Groundwater investigation and modeling of Buchir-Homeyran Plain, Hormozgan province, Iran

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Buchir-Homeyran plain with a total area of 78.25 KM sq has a catchment area of about 378 KM$^2$ and is located 360 KM west of Bandar Abbas port on the Persian Gulf. This catchment is the extension of the Southern Zagross mountain range covering the western boundary between Iran and its neighboring countries, Turkey and Iraq. The plain lies between 26$^0,57'$ and 27$^0,10'$ latitude and 53$^0,28'$ E 53$^0,49'$ E longitude. Maximum elevation in the catchment is 1470 m in the north western direction and minimum 210 m in the south western corner (a palm growing region). About 10% of the area of the plain is covered with alluvial fan deposits in the northern sector which are expected to contribute greatly to aquifer recharge. Depth of bedrock was estimated to vary between 70 and 125 meters. Out of the total 132 wells constructed in this plain, 99 are actively in operation. About 10% of these wells are used for domestic purposes and the rest for agriculture.

Favorable climate and a long growing season along with productive soils in the region have created increasing desire for agriculture development and hence increased number of requests for water well drilling in the region. Present water supply from these wells amount to about a minimum of 1430 m$^3$/year to a maximum of 530,000 m$^3$/year. Wells operate 186 days/year and have a depth of about 14 to 75 m. In order to respond to the increasing number of well permit requests, groundwater investigation of the Buchir-Homeyran aquifer was initiated using PMWIN 5/ software. Calibration of the model was done under steady and unsteady state conditions using groundwater fluctuation data from 13 scattered observation wells recorded bimonthly from 2001 to 2008. Hydraulic conductivity, specific yield and recharge–discharge estimates were created throughout the region with pest automatic calibrator, local experience and site investigation. Verification of the model made it possible to define a number of groundwater discharge and recharge management scenarios for the region, and investigate the impact of the accomplishment of these scenarios. It was determined based on the findings from this model that in order to keep the water budget balance for this aquifer, current groundwater withdrawal and discharge must be decreased by 20%.

1- Introduction

In Iran groundwater plays an important historical role as a source of water for agricultural and domestic use. Population growth and industrial development have increased the demand for water and at present freshwater resources of the country are under serious threat of shortage.

Total renewable water resources of Iran is about 413 BCM (billion cubic meter), 25 BCM of which infiltrates into soil and 92 BCM joins surface waters. Therefore, of the total rainfall resources 117 BCM is renewable. Total surface water including incoming from bordering countries which is about 13 BCM amount to about 105
BCM. About 41 BCM of the surface water is used and the rest enter the sea, internal water bodies, or leave to neighboring countries. About 18 BCM of the surface water used percolate downwards and join groundwater. Total groundwater recharge is thus about 56 BCM. Total groundwater abstraction on the other hand is about 61.5 BCM which is 5.5 BCM greater than groundwater recharge. This shortage has caused a rapidly declining groundwater table during recent years. The rapidly increasing number of water well development from 1965 to 1993 shown in fig. 1a is a witness to this trend.

Fig. 1a Water well development pace from 1965 to 1993

Fig. 1b Groundwater well abstraction from 1965 to 1993

This chart demonstrates that for the 11 year periods from 1978 to 1989 and 4 year period from 1989 to 1993, the number of water well permits issued for groundwater abstraction in the country have been about equal i.e. 100,000 tube wells. It is important to note that although for the 2 periods the number of wells constructed is the same, the extra withdrawal volume of water for the first period is 16 BCM while for the second period it is only 7 BCM (Fig. 1b). This decline in the withdrawal rate however is indicative of a decline in the aquifer yield due to ground water depletion. (Salehi, Azari. M.) which has been a cause for concern in undertaking this study on the groundwater conditions in Hormozgan Province. Study and investigation of groundwater conditions in a region for management purposes requires a knowledge about aquifer condition and prediction of the effect of abstraction and recharge on groundwater condition, at specified locations. This know
ledge can be acquired by gathering data from numerous exploration wells, performing pumping tests and geophysical measurements for a long period. This approach is lengthy and very expensive. Therefore mathematical models have been favored as a versatile tool and an indirect method for studying groundwater conditions of Buchir–Homeyran sub-catchment in Hormozgan Province and Suggest appropriate management strategies for the future by using Modflow (PMWIN) package.

2- Study area
The Buchir–Homeyran subcatchment is an extension of Southern Zagros mountain ranges with an area of about 378 KM² located 360 KM west of Bandar Abbas port on the coastal line connecting Lenge port to Bushehr port. Geographically It lies between eastern longitudes 53.28 and 53.49 and northerly latitudes 26.57 and 27.10 (Fig. 2). At present yearly abstraction rate of production wells in this region is about 6.573 (MCM). Ninetyfive percent of this withdrawal is used for agriculture and only 5 percent for domestic purposes. This abstraction rate creates 3.1 MCM of overdraft due to uncontrolled pumping or groundwater mining as a result of which a 2 meter drop in the water table level has occurred in the period 2000 to 2002. This abstraction rate creates 3.1 MCM of overdraft due to uncontrolled pumping or groundwater mining as a result of which a 2 meter drop in the water table level has occurred in the period 2000 to 2002.
3- **Data sets**

Hydrological and hydrogeological Data for B-H Catchment was made available through Hormozgan Water Resources Office in Bandar Abbas.

3-1- **Geology**

This catchment is located on the Southern Persian mountain range. Geological and lithological details can be seen on geological map in Reference. Alluvial fan deposits constitute about 10% of the plain area. These alluvial fans are mainly seen on the northern slopes (Buchir heights) and partly on Aghol highlands.

3-2- **Hydrogeology**

According to previous studies based on water table maps, wells and exploration data, the aquifer is unconfined. Geophysical cross sections also do not show extended clay pan layers which can create a confined aquifer.

3-3- **Aquifer thickness**

Aquifer thickness varied from 15-40 m. Medium thickness of aquifer is seen around Ahmad Abad village in the eastern part and around Morady palm garden on the west which have a thickness of about 40-65 m. Greatest aquifer thickness reaching to about 110 meters is seen in the middle of the plain.

3-4- **Bedrock**

Bedrock consists of limestone type deposits. Depth to bedrock is on the average about 70 meters, with a maximum of about 125 meters around the palm garden in the Plain center.
3-5- Hydrodynamic coefficients.
There was no record of pumping test data available. Therefore transmissivity was estimated using hydraulic conductivity measurements on well borings of geologic sections and saturated thickness of the aquifer from geophysical measurements. Maximum transmissivity is seen at the north which is about 3500 sqm/d and the lowest transmissivity which is about 100 sqm/d is around observation well No-8 and 12 towards south west.

3-6- Groundwater abstraction from wells
According to data collected for the year 2003 out of 132 existing wells only 99 were in use. Ninety wells were being used for agriculture and 9 of them for domestic purposes. Maximum abstraction rate was 53000 m3/year at Buchir site and minimum rate was 1430 m3/year for Dastkhair well. Production wells Operate on the average about 186 days per year. Depth of the wells vary between 14 and 75 meters. The total water abstraction for the year 2003 was 4,82,1382 MCM.

Table 1 gives detailed information about the production wells.

<table>
<thead>
<tr>
<th>Year</th>
<th>Season</th>
<th>Agr. Abstraction</th>
<th>Domestic for out of catchment</th>
<th>Domestic for B-H</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seasonal</td>
<td>Total No of wells</td>
<td>Seasonal Total No of wells</td>
<td>Seasonal Total No of wells</td>
<td></td>
</tr>
</tbody>
</table>

Table1 Number of obstruction wells and total withdrawal rate MCM/year

4- Computer model
The groundwater modeling package PMWIN (Chiang and Kinzelbach, 1998) was used in this study. This model uses a finite difference calculation scheme to solve the following equation:

\[ \frac{\partial}{\partial X} (K_X \frac{\partial h}{\partial X}) + \frac{\partial}{\partial Y} (K_Y \frac{\partial h}{\partial Y}) + \frac{\partial}{\partial Z} (K_Z \frac{\partial h}{\partial Z}) = S_s \frac{\partial h}{\partial t} - I \]

In which Kx, Ky and Kz are hydraulic conductivity in 3 principal directions, h is hydraulic head, Ss specific storage and t is time.
4-1- Model assembly
Step by step assembly by preparation of input variables continues. These input parameters will be assigned to model grids.

4-2- Grid system
The aquifer was covered by a grid system consisting of 23 rows and 53 columns. Cell dimensions were 500 × 500, 250 × 500 and 250 × 250 meters.

4-3- Boundary conditions
All the boundaries are no flow and streamline boundaries except for ..... which is taken as constant head.

4-4- Model parameters
Input parameters are:
Time
Initial head
Observation well data
Hydraulic conductivity
Specific storage

time
Since observation well data are given for each month, time steps are taken to be 30 days and stress period is taken 6 months. We had 5 year data of piezometers therefore total number of stress periods was 10.

Initial hydraulic head
Water table level for March 2000 was taken to be the starting point for calculations.

Observation well data
There were 13 observation wells in the area. Data for 11 wells were reliable. Weekly and biweekly observation well readings for these wells amounted to about 1771 observation well records.

Calibration
The optimization criterion is based on minimizing the difference between observed and calculated water levels predicted by the computer model according to root mean square error defined by

\[ RMSE = \sqrt{\frac{\sum (h_{obs,i} - h_{cal,i})^2}{n}} \]

Where \( h_{calc,i} \) are the calculated heads, \( h_{obs,i} \) the observed heads and \( n \) the number of observations. Calibration of the model was performed in 3 steps

Step 1: Steady state calibration for the estimation of aquifer hydraulic Conductivity

Step 2: Unsteady State Calibration for estimation of Specific yield.
Step 3: Unsteady State Calibration for the estimation of well pumping abstractions.

For steps 1 and 2 three months observation well data for spring of 2001 and for step 3 observation well data from March 2001 to March 2005 were used.

Calibration results
Hydraulic conductivity and specific yield maps created as a result of calibration with pest are shown in Fig. 4. Table gives values for the area close to piezometers.

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**Fig. 4a** Hydraulic conductivity map estimated by model calibration

**Fig. 4b** Specific storage map estimated by model calibration
Table 2  Hydraulic conductivity and specific yield results created by model calibration with pest at piezometer locations

<table>
<thead>
<tr>
<th>Piezometer location</th>
<th>Hydraulic conductivity</th>
<th>Specific yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2.96</td>
<td>0.014</td>
</tr>
<tr>
<td>P2</td>
<td>5.2</td>
<td>0.019</td>
</tr>
<tr>
<td>P3</td>
<td>2.69</td>
<td>0.014</td>
</tr>
<tr>
<td>P5</td>
<td>12.60</td>
<td>0.033</td>
</tr>
<tr>
<td>P6</td>
<td>4.00</td>
<td>0.020</td>
</tr>
<tr>
<td>P7</td>
<td>6.75</td>
<td>0.022</td>
</tr>
<tr>
<td>P8</td>
<td>3.20</td>
<td>0.017</td>
</tr>
<tr>
<td>P9</td>
<td>9.45</td>
<td>0.03</td>
</tr>
<tr>
<td>P10</td>
<td>2.96</td>
<td>0.014</td>
</tr>
<tr>
<td>P11</td>
<td>2.75</td>
<td>0.025</td>
</tr>
<tr>
<td>P12</td>
<td>2.96</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Comparison of calculated with observed water levels for observation wells are shown in Fig.5a and Fig.5b. Top figures show correlation between measured and calculated water levels with their variances. Bottom figures show the variation of the measured and calculated groundwater elevation head with time. Calculated and observed elevation heads are shown to be very close with a maximum difference of 0.025 m in observation well No 5 and a minimum of 0.019 m in observation well No 11. Root mean square error for observed and calculated water levels given in table is 0.887.

5- sing the model for groundwater management
To lower the aquifer withdrawal rate and reestablish a steady state condition with safe yield, the calibrated model was used. Groundwater withdrawal was decreased in successive steps while other parameters remained unchanged. This study showed that a 35% reduction of pumping rates for a period of 5 years, would reestablish the desired steady state condition sought. Model results for these successively decreasing pumping rates after 1,2 and 5 years are given in Fig.
Fig. 6 a Groundwater level contours as a result of reduction of 35% withdrawal After 1 year

Fig. 6 b Groundwater level contours as a result of reduction of 35% withdrawal After 2 year

Fig. 6 c Groundwater level contours as a result of reduction of 35% withdrawal After 5 year
References