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Water table rising consecutive to surface irrigation in alluvial aquifers: predictive use of numerical modelling

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Due to lack of integrated management of agricultural water worsened because of the application of incorrect irrigation methods with respect to local conditions, over-irrigation often occurs and may result in groundwater flooding. Instances for this default of sustainable development are observed in West-Azerbaijan province in Iran. The Mahabad plain has been selected to evaluate the effects of infiltration on the water table fluctuations. A finite difference model of the Mahabad plain silty / sandy aquifer has been developed by processing external constraints as the recharge input (R) due to IDN. The results show that the calibrated unsteady-state model has the ability to simulate the observed piezometric levels. The model is used to evaluate the recharge of the groundwater system from irrigation losses by using the recharge factor R as a tuner so as to honor the observed variations of the water table level within the aquifer. Results of two executed scenarios suggest that by continuing the current method of surface irrigation and crop pattern, in case of network development, the recharge of groundwater by irrigation will cause to change the farms to logged lands in central and eastern parts of the network. Numerical modelling of water table variations in alluvial aquifers and testing of some IDN management scenarios appears to be a cost-efficient approach to assess flooding hazard, suggest a modified and/or new method of irrigation, and design spatial extension of existing network.

Keywords: Irrigation network, Recharge, Groundwater flood, Modflow Scenario.

1. Introduction and problematic

Mahabad irrigation and drainage network (IDN) located on a plain with the same name is one of the important networks of Azerbaijan province in north-west of Iran (“Azerbayejan” in Persian). The irrigation water is supplied by surface water through a network of canals from Yousef-Kand diversion dam. Numerical estimation of irrigation efficiency for a vast plain like Mahabad with 18000 ha area is not practical. With regard to current irrigation system (i.e. surface methods) and also the irrigation efficiency (38%) in the network, it is derived that considerable amount of irrigation water has been lost by getting out from accessibility to the plant root zone.

A numerical model of groundwater flow using Modflow was conducted in a study site, the Mahabad plain, to qualify the groundwater recharge by irrigation. The study is focused on the assessment of impacts of irrigation losses on underlying groundwater system used as a decision-making tool and the paper is organized in five sections.

Rainfall is the principal source of recharge to the groundwater and the second important source is deep percolation from irrigated areas (Ghosh and Sharma, 2006). The increase in groundwater storage due to the naturally occurring rainfall infiltration and percolation is termed as “rainfall recharge”. In this study, the suggested linear relationship of GWREC (2009) between annual groundwater recharge from rainfall (R_p) and annual precipitation (P) has been employed:

$$R_p = \alpha \times P \quad (1)$$

where α is the rainfall recharge factor which has been approximated to be 0.35 (Dadmehr, 2002) for the plain of Mahabad.

Recharge to water table occurs in irrigated areas also due to irrigation. The portion of “irrigation recharge” R_i depends on the flow rate, time of application, size of the field, soil moisture, method of irrigation and depth to water table. Following the same approach as for the rainfall recharge factor, we propose the following relationship between the irrigation recharge R_i and the total annual irrigation I :

$$R_i = \beta \times I \quad (2)$$

According to very low total irrigation efficiency of the network, evaporation losses and the values suggested by Ghosh and Sharma (2006), the irrigation recharge factor β is approximated to be 0.40 as one of the initial conditions of the modelling. For this purpose, Modflow can be used to bring out the effects of recharge on groundwater level.

The unit of recharge is length/time, so in a cell with a recharge value of 0.04 (m/day), 0.04 meters of rainfall each day would be distributed across every m^2 of the cell.

2. Study area and data

In this plain, Water levels were recorded twice per month by the Mahabad irrigation network company and the average of these two values has been considered as the mean monthly water table level in each piezometer. The spatial distribution of the piezometers is illustrated in Figure 1.

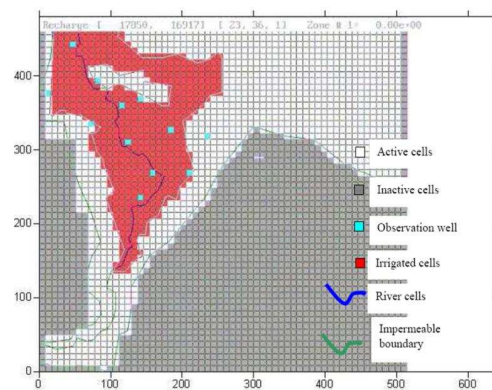


Figure 1. Grid map of study area in the model

The data recorded in the piezometers were used to two periods of 24 months; August 1994 to August 1996 for calibrating the model; then for another 24 months from August 2005 to August 2007 for verification of the calibrated model.

The available reports and local monitoring of operating wells in the plain shows that the average thickness of alluvial layer is 20 m, the maximum depth recorded is 60 m and mean depth to get water level within the aquifer is 5 m. Then the conceptual model was made and these initial values allocated to Modflow via appropriate packages. The sensitivity analysis showed that the model has the most sensitivity to hydrodynamic parameters and in the first step of modelling (without the irrigation network) there were the user control tool for calibrating the model.

With regard to the mentioned irrigation efficiency of the network (38%), it is evident that 62% of irrigation water loses due to evaporation from the water surface and soil, deep percolation to soil layers below the root zone and surface runoff whereby the water ends up in a drain. So considering a Recharge factor of 0.4 for all the plain and 365 mm of annual rainfall for the region and by regarding 205.74 Mm³ of Gross irrigation water requirement for 12700 ha of the irrigated field in the Mahabad IDN for a typical crop pattern considered for the network in development project during 6 months, the values of 0.0004 and 0.004 m/day respectively for outside and inside of the Mahabad IDN borders were calculated and allocated as groundwater recharge rate by surface sources (rainfall and irrigation) via RECHARGE package for Modflow. Emphasizing on this hydraulic relationship, the effects of the IDN on the groundwater system have been investigated.

3. Modelling: calibration and verification

The impermeable boundaries of the plain were determined (green line in Figure 1). The studying region was covered by 60×58 square cells with 500×500 meters dimension. From this system of gridding, 1723 cells were inside the region (active cells) with hydraulic head changes and 1757 cells were outside the region with no flow (inactive cells). By local observations and considering the map of the network borders surveyed by Ab-Ara-Sazeh (2003), the under-irrigation part of Mahabad IDN was determined and by intervention of MODELCAD pre-processor the borders of the irrigated lands were superimposed on the main region (red area in Figure 1). This border was set entirely on active cells and 508 cells cover the irrigated area. Then in RECHARGE package the plain was divided in two zones (inside the irrigation area border and outside it). According to the coordination of observation wells, 11 wells from 12 located inside and in border of irrigation area (Figure 1). Monthly data of the water table level in these wells were used for model calibration.

In first step of callibration, steady state run of model was performed for April 1995 (chosen as the regional balance month of groundwater level) by using the water elevation in observation wells. The trail and error method has been selected to calibration of the model by user-controlled tuning of the irrigation (and rainfall) recharge factors α and β inside the irrigation area. The best values for α and β in this step were 45.9% and 36.8% respectively. Then the steady state calibrated model was employed as an initial condition for unsteady state analysis of model. The unsteady model has been calibrated by using the observed monthly water table levels in 12 observation wells from August 1994 to August 1996 (24 stress periods) (Figure 2). This is because of the concentration of the piezometers at the center and so the better interpolation between the observation points. The values of α and β have modified to 42.8% and 33.1% respectively.

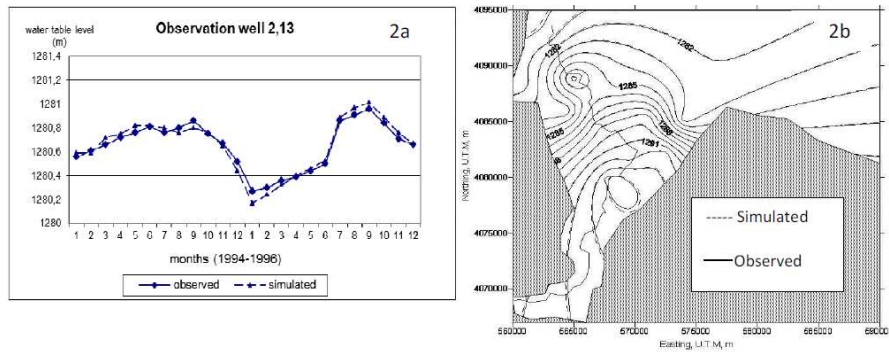


Figure 2. Two methods of comparison between simulated and observed hydraulics heads in study area: a) for 24 stress period (1994-1996) in observation well P1 (2,13), b) for April 1995 (one stress period)

The verification phase of the unsteady calibrated model has been done with the same procedure as the calibration by using observed water level data for 24 more recent stress periods, from August 2005 to August 2007. This time the values of groundwater recharge rate for inside and outside of the irrigation network were obtained as 0.00288 and 0.00042 m/day which correspond 0.42 and 0.32 for α and β respectively.

As the comparison is favourable, it gives the possibility to this argument that the model application can be used for prediction the future events with a reasonable assurance of accuracy.

The results of the calibrated model after the smooth parameter variation in verification phase with “Do nothing scenario” have the ability to be used for future hydrological events in the plain. In this final step, as a usage mode of the model, according to existing discussed problems in the plain and managing necessities for Mahabad IDN, two scenarios have been defined and applied in the model.

According to the potential of development of the farming lands, 4300 hectares of lands have been suggested to add to interior of the irrigated area in the model (Figure 3). Because of doing this scenario almost in all observation wells a remarkable increase in water table level has been calculated. In average, water table raises 2.4 m in the plain. It is anticipated that the central and eastern parts of the plain will change the feature to water logged land and consequently they will convert to saline land too.

In second scenario, regarding to this decision, to predict the result of improvement in irrigation efficiency, the verified model was used and the recharge in irrigated cells (just the red cells) was uniformly diminished to half and the calibrated-verified model was run again. According to results, water table has meanly 6.4 meters of drawdown and this descent is distributed uniformly under the irrigation area.

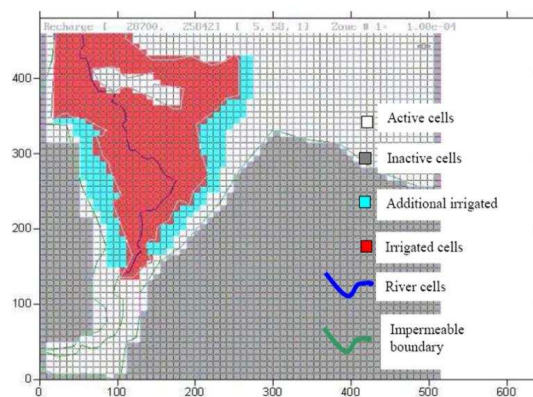


Figure 3. Development of irrigation area in scenario I

4. Conclusion

Assessment of irrigation as a recharge stress on groundwater has been done by using a Modflow model. According to the results a qualitative judgement can be derived from the executed scenarios as an alert for the regional water authorities in any decision for development of Mahabad IDN. It seems that a development project including improvement of the irrigation efficiency is much sure and prevents the groundwater rising and probable waterlogged lands in and/or near the irrigation network. On the other hand, the groundwater resource under the Mahabad plain is almost intact and by developing exploitation of groundwater by withdrawal wells for irrigation, some of irrigation water demand could be supplied from groundwater and at the same time dropdown of the water table would avoid groundwater flooding.

The results show that the groundwater system of this region has a high sensitivity to recharge from surface. Mahabad IDN is one of the important irrigated agricultural zones in north-west of Iran and by this study it was introduced as the main source of groundwater recharge in dry seasons.

According to the results of the two effectuated scenarios, the water table fluctuation must be considered as a dominant hydrological parameter in any project to develop the irrigation network. Regarding to potential of the network to cover more lands, it seems that development of the network without considering the effects on groundwater causes to water logging in some central and eastern parts of the network and it is a threat to change the feature of the region to waterlogged lands. So improving the irrigation efficiency to prevent water losses and deep percolation is inevitable in any suggestion to develop the network. Finally, the model can be used as a part of the integrated water resource management of this region.

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