# Adaptation strategies in alluvial aquifer under future climate change (Case study: Hamadan aquifer, West of Iran)

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**Abstract:**
Groundwater is the main source of water in arid and semi-arid regions, so it is very important to recognize vulnerable parts of aquifer in future under climate change. In this research, sixteen climate models were evaluated based on weighting approach. HADCM3 and CGCM2.3.2a models were selected for temperature and precipitation predictions in the future, respectively. LARS-WG was used for downscaling AOGCMs outputs. Results show that temperature will increase by 1.4°C and precipitation changes between +10% to -6% under B1 and A2 emission scenario, respectively. Simulated runoff by artificial neural network indicates reduction in the future runoff by -39% under A2 emission scenario and increase by +12% under B1 emission scenario. In order to simulate the direct impacts of climate change on groundwater resources, the projected precipitation and resulted runoff in the future were used as inputs to the groundwater model. Simulation of the groundwater head changes by MODFLOW software indicates more groundwater depletion under A2 scenario compared to B1 scenario. The groundwater model results indicate that areas with low aquifer transmissivity and high density of extraction wells are more vulnerable to the future climate change. According to the aquifer critical conditions in current situation, groundwater artificial recharge plans do not have adequate efficiency and the most suitable adaptation strategies in the aquifer include enhancement of irrigation efficiency, plugging of unlicensed wells and establishment of water markets. Because of the lack of water pricing in Iran, water marketing can make a fundamental attitude in adaptation to the future climate change and paving the way for other adaptation strategies.
**Keywords:** Adaptation strategies; Climate change; Emission scenario; Groundwater depletion; Hamadan aquifer; Vulnerable areas

## 1. Introduction

Groundwater is the source of ~35% of global human water withdrawals, and even of ~42% of global irrigation water withdrawals (Doll et al., 2012). Due to increased temporal variability of surface water flows, climate change is likely to lead to higher demands for groundwater (Taylor et al., 2013; Kundzewicz and Doll, 2009). In some arid and semi-arid regions, intensive irrigation caused significant groundwater depletion (Wada et al., 2012).To support a sustainable groundwater management, it is necessary to assess climate change impacts on groundwater resources, i.e. long-term average annual groundwater recharge or depletion in future period. Scenarios of future groundwater depletion under the impact of climate change can help to identify regions with significantly changing groundwater saturation thickness and flow patterns. This information can be useful for decision makers in planning of climate change adaptation strategies. Previous climate change studies in Iran indicate that many parts of the country will experience dryer condition in the future (Morid and Massah Bavani, 2008; Gohari et al., 2013; Razmara et al., 2013; Naderi, 2014). Due to high discharge of aquifers by deep wells, many aquifers tolerate a critical condition in Iran and the future climate change likely would cause a more pressure on groundwater resources. There is a notable lack of studies related to groundwater adaptation strategies, therefore the challenge of climate change will have to be met through adaptation. In this study, we try to link the climate change study to adaptation strategies in Hamadan aquifer and introduce the most suitable strategies with respect to aquifer restoration.

The study area, Hamadan aquifer, is one of the most important aquifers in the west of Iran that plays an important role in supplying water demands especially for agriculture and drinking usages. Recent droughts and excessive exploitation of groundwater by deep wells (including 2126 wells) cause high depletion of groundwater head. According to 20 years monthly-observed heads in 15 observation wells, the annual average of groundwater head depletion is estimated -0.72 meter in the aquifer.

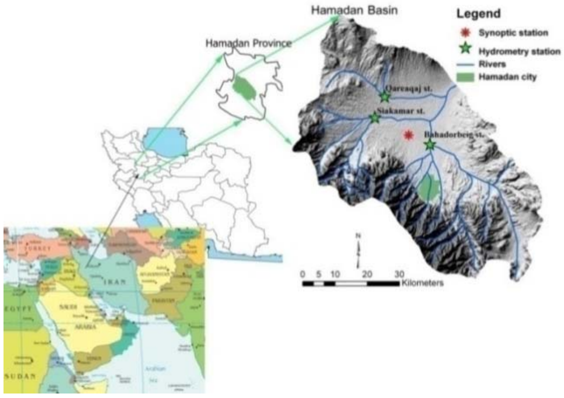



**Fig. 1** Hamadan Basin location in Iran and Hamadan province

## 2. Methods

The main steps of this study include:

- **Determination of suitable climate models (AOGCMs)**

In general, most of climate change studies indicate uncertainties related to the climate models (AOGCMs) and emission scenarios in groundwater predictions (Crosbie et al., 2011; Goderniaux et al., 2011; Allen et al., 2010; Toews and Allen 2009). In this paper, sixteen AOGCMs under A2 and B1 scenarios were evaluated based on the Mean Observed Temperature–Precipitation (MOTP) method (Morid and Massah Bavani 2008; Gohari et al., 2013). This method attends to the ability of each model in simulating the observed climate variables in the base period (1970-2000). To determine suitable GCMs, Each of the sixteen GCMs is weighted using Eq. (1).

$$W_{ij} = \frac{\left(\frac{1}{\Delta d_{ij}}\right)}{\sum_{j=1}^{13}\left(\frac{1}{\Delta d_{ij}}\right)} \qquad (1)$$

where: $W_{ij}$ is the weight of GCM $_j$ in month i; and $\Delta d_{ij}$ is the difference between average temperature or precipitation simulated by $GCM_j$ in month i of base period and the corresponding observed value in Hamadan synoptic station.

- **Stochastic downscaling**

The downscaling techniques are used to bridge the gap between the GCMs' outputs and required inputs of impacts assessment models (Wilby and Wigley 1997). Stochastic weather generators (WGs) are commonly used as downscaling tools to generate daily climate variables (Wilks and Wilby 1985; Semenov 2007). LARS-WG can generate daily time series from monthly climate change scenarios and historical daily climate data and is used to generate daily time series of temperature and precipitation in this study.

- **Predicting future runoff by artificial neural network**

Feed forward neural networks (FFNN) are very common in different hydrological issues (Singh et al. 2013; Lloyd et al. 2011; Coulibaly et al. 2000; Hsu et al. 1995: Zurada 1992) and are used for daily runoff forecasting in Hamadan basin. Common architecture of this type of neural network has three layers including input, hidden and output layers. According to error criteria ($\rho^2$, K and MARE), the best neural network structure was selected for daily runoff estimation. In order to simulate daily runoff, different patterns of input data were tested and pattern (f) was selected.

$Q_i = f(P_i)$ (a)

$Q_i = f(P_i, Tavg_i)$ (b)

$Q_i = f(P_i, T_i, Rs_i)$ (c)

$Q_i = f(P_i, Rs_i)$ (d)

$Q_i = f(P_i, Tmin_i, Tmax_i)$ (e)

$\boldsymbol{Q_i = f(P_i, P_{i-1}, Tmin_i, Tmax_i)}$ **(f)**

$Q_i = f(P_i, Tavg_i, Tmin_i, Tmax_i, Rs_i)$ (g)

where: Q is daily runoff; P is daily precipitation; $T_{avg}$ , $T_{min}$ and $T_{max}$ are average, minimum and maximum daily temperatures, respectively; and i is the time (at daily basis).

- **Predicting climate change impacts on Hamadan aquifer**

Groundwater modeling approach with MODFLOW software is used to predict climate change effects on groundwater resources in this research. Hydrogeology data and maps are used to make conceptual model of the aquifer (Fig. 2)

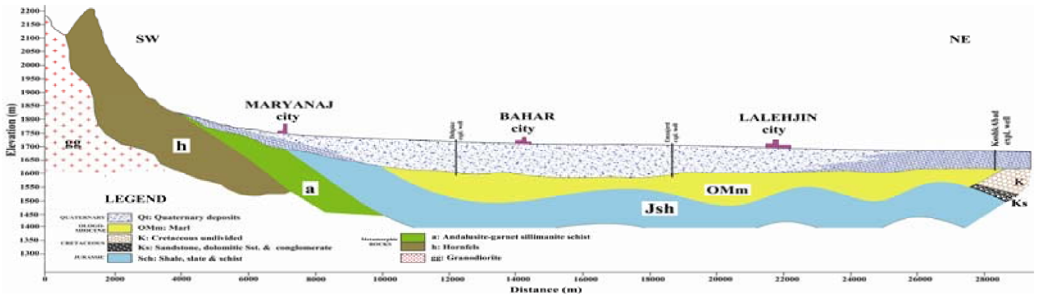


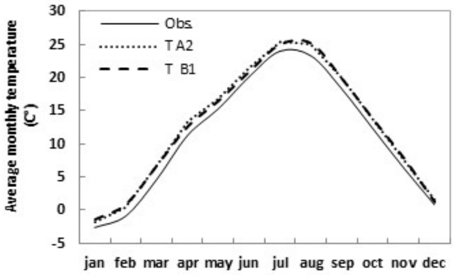

**Fig. 2** Two-dimensional profile of the aquifer in NE-SW direction

The aquifer model is calibrated manually by trial and error method in two steps. The first step includes calibration of the model in a year (1991-1992) in steady state condition. In the case of unsteady state, groundwater model is calibrated in a period of 14 years (1992-2006) in annual time steps. Root Mean Square Error (RMSE), Standard Error of Estimate (SEE) and Correlation Coefficient (R) are used to evaluate calibration process. After calibration process, groundwater observed heads during 2008 to 2011 were used to validate the model.The validated model was used for predicting aquifer responses to direct impacts of climate change. Finally, predicted runoff and precipitations were imported to the model and groundwater heads were simulated by MODFLOW during years 2015 to 2044.

## 3. Results

According to the weighting method, HADCM3 and CGCM2.3.2a climate models are suitable for temperature and precipitation prediction in the future, respectively. The projected monthly precipitation and temperatures were downscaled by LARS-WG.

According to the downscaled data, temperature would increase by 1.5°C and 1.4°C in the future period under A2 and B1 scenario, respectively and the aquifer would be warmer than the base period (Fig. 3). Predicted precipitation varies between scenario in the future and changes between -22% to +10% under A2 and B1 emission scenarios, respectively (Fig. 3).Annual average precipitation will change to 334 (mm) and 393 (mm) under A2 and B1 scenario, respectively whiles Annual average precipitation based on observed data in Hamadan synoptic is 356 (mm).



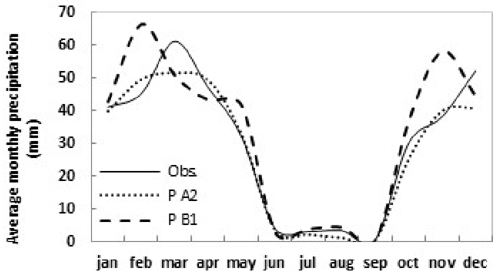




**Fig. 3** Average monthly temperature (left) and precipitation (right) changes under A2 and B1 emission scenarios in the future period

Annual runoff in the future is estimated using predicted daily runoff by artificial neural network in Qareaqaj, Siakamar and Bahadordeig hyrometry stations. In general, annual runoff volume under B1 emission scenario is more than annual runoff volumes under A2 emission scenario. The annual average of runoff volumes for Qareaqaj, Bahadorbeig and Siakamar rivers are 2.3, 1.7 and 13.2 MCM, respectively under A2 emission scenario and these volumes change to 4.2, 25, 2 MCM under B1 emission scenario. Simulated runoff by artificial neural network indicates reduction in the future runoff by -39% under A2 emission scenario and increase by +12% under B1 emission scenario.

Simulated changes of groundwater head in the aquifer indicate that groundwater depletion will continue in the future. Based on the groundwater observed heads in the base period (1991-2014), the annual average groundwater depletion is -0.72 (m/year) that will increase by -0.94 (m/year) and under A2 scenario and will decrease by -0.58 (m/year) under B1 scenario in the future. Considering that the aquifer saturation thickness is about 50 meters in the current situation, more groundwater depletion rate under A2 scenario will cause the formation of dry cells in the southern parts of the aquifer (Fig. 4). Predicted changes in the aquifer storage are about - 21 MCM/year and - 13 MCM/year under A2 and B1 scenario, respectively so adaptation strategies are required in the aquifer. Different applicable adaptation strategies in the aquifer include artificial recharge plans, enhancement of irrigation efficiency, plugging of unlicensed wells and establishment of water markets. Due to the aquifer critical conditions, groundwater artificial recharge plans do not have adequate efficiency and the most suitable adaptation strategies in the aquifer include plugging of unlicensed wells, enhancement of irrigation efficiency and establishment of water markets.

## 4. Discussion and conclusion

The weighting approach used in this study suggests that some AOGCMs are more suitable for predicting temperature whiles others are more suitable for predicting precipitation in the future. The study results indicate that the predicted temperature in the future has a lesser uncertainty compared to the precipitation. The results confirm that a relatively low reduction in precipitation will cause a considerable reduction in surface runoff in the future. In a similar study in Dez dam basin in the south west of

Iran, results represent that a decrease by -23% in precipitaion will cause a decrease by -50% in runoff volumes (Meshkin Nejhad et al., 2013).

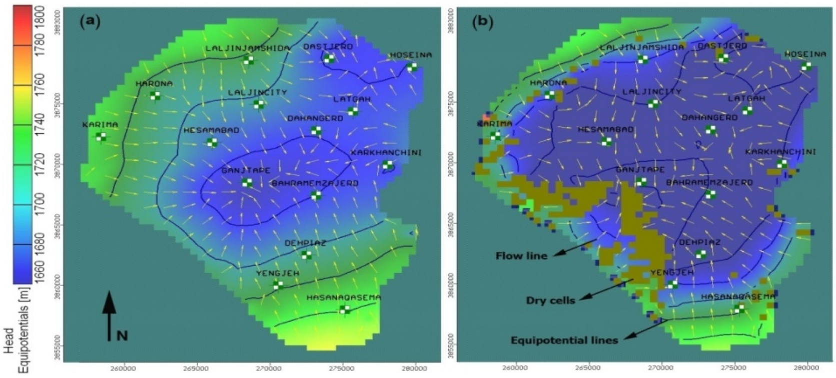



**Fig. 4** Groundwater head contours, dry cells and flow lines at the end of modeling period (year 2045) under B1 emission scenario (a) and A2 emission scenario (b)

Our primary research indicates that temperature increase, amout of precipitation and the number of precipitation events in the future are the most effective parameters on the future runoff. The groundwater model results indicate that average change in aquifer storage is about - 17 MCM/year in the future and this cause drying of aquifers in areas with low aquifer transmissivity and high density of extraction wells. According to the results of aquifer modeling, the most effective adaptation strategy is plugging of unlicensed wells. Based on published information about the aquifer groundwater resource, thirty percent of extraction wells have no license that is equivalent to 90 MCM/year withdrawals from the aquifer. Which adaptation strategy could be able to compensate this withdrawal by unlicensed wells? The main reasons for increasing the number of unlicensed wells in the aquifer and other aquifers in Iran include; inefficient management of groundwater resource mainly due to weak inspection, lack of government and judicature support in plugging of unlicensed wells and groundwater resources development policies in groundwater with the aim of self-sufficiency in agricultural production. The second adaptation strategy in the aquifer is enhancement of irrigation efficiency. The average irrigation efficiency in Iran is about 40 percent that is 25 percent less than the globe average. If we increase the efficiency about 10 percent then we will be able to save groundwater about 20 MCM/year and prevent the aquifer depletion in the future. The third adaptation strategy is establishment of groundwater markets. Because of the lack of water pricing in Iran, water marketing can make a fundamental attitude in adaptation to the future climate change and paving the way for other adaptation strategies. It must be noted that adaptive capacity building options are generally concerned with providing the necessary conditions for these forms of adaptation to be implemented successfully in the aquifer, rather than managing or avoiding climate or hydrological risks directly.

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