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The Use of Subsurface Barriers in the Sustainable Management of Groundwater Resources

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Abstract: Underground dams provide a valuable source of water for consumption of drought seasons. However the contaminant levels of the water would need to be monitored to ensure that they did not exceed standard limits. The objective of this study is investigation of subsurface dam construction and its effects on water table height in consumption location and interception of nitrate transport. Therefore the Shahrekord aquifer model was simulated by Modflow and MT3D models. Hydrodynamic coefficients and uncertain parameters of solute transport was calibrated using sampled data. Water table situation and nitrate concentration were drawn and analyzed using ArcGIS9.3 software before and after dam construction. The results show that the subsurface dam rise groundwater level in 4 kilometers distance of upstream areas, thereupon available volume of water increased about 1.5 MCM. Nitrate concentration didn't have considerable difference rather than initial state.

Key words: Subsurface dam · Shahrekord · Modeling · Nitrate

INTRODUCTION

Subsurface dams of one type or another (especially groundwater and sand dams) can be found in various countries, especially in semi-arid regions. The technology used is not new-but its efficiency in conserving groundwater, suitability for a participatory approach and relative simplicity has recently revived interest in the technique [1].

Subsurface dam structure is accounted as a viable option for groundwater management. It has many merits for example, unlike a surface dam, it does not submerge land to store water and there is no danger of breaching disasters. The surface area can be used in the same way before and after the construction of the subsurface dam [2]. Using concrete cut-off walls as subsurface dams to intercept or obstruct the natural flow of groundwater and provide storage for water underground is a common practice in many parts of the world, notably in India, Africa, Brazil, Japan and southwest of Saudi Arabia. The technology has been used to different application including the consumptions of industry [3] and agriculture [4] and controlling sedimentation [5].

A number of studies have been carried out to design subsurface dam [6] determining the optimum location [7] and the effect of underground structure on water quality change and salinity movement [8-10]. This technology has been implemented in some regions of Iran such as: Kerman (Kahnouj), western Azarbaijan, Semnan and Yazd provinces [11].

Contaminant transport modeling is an essential component of any risk assessment and risk management pertinent to groundwater quality [12]. Nitrate contamination of groundwater resources is one of the most important problems of the biological environment. The water quality in a region depends on the nature and extent of the industrial, agricultural and other activities in the catchments [13].

The simulation of groundwater flow to an underground structure has been used by many investigators to determine quality variation and determine heads and flows in the vicinity of the barrier. A geostatistical approach to the inverse problem of groundwater flow models has been used to estimate the hydraulic properties of aquifer from scattered measurements of piezometric head in two-dimensional steady state saturated flow [14-16].

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Yoshimoto *et al*., [17] developed a numerical model consisting of simplified equations was developed to simulate nitrate concentrations in groundwater in a reservoir area of a subsurface dam in Okinawa, Japan. The model was applicable to long-term prediction of changes in NO3-N in the reservoir area.

This study was developed a model to estimate changes in the spatial distribution of nitrate concentrations and the simulation of groundwater in Shahrekord aquifer, before and after the construction of subsurface dam using Modflow, MT3D and ArcGIS.

MATERIALS AND METHODS

Shahrekord plain with 551 km^2 area is located between 32° 07" to 32° 35" latitude and 50° 38" to 51° 10" longitude at Chaharmahal and Bakhtiari Province, the center of Iran (Fig. 1). The aquifer was depleted by 635 wells, 79 qanats and 40 springs. The discharge volume of depletion sources is about 250 MCM annually [18]. In the southern parts of plain the water table is fallen strongly because of immoderate discharge and decreased the quality water by urban wastewater entrance.

Isopiestic lines of water table show the flow path is from north to south by gradient hydraulic. The outflow of plain is at the end of south zone in Kharaji [19].

In this study groundwater flow and nitrate transport model was simulated in before and after the construction of hypothetical subsurface dam. The modeling was carried out by Modflow and MT3D Models, respectively from 1 July 2007 to 31 June 2008 that divided to 12 stress periods with daily time steps.

Conceptual model was developed by water table, bed layer, topography, inflow and outflow. Hydrodynamic coefficients in flow model and uncertain parameters of solute transport were calibrated in 12 months. 96 water samples were collected monthly from 8 wells of study area (Fig. 2). Nitrate concentrations were analyses in library by spectrophotometry method. In the next step was specified an underground dam in Horizontal-Flow Barriers tool of Modflow.

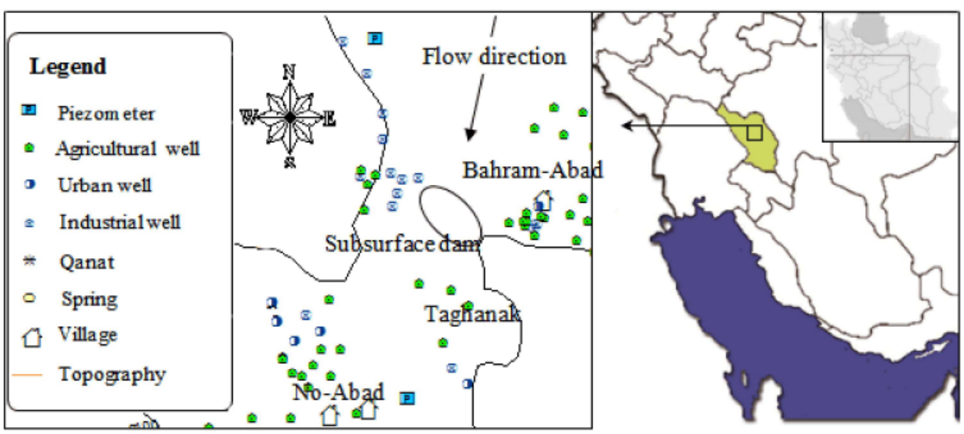

Fig. 1: Study area in Chaharmahal and Bakhtiari province and Iran

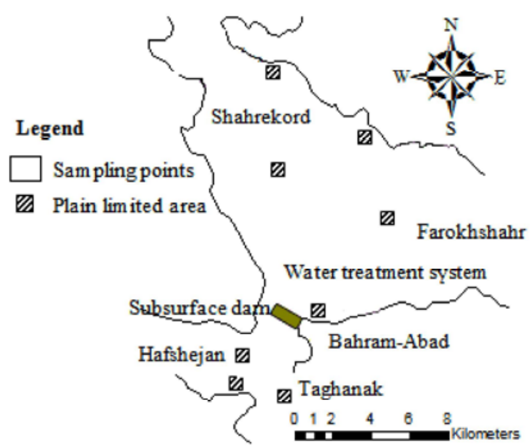

Fig. 2: Sampled wells to measure nitrate concentration

Table 1: The properties of hypothetical subsurface dam

Parameters	Values		Values
Bed layer elevation from sea level	1985 m	Effective porosity	25 %
Elevation from bed layer	40 m	Cell size	200×200 mm
Subsurface dam length	750 m	Hydraulic conductivity of dam	0.5 m/d
Hydraulic conductivity	16 m/d	Land-use in the area	Agriculture

Note: Subsurface dam limit only 50% of groundwater flow.

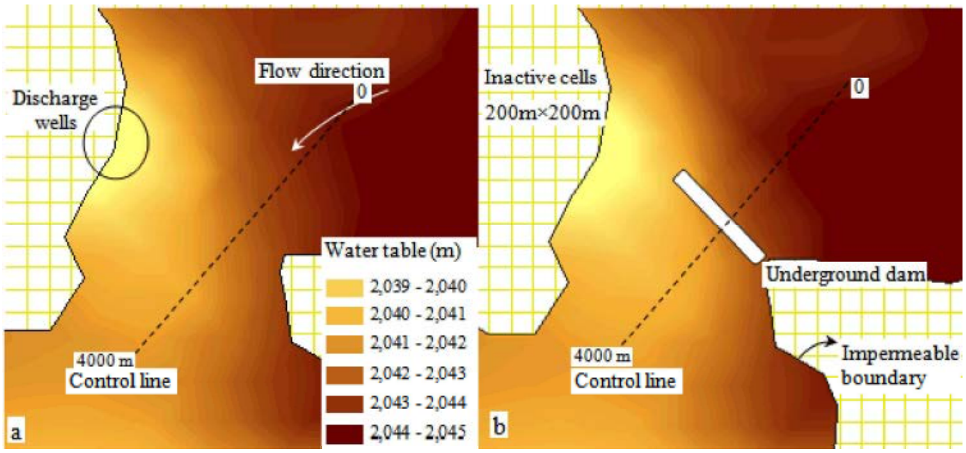

Fig. 3: Water table elevation before (a) and after (b) the subsurface construction

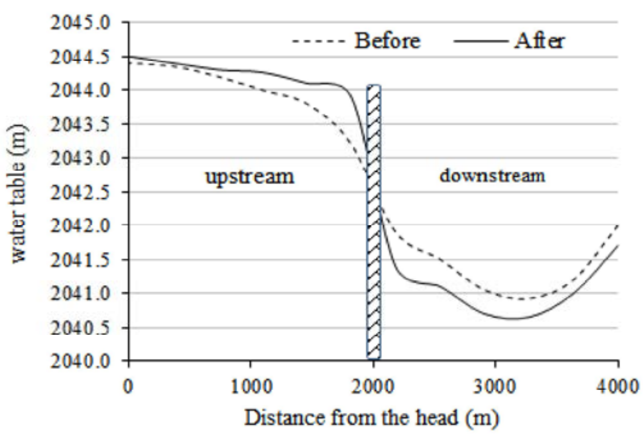

Fig. 4: Water table in the length of control line

Input data of model are shown in table 1. The developed model of flow treatment and nitrate transport was performed separately in before and after the subsurface dam construction. Calculated data including groundwater levels and nitrate concentration was extracted from the model in the end of study year.

The information was converted to the world coordinate system and was interpolated by Kriging technique and ArcGIS 9.3 software (Figs. 3 & 4).

According to figures, a control line was selected in effective areas and measurable. The effect of subsurface dam on the water table and nitrate values in the line path were analyzed.

RESULTS AND DISCUSSION

The simulation was carried out by numerical model and GIS technology to evaluate the effect of subsurface dam on quantity and quality components of aquifer. The results are discussed in two parts including isopiestic water table and nitrate distribution maps.

Water table map in the area are shown in Figs. (3a and 3b) at before and after the dam effect, respectively. Subsurface dam has increased the groundwater level about 4 km in upstream with 13 km^2 area. Height of rise is 1 m at the close of dam place and move downward gradually at far. Water storage exceed

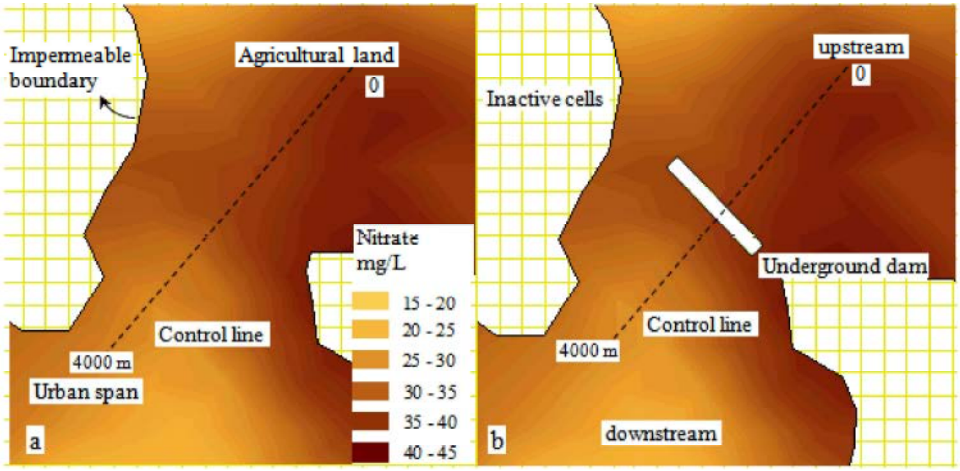

Fig. 5: Nitrate distribution before (a) and after (b) the subsurface dam construction

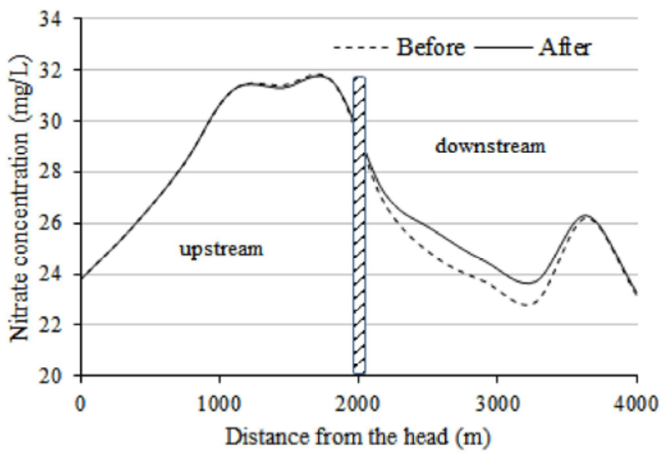

Fig. 6: Nitrate concentration in the length of control line

the initial volume was annually 1.5 MCM while the effective porosity has been 0.25 [20]. Total depletion volume of aquifer in the area is 6.5 MCM including 5.2 MCM by 24 agriculture wells, 0.85 MCM by 6 industrial wells and 0.45 MCM by one urban well. Therefore, the stored water is 23% of total discharge that used in summer for irrigation. Drawdown of water table was observed about 5km in downstream but don't have any problem because of the discharge sources are low.

The inverse effect of subsurface dam on southern part rather than north was considered by linear diagram (Fig. 4). The variation of water table in upstream was +45 cm and in downstream-45 cm.

Nitrate transport and distribution was simulated by MT3D in initial condition of aquifer (recharge, discharge and boundary conditions).

Calculated nitrate distribution is shown in Fig. 5a. According to the figure the highest nitrate concentration was about 2 km of distance from dam location that was less than standard limit of World Health Organization [21]. After the subsurface dam construction and simulation of nitrate for new condition, no considerable changes were observed for nitrate values (Fig. 5b). Ishida *et al*., [2] obtained similar results for the pattern of nitrate transport in Sunagawa, Japan. It is necessary to repeat the modeling for other chemical parameters because it is possible to pollution by wastewater and agricultural contaminant in the area [19].

A concern was efforts to ensure the sustainable quality of the local environmental conditions at the dam site and downstream of it, by setting a control line which can be monitored at before and after the underground dam simulation (Fig. 5). Nitrate variations after the hypothetical dam rather than before in the length of control line are shown in Fig. 6. The changes of nitrate concentration are positive and negligible in the downstream and upstream regions, respectively.

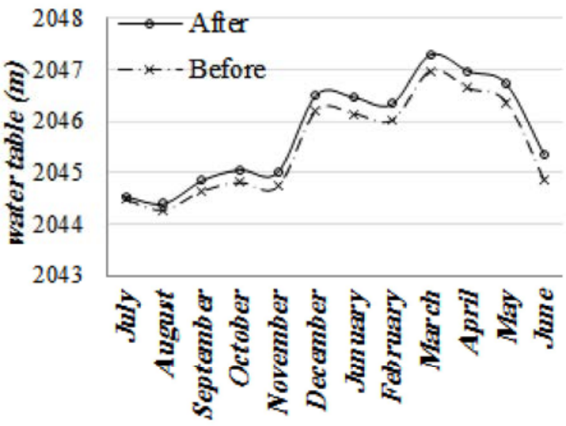

Fig. 7: Variation of groundwater level in Bahram Abad

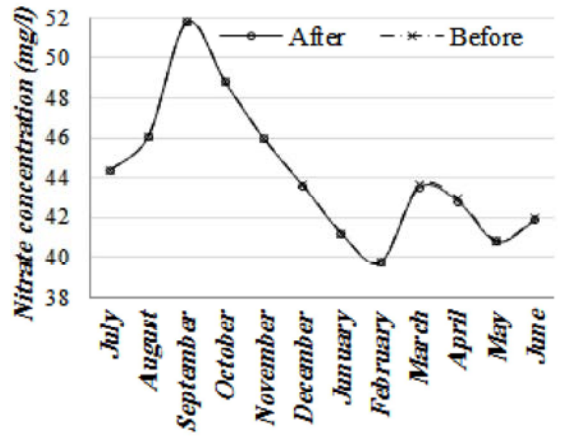

Fig. 8: Variation of nitrate concentration in Bahram-Abad

Bahram-Abad village located adjacent to the subsurface dam. Water health in the area is a serious problem and groundwater is vulnerable to contamination of storied water. Variation of water table and nitrate values affected by the construction of subsurface dam are shown annually in Figs. 7 & 8.

The minimum groundwater level and the maximum nitrate concentration were in summer because of agricultural activity. As shown in figure7, difference between before and after of flow barrier is increasing from July 2007 to June 2008. Therefore, the difference will increase in future.

The low difference between nitrate concentrations in the well of drinking water (Bahram Abad) confirmed the applicability of subsurface dam for groundwater storage and conservation of water quality (Fig. 8).

CONCLUSIONS

The results show that the underground flow barrier has increased water table and available water in upstream of subsurface dam about 0.5 m and 1.5 MCM respectively. The average of nitrate was 32.2 mg/L in upstream and after the simulation of subsurface dam was 32.22 mg/L. The previous studies confirmed the low variations in short time [17, 22].

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