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Groundwater Modelling of the North-Eastern Part of Barind Tract for its Sustainable Development and Management, Bangladesh

Rubaiyat Yasmin
Department of Information and Communication Engineering,
University of Rajshahi, Rajshahi, Bangladesh

Abstract: Groundwater is an important natural resource of the world. Large-scale groundwater utilization in the past world has resulted in adverse economic-cum-environmental problems such as continual decline of piezometric levels, land subsidence and groundwater quality deterioration. Groundwater modelling of the study area has been prepared for the assessment of groundwater resources and to prescribe a long-term development policy. FLOWNET and MODFLOW has been used and calibrated to simulate the groundwater levels in the aquifer system. The model is calibrated against the field hydrographs of the study area. The aquifer system responses to different pumping schemes are then predicted for different periods. The present model could be used for future planning of sustainable groundwater development and management of the area studied.

Key words: Groundwater, modelling, flownet, modflow, agriculture, D.T.W

INTRODUCTION

Bangladesh being mainly an agricultural country the growth of this sector is critical to the growth and development of the national economy. Groundwater is an economic resource. Apart from drinking purpose, it is used in agriculture, industries and municipalities. North-western region of Bangladesh is dependent mainly on Deep Tube Well (D.T.W.) irrigation during the dry 8 months from mid October to mid June when rainfall is minimum. Groundwater has been the backbone of the green revolution which has made Bangladesh virtually self-sufficient in rice production since, the mid 1990s (Asaduzzaman and Rushton, 1998). Groundwater study of an area requires the knowledge of the nature of lithological units occurring in the area, their structural disposition, geomorphic setup, surface water conditions and the climate, which provide detailed information about the large part of the surface of the earth in a very short time (Shahid, 2000). The specific objectives of the investigation are as follows:

- To study the groundwater geology as well as the hydrogeological parameters of the surface water system.
- To determine the groundwater flow direction.
- To delineate the groundwater potential zones.
- To study the transient behavior of the groundwater system.

MATERIALS AND METHODS

Location and extent of study area: The investigated area, Dhamoirhat thana of Naogaon district is located in the Barind region which lies between 25°01′ N to 25°13′ N latitude and 88°40′ E to 88°57′ E longitude (Fig. 1). The study area has a typical monsoon climate. There are 3 main seasons in the area Winter; Pre-monsoon and monsoon or rainy season (Asaduzzaman and Rushton, 1998).

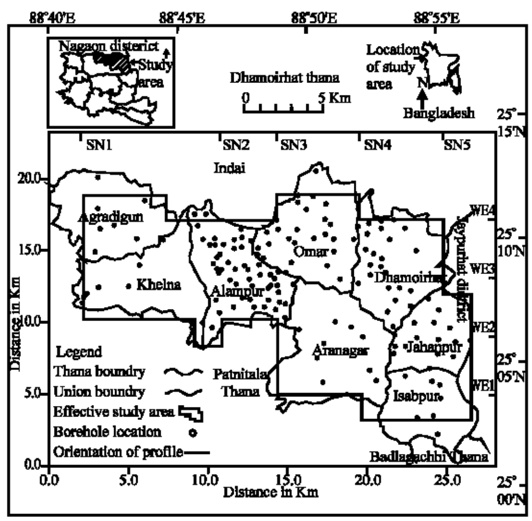

Fig. 1: Location map of the study area

The study area is located in the Dinajpur shield which is situated under the Barind Tract of the Pleistocene area. It was formed by the deposition of sediments carried by the river Padma and tributaries in the Pleistocene age (Morgan and McIntyre, 1959). The top soil of Barind area which is reddish in color is mostly clay though silt and fine sands are encountered in some places. It contains an excess of iron and lime and is deficient in silicon matter. When dry, this soil becomes very hard and in wet season it is slippery rather than soft. The formation of clay and silt underlain by fine, medium and coarse sand (Khan, 1991).

Data acquisition and interpretation: Surface lithological data are widely used for the exploration of groundwater in any geological setup. Borehole lithologs are an important source of valuable data for hydrogeological studies. In this regard, about 155 borehole information of the investigated area have been analysed and interpreted both qualitatively and quantitatively. Lithological data are collected from Barind Multiple Development Authority (BMDA), Bangladesh.

RESULTS AND DISCUSSION

Formation distribution: The distribution of data points in the area investigated is clearly observed in Fig. 1. The physical shape of different interfaces have been presented in a generalized form with respect to a datum chosen at a depth of 45 m below mean sea level. The classifications of the subsurface formations of the study area are: Top clay layer, sandy layer and impermeable zone. The thickness of top clay is found constant in the area and it is about 6 m. This clayey layer is overlying the only sandy formation recorded in the area studied. Sandy layer is clearly divided into 2 parts, one below the top clay which is fine in grains and thickness varies between 30-12.2 m and another below that is consists of medium to coarse grain generally termed as composite sand and thickness varies between 9.1-48.8 m. The composite sandy formation is overlying an impermeable clayey layer which is locally known as Black Plastic Clay (BPC) due to high plasticity. The interbeded views along with the earth surface have been presented in Fig. 2 for comparative study.

Stratigraphic views: The distribution of aquifers and aquitards in a geological system are controlled by lithology, stratigraphy and structure of the geologic formations. Groundwater in the investigated area occurs under water table condition. The area is covered by a thick blanket of clay horizon and the surface is sloping in nature. To observe the cross-sectional views in different parts of the effective investigated area 9 representative vertical sectionings along the profiles of both South-North (SN) and West-East (WE) directions have been prepared with the indication of water head position. The orientations of the profiles e.g., SN1, WE1, etc. are shown in Fig. 1. The figures have been drawn considering the heights of different interfaces with respect to the datum plane (45 m below the m.s.l.). The sectional views clearly distinguished the earth surface elevation, thickness of top clayey layer, fine sand and composite sand and the position of impermeable clay bed along the profiles. Figure 3 represents the vertical divisions of subsurface formations along different profiles. These figures found that the northwestern corner and southwestern corner of the middle area are not feasible for groundwater exploration due to thin sandy formation. However, in the rest part of the investigated area, the thickness of the composite sand is satisfactory for groundwater exploration. The undulating nature of the interfaces play an important role in groundwater flow direction.

Estimation of transmissivity: The aquifer transmissivity and storativity determine how effective it is as a groundwater reservoir. One of the most important properties of sediments is its permeability which controls the flow of fluids through the formation. The reansmissitivity of a water saturated zone represents its average water transmitting property which depends mainly on the number and diameter of the pores present.

The transmissivity of a formation would be calculated from the relation:

$$T = k^*b \text{ m}^2 \text{ day}^{-1}$$

Where,

k = Is the co-efficient of permeability.

b = Is the thickness of the aquifer.

The value of T all over the study area has been estimated and presented in the form of contour map as shown in Fig. 4. It is observed from the figure that the value of T lies between 250 m^2-1550 m^2 day^{-1}. In most of the areas this value covers 850 m^2 day^{-1} and above, which is favorable for groundwater exploration if the other parameters agree with. Whereas in some parts of northwestern corner and middle of southwestern corner it is recorded below 850 m^2 day^{-1}, which is not satisfactory for large scale groundwater exploration.

Groundwater flow model: Groundwater modelling is a tool that can help to analyze many groundwater problems.

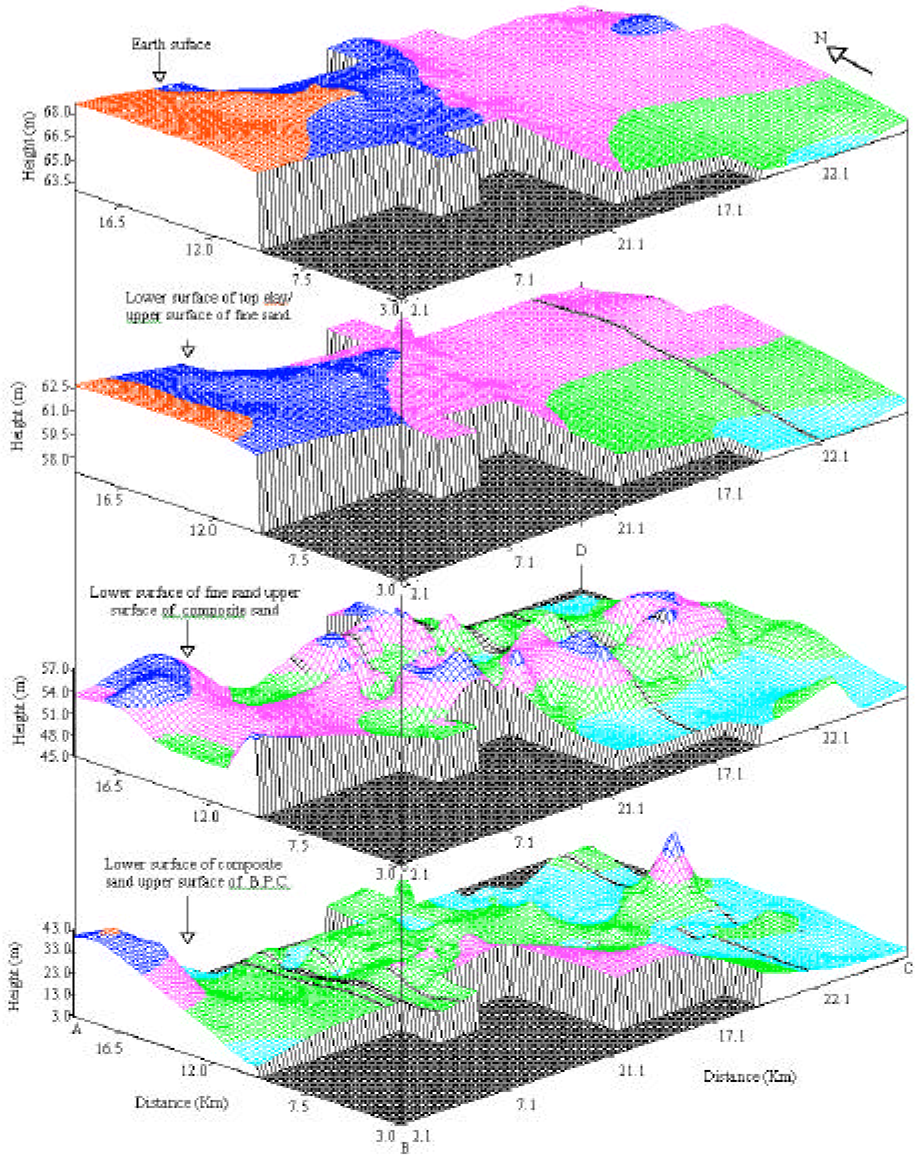

Fig. 2: Surface views of different interfaces (View from Southwest Corner)

Models are useful for, reconnaissance studies preceding field investigations, interpretive studies following the field program and predicative studies to estimate future field behavior. In addition to these applications, models are useful for studying various types of flow behavior by examining hypothetical aquifer problems. The complex problems related to functioning of groundwater systems could be solved with the aid of models that simulate the response of the groundwater system-the prototype (Karanth, 1990). The present study has adopted the popular modular Three Dimensional Finite Difference Groundwater Flow Model (MODFLOW) developed by the U. S. Geological Survey (McDonald and Harbaugh, 1984) and Two dimensional finite element model (FLOWNET). In the present study, a model of the groundwater system has been developed and the effect in groundwater flow and water head position for the exploration of groundwater has been observed. The study area consists of 24.514 km length and 15.759 km wide like a rectangular shape (Hasan, 2001). The area is subdivided into 9 rows and 14 columns that create 126 square blocks called grid. But 41 grids are omitted because they are located outside of the effective investigated area and are designated by inactive zone (green blocks) and the rest of 85 grids are considered for interpretation and is denoted by active zone (Fig. 5).

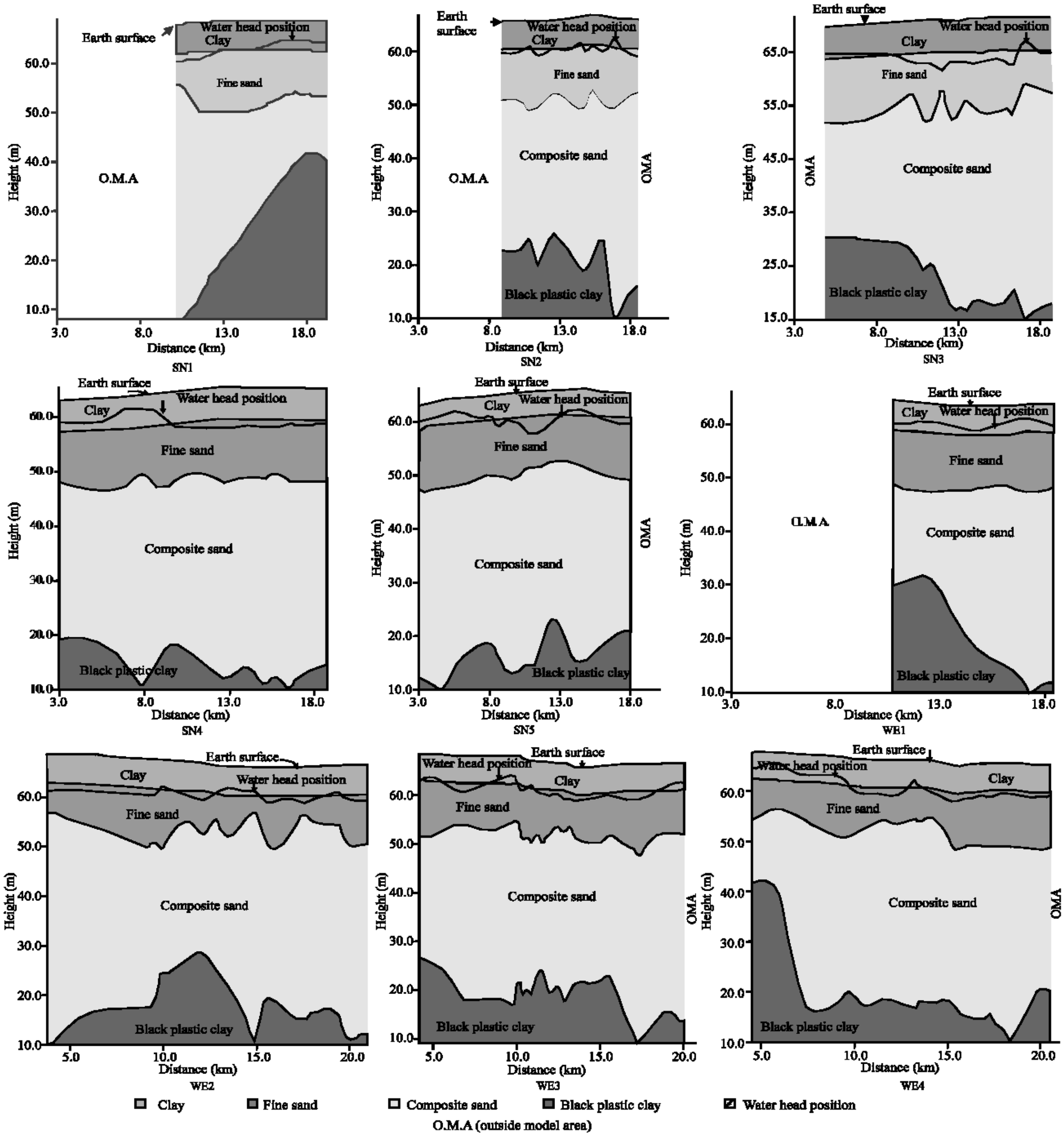

Fig. 3: Geologic cross-sectional views along different profiles

A geohydrologic system could be described by its hydraulic properties and associated boundary conditions. In the present study, 4 geologic formations have been considered and the top layer is defined unconfined as the water table lies within this formation and the second and third layer are defined unconfined / confined depending on the position of the water table. The flow direction of groundwater in the study area have been made using FLOWNET. The values of porosity, horizontal and vertical conductivity of each block and the hydraulic head of the active boundary blocks are assigned. The horizontal and vertical conductivities have been calculated with the formula:

$$\text{Horizontal conductivity, khor} = \Sigma\,(kd)/\Sigma d$$

$$\text{Vertical conductivity, kvert} = \Sigma d/\Sigma\,(d/k).$$

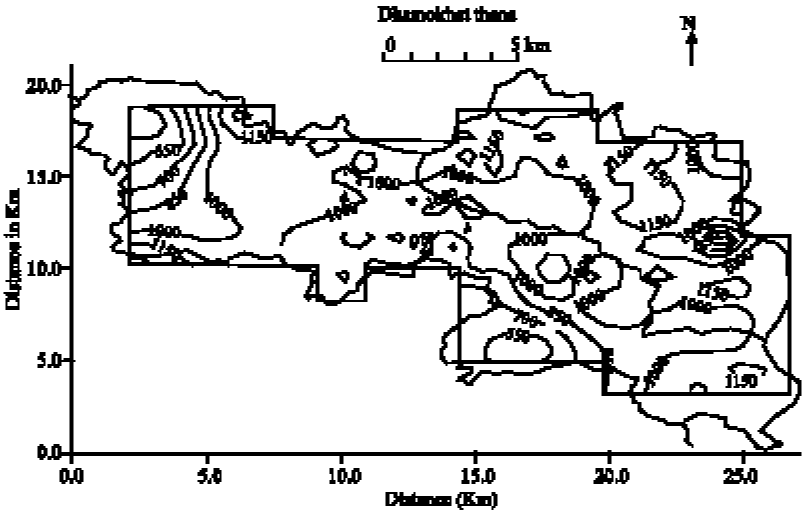

Fig. 4: Contour of map transmissivity in the effective study area

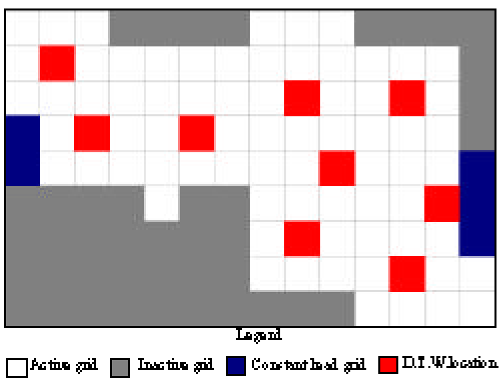

Fig. 5: Location and size of the geo-units of investigated area used for groundwater modelling

where,

k = Is the hydraulic conductivity of individual layers.
d = Is the corresponding thickness.

After simulation, the nature of groundwater flow of the study area has been obtained and depicted in Fig. 6 (a). The surface pattern of the water head position (Fig. 6b), clearly distinguishes the variation of the water head in the different parts of the area studied. The figure gives the idea that the stream lines are originating from north-west and south-east corner and directed towards south and east. In the eastern side a flow channel has been identified. This channel might be formed due to syncline structure at the top of the impermeable layer.

A model has also been developed to obtained the solutions of steady-state and transient flow problems of this area using MODFLOW. The boundary conditions of the model are shown in Fig. 5. The thickness, horizontal and vertical hydraulic conductivity and porosity of different geologic formations in each cell have been assigned. Figure 7 (a) and (b) show the hydraulic head positions for steady-state flow. It is observed from Fig. 7 (a) that in the north-western corner and some region of south-eastern position, the water table lies in the top clay formation. The white cell indicates the absence of water level in the first layer in that position. While Fig. 7 (b) indicating the presence of water level in the second layer of study area.

The amount of water discharge from an aquifer system is generally depends on the number of pumping set, discharge rate of each set and time period. In the present study, 9 Deep Tube Wells (D.T.W.) have been setup in the model area for pumping water from the aquifer (Fig. 5). The total pumping rate for a multi layer well is equal to the sum of those from the individual layers. The pumping rate for each layer Q_K could be approximately calculated by dividing the total rate Q_{total} in proportion to the layer transmissivities (McDonald and Harbaugh, 1988), that is:

$$Q_K = Q_{total} (T_K / \Sigma T)$$

Where,

T_K = Is the transmissivity of layer.
K and ΣT = Is the sum of the transmissivities of all layers penetrated by the multilayer well.

The total discharging rate of each pumping equipment is considered 1728 m^3 day^{-1} with pumping duration of 10 h day^{-1}. The basic model (MODFLOW model) has been subdivided into 4 zones indicating zone one-layer one to zone 4-layer 4 to represent the change in hydraulic head of individual layers.

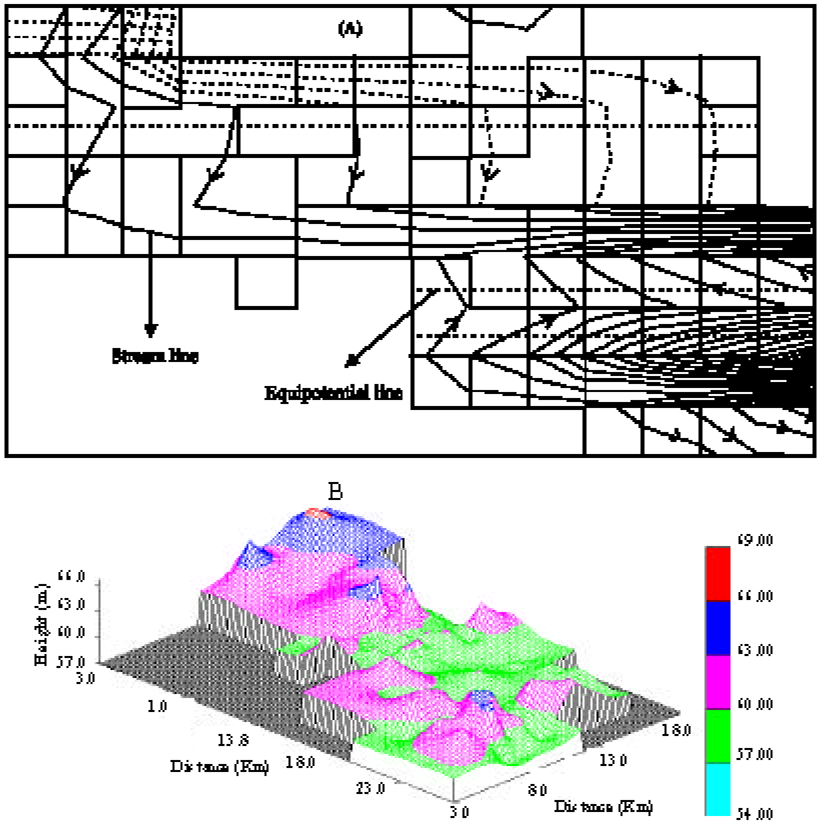

Fig. 6 (a): Flow pattern of groundwater in the study area, (b) The surface view of the water head position (View from Southwest corner)

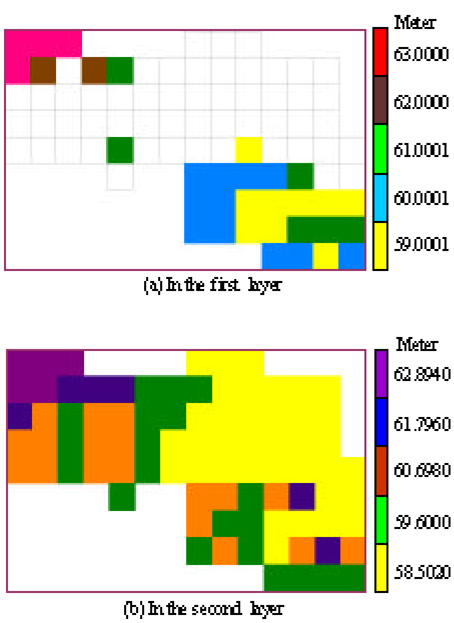

Fig. 7: Contour map of the hydraulic heads for steady state flow

In the present modelling, the transient state simulation is run for one stress period with a length of 300, 1200 and 12000 h. In the first step 300 h stress period has been considered equivalent to 9 tubewells operating 10 h day^{-1} for 30 days. The change of water head position in layer one and 2 are shown in Fig. 8a (i) and (ii), respectively. In the first and second layer a small change in groundwater level is obtained (between Fig. 7a and b and Fig. 8a (i) and (ii), respectively) as indicated in the scale.

Barind Tract at present is considered as highly irrigated area, mainly depends on groundwater. The pick period of irrigation is pre-monsoon session, generally, starts from January and continue to April, sometimes May. In the present transient modelling system an attempt has been made to study the effect of continuous groundwater exploration during these 4 months. Similarly, the pumping effect in the groundwater reservoir after 4 months has also been studied and the variation of water level in layer one and 2 are presented in Fig. 8b (i) and (ii), respectively. Still there is a minor change of water level in layer one but an appreciable change is happened in layer 2.

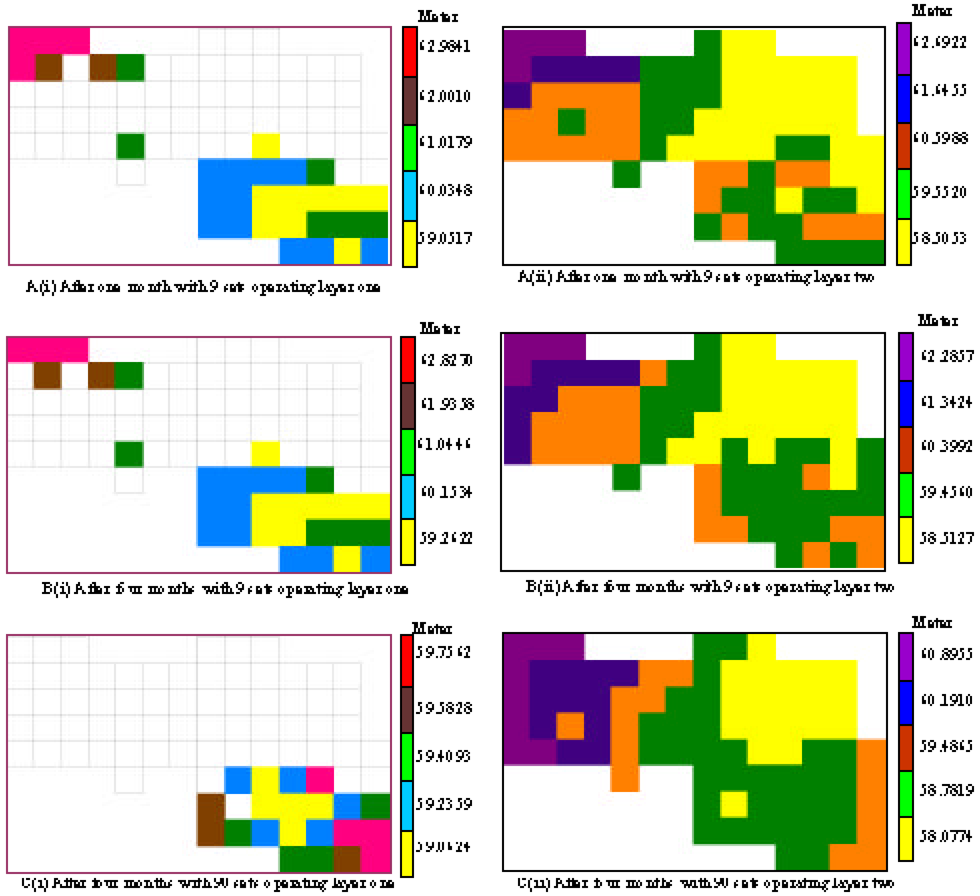

Fig. 8: Contour map of the hydraulic heads for transient flow

In the above interpretations in all cases 9 pumping sets are taken into consideration. If the number of sets are increased to 90, what would be the effect, that has also been studied in the final phase. In the present study, 12, 000 h pumping period has been considered equivalent to 90 tubewells operating for 4 months at the rate of 10 h day^{-1}. Figure 8c (i) shows a major change of water level in the first layer. In this layer, the water level exits only in the south-east corner and falls to 59.7 from 63 m as it is recorded in steady state solution (Fig. 7a). Likely effect has also been observed in layer 2. The increased number of discharging equipment resulted 2m declination of water level in this layer. In the above analyses it were observed that there is no change of water level in layer 3. Figure 8c (ii) indicate the minimum position of water level in 58 m. Analysis of borehole data indicates the lower level of second layer at 56.5 m. So, addition of more pumping set will definitely cause the water level to fall to the third layer which is the only explorable formation of the investigated area. Such a large-scale abstraction in this area, where there is uncertainty about the amount and mechanism of recharge to the aquifer, raises questions about the sustainability of the regime and its potential adverse impacts. Already enhanced drawdown in the aquifer of the area has led to the failure of boreholes fitted with pumps of lower lift and lower capacity. Since, the onset of irrigation pumping from the aquifer, shallow water levels in the overlying Barind clay have declined in some areas, causes water deficiency in domestic uses.

As groundwater flow models improved in efficiency and reliability, they began to be routinely applied to large-scale water supply problems. The groundwater flow direction of the study area has also been obtained using FLOWNET and different flow channels are identified (Fig. 6). These channels could be used for well sites.

Fluctuations in groundwater level are different for different locations, depending mainly on groundwater extraction. The predicted groundwater level fluctuations have been analyzed in terms of number of discharging equipments, time duration and pumping rate. The steady state flow models are shown in Fig. 7 (a) and (b). The change in model parameter due to different stress period has been studied (Fig. 8a-c) and it is observed that the water level is declined to the second layer (fine sand) after 4 months of pumping. The thickness of this layer is not large, so uncontrolled abstraction of groundwater might cause the water level to be declined to the third layer which is the only exploitable layer in this area. If it happens, the storativity will be decreased as well as the quality of groundwater will be deteriorated. From the overall observation it is found that excessive exploration of groundwater for the irrigation purpose is the main reason for the on going drying up of low lift pumps used for domestic uses.

CONCLUSION

This study builds on the understanding of the aquifer system of Dhamoirhat thana of Naogaon district. Groundwater study of an area could not be completed without understanding the subsurface water flow. An optimum groundwater potential modelling of an area could definitely be used for sustainable management of groundwater resources. Since, there are many conflicting demands and the health of the aquifer is difficult to assess, management issues are complex. But a continuous monitoring system would help to overcome this problem. In regions it has to be decided:

- What form of monitoring is necessary?
- What should be measured:
- How frequently should readings be taken?
  How should these readings be interpreted?

Models based on those data are important when planning future exploitation. However, groundwater legislation, covering both environmental and commercial aspiration, is necessary for the proper management and development of an aquifer system.

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