a short span of five years from the point of future ground water development and subsequently the water table will reach the bed rock. This necessitates artificial ground water recharge techniques in the study area to supplement the ground water recharge through rainfall.

1. INTRODUCTION

For Use of groundwater models has been applied to investigate a wide variety of hydro-geologic conditions. Ground water models describe the ground water flow and transport processes using mathematical equations based on certain assumptions. The objectives of ground water modelling in India are mainly for ground water recharge studies, study of dynamic behaviour of the water table, stream-aquifer interaction studies and sea-water intrusion studies (Panigrahi *et al.,* 1995; Kumar *et al.,* 1998). It is important to understand the general aspects of both ground water flow and transport models, so that application or evaluation of these models may be performed correctly. Visual MODFLOW is a complete and user-friendly, modelling environment for three dimensional ground water flow and contaminant transport simulation. It is a fully integrated package which combines MODFLOW, MODPATH, MT3D and PEST with the most intuitive and powerful graphical interface available. For complete three-dimensional ground water flow and contaminant transport modelling, Visual MODFLOW software package could be used effectively.

With the ever increasing population growth and to meet the demand of water for various purposes, there is a growing stress on the ground water resources. Management of ground water has become a great concern for the scientists, planners and administrators alike. Sustainable management of available ground water resources has thus become vital for the prevention of over exploitation and contamination of ground water (Panigrahi *et al.,* 1992). Malappuram is the most populous district of Kerala with highest decadal population growth rate. Kadalundi river of Malappuram has a total length of 130 km with a drainage area of 1122 km^2 and major portion of the catchment falls within Malappuram district and a small portion in Palakkad district of Kerala. Kadalundi river originates from the Western Ghats at the western extreme of the Silent Valley and cut across the district of Malappuram (Anitha *et al*., 2012). Kadalundi river basin covers major geographical area of Malappuram district comprising of 34% of the total area of the district and this river basin can be considered as a general representation of the district. Hence Kadalundi river basin is selected as study area of this research work (Fig. 1). The specific objective of the research is to develop a ground water flow model for the river basin using Visual MODFLOW and to map the ground water resources of the study area.

2. MATERIALS AND METHODS

In this study, Visual MODFLOW model was developed and calibrated with 4 years groundwater level and pumping rate data (2008 to 2011) and validated with 2 years data (2012 and 2013). After the development of a validated MODFLOW model, the model was used to predict the ground water scenario of next 15 years.

Conceptual Model of the Kadalundi River Basin

The conceptual model for the study area was developed based on the toposheet of the area, well logs at 30 sites and the data obtained from the geophysical studies conducted in the study area. An important tool to characterize the aquifer is hydro geological profile. The geological profile revealed that there were no distinct separation of layers and the profile consists of fine to coarse laterites, followed by weathered rock in some areas. In between these layers lithomargic clay was present in some areas (CGWB, 2013). The study of hydraulic continuity of the aquifer revealed that hydraulic continuity was existing in almost all parts of the study area. The correlation coefficient was calculated to check the correlation between water table variation and rainfall variation in these locations and is given in Table 1.

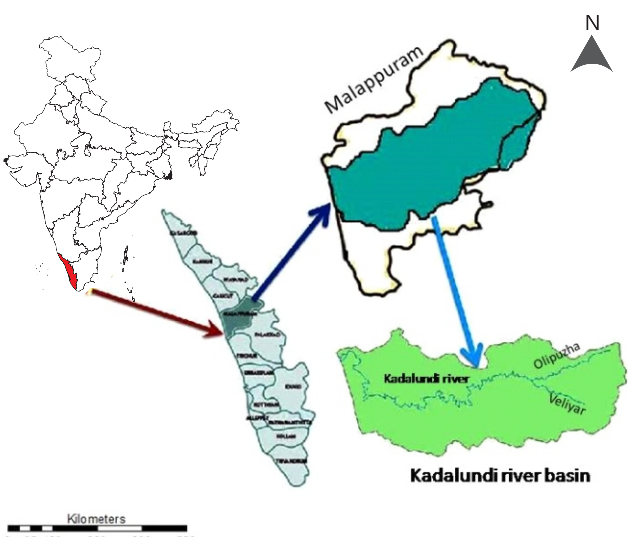


Fig. 1. Location map of the study area - Kadalundi river basin

Table: 1
Correlation coefficient between water table and rainfall

S.No.	Locations	Correlation coefficient	
		Dug well	Bore well
1	Kondotty	0.426	0.549
2	Thiruraangadi	0.546	0.217
3	Karuvarakundu	0.449	0.507
4	Anakayam	0.526	0.522
5	Pandikkad	0.369	0.644
6	Kottakkal	0.543	0.132
7	Perinthalmanna	0.426	-0.447
8	Kuttippuram	0.193	0.586

Hence the aquifer system of the study area for the modelling purpose was assumed as homogeneous, isotropic, single layer and unconfined aquifer, exploited by dug wells for domestic as well as irrigation purposes. More than 80% of the ground water extraction was from the first aquifer. The aquifers were recharged mainly by rainfall and the study area was hydraulically bounded in the west by the Arabian Sea.

Discretization of the Basin

After the conceptual model was developed, the study area was discretized by dividing it into 62 rows and 136 columns with a grid spacing of 500 x 500 m. Thus, the area was discretized into 8432 cells and the cells outside the boundary of the study area were made as inactive. Based on the groundwater level data availability, a time step of month was chosen within which all hydrological stresses can be assumed to be constant.

Wells

Visual MODFLOW permits to input field observations of pumping rate and water table observations from observation wells to get model output values. From the well drop-down menu of the software we can choose to graphically add, delete, move or edit pumping wells and head observation wells. Dug wells are mainly used for ground water abstraction in most part of the study area. Total 35 numbers of major pumping wells of Kerala Water Authority and Jalanidi Malappuram and 30 groundwater monitoring wells (consisting of 14 dug wells and 16 piezometers) of Ground Water Department (GWD), Government of Kerala were selected for this study in Kadalundi river basin.

Hydrogeological Properties

Visual MODFLOW model input includes hydro-geological parameters such as hydraulic conductivity, specific storage, specific yield, porosity and initial head values. Hydraulic properties of the aquifer are given in Table 2.

Initial Head

MODFLOW requires an initial value for the head distribution for steady state simulation and a starting head

Table: 2
Hydraulic properties of the layer

S.No.	Model Properties	Layer I Laterite
1	Hydraulic conductivity in longitudinal direction K_x, md^{-1}	30
2	Hydraulic conductivity in lateral direction K_y, md^{-1}	30
3	Hydraulic conductivity in vertical direction K_z, md^{-1}	3
4	Specific storage, S_s (m^{-1})	0.00035
5	Specific Yield, S_y	0.20
6	Effective Porosity	0.35
7	Total Porosity	0.40

distribution for a transient simulation. The draw-down is also calculated from the initial head and assigned based on the water level data obtained from observation wells.

Boundaries

Visual MODFLOW model needs boundary conditions of the model domain which includes constant head, rivers, general head, drains, walls (horizontal flow boundaries), recharge and evapo-transpiration. Atleast one head boundary must be specified for a steady-state simulation and the head boundary acts as a reference head for all calculations. Specified initial heads are sufficient for a determinant solution of the transient simulation. In general, transient conditions remain constant over a stress period and change abruptly between stress periods. A stress period can be defined as the time period during which all the stress on the system are constant. The constant heads are never constant unless the heads at the beginning and at the end of the stress periods are the same. In this study, the western side of study area is Arabian Sea and hence the boundary of the system is fixed as constant head of 'zero'. The MODFLOW river package input file requires the information of river stage, riverbed bottom and conductance for each grid cell containing a river boundary:

The conductance value (C) can be calculated using the following equation:

$$C = \frac{K \times L \times W}{M} \qquad ...(1)$$

Where, C = Conductance, m^2d^{-1}, K = Hydraulic conductivity, md^{-1}, L = Length of a reach through a cell, m, W = Width of the river in the cell, m and M = Thickness of the river, m

Visual MODFLOW is designed to simulate aerial distribution of recharge to the ground water system. To compute the recharge from rainfall, 6 years of rainfall data from 2008 to 2013 were collected and the recharge was calculated using the eq. 2 (Chandra and Saxena, 1975) and it was found to be about 20 to 25% of average annual rainfall. Hence the monthly recharge was taken as 23% of monthly rainfall of the study area:

$$R = 3.984\,(R_{av} - 40.64)^{0.5} \qquad ...(2)$$

Where, R = Areal recharge in cm and R_{av} = The average annual rainfall in cm.

Visual MODFLOW requires evapo-transpiration (ET) to simulate the effect of plant transpiration through capillary rise from the saturated zone. ET rate was assumed as 10% of the rainfall uniformly for the entire study area and the values are also entered as input (Rejani *et al*., 2008).

Visual MODFLOW Run

The model was run with all the above inputs for steady and transient conditions using WHS solver. Steady state run was done with the data during the period of 2008. Transient run was done for 4 years stress period with the data during 2008 to 2011. The simulations were compared with observed data.

Calibration

The monthly water level data collected from 30 wells of Ground Water Department, Govt. of Kerala for the period from 2008 to 2011 were used for the calibration purpose. The study involves transient state simulation which includes the length and time span of steps. In this study, 48 stress periods were defined for the calibration purpose having length of 30 days (one month). The model was calibrated by systematically adjusting values of selected parameters like hydraulic conductivity, specific yield and specific storage to achieve an acceptable match between observed values of water table elevation with corresponding computed values by the model. For the calibration, root mean square error (RMSE) has been chosen as the calibration criteria and calibration process was continued till no further reduction in RMSE values was possible.

Validation

The model was validated with the calibrated values of various parameters and using the observed data of groundwater level for the period of 2012 and 2013. The model was verified for its accuracy and predictive capability within acceptable limits of errors, independent of the calibration data. The model was then considered as validated and useful for predicting aquifer response for various water resource management strategies.

Prediction

The validated model was used for predicting the flow head for the next 5, 10 and 15 years with 5% decrease in recharge for every year and also predict the ground water condition after 15 years by increasing the pumping rate by 10, 25 and 50% of pumping rate of the validated period (2013).

3. RESULTS AND DISCUSSION

Visual MODFLOW output provides contours of head equipotentials, head difference, drawdown, elevation, net recharge and water table. It also provides graphs of calculated *vs.* observed heads, calibration of residual histogram, head *vs.* time, normalized RMS *vs.* time and drawdown *vs.* time. The model output also provides velocity vectors with direction of flow. By using the input and output screen the model is calibrated.

Steady State Calibration

The model was calibrated for steady state conditions. The aquifer condition of year 2008 is assumed to be the initial condition for the steady state model calibration. The steady state model calibration started by minimizing the difference between the computed and the field water level for each observation well. The hydraulic conductivity values of the aquifers varied iteratively so that RMSE could be kept below 10 m. The scatter plot for computed *vs.* observed head for 30 selected observation wells are shown in Fig. 2. From the figure it could be seen that there was a very good agreement between the calculated and observed water levels in most of the wells.

Transient State Calibration

The hydraulic conductivity values, boundary conditions and the water levels obtained from the steady state model calibration were used as the initial condition in the transient model calibration. The above values are used along with the specific storage and specific yield distribution, time variable recharge and dumping distribution. The transient (dynamic) calibration was carried out for the time period from year 2008 to year 2011 (1461 days). The storage coefficient values varied iteratively so that a reasonably good match was obtained between computed and observed water levels. The hydraulic properties of the layer obtained after calibration for both steady state and transient states are shown in Table 3.

The computed and observed ground water level hydrographs for the selected observation wells are shown in Fig. 3 and it could be seen that the computed water table

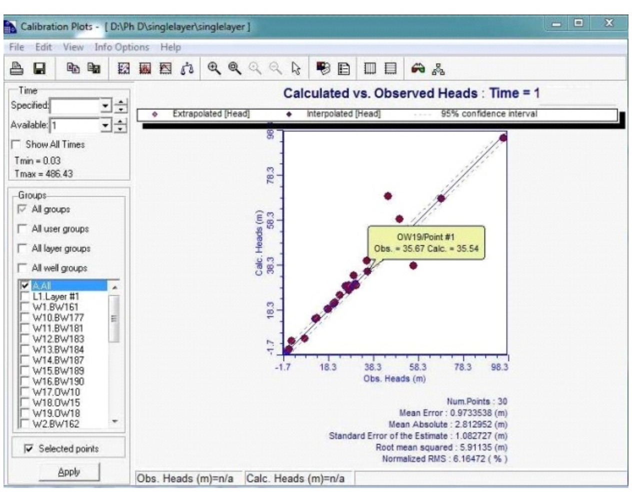


Fig. 2. Model computed vs. observed water level of the year 2008 (steady state)

hydrographs were comparable with the observed values. Computed water table contour map of the study area obtained from the model is shown in Fig. 4. From this figure it could be seen that in the coastal region the water elevation was very low ranging from zero to 15 m. At extreme west side, it is zero because of Arabian Sea as boundary.

In the central part of the study area comprising of Malappuram, Mankada and Manjery blocks, the water table elevation ranged from 15 to 32 m (bluish green shade) and 32 to 40 m (green shade), indicating that major part of study area was under same range of water table elevation. At some pockets of Wondoor and Kuttippuram blocks, the water table elevation was found to be high, ranged from 66 to 85 m and this may due to high elevation of that area. Some part of Vengara and Malappuram blocks, it ranged from 40 to 57 m.

The perusal of model run revealed that some dried cells has been seen in the Vengara and Perinthalmanna block comprising an area of 6.75 and 8.5 km^2, respectively. This indicated that this area comprising hard rock and it is supported by the results of earth resistivity studies carried out in this area (Sajeena and Kurien, 2015).

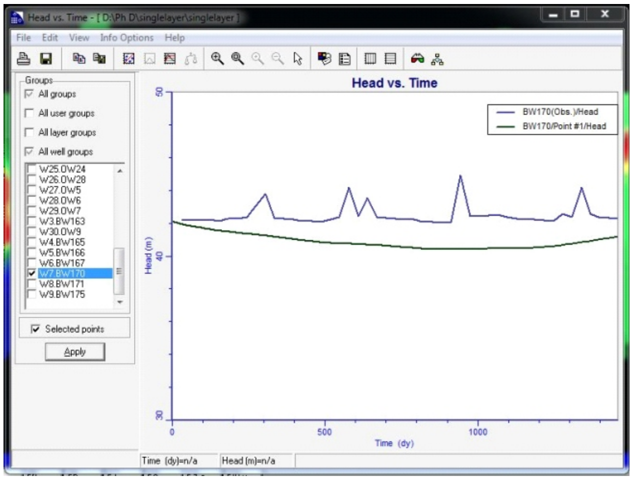
Model Validation

The model was validated with the water level data and the scatter plot for computed *vs.* observed heads for 24 selected observation wells as shown in Fig. 5. From this figure, it can be seen that the RMSE for almost all the wells during validation are reasonably low and are within acceptable limit except for dug well OW28 located at Malappuram and bore wells BW163, BW165 and BW 189 located at Kottakal, Mankada and Thirurangadi, respectively. Wells OW28 and BW189 are very close to the river and is most likely to be influenced by the interflow of river.

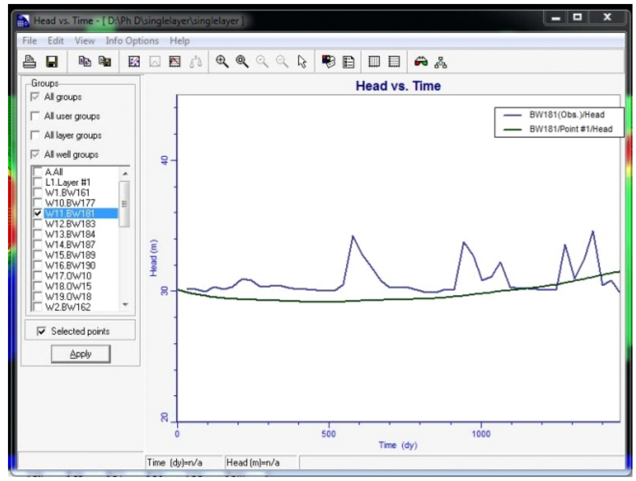
Bore wells BW163 and BW165 are located in hard laterite zone and the variations of piezometric water level in BW163 was not correlated with variations of rainfall. As a result, the average difference between observed and calculated ground water levels were relatively high. The hydrographs of computed and observed water levels for the

Table: 3
Hydraulic properties of the layer after calibration

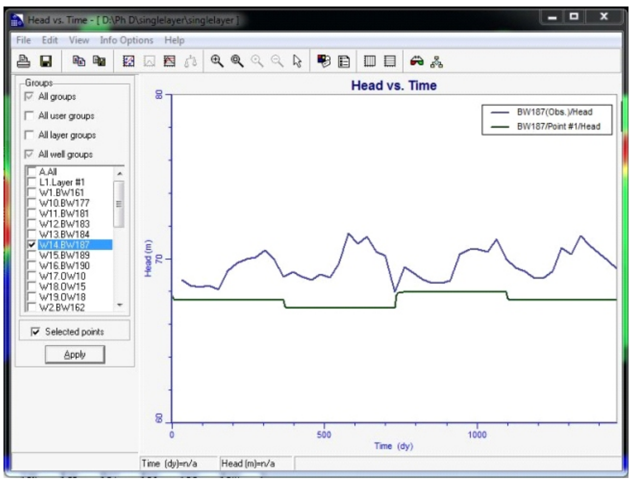
S.No.	Model Properties	Layer I Laterite
1	Hydraulic conductivity in longitudinal direction K_x,m d^{-1}	20
2	Hydraulic conductivity in lateral direction K_y, m d^{-1}	20
3	Hydraulic conductivity in vertical direction K_z, m d^{-1}	2
4	Specific storage S_s, m^{-1}	0.0005
5	Specific Yield, S_y	0.20
6	Effective Porosity	0.35
7	Total Porosity	0.40



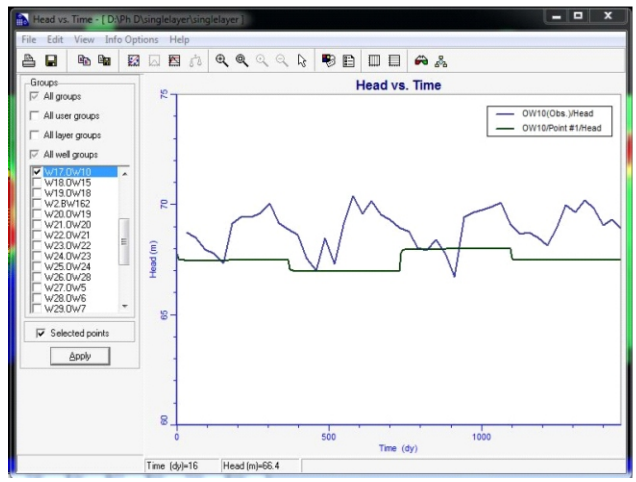
BW170 at Porur



BW181 at Morkanad



BW187 at Karuvarakundu



OW10 at Karuvarakundu

Fig. 3. Computed and observed ground water level hydrographs for the selected observation wells

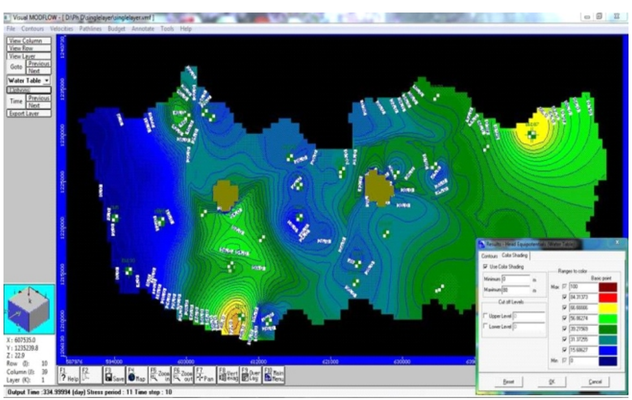


Fig. 4. Computed water table contour map after calibration

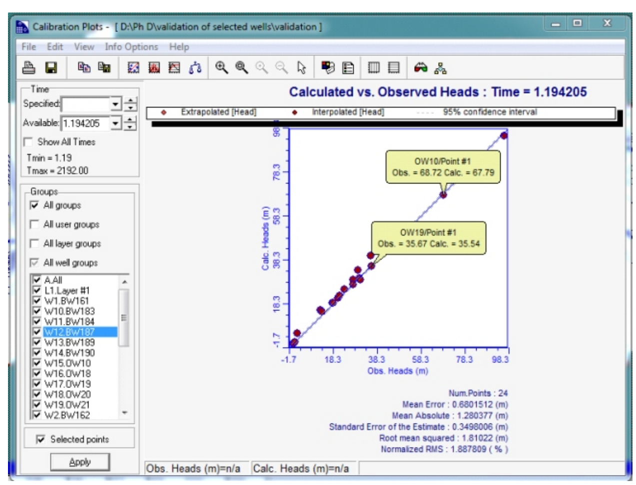
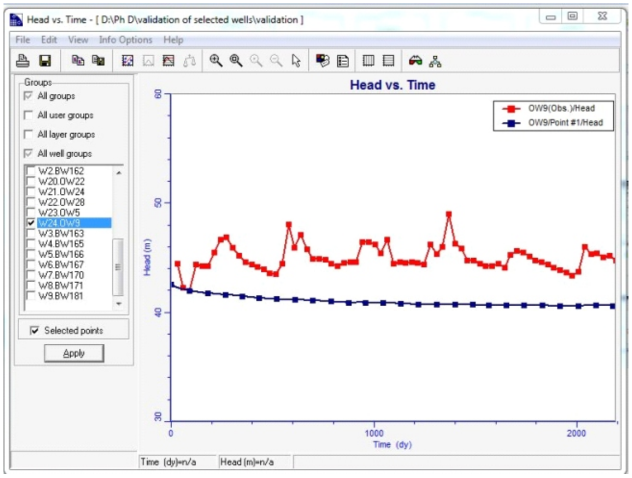


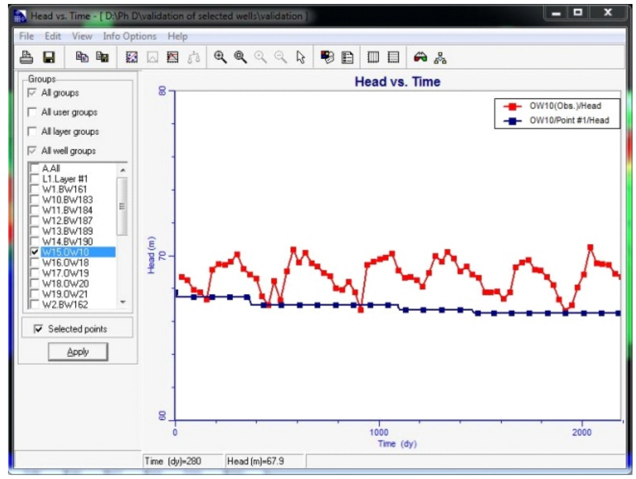
Fig. 5. Model computed vs. Observed water level after validation

selected observation wells after validation are shown in Fig. 6 and it showed fairly good agreement with observed values of head.

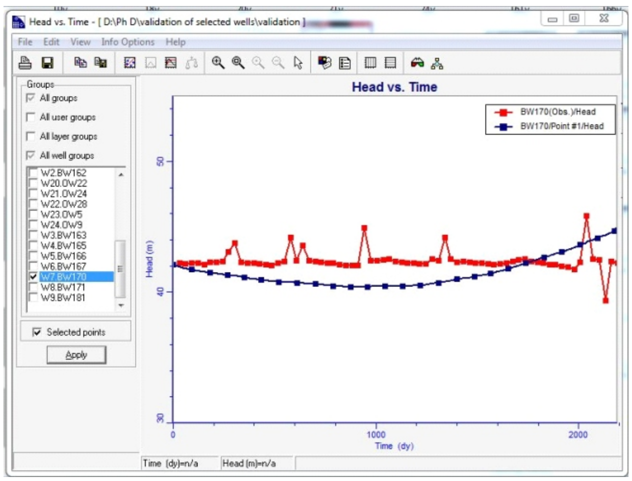
The ground water flow direction during pre monsoon and post monsoon are shown in Fig. 7. From this figures, it could be seen that flow was more active and towards the river and Arabian sea during post monsoon than pre-monsoon period. It was also noted that there was no reverse flow from Arabian sea even during pre monsoon period.



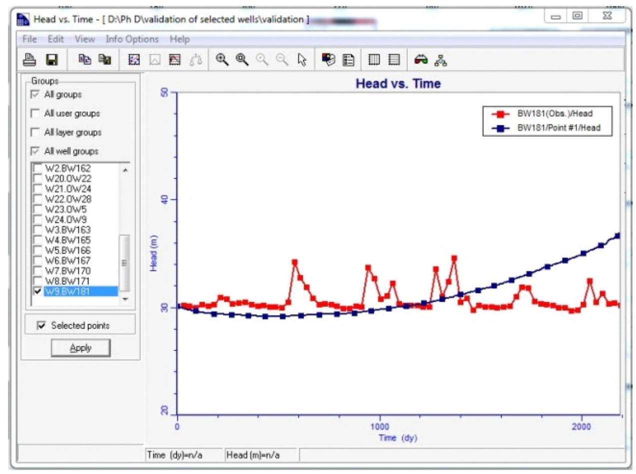
OW9 at Perinthalmanna



OW10 at Karuvarakundu

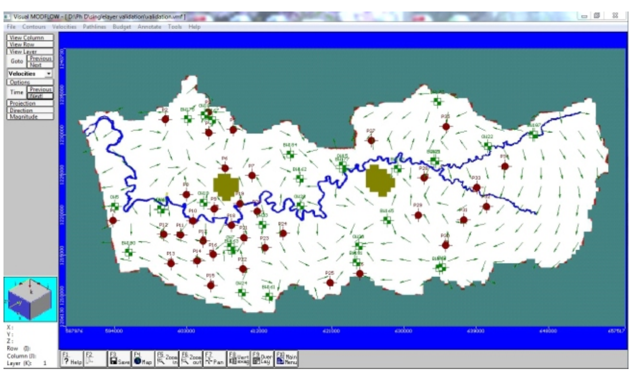


BW170 at Porur

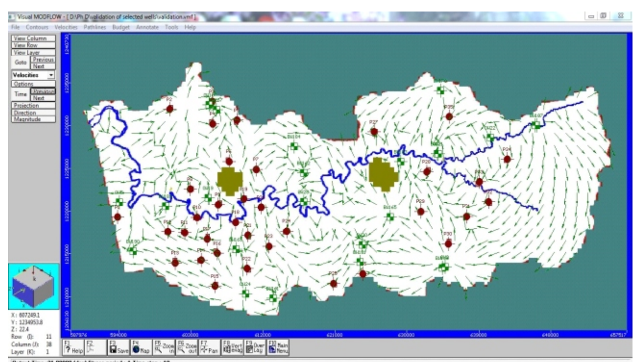


BW181 at Moorkanad

Fig. 6. Computed and observed ground water level hydrographs for the selected observation wells after validation



Pre-monsoon



Post-monsoon

Fig. 7. Velocity vector of groundwater flow during pre and post monsoon periods

Model Prediction

The validated model was run for predicting the trend of water level for next 5 years (4018 days), 10 years (5844 days) and 15 years (7668 days) from 2014 to 2018, 2023 and 2028 in order to evaluate the decline of ground water table by assuming that the recharge of the study area will be reduced by 5% every year. Prediction was also made by assuming that the increase of pumping rate by 10, 25 and 50% after 15 years to identify the area susceptible to ground water stress or the ground water deficit zones.

The predictive simulation was done for 180 stress periods using the data for 48 stress periods for calibration and 24 stress periods for validation. Decline of water table in the observation wells for a next 15 years from 2014 to

2028 was simulated using visual MODFLOW and the simulated water table hydrograph for the selected wells are shown in Fig. 8. From the figure, it could be seen that there can be a fast decline of water table during the first five years with the decrease of recharge. In the case of well at Karuvarakundu, the reduction of water table predicted was found to be from 66.49 m to 63.6 m and in the subsequent years it will be very meagre from 63.6 to 63.21 m. This is because of the reason that the ground water table reaches the level of bed rock in that area. Similar trend was observed in case of dug wells OW 24 and OW 28. In the case of OW24, the water table decline was about 68.1 to 53.8 m during the first five years and then attains a more or less constant level. High decline of water table predicted in this well may be due

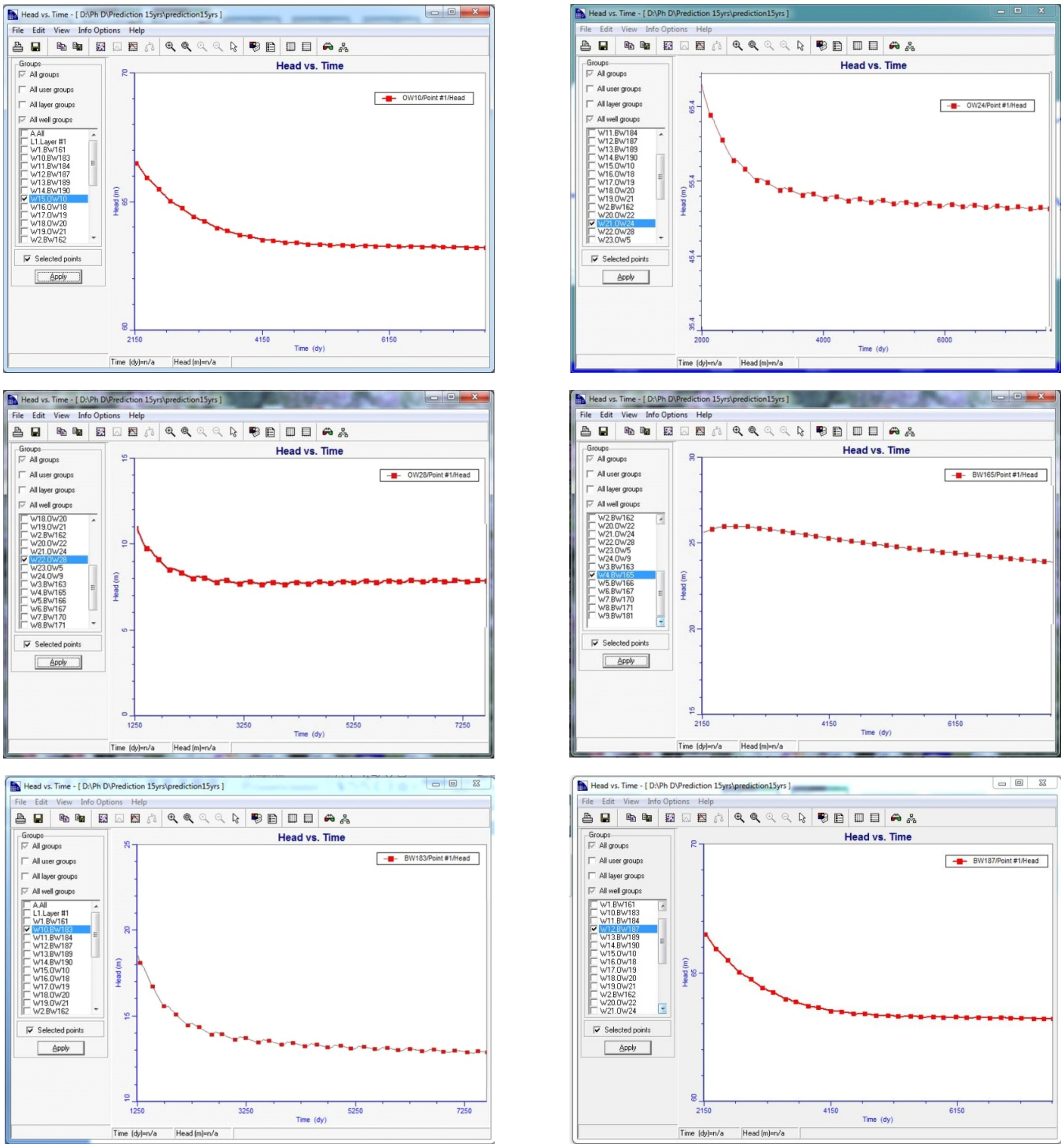


Fig. 8. Stimulated piezometric water level hydrograph of selected wells

to the reason that this well is located at high elevated area and also shows high fluctuation in the water table fluctuation study. In the case of stimulated piezometric hydrograph, the decline of piezometric level was very low (1.5 m for the next 15 years) in BW165 when compared to BW183 and BW187. It was also noted that, BW187 showed similar trend of decline in piezometric level as that of water table in that area and this is in agreement with the results of hydraulic continuity studies in that area (Sajeena and Kurien, 2017).

Predicted water table contour map of Kadalundi river basin for the next 5,10 and 15 years are shown in Fig. 9. From the figure, it is presumed that there could be a significant reduction in water table (from 2 to 14.3 m)

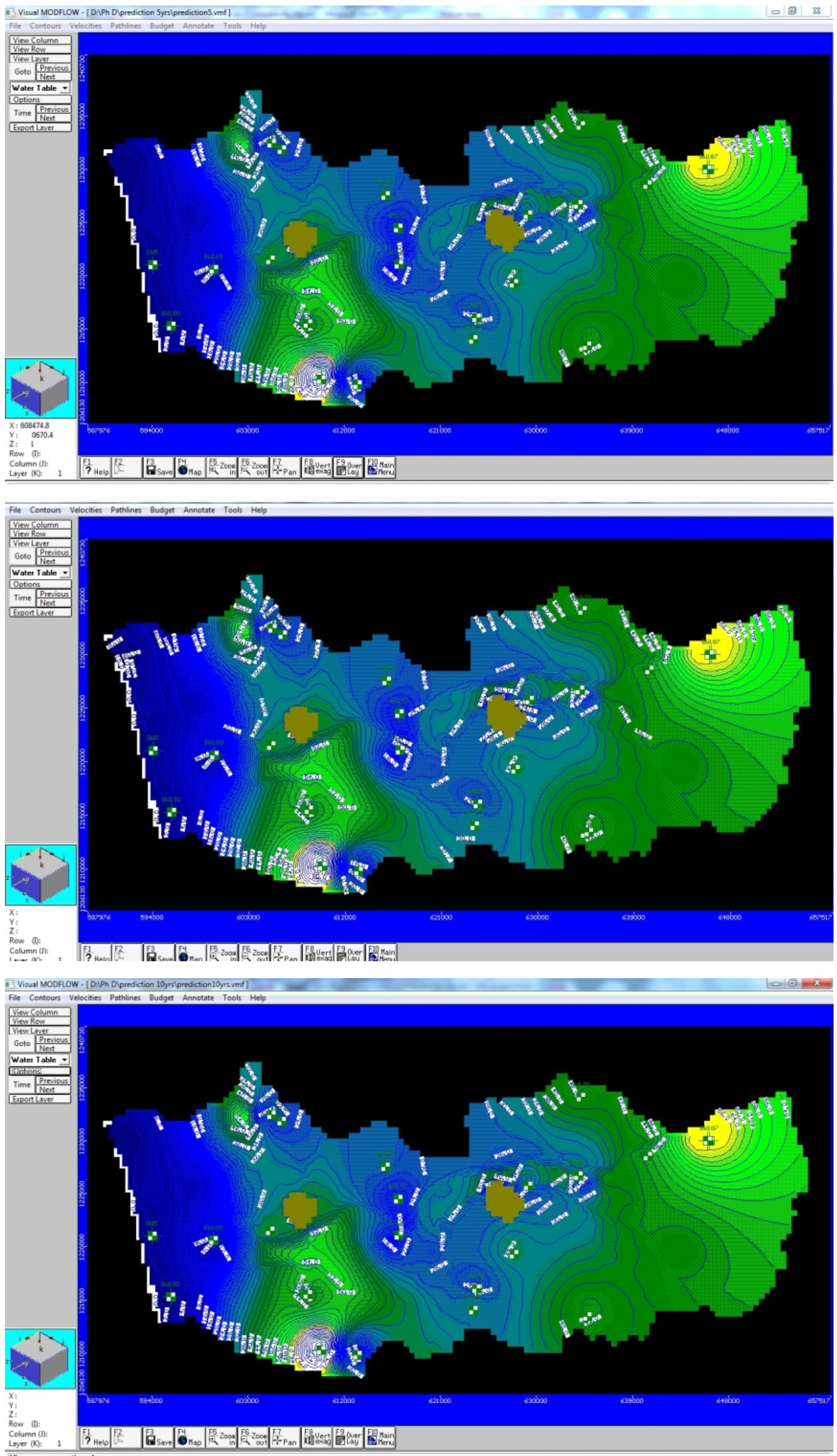


Fig. 9. Stimulated piezometric water level hydrograph of selected wells

during the first 5 years and after that it will be more or less constant. This is because of the reason that the ground water table reaches the level of bed rock in many areas and this indicate the necessity of artificial ground water recharge techniques in the study area to increase the recharge of rainfall to the groundwater.

Groundwater deficit or vulnerable zones were predicted using visual MODFLOW assuming increased pumping rate by 10, 25 and 50% with the existing recharge and other aquifer properties. From the figures, it could be seen that there will not be any further increase of existing deficit zone in the study area due to increase in the pumping of ground water draft by 10%. The vulnerable zone, would increase from 15.25 to 18.5 km^2 when pumping rate is increased by 25% and the area would further increase to 23 km^2 with 50% increase of pumping which infers that the thickness of aquifer formation of this areas is very less when compared to other areas of the Kadalundi river basin.

4. CONCLUSIONS

Visual MODFLOW can be effectively used for evaluation of the ground water resources and for the future prediction with specific strategies. From the modelling studies, it could be noted that the Kadalundi river basin may remain safe for a short span of five years from the point of future ground water development and subsequently the water table will reach the bed rock. This necessitates artificial ground water recharge techniques to be adopted in the study area to supplement the recharge of rainfall to the groundwater. A well planned programme for ground water development to meet both drinking and irrigation water requirement can be safely initiated for the optimum utilisation of ground water potential zones located in the Kadalundi river basin.

ACKNOWLEDGEMENTS

The authors are thankful to Kerala Agricultural University and Kelappaji College of Agricultural Engineering and Technology, Tavanur for sanctioning the research project and providing all financial assistance and also wish to express their gratitude to Groundwater Department, Malappuram, Govt. of Kerala, CWRDM, Kozhikode and Department of Civil Engineering, NIT Calicut for their assistance in field investigations, providing information, field data and helpful discussions.

REFERENCES

Anitha, A.B., Unni, P.N. and Jayakumar, K.V. 2012. *Hydrological studies of Kadalundi wetland in relation to the drainage basin.* Centre for Water Resources Development and Management, Kerala State Science Technology and Environment, Govt. of India, 54 p.

Central Ground Water Board (CGWB). 2013. Ground water information booklet of Malappuram District, Kerala. In: Ground Water information booklet of Malappuram District: 1-27.

Chandra, S. and Saxena, R.S. 1975. Water balance study for estimation of ground water resources. *Irrig. Power J.,* 32(4): 443-449.

Kumar, A., Shyam, R., Tyagi, N.K. and Peralta, R.C. 1998. Reconnissance optimal sustainable groundwater pumping strategies for lower Ghaggar basin. *In water and the Environment: Innovative issues in irrigation and Drainage*. L.S. Pereira and J.W. Gowing (eds). Publication E&FN Spons, 8 p. ISBN 0419237100.

Panigrahi, B., Sharma, S.D. and Behera, B.P. 1992. Irrigation water requirement models of some major crops. *Water Resour. Manag.,* 6(1): 69-77.

Panigrahi, B., Nayak, A.K. and Sharma, S.D. 1995. Application of remote sensing technology for evaluation of groundwater potential. *Water Resour. Manag.,* 9(1): 161-173.

Rejani, R., Jha, M.K., Panda, S.N. and Mull, R. 2008. Simulation modelling foe efficient groundwater management in Balasore coastal basin, India. *Water Resour. Manag.,* 22: 23-50.

Sajeena, S. and Kurien, E.K. 2015. Application of geophysical techniques for groundwater investigation- A case study of Kadalundi river basin, Malappuram, Kerala. *J. Trends Biosci.*, 8(6): 4238-4248.

Sajeena, S. and Kurien, E.K. 2017. Hydrogeological characteristics and groundwater scenario of Kadalundi river basin, Malappuram District, Kerala. *J. Trends Biosci.*, 10(12): 2193-2200.