Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2015, 7(1):298-306

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Study of impact on developed groundwater system around flow fields by using numerical approach in Purulia District

Pramita Debsarkar, Pankaj Kumar Roy*, Gourab Banerjee and Asis Mazumdar

School of Water Resources Engineering, Jadavpur University, Kolkata, India

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ABSTRACT

Seasonal variations of river stage, infiltration through rainfall, influence of pumping or recharging wells can lead to change of groundwater flow fields in an aquifer stream flow system. The aquifer stream water interaction system depends on several factors such as location, geometry elevation and physical setting and other inherent properties. In this present work collected data such as location by latitude and longitude, slope of the field, pumping rate etc. are used to develop the programming. The outputs of the programming are further developed by MATLAB to get the contour and 3D image of the flow field. The ground water flow field of that bounded area is to be changed due to impact of water withdrawal during pumping and slope variation. In this model recharge, soil properties such as storativity, hydraulic conductivity etc. is not considered. The contour map and 3D view model have been developed using numerical approach to show the variation of ground water flow field under the steady state and homogeneous condition.

Keywords: Finite Difference Method, Contour view, 3D view, groundwater system

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INTRODUCTION

Ground water is a precious and the most widely distributed resource of the earth and unlike any other mineral resource, it gets its annual replenishment from the meteoric precipitation. The pervasive and seemingly abundant supply of groundwater has led to its indiscriminate and sometimes excessive use. However, this use can have diverse and often wide ranging effects on the local and regional hydrology and ecology. These interdisciplinary aspects of groundwater utilization have brought into question the concept of safe yield, defined as the maintenance of a long-term balance between the amount of withdrawal and the amount of recharge [1]. Thus, the issue of groundwater sustainability has arisen [2].

The management of the groundwater resources is a challenging task worldwide against the backdrop of the growing water demand for industrial, agricultural, and domestic uses and shrinking resources. Singh [3] simulate modeling applications used for the management of groundwater resources. Groundwater resources are also essential to underpin the daily life of communities in remote regions. Hydro geological studies in these areas are complex, largely due to the absence of long water table records and to the difficulties involved in accessing some relevant locations. Rodriguez et.al [4] used numerical groundwater models to explore groundwater resources in desert areas. Modeling results suggest that the aquifer has been depleted by almost 30% due to groundwater extractions in less than 50 years. The average drawdown was found to be in the order of three meters. This corresponds to a total depletion in the order of 20–60 Mm^3.

The use of groundwater flow models is prevalent in the field of environmental hydrogeology. Yang et al [5] developed models have to investigate a wide variety of hydrogeological conditions. Recently, groundwater models have been applied to predict the fate and transport of contaminants for risk evaluation purposes. The model results help to identify the aquifer properties and to analyze the groundwater flow dynamics, the changes of groundwater levels, in addition, the improvement of the groundwater level monitoring network will be proposed through the analysis of groundwater levels. The calibrated transient model will be used later to predict the impacts of water resources management schemes on groundwater in the study area. Nguyen et.al [6] clarified the groundwater flow system in Tay Island, southwest Vietnam using 3-D groundwater simulation, together with a consideration of the subsurface hydrogeological setting, location of rivers/canals, and affected by seasonal changes especially by flood water during the rainy season. Moreover, groundwater pumping with a rate of 83600 m^3 per day in the dry season is considered one of the main factors which affect changes in the rate of groundwater pumping. Groundwater simulation results show that the groundwater flow system is strongly groundwater table through the dry and rainy seasons, at various locales on the Island.

Trowsdale et al [7] analyzed a simple modeling approach which was developed to link patterns of urban land-use with ground water flow and chemistry in three dimensions and was applied to characterize the origin of recharge in the aquifer beneath the old industrial city of Nottingham, UK. Piccinni et al [8] described the groundwater flow and its relation to slope deformation in order to simulate the effect of possible drainage measures both on piezometric levels and expected displacement rates. Timing and magnitude of piezometric responses at different depths are related to observed deformations and used to calibrate a transient 3D groundwater flow model.

In view of worldwide concern for the sustainability of groundwater resources, basin-wide modeling of groundwater flow is essential for the efficient planning and management of groundwater resources in a groundwater basin. Mohanty et al [9] evaluated the performance of finite difference-based numerical model MODFLOW and the artificial neural network (ANN) model developed in simulating groundwater levels in an alluvial aquifer system. Szekely [10] used the iterative composite mesh simulation (CMS) technique for a coupled system of point centered finite difference groundwater flow models. Kollet et al [11] described the interactions between surface and groundwater is a key component of the hydrologic budget on the watershed scale. Xu et al [12] estimated of groundwater recharge and discharge through evapotranspiration for sustainable water resources management in shallow water table areas by Soil-Water-Atmosphere-Plant (SWAP) Package in Hetao Irrigation District, upper Yellow River basin of North China. (SWAP) package was integrated into a groundwater flow model (MODFLOW) in such a way that the SWAP package calculates vertical flux for MODFLOW, while MODFLOW provides averaged water table depth to determine the bottom boundary condition for SWAP zones. Roy et al [13] developed a hypothetical aquifer stream water interaction system at four sites of Purulia District, India by using GMS software.

Bandilla et al [14] introduced a new iterative analytic element method (AEM) algorithm for solving 2D steady state groundwater flow models containing large numbers of head specified elements. Hardyanto et al [15] developed a three dimensional finite element groundwater model for density dependent flow and transport through saturated and unsaturated porous media into account uncertainty modeling by means of Latin Hyber cube sampling using a restricted pairing algorithm. The objective of present work is to develop contour image as well as 3D view of ground water flow field model by numerical approaches. The flow is in steady state condition and soil properties are homogeneous. It is a hypothetical model to show the impact of ground water flow field after withdrawal of the water during pumping stage.

EXPERIMENTAL SECTION

Study area

Purulia is one of the drought prone districts of West Bengal. It has a sub-tropical climate nature and is characterized by high evaporation and low precipitation. The increasing demand of water for irrigation, domestic and industrial use to make water deficiency in this district and thus tremendous pressure occur on the ground water. Therefore it is very important to make future water security plan for sustainable withdrawal of ground water.

The total study area is 2.85 sq.m. The area is bounded by the latitude 23.3912^{0}N, 23.3917^{0}N, 23.3766^{0}N, 23.3773^{0}N and longitude 86.1815^{0}E, 86.1976^{0}E, 86.1810^{0}E, 86.1990^{0}E (figure 1).

Digital computer models

With the widespread availability of digital computers has come the development of mathematical models of aquifer. Applications are expanding programming techniques are steadily improving and computer capabilities are growing so that it is safe to say that almost any type of groundwater situation can be studied by means of a digital computer model. Finite difference method is one of the methods which is well developed. This Finite Difference method is a computational procedure based on dividing an aquifer into a grid and analyzing the flows associated within a single zone of the aquifer.

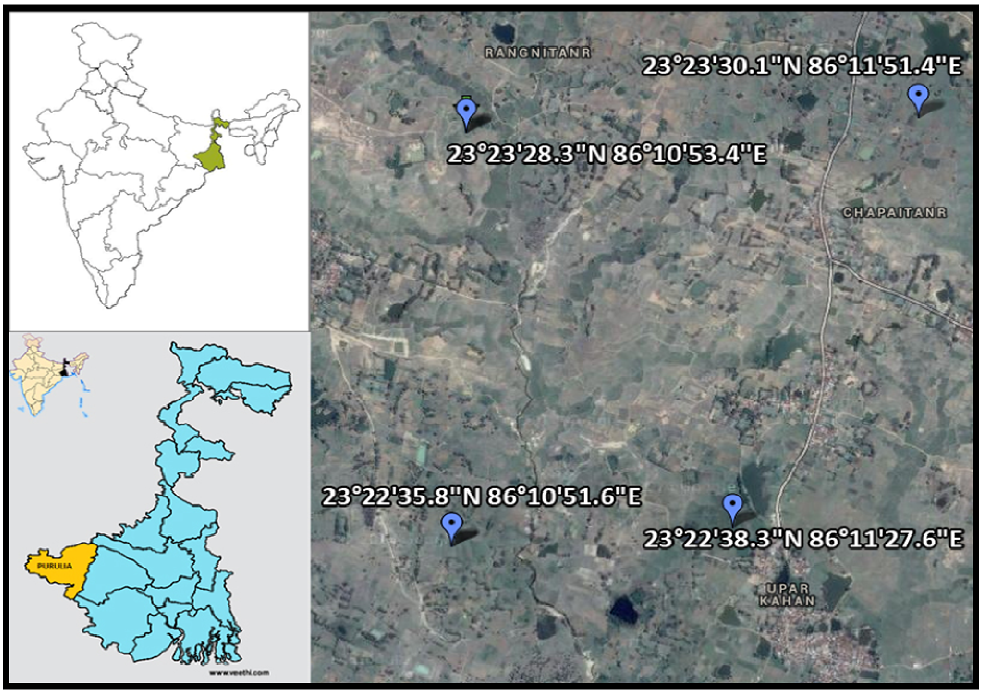

Figure 1 Locating Study Area

Finite – Diference Method

This method is a computational procedure based on dividing an aquifer into a grid and analyzing the flows associated within a single zone of the aquifer. The flow equation is based on the equation of continuity.

Inflow – outflow = change of storage

Modelling of ground water flow

Groundwater modelling begins with a conceptual understanding of the physical problem. The next step in modelling is translating the physical system into mathematical terms. In general, the results are the familiar groundwater flow equation and transport equations. The governing flow equation for three-dimensional saturated flow in saturated porous media is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-Q=S_s\frac{\partial h}{\partial t}$$

Where,

K_{xx}, K_{yy}, K_{zz} = hydraulic conductivity along the *x,y,z* axes which are assumedto be parallel to the major axes of hydraulic conductivity;

h= piezometric head;

Q= volumetric flux per unit volume representing source/sink terms, where negative values are extractions and positive values are injections.

S_s= specific storage coefficient defined as the volume of water releasedfrom storage per unit change in head per unit volume of porousmaterial.

For steady flow condition the right side of the equation reduces zero (flow remain constant with respect to time).
For homogeneous and isotropic condition the hydraulic conductivity will be same.

For steady flow, homogeneous and isotropic condition the two-dimensional equation is:

$$\frac{\partial}{\partial x}\left(\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial h}{\partial y}\right) - Q = 0$$

Numerical Solution

The finite difference approximation (figure 2) to the Laplace equation in two dimensions as follows:

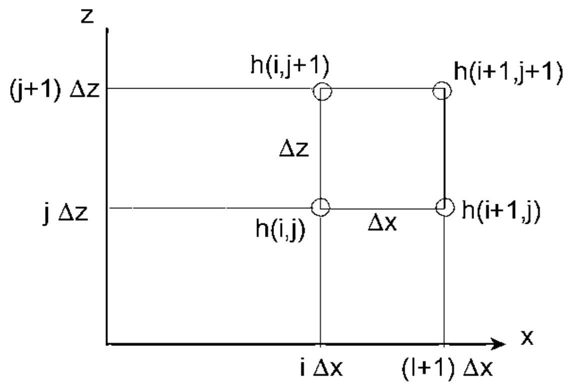

Figure 2. Nodal Configuration or grid approach

A central difference approximation to the second derivatives yields:

$$\frac{\partial^2 h}{\partial x^2} \approx \frac{h_{i-1,j} - 2h_{i,j} + h_{i+1,j}}{(\Delta x)^2}$$

$$\frac{\partial^2 h}{\partial z^2} \approx \frac{h_{i,j-1} - 2h_{i,j} + h_{i,j+1}}{(\Delta z)^2}$$

The numerical approximation to Laplace's equation simplifies to:

$$h_{i,j} = \frac{h_{i-1,j} + h_{i,j-1} + h_{i+1,j} + h_{i,j+1}}{4}$$

The above equation is often referred to as a five-point operator, moved throughout the domain of the problem, as shown below. It is practical to solve this equation using an iterative method.

The numerical approximation to Laplace's equation simplifies to:

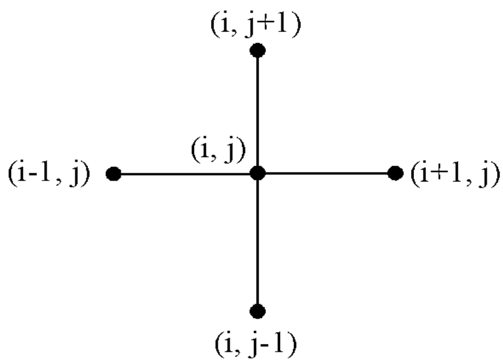

Figure 3. Gauss-Seidel Iteration

Gauss-Seidel iteration (figure 3) is a special case of Successive Over-Relaxation (SOR), and it uses two initial guesses in the trial and error method, iterating until convergence is reached. In the equation below *m* is the iteration level

$$h_{i,j}^{m+1} = \frac{h_{i-1,j}^{m+1} + h_{i,j-1}^{m+1} + h_{i+1,j}^{m} + h_{i,j+1}^{m}}{4}$$

Note that at the current iteration level, $m+1$, two of the nodes on the RHS of use the head values computed at the previous iteration level m. A computer program using this technique and results of its application are presented later.

Analytical Solution
The Laplace equation is an elliptic equation [16] presents an analytical solution:

$$h(x,y) = z_0 + \frac{cs}{2} + \frac{4cs}{\pi^2}\sum_{m=0}^{\infty}\left\{\frac{\cos[(2m+1)\pi x/s]\cosh[(2m+1)\pi z/s]}{(2m+1)^2\cosh[(2m+1)\pi z_0/s]}\right\}$$

COLLECTED DATA AND ANALYSIS
Four tubewells located at different points mentioned in Table 1 have been considered at field condition.

Table 1. Position of Tubewell and Static Water Table

No.	Latitude	Longitude	Depth of Water Table
1.	23.3912°	86.1815°	7.50 m
2.	23.3766°	86.1810°	6.9 m
3.	23.3917°	86.1976°	6.99 m
4.	23.3773°	86.1990°	8.21 m

Discharge point
Latitude: 23.3747°, Longitude: 86.1950°, Depth of Water Table: 7.40 m
The following assumptions were made for the modeling:
i) The flow is in steady state.
ii)The soil is homogeneous and isotropic
iii) There is no recharge only discharge is considered.

The algorithm can be described as
Initialization:
Set,
Hi (Initial Water Head)
slope (Bed Slope)
W (Discharge)
Dx (Depth of Water table).
Set each variable with an initial value of *h[i][j]* 2D matrix according to boundary condition.

Execution
Repeat steps *for* i = 1 to *mt*-1
Repeat steps *for* j=1 to*nt*-1
Set, *h[i][j] = slop* * (i+j) * *(Dx/1000)* + *h[i][j]*. [Setting the Slope]
h[xw][yw] = h[xw][yw] ±*w*. [Here *xw, yw* is the co-ordinate of Recharge/Discharge]

Search for a feasible data and minimize the error, Oldval stores the previous data and negligible error rate set to less than *0.001* as *amax.*

Repeat step *for* i = 1 to*mt*-1
Repeat steps *for* j=1 to*nt*-1
Set, *Oldval = h[i][j]&h[i][j]= (h[i+1][j]+h[i-1][j]+h[i][j+1]+h[i][j-1])/4.*
To calculate and normalize error set,*err = h[i][j] – Oldval.*
If(*err >amax*)
Set, amax = err.
If(amax> 0.001)
Break;
Else,
Continue;

Show and Save the data

Main dataset is stored as a 2D matrix form in *h[i][j]* but to show the changes in respect to time iterate the Step 2 according to our need and store in a text file in permanent storage.

RESULTS AND DISCUSSION

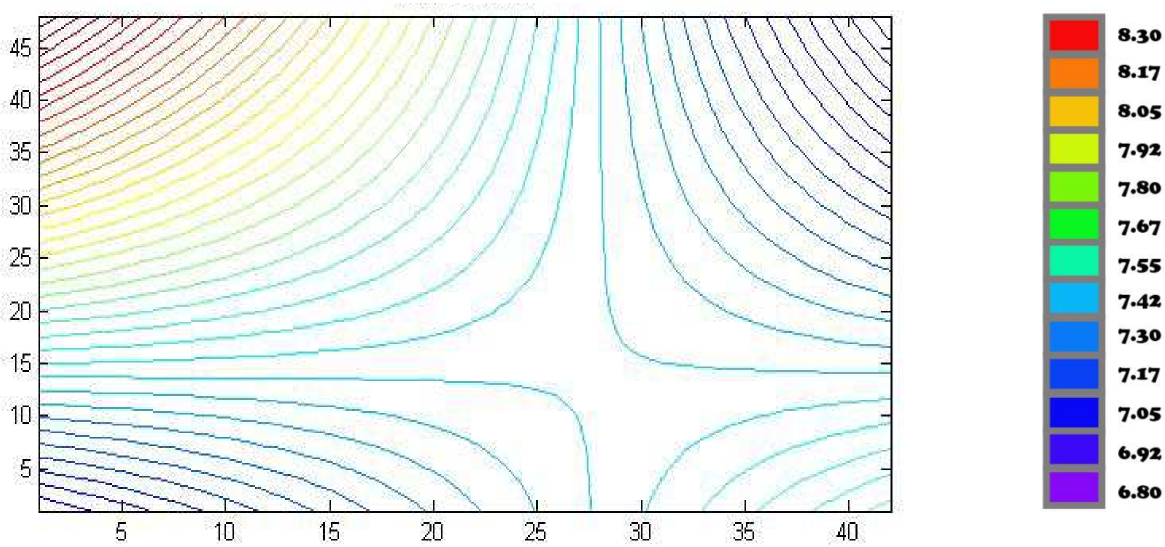

Figure 4. Contour image for initial condition

The above figure represent contour image for initial condition. The colour bar diagram represents the various water depth of the flow field.

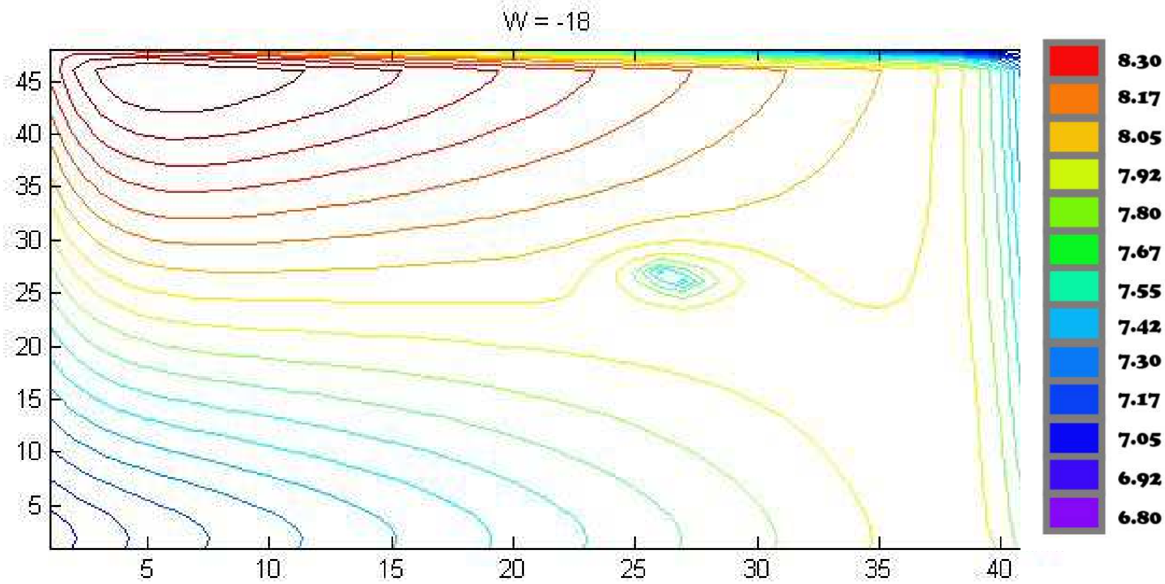

Figure 5: Contour image for 18 m^3/hr. discharge

The above figure (figure 5) represents contour image of ground water flow field after 18 m^3/hr. discharge during pumping test.

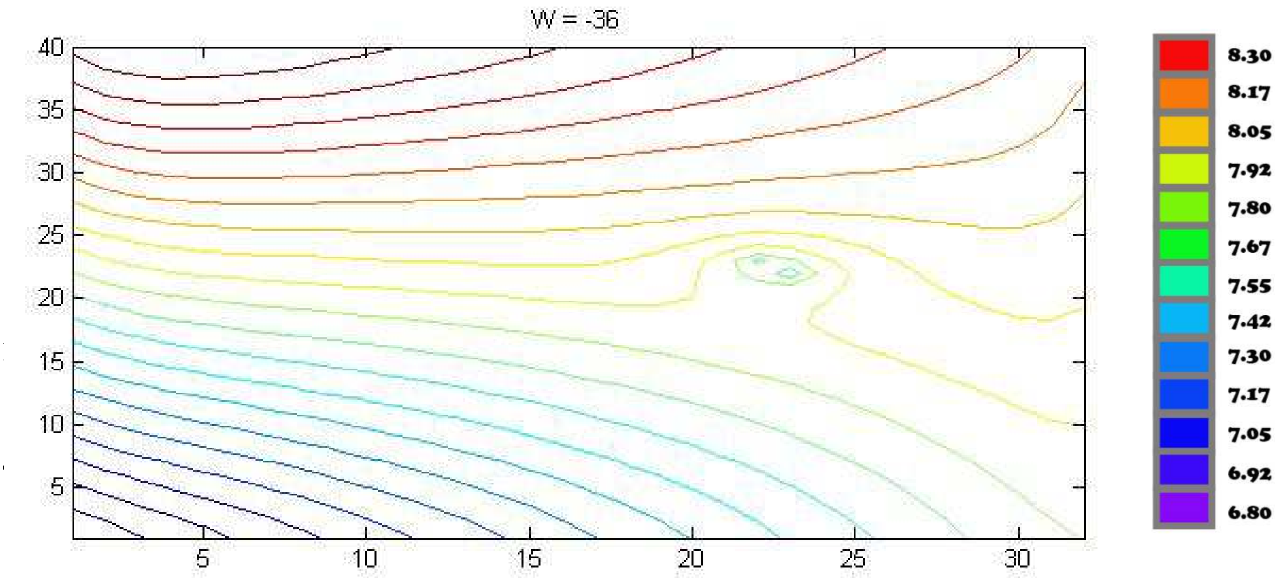

Figure 6. Contour image for 18 m^3/hr. discharge

The above figure (figure 6) represents contour image of ground water flow field after 36 m^3/hr. discharge during pumping test. Figure 7 depicts the initial condition of groundwater flow.

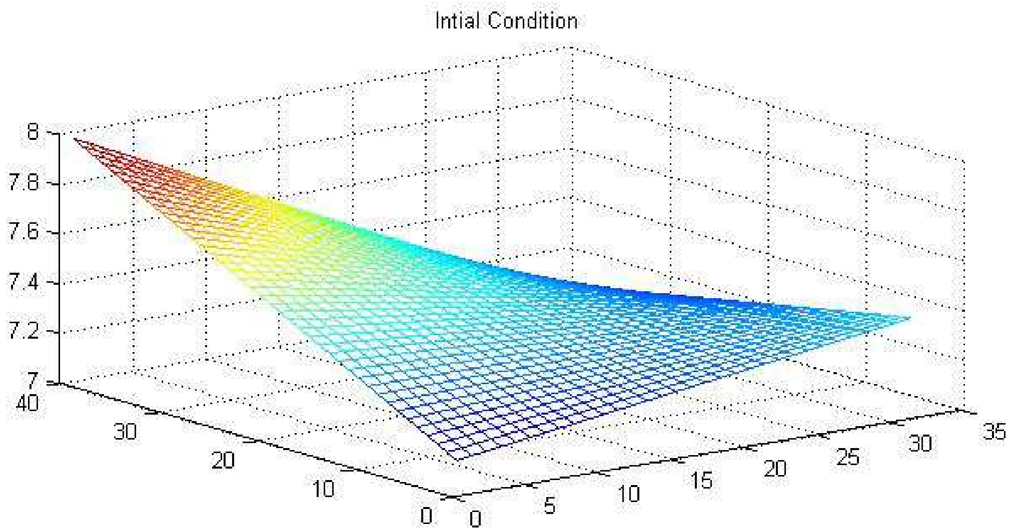

Figure 7. 3D image for initial condition

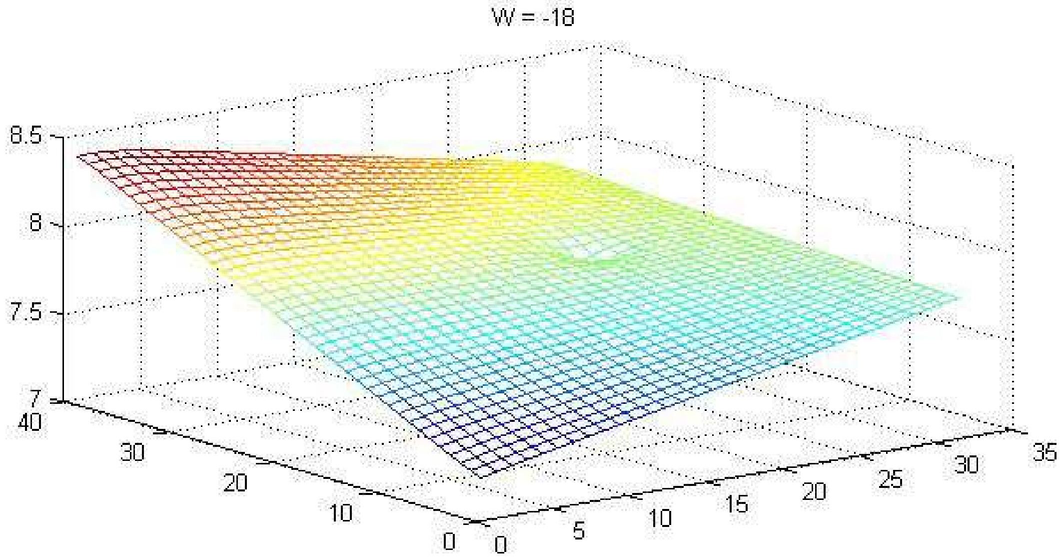

Figure 8. 3D image of ground water flow field after 18 m^3/hr. of pumping rate

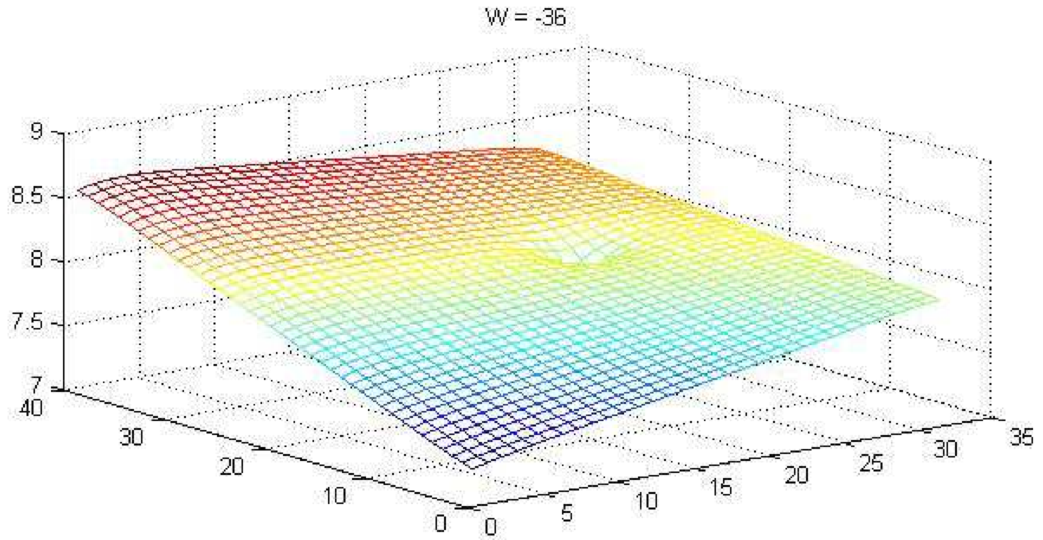

Figure 9. 3D image of ground water flow field after 36 m^3/hr. of pumping rate

The above figures represent the 3D image of ground water flow field in initial state, for pumping rate of 18 m^3/hr and for pumping rate of 36 m^3/hr respectively. Compare (figure 8) and (figure 9) the depression is to be increased due to increase in pumping rate and depth of water also be changed.

CONCLUSION

Here the study tries to build up a 3D model as well as contour view of ground water system due to withdrawal of ground water and slope variation of the flow field. So that in near future it will help to make water security plan for sustainable withdrawal. But it is a hypothetical model. It is not an accurate model but just to understand the effect of ground water due to withdrawal of water during pumping operation. To get the accurate model large numbers of data are required as input parameters and also GMS software can be used to get the correct representation.

Acknowledgement
This works is supported by the School of Water Resource and Hydraulics Engineering of Jadavpur University Kolkata.

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