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RESEARCH ARTICLE

ASSESSMENT OF GROUNDWATER QUALITY AND LEVEL BY FINITE ELEMENT MODELLING

***Rajaveni, S. P., Muniappan, N., Anto Amala Ancy R., Beulah, A., Golda Jebamiranda, D. and Jeya Suganthi, S.**

Department of Civil Engineering, V V College of Engineering, Tisaiyanvilai, India

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ABSTRACT

Safe drinking water is the primary need of every human being. Groundwater is believed to be clean and free from pollutants as compared to the surface water. Hence, it is being used invariably as a major source for drinking, domestic and irrigation purposes. The purposes of this study are to (1) asses the groundwater quality parameters such as pH, Hardness, Chloride, Fluoride, Sulphate and Nitrate; (2) prediction of groundwater head by numerical modelling. During this study, field visit was carried out to collect groundwater samples. The groundwater samples collected from the field were analysed in the laboratory by using standard procedures for different quality parameters. The results of analysis obtained were compared with the drinking water quality standards specified by Indian standard (IS 10500:2012). Finite element modelling was conceptualized in FEFLOW software. Hydro geological parameter were assigned and model calibration are successfully done using FEFLOW. The model was calibrated in steady state condition with R2 value of 0.959. Transient state calibration done with R2 value of 0.897. After successful calibration model was used to predict with the application of one of the artificial recharge structure of percolation pond. Prediction result shows that the increase of ground water head by 1.5m with the implementation of percolation pond. Thus, the increase of groundwater head can improve the groundwater quality in the study area.

Key words: Groundwater, FEFLOW, Quality parameters, Aquifer.

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INTRODUCTION

Demand of freshwater is rapidly growing due to increase in population, agricultural activities and industrialization in several parts of the world. Groundwater is one of the fresh water resources being used for millions of people for several purposes. The quality of groundwater is as important as its quantity because it is the major factor in determining its suitability for drinking, domestic, irrigation and industrial purposes. The concentration of chemical constituents which is greatly influenced by geological formations and anthropogenic activities. Groundwater flow modelling can be used as a management tool to assess the groundwater quality and quantity. Several studies have been carried out on groundwater flow modelling in order to understand various issues related to sustainable utilization and management of groundwater. Groundwater models are the mathematical and digital tools used to study and analyze present aquifer condition and predict future behavior of aquifer system under varying geological environment.

****Corresponding author:*** **Dr. Rajaveni, S. P.,**
Department of Civil Engineering, V V College of Engineering, Tisaiyanvilai, India.

The models act an important role in the management and predictive measures on groundwater resources (Zhou & Li 2011). The groundwater models are the good management tool used to understand past and present condition of aquifer system and used to predict the future reaction of aquifer for any hydrogeological stresses like rainfall recharge and groundwater pumping (Rajaveni *et al.,* 2016). Several researchers have analysed groundwater flow dynamics, groundwater level monitoring by numerical modelling using finite difference method (Senthilkumar & Elango 2001, Elango 2005, Alam & Umar 2013, Jean *et al.* 2013). The present study was carried out with the objective of assessing the groundwater head and improve groundwater quality by implementing managed aquifer recharge structures by using finite element three-dimensional groundwater flow model.

Study area

Study area is situated in the southernmost part of South India and is located between altitudes of 8 °08' and 8° 33' N and longitudes of 77° 28' and 78° 52' E. The study area covers an area of 0.83 sq.km. Figure 1 gives the location map of the study area obtained from Google earth. Sub dendritic pattern of drainage occurs on the study area. Climate of Sathankulam taluk consists of three main seasons, winter season starts from the middle of the November and continuous till the end of the February. Then follows summer from March till early June and the Monsoon season starts from June and continuous till the end of September. The rainfall for the study area was obtained from world weather website. The average high rainfall for the year of 2000 to 2012 is to be 420 mm in the month of October.

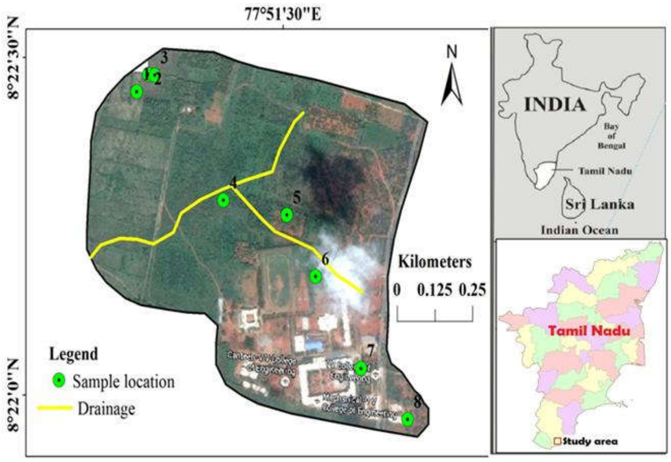

Figure 1. Location of study Area

MATERIALS AND METHODS

Groundwater sample were collected from 8 bore wells around the study area during the month of February and March 2016. Location of bore wells is measured by using Global Positioning System (GPS). Groundwater samples were collected after 10 minutes of pumping and stored in good quality polythene bottles of 1 L capacity previously soaked in 10 % nitric acid (HNO_3) for 24 h and rinsed with deionized water. The physio-chemical parameters such as pH, Hardness, Chloride, Fluoride, Sulphate and Nitrate are analyzed in the laboratory. All the analyses were carried out as per the standard procedures prescribed in American Public Health Association manual. Then the groundwater model was conceptualized in the FEFLOW demo version software.

RESULTS AND DISCUSSION

Physio-Chemical parameters of groundwater

Groundwater quality indicates the water usability for different purposes. Water quality may yield information about environments through which water has circulated. pH is the measure of acidity of an aqueous solution. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline. Pure water has a pH very close to 7. During the month of February 2016 pH varies from 7.65 to 8.71 (Table 1). As per IS10500 – (2012), allowable limit for pH 6.5 – 8.5. Sample 6 has excess amount of pH – 8.7. It is greater than allowable limit. During the month of March 2016 the value of pH varies from 7.36 to 8.43. Water hardness is the traditional measure of the capacity of water to react with soap, hard water requiring considerably more soap to produce a lather. Hard water often produces a noticeable deposit in containers. Hardness values ranges from 150 mg/l to 405 mg/l during February 2016 and 189 mg/l to 425 mg/l during the month of March 2016. As per IS10500 – (2012), allowable limit for hardness is 600mg/l. Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. Nitrate concentration in the study area ranges from 16 mg/l to 40 mg/l during the month of February 2016 and 17 mg/l to 50 mg/l during March 2016. The concentration of Nitrate is due to the decaying organic matter, sewage and fertilizer from agricultural runoff (Karnath 1987). Higher concentration of Nitrate can cause methaemoglobinaemia, gastric cancer, goiter, birth malformation and hypertension. As per IS10500 – (2012), allowable limit of Nitrate is 45 mg/l. Chloride is found naturally in groundwater through the weathering and leaching of sedimentary rocks and soils and the dissolution of salt deposits. Chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$). The taste threshold of the chloride anion in water is dependent on the associated cation.

The chloride ion is highly mobile and is transported to closed basins or oceans. The concentration of chloride varies from 71 mg/l to 186 mg/l (February 2016) and 94 mg/l to 200 mg/l (March 2016) (Table 1). As per IS10500 – (2012), allowable limit for Chloride is 250 mg/l. Fluoride is one of the very few chemicals that has been shown to cause significant effects in people through drinking water. Fluoride has beneficial effects on teeth at low concentrations in drinking water. Fluoride may be an essential element for humans (WHO 2004). The source of Fluoride in groundwater is normally attributed to leaching from fluoride rich rocks and easier accessibility of rain water to weathered rock, long-term irrigation processes, semiarid climate and long residence time of groundwater (Datta *et al.,* 1996; Srinivasamoorthy *et al.,* 2008). The concentration of Fluoride varies from 0.25 mg/l to 1.84 mg/l during the month of February 2016 and 0.32 mg/l to 1.92 mg/l during March 2016. As per IS10500 – (2012), allowable limit for Fluoride is 1mg/l. Sample No 2, 3, 4, 6 and 8 has excess amount of Fluoride which are greater than allowable limit during the month of February and March 2016. Sulphates are a combination of sulfur and oxygen and are a part of naturally occurring minerals in some soil and rock formations that contain groundwater.

The mineral dissolves over time and is released into groundwater. Sulphate ions do not have any significant detrimental effect on plants and animals. It is essential nutrient for plants. Excess sulphate concentration increases salinity and hardness of water. Samples with higher concentration of sulphate in drinking water are associated with respiratory problems (Subramani *et al.,* 2010). The values of sulphate varies from 163 mg/l to 577 mg/l during the month of February 2016 and 189 mg/l to 600 mg/l. As per IS10500 – (2012), allowable limit for Sulphate is 200mg/l. Sample 1, 3, 4, 5, 6, 7 and 8 (March 2016) has excess amount of Sulphate which are greater than allowable limit

Groundwater modeling

Description of the Model Conceptualization

The finite element groundwater model was conceptualized into 4 layers and 500 nodes. Since, this study have used the demo version of FEFLOW 6.2, this is the maximum discretization possible to done with demo version. Figure 2 shows the three dimensional conceptualization of the model area. Here, the aquifer thickness of 200 m was divided into 4 layers each layer has 50 m thickness.

Table 1. Physio-chemical parameters for the month of February 2016

Sample No	Well depth (m)	Hardness (mg/l)	pH	Nitrate (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Sulphate (mg/l)
1	98	150	8.37	21	115	0	330
2	98	200	7.65	16	124	1.78	165
3	98	155	8.46	16	133	1.43	412
4	128	300	8.44	32	89	1.54	494
5	114	270	8.39	25	80	0.76	577
6	107	205	8.71	21	71	1.84	330
7	122	335	7.98	37	106	0.25	342
8	85	405	8.52	40	186	1.26	163

Table 2. Physio-chemical parameters for the month of March 2016

Sample No	Well depth (m)	Hardness (mg/l)	pH	Nitrate (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Sulphate (mg/l)
1	98	189	8.17	23	126	0.42	345
2	98	210	7.365	18	148	1.81	189
3	98	175	8.315	17	184	1.45	500
4	128	215	8.215	28	94	1.58	550
5	114	255	8.315	29	96	0.82	600
6	107	185	8.305	19	100	1.92	359
7	122	300	8.1	35	130	0.32	386
8	85	425	8.43	50	200	1.32	250

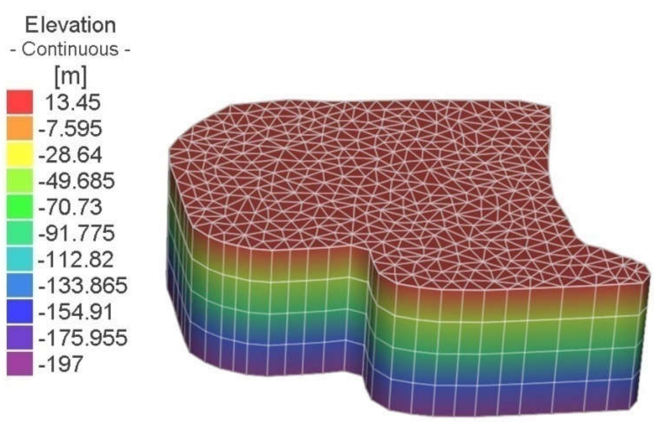

Figure 2. Three dimensional conceptualization of aquifer system

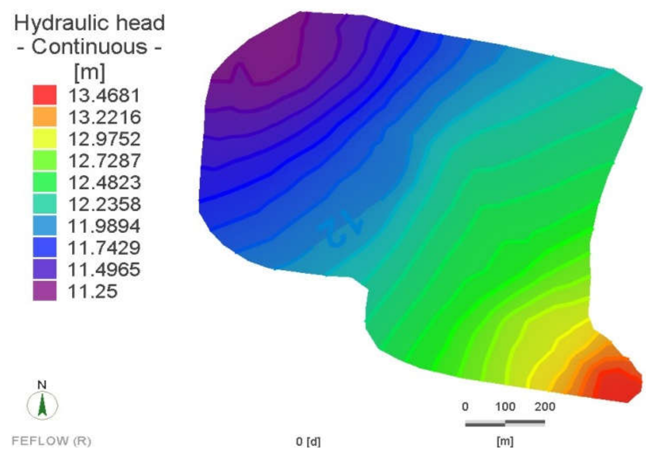

Figure 3. Initial groundwater head assigned in the model

Boundary Conditions

Boundary conditions are mathematical statements specifying the dependent variable (head or the derivative of the dependent variable (flux) at the boundaries of the problem domain. Boundary conditions are necessary to define how the site specific model interacts with entire flow system. It occurs at the edges of the active model area and it will make a piece of computer code a site specific model. Boundaries are largely responsible for how flow occurs in the system. The most likely source of error in the groundwater modelling process occurs while defining false boundary conditions. In this study, the head dependent boundary conditions were chosen in the west and eastern side. Other sides of the model boundary were considered as no flow boundary condition. Since, there is no groundwater flow from these sides.

Aquifer Parameters

Aquifer parameters quantitatively describe the physical characteristics of aquifers, aquitards and aquicludes. Hydraulic conductivity is the ability of a porous medium to allow water to flow; L/T. The range is typically between 10^{-5} and 10^{6} m/day. The hydraulic conductivity of 1 m/day was assigned in the model. Specific yield is the volume of water that will drain from a unit volume of unconfined aquifer. This parameter is dimensionless and has a range between 0 and 1. For most geological materials the parameter is less than 0.5. Groundwater pumping locations defined within the model domain and where water is abstracted from an aquifer having units m^3/day. The magnitude of abstraction or injection generally varies with time. The rate of groundwater pumping from 8 different wells was collected by field investigation of pumping test. Groundwater recharge is taken from the rainfall in Sathankulam area. For the purpose of calculating groundwater recharge, 10% of rainfall was considered to recharge into ground (GEC, 1997) based on the geological formation.

Initial groundwater head

The groundwater head during the year June 2009 was taken as initial groundwater head. The groundwater head from the 8 different pumping wells was interpolated to the full study area using AKIMA linear interpolation techniques. Initial groundwater head assigned to the model is shown in Figure 3. It varies from 11.2 m bgl in the western side to 13.5 bgl in eastern side.

Model Calibration

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria.

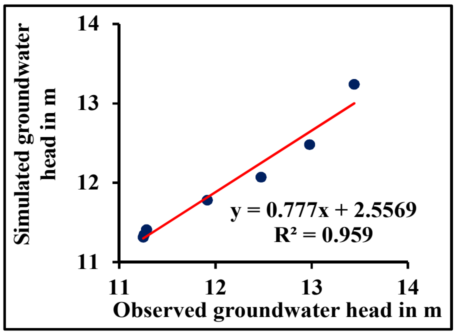

Figure 4. Simulated and observed groundwater head

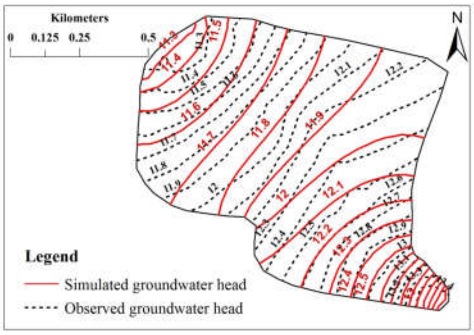

Figure 5. Observed and simulated groundwater head at steady state calibration

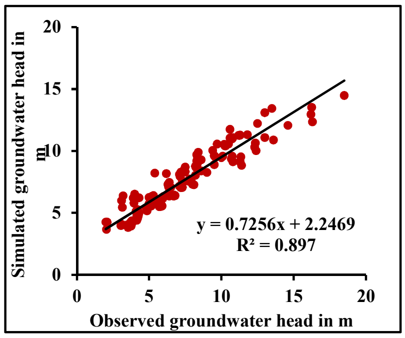

Figure 6. Transient state calibration results

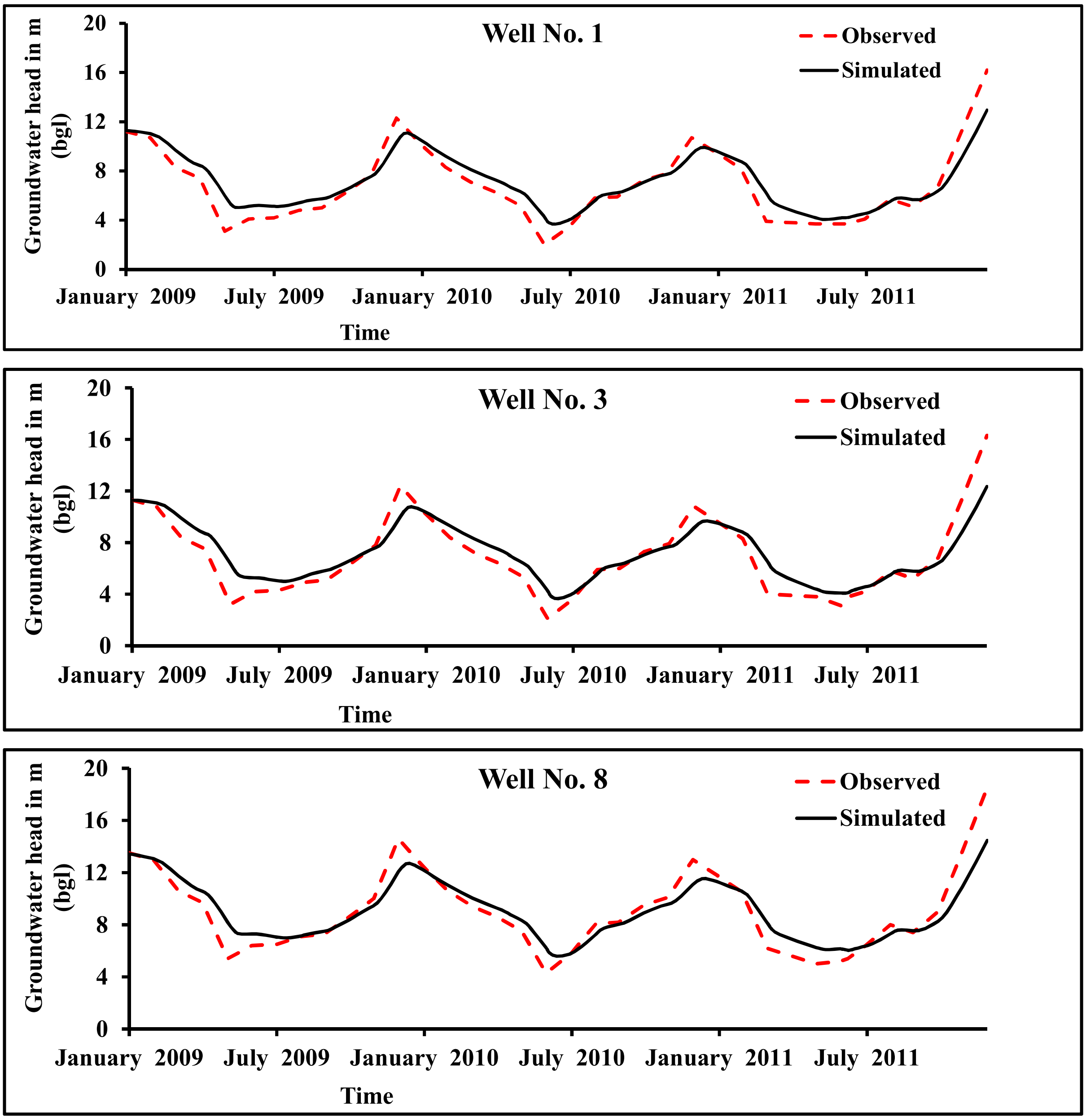

Figure 7 Observed and simulated groundwater head in transient state calibration

This requires that field conditions at a site be properly characterized. Lack of proper site characterization may result in a model that is calibrated to a set of conditions which are not representative of actual field conditions. The calibration process typically involves calibrating to steady state and transient conditions. With steady-state simulations, there are no observed changes in hydraulic head or contaminant concentration with time for the field conditions being modelled. In this model, steady state calibration was carried out for the period of June 2009. In order to match the observed and simulated groundwater head, the aquifer parameters were adjusted within the allowable range and calibrated the model. The calibrated results show maximum match between the observed and simulated groundwater head (Figure 4 and 5)

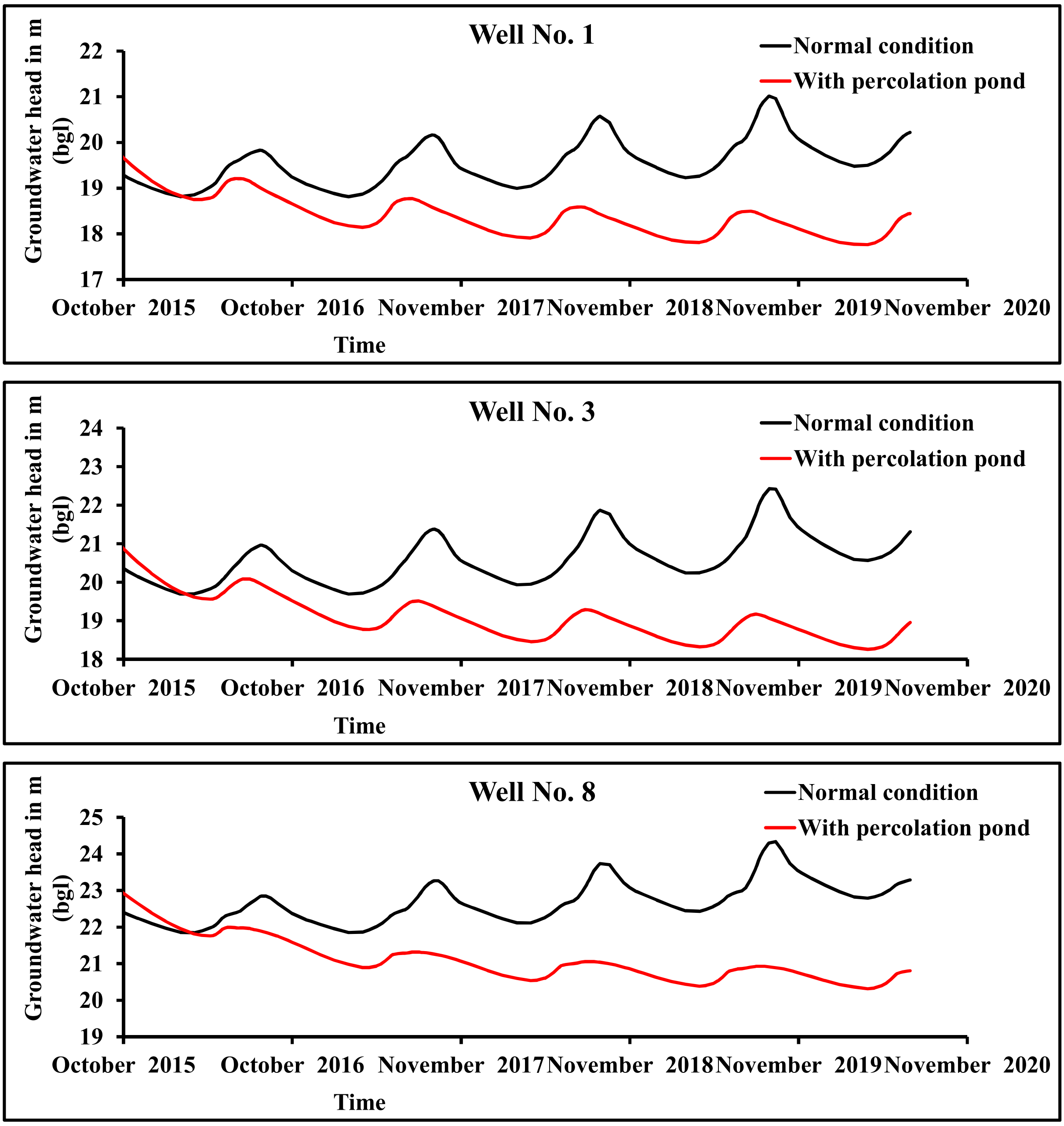

Figure 8. Predicted groundwater head with normal and artificial recharge structure

Transient state calibration

Transient simulations involve the change in hydraulic head or contaminant concentration with time. These simulations are needed to narrow the range of variability in model input data since there are numerous choices of model input data values which may result in similar steady state. Models may be calibrated without simulating steady state flow conditions, but not without some difficulty. Transient state calibration was carried out from the year June 2009 to December 2012. The observed and simulated groundwater head matched well are shown in Figure 6 and 7

Prediction of Groundwater head with Artificial Recharge Structure

The groundwater head was predicted from the year April 2016 to December 2020. First, the head was predicted with the normal groundwater recharge and pumping condition. In order to increase the groundwater head, one of the artificial recharge structures of percolation pond was implemented and simulated. The results of groundwater head with recharge structure are shown in Figure 8. The groundwater head is increased of about 1.5 m with the implementation of percolation pond.

Conclusion

A study was carried out to assess the groundwater quality parameters such as pH, Hardness, Chloride, Fluoride, Sulphate and Nitrate and the dynamics of groundwater head as simulated using finite element groundwater flow modelling. As per IS 10500 – (2012)Sample nos. 2, 3, 4, 6 and 8 are greater than allowable limit and sample nos 1, 3, 4, 5, 6 and 7 (February 2016) and sample 1, 3, 4, 5, 6, 7 and 8 (March 2016) are greater than allowable limit. Finite element modelling was conceptualized in FEFLOW demo version software. Hydrogeological and aquifer parameter were assigned in the model and it was calibrated under steady and transient state conditions. Steady state calibration was carried with R^2 value of 0.959. Transient state calibration was carried with R^2 value of 0.897. The calibrated model was used to predict with artificial recharge structure of percolation pond. The predicted results show that about 1 m of groundwater head increased by implementation of artificial recharge structure which can improve the groundwater quality too.

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