Potentialimpacts of climate change on groundwater resourcesin five small plains of a semi-arid region: uncertainty assessment using a nonparametric method

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Abstract

Understanding the hydrogeology of aquifers is fundamental to the management of groundwater resources especially in arid and semi-arid regions. However, understanding the responses of hydrogeological processes to climate change is complicated since climate change can affect hydrogeological processes directly and indirectly. This study aims at implementing a physically-based groundwater model to investigate the effects of climate change on groundwater system under fifteen General Circulation Models (GCMs) in a semi-arid region for the period of 2020-2044. A nonparametric Probability Density Function (PDF) estimator was used to quantify the level of uncertainties in the simulations. The methodology was applied in an area of 2073 Km^2 in south-west Iran, consist of five plains; Western Dez, eastern Dez, Sabili, Deymche and Lor. Results indicate that there is a decline in recharge in April, May, June, and October. The range of changes in recharge were determined between -%10 and +%13 in the Sabili plain, -%6 and +%10 in the Deymche plain, -%4 and +%10 in the western-Dez plain, -%6 and +%26 in the eastern-Dez plain, -%40 and +%100 in the Lor plain. The most significant decline in groundwater level occurs in the Sabili plain in September. The largest uncertainty in simulation of recharge under GCM scenarios was determined in August, September, and December.

Key words: Climate change; Groundwater; Hydrogeology; Semi-arid region, Uncertainty

1. Introduction

An increase in atmospheric concentrations of the greenhouse gases, due to human activity since about the 1950s (IPCC, 2013), resulted in changes in the magnitude and frequency of extreme climate events (Eckhardt and Ulbrich, 2003). The impact of rising greenhouse gases concentration on climate variables such as temperature and precipitation is inevitable (Scibek et al., 2007). The hydrological cycle and water resources have been affected due to alterations in precipitation, temperature, radiation and other climate variables (Kundzewicz et al., 2008; Quevauviller, 2011).

There are several methods for simulating present and future climate variables, of which the most reliable ones are three-dimensional general circulation models (GCMs) (Wilby and Harris, 2006; IPCC, 2007). However, there are high level of uncertainties associated with these models that rise from the parameters and the model structure and this can lead to errors in forecasting and planning (Murphy et al., 2004; Van pelt and Swart, 2011;Grillakis et al., 2011). Many studies use an ensemble of runs from multiple GCMs to cover the range of uncertainty in future climate predictions studies (Maurer, 2007;Vicuna et al., 2007; Hellmann and Vermaat, 2012;Kurylyk and MacQuarrie, 2013;Hosseinizadeh et al., 2015).

In recent years numerous studies have focused on impact of climate change on surface water (Shi et al., 2013; Adams and Sada, 2014), whereas climate impacts on groundwater has received much less attention from the scientific community (Goderniaux et al., 2009; Jackson et al., 2011). The impact of climate change on groundwater is important in arid and semiarid areas since groundwater is generally the main source of freshwater supply (Touhami et al., 2015; Jang et al., 2012).

In this study the simulated groundwater head using the MODFLOW model developed under fifteen GCMs combined with three scenarios of greenhouse gas emissions (A2, A1B and B1) in the Dezful aquifer. In addition, a nonparametric method, which estimates a Probability Density Function (PDF), was used to investigate and quantify the level of uncertainties in the simulations.

2. Study area

The Dezful plain with an area of about 2073 Km^{2}is the largest agricultural plain in Khuzestan province and is located in the northern part of Khuzestan in southwestern Iran. The plain contains five smaller plains: western Dez, eastern Dez, Sabili, Deymche and Lor (Fig. 1).

The Dez, Karkhe, Balarud, Kohnak and Shavoor rivers are located in the study area. This area is very important as a water resource and requires an efficient water resource management, and a correct planning and review of water policy in the region. All the plains have irrigation networks except the Lor plain. The cultivation period of wheat is usually between November and May, so the maximum recharge of groundwater by irrigation networks occurs in this period. The study area has a semi-arid climate with a mean annual rainfall of316.5 mm and a mean monthly temperature of 36.5°C in July and 11.8°C in January.

The Dezful aquifer with an average thickness of about 100 m is an unconfined aquifer system. There are over 2700 wells which pump about 500 million $m^3$of water per year in this area. Recharge to the aquifer is via direct rainfall infiltration and return water from irrigation networks. Hydraulic conductivities range is from 14 m/day for clayey sediments in Sabili to 49 m/day for sandy deposits, particularly in Lor. In this paper, 62 bores for the period of 2006-2013 were used.

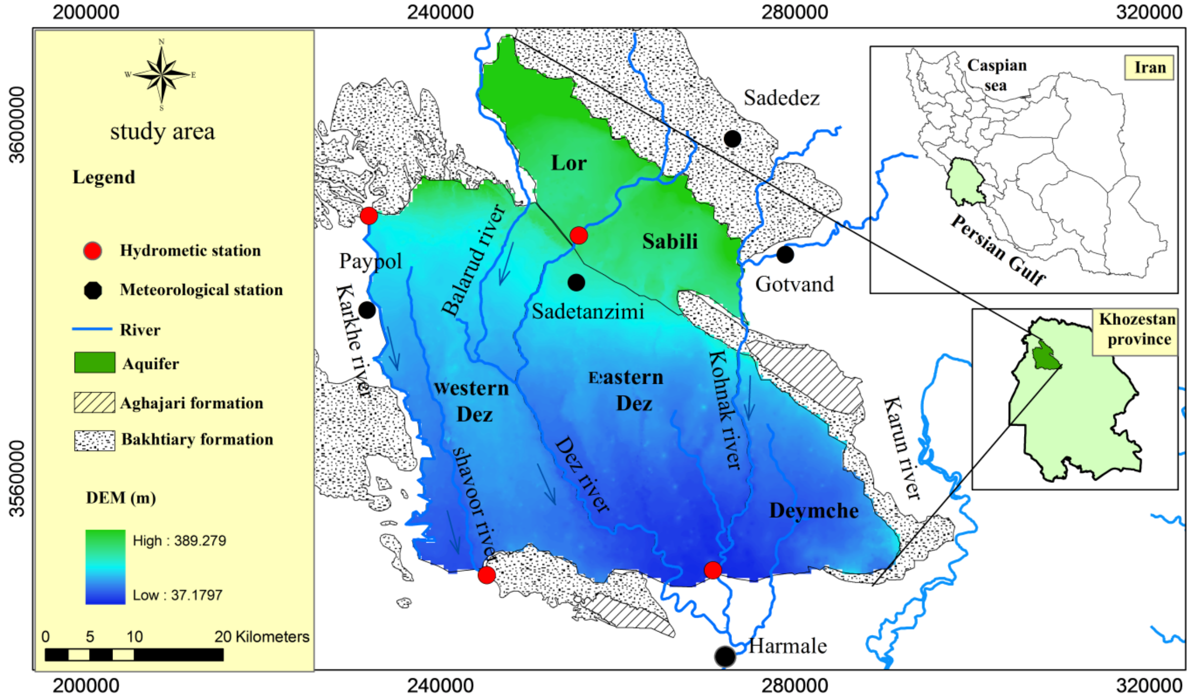

Fig. 1.Study area

3. Method

The methodological framework of this study consists of the following steps: 1) collecting and preparing observed data, 2) set-up, calibration and validation of a groundwater model, 3) Selecting GCMs and downscaling GCMs output, 4) simulating groundwater components, and 5) uncertainty assessment. These steps are described below.

3.1. Groundwater model

3.1.1. Conceptual model

In this study the input data for conceptual model comes from three types of coverage layers: 1) the first coverage layer was used to define rivers and pumping wells, 2) The second coverage was used to define parameters such as recharge, evapotranspiration, hydraulic conductivity, specific yield, as well as boundaries conditions, 3) The third coverage was used to define the groundwater table measured at 62 observation wells.

3.1.2. Numerical model

After defining the coverages, the conceptual model converts to 3D numerical in 500*500m grid network. The information related to topography of surface, bedrock, and initial head of groundwater was used in the 2D scatter data as point layers. Each of these layers were interpolated in GMS environment and incorporated in the numerical model.

3.1.3. Calibration and validation

The groundwater model was calibrated in both steady state and transient condition. First steady state model was calibrated using both automatic and manual methods. The model was calibrated in transient condition from 2006 to 2012 and was validated from 2012 to 2013.

3.2. Climate change scenarios

In order to cover future climate change in the study area, 15 GCMs and 3 scenarios from the IPCC AR4 Special Report on Emissions Scenarios (SRES) were considered in this study (Table 1). The base line data were used for the period of 1985-2009 from four climate stations. In this study, the LARS-WG model was used to downscale GCMs output.

Table 1. GCMs-scenarios used in this study

Number	Model	Emission scenarios
1	CGCM3T47	**A1B, A2, B1**
2	CNRMCM3	**A1B, A2, B1**
3	CSIROMk3.5	**A1B, A2, B1**
4	ECHAM5	**A1B, A2, B1**
5	ECHO-G	**A1B, A2, B1**
6	FGOALS-g1	**A1B, B1**
7	GFDMCL2.1	**A1B, A2, B1**
8	GISS-ER	**A1B, A2, B1**
9	HadCm3	**A1B, A2, B1**
10	HadGEM1	**A1B, A2**
11	INGV-SXG	**A1B, A2**
12	INMCM3	**A1B, A2, B1**
13	MIROC3.2	**A1B, A2, B1**
14	MRI CGCM2.3	**A1B, A2, B1**

15	NCARPCM	**A1B, A2, B1**

3.3. Uncertainty

In this study a non-parametric method, the Kernel estimation, was used to assess the model uncertainty. This method estimates a PDF function for climate variables obtained from GCMs output, such as precipitation and temperature. In the non-parametric method, the density function (f) is unknown and should be determined using statistical analysis. The Kernel estimator is defined as follows (Solaiman and Simonovic, 2011):

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{x - X_i}{h})$$

Where $K(\frac{x-X_i}{h})$ is the weight or kernel function applied to satisfy criteria such as symmetry, finite variance, and integrates to unity. Kernel density estimation highly depends on the selection of the smoothing parameter, bandwidth (h) and the type of kernel function K.

4. Results and discussion

4.1. Climate change impacts on groundwater

Results show that the pattern of changes in recharge follows the rainfall patterns. There is an increase in recharge from June to October and the largest reduction occurs in May. The amount of recharge differs in different sub-plain when groundwater balance components vary in each sub-plain. As a result, the average monthly recharge varies between +16% and +74% in the Lor sub-plain while it varies between +2% and +14%in the western-Dez-plain.

Results revealed that there is a decline in water-table in all the sub-plains except the Deymche sub-plain. The maximum and minimum decline in water-table occurs in October and September, respectively. This is due to the shift in precipitation from winter to the late summer which results in more infiltration in August, and consequently more influence on water-table in the following month.

4.2. Uncertainty assessment

There is a decrease in recharge in April, May, June, and October in the Dezful plain. The largest rise (%40) in recharge occurs in August. The most uncertainties were determined in September and December. Recharge varies between -%10 and +%13 in the Sabili plain, -%6 and +%10 in the Deymche plain, -%4 and +%10 in the western-Dez plain, and -%6 and +%26 in the eastern-Dez plain. The most pronounced changes (from -%40 to +%100) occurs in the Lore plain.

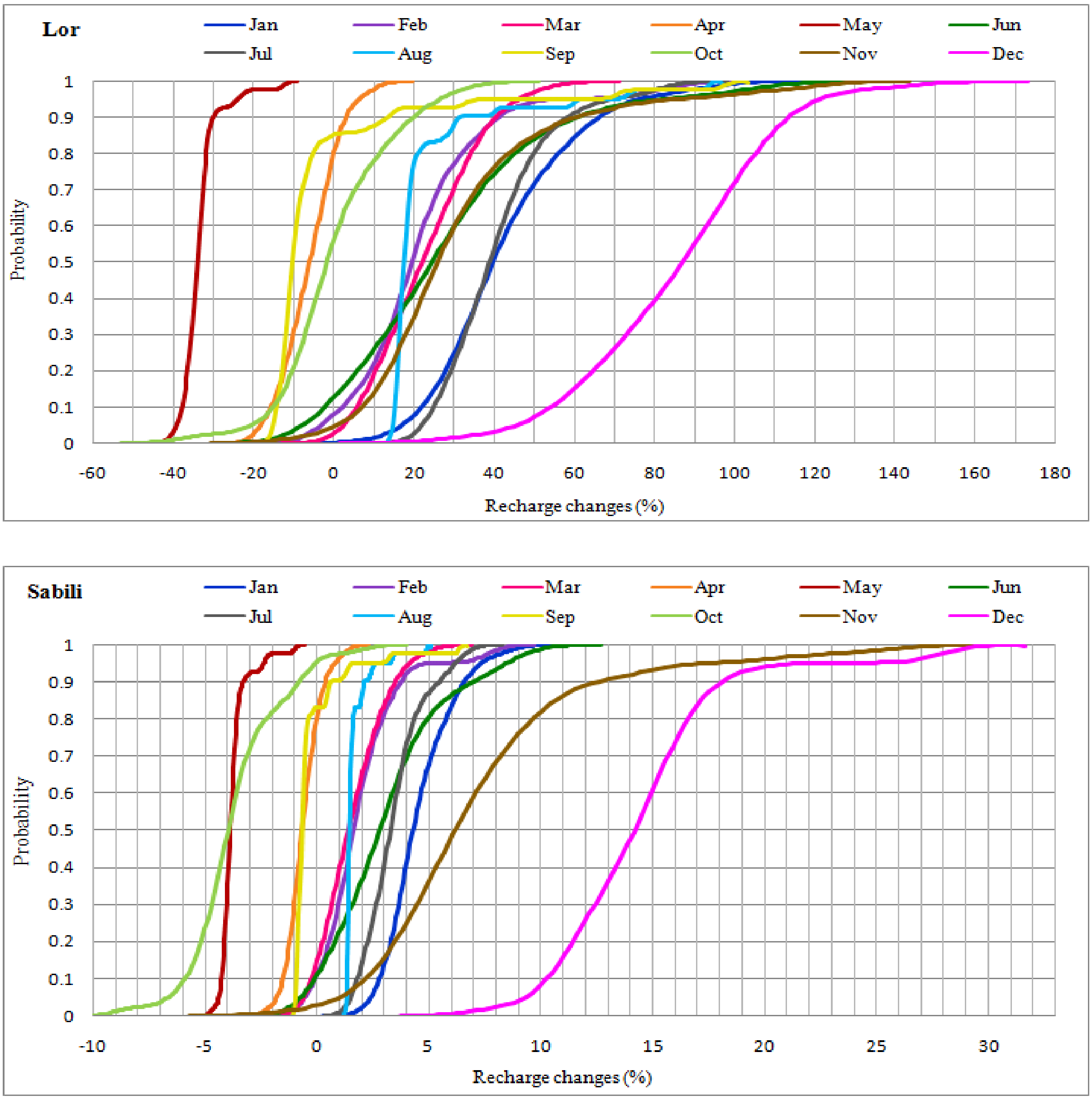

Fig. 2. Uncertainty in recharge for the period of 2020-2044 compared to the base period

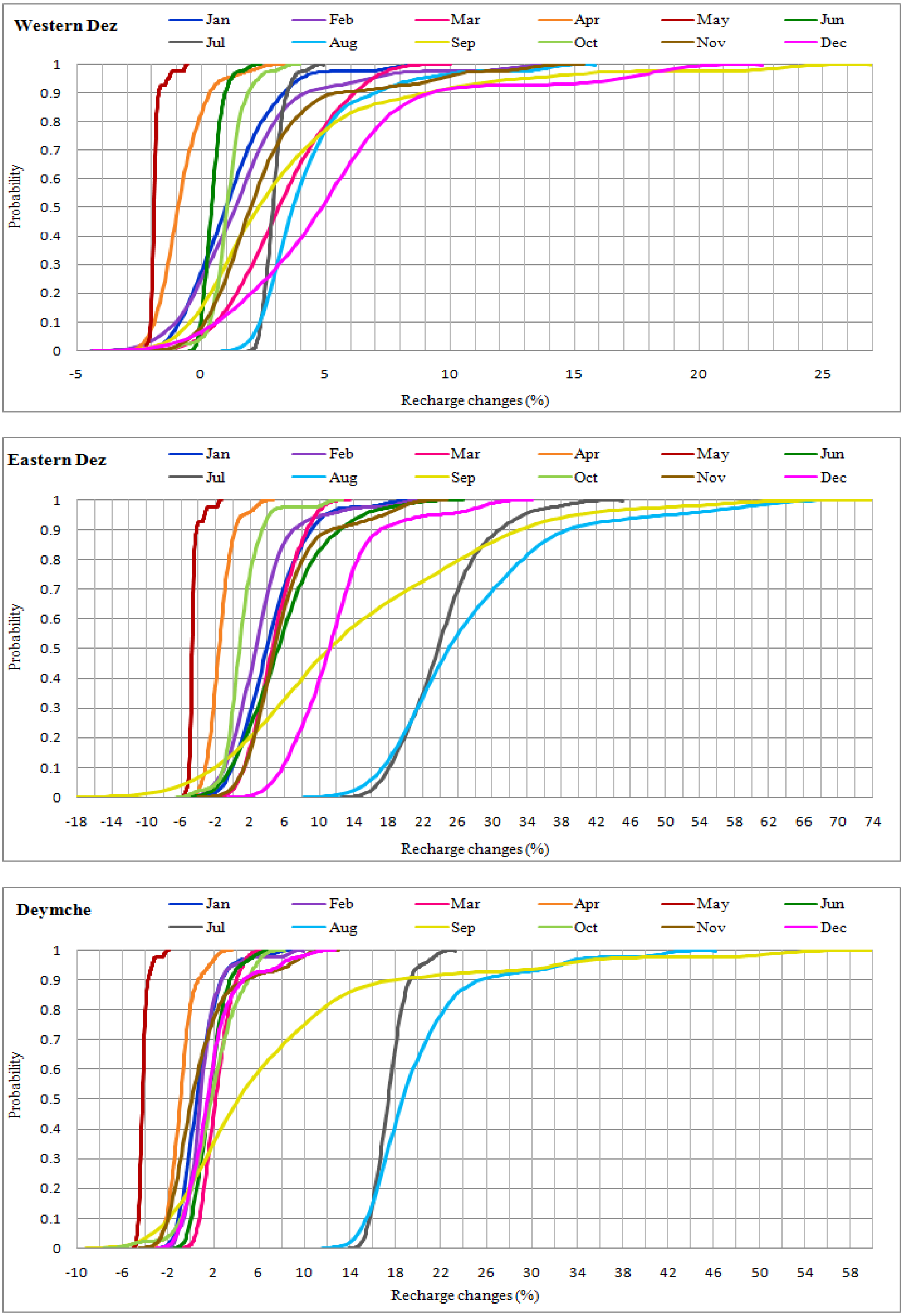

Fig. 2. Uncertainty in recharge for the period of 2020-2044 compared to the base period

5. Conclusion

The impact of climate change on the groundwater system of the Dezful was investigated under 15 GCM-scenarios for the period of 2020-2044. Results revealed that the largest increase in temperature occurs in May while the largest decline occurs in January and October. In other words, the rise in temperature is more pronounced in the wet season compared to the dry season. There is a shift in precipitation from fall to the late summer. The largest change in precipitation occurs in August.

The pattern of change in recharge follows the precipitation pattern of change. There is a decrease in recharge in April, May, June, and October. The largest of change in recharge occurs by %40 in the late summer whereas the most pronounced changes occur in the Lor plain.

The largest uncertainty in simulation of recharge under GCM scenarios was determined in August, September, and December. The range of changes in recharge were determined between -%10 and +%13 in the Sabili plain, -%6 and +%10 in the Deymche plain, -%4 and +%10 in the western-Dez plain, and -%6 and +%26 in the eastern-Dez plain. The largest decline in groundwater level occurs in the Sabili plain in September.

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