Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

ISSN NO. 2320-5407

RESEARCH ARTICLE

Source and Impact assessment of artificial recharge in water scarce interfaced multi-formation

Dr. P. K. Majumdar and Dr. S. Ram
Former Scientist and Senior Research Assistant
National Institute of Hydrology, Roorkee, Uttarakhand, India, 247667
Email: patmajum@yahoo.com

Manuscript Info

Manuscript History:

Received: 13 May 2013
Final Accepted: 20 May 2013
Published Online: June 2013

Abstract

Numerical modeling of groundwater flow in two interfaced geological settings of consolidated and unconsolidated formations; with integrated basin management in the background is usually not in practice. Therefore in the present paper, analyses of groundwater flow in such hydro-geological settings of Limbdi Bhogavo basin are carried out, using VISUALMODFLOW interface of USGS code MODFLOW. Prospects of artificial recharge are investigated in respect of source allocation and impact assessment.

Introduction

Saurashtra region in the state of Gujarat in India is an independent hydrologic unit having an areal extent of 48935 sq km, mainly surrounded by Arabian Sea (Figure 1). The Gulfs of Khambhat and Kuchchh separate it from the main land of Gujarat. Runoff from this peninsula drains off to sea or to these saline depressions. Geologically, it is an independent structural block consisting of many faults. Major rivers of the region are following the fracture trends in Sand stone and Deccan Trap, which cover about 5% and 60% of the area and rest 35% is covered by alluvium. Normal average precipitation in the region is around 550 mm, with runoff coefficient varies from 0.2 to 0.4 (Yoganarsimhan and Majumdar, 1990). Long-term depletion of groundwater table is noticed throughout the peninsula. In some places, it is to the extent of 1 m per year. Water scarcity is a routine feature in Saurashtra region, especially in summer months. The area also occasionally suffers from flash floods. Water supply from Sardar Sarovar Project has rescued some of the places; however, complete solution towards water management in the area is yet to be ascertained. A newly conceived project named Kalpasar Project is investigating the possibilities of storing the overland flow draining out to the saline depressions from the mainland of Gujarat and subsequently, supplying it in the much needed areas of Saurashtra.

Limbdi Bhogavo basin in the Surendranagar district is one of the 71 small basins existing in this water scarce region of Saurashtra (Figure 1). Groundwater regimes in all these basins have many similarities. Natural recharge in the basin is generally not sufficient to have necessary improvement in the groundwater table. Water storage structures and percolation tanks are the major source of groundwater recharge. The basin comprising of both hard rock and alluvial formations, very often faces water scarcity situation, with more severe effects in low rainfall years. Rainwater harvesting in such areas can be very effective, provided, proper artificial recharge practices are employed to use protected water from high evaporation losses and surface inundation during flash floods. In the present paper, modeling of groundwater flow and storage in Limbdi-Bhogavo basin is carried out, using USGS code MODFLOW. The main objective of the present modeling study is to develop a flow model to evaluate various possibilities of artificial groundwater recharge. Prospects of artificial recharge are evaluated in hard rock region and the availability of source water is explored in the alluvium formations. This necessitated analyses of groundwater flow in two different multi-aquifer settings of hard rock and alluvium, coupled on an interface. Similar approach can be translated to other basins having similar characteristics as and when required.

Background of the Study Area

Limbdi Bhogavo basin shown in Figure 2 lies between latitude 22^0 19' 11" to 22^0 35' 8" and longitude 71^0 8' 53" to 71^0 56' 30". The total catchment area up to Limbdi-Bhogavo III dam site comes out to be 1103 sq km. The catchment of Limbdi-Bhogavo II (LB-II) dam site is 612.94 sq km, out of which 341.87 sq km area is intercepted by other storage structures like Limbdi-Bhogavo I (LB-I), Nimbahani, Morshal and 4 minor irrigation tanks. Highest elevation in the catchment is located in 'Chotila' at around R. L. 372 m above mean sea level (amsl). Average ground slope towards LB-I dam site of the basin is about 1 in 250 and average run-off coefficient as considered in Shah and Patel (1997) is 28%.

Monthly rainfall (1961 to 2000) values at a location 'Sayla' are shown in Table 1. It shows that major proportion of rainfall occurs during the months from June to September. Average annual precipitation for thirty-seven year data comes out to be 444 mm with a coefficient of variation 0.44. Average annual precipitation and to a large extent its yearly variation, indicate frequent water scarcity scenarios existing in the region. An annual evaporation loss of 2746 mm is contributing additional problems towards water management of the region. Fitting of monthly precipitation and corresponding evaporation loss for the years 1999-2000, as shown in Figure 3, indicates that surplus water for overland flow and groundwater percolation is not available in low rainfall years. Prospects are better in good rainfall years like 1982 and 1997. However, in these years, the surplus water occurs mostly in abundance of flash floods and majority of which get released as waste to save storage structures. History of gauge records (1982-1988) in Limbdi station also shows minimum intermittent flow in the river. In such hydrological scenario, modeling with monthly time step may not be suitable.

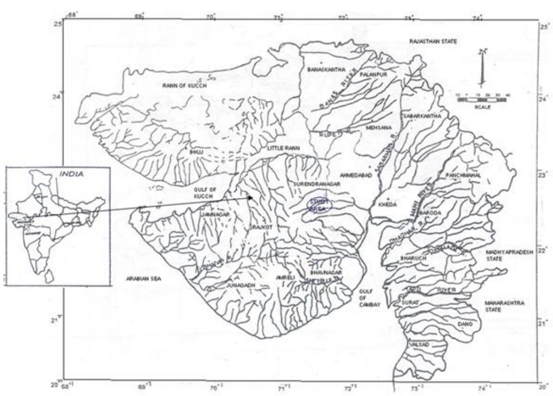


Figure 1 Location map of the study area

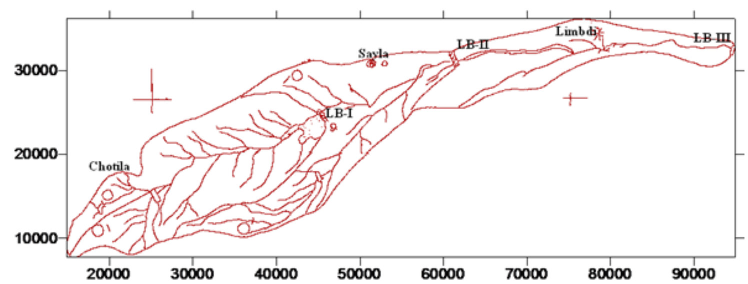


Figure 2 Basin map of the study area

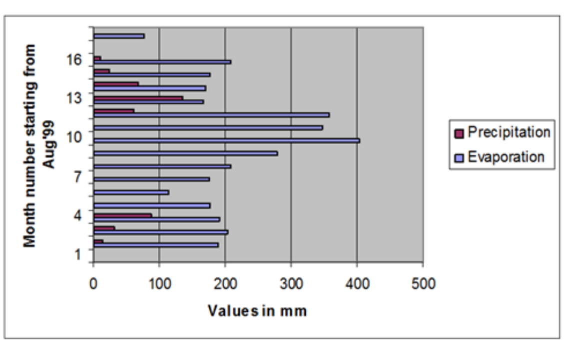


Figure 3 Monthly rainfall and evaporation values in the study area

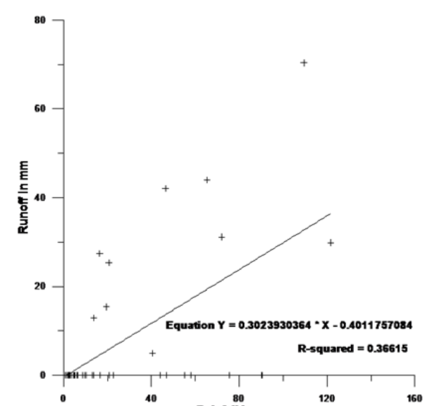


Figure 4 Regional lumped water balance in SCS analysis

Table 1 Annual and Monthly Rainfall pattern (mm) in Sayla location of Limbdi-Bhogavo basin

Sl.No	Rainfall Year	Months							Annual RainFall
		May	June	July	August	Sept	October	Nov-Apr	
1	1961		55.9	169.9	99.1	53.3			378.2
2	1962	17.8	12.0	48.4	127.0	138.1			343.3
3	1963		15.3	82.5	104.4	130.3	62.2		394.0
4	1964		71.1	217.8	81.2	123.3			493.4
5	1965			375.0	48.0				423.0
6	1966		15.0	172.5	25.0				212.5
7	1967		165.0	185.0		20.0		Dec-23.5	393.5
8	1968			103.0	138.0	55.0			296.0
9	1969		60.0	90.0	30.0				180.0
10	1970		58.0	86.0	447.5	285.0			876.5
11	1971-1973	Data not available							
12	1974	23.0	19.0	59.0	79.0	73.0	29.0		282.0
13	1975		141.0	51.0	149.0	100.0	37.0		478.0
14	1976		103.0	175.0	111.0	36.0		Nov-59.0	484.0
15	1977		217.0	181.0	62.0	96.0		Nov-8.0	564.0
16	1978		29.0	73.0	223.0				325.0
17	1979		90.0	57.0	525.0	11.0		Nov-108	791.0
18	1980		294.0	84.0	16.0	100.0		2.0/5.0	501.0
19	1981		138.0	225.0	186.0				549.0
20	1982			275.4	300.0		17.0	Nov-252	844.4
21	1983		55.0	235.0	141.0	104.0	3.0		538.0
22	1984			40.0	111.0	49.0			200.0
23	1985			88.5	33.0	10.0	170.0		301.5
24	1986		168.0	2.0	98.0				269.0
25	1987		119.0	7.0	28.0	6.0			160.0
26	1988		24.0	301.0	173.0	164.0	16.0		678.0
27	1989		35.0	516.0	56.0	37.0			644.0
28	1990		5.0	22.0	276.0	45.0	35.0		383.0
29	1991			92.0	36.0	31.0			159.0
30	1992		125.0	266.0	91.0	82.5	15.0		579.5
31	1993		52.0	371.0		88.0	2.0		513.0
32	1994		134.0	167.0	56.0	255.0			612.0
33	1995			279.0	14.0	26.0	3.5		322.5
34	1996		153.0	157.0	49.0	22.0			381.0
35	1997		734.0	23.0	56.0	44.0	7.0		862.0
36	1998		56.0	90.0	114.0	82.0	81.0		411.0
37	1999		75.0	105.0	14.0	31.0	87.0		312.0
38	2000		62.0	135.0	68.0	25.0	10.0		300.0
Average			109.3	151.5	119.0	77.4			444.2

Coefficient of Variation	1.242	0.766	0.972	0.866			0.439

Table 2 Groundwater Potentials of Limbdi-Bhogavo basin in the year 1997 (Source: GWRDC)

Sr No	Details	Values in MCM per year			
		Limbdi	Sayla	Chotila	Total
1	Total groundwater resources	42.82	80.22	71.64	194.68
2	Utilizable groundwater resources	34.26	64.18	57.31	155.75
3	Groundwater draft	21.01	24.61	26.39	72.01
4	Groundwater balance	4.25	29.02	19.61	52.88

Results of the SCS analysis (Figure 4), carried out for ten daily data for the years 1984 to 1987 indicates that 70% of the seasonal rainfall is lost within the basin in terms of mainly evaporation loss and recharge to groundwater. Initial soil moisture comes out to be 0.4 mm and 30% of the seasonal precipitation is found, reaching the catchment outlet as surface runoff. The results of SCS analysis are pertaining to the uninterrupted part of the catchment draining to LB-II reservoir, having minimum soil thickness. Initial soil moisture component may increase in the areas with more soil thickness especially in the upstream side of the basin and in the alluviums, without much affecting the criterion for temporal discretisation.

Geological map of the region in figure 5 shows Sand stones and Shales near Chotila, Basaltic formation underlain by Sand stone near Sayla and alluvium around Limbdi location. Many major faults and shear zones are located in and around the river basin, which may be controlling the groundwater flow regime to possible extent. Thick soil cover is seen in hard rock areas, where as in the alluviums of Limbdi, soil cover is around 0.45 to 0.9 m. Wells located in shear zones of sand stones are found with more yields. In sand stone formations bore wells of 100 to 150 m depth are discharging water at an average rate of 500 lpm. The average values of aquifer parameters in sand stone are observed as transmissivity (T) 10 to 200 m^2/day, permeability (k) 0.2 to 3.0 m/day and specific capacity (S) 0.15 to 1.3 l/s/m. The open wells located in trap aquifers have their yields varying from 50 lpm to 100 lpm.

Average annual rise of water level in Surendranagar district is analyzed as 2.05 m, resulting from an average rainfall of 439.33 mm. However, a long-term depletion of 5 to 13 m is noticed in the region, during last 17 years. Groundwater potentials in Limbdi Bhogavo basin, estimated by Gujarat Water Resources Development Corporation, Gandhinagar, India (GWRDC), in the year 1997, are as shown in Table 2. Poor groundwater quality is noticed in alluviums, whereas, hard rock formations possess more or less good quality of water. There are number of tanks existing in Surendranagar district. They serve dual purposes of surface storage structure and percolation tank in various times of the year.

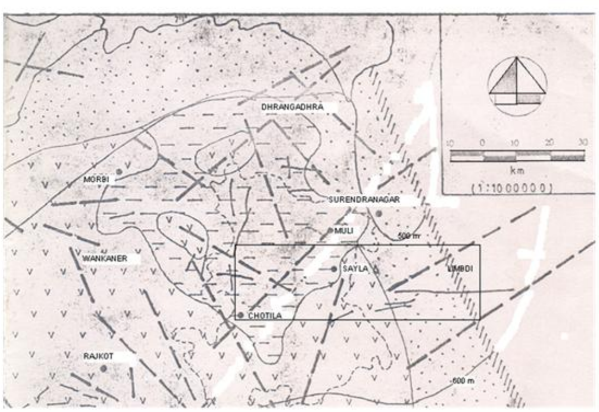


Figure 5 Geological map of the study area (Shah & Patel, 1997)

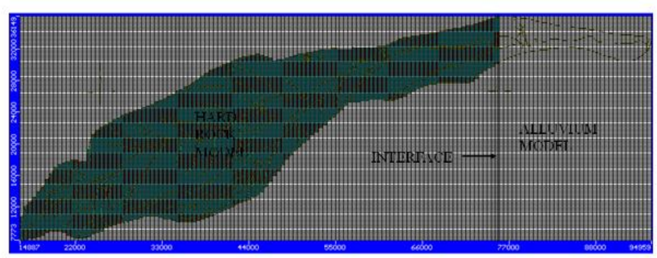


Figure 6 Schematic view of the conceptual model

Statistics of rainfall pattern in table 1, Hydrological water balance scenario of figure 4 and resulting water table fluctuation on long-term basis between 2 to 19 m (Shah and Patel, 1997), indicate that the natural water availability consists of high degree of variability. Prospects of artificial recharge applications in such areas need to be examined with major emphasis on source delineation and safety against loss due to evaporation. The comparative feasibility evaluation of surface and subsurface storage may provide information regarding viable methods of water conservation, especially when evaporation loss is so high.

Model Development

Two independent grids each for hard rock and alluvium with an interface between them have been conceptualized to represent the complex geological configuration in the Limbdi-Bhogavo basin (Figure 6). Both are having equal areal extent of 80270x29376 m^2 divided in to 150x150 numbers of blocks in each layer with different layer configuration and boundary conditions. The present methodology is formulated in view to analyze the different multi-aquifer systems of hard rock and alluvium formations, using VISUALMODFLOW interface. The SCS analysis has suggested the suitable time step to be 10 days for the present modeling study, with the initial time could be the very first day of the seasonal rainfall. Ten-daily stream discharge and reservoir water level records for the year 1997 are generated, assuming that the flow in the river to be intercepted mainly by these storage structures. These are tabulated in Table 3 and utilized for transient model runs.

Hard Rock Model

The grid analyzing the flow regime in an equivalent porous medium representing the hard rock region of the study area is considered to have 3-layered system comprising of soil, weathered and massive rock geology. Layer stratification is decided, based upon the available lithologs in hard rock areas, in and around the study domain. Available log geology supplied by GWRDC, fitted well with the geological map of the region developed by Shah and Patel (1997). Therefore rock zones for Sand stones and Basalt are considered as per the distribution shown in Figure 5. These are incorporated in the middle layer. Bottom layer is included mainly for the purpose of future extension of the model and presently provided with homogeneity in the literature-based value for Massive Basalt. No-flow boundaries are evoked all along the basin boundary; hence all the blocks outside the basin and in the alluvium region are kept inactive (Figure 6). This also makes the multi-layered settings in alluvium inactive in this part of the analysis (Figure 7). Outlet point for the basin is considered at a location 3337 m upstream of Limbdi gauging station. Initial parameter values used for the model calibration are taken from Shah and Patel (1997), supplemented by Moris and Johnson (1967) and are presented in Table 4.

Table 3 Computed ten daily discharges in the Limbdi- Bhogavo River.

Time Ends	Flow D/S LB-I (Cumec)	Flow D/S LB-II (Cumec)	Flow D/S LB-III (Cumec)	LB-I RL (m)	LB-II RL (m)
10-Jun	0	12.06062	29.15939	119.6137	76
20-Jun	0	27.10691	44.20569	120.6918	76
30-Jun	14.84705	27.10691	44.20569	120.9	76
10-Jul	0.701678	0.849399	1.772659	120.9	76
20-Jul	0.701678	0.849399	1.772659	120.9	76
30-Jul	0.701678	0.849399	1.772659	120.9	76
10-Aug	1.551077	2.068102	6.536681	120.9	76
20-Aug	1.551077	2.068102	6.536681	120.9	76
30-Aug	1.551077	2.068102	6.536681	120.9	76
10-Sep	1.772659	1.624938	7.792315	120.9	76
20-Sep	1.772659	1.624938	7.792315	120.9	76
30-Sep	1.772659	1.624938	7.792315	120.9	76

Table 4 Initial and Ultimate Hydraulic Conductivities during Calibration

Layer Item	Porosity (%)	Initial Hydraulic Conductivity (m/sec)			Final Hydraulic Conductivity (m/sec)		
		Kxx	Kyy	Kzz	Kxx	Kyy	Kzz
Soil	30	1.15e-6	1.15e-6	1.15e-7	3.4e-6	3.4e-6	3.4e-7
Weathered Sand Stone	33	2.89e-6	2.89e-6	2.89e-1	5.0e-6	5.0e-6	5.0e-7
Weathered Basalt	25	4.15e-7	4.15e-7	4.15e-8	6.35e-7	6.35e-7	6.35e-8
Massive Basalt	17	1.15e-10	1.15e-10	1.15e-11	1.15e-10	1.15e-10	1.15e-11
Sand	43	2.89e-5	2.89e-5	2.89e-6	2.89e-4	2.89e-4	2.89e-5
Clay	42	2.31e-9	2.31e-9	2.31e-10	2.31e-9	2.31e-9	2.31e-10

Table 5 Fitting of Observed and Computed head values during calibration in hard rocks.

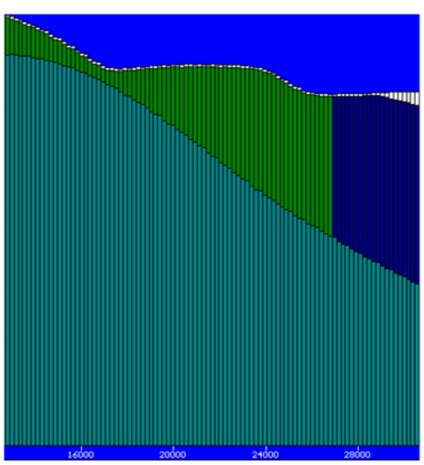
Sr No	Well Location	Formation	Steady State Match	
			Observed	Computed
1	Ughal	Basalt	8.05	7.33
2	Dhandhalpur	Sandstone	10.3	10.8
3	Thoriala	Basalt	5.8	5.74
4	Sudamda	Basalt	15.22	16.07

Table 6 Fitting of Observed and Computed head values during calibration in alluvium.

Sr No	Well Location	Formation	Steady State Match		Transient State Match	
			Observed	Computed	Observed	Computed
1	Limbdi	Alluvium	7.85	7.12	1.60	Flooded
2	Borna	Alluvium	6.5	7.18	3.45	Flooded

Table 7 Ten daily water balance components during transient run

Time	1	2	3	4	5	6	7	8	9	10	11	12
Inter-face (cum)	948	971	994	1016	1064	1088	1111	1135	1158	1182	1205	1205
Out-flow (Mcum)	0.16	0.157	0.155	0.154	0.152	0.15	0.149	0.148	0.147	0.146	0.145	0.144



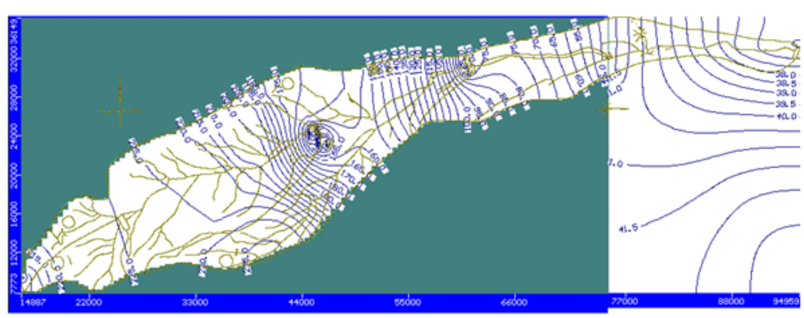


Figure 8 Computed steady state water table contours

Figure 7 Cross-sectional view of the models

The conceptual model is calibrated under steady state condition with constant head conditions at deepest level in Limbdi-Bhogavo-I (LB-I) at R.L. 104.38, Limbdi-Bhogavo-II (LB-II) at R.L. 64.90 m and the tail end of the active model boundary at 41.71 m, conceptualizing this scenario to exist during the month of May in a normal rainfall year. Initial hydraulic conductivity values are varied by trial and error to have pre monsoon head match at selected observation well locations. Ultimate hydraulic conductivity values arrived in calibration run are also reported in Table 4 and comparison of the head values at selected locations are shown in Table 5. Computed steady state water table contours are shown in Figure 8.

The calibrated model is run for transient condition for ten daily time steps for the year 1997. LB-I and LB-II storage dams in the Limbdi-Bhogavo River are activated during the hard rock model transient runs, using the computed values of table 3. Downstream end of the basin is provided with the general head boundary, according to the computed gauge readings at Limbdi gauging station. Initial water table contours plotted for May 1997 are used in this simulation. Recharge from ten daily precipitations is considered to follow Theissen polygon generated for the study area. Rainfall recharge rate of 9% is considered as per the Indian Groundwater Estimation Committee norms (GEC, 1997). Net draft in the study area, as an average, is estimated as 6.88E-5 m/day. Specific yield values considered for soil, weathered sand stone, weathered basalt and massive basalt formations are 21%, 27%, 14% and 7% respectively, under unconfined water table condition (after Johnson, 1967). Water table contours in the middle layer after 10 days and 120 days are shown in Figure 9 and 10 respectively. These are considered as base case scenarios for the evaluation of artificial recharge applications.

On the base case model, artificial recharge options are evaluated in a location 'Panchavda', upstream of 'Morshal', and the results of these trials are compared in Figure 11.

Alluvium Model

The model grid is activated on the right hand side of the interface with finite aquifer boundaries extended up to the model grid boundaries. Limbdi Bhogavo River with 195 m river width and cross-section available at Limbdi gauging station is considered as one of the major source of recharge. Vertically, hydro-geological settings in this part of the model are developed as per the correlations between the available lithologs of 7 locations in the alluvium region of the study domain. Six numbers of layers are introduced accordingly, to represent sequential formations of soil, sand, clay, sand, clay and sand from the top. Sixth layer bottom is assumed to have impervious boundary. Overall 4 aquifers and 2 aquitards are conceptualized in the alluvium model. The hard rock part of the domain is considered as inactive in the alluvium model. Initial hydraulic properties for steady state calibration are given in Table 4. General Head boundary conditions are evoked all along the interface, based on the observation well data of Ughal, Minapur and Vaniavadar locations. Steady state water level computations in 2 selected wells of the alluvium area are calibrated, using pre monsoon observed values in Table 6. Finally arrived hydraulic conductivity values are tabulated in Table 4. Computed water table trends are included in Figure 8.

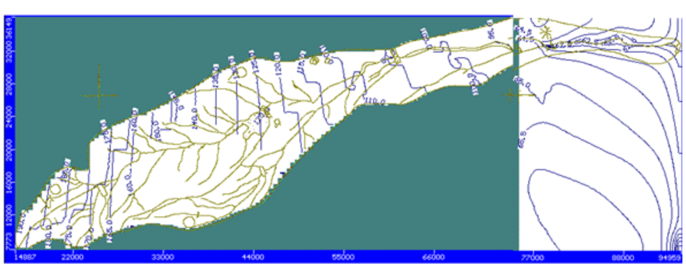


Figure 9 Base case water table condition in middle layer after 10 days

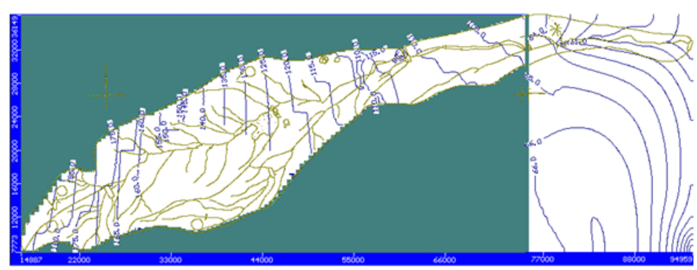


Figure 10 Base case water table condition in the middle layer after 120 days

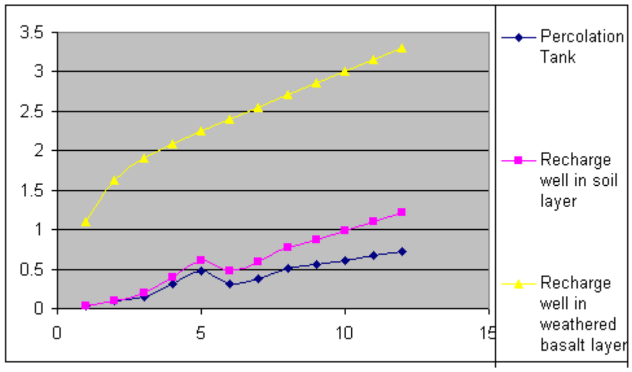


Figure 11 Comparison of temporal Head buildup (m) trends with Artificial Recharge measures

The calibrated model for the alluvium part is also processed for transient run, for ten daily time steps, during a season in the year 1997. Computed ten daily river flow data shown in Table 3 are utilized for the simulation purposes. Specific yield values considered for soil, sand and clay are 21%, 23% and 3% respectively (after Johnson, 1967) in the transient run. Rainfall recharge is considered as 20% of the rainfall occurred in Limbdi station, as per the Indian Groundwater Estimation Committee norms (GEC, 1997). Initial water table condition is introduced as per the observation well data for the month of May 1997. Time dependant general head boundaries are introduced in the interface and also in the eastern boundary. Computed post monsoon water table contours are shown in the alluvial part of Figure 9 and 10. The computed water table condition is in a flooding state and Table 7 indicates the volume of water entering through interface and leaving through eastern boundary each time.

Discussion

The conceptual models for hard rock and alluvium formations are calibrated independently with an interface in between them. Pre monsoon time is assumed to be under steady state condition, as an effect of negligible recharge and discharge potential, and is the time chosen for the calibration. SCS analysis results guided to prefer ten daily time steps for the transient run, with first ten-daily period in the month of June as initial time. Computed water levels in the selected wells of both the formations projected good match with the respective observed values, during calibration. This enhances the scope for generating a base case scenario for a season in the year 1997, a year of flash flood, to evaluate the impacts of artificial recharge options and to estimate available quantity of possible source water draining out to sea. Even in such a formidable rainfall year, artificial recharge requirements are not shaded away in an area lying between Morshal dam and Dhandhalpur in hard rocks. Source of water could be the computed quantity of water as shown in Table 7. Some part of the total quantity of water getting lost due to evaporation can also be saved and used as the source water. Comparison of the effects of percolation tank and recharge well is carried out in hard rock formation. Percolation tank shows development of recharge mound at slower rate as compared to recharge well and follows similar behavior during recession also. The effects shown in case of percolation tank are reciprocal of surface soil/weathered rock infiltration properties, where as in the recharge well, hydraulic conductivity of the rock mass is a predominant factor.

Conclusion

Groundwater flow modelling in a complex domain comprising of different layer settings in hard rock and alluvium formations of Limbdi-Bhogavo basin is conceptualized and the calibrated model is developed using USGS code MODFLOW. Unsteady base case scenarios are generated for the season in year 1997. Artificial recharge prospects are examined in terms of its impact and source evaluation. It is found that the prospects of artificial recharge are bright with plenty of source water could be available in some of the years. Study shows that by accumulating possible quantity of water during flash floods and minimizing evaporation loss, sources of water can be generated. Selection of the type of artificial recharge practice depends upon the purpose of recharged water utilization. Results of the present study could be considered as a sample behavior of the groundwater regime in the peninsula.

References

Groundwater Estimation Committee (GEC), (1997): Groundwater Estimation Methodology. Ministry of Water Resources, Government of India, Report, New Delhi, India.

Johnson, A.I. (1967): Specific Yield-Compilation of specific yields for various materials. U. S. Geological Survey, Water-supply Paper. no. 1662-D.

McDonald, M.G. and Harbaugh, A.W. (1988): A modular three-dimensional finite-difference groundwater flow model. Techniques of Water Resources Investigation, no.6-A1, USGS.

Morris, D.A. and Johnson, A.I. (1967): Summary of hydrologic and physical properties of rock and soil materials. U. S. Geological Survey Water-Supply Paper, no. 1839-D.

Shah, C. R., and Patel, P. P. (1997): Review of Hydrogeology and Water Resources Management Strategy of AKRSP(I) for Surendranagar and Junagadh Districts. Interim Report, Aga Khan Rural Support Programme (India), Ahmedabad, India.

Yoganarsimhan, G. N. and Majumdar, P. K. (1990): Graphic aided design of minor irrigation schemes in Saurashtra region of Gujarat. Navnirman, ,July-December: 38-65.

****