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ASSESSMENT OF GROUNDWATER FLOW MODEL FOR AN UNCONFINED COASTAL AQUIFER

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ABSTRACT: The groundwater flow modeling for an unconfined coastal aquifer surrounded by saline water bodies plays a significant role in providing the information on direction and magnitude of groundwater flow with respect to seasons and location. The modeling package MODFLOW was employed in the Visual MODFLOW Pro 2009.1 was applied to simulate the steady state run for Kalpakkam coastal aquifer. The performance of aquifer model was assessed in spatially by using statistical techniques. The steady state simulation was in good agreement with respect to groundwater flow field. The model output results show the groundwater flow was found to follow topography. The model outputs are helps to determine the groundwater flow paths, also helps to delineate the recharge and discharge areas in the Kalpakkam coastal aquifer.

Keywords: hydrogeology; groundwater flow modeling; groundwater velocity; residual analysis

1.INTRODUCTION

To properly assess the hydrologic regimes at sites for waste repositories and other nuclear installations good knowledge in groundwater flow, movement and occurrence is vital for any nuclear installations [1]. For the near surface disposal facilities (NSDF) at Kalpakkam, groundwater pathway has been identified as a predominant scenario for radionuclide release. Hence, understanding of groundwater flow and its direction assumes significance to model radionuclide migration for pre- and post-closure scenario of NSDF site remediation of disposal facilities.

Several researchers have reported on numerical modeling of the unconfined coastal aquifers around the world in last few decades [2-3]. Robinson et al (1999) [3] have carried out a field-scale groundwater model to simulate the near-shore hydrological processes associated with groundwater discharge from an unconfined coastal aquifer. The above model was able to simulate the movement of the near-shore water table, groundwater discharge rates and patterns.

The objective of this study is to establish the groundwater flow velocity and its directions by developing an aquifer model for Kalpakkam site using the Visual MODFLOW Pro Ver.2009.1.This site specific aquifer model helps to understand the hydro dynamics of Kalpakkam and also helps in siting the vital nuclear installations. The paper presents the comparison of the model calculated groundwater heads with field measured groundwater heads through regression plots.

Modeling the groundwater flow system provides insight about the areal distribution of recharge to and discharge from the aquifer system [3]. The paper also attempts to delineate the recharge and discharge areas from the model outputs and also discusses the performance of aquifer model based on statistical techniques.

2. DESCRIPTION OF THE STUDY AREA

2.1 Geography

The study area at Kalpakkam lies between N 80°09’39” to 80°11’06” E longitude ad 12°34’49” to 12°32’14” N latitude. It is situated nearly 75km south of Chennai city, the capital of Tamil Nadu, India (Fig.1). The study area is spread over ~ 6.89 km^2. About 17 % of the total area was covered with masonry structures, about 1 % with water bodies [4]. Kalpakkam aquifer is surrounded by surface water bodies on its three sides, by Bay of Bengal, Buckingham canal, and Edaiyur backwaters respectively. The Edaiyur backwaters on the north and it link the Buckingham canal on the west are saline and are at mean sea level (MSL). The Fig.1 also shows the location of borewells and pumping wells.

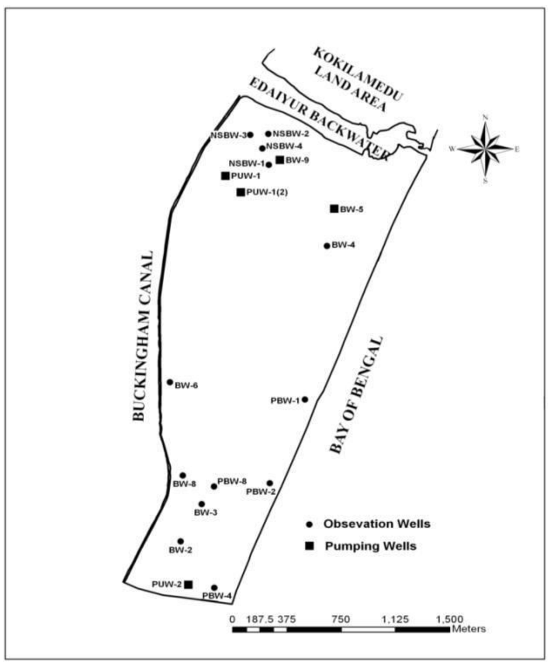

FIGURE 1. KALPAKKAM STUDY AREA

2.2 Geology and Hydrogeology

The Kalpakkam area forms a part of two geological formations peninsular crystalline rocks of Archean age overlain by unconsolidated quaternary/recent formations. The unconfined coastal aquifer is consisting of two layers sand layer is underlain by the weathered Charnockite. Sporadic tiny lenses of clay deposits were observed in the upper sand layer. Charnockite / Hypersthene granite is acting as an impermeable stratum of the aquifer. The depth to bed rock (Charnockite) varies from 12.9 to 46m deepest in the eastern part of the Kalpakkam aquifer [5]. The aquifer constitutes mainly of sand and weathered Charnockite with varying thickness of 3 to 15m [5]. The aquifer hydraulic parameters determined by field investigations [6] are given in Table-1.

TABLE-1 HYDRAULIC PARAMETERS OF KALPAKKAM COASTAL AQUIFER

Layers	Hydraulic Conductivity (m/day)	Specific Yield (Sy)	Effective Porosity
Sand	38.8 to 64	0.26	0.3
Weathered Charnockite	1.2 to 1.4	0.15	0.15

It can be seen from the hydrograph of the study area (Fig.2) that watertable fluctuations are influenced by the rainfall input during monsoon seasons. The hydrograph shows a good correlation between the rise in watertable the amount of rainfall and a month time-lag between rain fall and recharge. The watertable is increasing during September to December and start reducing from January onwards, indicating that recharge is mainly from rainfall infiltration during the monsoon periods [SW monsoon (July to September) and NE monsoon (October to December)]. The annual rainfall in the study area is 1347

± 342 mm (1971-1999). The recharge rate in the study area is reported to be about 19% of the annual rainfall [7].

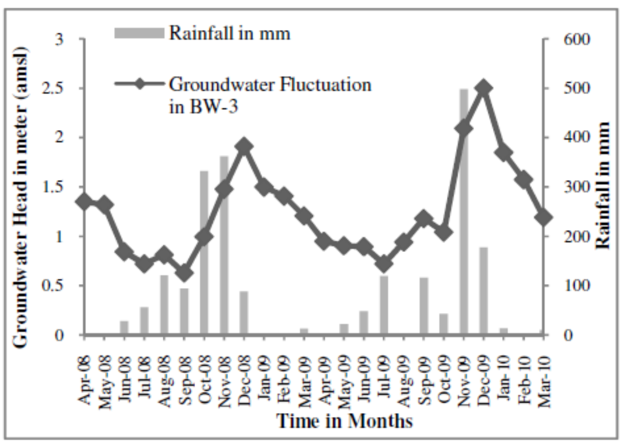

FIGURE 2 HYDROGRAPH FOR A TYPICAL BORE WELL LOCATION AT KALPAKKAM SITE.

3. METHODOLOGY

3.1 Model Development

The groundwater flow model for Kalpakkam unconfined coastal aquifer was develop ed using the MODFLOW-2000 [8], which is one of the modules in Visual MODFLOW Pro version 2009.1. T he simulation for steady state was solved by WHS solv er (Waterloo hydrologic Inc.). The flow chart indicating the methodology adopted is given in Fig.3.

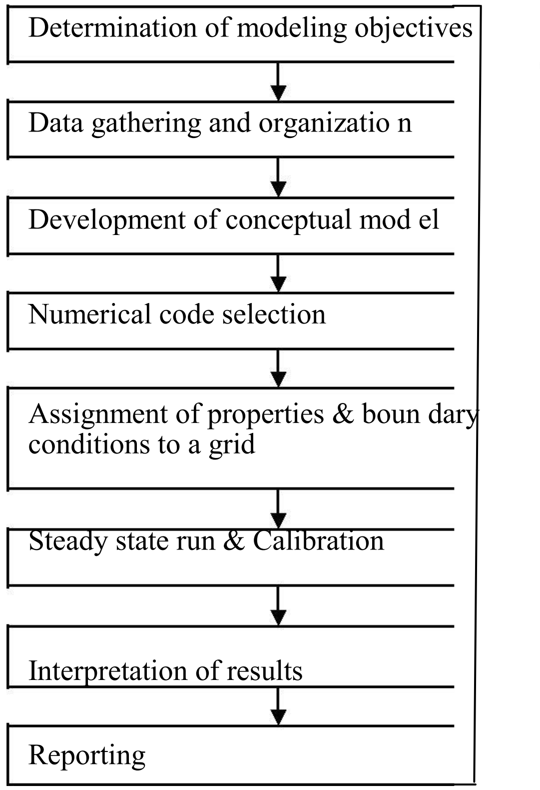

FIGURE 3. FLOW CHART ADOPTE D FOR KALPAKKAM AQUIFER MOD EL

3.2 Grid Design and Boundary Conditions

The study area map was digitized usin g the ArcGIS 9.2 software and imported into Visual MODFLOW as a shape file. The grid discretization was optimized to minimize numerical errors in the flow mo del. Based on the optimum grid size arrived, the model domain was discretized into 80 × 80 grids with cell dimensions of 35 m × 65 m. Further, finer grids were intro duced around the well locations (Fig.4). The figure-4 also shows the boundary condition cells for the Kalpak kam aquifer model. The total thickness aquifer model is 15m, and it is having two distinct layers comprising the 12 m thickness of upper sandy lay er, and 3 m thickness of weathered Charnockite.

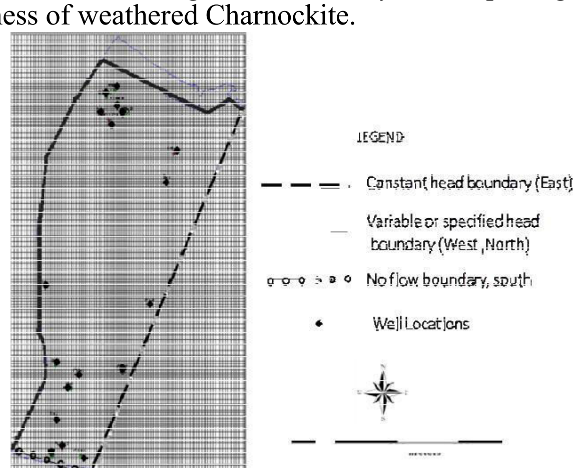

FIGURE 4 GRID DESIGN AND LOCATION OF BOUNDARY CELLS FO R THE KALPAKKAM AQUIFER MODEL

Recharge that is controll ed by the lithology of the subsurface, and therefore ass ociated with conditions of relatively shallow water tables, can be represented by a constant head boundary condition [9]. Constant head boundary condition was assigned on the eastern side of the model domain and 0.096 m (i.e. mean seal level at Kalpakkam) has been chose n as head value [6]. This type of boundary condition reported to be useful for steady state models of regional systems where the position of the watertable ca n be estimated fairly well [9]. More frequently, recharg e is limited to some extent by the amount of infiltration that is available at the land surface solely is dependent o n rainfall, for this situation the boundary condition in a groundwater model is more effectively represented by specifying the recharge flux [9]. Accordingly, specified o r variable head boundary condition was assigned on the western and northern side of the model domain. Based on groundwater divide, 'No flow boundary condition' was assigned in the southern side as well as to the i mpermeable Charnockite formation at the bottom of the aquifer. A uniform recharge boundary condition was assigned on top of the model cells.

3.3 Input Parameters

The groundwater heads for 13 bore wells and 2 open (pumping) wells were measured and recorded once in a month. Generally the water levels are deeper in higher grounds and shallower in t he low-lying areas. The locations of bore wells and pu mping wells are shown in Fig.1. The pumping rate for the above five pumping wells was chosen 25m^3/day during monsoon, and 40m^3/day for post monsoon. The hydrau lic properties viz., hydraulic conductivity, specific yi eld, specific storage, effective porosity were taken from the previous study for the study area [6], and are shown i n Table-1.

3.4 Steady State Simulation

Groundwater heads of December-2008 have been chosen as an initial condition to simulate steady state condition for Kalpakkam aquifer model. The aquifer model was calibrated by varying hydrau lic properties such hydraulic conductivity, and specific yi eld (Table-2) for steady state condition. The calculated groundwater heads were compared with measured field groundwater heads. The regression fits were plotted a nd analyzed. Surfer-9 software was used for mapping the groundwater head.

TABLE-2 CALIBRATION OF KALPAKKAM AQUIFER MODEL

Hydraulic properties	Layer-1		Layer-2	
	Initial	Calibrated	Initial	Calibrated
Hydraulic Conductivity (K, m/d)	38.8	49.83	1.4	1.3
Specific Yield (S_Y)	0.26	0.26	0.15	0.1
Effective porosity	0.3	0.3	0.15	0.15

4. RESULTS AND DISCUSSION

4.1 Steady State Run

Climate, topography and the geologic framework are three main factors that control water flow in the hydrologic landscape [10]. The outputs from steady state simulation (December-2008) for local groundwater flow appeared to follow topography. The groundwater contours are varying between 1.0 and 3.4 m amsl in the study area (Fig.5). The groundwater flow direction for the model is predominantly towards Buck ingham canal in the west and towards Bay of Benga l in the east (Fig.5). This was corroborated by a sim ilar study by Gnanasundhar and Elango, (2000) which shows a similar groundwater flow pattern for a coastal aquifer near Chennai city. The variability of the l ow and high topography and geologic framework wit hin the flow system causes different controls to operat e in different regions [9]. The recharge areas predomi nantly in the higher topography comprise of sandy soil in the eastern regions and discharge area in the low topography comprise of lenses of clay and clayey sand in the western region (Fig.5).

The regression plot between observed and calculated heads for steady state flow is shown in Fig.6. The regression plot shows a good correlation co-efficient of 0.91 and the root mean square error (RMSE) of 0.57 m for simulated groundwater heads, indicating a satisfactory model formulation for steady state flow.

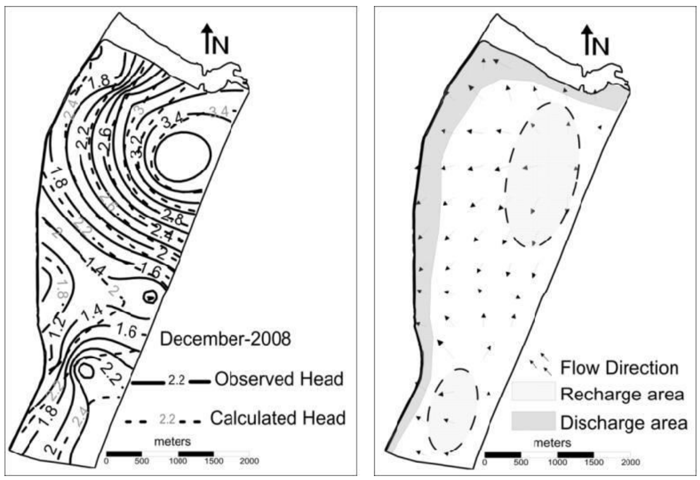

FIGURE 5. GROUNDWATER FLOW MAP FOR STEADY STATE SIMULAT ION (DECEMBER-2008) AND RECHARGE, AND DISCHARGE AREAS FOR STUDY AREA

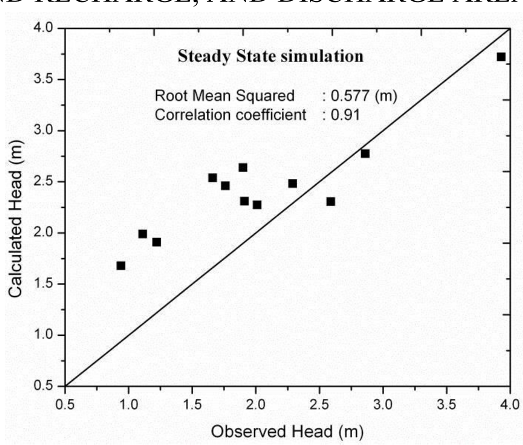

FIGURE 6. REGRESSION PLOT FOR STEADY STATE SIM ULATION

4.2 Groundwater Velocity

Computation of groun dwater velocities is an important component of mode ling contaminant transport in the subsurface [7] [11]. The groundwater velocity for different borewells in the recharge and discharge areas were estimated. The arithmeti c mean of model estimated groundwater velocities for above borewells locations were varying between 0.07 ± 0.04 and 0.60 ± 0.36 m/d for study area. Sasidhar (1993) reported groundwater velocity estimations near to the study area by tracer method. The groundwater velocities were varying between 0.03 m/d to 0.08 m/d. It was observed that model estimated groundwater velocities indicate larger range compared to the field measured data [7].

5. CONCLUSION

The unconfined coastal aquifer model was run with steady state conditions and December-2008 was chosen as initial groundwater head. The out put results show the groundwater flow was found to follow topography; the groundwater flow direction is predominantly towards Buckingham canal in the west and towards Bay of Bengal in the east. The model simulation identified north eastern and southern parts as recharge areas and western and northern parts as discharge areas. The arithmetic mean of groundwater velocities was varying between 0.07 ± 0.04 to 0.6 ± 0.36 m/d for the study period.

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