Bulletin of Pure and Applied Sciences.
Geology (Geological Science), Vol.41F, No.1,
January-June 2022: P.12-23
Original Article

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI: 10.5958/2320-3234.2022.00002.6
Available online at www.bpasjournals.com

Aquifer Response at the Proximity of Patalganga and Shriganwadi Micro-Watersheds, Nanded District, Maharashtra Using Groundwater Flow Model

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(Received on 24.08.2021, Revised on 28.02.2022, Accepted on 19.03.2022)

How to cite this article: Pawar S.V., Mondal N.C. and Ullagaddi P. (2022). Aquifer Response at the Proximity of Patalganga and Shriganwadi Micro-Watersheds, Nanded District, Maharashtra Using Groundwater Flow Model. *Bulletin of Pure and Applied Sciences- Geology*, 41F(1), 12-23.

ABSTRACT

Groundwater modeling is necessary to get correct information of aquifer response for management of groundwater resources. In this paper, we have simulated groundwater flow of two micro-watersheds (namely Patalganga and Shriganwadi) located Nanded, Maharashtra considering the field data such as aquifer properties, recharge, discharge, and other required information obtained from literature using Visual Modflow ver. 3.1.0 for the year 2021. Then the model compared with the observed groundwater level at the selected wells, which are reasonably matched in the field data. It was also simulated by changing a few dominant input parameters in a limited range. After the validation of the model, it was run for the different environmental stress scenarios, which can occur in future. The model reactions of the aquifer response had been checked and it has observed drying a few well sites in these micro-watersheds. It will help to the decision makers for sustainable management of groundwater resources.

KEYWORDS: *Aquifer, groundwater flow, micro-watersheds, validation, Visual Modflow, Nanded, Maharashtra.*

INTRODUCTION

Water is an essential factor of our day-to-day life (Srinivas et al., 2016). Development of human depends upon the availability of water. Around 70% of earth is covered with water but we can use only 1% water from total water. Nearly 97% of water is saline and 3% is fresh water. About 30% of fresh water is present in groundwater and about 1% only is in surface water (Chidambaram, 2013; Das, 2020).In developing countries, the requirement of water is increasing rapidly. In India, water demand is at peak because of increasing in population, agricultural, and industrialization. India is depending upon groundwater.

Around 80-90% people from rural areas are being depended upon groundwater in that 50% is utilized for the irrigation (CWC, 2015). Groundwater use increases because it is available easily and at lesser price. Groundwater table is decreasing due to continuous and excessive extraction of groundwater. Studies indicate that in next 1-2 decades, there will be shortage of surface water and groundwater in the monsoon seasons (Barlow and Clarke, 2002). Because of rapidly exploration of groundwater throughout the country is not allowing groundwater losses to recover. As compare to rate of groundwater extraction recharge is insufficient (Mondal et al., 2012; Mondal and Ajaykumar, 2021). As a result, aquifers are getting dry very fast and the drought condition is also occurring most parts of India throughout the pre-monsoon season. The groundwater situation of Maharashtra is turning into the poorest day-by-day. Nanded district of Maharashtra was facing drought condition in last four to five years. For drinking and irrigation purposes, mostly everyone is depending upon bore-well (Chandrasekhar et al., 1999). The Vishnupuri Dam water touches its lowest water limit in the year of 2016-2017 to recover this water of Yeldari and Siddheshwar dams were taken towards Vishnupuri dam. Groundwater level of Nanded district is reducing very rapidly. Groundwater table at a few places of Nanded was about 70-85 m in the year of 2002-2003, but now it reduced and went up to 200-250m (CGWB, 2020).

Because of this hazard situation, it is now becoming our necessity to understand the processes by which groundwater is made easily available. Groundwater study has led to development of complete theoretical model and to analytical solutions of groundwater modelling. For sustainable management of groundwater, modelling and simulation are most effective tools (Alley, 1999; Hariharan and Shankar, 2017; Pathak et al., 2018; Mondal, 2019). The necessities of building the models comprehensively increase in the regions which are complemented by undue exploitation of groundwater in order to fulfill the daily water demand. These models could be steady state or transient, confined or unconfined or combined, one-dimensional, two-dimensional, quasi three-dimensional or three-dimensional which can be solved by using finite difference methods or finite element methods or combination of both (Todd and Mays, 2005). It could be used using the Groundwater Modeling System (GMS), FEFLOW, and Modflow software. Also applied to assess the water logged area (Singh, 2013), simulate drawdown (Senthilkumar and Elango , 2011; Sklorz et al., 2017),characterize of aquifers (Mondal et al., 2009), determine the interaction between the surface and ground water (Lasya and Inayathulla, 2015), optimize pumping rate (Baneerjee and Singh, 2011), seepages of mines and tunnels (Surinaidu et al., 2013, 2015), migrate the contaminations/pollutions (Gupta et al., 1997; Mondal and Singh, 2005) ; seawater intrusion (Lathashri and Mahesha, 2015), and develop the strategies for groundwater exploitation to meeting the daily demand of this resource (Thagarajan, 1999; Neupane et al., 2020)Thus, groundwater flow model of two micro-watersheds (namely Patalganga and Shriganwadi watersheds) located at Kandhar taluka, Nanded District, Maharashtra, India has been made after a detail assessment and investigation of the study area using Visual Modflow 3.1.0. software. Also run to observe the aquifer responses due to the different environmental stresses for groundwater management and discussed in this article.

ABOUT AREA

The area selected for the present study is two micro-watersheds at the proximity of Patalganga and Shriganwadi villages in Kandhar Taluka, Nanded district Maharashtra, India, as shown in Figure 1. Bothwatersheds occur in between Longitude: 77°9′285″ to 77°8′397″ E, and Latitude: 18°49′857′′ to 18°46′217″ N, with the altitude of around 354 meter above the mean seal level (m, amsl), and allocated in the eastern part of Marathwada, Aurangabad Division of Maharashtra. It covers mainly two villages (Patalganga: micro-watershed-I and Shriganwadi: bmicro-watershed-II). It comes under MR 46B and topo-sheet number 56 F/1.The topography is very irregular in shape. In micro-Watershed-I: Patalganga is having area of 10 km^2, with total 188 families (District Census, 2019) The total population of this village is about 1031 in which 534 are males and 497 are females. Highest elevation in this watershed is around 432 m, amsl and the lowest is ~ 347m, amsl. In Micro-watershed-II:

Shriganwadi is having area of 6.9 km², with total 66 families. The total population of this watershed is ~279 in which 145 are males and 134 are females. The highest elevation is around 440 m, amsl and the lowest elevation is ~382m, amsl.

Both the watersheds are highly undulating with barren lands. Groundwater occurs under unconfined condition in weathered zone whereas it is semi-confined and confined conditions in fractured zones. The streams are dry after the monsoon months despite enough rainfall. Average annual rainfall in recent years is about709 mm.It gathers about 75% of the precipitation in June to August from the South-West monsoon. In the month of October to December, it collects total 16% rain. About 2% rainfall occurs from the winter monsoon, and about 7% from the pre-monsoon in the month of January and February. In August month, about 45% rainfall is recorded. The mean maximum temperature of ten years is 38.0°C; usually get in April and May months. In summer season, the highest temperature recorded is ~48°C. The mean minimum of 19°C, usually reached in the December and January months. Soil types are mainly clayey, medium to deep black. Crops grown in this area are jowar, sugarcane and cotton.

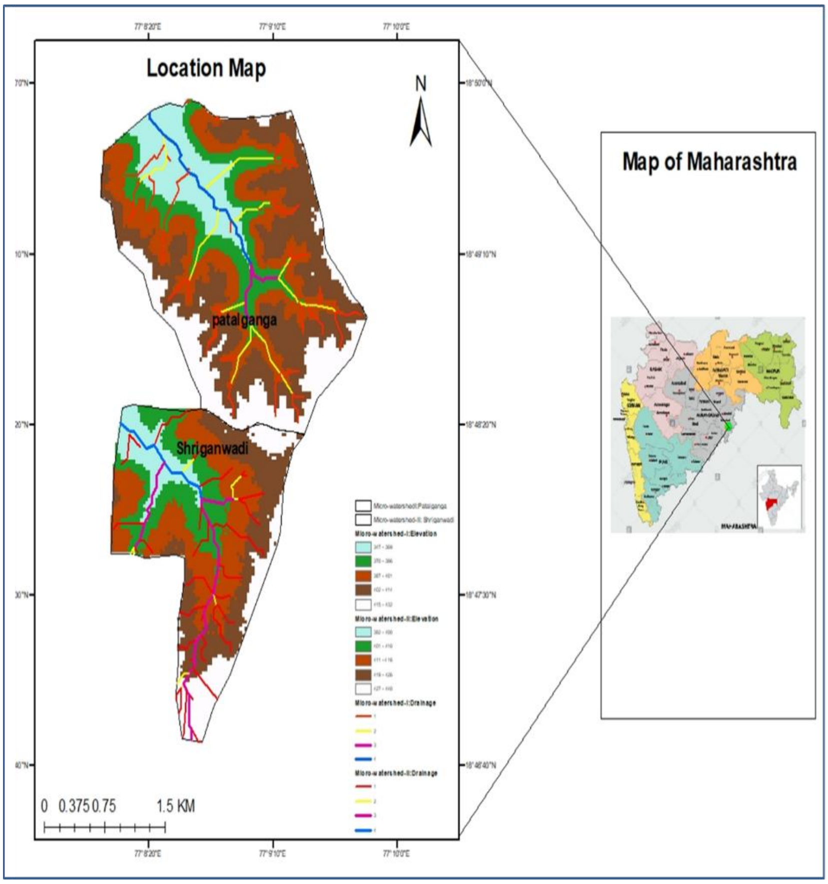

Figure 1: Location map of two micro-watersheds along with their topographies at Kandhar Taluka, Nanded district Maharashtra, India

MATERIALS AND METHODS

Methodology

Three dimensional (3-D) groundwater flow equation for the inhomogeneous anisotropic confined aquifer used for groundwater flow model (Rushton and Redshaw, 1979) using Visual Modflow 3.1.0 software as below as given below:

$$\frac{\partial}{\partial x}(K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_{zz}\frac{\partial h}{\partial z})=S_s\frac{\partial h}{\partial t}\pm W \qquad (1)$$

An unconfined condition followed by the Boussinesg equation as below:

$$\frac{\partial}{\partial x}(K_{xx}h\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}h\frac{\partial h}{\partial y})=S_y\frac{\partial h}{\partial t}\pm W \qquad (2)$$

where, K_{xx} , K_{yy} and K_{zz} are the hydraulic conductivities along the x, y and z-directions, h is the hydraulic head, S_s is the specific storativity, S_y is the specific yield ($S_y >> S_s$), W is the leakage or groundwater volume fluxes per unit area (positive for outflow and negative for inflow).The coordinates of x, y and z are the Cartesian coordinates.

Both the equations (1 and 2) were solved using a finite difference approximation technique. The starting point for the application of this method was discretization of small square sub-regions in a grid form (McDonald and Harbaugh, 1988). This leads to set of simultaneous algebraic equation, which was solved using the Visual Modflow 3.1.0 modeling code. This code has been widely used and is accepted to produce numerically stable solutions. The method selected for the numerical solution of the algebraic equation set is WHS.

Data Collection

The following data were collected for both micro-watersheds, and also used for the groundwater flow modeling:

- Digital elevation model (resolution: 30m×30m) covering the whole study area was created by digitizing the topographic map.
- Basic meteorological data required for the model like rainfall and temperature, recharge etc. were collected.
- Hydrogeological data such as hydraulic conductivity (K), storativity (S), and transmissivity (T) were gathered.
- Well inventory data such as the depth of groundwater, well depth, location of well, and well diameter of observational wells, and withdrawal data were collected during the field surveys.

Groundwater Flow Model

Model Creation

The base map of the study area was imported into the Visual Modflow for the grid preparation. A grid of 84m x 84m was used both the watersheds, as presented in Table 1, and also shown in Figure 2. The grids of micro-watersheds were divided vertically into two layers (first layer: weathered zone, and second layer: fractured zone) based on the bore log data. Figure 2. Shows the grid for both micro-watersheds in the study area and the active cells displayed in white whereas the inactive cells are shown as gree ncolor.

Table 1: Details of the grids in both micro-watersheds, Nanded district, Maharashtra

Sl. No.	**Item**	**Watershed-I (Patalgana)**	**Watershed-II (Shriganwadi)**
1	Area	10 km^2	6.9 km^2
2	Grid size	84m × 84m	84m × 84m
3	Row and column	33 and 32	25 and 32
4	Active cell	676	430
5	Model layer	2	2
6	Z minimum	347 m, amsl	382 m, amsl
7	Z maximum	432 m, amsl	440 m, amsl

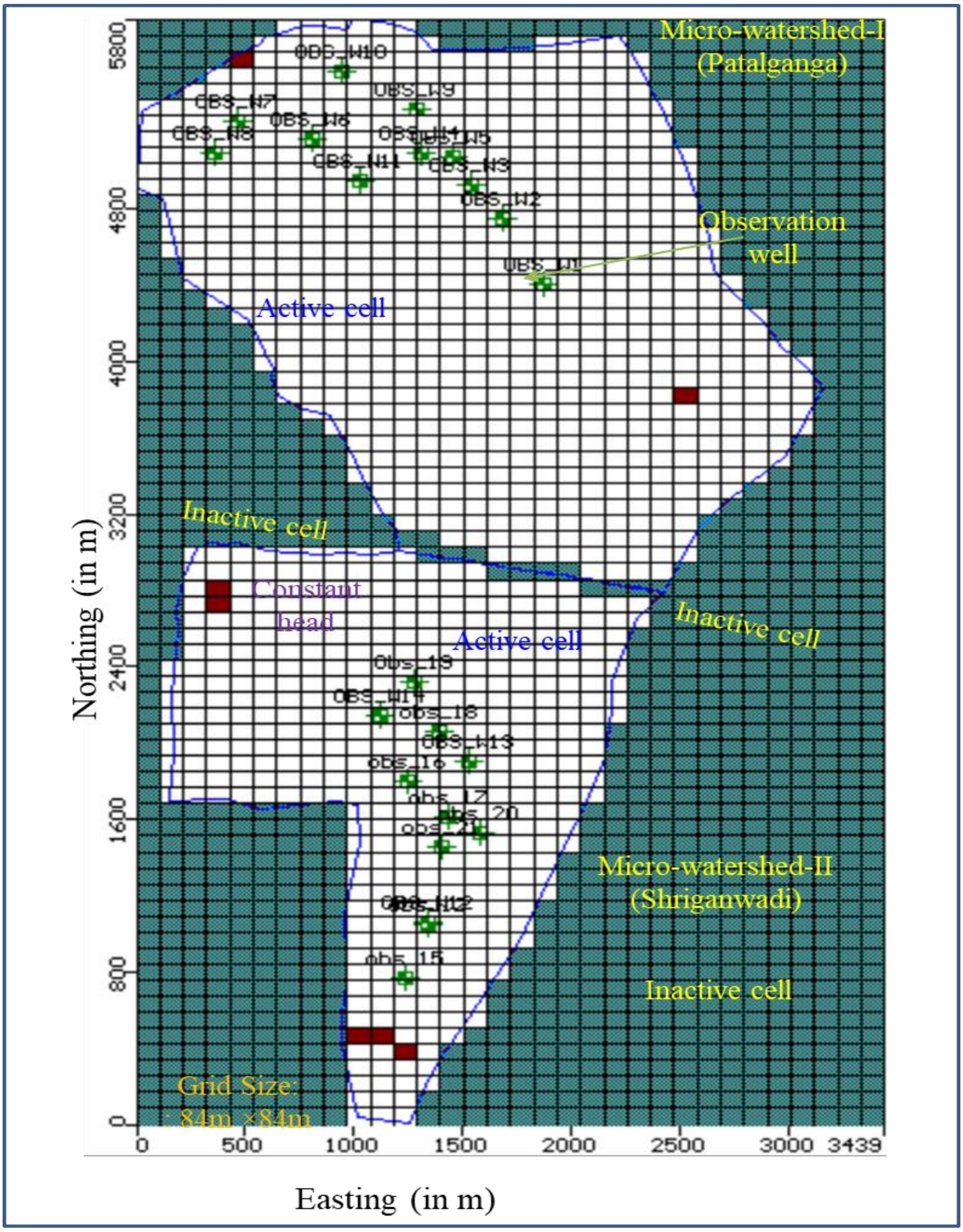

Figure 2: Showing the grids along with the active and inactive cells, constant head, and observation wells in both watersheds, Nanded district, Maharashtra.

Importing Elevation and Assigned Aquifer Properties

Due to unreliability of the pumping test, the hydraulic conductivities were collected from the literature (Kumar, 2002) and also estimated as weighted average. Investigating the bore logs, the vertical grid was divided into 2 layers as shown in Figure 3. The top layer which consists of weathered zone having the maximum depth of 15 m. Second layer of both the watershed sconsists of fractured zone with the maximum depth of 195 m, which are obtained from the bore well litho-logs. All required hydraulic properties, recharge, extinction depth and evapotranspiration were assigned, and also presented in Table 2.

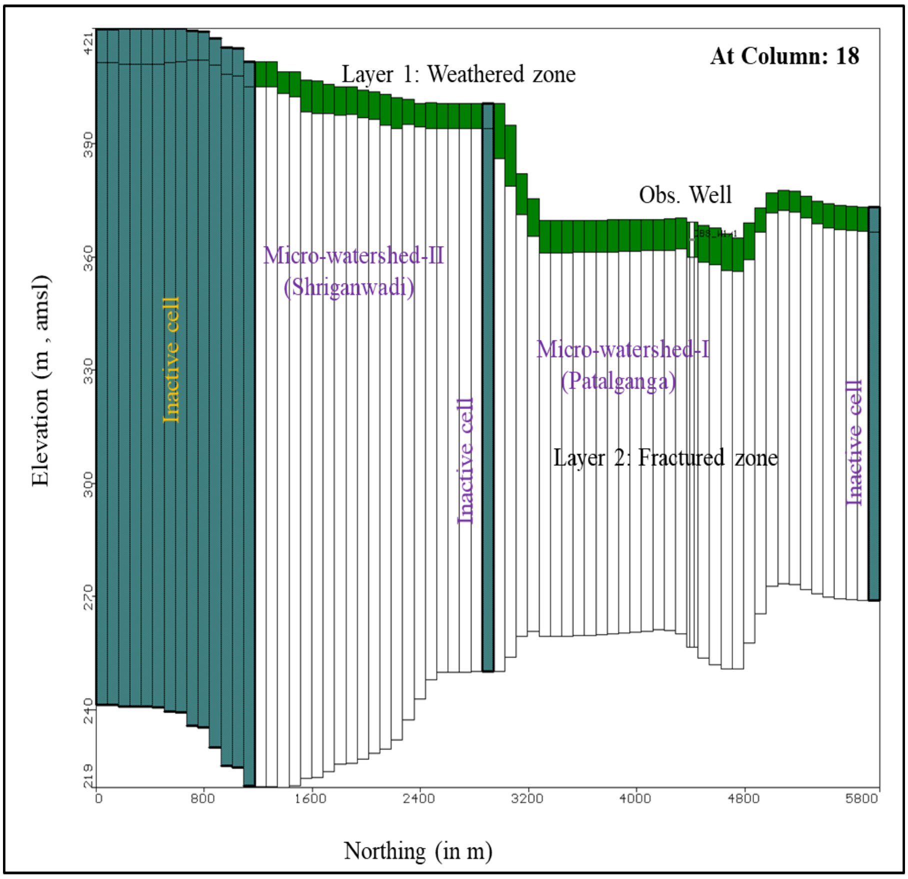

Figure 3: Vertical cross-section along the column no.18.

Table 2: Assigned hydraulic properties, recharge, extinction depth and evapotranspiration in both the micro-watersheds

Sl. No.	Parameter (s)	Watershed-I (Patalgana)	Watershed-II (Shriganwadi)	Unit (s)
First layer (Weathered zone)				
1	Kx	1.0	5.1	m/day
2	Ky	1.0	5.1	m/day
3	Kz	0.1	0.51	m/day
4	Specific Storage (Ss)	10^{-8}	10^{-8}	1/m
5	Specific yield (Sy)	0.02	0.02	m
6	Effective porosity	0.15	0.15	---
7	Total porosity	0.25	0.25	---
8	Recharge	65	75	mm/year
9	Extinction depth	3.0	3.0	m
10	Evapotranspiration	70.6	70.6	mm/year
Second layer (Fractured zone)				
1	Kx	3.0	3.0	m/day
2	Ky	3.0	3.0	m/day
3	Kz	0.3	0.3	m/day
4	Ss(Specific Storage)	10-5	10-5	1/m
5	Sy (specific yield)	0.02	0.02	m
6	Effective porosity	0.20	0.20	---
7	Total porosity	0.25	0.25	---

Pumping Wells

Groundwater aquifer is mostly observable for stresses by undergoing extraction of water schedules, which are causing changes in the groundwater table level, where it can study the locations where those schemes are useful as a boundary condition for the aquifer. Location of the wells assigned is shown in Figures 4 A and B, and the details are listed in Table 3.

Table 3: Details of the wells assigned in the model

Sl. No.	Well description	Micro watershed-I	Micro watershed-II
1	No. of wells	53	47
2	Observation wells	11	20
3	Pumping wells	42	27

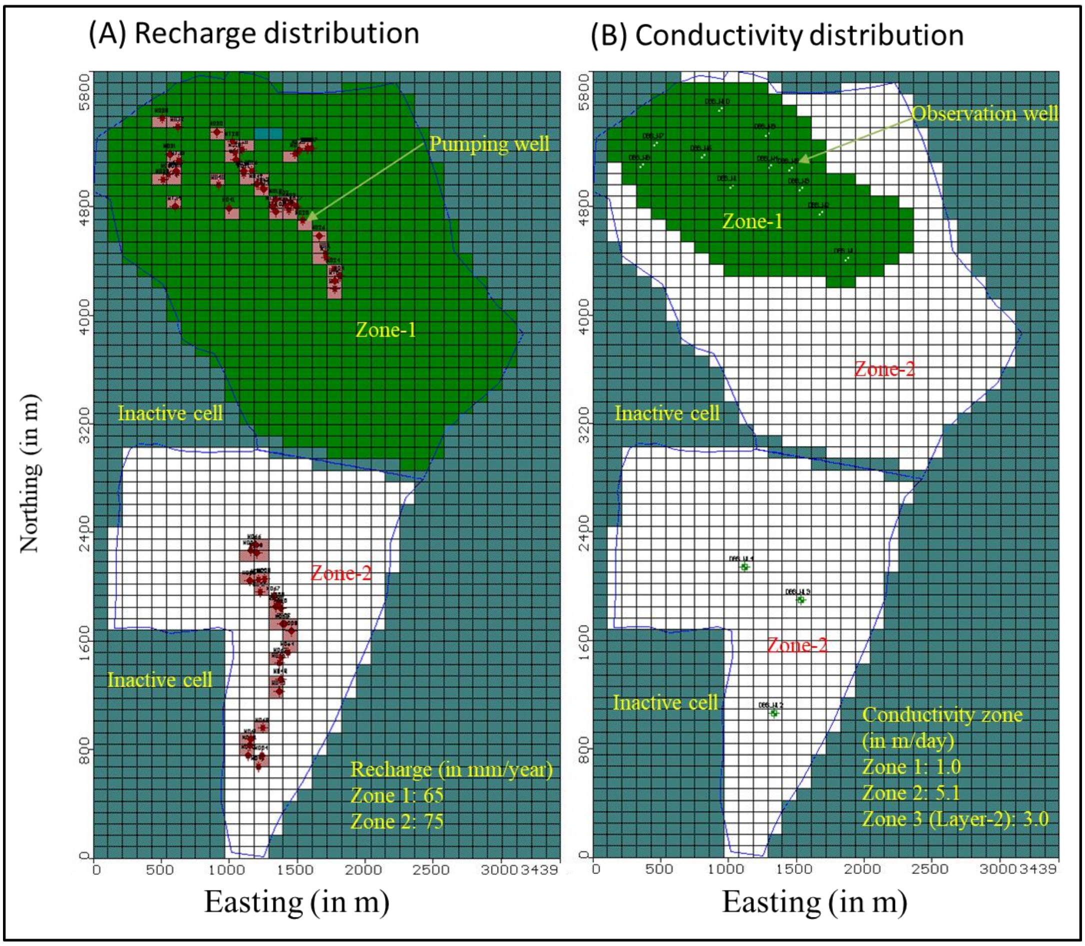

Figure 4: Showing (a) recharge distribution, and (b) conductivity distribution in the models

Constant Head

As observed in the field conditions and the movement of groundwater, constant heads were assigned along the boundaries, as shown in Figure 2. For the micro-watershed-I, the constant heads were assigned at two sites as 360m in the North and 370 m in the Northeast whereas for the micro-watershed-II, the constant head of 410 m assigned in the Southwest part and 440m in the southern part of the watersheds.

Defining the Stress Periods

The stress periods for the model simulation had been considered on the basis of weathering seasons, the overall simulation was divided into2 stress periods. Where the first stress period was a pre- monsoon season steady state simulation of the field data collected in the 120 days. A second stress period was taken in the monsoon season of 240 days, and third stress period was in the post-monsoon season 365 days.

Model Run

After assigning all the input parameters, the model was run for the steady state condition of the month of April 2021. This model was utilized to run for another two seasons of August and November 2021 considering the input stresses.

RESULTS AND DISCUSSION

The main reason of conducting this study is to check reaction of aquifer into different environmental stresses by groundwater modelling using Modflow 3.1.0. Both micro-watershed is having undulating topography, it causes more runoff and soil erosion. The reaction of the groundwater was precisely evaluated and the following results were achieved. Contours of water level, net recharge, head difference, drawdown, graphs of calculated versus observed heads, and velocity vectors with direction of flow as the outputs were achieved during the modeling.

Model Calibration

Groundwater model was calibrated for the steady state. Model calibration was done by changing hydraulic conductivity values. Calculated versus observed heads was plotted at the sites of observation wells after the calibrating model for both Micro-watersheds, as shown in Figures 5 A and B. It had shown a good match between the calculated and observed water levels in most of the observation wells. The root mean squared errors of the calibration were 0.767m and 1.182 m in the Patalganga and Shriganwadi watersheds, respectively. Figure 6 shows the water level contours and flow direction of groundwater in both the watersheds.

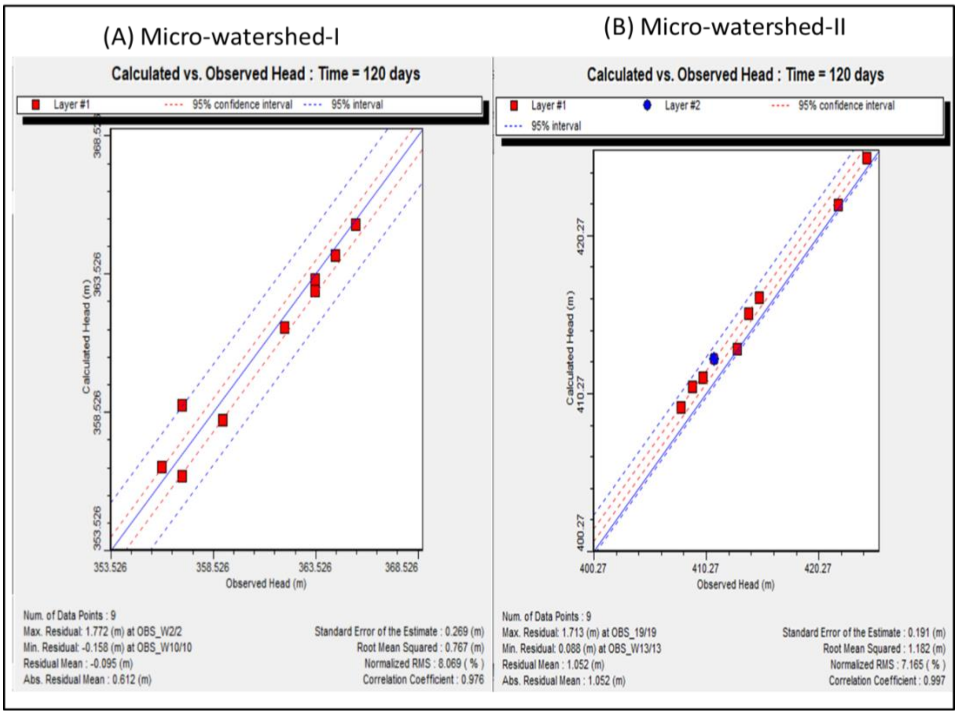

Figure 5: Showing calibrated vs. observed heads in the steady state model for both the watersheds during April 2021

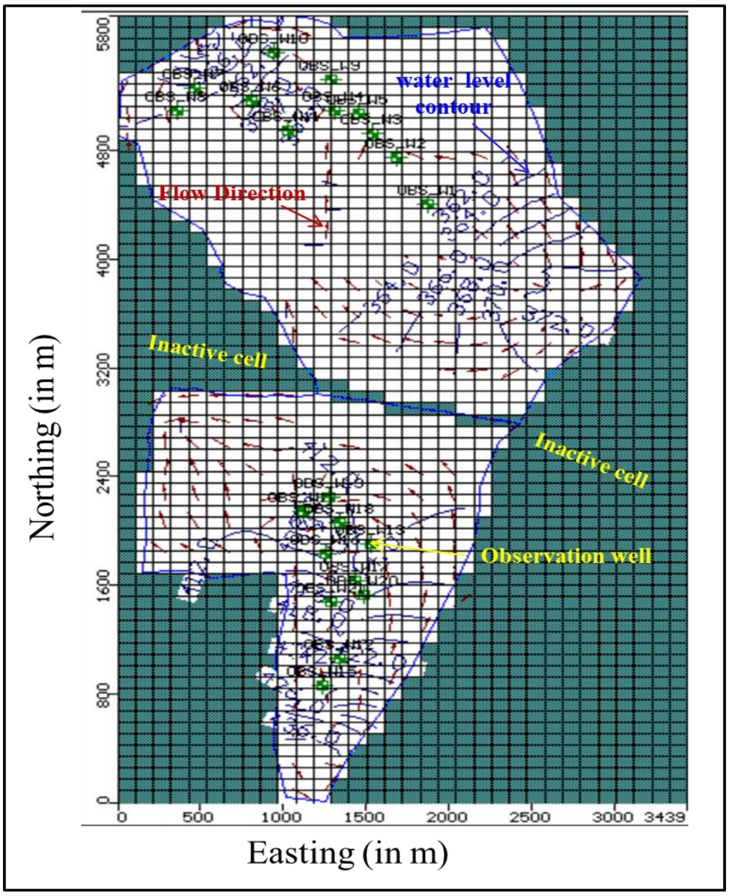

Figure 6: Water level contours and flow direction in both watersheds during April 2021

Different Environmental Stress Scenarios

The effect of different stress scenarios cases was studied to monitor and predict the reactions of aquifer system. These stress scenarios were selected on the bases of rainfall pattern and population data of both the micro-watersheds. These scenarios are possible to happen in future, as presented in Table 4. It had been observed that the current groundwater condition in the micro-watersheds is bad because the wells are getting dry at the present pumping rate. In the case-2, the pumping rate was increased by 5% because of this more area is getting dry and water level contours also reduced. Similarly, in the case-3 the pumping rate increased by 10% because of this more wells are getting dry, and the water level was reduced. In the case-4 the pumping rate was further increased by 20% and it was also showing the effect of lowering water head contours and more drying the area. Because of increasing of the pumping rate, water head contours were getting lower. Therefore, it was decided to reduce the pumping rate and keeping the recharge rate at the present scenario in the case- 5, 6 and 7, But the results were showing similar to the present field condition. There was no increasing in water level in both the watersheds. Because of independent pumping rates at the bore-wells were increasing so in the next case-8 and 9, we decided to increase the pumping rate by 5% and simultaneously increasing the recharge rate by 5% and 10% separately, but the results were same as in the case-2. Alter on, two case-10 and 11, the pumping rate was increased by 10% and the recharge rate was increased by 5% and 10%. The results were similar as in the case-3 (Table 4). In case-12, The recharge rate was reduced by 5% by keeping the current pumping rate because both the micro-watersheds are having the variation in rainfall pattern. The result was similar like the case-3. In the case-13, both the pumping and recharge rates were reduced by 5%, it had shown the similar results and the water level as in the case-1 which was simulated under the present rates of pumping and recharge.

Table 4: Showing the different environmental stress scenarios in the study areas.

Scenario(s)	Pumping rate (m^3/day)	Recharge rate (mm/year)	Combined results	Results (in watershed-I)	Results (in watershed-II)
Case-1	Current	Current	No dry wells	Well nos. 2,5 and 9: dry	No dry wells
Case-2	Increased by 5%	Current	More area getting dry and head value reduced	Well nos. 1,2,3,4,5 and 9: dry	More area getting dry
Case-3	Increased by 10%	Current	Well no 9: dry	Well nos. 1,2,3,4,5,8,9 and 11: dry	More area getting dry and head value reduced
Case-4	Increased by 20%	Current	Well nos. 5 and 9: dry	Well nos. 1,2,3,4,5,8,9 and 11: dry	More area getting dry and head value reduced
Case-5	Reduced by 5%	Current	Same as current field condition	Well nos. 1,2,3,4,5 and 9: dry	Same as current field condition
Case-6	Reduced by 10%	Current	Same as current field condition	Well nos. 5 and 9: dry	Same as current field condition
Case-7	Reduced by 20%	Current	Same as current field condition	Well nos. 5 and 9: dry	Same as current field condition
Case-8	Increased by 5%	Increased by 5%	Well no. 9: dry	Well nos. 1,2,3,4,5,8,9 and 11: dry	More area getting dry and head value reduced
Case-9	Increased by 5%	Increased by 10%	Well no. 9: dry	Well nos. 1,2,3,4,5,8,9 and 11: dry	More area getting dry and head value reduced
Case-10	Increased by 10%	Increased by 5%	Well nos. 5 and 9: dry	Well nos. 1,2,3,4,5,8,9 and 11: dry	More area getting dry and head value reduced
Case-11	Increased by 10%	Increased by 10%	Well nos. 5 and 9:dry	Well nos. 1,2,3,4,5,8,9 and 11: dry	More area getting dry and head value reduced
Case-12	Current	Reduced by 5%	Well no 9:dry	Well nos. 1,2,3,4,5,8,9 and 11: dry	More area getting dry and head value reduced
Case-13	Reduced by 5%	Reduced by 5%	Same as current field condition	Well nos. 1,2,3,4,5 and 9: dry	Same as current field condition

CONCLUSION

Groundwater flow model at the proximity of two micro-watersheds of Nanded district, Maharashtra is run for the steady state condition using Visual Modflow ver. 3.1.0. The field data such as aquifer properties, recharge, discharge, and other required information obtained from literature were used as the inputs for groundwater flow simulation. The results clearly show that the increasing of the pumping rate will make more area dry in both the micro-watersheds. So it should be reduced to control further damage in future. If we reduce the pumping by 10% of the current rate still some portion of the watersheds is remaining dry. Therefore, the pumping rate should not be increased, because the groundwater levels become lower than the present level.

REFERENCES

1. Alley, W.M., Reilly,T.E. and Franke., O.I. (1999). Sustainability of Groundwater Resources. U.S. Geological Survey Circular 1186.
2. Banerjee, P. and Singh, V.S. (2011). Optimization of pumping rate and recharge through numerical modeling with special reference to small coral island aquifer", Physics and Chemistry of the Earth, 36(16), 1363-1372.
3. Barlow, M. and Clarke, T. (2002). Who owns water? The Nation, 2(9), 11-14.
4. Central Ground Water Board-Central Region (CGWB-CR) (2020). Ground Water Year Book of Maharashtra and Union Territory of Dadra and Nagar Haveli, Year 2019-20, 139-140pp.
5. Central Water Commission (CWC) (2015). Ministry of Water Resources Water and Related Statistics, 253 pp.
6. Chandrasekhar H, Adiga S, Lakshminarayana V, Jagdeesha CJ, and Nataraju C. (1999). A case study using the model DRASTIC for assessment of groundwater pollution potential. In Proceedings of the ISRS national symposium on remote sensing applications for natural resources, 19-21.
7. Chidambaram, S. (2013). Identification of groundwater potential zone by using GIS and electrical resistivity techniques in and around the Wellington reservoir, Cuddalore district, Tamilnadu, India. European Scientific Journal, 9(17).
8. Das, S. (2020). Parched India-a looming crisis. Journal of the Geological Society of India, 95(4), 333-336.
9. District Census (2019). Handbook-Nanded village and town wise primary census abstract (pca) Directorate of census operations, Maharashtra.
10. Gupta, C.P., Thangarajan, M. and Rao, V.V.S.G. (1997). Assessment of groundwater pollution due to tannery effluents in the Upper Palar basin, South India", Engineering Geology and the Environment, 1-3, 1871-1875.
11. Hariharan, V. and Shankar, M. U. (2017). A review of visual MODFLOW applications in groundwater modelling. In IOP Conference Series: Materials Science and Engineering (Vol. 263, No. 3, p. 032025). IOP Publishing.
12. Kumar, C.P. (2002). Groundwater assessment methodology. Journal of Applied Hydrology, Association of Hydrologists of India, 15(4), 13-20.
13. Lasya, C. R. and Inayathulla, M. (2015). Groundwater Flow Analysis Using Visual Modflow. IOSR Journal of Mechanical and Civil Engineering 12(2), 5–9.
14. Lathashri, U.A. and Mahesha, A. (2015). Simulation of Saltwater Intrusion in a Coastal Aquifer in Karnataka, India, Aquatic Procedia, 4, 700–705.
15. McDonald, M. G. and Harbaugh, A. W. (1988). A modular three-dimensional finite-difference ground-water flow model. US Geological Survey.
16. Mondal, N. C., Singh, V.P. and Ahmed, S. (2012). Entropy-based approach for assessing natural recharge in unconfined aquifers from Southern India. Water Resources Management, 26(9), 2715-2732.
17. Mondal, N.C. (2019). Groundwater modelling using Visual MODFLOW in the last two decades in India: a review. International Journal of Science and Research, 8(1), 27-38.
18. Mondal, N.C. and Ajaykumar, V. (2021). Appraisal of natural groundwater reserve using entropy-based model at the proximity of Deccan Trap Basalt and Gondwana Sandstone in a part of Central India. Arabian Journal of Geosciences, 14(21), 1-15.
19. Mondal, N.C. and Singh, V.S. (2005). Modeling for pollutant migration in the tannery belt, Dindigul, Tamilnadu, India, Current Science, 89(9), 1600-1606.
20. Mondal, N.C., Singh, V.S. and Rangarajan, R. (2009). Aquifer characteristics and its modeling around an industrial complex, Tuticorin, Tamil Nadu, India: A case study, Journal of Earth System Science, 188(3), 231-244.
21. Neupane, P. K., Mondal, N. C. and Manglik, A. (2020). Envisaging the Sustainability of an Aquifer by Developing Groundwater Flow Model for a Part of ChoutuppalMandal, Nalgonda District, Telangana, India. Nepal Journal of Science and Technology, 19(1), 222-233.
22. Pathak, R., Awasthi, M. K., Sharma, S. K., Hardaha, M. K. and Nema, R. K. (2018).

Ground water flow modelling using MODFLOW-A review. Int. J Curr Microbiol App Sci, 7(2), 83-8.

23. Rushton, K. R. and Redshaw, S. C. (1979). Seepage and groundwater flow: Numerical analysis by analog and digital methods. John Wiley & Sons Incorporated.

24. Senthilkumar, M. and Elango, L. (2011). Palar River Basin, Southern India, Modeling the impact of a subsurface barrier, Hydrogeology Journal, 19(4), 917-928.

25. Singh, A. (2013). Groundwater modelling for the assessment of water management alternatives. Journal of Hydrology, 481, 220–229.

26. Sklorz S., Kaltofen, M. and Monninkhoff, B. (2017). Application of the FEFLOW Groundwater Model in the Zayandeh Rud Catchment. In: Mohajeri S., Horlemann L., editors. Reviving the Dying Giant. Springer, Cham

27. Srinivas, P., Aramani, R. A., Allam Ramakrishna, D., Kasthuri, D. K., Swamy, G. K. and Lakshmipathi, A. (2016). Significance of Jala Mahabhuta (Water) in Day To Day Life. WJPPS, 5(3), 1781-1793.

28. Surinaidu, L., Rao, V.V. S.G., Nandan, M.J., Khokher, C.S., Verma, Y. and Choudhary, S.K. (2015). Application of MODFLOW for groundwater Seepage Problems in the Subsurface Tunnels, Journal of Indian Geophysical Union, 19(4), 422-432.

29. Surinaidu, L., Rao, V.V.S.G. and Ramesh, G. (2013). Assessment of groundwater inflows into Kuteshwar Limestone Mines through flow modeling study, Madhya Pradesh, India. Arabian Journal of Geosciences, 6(4), 1153-1161.

30. Thangarajan, M. (1999). Numerical simulation of groundwater flow regime in a weathered hard rock aquifer: A case study", Journal of The Geological Society of India, 53(5), 561-570.

31. Todd, D.K. and Mays, L.W. (2005). Groundwater Hydrology. Third Edition. John Wiley & Sons Inc Arati, K. (2014). Droughts in Maharashtra: Lack of management or vagaries of climate change. India water portal, 18.

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