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SIMULATION OF GROUNDWATER QUANTITY USING HYDROLOGICAL MODEL FOR MITHAWAN SPATE IRRIGATED AREA OF DERA GHAZI KHAN, PAKISTAN

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In Pakistan, water resources are continuously declining due to failure in water governance. The management of scantily utilized hill torrent water resources has become imperative for meeting the grain demand of an increasing population. On an average, 50% of hill torrent water resources are lost due to inefficient conveyance and application practices, and resultantly, the irrigation trend in hill torrent command areas is shifting from spate irrigation to groundwater irrigation. Groundwater provides timely irrigation for potential production but uncontrolled installation of tubewells has created the problems of lowering of watertable and reduction in well yield. About 80% of the farmers of study area have installed tubewells and the installation was increasing at 5% per annum. This paper presents the simulated effects of excessive groundwater pumping in Mithawan spate irrigated area of Dera Ghazi Khan, Pakistan. The data were collected through field visits/observations, farmers' interviews and from relevant organizations. The watertable data were collected from nine observation wells on weekly basis from June 03, 2012 to June 01, 2014. A groundwater hydrological model MODFLOW was used to simulate the effects of groundwater pumping under three different scenarios. The result of Scenario-I indicated an average decline in groundwater level at 2.85m/10years. The result of Scenario-II showed an average decline of 3.64m/10 years. However, the simulated result of model under Scenario-III indicated rise in groundwater head at upstream of command area at 0.01m/simulation period with an average decline of 0.73m/10 years of simulation period. Based on the result, it may be concluded that the use of maximum hill torrent water for spate irrigation would raise groundwater level in the study area.
Keywords: MODFLOW model, hill torrent, spate irrigation, groundwater abstraction, groundwater simulation

INTRODUCTION

Water is one of the major sources for economic development and poverty reduction. In Pakistan, water resources are consistently losing due to failure in water governance in developing new reservoirs and efficient use of water. The available water supplies to support agriculture are quite deficient under the prevailing arid and semi-arid climatic conditions. There has been a gap between demand and supply of water, which adversely affected to rank Pakistan in the category of acute water deficit country (Shafique, 2015).
Groundwater provides timely irrigation for potential crop production but due to poor governance, the use of groundwater at filed level has been increased than surface water (Shafique, 2015). So far, 1050 thousands tubewells have been installed in the country to pump groundwater (GoP, 2015). The uncontrolled installation of tubewells in the country has created the problems of decline in watertable and saltwater intrusion, which is causing the deterioration of soils, and reduction in crop yields in many parts of the country. The lowering of watertable, in turn, increases the cost of pumping and lowers the well yields. In Punjab, about 4.5mha of land while in Sindh 56% of the area has been deteriorated due to application of poor quality of groundwater. In Balochistan, about 2-3m depth of watertable is dropped every year due to overexploitation of groundwater and about 15% of its cultivated area had been restricted (Qureshi *et al*., 2010).
The average annual potential in 14 major hill torrent areas in Pakistan is 23BCM (Sufi *et al*., 2011). A major part (>50%) of this water is lost due to mismanagement (PILDAT, 2003). The poorly managed hill torrent/ spate water moves towards the canal irrigated areas or falls in the river system and causes the variety of damages. Crop yield in spate irrigated areas is less than its potential, mainly due to inefficient irrigation and agricultural practices. Spate irrigation is applied once before the sowing of seed and subsequently, the crops are dependent on direct rainfall that satisfies less than 15% of the requirement (Qureshi *et al*., 2004).
Spate irrigation needs repairing of fields/ bunds and construction of diversion structures every year, which requires high cost. On the other hand, owing to uncertainty in the occurrence, spate water may or may not be available at the time of sowing. Due to aforementioned constraints and

advancement in the tubewells technology, the farmers of Mithawan spate irrigated area are shifting from spate irrigation to groundwater irrigation. The dependence on groundwater in this area has been significantly increased. Farmers have installed groundwater pumping units and they have choice to use either groundwater or spate water. It is estimated that if turbine installation and pumping trend continues with current rate, in future, water may not be available at this depth and all installed pumps would fail. So, there is need to focus on groundwater issue and its management.

Groundwater models play a pivotal role in the management of groundwater resources, their development and to foresee the effects of future management measures (Anderson and Woessner, 1992). The robust advancement in computer industry and their widespread availability has also instigated the use of models in the field of groundwater hydrology. The professional engineers and hydrogeologists are nowadays using groundwater models as a standard predictive tool for the management of this precious resource (Rao *et al*., 2013). The response of aquifers to the external stresses induced by the climate change can be successfully comprehended by numerical groundwater models (El-Yaouti *et al*., 2008). Different tools are used for the modeling of groundwater environment but the most widely used is MODFLOW, a 3-D finite difference groundwater flow model originally developed by United States Geological Survey (USGS) (McDonald and Harbaugh, 1988). MODFLOW can be very effectively utilized for the simulation of steady state as well as transient state simulations in a variety of environments including isotropic, anisotropic heterogeneous vertically discretized layered aquifer systems (Pollock, 1994).

The studies conducted so far on hill torrents in Pakistan, reported different options for the management of hill torrents, none of the study in the reported literature has addressed groundwater abstraction, its management and impact of pumping. The present study focuses on management of groundwater in a spate irrigated area and explores the impact of pumping under some proposed future groundwater use scenarios through modeling approach.

MATERIALS AND METHODS

***Study area*:** The study was conducted at Mithawan spate irrigated area of Dera Ghazi Khan (DG Khan) District, Punjab, Pakistan during the cropping year 2012-13 and 2013-14. The study area exists in Pachadh area and falls between latitude 29.731° N to 29.862° N and longitude 70.314° E to 70.487° E as shown in Figure 1. The gross study area is about 16000ha, out of which 98% is culturable and 2% is uncultivable.

***Collection of data*:** The data on various input parameters to populate hydrological models were collected from both in-situ as well as government organizations. The data regarding installed turbines were collected through reconnaissance survey while climatic and hill torrent data were collected from Pakistan Meteorological Department, DG Khan Observatory and Department of Irrigation, DG Khan, respectively. Fifty randomly selected farmers were interviewed, which included type of pumps, design parameters of pumps, sources of powers and yearly basis growth of pumps installation. Figure 2 shows the installation trend of groundwater pumps in the study area. The price of diesel and electricity was the major factors that influenced groundwater pumping and installation of new pumps. However, the analysis indicated that about 5% of installed

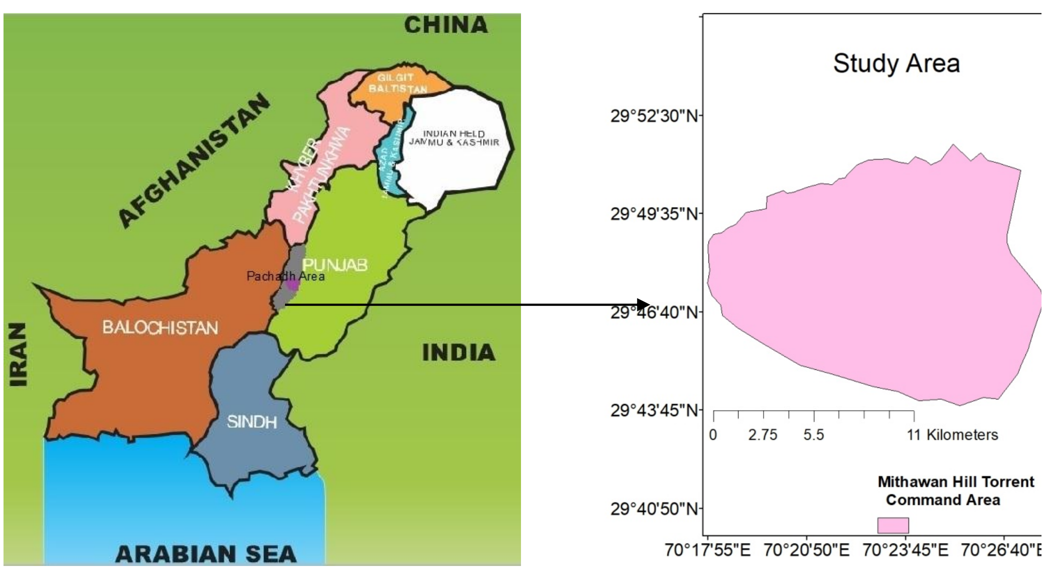

Figure 1. Location of the study area.

pumps were added to the system each year.

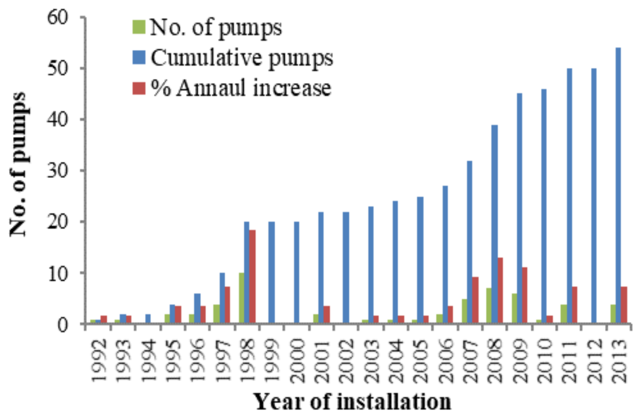

Figure 2. Installation trend of pumping units in the study area.

Likewise, nine boreholes available in the study area were chosen for the collection of watertable data. The location of selected boreholes/observation wells (OWs) and topographic map of the study area is shown in the Figure 3. To observe the changes in groundwater level and assess the recharge contribution, the watertable depth was recorded on weekly basis from June 03, 2012 to June 01, 2014. The data collected throughout the study period were utilized to simulate the groundwater heads using hydrological model.

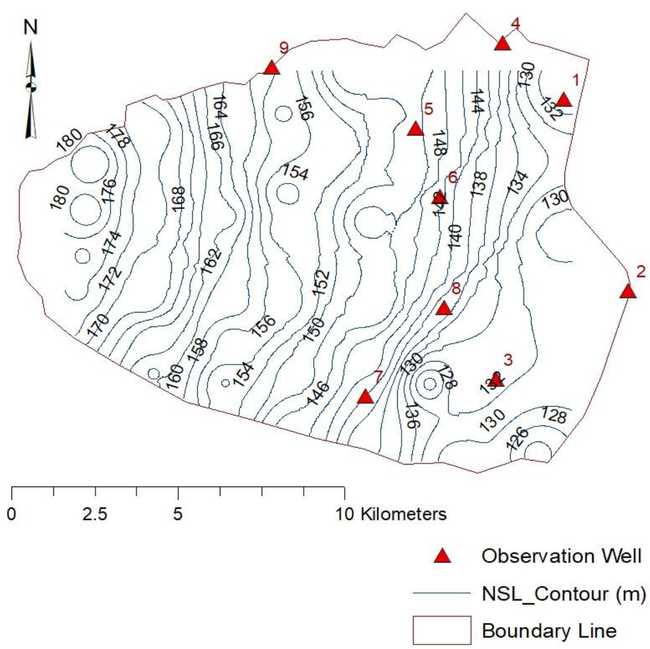

Figure 3. Location of observation wells and topographic map of the study area.

***Groundwater model*:** A 3D groundwater flow model, Processing MODFLOW for Windows (PMWIN) version 5.3.3 was used for this study. MODFLOW uses finite difference modeling approach which is comparatively simple and can produce more reliable results with scarce datasets. It utilizes the observed data on watertable records, climate, crop and soil in addition to hydraulic conductivity, evapotranspiration, and aquifer characteristics data. Therefore, the influence of rainfall, hill torrent floods, pumping activities, and irrigation water penetration to aquifer was simulated using this model. The model was calibrated and validated with 2 years data from June 01, 2012 to May 31, 2014. First year data from June 01, 2012 to May 31, 2013 were used for calibration and second year data from June 01, 2013 to May 31, 2014 were used for validation of the model. The length of stress periods were taken 183 and 182 days, for *Kharif* season (summer) and *Rabi* season (winter), respectively. In Kharif season, on an average about 28% of the study area is cultivated and remaining is left uncultivated. Similarly, in Rabi season, on an average about 50% of the area is cultivated and remaining is uncultivated. Cotton, maize, sorghum, millet and cluster bean (guar) were sown during Kharif season, while wheat, tobacco, sunflower, gram, brassica and arugula during the Rabi season. However, onion and fodders were cultivated in both the seasons. Out of aforementioned crops, cotton, wheat, onion, maize tobacco, sunflower and fodders were irrigated by the canal water and groundwater separately or conjunctively while sorghum, millet, gram, cluster bean (guar), brassica and arugula were sown through the spate irrigation.

The model grid consisted of 17500m in length from west to east. The modeling domain was horizontally discretized with 32 rows and 35 columns, and vertically with 4 layers. The model grid contained 1120 cells, with cell dimensions of 500 x 500m, out of which 670 were active and 450 were inactive cells. The inactive cells were defined using an IBOUND array in MODFLOW. The mathematical statements which specify dependent variables i.e. heads and their derivatives i.e. flux are represented by boundary conditions in a modeling domain (Anderson and Woessner, 1992). The western boundary of area is covered by the Suleiman Mountains and eastern side is occupied by the DG Canal. The River boundary condition was assigned at the eastern side to represent the lateral movement of flow from canal. Specified flux boundary conditions were assigned for the computation of recharge from different components, whereas no flow boundary conditions were assigned to the cells on the northern and southern part of the model where stream flow lines were not perpendicular to water level contours (Abu-El-Sha'r and Hatamleh, 2007). The geographic boundaries of the model domain are given in Universal Transverse Mercator (UTM) co-ordinates in Table 1.

Table 1. Geographic boundaries for the model of study area.

Easting	Coordinate	Northing	Coordinates
X_1 (bottom left x coordinate, m)	624952.974	Y_1 (bottom left y coordinate, m)	3289357.007
X_2 (top right x coordinate, m)	642452.974	Y_2 (top right y coordinate, m)	3305357.007

Table 2. Soil layers, horizontal & vertical hydraulic conductivity, specific storage and specific yield for study area.

Soil layer	Horizontal hydraulic conductivity (m/day)	Vertical hydraulic conductivity (m/day)	Specific storage (m^{-1})	Specific yield	Effective porosity range (average)
Clay silty with sand	1	0.1	0.001000	0.10	0.28-0.50 (0.39)
Sand with silt	30	3	0.000010	0.20	0.28-0.54 (0.41)
Clay	0.05	0.005	0.001000	0.05	0.27-0.50 (0.38)
Sand	100	10	0.000001	0.25	0.35-0.48 (0.42)

Source: CSIRO (2003)

The model required to specify the depth of each layer showing the homogenous strata having a specific horizontal and vertical hydraulic conductivity. Accordingly, the total depth was divided into 4 layers each of 6, 30, 19m and remaining depth to the bottom of aquifer. Horizontal and vertical hydraulic conductivity values were assigned to all the layers of model domain. Transmissivity of the layers was calculated using hydraulic conductivity and layer thickness by model itself. The values of horizontal and vertical hydraulic conductivities of the model layers along with other basic parameters used in the model are summarized in the Table 2.

There are numerous methods but Penman-Monteith method is most accurate method for reference crop evapotranspiration and crop water requirement calculations. The FAO CROPWAT computer model uses the Penman-Monteith equation and has proved relatively accurate in both humid and arid climate (Yin *et al*., 2008). Therefore, in this study, CROPWAT 8.0 model was used for the estimation of maximum evapotranspiration rate. The maximum evapotranspiration rate (ET_m) during stress period 1 (*Kharif* season) was 0.0068m/day and stress period 2 (*Rabi* season) was 0.0042m/day. The high rate of ET during stress period 1 was due to high temperature and wind velocity in the study area. The recharge values were computed using series of spreadsheet calculations based on rainfall and irrigation during the stress period. The estimates for recharge as cited by Ahmad and Chaudhary (1988) from previous studies were used for the estimation of recharge from rainfall and irrigation sources. Recharge through hill torrent/ spate water was assumed more at upstream of study area due to more occurrence, but low by the other sources of irrigation. While at downstream of study area more recharge was considered by the canal water and/or groundwater irrigation and low at upstream by these sources of irrigation. The recharge through rainfall was considered uniform for all cells during the stress period. The recharge fluxes estimated for stress period 1 ranged from 0.00021 to 0.00062m/day and stress period 2 ranged from 0.00016 to 0.00049m/day whereas; the average recharge flux during stress period 1 and 2 were estimated 0.00045 and 0.00049m/day, respectively. The more recharge in stress period 1 was due to more hill torrents and rainfall during the monsoon season. The high rate of recharge flux was assumed for downstream of the study area due to more cultivation as well as irrigation application. However, the recharge flux for the upstream was considered low due to low or no irrigation application except hill torrent/ spate irrigation.

The river module was used to estimate recharge from the canal. The width of canal was 52m, length of reach in canal 500m and bank to bed height was approximately 5m. The hydraulic conductivity of canal/riverbed material was assumed between 1-1.5m/day, as reported by Knipe *et al*. (1993). The hydraulic conductance of the canal was computed as 7800m^2/day. The recharge flux through canal was computed by the model. The elevation of riverbed bottom varied from 126 to 125m and values of head in the canal varied from 127-128 and 126.5-125.5m during the stress period 1 and 2, respectively.

During the calibration it is desirable to make comparison between the calculated and observed groundwater heads rather than interpolated water level because of the uncertainty involved in the interpolation process. However, the interpolated water heads have the advantage of being available in every model cell making it easier to judge the success or failure of each cell of the model. The calibrated water levels were compared with the observed water levels of selected observation wells. The observed water level data were used for the calibration and validation purposes. The hydraulic conductivity and recharge values were adjusted until reasonable matches were obtained between the observed and simulated water levels for all observation wells. Figure 4 shows the simulated and observed temporal variation of water level at the selected observation wells for this study. A close agreement was obtained between the observed and simulated heads, and the overall trend of observed groundwater is also followed well by the modeled data.

Statistical performance of model: The degree of fit between simulated and observed heads was checked through statistical analysis. The statistical analysis included Mean Error (ME), Mean Absolute Error (MEA), Root Mean Squared Error (RMSE) and Model Efficiency (MEF). The error indices are usually used for the model evaluation (Saatsaz *et al*., 2011). RMSE is one of the commonly used error index statistics (Singh *et al*., 2005). The results of ME, MAE and RMSE were calculated as -0.027, 0.14 and 0.16, respectively. Similarly, the model efficiency was computed as 0.99. The MEF clearly indicates that there is no systematic error involved between observed and modeled heads. Thus the model simulation for future scenarios would result the accurate heads of selected observation wells.

Water balance: Water balance was used to check the change in aquifer storage due to external stresses such as wells, recharge, evaporation and canal. Fig. 5 shows the water balance results of the calibration period and describes the volume of water entering, subtraction and net storage in the aquifer system. Water was entered into the aquifer system through recharge and river leakage while, subtracted from the aquifer by the pumping and evapotranspiration. The plus sign of storage refers to the water released from the aquifer and minus refers to the water added up in the aquifer system. Storage in the aquifer during stress period 1, 2, 3 and 4 was -2.638, 2.827, -1.868 and 3.839MCM, respectively.

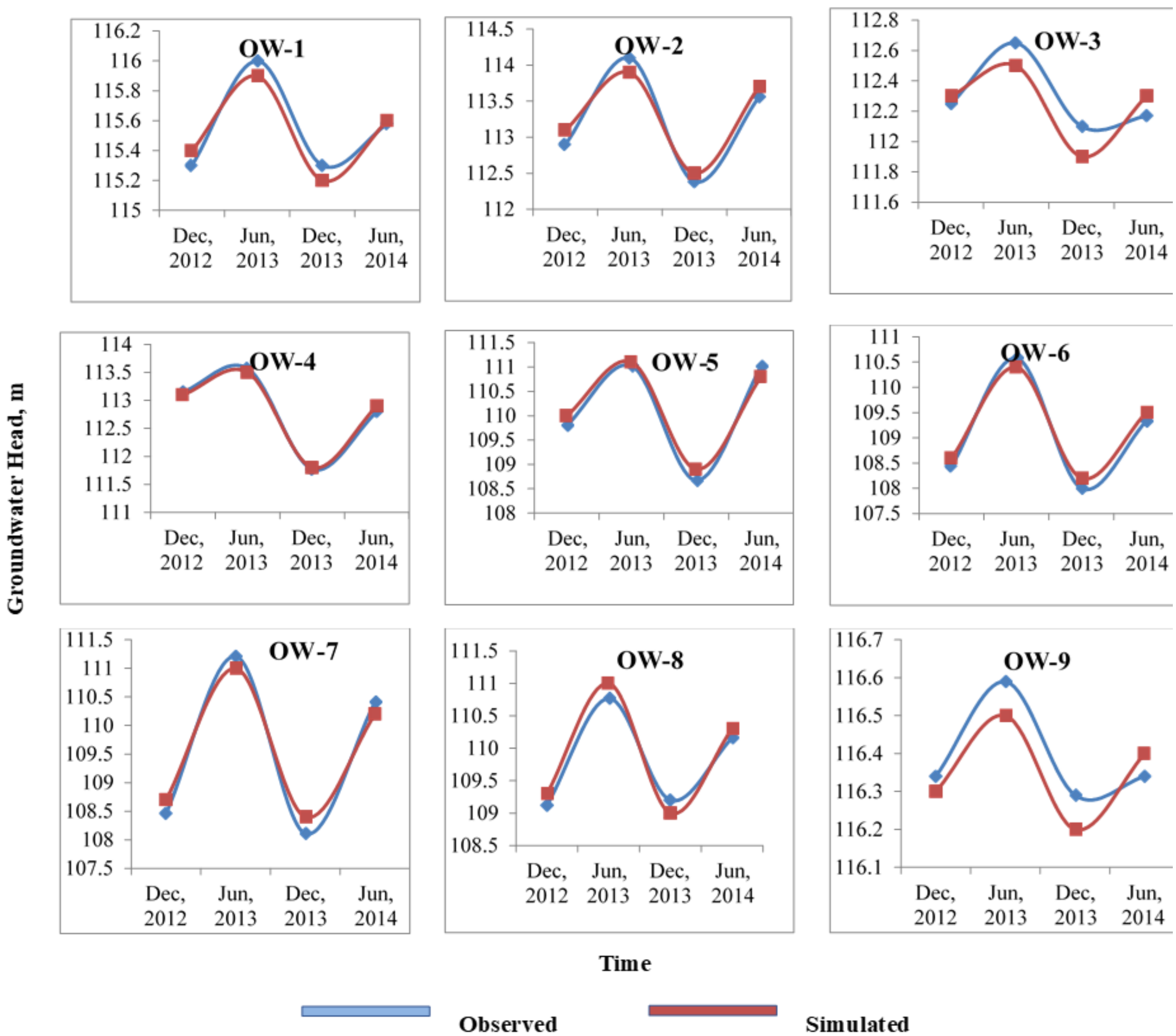

Figure 4. Simulated and observed groundwater heads of the observation wells.

Similarly, the volume of water abstracted from aquifer during the stress period 1, 2, 3 and 4 was 8.865, 11.855, 8.356 and 12.231MCM, respectively. It clearly indicates that during stress period 1 and 3 (i.e. from June, 2012 to December, 2012 and June 2013, to December, 2013) water was added to the aquifer system, while water was released from the aquifer during the stress period 2 and 4 (i.e. from December, 2012 to June, 2013 and December, 2013 to June, 2014) to meet the crop water requirement. The entering of water into aquifer during the stress period 1 and 3 was due to more water/ recharge from the rainfall, hill torrent and canal water (flow at its full supply level in summer season). Whereas, during the stress period 2 and 4 water abstraction was more due to more cultivation, less occurrence of rainfall and hill torrent in the study area.

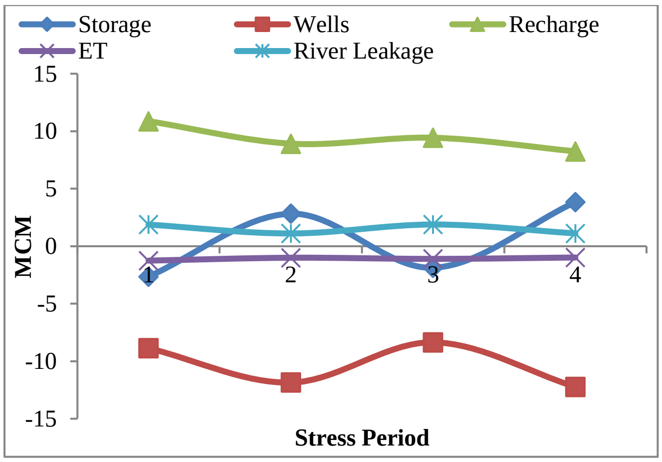

Figure 5. Water balance of the study area from June, 2012 to June, 2014.

RESULTS AND DISCUSSION

Considering the existing conditions and information got through research, three different scenarios were developed to simulate the groundwater heads from June 01, 2014 to May 31, 2024. First, the model was run to simulate the heads considering groundwater abstraction and recharge by all the means constant (Scenario-I). Second, it was assumed that all the stress factors except groundwater abstraction, which increases @ 5% of last year as mentioned in the discussion of Figure 2, remain constant (Scenario-II). Third, the model was run for simulation assuming the groundwater pumping and recharge through irrigation excluding spate irrigation is constant (Scenario-III). More than 50% of spate water is lost every year due to mismanagement and inefficient utilization of this precious resource. The model was run to simulate the groundwater heads, if 100% of spate water is used for irrigation in the command area. There was no accurate record of duration and number of occurrence of hill torrent with the concerned department. It was difficult to estimate the volume of water available from hill torrents during each year. The hill torrent water utilized for irrigation was estimated by the depth of water applied in the field multiply by the area irrigated through hill torrent.

Table 3 shows the change in groundwater heads under different scenarios. It was predicted by the model that under the Scenario-I there would be decline in groundwater head from 0.14-4.03m/simulation period (10 years) with an average decline of 2.85m/simulation period. The pumping unit density was decreasing from canal to foot of hills due to increase in groundwater depth from canal to hills. The decline in groundwater head at OW-1 and OW-9 was less due to recharge contribution from the canal and less pumpage, respectively. The all other observation wells were located between OW-1 and OW-9. At in-between OWs, the decline of groundwater head was more due to more pumpage and less recharge. Similarly, under the Scenario-II, the model predicted decline in groundwater head from 0.19-5.18m/simulation period with and an average decline of 3.64m/simulation period. Under this scenario, the decline in groundwater head was more than other scenarios and this may cause the failure of already installed pumps in the study area.

It was also predicted by the model that under the Scenario-III, there would be decline in groundwater head from 0.46-1.19m/simulation period for OW-1 to OW-8 but a raise in

Table 3. Predicted groundwater heads under different Scenarios.

Well No.	Scenario-I (m)			Scenario-II (m)			Scenario-III (m)		
	2014	2024	Diff.	2014	2024	Diff.	2014	2024	Diff.
OW-1	115.58	113.80	1.78	115.58	113.31	2.27	115.58	115.12	0.46
OW-2	113.56	111.00	2.56	113.56	110.26	3.30	113.56	112.98	0.58
OW-3	112.17	108.70	3.47	112.17	107.71	4.46	112.17	111.35	0.82
OW-4	112.80	108.80	4.00	112.80	107.67	5.13	112.80	111.81	0.99
OW-5	111.01	107.10	3.91	111.01	106.08	4.93	111.01	109.82	1.19
OW-6	109.33	105.30	4.03	109.33	104.15	5.18	109.33	108.39	0.94
OW-7	110.41	107.10	3.31	110.41	106.25	4.16	110.41	109.38	1.03
OW-8	110.16	107.70	2.46	110.16	106.99	3.17	110.16	109.61	0.55
OW-9	116.34	116.20	0.14	116.34	116.15	0.19	116.34	116.35	-0.01
Average loss in groundwater head			2.85			3.64			0.73

the groundwater head for OW-9 at 0.01m/simulation period due to low or no groundwater pumping and more recharge through hill torrent. While, there would be an average decline of 0.73m/simulation period in the whole study area. The model prediction indicated a rapid decline in groundwater heads under the Scenario-I and II but a very low decline in groundwater head under the Scenario-III. The model prediction also indicated a raise of water level at upstream of study area by the maximum use of hill torrent/ spate water for irrigation as well as groundwater recharge contribution in the study area.

Conclusions**:** The model predicted a rapid decline in groundwater heads under the Scenario-I and II, while under Scenario-III, the model predicted a recharge at upstream and decline at the middle as well as tail of selected spate irrigated area. The overall decline in groundwater head under the Scenario-III was very low as compared to Scenario-I and II. The model prediction indicated a rise of groundwater head at upstream of the study area by the efficient utilization of hill torrent/ spate water for irrigation as well as groundwater recharge contribution. Therefore, the use of maximum spate water for irrigation would bring more area under cultivation, recharge groundwater and it would also safe guard the failure of already installed pumps in the area.

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